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Atlantic States Marine Fisheries Commission

2020 American Lobster Benchmark Stock Assessment and Peer Review Report

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

ACKNOWLEDGMENTS

The Review Panel thanks the Atlantic States Marine Fisheries Commission's (ASMFC or Commission) American Lobster Stock Assessment Subcommittee and Technical Committee, as well as the Director of Fisheries Science of the ASMFC for assistance in conducting the peer review.

The ASMFC thanks all of the individuals who contributed to the development of the American lobster stock assessment and the terms of reference. The Commission thanks Dr. Kristen Anstead (ASMFC) for providing R scripts and support on regime shift analyses, Dr. Jeremy Collie (University of Rhode Island) for providing R scripts to estimate dynamic productivity; Dr. Kisei Tanaka and Cameron Hodgdon (University of Maine) for providing VAST outputs; Dr. Kevin Friedland (Northeast Fisheries Science Center) for interpolated bottom temperature products; Noelle Olsen (University of Maryland Eastern Shore), Aubrey Ellertson (Commercial Fisheries Research Foundation), and Heidi Henninger (Atlantic Offshore Lobstermen's Association) for providing biosampling data; Diane Cowan (The Lobster Conservancy) for providing juvenile growth data; John Swenarton (Dominion Nuclear Power Station) for providing daily temperature data; and Dr. Yong Chen's laboratory at the University of Maine for their work on the assessment model. The Commission also thanks the ASMFC American Lobster Technical Committee (TC) and Stock Assessment Subcommittee (SAS) members who developed the consensus stock assessment report. Members of the American Lobster Stock Assessment Subcommittee include Kim McKown (Chair, New York State Department Environmental Conservation, Bureau of Marine Resources), Jeff Kipp (ASMFC), Kathleen Reardon (Maine Department of Marine Resources, MEDMR), Joshua Carloni (New Hampshire Fish and Game, NHFG), Dr. Tracy Pugh (Massachusetts Division of Marine Fisheries, MADMF), Dr. Conor McManus (Rhode Island Department of Environmental Management, RIDEM), and Dr. Burton Shank (NMFS). Members of the American Lobster Technical Committee include Kathleen Reardon (Chair), Joshua Carloni, Kim McKown, Dr. Conor McManus, Chad Power (New Jersey Department of Environmental Protection, Bureau of Marine Fisheries), Dr. Tracy Pugh, Dr. Burton Shank, Somers Smott (Virginia Marine Resources Commission), Craig Weedon (Maryland Division of Natural Resources), and Colleen Bouffard (Connecticut Department of Energy and Environmental Protection). The Commission also thanks the additional staff from each of our member states who provided assistance with the assessment, especially Jes Waller (MEDMR).

The Commission appreciates the efforts of Commission staff Jeff Kipp, Caitlin Starks, and Tina Berger in development and review of the American lobster stock assessment. The Commission also recognizes Megan Ware (MEDMR) for her support as the previous ASMFC American Lobster Fishery Management Plan Coordinator and Atlantic Coastal Cooperative Statistics Program staff, especially Julie Defilippi Simpson for maintenance of the American Lobster Database.

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A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA15NMF4740069

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PREFACE

The 2020 American Lobster Benchmark Stock Assessment and Peer Review Report is divided into two parts:

Part A – 2020 American Lobster Benchmark Stock Assessment Peer Review
PDF pages X-XX

Part A provides a summary of the stock assessment results supported by a panel of independent experts through the ASMFC external peer review process. The Peer Review Workshop was held via webinar August 10-14, 2020. The Peer Review Terms of Reference provides a detailed evaluation of how each Stock Assessment Term of Reference was addressed by the American Lobster Stock Assessment Subcommittee (SAS).

Part B – 2020 American Lobster Benchmark Stock Assessment
PDF pages XX-XXX

Part B includes the benchmark assessment of American lobster (*Homarus americanus*) stocks of the U.S. Atlantic Coast including the Gulf of Maine/Georges Bank and Southern New England stocks. The assessment was prepared by the SAS. Data collation and review occurred at a Data Workshop attended by members of the American Lobster Technical Committee (TC) and SAS (Narragansett, RI; May 14-17, 2018), reference points were developed at a Reference Point Workshop attended by members of the SAS (Woods Hole, MA, October 16-17, 2019), and assessment results were developed and reviewed at two Assessment Workshops attended by members of the SAS (New Bedford, MA; January 28-31, 2019 and Narragansett, RI, February 24-27, 2020). Assessment results were subsequently reviewed by the TC and approved for peer review at a series of webinars on June 11 and June 26, 2020.

Atlantic States Marine Fisheries Commission

American Lobster Stock Assessment Review Report

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August 2020

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

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Atlantic States Marine Fisheries Commission

American Lobster Stock Assessment Review Report

Conducted on
August 10-14, 2020

Prepared by the
ASMFC American Lobster Stock Assessment Review Panel

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A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA15NMF4740069

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Acknowledgements

The Review Panel thanks the American Lobster Stock Assessment Subcommittee and Technical Committee, as well as the Director of Fisheries Science of the Atlantic States Marine Fisheries Commission for assistance in conducting the peer review.

Introduction

An independent peer review of the American lobster stock assessment was conducted via webinar from August 10-14, 2020. The Review Panel (Panel) was comprised of Michael Celestino (New Jersey Division of Fish and Wildlife, Chair), Dr. Adam Cook (Fisheries and Oceans Canada), Dr. William Harford (Nature Analytics), and Dr. Rebecca Selden (Wellesley College). The Panel was assisted by the Atlantic States Marine Fisheries Commission's (ASMFC) Director of Fisheries Science, Patrick Campfield. Supporting information for the stock assessment was presented by the American Lobster Stock Assessment Subcommittee (SAS): Kim McKown (SAS Chair, NY DEC), Josh Carloni (NHFG), Jeff Kipp (ASMFC), Dr. Conor McManus (RI DEM), Dr. Tracy Pugh (MA DMF), Kathleen Reardon (ME DMR), Dr. Burton Shank (NMFS), and Caitlin Starks (ASMFC).

The stock assessment report and supporting appendices were made available electronically to the Panel approximately four weeks prior to the review. The Panel met with the SAS on August 5, 2020 for introductions, to seek clarification on aspects of the assessment report, as well as highlight areas of the assessment the Panel would like to focus on during the review. The tone of the meeting and the full review was collegial, and the SAS was very responsive to Panel questions and additional tasks. The Panel was able to conduct a thorough review of the American lobster assessment and thanks the SAS and Science Director for their assistance in this regard.

The American lobster is a long-lived benthic crustacean found from Newfoundland to the Mid-Atlantic region of the U.S. Like all crustaceans, American lobsters grow incrementally through molting. A variety of factors are known to influence lobster growth, including water temperature, habitat type, substrate, and incidence of disease. Temperature plays an especially critical role in influencing lobster biology, including metabolism, spawning, development, and growth.

Currently, the lobster fishery is prosecuted in two main stock units: Gulf of Maine – Georges Bank (GOMGBK) and Southern New England (SNE). In the GOM, the fishery takes place primarily in inshore waters; GBK is primarily an offshore fishery. While SNE was historically an inshore-dominated fishery, warming waters and associated lobster habitat changes have resulted in a shift. In recent years, landings from offshore areas have been slightly higher than from inshore areas. Since 1982, the GOM has accounted for at least approximately 70% of total US landings, and the proportion has increased to over 90% in recent years. Historically, SNE accounted for the second largest fishery, but experienced dramatic declines in landings from the late 1990s through the early 2000s, and less dramatic, though continued declines, since. The GBK was historically the smallest component of the US fishery, and while the fraction of

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landings attributable to GBK have remained relatively constant, they have exceeded landings from SNE since approximately 2010.

The purpose of the 2020 stock assessment review was to evaluate work conducted by the SAS in relation to their Terms of Reference (TOR). The assessment provided several new developments since the previous assessment in 2015, including development of regime-based reference points and modeling time-varying fishery-independent survey catchability through use of environmental covariates.

The Panel concluded the SAS thoughtfully completed their TORs and the assessment is suitable for management advice. The Panel agrees with the SAS that trends in model outputs are less uncertain than their scale. The GOMGBK stock is at a time series high abundance and is not depleted nor experiencing overfishing. The SNE stock is at time series low abundance, significantly depleted, but not experiencing overfishing.

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Terms of Reference for Peer Review of the American Lobster Benchmark Stock Assessment

1. **Evaluate the thoroughness of data collection and presentation and treatment of fishery-dependent and fishery-independent data in the assessment, including the following but not limited to:**
    a. **Consideration of data strengths and weaknesses**

Due to the broad spatial domain of the fishery and assessment, there were numerous fisheries independent and dependent data sources examined. Having multiple surveys and data collection sources was a strength of the assessment, as multiple lines of evidence showing the same patterns gave confidence in the overall results.

The fishery independent data sources from GOMGBK and SNE assessment components used 6 and 10 bottom trawl survey time series, respectively. The bottom trawl surveys were examined both independently as well as through the VAST modelling framework (Thorson et al. 2015) in order to understand the broad scale patterns in changes and dynamics across the systems. Data were treated appropriately, incorporating survey designs into analyses and pruning survey strata to stock areas where surveys cover the two stock components.

In addition to the trawl surveys, the ventless trap survey (VTS) was included as a time series index of abundance. The trap survey gives contrast to the trawl surveys in their modes of capture, as the trawl surveys employ active sampling (trawl sweeping up catch), versus the passive sampling of traps (requires animals to enter traps). Again, having multiple lines of evidence to describe the trends in biomass was a real strength of the assessment. There was a thorough analysis of the VTS using both design based and model based statistics. The incorporation of model based statistics for the VTS was new for the assessment and provided a means to incorporate variables which influence total catch of traps, apart from the changes in population abundance. The variables explored were Day of Year, Soak Time, Site, and Numbers of Traps, each as random effects in a negative binomial generalized linear mixed-model (GLMM). The method for including the level of effort (trap hauls) into the model based VTS index (VTI) was discussed. Under the current framework, effort is directly included in the response variable as catch / trap hauls within each site and sampling period. Alternatively, the Panel recommends including the number of traps hauled at each sampling point as an offset term in the model to make the assumptions more appropriate to the sampling distribution chosen. It was noted the trends given by the VTS are likely minimally affected, but the predicted variances and CVs of the model would change. **It was recommended that future work explore the impact of treating effort as an offset term in the model rather than a random effect.**

There was some uncertainty as to whether the relationship between survey indices and true population abundance was proportional. It was documented that habitat suitability for lobsters has been changing in recent years, and the numbers of lobsters available to the trawl survey were likely overestimated. The pattern would suggest there is a nonlinear relationship between true lobster abundance and survey index lobster abundance. This weakness in the survey indices was well documented throughout the assessment and was addressed through the inclusion of an environmentally driven catchability covariate. Inclusion of catchability covariates was rational and well documented, improved model fits, and was a strong addition to the assessment model. See TOR1d for further discussion.

Length composition data from surveys and the fishery were available for much of the time series, covering the spatial and seasonal patterns in the fishery. When sufficient sample sizes were not available to characterize the length composition, a gap filling protocol (GFP) was followed. The GFP was improved in the current assessment and used an effective sample size metric to determine adequacy of sampling rather than an arbitrary cut-off of number of samples. Early years in the time series required significantly more gap filling than the more recent years. The previous assessment (2015) examined the impact of the gap filling procedure. The analysis conducted in the 2015 assessment should either be cited in the current assessment or updated to reflect the change in GFP and resultant impact on model runs (with and without early time series).

There were several fisheries dependent data sources available to the assessment. The longest time series of data was the total landings data from each fishing area. The landings data were only used from the early 1980s to present in the assessment, however, some historical data were included in the document. **The Panel recommended including plots of landings history, to the extent possible, to give a reflection of the long history of the fishery and current changes in dynamics.** There was discussion around the completeness of the time series of landings, and how much reporting error might exist in the data. The assessment team indicated there may be biases in the time series of landings, but these were likely only for a short duration during the changes in reporting mechanisms. **The Panel recommended to generate a timeline of changes and identify when the biases may have occurred. Evaluation of the timing and magnitude of potential biases through the University of Maine Model (UMM) should be explored.**

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Fishing effort was reported in several ways depending on the data available. For certain regions and areas, total numbers of licenses and trap limits were available. This does not account for the levels of latent effort which may be available to the fishery, and thus does not track changes over time. Over the past decade programs were implemented to improve the data collections for estimating fishing effort and are to be commended. Further collection of effort information to improve the estimates of total trap hauls, by season and location, will help to improve the understanding of the changes to the fishery, which will be important to pair with the documented changes in habitat suitability from fisheries independent data sources.

Updated size at maturity (SAM) information was included in the assessment. SAM is an important life history parameter in lobster and in population modelling. The SAMs had not been updated in decades and studies from other lobster stocks suggested SAM decreased in recent years. Similar patterns were observed in this assessment, with GOMGBK SAM decreasing, and a stable SAM in SNE where not all areas were sampled. The continued collection of SAM data will be helpful in understanding the patterns and processes which influence the SAM and the resultant impacts on lobster populations.

The growth transition matrix (GTM), a key component of the UMM, has not been updated in recent years. There are many assumptions that go into the estimation of the matrix and having a single fixed GTM (by sex and assessment area) will not capture the variability in growth which is known to occur at both small spatial scales and across time. **The current GTM is a weakness of the assessment and should be the focus of further research.**

b. Justification for inclusion or elimination of available data sources

The UMM limits the number of available survey indices (slots) used in model fitting to 16. This criterion restricts the ability to incorporate all of the available information. The Stock Assessment Team made decisions on the inclusion of specific surveys, the grouping of other surveys to a 'combined' index, and the exclusion of other indices. The justification for their decisions and the resultant impacts on assessment results were not always clearly documented. Where the decisions were examined in more detail, sensitivity analyses of the UMM were performed and did provide sound rationale for decisions. **The Review Panel recommended the inclusion of a broader discussion of the decisions for grouping surveys and the methodologies used to generate the combinations.**

The de-prioritization of updating the growth matrix for the GOMGBK stock assessment area was not clear. From discussions and presentations throughout the meeting, it was apparent the data were available for updating the GTM for the region. The growth matrix is a key input to the UMM model. It has been noted across several assessments that it is one of the weaknesses of the current modelling approach. **It is a research recommendation to update the GTM and explore the sensitivity of the change to UMM outputs.**

Justification for inclusions or omissions of data sets was appropriate for a number of metrics (maturity, shell disease, water temperature, environmental covariate, etc.). The volume and

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range of data examined for the assessment was extensive and the Assessment Team should be commended for their efforts.

Further details on specific data sets used only in Model Free Indicators will be discussed in respective ToR.

c. Calculation of catch-at-length matrix

Biological sampling from ports and at-sea vessels were used to inform multiple model inputs, including characterization of the catch at length. Due to sampling limitations, gap filling was necessary. The Panel thought Appendix 3 of the assessment document, and the presentation of the same during the review, was helpful in its description of pooling, borrowing, and calculation protocols. A detailed automated protocol for gap filling is instituted with reasonable justifications. A notable advancement since the previous assessment was use of effective sample sizes to trigger gap filling, eliminating the need to assume sampling trips carried equal weight for characterizing the commercial length data (Nelson 2014). Several supporting figures (Figures 78-81) were included in the assessment document and presented at the review that transparently depicted the amount of pooling by statistical area and quarter. Pooling was generally most common in quarters and statistical areas with the lowest catch, and most common early in the time series. The Panel expressed concern, however, that the degree of pooling to characterize length compositions might mask changes in fishing mortality over time and could be contributing to the stability observed in exploitation rates. **The Panel notes the importance of ensuring adequate sampling occurs to minimize the need for gap filling**. Appendix 4 of the assessment document suggests the situation has improved from earlier time periods.

An analysis conducted by the SAS (Appendix 4 and presented at the review) suggested that sampling to quantify landings and characterize the catch at length in 2018 was adequate. The analysis could be used to inform sampling effort in future years. A variety of biological data are collected from a variety of agencies, institutions, and groups at varying spatial and temporal scales. While there is a common subset of metrics collected, a workshop to standardize collection programs could be helpful. Additionally, information presented during the review relevant to Addendum XXVI to the Fishery Management Plan requires additional data reporting – higher spatial resolution, improvements to reporting effort, 100% harvester reporting within 5 years, improvements to biological sampling requirements – which will assist future characterization of the catch at length as well.

The treatment of recreational landings in the assessment, the scale of which is generally minor in relation to commercial landings, was a little unclear. The Panel requested additional information during the review and that the same is incorporated in the assessment document.

d. Calculation and/or standardization of abundance indices

The SAS explored standardizing several data sources. Extensive effort was put forth towards standardizing the ventless trap survey (VTS). The Panel thought the model-based

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standardization of the VTS was a useful addition to the assessment. The Panel thought the effort component of the survey would be more appropriately treated as an offset in the model, but thought its inclusion in the base run was acceptable. **Additional work on the VTS index would be informative and is a recommendation of the Panel.** For example, the SAS acknowledged it is not understood how VTS catchability is affected by temperature at different lobster densities, and how lobsters of different sizes interact and contribute to overall catch. The Panel thought the SAS justification for not including environmental covariates in the VTS model was satisfactory (see below). The model-based indices were more uncertain than the design-based indices. However, the Panel thought the SAS's choice was acceptable, particularly in light of results from the sensitivity analyses.

A notable advancement in the assessment was development of environmental covariates to potentially explain changes in fishery independent survey catchability. The Panel agreed with the SAS justification for their approach over standardization of individual surveys with environmental covariates. The Panel recognized this as a noteworthy advancement, **while noting further refinement of the environmental covariate could be informative**. As currently constructed, the covariate results in catchability increases or decreases directly with temperature (and inversely with abundance). However, a unimodal relationship might be appropriate. For example, as temperature continues to increase lobsters become less available as they move to more suitable habitat. Discussion ensued between the Panel and SAS regarding a habitat suitability model in future assessments that might better inform the habitat-catchability relationship.

Regarding fishery independent trawl surveys which were not standardized, the Panel thought representation of data using number of lobsters per unit area – i.e., expression of abundance not as catch per tow, but catch per unit area – might be a better representation of relative abundance among surveys, due to differing swept areas. The UMM estimates catchability, but an initial representation with number per unit area may have more intuitive meaning to readers of the raw index values.

The Panel found that exploration of the VAST modelling approach was a good addition to the assessment in order to understand variability in catch rates as a function of sample location, even if not incorporated into the final base run. The version explored in the assessment did not include environmental covariates. The SAS indicated during the review a version in press that did include environmental covariates did not improve model fit. Nevertheless, the Panel expressed support for continued exploration of the index as a means of combining multiple fishery independent surveys. The SAS indicated that an obstacle for incorporation in the current assessment was lack of length composition data. The Panel noted this was an area of active research by the VAST program developers.

e. Other

The Review Panel concluded that in most cases the assessment was clear. However, there were select instances where additional details would aid in transparency and replicability. The Review Panel identified two specific areas that would be improved by including additional

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information in the report that was shared during the assessment review meeting: (1) details on the *rpart* (recursive partitioning and regression tree) analysis, especially for the environmental regime shifts, and (2) the rationale for the re-stratification of NMFS survey data using gap-filling.

In section 2.9.5, the methodological details about how the number of breaks in the time series were chosen were not clear. The SAS provided figures that showed the relative error and R-squared associated with different splits for the abundance time series when generating the reference points, but we did not see those diagnostics for the environmental time series, nor were either included in the assessment document. The inclusion of an explicit consideration of environmental regime shifts is a considerable advance in the stock assessment. **However, the Panel recommends more detail be given for the rpart analysis** to provide more continuity for future assessments of lobster as well as provide important methodological detail for others looking to use similar methods for other species.

In 4.2.1.1 Trawl Survey Methods, the text does not describe the gap-filling approach for missing strata in the NEFSC trawl survey that was described to the Review Panel by the SAS during the review meeting. Due to vessel or weather issues, not all strata were surveyed every year and borrowing from adjacent years was required. The Panel agrees the justification for the gap-filling was sound, but the assessment document does not discuss the gap-filling approach. **The Panel recommends its inclusion to help readers understand data strengths and weaknesses.** It would also be useful to include a table showing the number of strata for which gap-filling was necessary in each year.

An issue also emerged during the review about substrate and not just population density also having the potential to affect catchability and effective fishing area in the ventless trap survey. Prior research found catchability for American lobster differs between boulder and mud habitats (Tremblay and Smith 2002). This may be an important factor for standardizing the abundance indices for the VTS survey. The SAS indicated bottom type data are not readily available in the region. Thus, **the Review Panel suggests further exploration of the dynamics between catchability and substrate as a worthwhile future research direction**.

2. **Evaluate the methods and models used to estimate population parameters and reference points for each stock unit, including but not limited to:**
    a. **Use of available life history information to parameterize the model(s)**

The Review Panel found the use of available life history information was appropriate overall. The document points to several examples of likely changes in life history parameters over time. The **Review Panel suggested an important additional feature of future assessments would be to allow for time-varying life history parameters directly in the model structure**, particularly for time-varying growth and molt dynamics, in addition to the exploration of time-varying natural mortality that was included in this assessment.

One surprising piece of available life history information that appears not to have been leveraged in the assessment was data available for expansion of the growth matrix to smaller size classes. The assessment document highlights the existence of "substantial information available for informing growth transition matrices for lobsters as small as 8mm and as large as 73mm" in three sites in coastal Maine. Since the growth transition matrices are separate for GOMGBK and SNE, it seems the lack of data availability for SNE should not impede its development for GOMGBK. Its omission in the assessment was surprising. Since this is such an important set of parameters for the assessment model, **we recommend expanding the growth transition matrix as a high research priority for future assessments**.

In Section 4.1.1.2 on discard mortality rates, it is assumed discard mortality is negligible based on prior studies from Smith and Howell (1987), while noting discarding happens more often in lobsters with damage to their shells. Given that shell disease acts upon the shell, it is possible that shell disease may increase discard mortality. **Revisiting the assumption of low discard mortality appears warranted, particularly for SNE**.

Given the uncertainty in natural mortality, and its importance in the model, the Panel found the data-driven approach to setting breakpoints in natural mortality a robust method. However, the value for higher natural mortality in the second stanza was based on findings from the 2015 assessment and not re-assessed given new data from intervening years. The SAS explored additional time-varying M options during the assessment review (Figure R1). However, **the endeavor merits a concerted effort to examine whether the most recent data suggests M is changing differently over time, and consequences for the inferred level of fishing mortality.** That said, given the reference points were based more on trends rather than on absolute abundance, the change is not likely affect status determinations in the assessment.

b. Model parameterization and specification (e.g. choice of CVs, effective sample sizes, likelihood weighting schemes, etc.).

The Panel recommends a process be established for specifying precision of survey indices, size composition, and landings data. The Panel was also uncertain in some cases as to exactly which parameters were fixed, and which were estimated (see also TOR4). The SAS should consider evaluating the effects of specifying arithmetic CVs on model preference. Informing model preference through iterative model reweighting should be done in conjunction with exploration of sensitivity of outputs to weighting schemes assigned to different data types (indices, size composition, landings). Such an approach may also be beneficial for resolving underlying causes of modest fits to size compositions for the SNE stock.

The Panel was supportive of the continual improvements made to the assessment approach but encouraged the SAS to provide more rigorous justifications when deferring to parameterization decisions made in previous assessments. For example, the Review Panel had some concern as to whether it was appropriate to carryover *M*=0.285 for 1998-2019 for SNE, given the quantity was estimated using a likelihood profile based on fits to a previous assessment model. Because changes were made to the assessment model during this benchmark assessment, it would be more appropriate to re-examine estimation of *M* using the current base case model. To examine the issue, the Panel requested the likelihood profile be carried out for the current base

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case model. After conducting the updated profile, SAS members advised that a global minimum was less well defined for *M* during 1998-2019 under the current base case model (Figure R2).

c. The choice and justification of the preferred model. Was the most appropriate model used given available data and life history of the species?

The Panel agreed with the SAS's choice of the UMM as the preferred model for stock status determination. The UMM was specifically created for lobsters, was used in previous assessments (ASMFC 2009, 2015), and has been simulation tested (Chen et al. 2005). Moreover, the Panel believed the extensive range of sensitivity runs explored by the SAS and the general insensitivity to various inputs provided additional justification for use of the UMM as the preferred model, especially in light of the model outputs used for management. The Panel agreed with the SAS that there is less uncertainty in trends than absolute scale (Figures 184-185).

While not currently appropriate for stock status determination, the Panel found the environmental indicator system very useful. **The Panel recommends continued use and exploration of the indicators to understand the relative merits of indicator-based management for various types of management controls.** For example, preliminary analyses conducted by the SAS during the review, while requiring additional considerations (e.g., detrending), suggested relatively strong correlations between model outputs and select indicators that may be useful for management, with continued exploration.

3. Evaluate the identification and characterization of environmental/climatic drivers.

The breadth of potential environmental and climate drivers were thoughtfully considered by the SAS. For both stocks, stock-wide seasonal bottom temperatures and temperature time series from fixed stations in each region were analyzed. For GOMGBK, breakpoints in the contribution of Labrador Slope Water, and zooplankton composition metrics from EcoMon were also explored. For the SNE stock, the number of degree days >20°C and anomalies in the Mid-Atlantic cold pool were considered. The variables included are comprehensive of the set of environmental variables likely to be important for population dynamics.

As described in our remarks on TOR1, **additional detail on the methodology of the *rpart* analysis and the statistical support for each break point would be valuable**. It was at times unclear when regime changes were based qualitatively vs. quantitatively. This should be clarified in the assessment document. A table with the region, time series, the method for detecting the breakpoint, the breakpoint(s) identified, and the statistical criteria for support would provide the necessary detail for any practitioners looking to repeat such analysis. Support for the breakpoints chosen could be bolstered by complementing the *rpart* analysis with an analysis that provides the probability of change across various time points. Bayesian change point analysis is one such tool that is used by DFO (Fisheries and Oceans Canada) in their assessment of changes in productivity of Canadian lobster stocks (Cook et al. 2017). The

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consistent regime shift around 2010 in GOMGBK across most of the environmental time series and the abundance time series suggest a robust breakpoint. However, given weaker support for the second earlier breakpoint, it would be informative to examine this breakpoint with another tool that provides the probability of change across time points. The timing for regime shifts in SNE across different environmental variables were less consistent.

One of the environmental time series for SNE was the number of degree days >20°C at the Millstone station in coastal Connecticut. The metric was also included as an indicator. Upon closer inspection of Figure 57, the number of degree days seems implausibly high. According to Table 63, there were 75 days >20°C in 2010, but a value in Figure 57 of 1500 which would indicate each of those days was 20 degrees higher than 20°C. Additional clarification on how degree days were calculated, and a check on the value of the axis in Figure 57 would be informative. Since the number of degree days >20°C is still quite small in GOMGBK, one might consider an analysis of the number of "good days" 12-18°C as a complementary indicator that might be an early warning signal in GOMGBK and be equally useful as a metric in SNE. Dr. Tracy Pugh indicated recent laboratory work on the effects of good days on metrics of performance are ongoing and could potentially be included in future assessments.

Given the stated goal of finding repeated patterns across datasets, **an improvement to the analysis of environmental regime shifts would be to formally assess correspondence in the timing across different environmental variables**. One option to consider would be dynamic factor analysis (DFA) to reduce the number of dimensions of environmental variables and the degree of covariance between a suite of time series. Using the combined scores would collapse the environmental variables into a single coherent trend. Using that for the *rpart* analysis could provide more support for a true regime shift. DFA can also be used to evaluate the relationship between a variable of interest (reference abundance) and environmental factors (Barber et al. 2018). Directly relating the trends in reference abundance to the environmental time series would provide a more mechanistic understanding. It may improve management as conditions continue to change in the Gulf of Maine with warming and provide guidance on key environmental covariates to prioritize ongoing monitoring efforts.

The dynamic linear model analysis that demonstrated time-varying Ricker steepness parameters as *ex facto* output from the model supports the finding of a change in environment changing stock productivity. **Including such an analysis is a positive advancement for the assessment that will provide useful hypotheses for further exploration to understand the drivers of changes in productivity**.

Finally, the assessment document summarizes the strong evidence for warming increasing suitable settlement habitat in GOMGBK. Given the evidence provided from Goode et al. (2019) that ignoring suitable habitat can qualitatively change your interpretation of the YOY indices, **interpreting the YOY index in concert with an index of predicted areal extent of settlement habitat seems appropriate.**

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4. Evaluate the estimates of stock abundance and exploitation from the assessment for use in management. If necessary, specify alternative estimation methods.

The Panel agrees with the SAS that trends in reference abundance and effective exploitation are less uncertain than their scale. The reference points (see TOR8) paired with the corresponding model outputs are appropriate for management.

The Panel concluded that diagnostics presented in the assessment document, supporting appendices, and presentations from the review suggested reasonable fits to the data. However, the Panel discussed exceptions with the SAS. For example, the model struggled to fit the NEFSC trawl survey index and length composition data resulting in residual patterns. The Panel also discussed whether, in light of challenges encountered modelling NEFSC trawl selectivity in SNE, there was evidence for a change in selectivity over time due to changes in lobster distribution and availability, and suggested this could be something to monitor as part of future assessments. More broadly, the Panel agreed with the SAS that the model tended to struggle fitting the largest (> ~100 mm CL) as well as the smallest sizes (~50-60 mm CL) of lobsters, or landings in years when molt timing was misaligned with the static growth transition matrix used in the model. **The Panel agreed with the SAS that updating and incorporating time-varying growth transition matrices is a high research priority.**

The Panel sought additional information during the review regarding recruitment covariates used in the model. For example, the Panel discussed whether the assumption of monotonic changes in recruitment as a function of year or temperature in the GOMGBK in light of indicator results was appropriate but was ultimately satisfied that sensitivity runs adequately explored this source of uncertainty. The SAS provided additional context and discussion for future research (e.g., autocorrelated recruitment function). Without a recruitment covariate, estimates of recruitment were unreliable and resulted in model instability.

The Panel thought the projection module developed since the previous assessment was a useful advancement. The Panel sought clarification on details related to the methodology that were unclear from the assessment documents. The SAS provided this information during the review and updated the assessment report to reflect the same. The Panel believed the projection methodology was sound, though additional exploration could aid in understanding sensitivity to assumptions – e.g., using terminal year selectivity versus a multi-year average selectivity in projections.

The Panel discussed the need for careful consideration of the abundance and exploitation statistic used for comparison with reference points. The SAS proposed a 3-year running mean that led to lengthy discussion regarding the inherent 'memory' resulting from moving averages. The Panel noted running averages are slow to react to trends – e.g., underestimate abundance during periods of increasing abundance and overestimate abundance during periods of decreasing abundance. **The Panel recommended further exploration of smoothing techniques that are robust to trends for use in future assessments**. See TOR 8 for additional details.

The SAS was able to provide supplemental information on procedures used to fix survey selectivity parameter values, particularly in association with challenges experienced with the

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SNE stock. The Panel was satisfied with the protocols, though ambiguities remained regarding additional model parameters – e.g., the order of model fitting when fixing parameters to specific values was somewhat unclear (see TOR 2b). The Panel was unclear as to exactly which and how many parameters were fixed and hence not estimated in the final base run and requested this information during the review. The SAS was able to provide the information to the Panel after the review. During the review, the Panel noted more parameter specifications would be informative additions to the assessment report and requested their inclusion.

5. **Evaluate the methods used to characterize uncertainty in estimated parameters. Were the implications of uncertainty in technical conclusions clearly stated?**

The SAS recognized that asymptotic standard errors grossly underestimate uncertainty in the base case results and relied on sensitivity runs as a more appropriate means of capturing a wider range of estimates. The SAS also recognized that underestimation of uncertainty in model results occurred because fishery selectivity, natural mortality, and growth parameters were not estimated in the model. Additional uncertainty is likely underestimated through fixing model parameter values – e.g., fixed survey selectivity parameters identified in Tables 66 and 67. The Panel supports the use of the thorough set of sensitivity runs as an appropriate approach for characterizing uncertainty, especially as it pertains to determining whether conclusions about stock status remained consistent across alternative modeling assumptions.

6. **Evaluate the diagnostic analyses performed, including but not limited to:**
    a. **Sensitivity analyses to determine model stability and potential consequences of major model assumptions**
    b. **Retrospective analysis**

Sensitivity analysis included a thorough set of alternative model configurations that were contrasted against the base case model. For the GOMGBK stock, the scales of reference abundance and reference exploitation were affected by changes to the growth transition matrix, and gear selectivity. Despite changes to the absolute scale of model results, sensitivity runs produced relatively stable trends in abundance and exploitation.

For the SNE stock, sensitivity runs suggested the scales of reference abundance and reference exploitation were affected by specified natural mortality-at-length and time-varying *M*, gap-filling biosample characterization, and exclusion of Long Island Sound and the CT trawl survey. Like GOMGBK, sensitivity runs for SNE produced relatively stable trends in abundance and exploitation.

The Review Panel supports the SAS's conclusion that retrospective patterns for GOMGBK were mild and estimated abundance and exploitation trends were stable for recent years. The retrospective patterns in recent years for SNE were less stable. The Review Panel supports the SAS's recommendations to further consider spatio-temporal patterns in recruitment and time-varying growth as possible underlying causes of retrospective patterns.

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The Panel recommends conducting a diagnostic involving modifying initial starting values in the stock assessment model (i.e., jitter analysis). By modifying the initial values over repeated model models runs, jitter analysis provides an evaluation of whether the model continually converges on the same solution. Jitter analysis provides confidence that the global minimum has been found by the search algorithm. Given the set of sensitivity runs produced similar trends, it is unlikely the assessment model is becoming caught in local minima, however, formal evaluation is advisable.

7. **Evaluate the preparation and interpretation of indicator-based analyses for stocks and sub-stock areas.**

The incorporation of an indicator-based or model-free evaluation of data sets relevant to the lobster stocks was a strength of the assessment. Categorizing the indicators into Abundance, Mortality, Stress, and Fishery Performance provided context on how the indicators can be used to describe changes to lobster stocks. This component of the assessment was geared toward communicating trends in the numerous data series available to the assessment team in a simplistic manner. The use of percentile breaks (25%, 75%) of the distribution for the entire time series to delineate negative – neutral – positive years has advantages in its simplicity. There are also disadvantages to the percentiles approach, particularly as there will be 'shifting-baselines'. Specifically, as additional years are added onto the time series, the absolute value associated with percentile breaks will change, leading to blocks being labelled 'neutral' in some years which may become 'positive' or 'negative' in others. The issue can be alleviated by using a reference period and fixing thresholds for percentiles. The thresholds can be revisited or updated during subsequent assessment frameworks. **The Panel recommended describing how the quantiles will be continued through update years, in between assessments.**

The Assessment Team recommended using a subset of indicators for update years between full assessments. The justification for inclusion of specific indicators was not clearly documented. However, it was discussed in the meeting. **Including additional details on the justification for updating a subset of indicators was recommended by the Review Panel.**

Updating the model-free indicators on an annual basis is a strength of the approach. Providing a communication tool to allow fishery managers and industry to have the best information at hand when making decisions affecting the fishery decreases the risks associated with multiple years between stock assessments. **Further development of a science-based 'rule' (e.g., if 3 of 4 indicators change from positive to neutral) that would trigger an earlier than scheduled stock assessment would be a strong addition to the model free indicators and is a recommendation from the Review Panel.**

Stress indicators were a new addition to the model free indicators in the assessment. They are an excellent inclusion, to portray changing conditions in the environment (days above 20°C) as well as new pressures on lobster stocks (shell disease). There were concerns raised on the communication of the percentile groupings using the negative-neutral-positive categories. It is difficult to consider a moderate stress (26% – 74%) time period as neutral. More appropriate terminology might be low-medium-high, or similar, to better describe the gradient of stress. **The Review Panel recommended altering terminology for the stress indicators.**

There was discussion surrounding the use of Days >20°C as the indicator of thermal stress, given lobsters' non-linear physiological response to temperature. A more appropriate metric would likely be <u>degree days</u> above 20°C which would reflect the increasing thermal stress as temperatures rise well above 20°C. I.e., 25°C is more stressful than 21°C. **A research recommendation was made to develop a physiological model of thermal stress that will aid in understanding the relationship and develop appropriate thresholds.**

Included in the Abundance Indicators was one designed to identify changes in spatial extent of lobsters through the proportion of positive survey sets. The indicator estimates the proportion of sets in a trawl survey where lobster were captured. A more statistically appropriate metric where the survey design is incorporated into the estimate of distribution would be the design weighted area occupied (DWAO; Smedbol et al., 2002).

$$DWAO = \sum_{i=1}^{n} a_i I \; where \; I = \begin{cases} 1 \; if \; y_i > 0 \\ 0 \; otherwise \end{cases}$$

where n was the number of tows within the survey year, y_i is the number of lobster caught in tow i, and a_i is the area of the stratum fished for tow i divided by the number of sets fished in that stratum. **It is recommended that DWAO be considered for adoption as the indicator of distribution.**

Another indicator that compliments DWAO is the evenness of the catch rates across the survey. In the current assessment no indicator of spatial evenness was included. However, it was **recommended by the Review Panel that spatial evenness would be a useful addition to the Abundance Indicators.** Several metrics have been proposed in the literature. However, one that has been used in other lobster stock assessments was the Gini Index (Myers and Cadigan 1995). Specifically, the Gini index quantifies the areal difference between Lorenz curves of the sorted cumulative proportion of total area to cumulative proportion of total catch relative to the identity function (0,0) → (1,1). If lobsters were identically distributed across all strata, the Lorenz curve would be the identity function. Typically, densities are not uniform across space and the Lorenz curve has a characteristic convex relationship as some strata provide greater proportions of the cumulative density. The Gini index quantifies the difference between the Lorenz curve and the identify function and represents a measure of inequality or patchiness. High levels of the Gini index can occur at any abundance, but are more likely to occur at low abundance, when small pockets of relative high abundance may persist.

Fishery performance indicators including fishing effort, landings (partial and total), CPUE, price per pound, total revenue, and revenue per trap were estimated. They are important indicators to communicate to fisheries managers and stakeholders to gain insights into how the fishery is operating at an aggregate level. There were concerns raised by the Review Panel regarding the

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use of several fishery indicators. Similar to the issue raised with terminology for the Stress indicators, the appropriateness of negative – neutral – positive categorization for fishing effort was discussed. Low effort, considered a positive situation in the assessment, can occur when the stock is in low abundance and the fishery is less profitable and would therefore be considered negative from the fishery performance perspective. **It is possible that low effort may represent a decrease in fishing mortality. However, it is key to understand the relationship between effort (trap hauls) and exploitation for application of the indicator. This constitutes a research recommendation from the Review Panel**. Additionally, the use of price per pound as an indicator of fishery performance was questioned by the Review Panel. There are many factors affecting the valuation of the lobster entering the market that go much further than how the fishery is performing. **The importance of price indicator to the fishing industry was discussed by the Assessment Team, and the Review Panel concurred, but recommended a separate category of indicators be explored** (e.g., Economic Indicators).

8. **Evaluate the current and recommended reference points and the methods used to calculate/estimate them. Recommend stock status determination from the assessment or specify alternative methods.**

The Panel agreed with the SAS's justification for not using equilibrium reference points and with the SAS's reliance on reference point definitions as described in ASMFC (2008).

The Panel concluded the development of regime-based reference points and use of multi-year averages to determine stock status was commendable and appropriate. The Panel thought while the indicator system was very helpful, it was not appropriate for status determination. Preliminary correlation analyses between the indicators and model outputs explored during the review provided several avenues of future research.

The Panel agreed with the SAS position that the reference points from the 2015 assessment were no longer appropriate given environmental and abundance changes during the time series. During the review the SAS provided additional details regarding the regression tree analyses used for reference point development that resolved some ambiguities discussed during the pre-review meeting as well as during the review itself. The assessment report text was updated in response.

The proposed new reference points led to lengthy discussion between the Panel and SAS in order to fully understand the justifications for various decision points. For example, the SAS currently proposes to base stock status on a comparison between a running 3-year average of model estimated reference abundance and exploitation with their respective reference points. While supportive of a multi-year smoothing algorithm given model uncertainty and inter-annual variability, the Panel found the running average results in values that are systematically lower than terminal year estimates over increasing trends and systematically higher than terminal year estimates over decreasing trends (Figure R3). The Panel proposed an alternate smoothing algorithm based on weighted medians (Tukey end rule median) and the SAS explored it during the review (Figure R3). Under the years evaluated, the weighted median tended to follow terminal year reference abundance values. Exploitation rates tended to be similar to the

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running average results given the general lack of multi-year trends. Some SAS members expressed support for the weighted median approach, noting it is more conservative during periods of declining abundance, but were also concerned with the approach's heavier weighting towards terminal year estimates. The Panel suggested that given the current and likely near term trends relative to proposed reference points, the choice of smoothing algorithm was not likely to change status determinations. I.e., reference abundance in GOMGBK is well above the target and well below the threshold in SNE. Given the variable nature of exploitation (relative to reference abundance), the two approaches considered resulted in similar values when tracking exploitation. Therefore, **the Panel supported the SAS's running average approach for the present assessment and suggested exploring the consequences of alternate smoothing algorithms that are robust to trends for the next benchmark assessment.**

During the review the SAS provided biological justification, in addition to the justifications tied to environmental data analyses, for setting abundance reference points that spanned multiple regimes, noting that, for example, in the GOMGBK, the target abundance may be at an ecologically unsustainable level near carrying capacity. The SAS noted there is support in the literature for their position (Tanaka and Chen 2016), though they acknowledged this determination was also rooted in professional judgement. The Panel discussed whether there was evidence to the contrary but was ultimately satisfied with the SAS's justifications for proposed reference points. The Panel also strongly supported the SAS recommendation for an economic analysis to provide advice on appropriate action to stabilize the fishery when abundance falls below the target (GOMGBK).

The Panel noted the range of exploitation values encompassed by the target and threshold was narrow and has the potential to result in frequent and possibly unnecessary management action. Nevertheless, the Panel was satisfied the range put forth by the SAS – 25th-75th percentiles of exploitation within the current abundance regime – were adequately justified. **The Panel suggested a management strategy evaluation (MSE) could, among other things, inform an appropriate range of exploitation values**.

The Panel also discussed the importance of a stakeholder communication strategy regarding the new reference points. For example, the change in exploitation reference points related to regime shifts may give the appearance that fishing was responsible for declines in SNE abundance. However, much of the assessment document and review suggest the stock is in a new abundance/productivity regime and the driving force of change in historical abundance was likely changes in the environment. This will require consideration as to how the results are communicated to stakeholders.

The Panel agreed with the SAS that trends are less uncertain than the scale or magnitude of the model outputs. The Panel supports the use of reference points put forth by the SAS. Based on the updated reference points, the GOMGBK stock was not depleted and not experiencing overfishing. The SNE stock was significantly depleted but not experiencing overfishing.

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9. Review the research, data collection, and assessment methodology recommendations provided by the Technical Committee and make any additional recommendations warranted. Clearly prioritize the activities needed to inform and maintain the current assessment, and provide recommendations to improve the reliability of future assessments.

The Panel thought the SAS developed a well thought out list of prioritized research items. No adjustments to prioritization are needed. From the SAS items provided in the assessment document, the Panel identified what we viewed as the 3 highest priority items below. The Panel also identified several additional areas of potential research exploration.

First, the Review Panel found all aspects of growth were very high research priorities. E.g., expansion of growth transition matrix, allowance for time-varying growth in UMM, continued monitoring and study of changes in size at maturity due to its influence on growth, and temperature-molt dynamics. The growth transition matrix (GTM) is a key component to the model and one that is strongly affected by environmental changes. Expanding the GTM to include smaller size classes where data currently exist (GOMGBK) and modifying the model to allow for time-varying growth will be key improvements to the assessment.

Second, the Panel suggested additional research could be beneficial to address time-varying natural mortality, particularly for the SNE stock. For the SNE stock, natural mortality was 0.15 for 1979-1997 and 0.285 for 1998-2019 to capture effects of recent warm water conditions. Two considerations led the Review Panel to suggest further research could be beneficial. First, reference abundance and reference exploitation were sensitive to different assumptions about time-varying M (Shell Disease Trend). Thus, partitioning of Z into components F and M could be affected by time-varying M and could accordingly affect perceived overfishing status. Second, the Panel's understanding was that M=0.285 was estimated using a likelihood profile following the 2009 assessment (see Figure 11). The Panel requested the likelihood profile be conducted on the current base case model. After conducting the updated profile, SAS members advised that a global minimum was less well defined for M during 1998 to 2019 under the current base case model (Figure R2). Taken together, the two considerations could affect estimation of overfishing status and led the Review Panel to recommend additional research into time-varying M for SNE. One option discussed during the review was to explore whether the model could be adapted to incorporate a random walk in M if model diagnostics are not improved by setting multiple M stanzas.

Third, given the large change in the model in the 2015 assessment to combine GOM and GBK and the uncertainty surrounding the extent to which the stocks are connected by adult movement or larval dispersal, understanding stock structure is a high research priority. The Panel also agreed with the SAS that historical spatio-temporal patterns of distribution and abundance in SNE may not be representative of current conditions, raising questions about how the stock should be defined, and whether existing surveys are adequately capturing lobster dynamics. The Panel agreed with convening a stock structure working group that includes Canadian researchers would be a fruitful endeavor.

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In addition to the three priority areas identified above, the Panel also considered the following potentially useful avenues of research:

- Substrate and catchability
    - Prior research found catchability for American lobster does differ between boulder and mud habitats (Tremblay and Smith 2002), suggesting substrate may be an important factor for standardizing the abundance indices for the VTS survey. The SAS indicated data on bottom type is not readily available in the region. Thus, the Panel suggests further exploration of the dynamics between catchability and substrate as a worthwhile future research direction.
- Analyses of environmental regime shift
    - An improvement to the analysis of environmental regime shifts, given the stated goal of finding repeated patterns across datasets, would be to formally assess the correspondence in shift timing across different environmental variables. One option to consider would be dynamic factor analysis (DFA) to reduce the number of dimensions of environmental variables and the degree of covariance between a suite of time series. Using the combined scores would collapse the environmental variables into a single coherent trend. Using a single trend for the *rpart* analysis could provide more support for a true regime shift.
    - Support for the breakpoints chosen in the current analysis could be bolstered by complementing the *rpart* analysis with an analysis that provides the probability of change across various time points. Bayesian change point analysis is one such tool that is used by DFO in their assessment of changes in productivity in Canadian lobster stocks.
- Suitable habitat and YOY indices
    - Given the evidence provided from Goode et al. (2019) that ignoring suitable habitat can qualitatively change the interpretation of YOY indices, interpreting the YOY index in concert with an index of predicted areal extent of settlement habitat seems appropriate. Further research could explore what extrapolation is biologically realistic to adjust lower YOY densities with greater suitable settlement habitat to generate recruitment indices that better reflect dynamics.
- Sensitivity runs
    - An exploration of diagnostics from sensitivity runs could help identify potential sources contributing to retrospective patterning and as well as assist with judgements related to model parsimony.

10. Review the recommended timing of the next benchmark assessment relative to the life history and current management of the species.

The Panel agreed with the timing put forth by the SAS: a benchmark stock assessment in 5 years would allow the SAS to address important research recommendations to improve upon the UMM. The Panel agreed with the SAS proposal to initiate an annual data update. The Panel supported annual updates of all indicators to provide insights into lobster and fishery dynamics that might adjust the recommended timing of the next benchmark. Moreover,

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further development of a science-based ‘rule’ that would trigger an earlier than scheduled assessment would be a strong addition to model free indicators and was a recommendation from the Review Panel. E.g., if 3 of 4 indicators change from positive to neutral, advance the timing of the next benchmark assessment.

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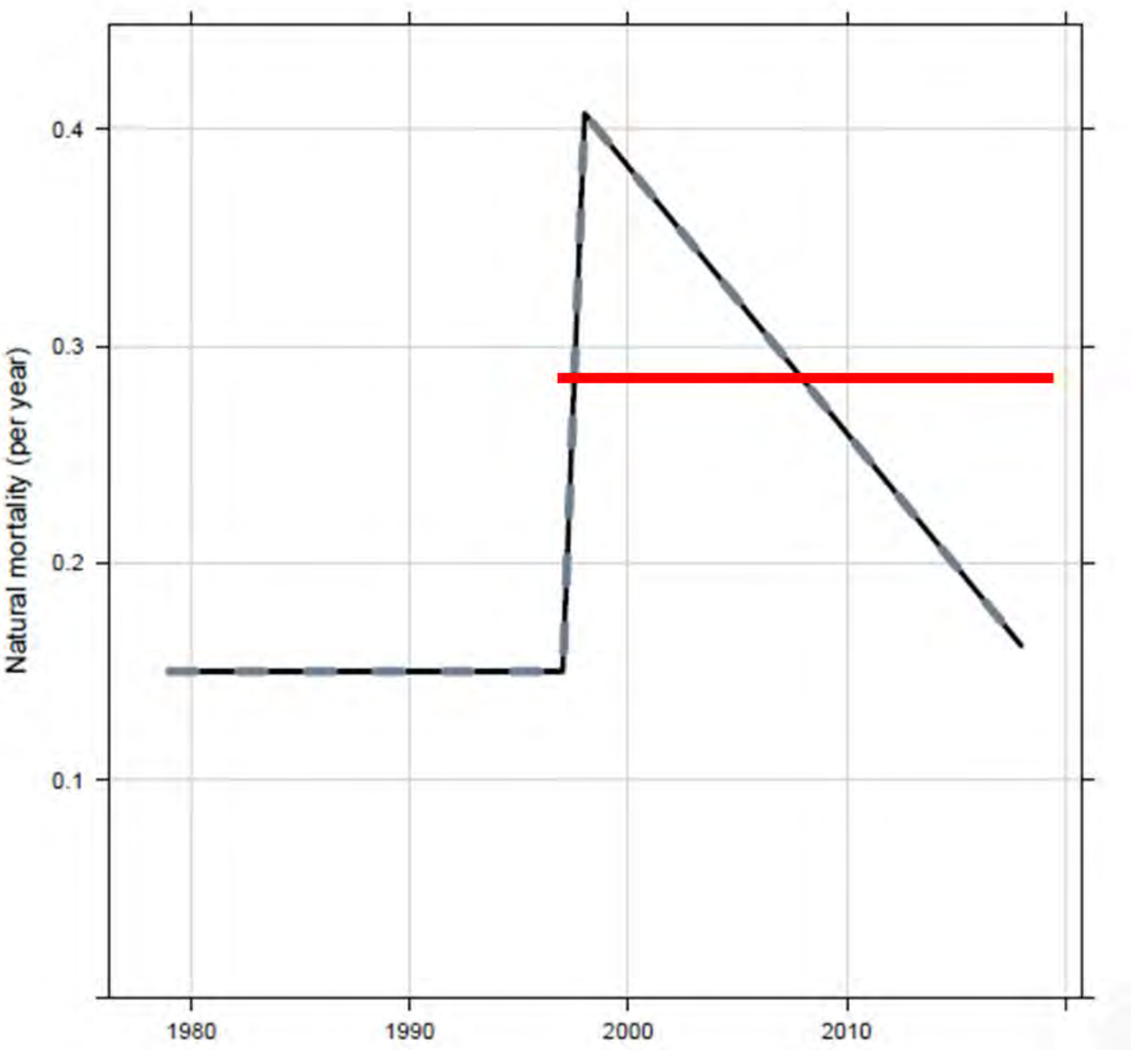

Figure R1. Alternate time-varying natural mortality scenario for SNE explored during review. In the base case and alternate run, M = 0.15 from 1979-1997. After 1997, the black and grey line represents the alternate M scenario, and the red line represents the base case model scenario.

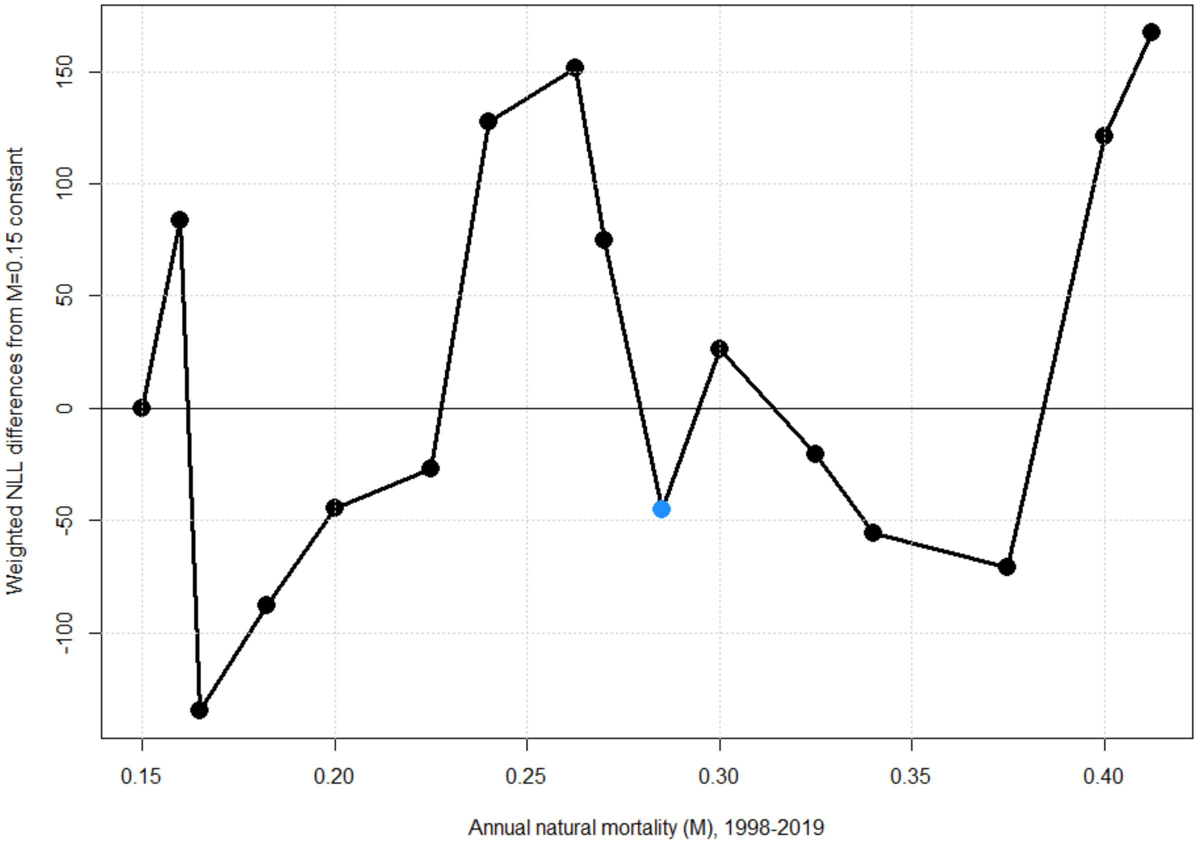

Figure R2. Likelihood profile for M for 1998-2019, SNE stock, with NLL weighted relative to a model with the baseline constant M of 0.15 after 1997. The blue point represents the assumed M after 1997 in the base case model.

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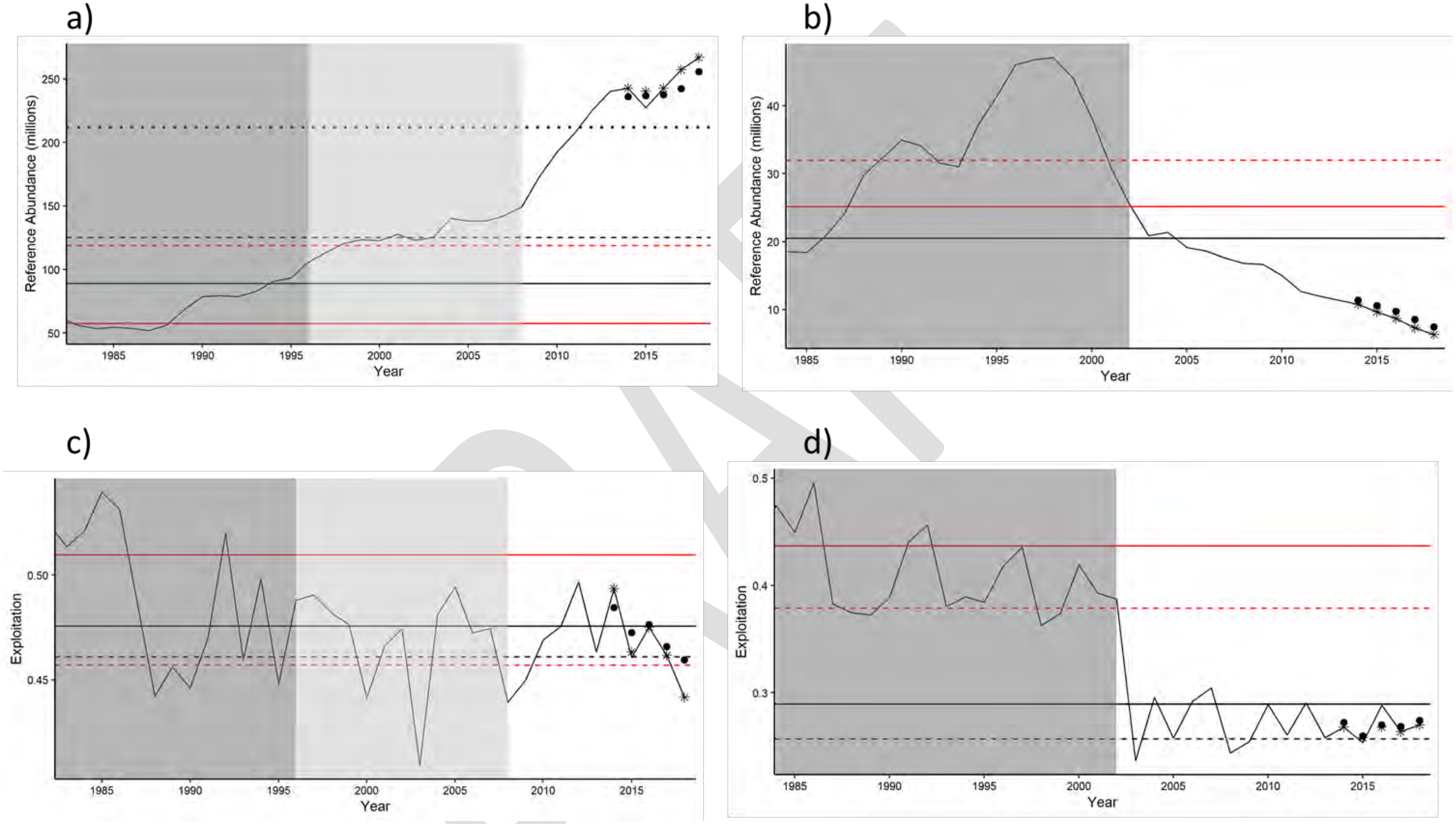

Figure R3. GOMGBK reference abundance (a) and exploitation (c); SNE reference abundance (b) and exploitation (d). Star symbol = running weighted median; solid circle = running average.

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Advisory Report

A. Status of Stocks: Current and projected

New reference points to determine stock status were developed for the assessment (see F., below). Additionally, given model uncertainty and inter-annual variability in model estimates, three-year averages of lobster abundance or exploitation were compared to their respective reference points to determine stock status.

The Gulf of Maine-Georges Bank (GOMGBK) stock was not depleted, as the three-year average abundance from 2016-2018 was greater than the abundance target. The stock was at record high abundance levels. Stock projections conducted as part of the assessment suggested a low probability of abundance declining below the abundance target over the next 10 years. Trends in exploitation in GOMGBK have been more variable than trends in lobster abundance. However, the stock was not experiencing overfishing as the three-year average exploitation was below the target level.

The Southern New England (SNE) stock was significantly depleted as the three-year average abundance from 2016-2018 was considerably below the abundance threshold. The stock was at record low abundance, and stock projections conducted as part of the assessment show a low probability of the condition changing among the most credible scenarios. Trends in exploitation in SNE have been more variable than trends in lobster abundance. However, the stock was not experiencing overfishing as the three-year average exploitation was between the threshold and target levels.

B. Stock Identification and Distribution

American lobster have historically been considered as three distinct stocks: The Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE). While the stocks appear genetically mixed, regional differences in demographic rates, including maturity and growth, supported separate stock designations for management. As populations grew and size compositions shifted in the Gulf of Maine in recent years, survey data suggested migrations of large female lobsters between GOM and GBK. This connectivity led to poor model performance when GOM and GBK were considered separately, and the 2015 assessment combined the stocks as a result.

However, substantial uncertainty remained regarding the extent to which the stocks are connected by adult movement or larval dispersal. The Review Panel agreed that convening a stock structure working group with both US and Canadian researchers would improve future assessments. Additional surveys or analyses to address stock structure issues should be pursued.

C. Management Unit

The United States' management unit for American lobster is the Northwest Atlantic Ocean and its adjacent inshore waters where lobster are found from Maine through North Carolina. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery in state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore), both under the authority of the Atlantic Coastal Fisheries Cooperative Management Act.

D. Landings

In the 1800s, the lobster fishery produced large lobsters for fresh markets in New York and Boston. From the 1840s to 1880s a cannery market grew for smaller lobster that were not sent to the fresh markets. By 1840, wooden lath traps were the dominant gear, and early vessels were row boats or powered by sail. Landings declined through the latter decades of the 1800s and through the first few decades of the 1900s. However, using more efficient vessels, the offshore trap fishery intensified through the second half of the twentieth century leading to increases in landings. Since the 1970s, landings have quadrupled, exceeding 60,000 mt since 2012.

Management measures include minimum carapace length, v-notching closed seasons, maximum size, slot limits, trap limits, and protection of egg bearing females. Many of the regulations have been in use for at least 100 years.

The modern fishery consists of landings from inshore (0 to 12 nautical miles) and offshore components. The Gulf of Maine and Southern New England have historically supported the largest fisheries, predominantly from landings from inshore waters (Figure 62). Landings in the Gulf of Maine averaged 14,600 mt through the 1980s, then climbed steadily, averaging 63,016 mt since 2014. Southern New England had the second largest landings, reaching a high of 9,902 mt in 1997. However, since that time landings have declined reaching a low of 1,243 mt in 2018 (Figure 65). The smallest fishery produces landings from Georges Bank, with landings reaching a high of 2,039 mt in 2018. Currently, Georges Bank and Southern New England each represent less than 10% of the total landings.

E. Data and Assessment

a. Data

For each stock area, there were numerous fisheries independent and fisheries dependent data sources available to provide information on lobster abundance, distribution, length frequencies and sex ratio. The large number of data sets available was a strength of the assessment in that spatial and temporal patterns can be evaluated.

The statistical analyses done to standardize the various time series and account for factors outside of changes in lobster abundance were carefully thought out and provided robust information for the assessment. There were some areas where further research may improve analyses. However, the work done for the current assessment were enhancements over previous assessments.

b. Assessment

Two main approaches were used in the assessment: model-free indicators and a statistical catch at length model. The model free indicators provided information about the overall health

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of each stock (GOM, GBK, and SNE) independent of statistical models. Four categories were developed: indicators related to abundance, mortality, stress, and fishery performance. This component of the assessment was geared toward communicating trends in the numerous data series in a straightforward way that is free of modeling assumptions. The average of the most recent five-years of data are compared to percentile breaks (0-25%, 25-75%, and 75-100%) derived from the entire time series to summarize indicator condition, and generally are described as negative, neutral, or positive, depending on the specific indicator. The Panel recommended alternative terminology for several indicators. E.g., for the stress and effort indicators, consider low-medium-high instead of negative-neutral-positive. The indicators should be interpreted somewhat cautiously, and in relation to other indicators.

The statistical catch at length model, the University of Maine Model (UMM), was the assessment tool used to quantitatively determine stock status and was the recommended model for management. The scale of the model outputs was less certain than the trends, an outcome consistent with previous lobster assessments using the model.

F. Biological Reference Points

New reference points were developed for the assessment to acknowledge that previous reference points may not be appropriate in a changing environment because they used a fixed time period of abundance or exploitation to judge stock status. Conditions during the fixed period of time may not be comparable or relevant to current conditions. The statistical method of regression trees was used to develop abundance reference points, whereby sequential years of data were grouped in a way that minimized an estimate of variation within and between each group of years.

Abundance reference points were linked to 'regimes' identified in the regression tree analyses and defined based on SAS level and perspective of concern about corresponding stock abundance condition. The assessment adopted reference point definitions provided in ASMFC (2008): a target reference point indicates a desirable state of a fishery; a limit reference point indicates an undesirable state of a fishery which management action should be taken to avoid; and a threshold reference point indicates a 'red area' where continuity of resource production is in danger and immediate action is needed.

Exploitation reference points were defined to assess the status of the stock with respect to fishing mortality (overfishing vs. not overfishing). Target and threshold exploitation reference points were defined as the 25th and 75th percentiles, respectively, of annual exploitation during the current abundance regimes for each stock.

G. Fishing Mortality

Overfishing status was determined using a metric known as effective exploitation. Effective exploitation was the annual catch in numbers divided by reference abundance. Reference abundance was the sum of the estimated number of lobsters 78+ mm on January 1 and abundance of lobsters that will molt and join the 78+ mm group later in the year. Overfishing status was determined by comparing current effective exploitation to an effective exploitation

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reference point. The 2020 American lobster stock assessment concluded that overfishing was not occurring for the GOMGB stock. Likewise, overfishing was not occurring for the SNE stock.

H. Recruitment

Recruitment was examined in both the model-free indicators as well as the UMM. In the GOMGBK, recruitment indicators from the trawl surveys remained positive or neutral (high levels) in the most recent years. Young-of-year settlement has been variable in GOMGBK, but there remains uncertainty in whether settlement habitat has changed, leading to potential biases in the YOY index. The UMM suggested recruitment was high recently, but the most recent years of data (i.e., 2019 and 2020) were not included in model runs.

In SNE, both model-free indicators and the UMM model results suggested recruitment remains low with no signs of improvement.

I. Spawning Stock Biomass

Spawning stock biomass (SSB) was not estimated directly in the UMM, it was derived in two forms: model output and survey indices as model-free indicators. The derived SSB estimates represented maximum reproductive potential, as static size at maturity and weight and length relationships are used. In reality, other factors are affecting SSB, such as differential mating success and abnormal clutches. Recent studies have shown realized reproductive potential may be substantially lower than maximum reproductive potential (Tang et al. 2018).

GOMGBK SSB estimates from the model free indicators were all positive or neutral, suggesting high levels of spawning stock. In comparison, SNE SSB estimates from the model free indicators were all negative, owing largely to the long-term low levels of incoming recruitment.

J. Bycatch

Discards of lobster in the offshore commercial lobster fishery are not well characterized. Sea sampling indicated significant regulatory and market-driven discards of sublegal, oversized, v-notched, and ovigerous females. Discard mortality was assumed to be low. However, research suggested that discard mortality was higher when the shell was damaged. Given that shell disease acts upon the shell, shell disease may increase discard mortality. The Review Panel recommended revisiting the assumption of low discard mortality for SNE.

Lobsters are caught as bycatch in other federally-managed fisheries including otter trawl, scallop dredge, and sink gillnet. Total discards are estimated from the ratio of discard weight to target species weight from observer data and extrapolated to the fleet based on the retained catch from vessel trip reports. The Panel concluded the existing methods were appropriate for incorporating discards as a data source in the assessment.

K. Other Comments

a. Environmental impacts/drivers

A major advance in the assessment was the consideration of environmental and climatic drivers on stock dynamics. Environmental regime shifts were explored in each of a suite of

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environmental variables, including water temperatures, degree days, and oceanographic features such as Labrador Slope Water and the Mid-Atlantic Cold Pool. Bottom-up drivers on lobster dynamics were explored by examining time series of zooplankton communities. In GOMGBK, breakpoints emerged for the majority of time series around 2010, providing support for a regime shift. The timing for regime shifts in SNE across different environmental variables were less consistent.

Moving forward, the Panel recommended additional detail be provided on the methodology of the regime shift analysis and the statistical support for each break point. Further, evaluating formal correspondence between the timing of shifts across environmental time series and the degree to which lobster reference abundance varies explicitly in relation to the time series will provide greater mechanistic understanding of how the environment affects lobster populations.

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Atlantic States Marine Fisheries Commission

2020 American Lobster Benchmark Stock Assessment

Prepared by the
ASMFC American Lobster Stock Assessment Subcommittee

October 2020

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EXECUTIVE SUMMARY

American lobster (*Homarus americanus*) supports one of the most valuable commercial fisheries in the Northeast U.S. with an annual estimated revenue in excess of $631 million in 2018 (NMFS, 2020). The United States' management unit for American lobster is the Northwest Atlantic Ocean and its adjacent inshore waters where lobster are found from Maine through North Carolina. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery in state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore), both under the authority of the Atlantic Coastal Fisheries Cooperative Management Act. For management purposes, the management unit is subdivided into seven lobster conservation management areas that cut across the two biological stock unit boundaries.

Currently, American lobster is managed under Amendment 3 to the Interstate Fishery Management Plan and its subsequent Addenda, I-XXVI. The plan is designed to minimize the chance of population collapse due to recruitment failure. The goal of Amendment 3 is to have a healthy American lobster resource and management regime, which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders.

Total commercial landings remained low, averaging approximately 5,000 metric tons (mt) from the 1920s through the 1940s. Total landings increased slowly from 1940 through 1970, averaging near 14,000 mt through the late 1970s. Landings have since quadrupled and have exceeded 60,000 mt since 2012. US lobster landings are primarily comprised of catch from inshore waters (0 to 12 nautical miles).

Historically, the population has been divided into three biological stocks based on regional differences in life history parameters. They are the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE). Each stock is comprised of both an inshore and offshore component with the GOM and SNE areas being predominantly inshore fisheries and the GBK area being predominantly an offshore fishery.

GOM supports the largest fishery. Commercial lobster landings in the Gulf of Maine were stable between 1981 and 1989 averaging 14,600 metric tons (mt), and then increased steadily from approximately 20,000 mt in early 1990s to approximately 35,000 mt in the mid-2000s. From 2007 to 2013 landings nearly doubled and reached the time series high of 68,456 mt in 2018. Since 2014 total GOM landings have averaged 63,016 mt.

GBK constitutes a smaller portion of the U.S. fishery. Commercial lobster landings in the GBK varied around a mean of 1,316 mt between 1982 and 2002. From 2003 to 2018 landings increased substantially, reaching a time series high of 2,039 mt in 2018, and have remained well above the time series mean through 2018.

Before 2011, SNE was the second largest U. S. fishery. Commercial landings in the SNE stock increased sharply from the early 1980s to the late 1990s, reaching a time series high of 9,902 mt in 1997. Landings remained near time series highs until 1999, then declined dramatically so that by the mid-2000s landings were near levels observed in the early 1980s. Since the mid-2000s landings have continued to decline, and in 2018 reached a time series low of 1,243 mt.

The previous stock assessment in 2015 concluded that the GOM and GBK stocks should be combined into a single stock unit (GOMGBK). Analysis of the NMFS Northeast Fishery Science Center (NEFSC) trawl survey data and model performance issues for the GBK stock suggested small, immature females were recruiting to the GOM and then migrating back and forth between the GOM and GBK after growing to larger sizes. This stock structure is maintained in this assessment.

In this assessment, the University of Maine statistical catch-at-length model was used to estimate abundance and mortality of male and female lobsters by size for each stock unit. This was the primary model used in the last two stock assessments (2009, 2015). In addition, trends in a suite of stock status indicators of mortality, stress, abundance, and fishery performance were examined independent of the assessment model.

Current abundance of the GOMGBK stock is at a record high. Abundance estimates show an increasing trend starting in 1988 and accelerating in 2009. Recent recruitment and spawning stock biomass levels are also at or near record highs. Effective exploitation estimates declined from the highest rates in the time series in the mid-1980s to remarkably stable levels since the late 1980s.

Contrastingly, abundance estimates for the SNE stock show a sharp decline through the early 2000s to a record low level in 2018. Estimates for recent recruitment are also at or near record lows. The contraction of the SNE stock has continued since the last assessment and is becoming apparent in the offshore portion as well as the inshore according to survey encounter rates. Effective exploitation was greatest during the period of 1979 to 2002, with a stark decrease in 2003, where exploitation levels have remained low and relatively stable since.

Reference abundance and effective exploitation are used as reference points in the assessment. Reference abundance is the number of lobster 78+ mm CL on January 1 plus the number that will molt and recruit into the 78+ mm CL group during the year. Effective exploitation is the annual catch (in number) divided by the reference abundance. Given the impacts of environmental changes on lobster population dynamics and drastic changes in abundance observed, regime-based reference points are recommended for assessing the status of the stocks. Three abundance reference points are defined for the GOMGBK stock based on regimes in reference abundance detected with regime shift analysis, including one, the Fishery/Industry Target, to assess the stock condition from an economics perspective and two, the Abundance Limit and Abundance Threshold, to assess the status of the stock from a biological perspective. Only the Abundance Threshold is provided for the SNE stock due to the different abundance trajectories estimated in previous and the current assessments, the difference in regimes detected from these abundance trajectories, and low likelihood of reaching even the most precautionary reference point due to documented changes in natural mortality and recruitment failure in SNE. A stock is considered depleted if reference abundance is less than the Abundance Limit (GOMGBK only) and significantly depleted if reference abundance is less than the

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Abundance Threshold. Overfishing would occur if effective exploitation is greater than the 75th percentile of effective exploitation during the stock's current abundance regime.

The GOMGBK stock is in favorable condition based on the recommended reference points. The stock is well above the Abundance Threshold and below the effective exploitation threshold. **Therefore the GOMGBK lobster stock is not depleted and overfishing is not occurring.** Further, the stock is above the Fishery/Industry Target and below the effective exploitation target. **The assessment does not recommend any management action at this time for the GOMGBK stock.**

The SNE stock is in poor condition based on the recommended reference points. The stock is well below the Abundance Threshold and below the effective exploitation threshold. **Therefore the SNE lobster stock is depleted but overfishing is not occurring. The assessment recommends significant management action to provide the best chance of stabilizing or improving abundance and reproductive capacity of the SNE stock.**

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Terms of Reference for Stock Assessment
2020 American Lobster Stock Assessment

1. Estimate catch and catch-at-length from all appropriate fishery dependent data sources including commercial and potential discard data.
    a. Provide descriptions of each data source (e.g. geographic location, sampling methodology, variability, outliers). Discuss data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivities, sample size) and their potential effects on the assessment.
    b. Justify inclusion or elimination of each data source.
    c. Explore improved methods for calculating catch-at-length matrix.

2. Present the abundance data being considered and/or used in the assessment (e.g. regional indices of abundance, recruitment, state-federal and other surveys, length data, etc.).
    a. Characterize uncertainty in these sources of data.
    b. Justify inclusion or elimination of each data source.
    c. Describe calculation or standardization of abundance indices.

3. Evaluate new information on life history such as growth rates, size at maturation, natural mortality rate, and migrations.

4. Identify, describe, and, if possible, quantify environmental/climatic drivers.

5. Evaluate the implications of habitat expansion or contraction on population productivity.

6. Use length-based model(s) to estimate population parameters (e.g., effective exploitation rate, abundance) for each stock unit and analyze model performance.
    a. Evaluate stability of model(s). Perform and present model diagnostics.
    b. Perform sensitivity analyses to examine implications of important model assumptions, including but not limited to growth and natural mortality.
    c. Explain model strengths and limitations.
    d. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    e. State assumptions made and explain the likely effects of assumption violations on synthesis of input data and model outputs.
    f. Conduct projections assuming uncertainty in current and future conditions for all stocks. Compare projections retrospectively with updated data.

7. Review evidence for stock boundaries and associated stock structure and confirm the current stock units are appropriate.

8. Update and develop simple, empirical, indicator-based trend analyses of reference abundance, effective exploitation, and develop environmental drivers for stock areas.

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9. Update the current exploitation and abundance reference points (i.e., targets and thresholds). Explore and, if possible, develop alternative reference points and reference periods that may account for changing productivity regimes due to environmental effects.

10. Characterize uncertainty of model estimates, reference points, and stock status.

11. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters and reference points.

12. Report stock status as related to overfishing and depleted reference points (both current and any alternative recommended reference points). Include simple description of the historical and current condition of the stock in layman’s terms.

13. Address and incorporate to the extent possible recommendations from the 2015 Benchmark Peer Review.

14. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

15. Recommend timing of next benchmark assessment and intermediate updates, if necessary relative to biology and current management of the species.

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External Appendices, which address lobster maturity assessment (Appendix 2), model-based ventless trap survey indices of abundance (Appendix 6), GOMGBK model outputs (Appendix 7), and SNE model outputs (Appendix 8), are available from the Commission upon request at info@asmfc.org.

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1 INTRODUCTION

American lobster (*Homarus americanus*) supports one of the most valuable commercial fisheries in the Northeast U.S. with an annual estimated revenue in excess of $631 million in 2018 (NMFS, 2020). The U.S. lobster resource occurs in continental shelf waters from Maine to North Carolina. Historically, three stocks have been identified based primarily on regional differences in life history parameters. They are the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE) (Figure 1). During the last stock assessment (ASMFC 2015a), evidence of connectivity between the GOM and GBK stocks supported combining these stocks, now referred to as sub-stocks, into one stock unit (GOMGBK). This stock structure is maintained in this assessment with more detail found in Section 2.8, but some information throughout the report, including model free indicators (Section 5), continues to be presented for each sub-stock area to avoid masking trends within these sub-stocks. Each stock supports both an inshore (0-3 miles) and offshore (3-200 miles) component; however total U.S. lobster landings are primarily comprised of catch from nearshore waters (0 to 12 nautical miles).

1.1 Management Unit

The management unit for American lobster is the entire Northwest Atlantic Ocean and its adjacent inshore waters where lobster is found from Maine through Virginia. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery in state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore), both under the authority of the Atlantic Coastal Fisheries Cooperative Management Act. The fishery management plan (FMP) is written to provide for the management of lobsters throughout their range. The FMP is designed to specify a uniform program regardless of lines that separate political jurisdictions, to the extent possible. The different management authorities are expected to take necessary actions to apply the provisions of this FMP in waters under their respective jurisdictions. For management purposes, the management unit is subdivided into seven Lobster Conservation Management Areas (LCMAs) that cut across stock boundaries in many cases (Figure 1). Management units do not correspond to stock units defined in this assessment.

1.2 Regulatory History

The ASMFC American Lobster Board approved Amendment 3 to the FMP in December of 1997. The plan is designed to minimize the chance of population collapse due to recruitment failure. The goal of the amendment is to have a healthy American lobster resource and management regime, which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders. To achieve this goal, the plan adopts the following objectives:

1. Protect, increase or maintain, as appropriate, the brood stock abundance at levels which would minimize risk of stock depletion and recruitment failure;

2. Develop flexible regional programs to control fishing effort and regulate fishing mortality rates;

3. Implement uniform collection, analysis, and dissemination of biological and economic information; improve understanding of the economics of harvest;
4. Maintain existing social and cultural features of the industry wherever possible;
5. Promote economic efficiency in harvesting and use of the resource;
6. Minimize lobster injury and discard mortality associated with fishing;
7. Increase understanding of biology of American lobster, improve data, improve stock assessment models; improve cooperation between fishermen and scientists;
8. Evaluate contributions of current management measures in achieving objectives of the lobster FMP;
9. Ensure that changes in geographic exploitation patterns do not undermine success of ASMFC management program;
10. Optimize yield from the fishery while maintaining harvest at a sustainable level;
11. Maintain stewardship relationship between fishermen and the resource.

Amendment 3 defined overfishing for the American lobster resource to occur “when it [any stock] is harvested at a rate that results in egg production from the resource, on an egg-per-recruit basis, that is less than 10% of the level produced by an unfished population” (ASMFC, 1997). The primary management measures used to prevent overfishing include a minimum size, protection of ovigerous females, and trap limits.

Amendment 3 also established a framework for area management, which includes industry participation through seven Lobster Conservation Management Teams (LCMT). LCMTs were encouraged to develop recommendations for a management program, which suits the needs of the area while meeting targets established in the plan. The Board adopted a three-phase approach to incorporate the LCMT recommendations, which involved three addenda to Amendment 3. Addendum I incorporated measures from the LCMT proposals directed at effort control. After consideration of the stock assessment and peer review results in ASMFC (2000), the Board initiated the development of Addendum II in August 2000 to continue implementation of the 1998 LCMT proposals. Addendum III incorporates the alternative management measures presented to the Board for the purposes of meeting F10% by calendar year 2008.

Addendum IV addressed four different issues of lobster management: a proposal from the Area 3 LCMT; concern about stock conditions in Area 2; new information about vent selectivity; and a desire to change the interpretation of the most restrictive rule. First, Addendum IV outlined a transferable trap program for LCMA 3. This program allows LCMA 3 lobster fishermen to transfer trap tags to other lobster fishermen. Along with other measures, the addendum LCMA 3 transferability program establishes an overall trap cap and conservation taxes for transferring

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traps. Second, Addendum IV included an interim benchmark goal based on survey information and a Total Allowable Landings to be used as a performance measure. This Addendum included an effort control program and gauge increases for LCMA 2. Third, Addendum IV changed the circular vent size requirement from 2 1/2 inches to 2 5/8 inches. In addition, vent sizes of 2 1/16" rectangular and 2 11/16" circular are required for those LCMA's (LCMA 3, 2, OCC) that have scheduled increases to a 3 1/2" minimum legal carapace length. Fourth, Addendum IV applies the most restrictive rule on an area trap cap basis without regard to the individual's allocation. Fishermen who designate multiple management areas on their permits are bound by the most restrictive management measures of those areas' trap caps; they are allowed to fish the number of traps they are allocated in that most restrictive area.

Addendum V amended the overall trap cap set by Addendum IV based on comments gathered at public hearings expressing concern that the overall trap cap of 2600 may be too high. Addendum V set an overall trap cap of 2200 with the higher tax imposed when the purchaser owns 1800 to 2200 traps.

Addendum VI replaces two of the effort control measures of Addendum IV: permits and eligibility period. No new LCMA 2 permits will be distributed after December 31, 2003 and to qualify for an LCMA 2 permit endorsement, a permit holder must document landings between January 1, 1999 and December 31, 2003.

Addendum VII established a multi-state effort control program for LCMA 2 that governs traps fished in state and federal waters to cap effort (traps fished) at 2003 levels and allows adjustments in traps based on future stock conditions. The plan limits participation to permit holders who have been active in the fishery in recent years, creates permit-holder specific trap limits that are unique and based on reported traps fished and landings, and establishes a transfer program that allows the transfer of trap allocations with a conservation "tax".

Addendum VIII established reporting and monitoring requirements, which were replaced by Addendum X. Addendum VIII also established new reference points recommended by the 2005 assessment and peer review report.

Addendum IX set a 10% conservation tax for LCMA 2 trap allocation transfers.

Addendum X established a coastwide reporting and data collection program that includes 100% dealer and at least 10% harvester reporting, at-sea sampling, port sampling, and fishery-independent data collection replacing the requirements in Addendum VIII.

Addendum XI incorporates rebuilding measures in response to the 2005 assessment finding that the SNE stock is depleted and overfished, including a 15-year rebuilding timeline (ending in 2022) with a provision to end overfishing immediately. The Addendum also established measures to discourage delayed implementation of required management measures.

Addendum XII established measures for a trap transfer program. In order to ensure that the various LCMA-specific effort control plans remain cohesive and viable this addendum does

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three things. First, it clarifies certain foundational principles present in the Commission's overall history-based trap allocation effort control plan. Second, it redefines the most restrictive rule. Third, it establishes management measures to ensure that history-based trap allocation effort control plans in the various LCMAs are implemented without undermining resource conservation efforts of neighboring jurisdictions or LCMAs.

Addendum XIII solidified the transfer program for OCC and stopped the ongoing trap reductions. Addendum XIV altered two aspects of the LCMA 3 trap transfer program. It lowered the maximum trap cap to 2000 for an individual that transfers traps. It changed the conservation tax on full business sales to 10% and for partial trap transfers to 20%. Finally, Addendum XV established a limited entry program and criteria for Federal waters of LCMA 1.

Addendum XVI established new biological reference points to determine the stock status of the American lobster resource (fishing mortality and abundance targets and thresholds for the three stock assessment areas). The addendum also modified the procedures for adopting reference points to allow the Board to take action on advice following a peer reviewed assessment.

Addendum XVII established a 10% reduction in exploitation for LCMAs within SNE (2, 3, 4, 5, and 6). Regulations are LCMA specific but include v-notch programs, closed seasons, and size limit changes.

Addendum XVIII reduced traps allocated by 50% for LCMA 2 and 25% for LCMA 3, with the intent of scaling the size of the SNE fishery to the size of the resource. Specifically, a 25% reduction in year 1 followed by a series of 5% reductions for five years was established in LCMA 2; a series of 5% reductions over five years was established in LCMA 3.

Addendum XIX modified the conservation tax for LCMA 3 to a single transfer tax of 10% for full or partial business sales.

Through Addendum XX, the American lobster offshore pot fleet fishing in Closed Area II developed an agreement with the groundfish sector to prevent gear conflicts and protect concentrations of ovigerous female lobster. The two industries drafted an agreement that would give equal access to the area.

Addendum XXI (2013) addressed changes in the transferability program for Areas 2 and 3. It modified some of the transferability rules originally established in Addenda XII and XIV, and established additional guidelines.

Addendum XXII was the third in a series of addenda that responded to the depleted condition of the SNE lobster resource by scaling the capacity of the SNE fishery to the size of the SNE resource. It implemented Single Ownership and Aggregate Ownership Caps in LCMA 3 (federal waters). These measures were intended to enhance the ability of lobster business owners to plan for their future fishing operations as trap reductions were initiated. The Single Ownership Cap allows LCMA 3 permit holders to purchase lobster traps above the trap cap of 2,000 traps.

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Any traps purchased above the trap cap may not be fished until approved by the permit holder's regulating agency once the trap reductions commence. This allows permit holders to maintain a profitable business over the course of the trap reductions while reducing latent effort (i.e. unfished traps) in the fishery. The Aggregate Ownership Cap limits permitted LCMA 3 lobster fishermen or companies to owning no more traps than five times the Single Ownership Cap, unless the permit holder had the ability to purchase a higher amount prior to NOAA Fisheries publishing a present day control date. Similar management caps were approved for LCMA 2 in August 2013.

Addendum XXIII updates Amendment 3's habitat section to include information on the habitat requirements and tolerances of American lobster by life stage.

Addendum XXIV aligns state and federal measures regarding trap transfer measures. Specifically it removed the 10% conservation tax when whole fishing businesses are transferred, sets a minimum 10 trap allocation transfer increment, and allows transfers between states among permit holders who are authorized to fish both state and federal waters within a single LCMA. Table 1 summarizes the current regulations used to manage the seven LCMAs.

In August 2017, the Board decided not to move forward with Addendum XXV for management use. The Addendum sought to address the depleted condition of the SNE stock while preserving a functional proportion of the SNE lobster fishery, through the consideration of management tools such as gauge size changes, trap reductions, and season closures to achieve a 5% increase in egg production. After reviewing TC input, which found only one out of the five proposals put forth by the LCMTs to be sufficient to achieve a 5% increase in egg production, the Board decided not to approve the Draft Addendum. Some members felt the proposed measures did not go far enough to protect the stock and were concerned that the majority of LCMT proposals would not achieve the required 5% increase in egg production. Others believed significant reductions had already occurred in the fishery and no further action was needed.

Addendum XXVI addresses deficiencies in the harvester reporting and biological data collection requirements for the lobster and Jonah crab fisheries. Specifically, the Addendum improves the spatial resolution of data by requiring fishermen to report via 10-minute squares, which further divide the existing statistical areas. In addition, the Addendum established a one year pilot program to explore electronic tracking devices in the fishery. Regarding harvester trip reports, the Addendum requires additional data elements including 'number of traps per trawl' and 'number of buoy lines' in order to collect information on gear configurations. The Addendum also requires the states to implement 100% harvester reporting within a five year deadline, with the prioritization of electronic harvester reporting development during that time. In the interim, jurisdictions with less than 100% harvester reporting should redistribute the current effort associated with harvester reporting to focus on active, as opposed to latent, permit holders. Finally, the Addendum improves the biological sampling requirements by establishing a baseline of ten sampling trips per year in the lobster/Jonah crab fishery and encourages states with more than 10% of coastwide landings in either the American lobster or Jonah crab fisheries to conduct additional sampling trips.

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1.3 Assessment History

The models used to assess American lobster stocks starting in 1992 (NEFSC 1992; NEFSC 1993; NEFSC 1996; ASMFC 2000) and prior to the currently used University of Maine model (ASMFC 2006, ASMFC 2009, ASMFC 2015a) included length cohort analysis, the Collie-Sissenwine (a.k.a. modified DeLury) model, and the life history (a.k.a. egg production per-recruit or EPR) model. The Collie-Sissenwine model (CSM) was used to estimate abundance and fishing mortality rates in the stock using landings and bottom trawl survey data. The life history model was used to estimate egg production per-recruit reference points such as $F_{10\%}$, the fishing mortality rate that allows female lobster recruits opportunity, on average, to spawn 10% of the number of eggs that would be spawned in the absence of a fishery. The $F_{10\%}$ reference point was used in lobster stock assessments to determine if overfishing was occurring until ASMFC 2000. Previous stock assessments generally concluded that fishing mortality rates were high for lobster and above the $F_{10\%}$ reference point in particular, especially in near shore regions that are heavily fished.

Early in 1996, a Lobster Review Panel was convened by ASMFC and NMFS to provide advice on stock structure, stock assessment, abundance changes, management, and benthic ecology (ASMFC 1996). The Panel concurred with NEFSC's (1996) conclusion that the lobster resource was experiencing overfishing ($F> F_{10\%}$) in all areas. The Panel endorsed the stock assessment methods and stock definitions used by NEFSC (1996) and made a number of recommendations for future research and development.

Conclusions and recommendations from the 2000 assessment (ASMFC 2000) were similar to conclusions and results from previous assessments. Overfishing was occurring in all three stock areas (Gulf of Maine-GOM, Georges Bank and southern New England outer shelf-GBS, and South of Cape Cod to Long Island Sound-SCCLIS) according to the overfishing definition in the Fishery Management Plan for American lobster (i.e. recent fishing mortality rates > $F_{10\%}$, ASMFC 1997). SAS members agreed that all three stocks assessed were subject to growth overfishing, the fishing mortality rate that maximizes yield in weight per-recruit. Abundance and recruitment levels were high and the majority agreed that recruitment overfishing was not occurring. At this time, a number of new assessment approaches were investigated for American lobster. A panel of reviewers (ASMFC 2000b) generally supported results and conclusions from the 2000 assessment (ASMFC 2000) but noted serious shortcomings in biological and fishery data used to assess the stocks, and recommended further work on new modeling approaches.

In preparation for the 2006 assessment, the American Lobster Stock Assessment Model Technical Review Panel (ASMFC 2004) evaluated the CSM model and three new potential modeling approaches for lobster based on simulation analyses. Problems were identified in all three new approaches and shortcomings in biological and fishery data were noted. The 2004 Model Review Panel recommended that the University of Maine model (UMM), a forward-projecting size-based approach that tracks numbers of lobster in a range of size groups by sex, season, and year in addition to estimating yield and spawning biomass per-recruit reference points (Chen et al. 2005a), be implemented for lobster stocks once the necessary data became available and when analysts could demonstrate sufficient information content in the size data.

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Based on these recommendations the TC moved forward in the 2006 assessment using a modified UMM (ASMFC 2006). The 2006 Peer Review Panel also recommended using the UMM because it provides a better foundation for incorporating size composition data from multiple sources simultaneously, capturing the seasonality of the fishery and the lobster life history, and providing a comparable estimate of fishing mortality and reference points.

The 2006 peer-reviewed stock assessment report, which included data through 2003, indicated the American lobster resource presents a mixed picture, with stable stock abundance throughout most of the GOM and GBK, low abundance and recruitment in SNE, and decreased recruitment and abundance in Massachusetts Bay and Stellwagen Bank, (NMFS Statistical Area 514). Of particular concern was SNE, where depleted stock abundance, low recruitment, and high fishing mortality rates had led the Peer Review Panel to call for additional harvest restrictions. Threshold reference points for determining stock status were defined as the medians of abundance and fishing mortality from 1982 to 2003 for GOM and GBK and 1984 to 2003 for SNE. One of the shortcomings of these reference points was that the status of each stock is solely based on comparison with a relatively recent 20 to 22-year trend. Trends for a suite of model-free indicators were also examined for the same time period. Abundance of the GOM stock overall was relatively high compared to the 22-year time series. Fishing mortality was low compared to the past. Recruitment and post recruitment abundance for the southern GOM (NMFS Statistical Area 514) declined to historical lows. The GBK stock appeared to be stable; current abundance and fishing mortality were similar to their medians for the 22-year time series. The SNE stock abundance was relatively low compared to the 20-year time series and fishing mortality was relatively high.

For the 2009 peer-reviewed stock assessment, the UMM was used again to estimate abundance and mortality of male and female lobsters by size for each stock unit. The CSM used in the 2006 assessment was updated as well for continuity purposes. In addition, trends in the suite of model-free indicators of mortality, abundance, and fishery performance were examined using a “traffic light approach.”

The 2009 report indicated the American lobster resource presents a mixed picture, with record high stock abundance and recruitment throughout most of the GOM and GBK, continued low abundance and poor recruitment in SNE, and further declines in recruitment and abundance in NMFS Statistical Area 514 since the last assessment. Abundance of the GOM stock was at a record high compared to the 26-year time series. Recent exploitation rates had been comparable to the past whereas recruitment has steadily increased since 1997. Abundance of the GBK stock was at a record high compared to the 26-year time series and recent exploitation rates were at a record low. Recruitment had remained high in GBK since 1998. Sex ratio of the population in recent years was largely skewed toward females (~80% from 2005 to 2007). The TC noted the stock could experience recruitment problems if the number of males in the population are low. The Peer Review Panel noted particular concern regarding the status of the stock throughout the SNE assessment area and within NMFS Statistical Area 514 and recommended further restrictions for both areas. The assessment showed current abundance of the SNE stock was the lowest observed since the 1980s and exploitation rates had declined

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since 2000. Recruitment had remained low in SNE since 1998. The assessment recommended revisions to the set of reference points used in the previous assessment (ASMFC 2006) for management of American lobster stocks, including the use of reference abundance (the number of lobster 78+ mm CL on January 1 plus the number that will molt and recruit to the 78+ CL group) and effective exploitation (annual catch in numbers divided by reference abundance) in place of total abundance and instantaneous fishing mortality, but these recommendations were not approved by the ASMFC American Lobster Management Board.

The most recent stock assessment, peer-reviewed in 2015, continued use of the UMM as the primary analysis to determine stock status with supporting information on population and fishery trends from the suite of model-free indicators. The CSM was not updated in this assessment. One of the most notable developments in this assessment was the conclusion that the GOM and GBK stocks should be combined into a single stock unit (GOMGBK). Analysis of the Northeast Fishery Science Center (NEFSC) trawl survey data showed migration patterns between GOM and GBK, with higher catch rates of large female lobsters (>100 mm CL) in GOM strata during the spring than in fall and the opposite pattern in GBK strata with higher catch rates in the fall than in the spring. This pattern was not apparent when looking at catch rates collectively across GOM and GBK strata. These dynamics created model performance issues, with the GBK model estimating size distributions of new recruits indicative of larger females migrating into the GBK stock as opposed to smaller lobsters growing from GBK-distinct pre-recruits and recruiting to the modeled size structure. This suggested small, immature females were recruiting to the GOM and then migrating back and forth between the GOM and GBK after growing to larger sizes. Another notable development was the adoption of a step increase in SNE natural mortality in the basecase model from 0.15 to 0.285 in 1998 due to widespread change in habitat suitability and documented mortalities in Long Island Sound.

The recommended reference points from the 2009 assessment in terms of reference abundance and effective exploitation were recommended again in this assessment and adopted with the reference periods from the previous assessment (1982-2003 for GOMGBK and 1984-2003 for SNE) carried forward in this assessment to determine stock status. The thresholds were recommended as the 25th percentile of the reference abundance during the reference period and the 75th percentile of the effective exploitation during the reference period. The targets were recommended as the 75th and 50th percentiles of the reference abundance during the reference period for the GOMGBK and SNE stocks, respectively, and the 25th percentile of the effective exploitation during the reference period for both stocks. The use of per-recruit reference points was not recommended based on their equilibrium assumptions and non-stationarity in environmental conditions known to affect various life stages of lobsters. The assessment found the reference abundance for the GOMGBK stock was above the target at all-time highs. The stock was not experiencing overfishing. The SNE stock was depleted and, conversely to the GOMGBK stock, was at historically low levels well below the threshold. The SNE stock was not experiencing overfishing, indicating environmental conditions were contributing to the continued declines in SNE stock abundance, to an unknown degree, and explaining the use of “depleted” in place of overfished to describe the abundance status. The model-free indicators generally supported the status findings for both stocks.

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2 LIFE HISTORY

2.1 Critical Components of Lobster Habitat

[Portions excerpted from Addendum XXIII to the ASMFC Lobster Fisheries Management Plan: Habitat Considerations, written by Jason Goldstein, 2013]

Habitat components which play a vital role in reproduction and growth, and therefore the long-term sustainability of lobster fisheries, include temperature, salinity, dissolved oxygen, pH, light and photoperiod, substrate, diet, and ocean currents and stratification. The first four habitat components play the largest role in stock sustainability (see summary in Table 2). The potential effects of all habitat components on stock status are discussed below.

2.1.1 Temperature

Temperature is the primary driving force influencing lobster metabolism, activity levels, spawning, development, growth, and possibly life span (Hawkins 1996; ASMFC 1997). Lobster of all life-stages are reported to live in areas that range broadly in water temperature from -1° C to over 25° C (Aiken and Waddy 1986; ASMFC 1997). It is the broad range in temperature regimes observed across their range that causes the significant variability in population vital rates such as growth, maturation, and recruitment.

Temperature is the key factor that determines the length of time females carry eggs and when eggs will hatch (Templeman 1940; Perkins 1972; Aiken and Waddy 1980; Tlusty et al. 2008; Goldstein and Watson 2015). Egg hatching typically occurs when surface water temperatures are generally above 12° C (MacKenzie 1988), varying between June-September depending on the region. After hatching, larval lobsters pass through four stages, a process that is usually completed in 25-35 days (Herrick 1896; see Table 1 in Templeman 1940). However, their pelagic duration is highly temperature dependent (MacKenzie, 1988), and it has been suggested that it can be markedly shorter than previously thought (Annis et al. 2007). If larvae hatch at 10° C they can develop successfully through Stages I and II; however, beyond that, warmer water is needed to complete their development to Stage IV and the early benthic phase, Stage V (MacKenzie, 1988). Water temperature had a direct effect on the total cumulative survivorship to Stage IV, whereby 4%, 56%, 64%, 68%, and 47% survivorship was observed at 10° C, 12° C, 15° C, 18° C, and 22° C, respectively (MacKenzie 1988). The temperature range observed with the highest survival rates also corresponds with the temperature range at which larval duration is shortest (Templeman 1940; MacKenzie 1988). Similarly, Sastry and Vargo (1977) reported significantly lower survivorship to Stage V at 10° C.

Differences in temperature also can influence growth patterns such as onset of molting in juveniles or the start or spawning in adults (Aiken and Waddy 1986; Little and Watson 2005). Variations among thermal regimes have been documented to influence size at maturity and overall somatic growth (Estrella and McKiernan 1989; Little and Watson 2005; Wahle and Fogarty 2006; Bergeron 2011). There is a strong influence of water temperature on all aspects of reproduction, including maturation, spawning, molt cycle, oogenesis and hatching (see Waddy and Aiken 1995 for review). While elevated temperatures accelerate the onset of

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reproductive maturity, low temperatures tend to delay ovarian maturation (Templeman 1936; Waddy and Aiken 1995). Adult lobsters respond to even small changes in temperature (Crossin et al. 1998; Jury and Watson 2000) both behaviorally (e.g., movement) and physiologically (e.g., changes in cardiac cycle) (McLeese and Wilder 1958; Worden et al. 2006). Crossin et al. (1998) showed that lobsters tend to avoid water temperatures below 5° C and above 18° C and exhibit a thermal preference of 15.9° C. A similar thermal preference value of 16.5° C was also found by Reynolds and Casterlin (1979).

Temperature has direct effects on physiological processes such as gas exchange, acid-base regulation, cardiac performance, and protein synthesis among others that can negatively affect these animals under stressful thermal conditions (Whiteley et al. 1997). Laboratory work on lobsters in Long Island Sound (LIS) has shown that as water temperature increased beyond a threshold of ~ 20.5° C, the respiration rate of lobsters increased significantly leading to stress as indicated by marked hemolymph acidosis (Powers et al. 2004, Dove et al. 2005) and depression of immunocompetence (Dove et al. 2005; Steenbergen et al. 1978). Lobsters held at 21° C and 23° C had significantly higher respiration rates than those held at 18° C and 19.5° C (Powers et al. 2004). A key point is that lobsters exposed to seawater temperatures below 20° C are not generally stressed as long as oxygen concentrations remain > 2 mg O_2L^{-1}. Prolonged exposure to water temperature above 20° C has also been linked to increased incidence of disease including epizootic shell disease (Glenn and Pugh 2006) and excretory calcinosis (Dove et al. 2004). Thus, 20.5° C appears to be a key physiological threshold value for lobster.

2.1.2 Salinity

Lobsters can be found inhabiting shallow coastal areas, bays, estuaries and subtidal areas where they are frequently subjected to conditions of dramatic fluctuations in salinity (e.g., spring run-off and large storm events). In general, the capacity to osmoregulate when exposed to low salinity varies with developmental stage, and the ability to osmoregulate is heavily influenced by temperature (Charmantier et al. 2001). Energetic demands on juvenile and adult lobsters engaged in osmoregulation influence their distributions and movements, particularly in estuarine habitats (Watson et al. 1999) and as a result, adult lobsters adopt behavioral strategies to avoid areas of low salinity (Jury et al. 1994a,1994b).

2.1.3 Dissolved Oxygen

Lobsters require more oxygen as water temperature increases, and hypoxic waters become more stressful as waters warm. For larvae, dissolved oxygen (DO) concentrations < 1.0 mg O_2/L and pH levels < 5.0 and > 9.0 are lethal (Ennis 1995). The lower lethal oxygen level for juveniles and adults ranges from 0.2 mg O_2/L at 5° C to 1.2 mg O_2/L at 25° C in 30 ppt (Harding et al. 1992). A study conducted in western Long Island Sound (WLIS) showed that in general, lobsters demonstrated a behavioral avoidance of DO levels < 2 mg/L, a lower critical threshold than other finfish and squid (Howell and Simpson 1994). During a severe hypoxic event in 1999 in WLIS, large congregations of lobsters were documented near the edges of hypoxic zones where DO was > 2 mg/L, having moved away from areas with lower DO (see review in Pearce and Balcom 2005). Prior to molting, juveniles and adults become more susceptible and sensitive to low DO as oxygen consumption peaks at molting (Penkoff and Thurberg 1982) and molting lobsters have been found to be less resistant to high temperature, low DO and salinity than lobsters during intermolt periods (Waddy et al. 1995). Because *H. americanus* exhibits prolonged maternal care of its brood (e.g., ventilation and fanning of eggs), it is probable but not documented that ovigerous females require different conditions to successfully carry egg clutches through to hatch and may select habitats that contain sediments providing a high rate of oxygen exchange (e.g., Dungeness crabs, Stone and O'Clair 2002).

2.1.4 Ocean Acidification

In recent years the effects of ocean acidification (OA), resulting from the global increase in atmospheric CO_2 concentration, have been heavily studied in marine invertebrates. Reviews of these works show that responses to projected OA conditions vary significantly across taxa and that many crustaceans appear relatively resistant to OA as a single stressor (Whiteley, 2011, Gledhill et al. 2015). Several OA studies to date have focused on the larval stages of the American lobster under acute OA laboratory treatments. Two initial studies on the development of newly hatched *H. americanus* larvae (Hall and Bowden 2012) and larvae of the congener *H. gammarus* (Arnold et al. 2009) cultured in OA treatments showed that larvae exhibited compromised exoskeletons (disruption of the calcification process) and decreased carapace masses. More recent works have also shown that the interactive effects of OA and rising temperatures can have significant implications for larval growth, gene expression, and behavior (Waller et al. 2017, Niemisto 2019). Further research is needed to determine how other factors may exacerbate or mitigate these interactive effects. Other American lobster studies have reported a range of results highlighting that the species' response to OA conditions is complex with significant differences between life stages and between subpopulations (Waller et al. 2017, McLean et al. 2018, Harrington and Hamlin 2019, Niemisto 2019). Long-term, multigenerational studies would also provide insight into potential sublethal effects and the species' ability to compensate for these environmental changes over time.

2.1.5 Light and Photoperiod

Daily rhythms in lobsters are influenced by endogenous circadian clocks, synchronized to natural light:dark cycles (Lawton and Lavalli 1995). For pre-ovigerous adult females, reproduction seems to be regulated by photoperiod when temperatures rise above a minimum threshold; photoperiod becomes the overriding factor when winter water temperatures remain elevated (Hedgecock 1983, Aiken and Waddy 1980). In a field study of LIS lobsters, Weiss (1970) found that light intensity strongly affected burrow occupancy and foraging behavior. Juvenile lobsters usually stayed in their burrows whenever ambient light intensity exceeded 0.04 μWcm^{-2}.

2.1.6 Substrate

Post-larvae utilize a variety of habitat types (e.g., nearshore rocky areas, offshore canyons, enclosed embayments, estuaries) that differ in their abiotic and biotic features over spatial and temporal scales (Wahle 1993, Wilson 1999, Wahle et al. 2013). Although subtidal cobble beds are largely considered preferred settlement areas (Wahle and Steneck 1991), the plasticity in substrate settlement choice remains broad (Caddy 1986) and selection of substrate types is a complex process (Boudreau et al. 1990, Cobb and Wahle 1994, Wahle and Incze 1997). Howard

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and Bennett (1979) and Pottle and Elner (1982) found that lobsters tend to choose gravel rather than silt/clay substrates. Cobb et al. (1983) and Able et al. (1988) found postlarvae settle rapidly into rock/gravel, macroalgal-covered rock, salt-marsh peat, eelgrass, and seaweed substrates. Wahle et al. (2013) observed recently settled lobsters as deep as 80 m, although most were abundant above the thermocline (typically < 20m, Boudreau et al. 1992) in summer-stratified regions (e.g., W. Gulf of Maine and S. New England); likewise, depth-related differences were diminished in thermally mixed waters. Recent work suggests that warming in the Gulf of Maine on the scale of decades has expanded thermally suitable habitat areas and played a significant role in the increase of observed settlement into deeper areas, particularly in the Eastern Gulf of Maine (Goode et al. 2019). In the absence of shelter, juvenile lobsters require substrate that they can manipulate to form a shelter, especially YOY lobsters (Lawton and Lavalli 1995). The need for specific shelter size may be resolved by the lobster's ability to manipulate its environment, resulting in the construction of suitable shelter from otherwise uninhabitable substrate. Based on tag returns (Geraldi et al. 2009), lobsters that were initially caught and released on barren sediment moved farther and faster than those initially caught in traps on rocky substrate. Complex hard-bottom areas between soft-sediment patches (e.g., eelgrass beds) can serve as corridors and passageways (see Micheli and Peterson 1999) for decapod crustaceans engaged in short- or long-term movements (Selgrath et al. 2007).

2.1.7 Diet

Lobsters forage among a wide spectrum of plants and animals that include crustaceans, mollusks, echinoderms, polycheates, macroalgae, and plankton. The natural diet of larval and postlarval lobsters includes the wide variety of phytoplankton and zooplankton available to them (Ennis 1995). Zooplankton has been shown to provide an adequate diet for the growth and survival of shelter-restricted juveniles and supplements the diet of emergent phase juveniles (Barshaw 1989, Lavalli 1991). Lobsters are known to temporally shift their diet depending on season or habitat (Elner and Campbell 1987, Conklin 1995) and are considered keystone predators, capable of driving the trophic dynamics in many benthic communities (Mann and Breen 1972). There is typically peak feeding activity for adults between June and July; feeding activity then remains high in September even as temperatures begin to fall, and females maintain a higher level of feeding activity than males, at least until mid-February (Lawton and Lavalli 1995). Given the widespread use of baited traps, it is very likely that the presence of this food source plays a role in habitat selection in some areas. Since many lobsters, especially sublegal sizes, enter and vacate traps repeatedly (Jury et al. 2001), it is likely that most lobsters feed from traps before they are finally captured. In areas of intense fishing pressure, trap bait may provide a significant energy subsidy, supplementing the natural food resources available on lobster grounds (Lawton and Lavalli 1995, Grabowski et al. 2010); however, determining the value of bait as a dietary component requires more work (see Goldstein and Shields 2018).

2.1.8 Ocean Currents and Stratification

2.1.8.1 Ocean Currents in GOM

[Excerpts from January 12, 2017 TC Memorandum on the GOMGBK Stock]

Circulation changes in the Gulf of Maine may have implications for future recruitment and spawning stock of American lobster through population connectivity. Recent genetic work indicates lobsters north of Nova Scotia and in the Gulf of St. Lawrence may be genetically different than the GOMGBK and SNE stocks; however, lobsters within the U.S. managed stocks appear to be genetically indistinguishable, suggesting possible stock mixing (Benestan et al. 2015; see Section 2.7). Synchrony between settlement densities and models that predict larval transport suggests there is strong connectivity between these life stages that rely on physical oceanography (Incze et al. 2010). Given the apparent significance of circulation on recruitment, Gulf of Maine current systems are summarized below to evaluate prospective future challenges under a changing environment.

The Gulf of Maine is a semi-enclosed system with an overall counterclockwise circulation (Figure 2). The majority of deep water entering the Gulf of Maine is through the Northeast Channel, located between Georges Bank and Browns Bank (Figure 3). Water masses entering deep through the Northeast Channel are largely influenced by current systems north and south of the domain and are reflective of the slope water outside of the Gulf (Townsend et al. 2004). The slope water conditions vary based on the predominance of two types of slope water: the Labrador Sea Slope Water (LSSW) and the Warm Slope Water (WSW) (MERCINA 2001, Townsend et al. 2010). The LSSW originates from the Labrador Current, moves south around the Grand Banks towards the Northeast Channel, and is characterized as cold, fresh, and low in nitrate. The WSW originates from the Gulf Stream, moving north/northeast, and is typically warmer, saltier, and higher in nitrate than the LSSW. Prevalence of either water mass on the slope and that enters the Gulf of Maine typically depends on the strength of the Labrador Current and/or Gulf Stream. The strengths of these current systems are linked to the atmospheric pressure system over the North Atlantic, represented as the North Atlantic Oscillation (MERCINA 2001; Pershing et al. 2005). North Atlantic Oscillation phase shifts and changes in slope water temperatures have implications for water column mixing, primary productivity, and zooplankton abundances in the Gulf of Maine (MERCINA et al. 2001, 2004). With strong tidal mixing and progressive counter-clockwise circulation in the northern Gulf of Maine, deep water entering via the Northeast Channel is vertically mixed with surface waters. At the surface, these waters move counterclockwise in the Gulf of Maine and eventually exit through the Great South Channel between Georges Bank and Nantucket Shoals, or the Northeast Channel.

Fresh, less dense surface water enters the Gulf of Maine from the Scotian Shelf (Brown and Beardsley, 1978; Pettigrew et al. 1998). It is this northern portion of the Gulf of Maine, near the mouth of the Bay of Fundy, where the Gulf of Maine's coastal current system begins, known as the Gulf of Maine Coastal Current (GMCC). The GMCC is a pressure gradient current driven by freshwater inflows to the Gulf of Maine (Pettigrew et al. 2005). GMCC surface waters flow south as part of two major branches. The Eastern Maine Coastal Current (EMCC) is characteristic of a cold band that extends southwestward from the Bay of Fundy towards Penobscot Bay. At this juncture, the EMCC bifurcates (Figure 3). One pathway includes water moving offshore to the center of the Gulf, contributing to the cyclonic circulation around Jordan Basin (Pettigrew et al. 1998). The other branch continues along the coast to what becomes the

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Western Maine Coastal Current (WMCC) (Brooks, 1985; Pettigrew et al. 2005). The WMCC is a buoyant, wind-driven current which accumulates plume water from several Maine rivers (e.g. Kennebec, Androscoggin, Penobscot, Merrimack and St. John Rivers) as it flows southwest (Geyer et al. 2004; Janzen et al. 2005). Plume thickness within the WMCC can be 20m in depth up to 100m, suggesting the WMCC can be stratified over the water column depending on the amount of freshwater (Geyer et al. 2004). Once around Cape Ann, the WMCC either enters northern Massachusetts Bay or moves offshore along the eastern edge of Stellwagen Bank towards Georges Bank, depending on the wind conditions (Lynch et al. 1997; Jiang et al. 2007).

The physical structure of the GMCC and its two branches (EMCC, WMCC) can change from year to year. Pettigrew et al. (2005) described the three GMCC summer scenarios at the interface of the EMCC and the weaker WMCC. The typical condition of the GMCC is “gate ajar” where most of the EMCC deflects offshore at Penobscot Bay, though there is some spillover in the nearshore into the WMCC. The two other scenarios are when the EMCC is connected to the WMCC increasing the western flow and connectivity as a “gate open” condition, or the “gate closed” condition where the EMCC does not flow west of Penobscot Bay and is deflected offshore. These three scenarios can impact larval settlement differently.

The GMCC strength and water properties have implications for downstream nutrient and particulate loading (Balch et al. 2012), phytoplankton species composition (Jiang et al. 2014) harmful algal bloom prevalence (Franks and Anderson 1992), primary productivity (McManus et al. 2014), and larval fish transport and survival (Churchill et al. 2016). Particularly for the clockwise gyre circulating around Georges Bank, phytoplankton biomass produced in GMCC can support biological productivity on the Bank (Hannah et al. 1998).

As such, lobster settlement in coastal Maine may be influenced by the transport and the habitat structure of the GMCC. Physical transport, behavioral responses to changing environments, and reduced survival are all mechanisms that the GMCC may have on lobsters from hatch to settlement. Annis et al. (2013) found that while larval lobster abundances did not vary across different bottom temperature regions in coastal Gulf of Maine, settlement abundances were higher in the warmer (>12ºC), coastal areas. Barret et al. (2016) also identified temperature as critical in dictating larval survival, settlement behavior, and post larval energetics. The authors found that thermoclines in the water column reduce settlement (Barret et al. 2016), thus prospective stratification in the GMCC could impact recruitment for the GOMGBK stock. Differences in the EMCC and WMCC systems may transcend to spatial differences in lobster recruitment patterns along the coastal Gulf of Maine. Chang et al. (2016) found that stock-recruitment relationships, both fitness, form, and parameter estimates, varied between eastern and western Gulf of Maine. Further, the authors note that data aggregation and analyses at a medium scale were best in identifying stock-recruitment relationships. Thus, while it is known that fine-scale oceanographic processes are important to larval settlement, there is not a good understanding of how to scale this fine-scale information up to the population level.

Future changes in Gulf of Maine oceanography and the GMCC may have implications for larval transport and settlement locations. Given lobster larval transport relies heavily on the GMCC

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and varies with strength of the GMCC and prevailing winds (Xue et al. 2008), long term changes in stratification, river runoff, and temperature may influence mortality rates through thermal tolerance, larval drift offshore and food supply. Sea surface temperatures and days above thermal thresholds in coastal Gulf of Maine have increased since the 1980s (Figure 4). The northwest Atlantic is projected to further increase in temperature in the coming decades (Saba et al. 2016), which could increase Gulf of Maine temperature and stratification, as well as alter the water masses circulating in the Gulf of Maine.

2.2 Disease

Diseases in American lobsters appear to be predominantly environmental or opportunistic (Sindermann 1989; Shields 2013; Groner et al. 2018), with infections resulting from a stressed or damaged host. Gaffkemia occurs when there is damage to the cuticle that allows the bacterium Aerococcus viridians var. homari to enter the system and cause infection (Stewart 1980). The WLIS die-off in 1999 has been attributed primarily to a suite of environmental stressors including unusually high bottom water temperatures and low dissolved oxygen coupled with infection by a paramoebae (Mullen et al. 2005; Pearce and Balcom 2005). Increased prevalence of shell disease (enzootic) and black gill disease have been reported in lobsters captured in areas with high contaminant loads or near offshore dumpsites (Estrella 1984; Sindermann 1989; Kapareiko et al. 1997), and impoundment shell disease is associated with stressful holding conditions in lobster pounds (Smolowitz et al. 1992).

Since the late 1990s several new ‘emergent’ diseases have been identified in SNE, including the most recognizable and infamous epizootic shell disease (reviewed in Shields 2013). Epizootic shell disease was first identified in Rhode Island waters in 1996 (Castro and Angell 2000) and later characterized as differing from classical or “enzootic” shell disease based on histological examinations (Smolowitz et al. 2005). Infections by the naturally occurring parasitic Neoparamoeba were associated with the 1999 WLIS die-off and subsequent smaller-scale mortality events (Mullen et al. 2004, 2005). Examination of dead and dying lobsters from another mortality event in western and central LIS (summer 2002) identified excretory calcinosis as the culprit, which is the deposition calculi and development of granulomas in the anntennual glands and gills that in severe cases disrupt respiration and result in death (Dove et al. 2004). The authors attributed this disease to extraordinarily warm water conditions (23° C) in portions of LIS at the time of the event. Lesions in the eyes of lobsters from LIS were first described in the early to mid-2000s as idiopathic blindness (Maniscalco and Shields 2006; Magel et al. 2009), and subsequently documented in lobsters from Rhode Island (Shields et al. 2012). While idiopathic blindness is not known to cause mortality, its sublethal effects are unknown. Finally, necrosis of the hepatopancreas was identified in lobsters collected from Rhode Island in 2008, and while implications of this disease are unknown, loss of function in the affected portions of the hepatopancreas is certain (Shields et al. 2012).

Several of the emergent diseases described above were present to varying degrees in lobsters collected from Rhode Island waters in 2008, and not necessarily associated with presence of shell disease. While general infections with a Vibrio-like bacterium were higher in lobsters with shell disease, idiopathic blindness, hepatopancreatitis, and early stages of calcinosis were not correlated with shell disease (Table 3, Shields et al. 2012). This suggests that shell disease is likely one of several diseases occurring in SNE lobsters, all of which may have varying levels of lethal and sublethal impacts on the population.

Comparisons between the health status of lobsters from Rhode Island and those sampled in Maine showed that, while Maine lobsters were not completely without disease, those from Rhode Island waters had much higher levels of Vibriosis, idiopathic blindness, and hepatopancreatitis (Table 4, Shields et al. 2012). Additionally, work comparing immunocompetence of lobsters from ELIS to those from WLIS and from Maine documented significantly lower immunocompetence in the ELIS lobsters compared to the other locations (Homerding et al. 2012) (see Section 2.7 for information on the genetic differentiation of LIS lobsters). These authors also determined that lobsters with more severe shell disease were immune-compromised and had higher levels of bacteria in the hemolymph, and they were also generally more lethargic than non-diseased lobsters. Shields (2013, 2019) suggests that these emergent diseases are indicative of increasingly stressful environmental conditions that negatively impact lobsters' susceptibility to pathogens.

2.2.1 Epizootic Shell Disease

As the most readily identifiable disease impacting lobsters, epizootic shell disease has received much attention by the research community as well as by the fishery and media. This form of shell disease was first identified in Rhode Island waters and increased in prevalence from very low levels in 1996 to much higher levels in just four years (Castro and Angell 2000). There is a distinct south to north gradient of decreasing disease prevalence (Glenn and Pugh 2006; Castro et al. 2012; ASMFC 2015a) that appears to be related to the interacting factors of water temperatures, size at maturity and intermolt durations (Glenn and Pugh 2006). In all regions with monitoring programs, ovigerous females consistently have the highest prevalence of disease relative to males and other females, and larger individuals tend to have higher disease prevalence than smaller individuals (Castro and Angell 2000; Glenn and Pugh 2006; Castro et al. 2012; Reardon et al. 2018; DNC 2019). Monitoring in Maine indicates that very large lobsters of both sexes (>127 mm CL, "oversize"), but particularly oversize females with eggs, had the highest prevalence of shell disease (Reardon et al. 2018). Lobsters in this size range have extended intermolt durations (Waddy and Aiken 1986), thus this pattern may be the case in most inshore regions, but such large lobsters are rare in other monitoring datasets.

Shell disease symptoms accumulate and worsen on the shell over time (Tlusty and Metzler 2012; Barris et al. 2018), with highest annual prevalence in a population immediately prior to the time of molting (Tlusty et al. 2014; Groner et al. 2018). Lab studies show that severity worsens more quickly in warmer waters (18° C vs 12° or 6° C; Barris et al. 2018). Groner et al. (2018) illustrated the relationship between warming waters, molting phenology and disease; earlier spring molts resulted in longer exposure times to warm summer water temperatures and consequently increased disease prevalence by October compared to years with later spring molts. Increased number of days above 20° C also resulted in increased disease prevalence by October (Groner et al. 2018). Lobsters can successfully molt out of a diseased state (Stevens 2009; Feinman et al. 2017; Barris et al. 2018), however in some instances when disease has penetrated deep into the cuticle, the lobster is unable to complete molting and will die (Stevens 2009; T. Pugh pers. obs.). Estimates of shell disease related mortality based on the Millstone (DNC) tagging program were high, with only 30 – 45% survival rate of diseased lobsters relative to healthy lobsters (Hoenig et al. 2017), although the analysis did not account for potential emigration.

Although the exact causes behind shell disease remain unclear, advances continue to identify factors that may influence individual susceptibility to disease, as well as increased understanding of bacterial involvement. Recent work indicates that an abnormally thin calcite layer in the shell, potentially related to insufficient accumulated stores of $CaCO_3$ during prior instars, is correlated with shell disease presence (Kunkel et al. 2018). The authors suggest that ocean acidification resulting from climate change may negatively impact the availability of $CaCO_3$ resulting in thinner calcite layers and shells that are vulnerable to penetration by bacteria. Interference in shell hardening related to the presence of alkylphenols may also make the shell of some individuals more susceptible to disease than others (Laufer et al. 2012), and alkylphenol contamination of lobster hemolymph appears to be relatively wide-spread in lobsters sampled from various SNE locations (Jacobs et al. 2012). Other researchers have identified changes in the bacterial community on the shell associated with disease lesions. This has been characterized as a dysbiosis of the bacterial community (Meres et al. 2012). More recently a spatial gradient of changes in the bacterial community from a lesion towards lesion-free shell was observed with researchers classifying the communities as affected, transitional, and unaffected (Feinman et al. 2017). Thus it is becoming even clearer that an interaction between environmental stressors that impact the resilience of individual lobsters and the bacterial communities on the shell ultimately lead to shell disease.

The timing of the increase in shell disease prevalence coincides with the decline of the SNE stock, and previous work integrating a disease parameter into a settlers-recruits relationship based on Rhode Island data improved the model fit after 1997, suggesting the disease parameter played an important role in explaining recruitment dynamics (Wahle et al. 2009). However, the timing of the SNE decline was also coincident with an increase in stressful water temperatures (specifically days exceeding 20° C; Figure 5) and the emergence of these other diseases, making it unclear as to whether shell disease was directly responsible for the stock decline or just a symptom of a suite of problems experienced by the SNE stock that impacted natural mortality and abundance. In addition, lobsters from WLIS and central LIS have little to no shell disease, but decreased in abundance due to other causes. Regardless, the ease of detecting shell disease in field monitoring programs makes it a suitable candidate for use as an indicator of deleterious conditions influencing lobster population abundance. This is not the first time the use of shell disease as an indicator of stress has been proposed. Prior to the onset of epizootic shell disease, Sindermann (1989) stated “Prevalence of the shell disease syndrome in Crustacea may well prove to be an excellent indicator of abnormal environmental conditions, and a measure of stress on individuals.” As such, use of disease as an indicator of increasing physiological stress was included in this assessment.

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To determine which size classes of lobsters to include in this analysis, data from the Massachusetts Ventless Trap Survey (VTS; see Section 4.2.2) were examined, which has both a northern (SA 514) and southern (SA 538) survey so can be used to examine data from both GOM and SNE stocks. Female and male disease prevalence were examined in 10 mm size bins (from 41 mm to 100 mm CL) for all survey months combined. Disease prevalence in both areas was higher in females starting with the 71-80 mm size bin (Figure 6a and Figure 6b), which coincides roughly with the size range in which females reach maturity. In males there was no clear size delineation for increased disease prevalence, but larger males did tend to have slightly higher disease prevalence. Based on these data, lobsters 71 mm and larger were used to calculate the index. Commercial trap monitoring programs from each state and NMFS Statistical area were used as the data source for the shell disease based indicator. These monitoring programs have been in place longer than the VTS, providing a longer time series for the indicator. Sampling takes place over several months or over the entire year in some states, which complicates analysis of shell disease prevalence because these time frames straddle the molt (thus capturing both increasing disease and the low levels observed after the molt). To standardize the time period of disease monitoring for use as an indicator, Quarter 2 (April – June), the quarter which is prior to the molt in all regions with monitoring data (ME, NH, northern and southern MA, RI, and LIS (NY and CT combined)), was selected. While monitoring programs describe disease status on individual lobsters as none, light (<10% shell coverage), moderate (11-50% shell coverage), and severe (>50% shell coverage) (as described in Landers 2005), due to the potential difficultly in detecting instances of light disease when catch rates are high (and samplers must hurry to keep up), only lobsters with moderate or severe cases were included as “diseased” for the indicator. The new shell disease based indicator for physiological stress is presented as a model-free indicator of stock status (see Section 5).

2.2.2 Shell Disease Modeling

To further understand variables associated with the presence of shell disease in American lobster, the SAS evaluated data from the coastwide VTS. For this evaluation, individual lobsters were classified as either having or not having shell disease (1=yes, 0=no); disease presence was defined as the individual having either moderate or severe disease, similar to the definition used for the disease indicator (see previous section). All states data were included in this analysis: ME, NH, MA, RI, and NY. Only lobsters within the 95th percentile range of size (47-89mm, inclusive) were included, as lobsters outside of this size range were deemed outliers. Disease prevalence was modeled using generalized additive models (GAMs) with a binomial error distribution and logit-link function. Models were built for each stock – GOMGBK and SNE separately. Covariates used to predict shell disease prevalence in lobsters included Month, Sex, NOAA Statistical Area, Carapace Length, and Year. All covariates were considered factors except for carapace length and month; month was modeled with a cubic spline and a suggested 5 knots, where carapace length was modeled with a suggested 5 knots and regression spline. GAMs were fit using R package ‘mgcv’ (Wood 2006).

Sample sizes for the GOMGBK and SNE models were 923,249 individuals and 87,853 individuals, respectively. The percent of lobsters diseased from the GOMGBK data was 0.07%, and 1.89% for SNE. Models converged for both GOMGBK and SNE models, with all covariates significant in

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the model fits. The R^2 values for the SNE and GOMGBK models were 0.09 and 0.02, respectively. In the SNE model, disease prevalence was predicted to be greatest for females with eggs, in NOAA Statistical area538, June, and in 2018 (Figure 7). Disease by size indicated low prevalence between 50-60mm, but increased towards 80mm, with a slight decline towards 89mm. In the SNE model, disease prevalence was greatest in June with a decrease toward August and increase thereafter towards October. The GOMGBK disease model shared some patterns with the SNE model, but some divergences emerged. Disease prevalence was predicted to decrease with latitude, as reflected from the NOAA Statistical areas (Figure 8). Seasonally, June had the greatest disease prevalence, but it was then predicted to decrease linearly towards October. The effect over carapace length in GOMGBK was simpler than that modeled for SNE, with a linear increase in disease presence from 50-70mm and with prevalence plateauing from approximately 70-89mm. Predicting the GAMs over fixed and varying values further highlight these dynamics; using the most positively influencing effects from Month, Statistical area, and Year, predicting the disease prevalence by size and sex category indicates the strong effect of females with eggs on shell disease probability (Figure 9 and Figure 10). These results highlight how this consistent coastwide sampling can be used to understand changes in epizootic shell disease over a large latitudinal range and through time.

2.3 Natural Mortality

All assessment models are sensitive to the values chosen for natural mortality (*M*) and to the interaction between *M* and other parameters (Bannister and Addison 1986, Vetter 1988). Uncertainty in the nature of *M* for American lobster is compounded by the fact that ageing techniques have not yet been fully developed and employed to determine a reliable maximum age for inshore and offshore stocks (see Section 2.4). For this reason, previous assessments have adopted the convention of holding *M* constant over time and among all size and age groups (Quinn and Deriso 1999) based on life history criteria such as longevity, growth rate, and age-at-maturity (Pauly 1980, Hoenig 1983). American lobster's many traits fostering a relatively long life span and slow reproduction have led to the species' classification as "k-selected" with low *M* after the larval stage. A low and stable *M* rate seems reasonable for American lobster inhabiting stable environments in offshore canyons where they can attain very large size (>190 mm CL, Thomas 1973). A value of *M* = 0.15, based on an assumed maximum age of 20, was applied to all recruit and legal size lobsters in all early assessments (Fogarty and Idoine 1988, NEFSC 1993, 1996, 1999), as well as the most recent assessments (ASMFC 2006, 2009, 2015), except for the SNE stock where there was direct evidence of increased *M* after 1997. Research conducted by several institutions following a widespread die-off of lobsters in LIS in the fall of 1999 concluded that increasingly high water temperatures, in concert with hypoxia, infection by a paramoeba, and possibly other environmental factors, were the cause of the die-off (Pearce and Balcom 2005; Balcom and Howell 2006).

In light of the widespread change in habitat suitability for the SNE stock, as well as the documented mortalities in LIS, alternate runs of the UMM were generated in the 2009 assessment (ASMFC 2009) for the SNE stock using a 50% (M = 0.225) and 100% (M = 0.30) increase in the value of *M* for the years 1998-2007. Following the 2009 assessment, alternative runs of the UMM were carried out for SNE to further address uncertainties about the assumed value of *M* by determining which higher value of *M* during 1998-2007 would best fit the observed abundance-at-length and landings data, assuming *M* = 0.15 in 1984-1997 and a higher value thereafter. For each alternative run, the base *M* (0.15) was multiplied by values ranging from 1.1 to 3.0 in increments of 0.1 resulting in 20 alternative runs. Additional alternative runs were conducted assuming *M* in later years was 4, 5, and 6 times the base value of 0.15. The alternative model where *M* in later years was 1.9 times the base (*M* = 0.285) was the best fit, exhibiting the lowest total unweighted negative log likelihood, of all the model runs. These results showed that doubling the value of *M* in 1998-2007 allowed the model to better fit the observed data (Figure 11).

Laboratory and field studies with American lobster have shown a preferred temperature range of 12° - 18° C, and a physiological stress response at temperatures exceeding 20° C (see Section 2.1.1). There is a significant negative correlation between the annual relative abundance of recruit-size lobsters (71-80 mm CL, Table 60), as measured in four fall surveys (NMFS_SNE, MA, RI, CT) from 1984-2018 and the annual number of days with average temperature $\geq$ 20° C (r = -0.651) as recorded at the submerged intakes of Millstone Power Station (Table 5, Figure 12). Regression of the residuals of recruit abundance over years versus residuals of duration of stressful temperature over years resulted in a significant positive trend (df = 34, F = 5.07, p = 0.03), giving further evidence of synchronization if not causation between the duration of stressful water temperature and resulting recruitment.

The negative relationship between recruit abundance and stressful-days (1984-2018, $R^2 = 0.42$, df = 34, p < 0.0001) can be used to infer the effect of temperature on resulting recruitment. Regression of the predicted recruitment pattern based on the temperature pattern gives a significant ($R^2 = 0.58$, df = 34, p < 0.0001) negative slope of -0.257, equivalent to 2.95% of the mean recruit index (mean = 8.7, Figure 13). This predicted slope indicates that recruitment from 1984-2018 declined on average 2.95% each year due to, or in synchrony with, the increase in the number of days with stressful temperature. This information was used to develop a SNE-specific recruitment covariate as a sensitivity run for the UMM (see Section 6.4.2). An annual recruitment covariate based on the number of days with a mean bottom temperature $\geq$ 20° C each year was developed with the following equation:

$$K_t = 1 + \left(\frac{D_t - \overline{D}}{\overline{D}}\right)$$

where K_t is the covariate in year *t*, D_t is the annual number of days $\geq$ 20° C and $\overline{\mathrm{D}}$ is the mean number of days (Table 5).

2.3.1 Fish Predation on Lobster

An analysis of data from NEFSC and Northeast Area Monitoring and Assessment Program (NEAMAP) surveys was completed for the 2015 assessment. The approach is explained in the 2015 assessment and was not updated in the current assessment but is summarized here. These extensive food habits datasets from NEFSC and NEAMAP bottom trawl surveys show little evidence of predation on lobster. However, NEFSC surveys were in federal waters deeper than typical habitat for small lobsters. NEAMAP surveys were carried out in relatively shallow state waters but not in juvenile habitats which were too shallow for bottom trawls. Also, NEAMAP surveys occurred when lobster abundance was relatively low in SNE. Thus, available finfish diet data may understate consumption, particularly for small juvenile lobsters.

Le Bris et al. (2018) did incorporate predators into a climate vulnerability modeling study of lobster population productivity in both GOMGBK and SNE. The study modeled the impact of historical and predicted regional temperature changes on lobster life history parameters and abundance and size distribution of the predatory fish complex while also considering impacts of conservation practices of v-notch and maximum size protections and fishing pressure on both lobster and predators over time in the two stocks. Shell disease prevalence was also incorporated into *M*. While fishing effort removed the larger predatory fish at all temperatures, they found that warm conditions increased the abundance and diversity of smaller predatory fish and therefore the impact on the *M* of smaller lobsters. While temperatures tipped into more optimal levels augmented lobster growth and recruitment in GOMGBK, they also found that the removals of larger predatory fish amplified increases in lobster population productivity. In SNE, the increase in abundance and diversity of small fish predators and the associated elevated mortality of small lobsters, in combination with elevated shell disease, canceled out the removal of larger predators and reduction of *M* for larger lobsters (Le Bris et al. 2018).

2.4 Age

The American lobster is a long-lived species known to reach more than 18 kg (40 pounds) in body weight (Wolff 1978). The maximum age of American lobster is unknown because all hard parts are shed and replaced at molting, leaving no accreting material for traditional age determination. All previous assessments have estimated lobster age from per-molt growth increments and molt frequencies. Based on further assumptions regarding lobster molt probabilities, Cooper and Uzmann (1980) estimated that American lobster may live to be 100 years old.

Studies conducted in the United Kingdom (UK) have aged European lobsters using lipofuscin measurements from neural tissue (Sheehy and Bannister 2002). These researchers have concluded that changes in lobster carapace length (mm CL) explained less than 5% of the variation in true age for 41 European lobsters examined over 12 years. Moreover, Sheehy reported that molting was so erratic and protracted that European lobsters between 70-80 mm CL required at least five years to fully recruit to legal size (81mm CL) in the trap fishery off the UK (Sheehy et al. 1996). Sheehy’s findings suggest that as many as five to eight year-classes, rather than two based on length frequencies, recruit to the European lobster trap fishery each year.

American lobster brain tissue has been isolated and analyzed (Wahle et al. 1996) using a methodology similar to that of Sheehy (1996) for known-age animals up to two years old. Giannini (2007) continued this work and the results are consistent with other findings for lipofuscin concentrations in wild populations of crustaceans (Sheehy et al. 1995, 1998; Medina et al. 2000; Ju et al. 2003; Kodama et al. 2005, 2006). The addition of more known-age animals, especially of older ages, will greatly improve the predictive capabilities of this relationship.

Variability in lipofuscin in animals of the same carapace length can be due to differences in age as well as environmental factors such as temperature (O'Donovan and Tully 1996, Tully et al. 2000). The effect of temperature on lipofuscin concentration rate was not included in the Giannini (2007) study and would be expected to have an effect on the predicted age structure, especially in inshore versus offshore populations. All of the wild-caught animals examined by Giannini were captured from LIS, minimizing confounding variability due to differing temperature regimes. Even within this fairly homogeneous group, animals one molt-group below the minimum legal size (72-83 mm) represented as many as eight year-classes. This large range in age over a small range of size for lobsters just below harvestable size is very similar to the range in age Sheehey et al. (1996) found in recruit-size European lobsters, and again highlights the probability that recruitment to the fishery for most lobster populations is far more protracted than the size frequency alone would indicate.

Kilada et al. 2012 asserted that growth bands are detectable in the endocuticle of the gastric mill of American lobster, and that routine measurements of growth may be possible. Unfortunately, recent research and debate has developed over the mechanism for band formation in the gastric mill. A recent study led by University of Maine (Wahle et al. 2019), confirmed that the cuticle and associated ossicles of the gastric mill are lost at ecdysis, as has been recently reported in other species of crustacean (Vatcher et al. 2015; Sheridan et al. 2016; Becker et al. 2018; Sheridan & O'Connor 2018). Despite these findings that the gastric mill is lost rather than retained with accreted material at each molt, the study also used known age animals, up to four years, and found a one-to-one relationship between band counts and age in years (Wahle et al. 2019). The study did not have older individuals of known age available, but they did evaluate larger lobsters from three thermally contrasting regimes (SNE, western and eastern GOM). Wahle at al. (2019) found evidence that band counts were significantly greater at size in cooler regions as predicted by assumed slower growth and conversely lower band counts in the warmest region consistent with faster growth. This study revealed potential indicators of chronological age, especially at younger sizes, and evidence of corresponding bands for differing growth rates in varying thermal regimes, but also confirmed the uncertainties in the mechanism of band formation opening more questions about the method necessitating further research.

2.5 Growth

American lobster, like all crustaceans, grow incrementally in distinct molting events called ecdysis. Although growth appears to take place entirely during the molt, lobster actually spend much of their lives preparing for, or recovering from, molting (Waddy et al. 1995). Growth rates are affected by two separate components, the size increase per molt, or molt increment, and the frequency of molting. Molt increments are reported as a percent change in carapace length or as the actual change in carapace length per molt. Increments are usually measured from tagged and recaptured lobster or lobster that molted and grew while held in captivity (including those in lobster traps). The frequency of molting is often reported as the probability of lobster

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at a given size molting in a given year but is sometimes reported as intermolt duration (the time spent between molts).

The steady state nature of most growth models do not permit growth rates to be linked to variable conditions such as nutrient availability (Aiken 1980; Castell and Budson 1974; Bordner and Conklin 1981; Capuzzo and Lancaster 1979), density of lobster (Stewart and Squires 1968; Aiken and Waddy 1978; Van Olst et al. 1980; Ennis 1991), presence of larger, more dominant lobster (Cobb and Tamm 1974, 1975), disease (Castro et al. 2006; DNC 2019), or variations in temperature (Hughes et al. 1972; Aiken 1977). All of these variables have, however, been shown to influence the frequency of molting and/or the size of molt increments.

In general, the frequency of molting increases with temperature (Aiken 1977). However, this increased frequency can be countered by a reduction in molt increment. Blue crabs raised in warmer water were shown to have smaller molt increments (Leffler 1972). Comparison between molt increments of lobster estimated from tagging studies in US offshore waters (Uzmann, Cooper, and Pecci, 1977; Fogarty and Idoine 1988) and those measured in warmer areas (DNC 2008) indicates this also is true of adult lobster. In addition, summer seawater temperature appears to have confounding effects on growth by decreasing the size at which lobster become sexually mature (Templeman 1936; Estrella and McKiernan 1989; DNC 2008; Waller et al. 2019; see Section 2.6.1). Mature females sacrifice somatic growth for ovarian growth and tend to molt on a slower (at least two-year) cycle, extruding eggs and molting in alternate years (Herrick 1911, Aiken and Waddy 1976). Some studies suggest that a proportion of mature females, particularly first time spawners, molt and extrude eggs during the same season (Aiken and Waddy 1976, 1980; Ennis 1980, 1984; Robinson 1980; Briggs 1985). The overall consequences of these competing temperature related factors affecting the frequency of molting and the size of molt increments in females is that somatic growth is generally slower in warmer regions.

Recent work by Tang et al. (2015) would suggest that habitat type impacts lobster growth. They report that age three and four lobsters are larger in mud habitats than in cobble habitats. Direct age determination followed Kilada et al. (2012) methodologies so conspecifics were followed. These results are intriguing as cobble bottom is generally considered a preferred habitat (Wahle and Steneck 1992) for lobster. If the lobster population expands into previously underutilized habitats, differential growth will again confound estimates. If the demographic bottleneck (Wahle and Steneck 1991) is released for lobsters, allowing occupation by vulnerable life stages in previously marginalized soft bottom habitats, and these habitats are advantageous for growth, current estimates for growth will again need to be evaluated.

Recent work by Wahle et al. (2019) using direct ageing techniques compared observed length-at-age to sex-specific growth models for SNE, and western and eastern GOM developed by Bergeron (2011), and the projected length-at-age distributions from the growth model used in the current stock assessment (ASMFC model). Both models and direct aging data agree well for SNE females through all sizes and ages and SNE males agreed well through about 7 years of age and 100mm CL, after which the Bergeron model projected faster growth than the ASMFC

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model. Both direct ageing and the Bergeron model project faster growth than the ASMFC model in western and eastern GOM females. For GOM males, the direct ageing data fit the Bergeron model marginally better for western GOM but fit the ASFMC model marginally better eastern GOM.

While growth transition matrices for crustaceans and other species that are hard to age have historically been constructed using tag-recapture data, the SAS recognizes the availability of a broader set of data that could inform a future, updated growth model for lobsters, including results from direct ageing techniques and using size-at-maturity data to inform molt probabilities for female lobsters. Additionally, there is growing evidence that maturity and therefore growth is changing over time as a result of increasing temperatures and exploitation (LeBris et al. 2017; Haarr et al. 2018; Waller et al. 2019). Thus, the SAS proposes developing methods for constructing growth models using these disparate data sources and allowing for time-varying growth in future assessment models.

2.5.1 Growth matrices

Growth transition matrices used in assessment modeling were not updated from the 2015 assessment where methods and matrices were updated for both stocks. Methods for construction of these matrices are discussed in detail in ASMFC 2015a and are briefly summarized here.

SNE growth transition matrices were updated from ASMFC 2009 with new data and updated methods. Data for GOM and GBK areas were combined to estimate a single growth transition matrix for the GOMGBK stock. Growth calculations were separated by stock, quarter and sex. All growth calculations were carried out for pre-molt sizes in increments of 1 mm and then aggregated to the 5 mm size groups for growth transition matrices used in the UMM.

Lobster growth is modeled in terms of molt increments (size increase per molt) and the probability of molting. Increments are usually measured from tagged and recaptured lobsters or individuals that molted and grew while held in captivity or caught in traps. Mature females are thought to molt less frequently than males because eggs extrusion and molting rarely occur during the same year. In modeling, lobsters were assumed to molt at the beginning of summer (July 1) with relatively small immature individuals molting again at the beginning of fall (September 1). See ASMFC (2009) for more information.

For this assessment, early efforts were made to extend the growth matrices to size bins smaller than 53mm by evaluating other sources of small lobster molt increment and probability data to include in the growth matrices. The goal was to expand the growth matrices to allow for additional fisheries-independent data to be incorporated into the assessment model (such as smaller lobsters caught in trawl surveys as well as settlement survey data) and better understand the population dynamics of younger lobsters. Mark-recapture data from the Lobster Conservancy were evaluated to determine its suitability for inclusion in the growth matrices (Cowan et al. 2001; McMahan et al. 2012; McMahan et al. 2016). The Lobster Conservancy's tagging efforts have been in subtidal waters (~0.3m below mean low water) at three sites in coastal Maine since 1993. Preliminary analyses of the data suggested there is substantial information available for informing growth transition matrices for lobsters as small as 8mm and as large as 73mm. Concerns were raised as to how information from these three sites represents the entirety of the stock, and whether such information existed for SNE to make the assessment models for both stocks consistent. Ultimately, the extension of the growth matrices to smaller sizes was deprioritized for this assessment and remains a research recommendation for future assessments.

2.5.1.1 Molt Probability

Annual probabilities for lobsters in the main summer molt were calculated from logistic functions using parameters (Table 6) for female lobsters in GOM and SNE (ASMFC 2009) and for female and male lobsters in GBK from Fogarty and Idoine (1988). Molt probability curves for males and females in SNE and GOM were assumed the same for lack of better information. The molt probability curves for the GOMGBK stock were calculated by averaging curves for GOM and GBK using the mean number per tow at length in NEFSC spring and fall bottom trawl surveys as weights.

Assessment model calculations include “double” molting by small immature lobsters in the fall, after the summer molt (Table 7). Molting probabilities in the summer and fall differ, but molt increment distributions were assumed the same.

2.5.1.2 Molt Increments

Molt increments are estimated using “broken stick” models for GOMGBK with mean molt increment increasing linearly with pre-molt size until lobsters reach a threshold. After reaching the threshold, mean molt increment is constant. The mean molt increment model had three parameters for each sex and region. For a lobster starting at pre-molt size L:

$$\bar{\mathrm{I}}_{\mathrm{L}} = \begin{bmatrix} \mathrm{a+bL\ \ for\ L < f} \\ \\ \mathrm{a+bf\ \ for\ L \geq f} \end{bmatrix}$$

where $\bar{\mathrm{I}}_{\mathrm{L}}$ is the predicted mean increment, a is an intercept parameter, b is a slope and f is an inflection point. The parameters a, b and f were estimated by fitting the model pre-molt size and increment data available for each sex and area. The model for GOMGBK predicts mean molt increments intermediate between GOM and GBK in the 2009 assessment (Table 8). Residual variances from models for each stock were similar to variances in the 2009 assessment.

There was no evidence in the molt data for SNE of an initial increase in mean increments or an inflection point so median molt increments (8 mm for females and 11 mm for males) were used for all pre-molt sizes (Table 8). The mean increment estimate was similar to the maximum increment in the 2009 assessment (ASMFC 2009).

The distribution of molt increments around their mean is important in modeling growth. Beta distributions $\mathrm{B}(\alpha_{\mathrm{L}}, \beta_{\mathrm{L}})$ and results from the mean molt increment model were used to describe this variability. The first step was to transform the predicted mean molt increment and variance of residuals from the model to proportions of the range between the minimum and maximum increments assumed in calculations. The parameters α_L and β_L were calculated from the transformed mean and variance by the method-of-moments. Next, 10,000 random numbers representing transformed increments were drawn from $B(\alpha_L, \beta_L)$ for each 1 mm pre-molt size and converted back to the original scale. Finally, the starting size and final size (pre-molt size + increment) were assigned to size bins used in modeling to determine the distribution of sizes after molting for each size group.

2.5.2 Growth Transition Matrices

Growth transition matrices used in the UMM reflect both molt probability and molt increment distributions for each pre-molt size group. Pre- and post-molt size groups in the model were 5 mm wide (i.e. 53-57.9, 58-62.9, …, 218-222.9, 223+ mm CL) where 5 mm is smaller than the minimum molt size so that all molting lobsters must exit their pre-molt size group. In quarters where no growth occurs, the transition matrices are all one along the diagonal because lobsters all stay in the same size group. In quarters where growth occurs, there are probabilities along the diagonal that reflect the probability that lobsters in a pre-molt size group did not molt or grow. The remaining probability for each size group is spread among the size groups reached by lobsters that molted. The probability for the post-molt size group adjacent to the pre-molt group will be zero if the minimum molt increment exceeds 10 mm, for example. The distribution of molt increments is usually bimodal with a mode at the pre-molt size group for lobsters that did not molt and a mode at a larger size group for lobsters that molted.

Apparent growth is the mean and distribution of body size for a cohort at the beginning of the winter quarter in the years after recruitment with no fishing mortality. Apparent growth is automatically calculated by the assessment model and can be used to illustrate changes in growth assumptions. For comparisons, during the last assessment (ASMFC 2015a) apparent growth in preliminary model runs was calculated for each stock using the new growth transition matrices. In a second run, the distribution of new recruits was fixed at their estimated values and apparent growth was recalculated using growth transition matrices from the 2009 assessment (ASMFC 2009). Results indicate that lobsters of both sexes in all areas are assumed to grow more slowly than previously and that the difference in assumptions is pronounced for SNE (Figure 14).

2.6 Reproduction

American lobster, like many decapods, has a polygynous mating system, where a single male mates with multiple females, and a male's relative social dominance appears to be correlated to his mating success (Atema 1986; Cobb 1995). In this type of mating system, the female gametes (eggs) are generally considered to be the limiting resource, which suggests females should be protected from harvest. This has typically been the case in management of crustacean fisheries, with the purpose of protecting the spawning stock. However, when there is competition for mates and mate choice that affects fitness, intensive fishing may have a strong negative impact on reproductive success (Rowe and Hutchings 2003).

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Research in several crustacean fisheries has suggested that the assumption of plentiful sperm may not be safe in certain circumstances (see, e.g. MacDiarmid and Butler 1999; Hines et al. 2003; Sato et al. 2005; Pardo et al. 2015). Sperm limitation occurs when the amount or quality of sperm received by females is insufficient to fertilize the entire compliment of potential eggs. This could happen when there are an insufficient number of mature males, or when the males that are available cannot (or do not) provide enough sperm to their female partners. Thus, if the sex ratio is too female-skewed, and/or the mature males present are all relatively small, the potential for sperm limitation exists. With regards to American lobster, while male lobsters can mate with multiple females in relatively quick succession (Pugh 2014; Waddy et al. 2017; Gutzler et al. in press), some evidence exists that the species may be vulnerable to sperm limitation. Gosselin et al. (2003) reported that male size was related to female seminal receptacle load, and multiple paternity in some clutches suggests that females may need to resort to mating with multiple males where exploitation rates are high (Gosselin et al. 2005). More recent work suggests that sperm limitation may result from large discrepancies between the sizes of males and females or from highly female-skewed sex ratios coupled with a synchronous female molting period (Pugh 2014). Tang et al. (2018) documented abnormally small clutch sizes in ~6% of ovigerous female lobsters observed in an extensive sampling program throughout Canada, and in subsequent work Tang et al. (2019) were able to attribute partial or complete clutch loss to low quality ejaculates stored by the female (“soft” or no sperm plugs), consistent with hypotheses of sperm limitation. There is now sufficient evidence in multiple commercially exploited crustacean species to suggest a need for heightened awareness of population size structure and sex ratio with regards to impacts on reproductive success (see MacDiarmid and Butler 1999, Hines et al. 2003, Sato et al. 2005, MacDiarmid and Sainte-Marie 2006; Sainte-Marie et al. 2008; Pardo et al. 2015; Ogburn 2019; Tang et al. 2019).

Reproduction in American lobsters affects both annual egg production and growth, as female lobsters must trade-off between brooding eggs and molting. Generally, once a female has reached sexual maturity, it is assumed that she molts in one year, then extrudes eggs the next year to brood and hatch the following year when she molts , resulting in a biennial cycle of growth and reproduction (see Waddy et al. 1995 for review). Very large females (> 120 mm CL) may skip molts to produce two clutches of eggs (Waddy and Aiken 1986), further increasing intermolt duration. Changes in intermolt duration after sexual maturity affect the growth matrix that underlies the UMM.

Fecundity is currently not implicitly utilized in the assessment process; instead it is assumed that because fecundity increases with female size (Herrick 1896; Estrella and Cadrin 1995), spawning stock biomass (SSB) is an appropriate substitute for estimating the reproductive potential of a stock. As such, SSB is included as a model-free indicator of stock health (see Section 5.1.1).

2.6.1 Maturity

Determination of female size at maturity (SAM) is critical for generating accurate estimates of SSB and growth. Female SAM has been negatively correlated to warm summer water temperatures, such that higher summer temperatures lead to maturation at smaller sizes (see

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Waddy et al. 1995 for review; Little and Watson 2003; Watson et al. 2013; LeBris et al. 2017; Waller et al. 2019). Maturation at small size occurs in relatively warm water locations in the Gulf of St. Lawrence and inshore SNE (Aiken and Waddy 1980, 1986; Van Engel 1980; Estrella and McKiernan 1989; Landers et al. 2001; Comeau and Savoie 2002), while larger SAM has been documented along the Maine coast and into deeper, offshore Gulf of Maine waters as well as the Bay of Fundy (Krouse 1973; Campbell and Robinson 1983; Fogarty and Idoine 1988).

With warming ocean temperatures associated with climate change (see Section 2.9), there have been several recent efforts to document potential changes in lobster SAM in various portions of its geographic range. In SNE, decreases in SAM have been documented in ELIS (Landers et al. 2001; DNC 2019). Work in the Gulf of Maine and Bay of Fundy indicates downwards shifts in size at maturity in Massachusetts Bay (Pugh et al. 2013), the Boothbay region of Maine (Waller et al. 2019), and near Grand Manan in the Bay of Fundy (Gaudette et al. 2014). LeBris et al. (2017) also provide evidence of declining SAM in multiple locations throughout the US and Canada utilizing fishery-dependent data from commercial sea sampling programs.

Evidence also exists that intense exploitation can drive down SAM. This has been suggested by Landers et al. (2001) as a potential factor for decreases observed in LIS and has been recently documented in Canada as driving SAM downwards in multiple locations (Haarr et al. 2018). Based on the accumulating evidence of declining size at maturity, the ASMFC Lobster TC initiated work to generate new maturity indices for use in this assessment (see below and Appendix 1).

Maturity is most accurately determined by dissecting the female and determining the ovary stage, a technique that incorporates the color and weight of the ovaries, the size of oocytes within the ovary, and the female's body size (Aiken and Waddy 1980; Waddy and Aiken 2005). The ovarian staging methodology represents a highly accurate means of evaluating female maturity but requires the sacrifice of the animal and the developing eggs. Cement gland staging was developed as an alternative technique which could be performed in the field without sacrificing the female (Aiken and Waddy 1982). Using this technique, the maturity stage is assessed based on the degree of engorgement of cement glands on the female pleopods. However, this method is only accurate when employed one to two months prior to spawning and produces spurious results outside this time frame (Waddy and Aiken 2005). There were also subsequent problems with stage interpretation and regional variability in results, which may have been due to geographic variation in the proportion of females that molt prior to spawning in a given year, as well as variation in the timing of molting and spawning within a season. These issues with cement gland staging prompted the ASMFC Lobster TC to declare that the more definitive ovarian staging procedure is the preferred standard.

Estimates of the proportion of females that were mature at given sizes have been derived from logistic regressions fit to proportion mature at-length data. A major bias in determining female size at maturity stems from management measures that protect mature females from fishing once they reach legal size (namely the prohibition on harvesting ovigerous females and the practice of v-notching). Because of such protection, the proportions of mature legal-sized

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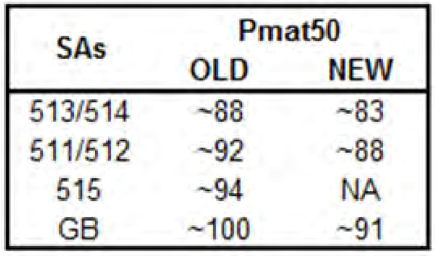
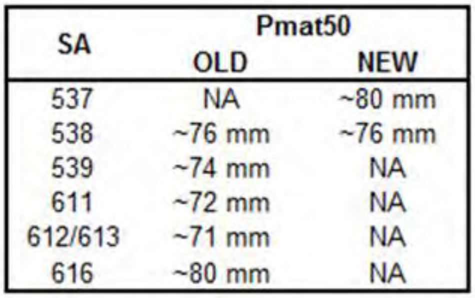
females are artificially inflated as fishing differentially removes immature females. This results in a biased profile of the proportion mature-at-size above the minimum legal size. There is no good way to overcome this bias but it does make it particularly necessary to obtain sufficient samples in the sublegal size range to set the lower portion of the fitted maturity ogive.

New datasets for use in this assessment were supplied by MEDMR for SA 513 (see Waller et al. 2019) and SA 511, by MADMF for SAs 537, 538 and 562, and by a joint effort between the Commercial Fisheries Research Foundation (CFRF) and MEDMR for SAs 537 and 562 (see Appendix 2). After evaluating the available historic and new data, the Lobster SAS decided to use only the new data to generate landings-weighted maturity ogives for use in this assessment (see Appendix 1 for more details). The old and new values for maturity by SA are:



SAs	Pmat50	
	OLD	NEW
513/514	~88	~83
511/512	~92	~88
515	~94	NA
GB	~100	~91



SA	Pmat50	
	OLD	NEW
537	NA	~80 mm
538	~76 mm	~76 mm
539	~74 mm	NA
611	~72 mm	NA
612/613	~71 mm	NA
616	~80 mm	NA

To account for differences in maturation schedules in different regions within a stock, the maturity data from each area were weighted based on the landings from each area (as an approximation of population abundance). The GOMGBK stock was divided into eastern (SAs 511 and 512) and western (SAs 513 and 514) GOM and GBK (SAs 561 and 562) in order to apply landings data to the most spatially appropriate maturity data. Landings for each of these groupings were averaged over the last five years (2014 – 2018), and the total landings for these SAs were calculated. The proportion the total represented by each area was calculated, and these proportions were applied to the updated maturity ogives associated with each area (eastern = 511, western = 513, GB = 562). The resulting landings-weighted ogives were then combined to generate a maturity ogive that represented the entire GOMGBK stock area.

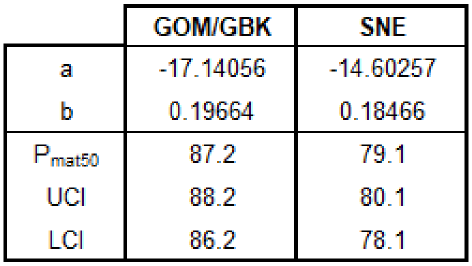
Similarly, for SNE the new maturity data for SAs 538 and 537 and landings for just these statistical areas were used to weight the maturity data and generate a maturity ogive to represent the entire SNE stock area. Please see Appendix 1 for more details on the generation of these ogives.

All ogives were defined by the logistic function:

$$P_x = \frac{e^{a+bx}}{1 + e^{a+bx}}$$

where P_x is the proportion mature at each x = carapace length (CL).

The final parameters for each stock-wide landings-weighted maturity ogive and the estimated size at which 50% of females are mature (with upper and lower confidence intervals) are:



	GOM/GBK	SNE
a	-17.14056	-14.60257
b	0.19664	0.18466
P_{mat50}	87.2	79.1
UCI	88.2	80.1
LCI	86.2	78.1

For the GOMGBK stock the new landings-weighted size at 50% maturity is 87 mm, which is a decrease from the previous assessment's values (GOM: 91 mm, GB: 100 mm). The new SNE landings-weighted size at 50% maturity is 79 mm, which is an increase from the previous assessment's SNE value of 76. This increase in the SNE size at 50% maturity is reflective of the increased influence of the offshore statistical area (537), which reflects the current distribution of this stock.

2.7 Genetic Information

The most recent work on American lobster genetic population structure suggests a high level of connectivity throughout the range examined for ovigerous females (late-stage eggs), but with a distinct north-south differentiation and evidence of some finer scale population structure (Benestan et al. 2015). The work focused primarily on Canadian waters and the Gulf of Maine but did include two sampling locations in the northern portion of the SNE stock (Rhode Island and southern Massachusetts). Sampling locations to the north of Nova Scotia differed from those in the Gulf of Maine and south (Benestan et al. 2015; Benestan et al. 2016b), similar to the large-scale north-south division described by Kenchington et al. (2009). These results also appear to validate previous work documenting slight distinctions between Gulf of Saint Lawrence and Gulf of Maine lobsters (Harding et al. 1997; Kornfield and Moran 1989). At the finer scale, unique sampling locations or clusters of locations were described by the authors as "weakly differentiated" (Benestan et al. 2015). Individuals could be re-assigned to their identified region (north or south) with a high level of success, supporting the certainty of this regional division (Benestan et al. 2015, 2016a). However, re-assignment of individuals to the finer scale groupings was much less successful and further details on location-specific assignment success were not provided (Benestan et al. 2016a).

In the southern portion of the lobsters' range, Crivello et al. (2005b) documented differences between ovigerous females from WLIS when compared to those from ELIS, Central LIS, and Hudson Canyon (females from these three locations could not be genetically distinguished). The authors suggested that the differentiation of the WLIS lobsters may be a recent event, resulting from the 1999 die-off, as the differentiation was much greater than would be expected based on any geographic separation among these groups. An interesting additional note of support to the premise that WLIS lobsters may be relatively isolated from the rest of LIS is the high immunocompetence of WLIS lobsters compared to ELIS lobsters (Homerding et al. 2012). These

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separate studies seem to support the idea that the genetic structure of WLIS lobsters is a result of selective forces producing a lobster adapted to the stressful environment of WLIS. Crivello et al. (2005a) reported that WLIS does receive larval input from maternal sources from more ELIS locations, as well as offshore areas, so persistence of the observed genetic differentiation over time will further support the contention that WLIS lobsters are uniquely adapted to survive in this environment at the southern extent of their inshore distribution.

Thus far, none of these studies provide compelling evidence to support incorporating genetic data into the definition of US lobster stocks or sub-stocks for the purposes of fisheries management and stock status assessment. The study of genetics in relation to lobsters continues to evolve and improve and should be monitored closely in the future to assist with the understanding of stock structure and linkages. Additional work that ties together adult movements, ocean currents and larval dispersal, and genetic population structure should be explored in order to characterize source/sink dynamics and identify whether sub-populations exist that disproportionately influence recruitment. This may be particularly important as changing climate conditions continue to influence recruitment dynamics.

2.8 Stock Definitions

As Section 2.7 indicates, there is no clear genetic basis for stock delineation for American lobster, therefore, stock definitions have been based on other population attributes. Difference in life history traits, particularly growth and maturity were used to delineate stocks initially (NEFSC 1993). Distinct difference between coastal lobster populations in the GOM, offshore lobsters in GBK and offshore SNE and the warmer water populations inshore south of Cape Cod were used to define three stock units; 1 – Gulf of Maine (GOM) - inshore and offshore waters, 2 – Georges Bank and South (offshore), and 3 – South of Cape Cod and Long Island Sound (inshore). An important reason for the stock delineation was due to the differences in these life history traits which have important implications for determining biological reference points such as yield or egg per recruit. Stock definitions were reevaluated in the 2006 assessment and used in 2009 (ASMFC 2006, 2009). The stocks were redefined as; 1 – GOM (inshore and offshore), 2 – Georges Bank (GBK), and 3 – Southern New England (SNE - inshore and offshore). The GOM stock definition remained the same, while GBK was split from other offshore areas and SNE was a combination of inshore and offshore waters. Stocks were differentiated on the basis of multiple factors including; regional rates of maturity and growth, size distribution, distribution and abundance trends of adults and juveniles, patterns of migration, location of spawners, the dispersal and transport of larvae, and considerations for large scale patterns in physical oceanographic processes (temperature regime and currents). A primary consideration for stock differentiation was evidence of the relative importance of inshore-offshore connectivity and individual movement rates along the coastline and continental shelf. However, likely due to population increases and shifts in size compositions in the GOM over the intervening years, it became evident from both survey data and model performance that migrations of large female lobsters between the GOM and GBK stock areas are sufficiently common to complicate the assessment of either of these stock areas in isolation from the other and thus, in the 2015 assessment, the GOM and GBK stocks were combined (ASMFC 2015a).

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There are, however, unknowns and the SAS has acknowledged uncertainty in stock boundaries based on both tagging and larval retention within the Georges Bank Gyre. This has continued to be a high research priority coming from the SAS. The following section provides a summary of what is known about stock structure from tagging, current research being conducted on this subject, as well as a brief explanation of the basis for combining stocks in 2015. For full details of the justification for combining GOM and GBK please refer to ASMFC 2015a.

2.8.1 Lobster Movement and Stock Structure

American lobster movement has been studied dating back to 1898, when Herman Bumpus released approximately 500 mature females near Woods Hole, Massachusetts (reviewed in Krouse 1980). This tagging study, as well as others that followed through 1950 showed that lobster movement was limited to <18km. It was not until 1957-59 when Robert Dow tagged 162 non-legal lobsters (i.e. sublegals, ovigerous, v-notch and oversize) on the coast of Maine that it was discovered lobsters can take on extensive movements (Dow 1974). One lobster in Dow's study traveled 138 miles in 7 months.

Since the early tagging studies conducted from 1898-1960, a plethora of additional information has been gathered on lobster movement. To date there have been well over 40 studies conducted with some form of active or passive tagging device. There are certain patterns that tend to hold true for lobster movement throughout the range, but also some discrepancies and questions that remain unanswered.

It is well established in literature that smaller lobsters, in particular early benthic phase lobsters, are cryptic and move little from areas which provide shelter from predators (Wahle and Steneck 1992). Larger immature lobsters show limited movement whereas movement increases as individuals reach sexual maturity (Morrissey 1971; Dow 1974; Krouse 1980; Campbell and Stasko 1985, 1986; Campbell 1989). Sexually mature lobsters tend to exhibit seasonal patterns of movement towards deep waters in the colder months and towards shoal waters in the warmer months (Cooper and Uzmann 1971; Krouse 1980; Campbell et al. 1984; Campbell and Stasko 1986; Campbell, 1986). Hypotheses for these directed movements focus on lobsters striving to obtain sufficient heat units for egg development. Furthermore, Aiken and Waddy (1992, 1995) suggested that temperatures must decline to less than 8°C in the winter for proper synchronization of the molt/reproduction cycle. There is a strong association between lobsters and temperature, and it has been demonstrated they will behaviorally thermoregulate (Crossin et al. 1998) and can detect very small changes in temperature (Jury and Watson 2000).

While these movement patterns are corroborated across many studies, attempting to use these past tagging studies to assess impacts of movement on stock structure has proven quite difficult. Tagging conducted in Canada near Grand Manan and on Browns Bank has shown some movement of animals throughout the GOM and GBK (Campbell and Stasko 1985, 1986). Furthermore, preliminary results from a tagging study conducted in the 1980s that was recently brought to the attention of the TC indicate that some lobsters tagged in offshore GOM moved

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both to GBK and to inshore GOM. The rate of exchange between these areas is still unclear, but further TC work includes deeper analyses of these data.

Another approach to determining mixing between the stocks is to tag lobsters on GBK and assess movement from tags recaptured inshore. Past tagging studies using this method have shown limited movement between the stocks (Cooper and Uzmann 1971; Campbell et al. 1984). Between 1968 and 1973, a total of 5,500 lobsters were tagged on GBK and Browns Bank and none were recaptured inshore north of Cape Cod.

In an attempt to better determine movement between GBK and GOM, Atlantic Offshore Lobstermen's Association (AOLA), NH Fish and Game and Maine DMR have carried out a broad-scale tagging project from nearshore GOM (>12nm) to GBK since 2015. Approximately 17,000 tags have been deployed by a combination of both fishery-dependent and fishery-independent tagging platforms. To date, there have been approximately 1,500 recaptures (9.3% recapture rate). Tags are still being reported, however, the researchers will be analyzing these data in coming months with stock boundaries as one of their objectives.

There are inherent limitations associated with the passive tagging method described above; mainly the days-at-large for many of these studies are on the order of weeks and spatiotemporal patterns of fishing effort can create biased patterns in tag-return rates. Empirical data presented in the 2015 assessment (ASMFC 2015a) suggests movement between stocks. This analysis was based on NMFS trawl survey data as there are high catches of large females (>100 mm CL) in the fall which are not present in the spring. Furthermore, the catch rate of these large females was greater in the spring in GOM and they were not as prevalent in the fall. By combining these indices, abundance estimates were similar in both seasons. This was the primary basis for combining the GOM and GBK into one stock (ASMFC 2015a).

In conclusion, inshore tagging studies in the GOM have shown movement throughout inshore GOM and to the OCC, but little to no movement to GBK proper. Additionally, lobsters tagged on GBK have shown limited movement to the GOM, however, NMFS trawl survey catch data suggest that large females are moving between stocks. Lobster movement appears to be quite complex with long distance movements between some areas, but little to no evidence of it in other areas. Although there appears to be some movement between GOM and GBK, the impact of this movement on population structure, looking solely at tagging studies, is currently inconclusive. A primary research recommendation coming out of this assessment is to further investigate stock structure.

2.9 Impacts of a Changing Environment

2.9.1 Climate vulnerability analysis

Hare et al. (2016) conducted a climate vulnerability assessment on 82 fish and invertebrate species in the Northeast U.S. Shelf (NEUS). The approach utilized both quantitative and qualitative information to assess species' exposure and sensitivity to various climate stressors. Included in this assessment was American lobster, which was determined to have Moderate Vulnerability Rank (Hare et al. 2016). Lobster was deemed highly exposed to climate changes

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via ocean surface temperature and ocean acidification and a moderate biological sensitivity rank given scores of the species' attributes (principally population growth rate, spawning cycle and other stressors). The distributional effect of climate change on lobster was deemed neutral given over the NEUS, lobster has decreased in its southern part of its range but increased in its northern part. Data quality that was used for the basis of lobster's climate vulnerability determination was scored at 88%, considered to be moderate data availability on the species.

2.9.2 Changes in Phenology of Egg Hatch in the Gulf of Maine

Warming waters in the GOM may be affecting the timing of egg hatch, which could lead to changes in the success of young-of-year (YOY) recruitment due to the potential for a mismatch with food supply (Cushing, 1990). The onset of hatching and the rate of clutch development both advanced to earlier in the season in the Gulf of Saint Lawrence (Harr et al. 2020). In the GOM, state agencies (i.e. MEDMR, NH F&G & MADMF) collect egg developmental stage information during commercial sea sampling. Although specific egg stages vary by jurisdiction changes in the proportion of eggs hatching or spent for the month of June could be assessed throughout the GOM. The month of June was used as it represents the month in which eggs generally begin to hatch throughout this region.

In Eastern ME, the time series shows a general upward trend to earlier hatch later in the time series, however, the trend is not significant (Figure 15, Mann Kendall $P>0.05$). There is a significant upward trend in the onset of hatching with both Maine and New Hampshire data for SA 513 (Figure 16 and Figure 17, Mann Kendall $P<0.05$). In Massachusetts the time series varied without trend (Figure 18, Mann Kendall $P<0.05$). The onset of hatching is largely dictated by spring warming in the months of April through June (Goldstein and Watson 2015), and increasing temperature decreases the time for egg incubation in decapod species (Green et al. 2014). The water mass in the GOM is warming at an alarming rate (Pershing et al. 2015). The general trend of earlier larval release in Eastern Maine and the significant trend in portions of western Maine are in step with current warming trends.

Carloni et al. (in prep) assessed changes in phenology and match/mismatch of lobster larvae and copepods along the coast of New Hampshire. They found that the appearance of stage I larvae trended significantly earlier in the season over the 30-year neuston survey conducted along the coast of New Hampshire by Normandeau Associates, which correlated well with warmer spring water temperatures. Following up on the food limitation hypothesis proposed by Carloni et al. 2018, they also tracked phenological changes in a potentially important food source (*Calanus finmarchicus*) for lobster larvae to assess match/mismatch. The end of the season for *C. finmarchicus* trended significantly downward over the same 30-year time period, providing evidence that the season of *C. finmarchicus* has also been ending earlier in recent years.

To better understand how lobster larvae and *C. finmarchicus* overlap through time, they modified a mismatch index based on Burthe et al. 2012. The index shows how peak annual abundance of stage I lobster larvae and *C. finmarchicus* (end of season) vary through time and trend significantly downward towards 0 and negative numbers (Figure 19). This indicates the

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end of the *C. finmarchicus* season is occurring earlier than the timing of the peak stage I lobster larvae in recent years, suggesting that although changes are occurring in the timing of egg hatch, changes are also occurring in the timing of a potentially important food source which does not appear to be in high abundance during an important developmental period. This work being prepared for publication, and past work with these long-term datasets (Carloni et al. 2018), suggests that both abundance and timing of this potentially important food source could be affecting recruitment. Additional work is being conducted in the GOM to assess if the correlations found between lobster postlarvae/YOY abundance and copepod abundance are indeed a predator prey relationship or if a large-scale driver may be influencing both species in a similar manner. These data collected along the coast of New Hampshire for the abovementioned work are spatially limited, and although there has been good agreement between data collected in this area for copepods and lobster larvae with the broader Western GOM region, results from this work should not be extrapolated to a larger region with regards to phenology and mismatch between *C. finmarchicus* and lobster larvae.

The proportion of eggs hatching in the month of June appears to be trending to earlier in the season in much of the GOM but varies without trend in Massachusetts (SA 514). There is evidence of changes in the timing of early stage lobster larvae in New Hampshire and changes in the end of season of *C. finmarchicus*. There is also evidence that the overlap in timing between *C. finmarchicus* and peak stage I has changed and this potentially important food source may not be as readily available during critical developmental time periods. Research is currently being conducted through National Sea Grant to better understand the feeding behaviors, food preference and vertical distribution of early stage lobster larvae, as well as how shifts in the distribution of egg bearing lobsters influence recruitment processes in the Gulf of Maine (https://seagrant.umaine.edu/extension/american-lobster-initiative/research-projects/).

2.9.3 Population and Environmental Effects on Catchability

Catchability refers to the relationship between the observed density of a sampled organism and the total population abundance (Quinn and Deriso 1999). Catchability may vary spatially within a survey domain due to changes in the efficiency or ability of sampling gear to sample different habitats or interactions between gear and organism behavior (Miller 1990). Catchability should also be expected to change temporally, either due to behavioral interactions or changes in spatial overlap between the species distribution and the survey domain (Wilberg et al. 2009).

Behavior and catchability of American lobster, as well as other lobsters, is well known to be environmentally mediated (McLeese and Wilder 1958; Flowers and Saila 1972). Catchability can be density-dependent and vary across habitat type (Tremblay and Smith 2001), also changing as lobster distributions across habitats change when population density exceeds the capacity of preferred habitat (Miller 1990). Temperature, in particular, has been shown to affect the catchability of lobsters (McLeese and Wilder 1958; Zeigler et al. 2003). Higher temperatures are hypothesized to affect catchability both due to increased metabolic demand and more effective dissolution and diffusion of bait scent, in the case of trap fisheries (Morrissy 1975). Thus, catchability can change across years as a result of inter-annual temperature variations (Zeigler et al. 2003) or episodically in response to oceanographic or weather events (Drinkwater et al.

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2006). Considerable evidence of changes in survey catchability through time, driven in part by changing temperature (see Section 2.9.4), came to light during this assessment and is further discussed in Section 4.2 and Section 6.

There is an extensive literature on techniques for standardizing catchability indices to address catchability concerns, particularly for fishery-dependent Catch Per Unit Effort indices (Gulland 1983), but this standardization is typically performed outside of the assessment model (Maunder and Punt 2004, but see Maunder 2001; Wilberg and Bence 2006). Standardization outside of the model due to environmental change presents a potential problem if there is a temporal correlation between the environmental correlate and the actual population abundance, as adjusting the index for the change in environment may actually remove the signal from the changing population. Thus, fitting the environmental effect on catchability within the assessment model is preferable and is the approach taken in this assessment for several identified temperature-driven catchability effects. Section 4.2.4.1 discusses environmental covariates evaluated to explain changes in survey catchability and Section 6.1.4 discusses how these covariates were treated in the UMM.

2.9.4 Changes in Spatiotemporal Distribution

The Northwest Atlantic Ocean is experiencing numerous physical changes that can affect lobster abundance, distribution, and productivity. Not only have inshore sea surface temperatures (SST) at Boothbay Harbor, Maine and Woods Hole, Massachusetts seen increasing trends (Figure 20 and Figure 21), the offshore Northwest Atlantic Shelf SST has also been increasing since the 1860s (Figure 22). Changes in SST have the potential to influence lobsters during the larval stage, but bottom water temperatures better reflect changes in thermal habitat for post settlement lobsters, especially in stratified systems. NOAA Fisheries 2020 Mid-Atlantic and New England State of the Ecosystem reports (Gaichas et al. 2020a, 2020b) indicate that bottom water temperatures have increased in the Mid-Atlantic Bight, GBK, and GOM since the late 1970s (Figure 23). The number of days that bottom waters of inshore SNE have been above 20° C (a physiological threshold in lobsters) has been increasing. Since the early 2000s the number of days above 20° C have been above the long-term average at Cleveland Ledge in Buzzards Bay, Massachusetts and at the Dominion Nuclear Power Station (DNPS) on Niantic Bay, CT (personal communication J. Swenarton, DNPS; Figure 24 and Figure 25). Kavanaugh et al. (2017) examined bottom temperatures in the Northwest Atlantic and found that temperatures were increasing at a rate of 0.1 to 0.4° C per decade. The largest increases were in shallow nearshore regions and GBK. Regression analysis indicated that the increases in SNE and Mid-Atlantic shallow shelf area were associated with SST, while increases in the GOM and GBK were related to regional and basin-wide changes in ocean circulation.

NOAA Fisheries 2020 Mid-Atlantic and New England State of the Ecosystem reports (Gaichas et al. 2020Aa, 2020b) indicate that other oceanographic changes are also occurring in the Northwest Atlantic. Over the last decade, the position of the Gulf Stream has been shifting northward (Figure 26), and as a result, warmer waters are now entering the GOM through the Northeast channel (Figure 27). The changes in the GOM current system can have impacts on larval lobster transport throughout the system.

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Concurrent with these oceanographic changes, American lobster stocks have exhibited extreme changes in abundance over the last several decades. The abundance of the GOMGBK stock has more than tripled compared to the 1980s and is at its time series peak. While legal and recruit abundance and female spawning stock biomass (SSB) are at peak levels, recruitment of newly settled or YOY lobsters has generally been at medium to low levels for the last decade, particularly in the southwest area of GOM (see Table 47; ALSI 2018). In contrast, abundance of the SNE stock has declined by 85% since the peak in the late 1990s and is now at the time series low. Indicators of SNE YOY have also declined over time (see Table 62; ALSI 2018) and there is concern that the SNE stock may be experiencing recruitment failure (ASMFC 2015a).

As described in Section 2.9.2, Carloni et al. (2018) examined trends in lobster larvae to explore linkages between SSB and YOY abundance. The study found a significant increasing trend in stage I larval abundance consistent with the increases in SSB in the GOM (Figure 28). Planktonic postlarva on the other hand, had a declining trend in abundance similar to trends for YOY settlement in southwest GOM (Figure 29). The study also found similar declining trends for both lobster postlarvae and the copepod *C. finmarchicus*, but there were no relationships with other zooplankton (Figure 30). This suggests that the relationship between SSB and YOY is established at the postlarval stage and that declines in YOY abundance and recruitment rate may be linked to changes in zooplankton assemblages.

As mentioned above, the dynamics between SSB and YOY settlement are very different in SNE compared to the GOM. In SNE, both SSB and YOY have been declining. Fishery-dependent data from LCMA 2 in SNE indicate that ovigerous female lobster have shifted their distribution from inshore to deeper nearshore waters (Glenn et al. 2011). Casey (2020) simulated larval transport into Buzzards Bay using a coupled individual based model driven by oceanographic conditions. The simulation found that as June-July bottom temperatures increased over the modeled years, the changes in distribution of egg-bearing females allowed them to remain within the preferred temperature range of 15° - 16° C. Modelling results confirmed that while there was a high degree of self-retention in Buzzards Bay, the probability of postlarval settlement in Buzzards Bay was more related to changes in SSB than to the redistribution of egg-bearing females. Casey (2020) also demonstrated a clear decrease in the thermal suitability for larval settlement from the mid-1990s to 2017.

Goode et al. (2019) examined changes in thermal settlement habitat in relation to increasing bottom water temperatures, stratification and larval settlement. The study estimated the amount of bottom habitat with temperatures greater or equal to 12° C and less than 50 m depth that would therefore be suitable for YOY settlement. YOY density was then extrapolated across the expanded settlement habitat using YOY indices. Due to the strongly stratified water column in the southwest GOM, thermal habitat in the area expanded only moderately. Northeast GOM has strong tidal mixing and the Eastern Maine Coastal Current which prevents strong stratification. The analysis found that increases in bottom temperature have expanded the area of northeast GOM suitable for settlement habitat. The study found that the recent declines in the YOY settlement indices in shallow water correlated with the increases in thermal settlement habitat (Figure 31). The study predicts that the recent decline in the YOY index

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would not be as dramatic if settlement is extrapolated over the expanded thermal habitat, especially in northeast GOM (Figure 32). Recruitment projections from YOY densities that did not account for increased thermal habitat predicted that lobster landings would have a declining trend (ASLI 2018; Oppenheim et al. 2019).

Many studies have documented environmental correlates with lobster, and how abundance and habitat have changed through space and time (Fogarty et al. 2007; Chang et al. 2010). A northeast shift in the center of lobster biomass has also corresponded with the center of lobster landings shifting northeast since the 1970s (Pinsky and Fogarty 2012). Understanding these changes in abundance and habitat can then provide insight into changes in stock productivity (see Section 6.3). In recent years, many studies have emerged quantifying the changes in lobster abundance and habitat over the last several decades, as well as predicting how future environmental conditions may translate to continued change.

Tanaka and Chen (2016) examined changes in lobster habitat suitability in the GOM in relation to environmental variables (i.e. temperature, salinity and depth) using ME/NH bottom trawl survey data to develop bio-climate envelopes by season, sex, and stage. A significant increasing trend in habitat suitability was identified for the spring, but not the fall, suggesting the number of days that bottom temperature and salinity are in lobster's optimal range is increasing in the spring. The model found higher habitat suitability in the fall and no trend, indicating temperatures and salinities are consistently within optimal range. The one exception was upper Penobscot Bay, which had an overall declining trend in habitat suitability, suggesting that contraction of lobster habitat is driven by temperature and salinity. Tanaka et al. (2018) developed a model to quantify the environmental effects on changes to lobster distribution, and found that bottom temperature and salinity impacts on lobster distribution in the GOM were more pronounced in the spring compared to the fall. The climate niche model predicted significantly higher abundance during the hypothetical warm climatology scenario (based on the 5 warmest years between 1982 through 2013).

Models have also been developed to span the entire Northeast U.S. Continental Shelf. Using a suite of habitat predictor variables (such as temperature, salinity, bathymetry, and primary and secondary production) Mazur et al. (2020) found that secondary production, bathymetry, and temperature were significant in predicting lobster abundance. Results show that lobster habitat has changed regionally, with increases in habitat in the GOM, particularly mid-coast Maine, and declining habitat in SNE (Figure 33). There is also an indication that habitat has declined in the inshore region of the GOM and expanded offshore. Tanaka et al. (2020) highlighted similar regional abundance changes through time linked to temperature, with increasingly more habitat becoming available through time in the deeper GOM in spring and fall, GBK and offshore SNE in the fall, and a decline within inshore SNE. These trends were also projected to continue in 80 years based on climate forecast data. The projections in abundance match with the temperature projections of Rhueban et al. (2017), which projected that the number of optimal temperature days (12 to 18° C) would continue to decline in inshore areas of SNE and increase in offshore SNE, GBK and GOM (Figure 34). While the optimal temperature days are projected to continue to decrease in inshore SNE, the number of days with temperatures stressful to lobsters (above 20° C) are projected to continue to increase (Figure 35). Inshore SNE is projected to become increasingly inhospitable for lobsters, while thermal habitat will expand in offshore areas (Figure 36). Both the temperature correlate to lobster abundance and projected increasingly inhospitable environment for the species in SNE has been further supported by a LIS-centric studies (Tanka and Chen 2015; Georgas et al. 2016).

These habitat suitability efforts were advanced by Hodgdon et al. (In Press) using a delta-generalized linear mixed model (VAST, Thorson et al. 2015) that incorporates multiple trawl surveys' data for standardized predictions of abundance and accounts for spatial autocorrelation. Briefly, lobster densities were predicted at locations known as "knots", whose locations are assigned by the program based on the density of input data in a pre-defined bounded spatial area. The spatial areas for predictions were assigned as the statistical areas that comprise the stock region (GOMGBK or SNE). The ME/NH, MA, and NEFSC surveys are used for the GOMGBK area and the NEFSC, NEAMAP, NJ, CT, and RI surveys for SNE. The delta model approach uses two linear predictors to calculate a) presence-absence of lobster and b) lobster catch, given lobster is present. Density at each knot was estimated as a combination of spatial random effects and spatiotemporal random effects, and then extrapolated onto a grid. Annual predictions through time for both sexes and seasons again highlight the resounding message of abundance has been increasing with latitude over the last 40 years: SNE has experienced decreasing abundance overall, with greater abundances shifting from inner to outer parts of the stock, and the GOMGBK stock has increased in abundance through time (Figure 37-Figure 44). These efforts have not only provided a tool to systematically understand how abundance has changed through space and time, but the mixed effects models provide the opportunity for constructing a unified fisheries-independent survey index for future assessments as opposed to using several indices by survey.

2.9.5 Exploration of Environmental Regime Shifts

We explored various environmental data sets with a rpart (recursive partitioning and regression trees) analysis (Therneau et al. 2015; R package rpart) to determine if environmental regime shifts were evident and potentially supported the use of regime shift analysis to determine stock reference points. The rpart analysis applies regression models to build binary classification trees that minimize the residual sum of squares within clusters of chronological observations. Classification tree splits were used to identify shifts in environmental variables to new regimes. Several analyses are common to both stocks including (1) Stock-wide seasonal (spring and fall) bottom temperature time series and (2) analysis of time series from fixed temperature monitoring sites by months across years. The identification of individual regimes and regime shifts can be sensitive to model configurations, lengths of time series and statistical power. Further, it is unclear what the false positive error rates are for this method, this analysis is primarily intended to describe where regime breaks tend to occur and if these breaks are reflected in lobster stock dynamics. Thus, all regime shifts identified in this analysis contribute to an overall goal of looking for repeating patterns across data sets.

For the stockwide seasonal time series, interpolated bottom temperatures from the NEFSC spring and fall surveys from Friedland et al. (2018) were used to get mean bottom temperatures for each stock area. An rpart analysis was performed for each season and the first two detected regime breaks were retained in the analysis of each time series, identifying three regimes in each time series. The regime shift analysis was also performed on each time series with a moving-average smoother to see if the identifications of regimes were robust.

For analysis of fixed monitoring sites, monthly means for each year were calculated, then regime shift analysis was performed across years for each month, keeping only the first regime break to examine magnitude and consistency of timing across months. In the case of the GOM, the time series for 50m depths across NERACOOS Buoys B, E, F, and I were averaged, which represent various inshore or nearshore habitats in the GOM (neracoos.org), and analyzed the aggregated time series.

2.9.5.1.1 Gulf of Maine Environmental Time Series

For the GOMGBK stock-wide analysis, both the raw and smoothed time series for both spring and fall strongly supported a breakpoint around 2010 with temperatures rising dramatically in the recent period, particularly for the fall (Figure 45). Weaker break points were identified around 1984 for the spring and 1993 for the fall but are only marginally statistically significant.

For monthly time series from NERACOOS buoys, the strongest evidence for regime shifts were evident for July – November with temperature shifts in excess of 1 degree C between regimes (Figure 46). For all months a regime shift was identified in 2010 except January where the regime shift was identified in 2012 and July, September, and December where the regime shift was identified in 2009 (Figure 47).

Recent changes in bottom water temperatures in the GOM have been attributed to changes in the composition of water entering the GOM with warming conditions resulting from greater influx of Atlantic Temperate Slope Water and proportionally less Labrador Slope Water (LSW, NEFMC 2020b). This shift in the waters entering the GOM through the Northeast Channel affects the temperature, planktonic productivity and structure of the zooplankton community in the GOM. Thus, for the GOM, time series of Labrador Slope Water and zooplankton composition were analyzed as indicators of regime shifts occurring in the GOM ecosystem. There is a general decreasing trend in Labrador Slope Water entering the GOM over the time series with values reaching zero in the most recent years (Figure 48). Analysis of the LSW time series indicated a strong candidate regime beginning in 2010 and a weaker regime shift between 1984 and 1985.

The NEFSC conducts periodic Ecosystem Monitoring (EcoMon) cruises to measure ecosystem and oceanographic conditions throughout the Northeast U.S. Large Marine Ecosystem, including plankton tows to monitor the composition and abundance of zooplankton and fish larvae. This data was analyzed for trends in the copepod Calanus finmarchicus which is a key trophic link in the productivity of the GOM ecosystem (Record et al. 2019) with potential linkages to lobster larval nutrition and survival (Carloni et al. 2018). A principal component analysis (PCA) was also performed on the 25 most common zooplankton taxa observed in

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EcoMon surveys. In both cases, data sets were constrained to surveys conducted in the late summer and early fall period.

Analysis of the *C. finmarchicus* time series identified three candidate regimes with shifts occurring in 2001 and 2010 (Figure 49). *C. finmarchicus* densities were moderate in the early portion of the time series, high in the middle regime, and have declined steeply in the recent regime. With the PCA, the first and third components were identified as having strong temporal components. The first component, associated with low densities of siphonophores, protozoans, chaetognaths, and two copepods (*Oithona spp*. and *Calanus minor*), showed two strong regime shifts at 2001 and 2011 with the species assemblage having lower densities (high PCA values) in the middle regime and high densities (low PCA values) in the recent regime (Figure 50). Similarly, the third component, associated with four copepod species including *C. finmarchicus*, showed strong regime shifts in 2001 and 2010 with the recent regime associated with high densities of *C. minor* and low densities of *C. finmarchicus*, *Metridia lucens* and *Pseudocalanus* (Figure 51).

2.9.5.1.2 Southern New England Environmental Time Series

Temperatures generally increased across the stock-wide time series in SNE, particularly in the fall, with no clear regime shifts (Figure 52). In this case, the regime shift analysis tends to break time series into approximately equal segments to account for the trend. Thus, candidate regimes were identified starting around 1985 and 2012 (2008 for the smoothed time series) in the spring. In the fall, candidate regimes were identified starting in 1994 and 2008 with agreement between the raw and smoothed time series.

We analyzed two fixed stations for monthly trends, a long-term monitoring station maintained by Massachusetts DMF at the mouth of Buzzards Bay in about 20m depth and a monitoring station near the Millstone Power Station on the eastern end of LIS. In Buzzards Bay, there is a strong seasonal trend in the statistical support for a regime shift, being highest from June to October and lowest from January to April (Figure 53). This pattern corresponds to the magnitude of the regime shift detected with temperature shifts above 1° C for the summer and fall and smaller shifts for the winter and spring, actually reporting a negative temperature change for February. Timing of regime shifts were inconsistent across months, though tending to happen early in the time series in the spring and later in the time series for summer and fall (Figure 54).

In LIS, there is a similar seasonal pattern in the statistical support for regime shifts in the temperature series, being higher in the summer and fall and lower in the winter and spring. However, the magnitude of the detected temperature shift tends to decrease through the years, generally being about 1° C (Figure 55) but higher in January through March. The higher magnitude regime shifts reported in the early months all occur early in the time series while the remaining shifts tend to occur between 1997 and 1999 (Figure 56). Analysis of the number of degree days equaling or exceeding 20° C, discussed earlier, finds strong evidence for three regimes with shifts in 1998 and 2012 (Figure 57).

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Finally, a time series of temperature anomalies for the Cold Pool on the SNE and Mid-Atlantic shelf were analyzed, an oceanographic feature that includes historical lobster habitat around Hudson Canyon and heads of submarine canyons, persists from spring through fall, and affects productivity and the spatial distribution of marine life in the region (NEFSC 2020a). The cold pool temperature anomaly generally increases across the time series, increasing in mean temperature by about 2° C since 1980 (Figure 58). Candidate regime shifts were detected in 1985 and 2009, each corresponding to a mean increase of about 1° C. This can be interpreted as continuously increasing index with regime shifts placed to address the trend.

3 FISHERY DESCRIPTION

3.1 Brief History of the Lobster Fishery

Documents about New England colonies often describe American lobster as an abundant species and a dependable source of bait and food. Wood (1635) commented on the commonness of lobster, stating that “their plenty makes them little esteemed and seldom eaten.” Numerous citations indicate that lobsters were easily captured in Canada and New England and were used for food, bait, and fertilizers. Early fisheries were conducted by hand, dip net, and gaffs in shallow waters along the shoreline (Nicosia and Lavalli 1999). Lobsters were also harvested in a labor-intensive fishery using hoop nets along the shoreline. Wooden lath traps became the dominant gear by 1840. Early vessels were row boats or powered by sail. The use of gasoline powered engines started around 1905.

Rathbun (1884) described the lobster fishery as beginning around 1800 along the coast of Massachusetts, in particular on Cape Cod and near Boston. The initial fishery supplied large lobsters (> 3 lb) for the fresh market located in New York and Boston. The fishery was conducted in shallow, near-shore areas. Smack boats cruised the coast catching and/or buying lobsters from local fishermen and would carry the catch to Boston and New York markets. When declining catch rates of marketable lobsters were unable to supply the markets, the fishery expanded to New Hampshire and Maine waters in the 1840s. A second market for “small” lobsters (between 2-3 lb) for canning developed in Maine. Canning began in 1843 and by 1880, 23 canneries were operating in Maine. In 1855, market lobsters were 3 lb or greater, culls for the cannery market were between 2 and 3 lb, and lobsters less than 2 lbs were discarded. Rathbun reported the following “average” sizes, in total length, at the four principle markets for lobster in the early 1880s:

Portland, Maine	10.5” TL	(92 mm CL)
Boston, Massachusetts	11-11.5” TL	(97-101 mm CL)
New Haven, Connecticut	10.5” TL	(92 mm CL)
New York, New York	10.5-15” TL	(92-133 mm CL)

From 1870 to 1880, the lobster fishery experienced declines in catch per trap and average size of lobsters. The fishery responded by expanding the area fished, increasing the number of pots set, extending the fishing season, and fishing single pots instead of trawls in order to cover more area. As the average size of the catch declined, markets adjusted by lowering the size of acceptable lobsters. Similar trends occurred throughout the range of the lobster fishery. In Buzzard Bay (SNE stock), lobsters averaged 3 lb (approximately 120 mm carapace length) in 1840 and 2.5 lb in 1880. In 2017 an average lobster landed from the Buzzards Bay region weighed 1.2 lbs (MADMF unpublished data).

A comparison of length frequency also confirms that size structure in the inshore waters was wider in the 19th century than today. The length frequency of ovigerous females captured in 2007 from Buzzards Bay and in 1894 from Cox Ledge (Buzzards Bay) are shown in Figure 59. Despite concerns about the declining size of the catch in the 19th century, it is obvious that the size structure in the 1890s was much broader in Buzzards Bay than is found today.

The decline in lobster landings coastwide led states to implement minimum sizes and closed seasons. The decline of the fishery, beginning in Massachusetts' waters, spread along the coast. The New Jersey fishery was carried out extensively in the 1860s, but was nearly wholly abandoned as unprofitable by 1870, despite proximity to the largest lobster market in New York. Even with indication of a revival in 1872, the lobster fishery in New Jersey has remained small to present day. The fishery in New York and Hell's Gate was also extensive before becoming diminished due to unprofitable fishery conditions. The Provincetown fishery was also abandoned, except for harvesters that were too old to participate in alternative fisheries. Large decreases in landings, catch rate, and average sizes were noted in Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine.

The decline caused the implementation of a series of management regulations in Maine (78.9 mm minimum carapace length April 1 to August 1, remainder of year 92.3 mm, closed season August 15 to October 1), New Hampshire (92.3 mm), Massachusetts (92.3 mm, closed season June 20 to Sept 20), Rhode Island (87.8 mm), Connecticut (87.8 mm), and New York (92.3 mm). Maine also instituted protection for egg-bearing females.

Landings, average size, and catch per trap continued to decline over the next twenty years in all states and Canada. In Massachusetts, the number of lobsters > 92 mm per trap declined from 80 per trap in the early 1880s to approximately 30 per trap in 1907 (Figure 60). In comparison, the catch per trap of lobster > 92 mm in Massachusetts fishery in 1995-1998 ranged from 5 to 7 per trap (Figure 60). Concerns about the growing crisis in the fishery led to a Convention in 1903 to develop recommendations for uniform legislation in states to protect lobsters. Representatives from Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Canada attended. Lobster stocks were deemed to be in a critical state with declines in average size of the catch and catch per trap haul. Management measures under consideration were increases in minimum size, slot limits, gear modifications to change selectivity, closed seasons, trap limits, v-notching protection for females, limited access for permitted fishermen only, and hatchery stock enhancement through hatchery propagation. The slot limit was advocated to increase egg production by protecting the larger, more fecund

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lobsters. Protection of berried females and prohibition of landing shelled lobster meat were enacted.

The Convention of 1903 failed to establish uniform regulations because of a concern to tailor regulations to meet local conditions. Enforcement of existing regulations was considered to be problematic everywhere. Scientists also noted the inadequacy of landing statistics. In general, scientists believed that stock declines were fishing-related and landings were inflated through increased effort, technological improvements, and spatial and temporal expansion of the fishery. The relative impacts on lobster abundance resulting from fishing mortality versus natural mortality through predation and disease were debated.

States responded to the crisis in various ways. Rhode Island and Massachusetts lowered the minimum size to 78.9 mm carapace length, Connecticut raised the minimum size from 78.9 mm to 79.3 mm. In 1907, Maine increased the size limit to 4.75” total back shell. From 1907 onward, states implemented many small changes in the minimum size, protection for egg-bearing females, and prohibition on landing lobster meat. Maine instituted a maximum carapace length. Voluntary v-notching programs were enacted in Maine and Massachusetts.

Landings remained low, averaging approximately 5,000 metric tons (mt) from the 1920s through the 1940s. Total landings increased slowly from 1940 through 1970, averaging near 14,000 mt through the late 1970s. Landings have since quadrupled and have exceeded 60,000 mt since 2012. With the advent of more efficient vessels, the offshore trap fishery intensified after the mid-1960s with 2,500 mt landed from the offshore canyons in 1965. The deep water trap fishery has dominated offshore landings since 1972, while prior to that offshore landings primarily consisted of bycatch in the otter trawl groundfish fishery. The size distribution of lobsters in the offshore fishery was much wider than in the inshore fishery. Skud (1969) concluded that “canyons that were more heavily fished had lower catch per trap and a smaller mean size.” He also reported that the modal size of lobsters from Veatch and Lydonia Canyons was smaller in 1965-67 than in 1956 and the decrease in size was greatest in Veatch Canyon. The length frequency of lobsters in Hudson Canyon was similar to Veatch Canyon in 1965-1967. A comparison of length structure in Veatch Canyon in 1965-1967 with length frequency in Hudson Canyon in 1991 and 2003 indicates continued truncation of the length frequency (Figure 61), although some of the changes can be attributed to differential gear selectivity. In 2003, 80% of lobsters from Hudson Canyon were within 1 molt group of the minimum legal size.

Several conclusions can be drawn from reviewing lobster history. Large lobsters were found in inshore shallow water throughout the species’ range. Declines in size structure and catch per trap that occurred in the 1880s were attributed to increased fishing effort throughout the range of the fishery. These declines were initially local (Boston to Provincetown) and then spread coastwide. Terms such as “commercial extinction” were in use in 1903. Low productivity, as measured by landings, extended for long periods; coastwide landings declined over a 25-year period from 1889 to 1915 and remained low for another 30 years. These historical landings data provide a general characterization of lobster population trends over the past two centuries

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but must be viewed with caution since all fishery-dependent data are confounded in terms of size, location, and other market-driven forces. Discarded sizes were never recorded, and only economically productive areas were fished.

Most of the management measures in use today (minimum sizes, v-notching, closed season, maximum size, slot limits, trap limits, protection of egg bearing females) were either discussed or implemented over 100 years ago. In many cases, regulations such as minimum sizes and closed season are less restrictive today than 100 years ago. Arguments about the merits of uniform measures were countered by the need to tailor management measures to meet local needs. With the exception of private property rights, resource managers from the late 19th to early 20th century would be familiar with scientific, socioeconomic, and political arguments present in the decision-making process for managing lobster today.

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3.2 Current Status of the Fishery

The U.S. lobster fishery is conducted in two main stock units: GOMGBK and SNE. In order to continue to monitor dynamics specific to the GBK fishery, it is treated separately from the GOM in this section (and in the model-free Indicators, Section 5). Each area has an inshore and offshore component to the fishery. In the GOM, the inshore fishery dominates the total stock harvest (> 98% from inshore SAs). The offshore fishery dominates in the GBK stock unit, with catch from the inshore portion (SA 521) averaging around 24% of the total since 2000. While historically the inshore fishery dominated in SNE, since the late 1990s the landings from inshore statistical areas have declined, and since 2013 landings from offshore SAs have been slightly higher than from inshore SAs. This change is related to warming waters in the inshore portion of SNE, with summer temperatures often exceeding the thermal stress threshold of 20° C for lobster. The GOM supports the largest fishery, constituting an average of 81% of the U.S. landings between 1982 and 2018 (Figure 62). It has accounted for at least 90% of the total U.S. landings since 2009 and has averaged 94% of the total since 2014. SNE historically accounted for the second largest fishery, with an average of 22% of the U.S. landings between 1981 and 2001. However, this fishery has experienced dramatic declines in landings, accounting for 9% or less of the U.S. landings since 2002, and since 2013 has been only 2% of the total. GBK historically was the smallest portion of the U.S. fishery, averaging 5% of the landings from 1982 to 2013, and 4% since 2014. During this time period the relative contribution of the GBK fishery to the total U.S. fishery has remained fairly stable.

The total number of commercial fishing permits issued in the U.S. lobster fishery varied without trend between 1982 and 1995 (Table 11). Starting in 1996, the total number of state permits steadily declined; the average total number of permits issued by the states from 2014-2018 was 8,748. This pattern is not homogeneous among states. The states of Connecticut and Massachusetts have exhibited declines in the number of licenses issued from highs observed in the early to mid-1980s. The number of permits issued in Maine increased from the 1980s into the early 1990s, then declined until around 2010, after which time permits have varied around an average of 5,931 (2010 – 2018). The number of permits issued in Rhode Island varied in a saw-tooth fashion from 1990 to 2001, but have declined steadily since that time, reaching a time series low of 796 permits issued in 2018. In New Hampshire, the number of permits issued has varied without trend around a time series mean of 324 permits over the entire time series. The state of New York had a sharp increase in the number of permits issued from the early 1980s to the mid-1990s, reaching the high of 1,265 permits in 1994. Subsequently, the number of New York permits issued dropped dramatically from 1995 to 2018, where it reached a time series low of 265 permits. The number of Federal permits increased until the early 1990s then was relatively stable until 2006, since which time it has gradually declined.

Traps are the predominant gear type employed in the U.S. lobster fishery, and the only gear type used in Maine. Between 1981 and 2018 traps accounted for an average of 98% of the total landings. All other gear types (otter trawl, gill net, dredge, SCUBA) accounted for the remaining 2% of the total landings. The standard unit of fishing effort is difficult to define in the American lobster fishery; there is no linear relationship between the number of traps fished and fishing effort. Many factors affect the catch rates of lobsters in traps including location, bait, trap design, soak time, temperature, and the presence of other animals (Cobb, 1995). This complicates the relationships between catches or CPUE and abundance and/or densities, as well as between effort and mortality (Miller 1989, 1990; Karnofsky and Price 1989; Addison and Bell 1997; Addison and Bannister 1998). A comprehensive description of the factors affecting lobster catchability and trap efficiency is provided in a previous assessment (ASMFC 2000). The number of trap hauls would be a better metric of fishing effort, but unfortunately these data are either not currently collected, or not historically available from most jurisdictions within the U.S. lobster fishery. To characterize fishing effort, the total number of traps reported fished by state (or trap tags issued for Maine) within each stock are presented. Although it is not the best characterization of fishing effort in a trap fishery, it is the only metric that is broadly available. The total number of trips that landed lobsters are also presented, a dataset that is available from several jurisdictions but only since the late 2000s.

The operational characteristics of the U.S. lobster fishery have changed significantly over the time series of data presented in this assessment. There have been substantial increases in the average trap size and average boat size. The predominant type of trap used in the fishery has changed from the traditional wood lath traps to wire mesh traps. Advances in radar, sonar, and navigational electronics have increased the efficiency of fishing vessels. Each of these factors affects catch rates and overall yield and has substantially increased the fishing power of the U.S. lobster fleet since the 1980s.

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3.2.1 Gulf of Maine

The Gulf of Maine fishery is primarily carried out by fisherman from the states of Maine, Massachusetts, and New Hampshire. This fleet is comprised mainly of small vessels (22 to 50 ft) that make day trips in nearshore waters (< 12 miles). The Gulf of Maine also has a smaller scale offshore fishery comprised of larger boats that make multi-day trips.

Commercial lobster landings in the Gulf of Maine were stable between 1981 and 1989 averaging 14,600 metric tons (mt), and then increased steadily from approximately 20,000 mt in early 1990s to approximately 35,000 mt in the mid-2000s. From 2007 to 2013 landings nearly doubled and reached the time series high of 68,456 mt in 2018. Since 2014 total GOM landings have averaged 63,016 mt (Table 12). More than 98% of the total GOM catch has come from the inshore NMFS statistical areas (SAs) 511, 512, 513, and 514, with only small contributions from the offshore SAs of 464, 465, and 515. The increase in landings in GOM was dominated by catch from Maine, particularly from the mid-coast portion of the state (SA 512) which has accounted for an average of 54% of the entire GOM catch since 2014. In Maine there was a more than five-fold increase in landings from 1982 to 2016, with 2016 values representing a time series high. Landings from New Hampshire varied without trend around a mean of 630 mt between 1981 and 2007, then more than doubled to a time series high in 2016 of 1,986 mt. Massachusetts landings increased from 1981 to 1990 and remained high between 1991 and 2000 (averaging 4,979 mt). Starting in 2001, Massachusetts landings declined reaching a time series low in 2005 (3,189 mt), with six out of the seven lowest landings values in the time series occurring between 2001 and 2007. Since 2007, landings in Massachusetts have nearly doubled to the time series high of 6,251 mt in 2016. A very small amount of landings have been reported from other states (primarily RI, but including CT and NY), but the amounts are very small (and confidential) relative to the total GOM landings, thus are not included in Table 12.

The number of traps fished in the Gulf of Maine was fairly stable between 1982 and 1993 averaging approximately 2.3 million traps (Table 13). From the mid-1990s through the early 2000s traps increased gradually to a time series high in 2006 of 3.7 million (Table 13). The number of traps fished remained above the time series median of 3.2 million since 2000, dropping to the median value in 2018. For the state of Maine, traps were calculated using the number of annual licenses sold and the average number of traps fished per boat estimated from port sampling from 1982-1996. After 1996, Maine effort is based on trap tags sold, not necessarily traps fished. The state of Maine accounts for the greatest proportion of the total fishing effort within the GOM stock. Maine accounted for an average of 88% of the total number of traps in the GOM between 1982 and 2018. In the Maine fishery, traps varied without trend around an average of 2.3 million between 1982 and 1993, and then increased substantially reaching a time series high of 3.29 million in 2006. Since that time, there has been a slight decrease in the number traps reported in Maine. The trend in the Massachusetts portion of the fishery is markedly different. Traps increased substantially from a time series low in 1982 (247,415 traps) to a time series high in 1991 (399,010 traps), remained fairly stable between 1992 and 2002, averaging 382,543 traps, declined gradually from 2003 to the time series low in 2014, and has since averaged 298,356 traps. Effort data for the New Hampshire fishery is only available from 2004 to present, during which time traps fished varied with a slight decline since 2012, recently varying at or below the time series median of 70,647 traps.

The number of trips with lobster landings has been available from most states starting in the late 2000s, which makes it a short time series for now. Since 2008 the number of trips in Maine has generally varied around a mean of 275,045, with a time series high in 2016 of 293,919 trips (Table 14). The number of trips in New Hampshire has declined over time since a high 12,184 at the beginning of the time series to a low of 8,901 in 2018. In Massachusetts the number of trips appears to have declined since the beginning of the time series in 2010 to a time series low of 38,482. It is notable that in all three states (ME, NH, MA) the number of trips was higher in 2016 than in surrounding years. There are a very small number of trips to the GOM stock from

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vessels landing in Rhode Island, averaging less than 30 in the last five years. Note that while most trips in GOM are day trips, there are some multi-day trips included in this dataset.

3.2.2 Georges Bank

The Georges Bank fishery is primarily carried out by fisherman from the states of Massachusetts, New Hampshire, and Rhode Island, with a very small number of participants from states further south. This fleet is comprised of larger vessels (55 to 75 ft) which make multi-day trips in offshore waters (> 12 miles). Georges Bank also has a smaller-scale inshore fishery comprised of smaller boats that make day trips along the outer arm of Cape Cod, Massachusetts (SA 521).

Commercial lobster landings in the GBK varied around a mean of 1,316 mt between 1982 and 2002 (Table 15). From 2003 to 2018 landings increased substantially, reaching a time series high of 2,039 mt in 2018, and have remained well above the time series mean through 2018. Since the late 1980s catch from the state of Massachusetts comprised the majority of the GBK landings, averaging 66% of the total GBK over the time series. The proportion of the Georges Bank fishery attributable to Massachusetts has increased over time, whereas the proportion attributable to Rhode Island has decreased. This trend is related to where the respective fisheries in Massachusetts and Rhode Island occur on Georges Bank. The majority of the Massachusetts landings from the Georges Bank stock are harvested on the northern and eastern side of the bank (NMFS SAs 521, 522, 561, and 562), which have experienced lobster landings increases over the course of the time series. Conversely, the majority of the Rhode Island fishery on Georges Bank occurs on the southern edge of the bank (NMFS SAs 525 and 526), in which landings have been highly variable but generally lower in the latter half of the time series. Prior to 1993, New Hampshire did not have consistent landings in GBK. Landings from New Hampshire have increased over time since 1993, but are confidential data so are not included in the total here. Landings from all other states comprised less than 1% of the GBK landings throughout the time series.

The number of traps fished on Georges Bank is not well characterized due to a lack of mandatory reporting and/or a lack of the appropriate resolution in the reporting system. Massachusetts is the only state that has a time series of effort data for this stock. As such, Massachusetts data are discussed here as an index of relative effort for the Georges Bank stock. The number of traps fished on Georges Bank increased by roughly 30% from 1982 to 1992 (Table 16). From 1993 to 2009 the number of traps varied without trend around a mean of 43,012 traps. Since 2009, the number of traps increased and has varied around a mean of 46,742 traps. Data from Rhode Island became available starting in 2001. The number of traps from Rhode Island fished in GBK reached a time series high of 18,437 in 2007 but have since declined with an average of 10,081 traps since 2010.

Fishing activities on Georges Bank have responded to the shifts in availability and abundance of lobsters on the bank (see Section 5.2.2). While landings have increased in all months over the time series, landings have increased disproportionately in the summer and fall months since about 2005 (Figure 63). This increase in landings is mirrored in the fishing effort which exhibits

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a similar rapid increase in trips reported for the summer and fall starting around 2005 (Figure 64). This seasonal increase in effort on Georges Bank may help explain the reported increase in traps fished on the bank in recent years.

Vessels from Massachusetts made the most trips to Georges Bank with an average of 2,977 trips from 2010 to 2018, although the number has declined since 2014 (Table 17). Rhode Island and New Hampshire are the other two states contributing the most to effort on GBK. Effort from Rhode Island has declined over time. Data from New Hampshire are confidential. Data from other states with vessels fishing GBK were not available.

3.2.3 Southern New England

The Southern New England fishery is carried out by fishermen from the states of Connecticut, Massachusetts, New York, and Rhode Island, with smaller contributions from the states of New Jersey, Delaware, and Maryland. This fleet is comprised mainly of small vessels (22 to 42 ft) that make day trips in nearshore waters (< 12 miles). A portion of the inshore fleet has reportedly shifted to making overnight trips slightly farther out in nearshore waters, although there is currently insufficient data to characterize this shift. Southern New England also has a considerable offshore fishery comprised of larger boats (55 to 75 ft) that make multi-day trips to the canyons along the continental shelf.

Commercial landings in the Southern New England stock increased sharply from the early 1980s to the late 1990s, reaching a time series high of 9,902 mt in 1997 (Table 18). Landings remained near time series highs until 1999, then declined dramatically so that by the mid-2000s landings were near levels observed in the early 1980s. Since the mid-2000s landings have continued to decline, and in 2018 reached a time series low of 1,243 mt. The majority of the catch from 2014 to 2018 in SNE was landed by Rhode Island (mean = 47% of total), followed in descending order by Massachusetts (25%), New Jersey and South (16%), New York (5%) and Connecticut (5%). This represents a marked change from previous periods when New York and Connecticut were the 2nd and 3rd largest producers, respectively, and reflects the dramatic declines in catch from Long Island Sound (SA 611). In general, catch in the inshore statistical areas (538, 539, and 611) in SNE has had the largest decline and landings in all three SAs are all now below previous lows observed in the early 1980s (Figure 65). Landings in the offshore/nearshore statistical areas (537, 612, 613, 614, 615, and 616) have less variability throughout the time series, but since 2014 have been steadily declining to a time series low in 2018 (Figure 65). Landings in the offshore area have been consistently higher than the inshore area since 2008.

Available data for the number of traps fished in Southern New England is limited to Massachusetts, Connecticut, and New York for the first half of the time series, with Rhode Island data becoming available starting in 2001. Using just the Massachusetts, Connecticut, and New York data to summarize the entire time series, the total number of traps fished increased steadily to peak in 1998 at 588,482, then declined steeply until 2013, after which time it varied slightly around the recent (2014 – 2018) mean of 93,334 traps (Table 19). Each of these three states generally followed the same pattern reflected in the total, however it is worth noting that traps fished in Massachusetts in 2017 and 2018 were higher than they had been in over a

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decade. Traps fished in Rhode Island have declined since the initial values reported in 2001, reaching a time series low for Rhode Island in 2017 of 49,549 traps. This large decline in fishing effort is most likely the result of a combination of declining stock size, decreasing participation, and substantial increases in operating cost in the fishery associated with fuel and bait. Recently, a trap reduction plan for LCMA 2 was implemented starting in 2016 with a 25% cut, followed by additional 5% reductions in both 2017 and 2018 (5% reductions will continue annually through 2021) which would mostly affect Rhode Island and Massachusetts traps.

Data on the number of trips for Southern New England are currently available only from Massachusetts, Rhode Island, and New York (Table 20). The number of trips by Rhode Island vessels has declined dramatically since the beginning of the time series in 2007. The number of trips from Massachusetts and New York vessels has varied without trend since the beginning of those time series (2010 and 2012 respectively). While these time series are too short to demonstrate it, the number of trips in all three of these states are likely much lower than at the height of the fishery, as inferred from the declines in traps fished and in number of licenses.

3.2.3.1 Mixed-crustacean Fishery Issues

Quantifying fishing effort on the southern New England American lobster stock has become partially confounded by the newly developed Jonah crab (*Cancer borealis*) fishery. In recent years, Jonah crab has been increasingly targeted by lobstermen given the decline of the SNE lobster population and an increase in demand for crab meat and prices per pound. The commercial Jonah crab fishery is limited to those who possess a lobster fishing permit or those who can prove that their participation in the crab fishery started before a specified control date (ASMFC 2015b). Perhaps the most confounding attribute of the fishery is that there is no distinction between lobster and Jonah crab traps, making it difficult to understand how trap numbers correspond to directed effort on either species. To tease out the commercial effort on these species, Truesdale et al. (2019) interviewed 15 participants of the southern New England Jonah crab fishery, documenting their ecological knowledge on Jonah crab, descriptions on the seasonal commercial effort on the two species, and their perspectives on the current Jonah crab management system. The authors found that the target species varied seasonally, with lobster primarily targeted in summer months and Jonah crab in the winter. More specifically, respondents indicated a 73% increase in the number of traps set to target Jonah crab over American lobster in the winter compared with the summer months. Given such information is not included in vessel logbooks, these findings present the first estimate of fishing effort seasonally dedicated to harvesting Jonah crab over lobsters in this new mixed-crustacean fishery.

4 DATA SOURCES

4.1 Fishery-Dependent Data Sources

4.1.1 Commercial Catch

4.1.1.1 Data Collection Methods

Maine

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Lobster landings information from dealers is compiled in the NMFS weighout and canvass database by port and month. Landings reporting was voluntary by dealers prior to 2004, after which time monthly landings reports became mandatory and a requirement for license renewal. In 2008, the mandatory dealer reporting increased its resolution of data to the daily trip level. A lookup table was supplied by the Maine DMR to the ASMFC, linking port landed (designated by NMFS port codes) with likely statistical area from which lobsters were harvested. For all years it was assumed that port codes sufficiently characterized the spatial distribution of landings in Maine. Since 2008, the annual landings are calculated from the 100% dealer reported data at the trip level.

During the 1990s, the Maine lobster fishery was in a period of rapid growth. New dealers were buying significant quantities of lobsters in locations where previously minor fisheries existed, seasonal dealers began buying lobsters out of trucks/vans and lobster smacks, and Canadian processing plants began buying excess lobsters from Maine. Given the magnitude of the changes in the fishery, it is very likely that significant landings were missed through the voluntary landings reporting program during the period of 1997 through 2003.

It has been estimated that prior to 2004 landings were underestimated by 25-35% (Wilson et al. 2004). The underestimate for this period is based on a comparison between reported landings and expanded estimates from Maine port sampling. From 1967 until 1997, these two data streams were significantly correlated (r=0.852, p=0.000). That significant relationship broke down from 1997 until 2004, when mandatory reporting was implemented. Maine port sampling provides an alternative trajectory of landings during this period and allowing for calculation of estimates of underreported landings (Wilson et al. 2004).

Since 2008, the Maine Harvester Logbook Program has been using a stratified random 10% sample of harvesters to produce a representative dataset of Maine harvesters to collect the ACCSP required data elements plus a Maine management zone and distance from shore (0-3nm, 3-12nm, >12nm). More specifically, fishermen are categorized by their license type and fishing zone, and 10% of harvesters from each combination of license type and zone are selected to report for the upcoming calendar year. All Maine lobster license holders, except those chosen the previous year, are included in the annual random draw, including licenses that had no landings the previous year and permits that require Federal Vessel Trip Reports (VTRs). Those permit holders that are required to submit VTRs do not submit duplicate reports to the Harvester Logbook Program but continue to report only through NMFS's VTRs. To complete the data set of all licenses selected, the VTR permits selected as part of the annual 10% process were added to the Maine harvester logbook dataset.

New Hampshire

New Hampshire lobster harvesters have been reporting annual lobster landings from state waters since 1969 to the New Hampshire Fish and Game Department (NHFG). Between 1969 and 1985 lobster harvesters were required to report landings on an annual basis and those reports were compiled to produce total annual landings. No effort data were reported during this time period. Between 1986 and 2005, a random selection (RSL) of a percentage of licensed lobster harvesters and all new entrants into the lobster fishery were required to report harvest and effort data. The reported data were expanded to reflect the total estimated inshore landings of lobsters. The RSL reports were submitted monthly and collected the following trip-level information: month and day fished, number of gear fished (both monthly and daily totals), area fished, average set over days/pot, weight of harvest, gear size, did fish or did not fish, and incidental catch. The reports submitted by new entrants were submitted annually and represented monthly-summarized catch and effort information from New Hampshire state waters. Beginning in 2006, all licensed lobster harvesters were required to report harvest and effort data. Harvesters are required to report monthly, trip-level data including all the Atlantic Coastal Cooperative Statistics Program (ACCSP) standard data elements if they land 1,000 pounds or more the previous year, or annual, monthly-summarized data if they land less than 1,000 pounds the previous year.

In cooperation with NMFS, New Hampshire instituted mandatory lobster dealer reporting in 2005 and began collecting all data required under ACCSP standardized data submission standards. New Hampshire lobster dealers report transaction-level data on a monthly basis through use of paper logbooks and flat files to NHFG for entry into the EDR (Electronic Dealer Reporting program), or directly to EDR.

Historically, the quantity of lobsters landed in New Hampshire harvested from federal waters was derived from a combination of NMFS weighout and canvas database and federal vessel trip reports (VTRs). NMFS has mandatory reporting of harvest data from the majority of federally permitted vessels that land in New Hampshire through VTR data.

For the current assessment, total monthly landings from dealer reports (EDR), catch data from federal VTRs, and catch data from state logbooks were used to calculate landings values. In order to assign areas to the dealer report records and calculate effort estimates, VTRs and state logbooks were used to identify statistical areas and effort values. This was necessary as dealer reports do not contain area and effort data.

Massachusetts

Prior to 2008, all commercial lobster permit holders (coastal, offshore, and seasonal or student) received a detailed annual catch report form with their license renewal application. This report requested the following information on a monthly basis: method of fishing; number and type of gear used; effort data (set-over days, number of trips per month, etc.); pounds of lobsters caught; areas fished; principal ports of landing; and information relative to the vessels and traps used in the fishery.

In 2008, the Massachusetts Division of Marine Fisheries (MADMF) began the transition to a trip-level reporting system, which included all the previous information reported but on a finer time scale. For 2008, 10% of harvesters were randomly selected to provide trip-level reports, with the remainder reporting using the old method. In 2009, 20% of harvesters provided trip-level reports, and starting in 2010, 100% of harvesters were required to provide trip-level reports. Those vessels with Federal reporting requirements reported lobster landings to NMFS via the VTR system and not to MADMF after 2009. For this assessment, total landings for the time

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period since 2010 were the combined data from MADMF state-permitted harvester trip-level reports and VTR data from federally permitted Massachusetts vessels. Landings data prior to 2010 are from annual and trip-level reports provided to MADMF from all Massachusetts permit holders (including those who also had Federal permits).

Rhode Island

Commercial lobster fishery landings data prior to April 1994 were collated directly from the NMFS weighout and canvass database. In 1999, Rhode Island initiated a mandatory commercial lobster catch/effort logbook reporting program as part of the ACCSP. These data are used in conjunction with the NMFS Vessel Trip Report (VTR) landings data system to calculate total Rhode Island lobster landings by statistical area. Beginning in 2003, Rhode Island logbook data and NMFS VTR data were used in place of NMFS dealer reports for the assessment. Based on an analysis of logbook versus NMFS dealer data (M. Gibson, RIDEM, pers. comm.), landings in some earlier years (1981-1982 and 1995- 1998) were adjusted upward to compensate for likely under-reporting of landings in those years. For the years 1981-1982, the sum of 1982-1989 NMFS weighout and canvass numbers were divided by the sum of 1982-1989 NMFS weighout numbers and that ratio (~1.041) was then multiplied by 1981-1982 canvas numbers to obtain final adjusted landings for each year. For the years 1995-1998, the sum of 1999-2003 NMFS weighout and canvas numbers were divided by the sum of 1999-2003 NMFS weighout numbers and that ratio (~1.118) was multiplied by 1995- 1998 canvas numbers to obtain final adjusted landings for each year. For the years 2004 to the present, total commercial lobster landings are compiled from combined Rhode Island logbook and NMFS VTR data.

Connecticut

Landings are recorded in the NMFS weighout and general canvas database as landings at state ports. Connecticut also records landings by licensed commercial fishermen in any port (inside or outside Connecticut) by means of a mandatory logbook system that provides catch and effort information from 1979 to the present. This mandatory monthly logbook system provides detailed daily catch data by species, area, and gear as well as port landed, traps hauled, set over days, and hours trawled (for draggers). The logbook provides a means to look at fundamental changes in the operating characteristics of the lobster fishery within Long Island Sound. Since 1995, the program has required fishermen to report information on the sale and disposition of the catch, including the state or federal permit number of the dealer to whom they sold their catch. Seafood dealers are also required to report all of their individual purchases from commercial fishermen using either the NOAA form Purchases from Fishing Vessels, a Connecticut Seafood Dealer Report, Abbreviated Form for Lobster Transactions Only, or through the ACCSP's Standard Atlantic Fisheries Information System (SAFIS). A quality assurance program has been established to verify the accuracy of reported statistics through law enforcement coverage and electronic crosschecking of fisherman catch reports, law enforcement boarding reports, and seafood dealer reports.

New York

New York commercial lobster landings from 1981 through 2003 were obtained from the NMFS weighout and canvass database. The NMFS weighout and canvass data from 1998 through 2006

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were compared to NY Recall Survey data for the same years. The difference in reported landings ranged from -4% (NY recall higher than NMFS) to 33% (NMFS data higher than NY recall). The three highest percentage differences occurred in 2004 through 2006. Preliminary comparison of Federal dealer data and NY recall survey information from this time period indicated there was some double counting of landings. Since the differences between NMFS and New York landings were not large before 2004, lobster landings data provided by NMFS for the period from 1981 through 2003 were utilized. Due to the potential magnitude of double counting from 2004 through 2007, New York conducted an analysis to reconcile the lobster landings data. New York and NMFS staff collaborated on the development of the reconciliation process, and New York staff conducted the analysis. This reconciliation process is described in the 2009 ASMFC Lobster Assessment (ASMFC 2009).

In 2008, New York required lobster permit holders to fill out State Vessel Trip reports (SVTR), which collected similar information as the Federal VTR. Due to concerns about compliance with the new requirement, the NY recall survey was also continued through 2011. Starting in 2012, the NY recall survey was discontinued. Staff at the ACCSP took over the reconciliation process described in the last Assessment (ASMFC 2009) to determine the best annual estimate of commercial landings for New York.

The number of pots fished was collected through the NY recall survey from 1998 through 2011. Starting in 2008, New York has collected daily trap haul data through the SVTR.

New Jersey South

New Jersey, Delaware, Maryland, Virginia, and North Carolina collect no landings data for American lobster. Total monthly landings from the NMFS weighout and canvass database were used to calculate landings data for this stock assessment.

4.1.1.2 Commercial Discards/Bycatch

4.1.1.2.1 Discard Mortality Rates

Studies describing discard mortality in the trap fishery and/or bycatch mortality in the trawl fishery are limited but consistent in their findings that most mortality factors are relatively low. A two-year study of both trap and trawl catches in Long Island Sound showed that hardshell (intermolt) lobsters suffered little damage by commercial trawling, with the incidence of immediate mortality by month never exceeding 0.5% in the trap fishery or 2.2% in the trawl fishery (Smith and Howell 1987). Additionally, this study examined delayed mortality (up to 14 days) in the laboratory and found it occurred almost exclusively in hard-shelled lobsters that sustained major damage to the carapace or tail, or in new-shelled (recently molted) lobsters. Ganz (1980) also found low immediate mortality to trawl-caught American lobsters in Narragansett Bay, RI, and low damage rates during intermolt periods. Both of these studies found that damage rates were higher immediately following molting, but that newly molted animals made up a very small percentage of the catch because of their reclusive behavior. Two other studies of the scallop (Jamieson and Campbell 1985) and rake (Scarratt 1972) fisheries found that although the gear could damage American lobster, the lobsters emigrated from the area during the harvest season and so the gear had no significant impact on the lobster population present on the grounds at other times of the year. The model used in this assessment assumes a 0% discard mortality rate.

4.1.1.2.2 Lobster Trap Fishery Discards/Bycatch

Data are currently available on commercial discards of lobsters for the inshore lobster fishery based on sea sampling programs conducted by state agencies. However, data to characterize discards from the offshore (Federal waters) portion of the fishery are limited. Sea sample data provide evidence for substantial regulatory and market driven discards of sublegal, oversized, v-notched females, and ovigerous females. The regulatory discards are accommodated in modeling as a component of gear selectivity, legal selectivity, and as conservation discards.

In recent years, with declines in other commercial fisheries and evaluations like the Marine Stewardship Certification Program, bycatch of commercial fish species in the lobster fishery is a topic of interest and research. Both federal and state at-sea observer programs now collect bycatch data as a standard data metric on commercial sampling trips. Boenish and Chen (2018) used Maine's lobster sea sampling and Atlantic Cod (*Gadus morhua*) bycatch data and found the data cannot be expanded and used directly to estimate the cod bycatch in Maine's fishery because of spatial and seasonal trends in sampling, the fishery, and cod habitat use. To estimate bycatch, Boenish and Chen used the sea sampling data in addition to total landings by month and zone to develop spatial and temporal models of both cod bycatch per unit effort and lobster catch per unit effort and estimate cod discards in the Maine lobster fishery. Limited research has been published on the mortality of fish discards in the lobster fishery. Anderson et al. (2020) evaluated the impacts to two non-commercial species, Sea Raven (*Hemitripterus americanus*) and Longhorn Sculpin (*Myoxocephalus octodecemspinosus*) in the southern Maine fishery. They found that both species were resilient at time of capture but did suffer some behavioral and physiological stress and more research was needed to understand long term effects (Anderson et al. 2020).

4.1.1.2.3 Discards/Bycatch in Other Fisheries

Bycatch and discards of lobsters were calculated for major federally-managed fisheries, including otter trawl, scallop dredge and sink gillnet for Southern New England, Georges Bank and the Gulf of Maine, based on the Standardized Bycatch Reporting Method (Wigley and Tholke 2019). In brief, the ratio of discard weight to target species retained based on observer data (discard weight) and vessel trip reports (retained catch). This ratio is estimated across all observed trips within a fleet, area and quarter and then applied to the total landings of the target species for the fleet, area and quarter to get an estimate of the total discards from the fishery (Figure 66). Note that these discard rates make no assumptions of discard mortality rates, so estimates by disposition (i.e., live and dead) are not available.

Otter Trawl Fishery Discards

Since 1990, discards in otter trawl fisheries have declined in SNE from a time-series high of about 530 mt in 1992 to a five-year average of 29 mt in the terminal years (Table 21). Discards on Georges Bank increased to a time-series peak of almost 500 mt after 2010 but have decreased some with a five-year average of 254 mt in the terminal years. Discards for the Gulf of Maine varied without trend with peaks around 300 mt and a five-year average of 214 mt in the terminal years. It is notable that lobsters are also retained as bycatch in the otter trawl fishery but this is treated as landings and not included here.

Scallop Dredge Fishery Discards

Lobster discards in scallop dredges are generally highest on Georges Bank, varying without trend with peaks around 70 mt and a five-year average of 22 mt in the terminal years (Table 22). Estimated lobster bycatch in SNE experienced one peak over 100 mt in 1992, though with high uncertainty, and has otherwise been low throughout the time series with a five-year average of 1.5 mt in the terminal years. Bycatch in the Gulf of Maine has been historically low with some higher rates in the recent years, peaking at 67 mt in 2011 and a five-year average of 7.2 mt in the terminal years. While lobster bycatch is currently low in the GOM for the federal scallop fishery, it may be expected to increase if scallop fishing effort continues to increase in this region (NEFSC 2018).

Sink Gillnet Fishery Discards

Lobster discards in the sink gillnet fishery is generally highest in the Gulf of Maine with a peak of 252 mt in 2005 and a five-year average of 136mt in the terminal years (Table 23). Bycatch in the SNE sink gillnet fishery is actually estimated to be increasing with a peak of ~27 mt in 2011 and 2012 but declined in recent years to a five-year average of 3.1 mt. Discards on Georges Bank were low before 2000, average less than 3 mt per year but increased to an average of 29 mt per year since 2000, with a five-year average of 17 mt in the terminal years.

4.1.2 Recreational Catch

Maine

In 1997, a five-trap recreational lobster license was established. The number of licenses issued has ranged from 162 in 1997 to 2,182 in 2018 with a peak of 2,187 in 2017. Since 2001, all license applicants must complete a 50 question exam on Maine lobster laws and lobster biology. A maximum of two recreational licenses may be assigned to each vessel. In 2008, a mandatory harvester logbook program was initiated, where 10% of each Maine Lobster Management Zone licenses were selected for trip level reporting. While landings are not available for the recreational component of the Maine fishery, the recreational licenses represented a peak of 26.8% of the total licenses in 2018 and only 0.36% of the total trap tags sold so Maine does not consider this component of the fishery to significantly impact harvest relative to the commercial component.

New Hampshire

Recreational lobster fishing in New Hampshire represents those harvesters that fish with 5 traps or less with no sale of harvested lobsters allowed. Recreational catch and effort data have been collected in the same manner as the commercial lobster harvest for state landings. Between 1969 and 1985 mandatory annual reports from all lobster harvesters in state waters were compiled to produce annual lobster harvest totals. Between 1986 and 2005, a random selection (RSL) of a percentage of recreational licensed lobster harvesters and all new recreational entrants into the state lobster fishery were required to report catch and effort

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data. The reported data were expanded to reflect the total estimated inshore landings of lobster. The RSL reports were submitted monthly and collected the following trip-level information: month and day fished, number of gear fished (both monthly and daily totals), area fished, average set over days/pot, weight of harvest, gear size, did fish or did not fish, and incidental catch. The reports submitted by new entrants were submitted yearly and represented monthly-summarized catch and effort information.

Beginning in 2006, all recreational lobster harvesters are required to report monthly-summarized harvest and effort data on an annual basis. Any recreational harvester may elect to use the Electronic Harvester Reporting Program (EHTR) to report trip-level data on a monthly basis. Recreational catch in New Hampshire state waters from 1989-2012 averaged 0.5% (range of 0.2%-0.8%) of the total New Hampshire inshore lobster landings, with licenses making up 32% (range of 26%-37%) of the total New Hampshire state lobster licenses.

Massachusetts

The Massachusetts recreational lobster license allows harvest of lobsters using a maximum of 10 traps, SCUBA gear, or a combination of both. Recreational harvesters may take no more than 15 lobsters per day. Basic recreational lobster catch and effort data (i.e. number of lobsters harvested, number of traps fished) have been collected via the permit-renewal process since 1971. Number harvested is converted to pounds using 1.46 lbs per live lobster (Whitmore et al. 2019).The report form was modified in 2007 to include an "area-fished" component. Consequently, recreational catch and effort data are now available by stock area. In 2010, the recreational lobster permit and reporting systems were incorporated into the new Massachusetts Saltwater Fishing licensing system. Data were available through 2015 for this assessment. The average number of permits issued has been declining since 2000 with 6,842 permits issued in 2015; an average of 73% of recreational permits were reported fished over the time series (Whitmore et al. 2019). The average non-reporting rate for permits issued was 25% over the 2000 – 2015 time series. Approximately 220,864 lbs were landed by the Massachusetts recreational fishery in 2015 (Whitmore et al. 2019), which is approximately 1.3% of the total Massachusetts commercial lobster catch.

Rhode Island

Prior to the implementation of the Rhode Island/ACCSP catch/effort logbook data collection program in 1999, no catch/effort data were collected regarding the Rhode Island recreational lobster trap and lobster diver fisheries. In 1999, recreational lobster trap and lobster diver license holders were asked to provide their monthly lobster catch and effort data in a report that is submitted annually. The submission of recreational lobster catch/effort data is voluntary. During the period 1999-2007, Rhode Island recreational lobster landings have averaged 0.224% of the total Rhode Island lobster landings. Reporting decreased significantly after this period; as such, the voluntary recreational lobster fishery catch/effort logbook report was discontinued after 2010. Annual number of recreational lobster pot and diver licenses are available.

Connecticut

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From 1983 to 1999, the recreational lobster fishery in Connecticut landed between 38,000 and 105,000 lobsters annually, equivalent to a maximum of 6% of commercial landings during those years. Since the mortality event that occurred in Long Island Sound in 1999, the recreational lobster fishery in Connecticut waters has landed 15,000 – 30,000 lobsters, equivalent to about 2% of commercial landings. Total pots fished recreationally ranged from 4,000 - 9,500 in 1983-1999 then declined to less than 2,000 in 2001 following the 1999 die off. The number of license holders has also declined, ranging from 1,200–2,800 issued between 1983 and 1999, and dropping to 900-377 issued between 2000 and 2011. On average, 73% of recreational lobster license holders reported using their licenses between 1983 and 1999. Following the die-off, not only were fewer licenses issued, fewer license holders reported fishing, with an average of only 50% actively fishing between 2000 and 2006. However, with the lowest number of recreational licenses in 2011 due in part to decreased availability and also to an increase in the license fee in 2011, most license holders (76%) reported fishing their license in 2011. Approximately one in five license holders captured lobsters recreationally while diving in Connecticut waters between 1983 and 1999. From 2000 to 2006, that number dropped by almost half, with approximately one in ten capturing lobsters while recreationally diving. The number of people recreational harvesting by scuba diving dropped to less than 4% in 2011. From 1983 to 1999, three in four active license holders set traps to capture lobsters. Since 2000, the majority of recreational lobstermen in Connecticut fished for lobsters with traps.

New York

Recreational lobster permit holders are required to complete an annual Recall Landings Survey for the previous year when they apply for their current year's license. These data have been collected since 1998. New York recreational lobster landings from 1998 – 2018 averaged 1.1% (range of 0.1%-2.2%) of the total New York landings. Even though recreational landings have been declining over time, their proportion of New York's total lobster harvest has been increasing. New York has required non-commercial lobster permits to harvest lobster recreationally since 1977. The number of licenses ranged from 2,549 in 1991 to 585 in 2018. On average, 56% of the harvest was from traps and 39% from diving.

New Jersey

New Jersey collects no recreational landings data for American lobster. However, a recreational lobster pot permit is available which allows the permittee to fish up to 10 lobster traps in state waters. Hand-harvest by divers is also allowed and requires no permit; spearfishing for lobster is prohibited. Recreational harvesters may take no more than six lobsters per day.

4.1.2.1 Recreational Contribution to Lobster Fishery

Collection of recreational landings information is not a compliance measure, so information collected varies by state (see above state by state recreational information). Several types of fishery information were evaluated to determine the contribution of the recreational fishery to the total lobster fishery. Evaluation of recreational landings compared to total state landings was the preferred, since fishery removals have direct impacts to the lobster population. Table 24 presents recreational landings data and their contribution to total state landings for states which had the information available.

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New Hampshire recreational landings in the GOMGBK stock area varied from 1,738 lbs to almost 9,000 lbs from 1969 – 2019. Data were unavailable from 1982 – 1988. Recreational landings contributed less than 1% to total New Hampshire landings, and the percent contribution has decreased over time. Massachusetts recreational landings are total state landings from both stock areas combined. Massachusetts has much higher recreational landings compared to New Hampshire and they have contributed 1.32% to 2.74% of total landings. Massachusetts recreational landings declined somewhat over the time series, as has the percentage of recreational landings to total landings. New York recreational landings from the SNE stock area are similar in magnitude to New Hampshire ranging from 2,245 to 14,057 from 2001 to 2019 with a steep decline since peak landings in 2006. The contribution of New York's recreational landings to total landings catch ranged from 0.43% in 2001 to 2.16% in 2015. New York's recreational landings have contributed a higher proportion in recent years due to declines in New York's commercial landings since 2000. Delaware reported no recreational landings since 2016.

Several states were unable to provide recreational landings but provided recreational license information and trap tag information if available. The recreational license and trap tag information was compared to total state information to determine the recreational contribution to the fishery (Table 25).

ME provided information on both recreational licenses and the number of trap tags sold to examine the contribution of the recreational fishery to ME's total fishery. Recreational licenses ranged from 162 in the late 1990s to greater than 2,000 in recent years and contributed 2.2% (1997) to 26.8% (2018) of total licenses. The information provided on the number of trap tags sold to ME's recreational license holders may be more informative about the contribution of the recreational fisheries to the state's total lobster fishery. Recreational trap tags sold ranged from 771 in 1997 to 10,288 in 2018 but contributed less than 1% of the total number of trap tags sold to Maine license holders. Rhode Island recreational lobster licenses ranged from 885 in 2010 to 490 in 2019. While recreational licenses contributed a high percentage of total Rhode Island licenses, they declined over time. New Jersey has a short time series for recreational lobster information with no discernable trends.

The information provided indicates that the recreational fishery contributes a very small percentage to the total lobster fishery in both GOMGBK and SNE stocks based on landings and trap tags sold. Recreational licenses are a much greater proportion of total licenses, but generally recreational lobster licenses only allow license holders to fish 5 to 10 traps. Commercial trap allocations are generally several orders of magnitude higher than recreational, which would make the fishery impact of each commercial lobster licenses much greater on the lobster population compared to recreational licenses. Given the apparent small recreational fishery contribution and high data uncertainty, including lack of a landings time series from the state accounting for a majority of the lobster fishery (Maine) and a lack of biological sampling, recreational catch is assumed negligible and is not included in the stock indicators or assessment model catch inputs.

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4.1.3 Biological Samples

4.1.3.1 Data Collection Methods: Port and Sea Biological Samples

Maine

Fully implemented in 1967, DMR conducted port sampling during ten randomly selected days each month from April through December through 2011 when the program was discontinued. Port samplers surveyed lobster dealers along the entire coast who bought from at least five commercial lobstermen. This survey was designed to produce unbiased expanded estimates of catch, effort, sex, and size distribution of the landed catch for the entire fishery on a monthly and annual basis. Recorded data included number of traps hauled during each trip, number of days traps were immersed, total weight of catch, number of lobsters caught, and ten minute square information. Ten lobsters from each boat were randomly selected to provide individual length and weight data, as well as sex, claw, and shell condition.

A sea sampling program was started in 1985 during the months of May through November aboard commercial lobster vessels using observers to record data. Prior to 1998, sea sampling was limited to only three locations with repeated trips made aboard the same vessels. This program was expanded in 1998 to sample each of Maine's seven lobster management zones three times a month during the months of May through November. A limited winter sampling program has been developed in recent years that averages one sampling trip per month per statistical area from December through April. Biological data collected include carapace length (mm), cull status, sex, v-notch/mutilation condition, presence and condition of eggs, molt condition, and finfish bycatch (species and length). In 2003, the incidence of shell disease and dead lobsters in traps were incorporated into the sampling protocol.

New Hampshire

NHFG conducts a monthly sea sampling program from May through November aboard commercial fishing vessels in three general areas off the coast of New Hampshire, all located within SA 513. Data collected since 1991 include catch per unit effort (CPUE), bait type, carapace length, sex, molt stage, cull status, v-notch condition, and presence of eggs.

A port sampling program was initiated in 2005 to collect both CPUE and biological data on harvest landed in New Hampshire. Currently, one sample is taken each month from January-December from vessels fishing in federal waters. During each visit, 100 lobsters are sampled and an interview with the captain is conducted. Biological data collected include carapace length (mm), sex, molt stage and cull status. The captain’s interview consists of a variety of questions including: number of trawls hauled, traps per trawl, number of set days, percent of traps that were single parlor, location of area fished and average trap depth.

Massachusetts

The MADMF has conducted a commercial lobster trap sea sampling program since 1981 to collect both biological and CPUE data. Seven fixed regions (the Provincetown region was added in 2008) are distributed throughout state waters to represent all three stock areas, and are sampled at least once per month from May-November by observers aboard commercial lobster boats. Recorded data include carapace length (mm), sex, shell hardness, culls and/or other shell damage, external gross pathology, mortality, presence of extruded ova on females, as well as trap locations (latitude and longitude) and water depth (from chart plots).

The MADMF conducted a port-sampling program from 2006 - 2009. This program was specifically structured to obtain data from offshore lobster fisheries conducted in the Gulf of Maine and on Georges Bank, and targeted NMFS Statistical Areas which comprised the majority of offshore landings within each stock unit. NMFS SA 515 was sampled for the offshore Gulf of Maine, and SA 562 was sampled for Georges Bank. One trip per month was conducted in each area. A target number of 600 lobsters were sampled during each trip. Biological characteristics including, carapace length (mm), sex, shell hardness, cull status and/or other shell damage, and external gross pathology were recorded.

In 2016 and 2017 at sea lobster sampling data were collected from offshore vessels opportunistically during a Jonah crab tagging project. Four NMFS SAs were represented in 2016 sampling (525, 526, 537, and 562) and three SAs were represented in 2017 sampling (526, 537, and 562). Lobster sampling data followed standard MADMF lobster sampling procedures (as above), and data were provided to this assessment.

Rhode Island

The Rhode Island Department of Environmental Management has conducted an inshore and offshore trap sea sampling program since 1990. Sampling areas over time have included Narragansett Bay, Rhode Island Sound, mid-continental shelf areas (30-60 fathoms; discontinued after March 2003), and canyon areas (70-200 fathoms). Collected data include catch (weight and number), effort (number of trap-hauls, set-over days), trap type, bait type, bottom type, depth, trap location (LORAN or latitude/longitude), surface and bottom water temperature, carapace length, sex, presence and developmental stage of extruded eggs, relative fullness of egg mass, shell hardness (molt status), cull status, shell damage/disease, v-notch status, and mortality. Inshore sea sampling was conducted each month (2 sea sampling trips per month) and offshore sea sampling was conducted quarterly (February, May, August, and November). In 2008, offshore sea sampling (LCMA 3) was discontinued for safety reasons; however, additional sea sampling was initiated in the "offshore" portions of LCMA 2 as compensation. In 2012, all sea sampling was discontinued beginning May 1 due to discontinuation of federal funding; however, sea sampling did continue during June-December 2012 with support of Rhode Island state funds. With partial federal funding, the program was reinstated in June 2013, albeit a reduced sea sampling regimen for LCMA 2 only. The program currently targets one sea sample trip per month, or 12 trips per year.

An offshore port sampling program was initiated in January 2006. The primary objective of the Offshore Port Sampling Program is to collect lobster length frequency and other biological data (i.e. sexual maturity, shell disease frequency and severity,) from offshore NMFS statistical areas (LCMA 3) where lobster landings are emanating, but do not have any sampling data to properly characterize the length frequency distribution of the landings from those areas. Accurate area-specific length frequency data are vital for lobster stock assessment purposes in order to provide higher quality data used for stock status determinations. This program was also discontinued in 2012 as noted above for the sea sampling. With the partial funding re-established, at least one port sample is collected monthly. NMFS Statistical Areas commonly sampled in recent years include 525, 526, 537, 616, 622, 515, and 514.

Connecticut

The Connecticut Department of Environmental Protection Marine Fisheries Division has conducted sea sampling trips since 1982 with commercial trap fishermen within Long Island Sound. From 1982-1999, an average of 15 sea sampling trips were taken each year (range 6-28 trips per year). Following the die-off in 1999, expanded sampling effort increased the annual average to 41 trips for 2000-2007 (range 19-77 trips per year). With reduced landings and effort, sea sampling trips were scaled back from 2008 to 2012 with an average of 19 trips taken (range 9 to 29). Two trips were taken in 2013 as trips were scaled back due to the loss of funding which supported lobster monitoring. No data are available since 2013. Biological information was recorded for all lobster of all sizes in as many trap hauls as possible. These data include: carapace length (to the nearest mm; 0.1mm for the mm interval encompassing the legal minimum), sex, shell hardness, relative fullness of egg mass, developmental stage of eggs, cull status, and any signs of shell damage or disease. From 1992-1998, pleopods were taken from a large number of females for cement gland staging to determine length at maturity.

New York

New York State Department of Environmental Conservation sea sampling data are collected on cooperating commercial vessels in Long Island Sound (NMFS SA 611) and the Atlantic Ocean side of Long Island (SA 612 and 613). Data collected include catch, size, sex, egg status, shell disease, soak time, and water quality. Additional analysis of the fishery has been conducted using information supplied on lobster permit applications, such as catch, pots fished, area fished, and number of participants. Fishing effort (number of traps used) can be calculated from this information. Sampling in SA 612 and 613 has always been sporadic and sampling in SA 611 was very poor during 1995-1998, 2003, and 2012-2018.

A port sampling program began in 2005. The main objective of the program is to enhance the collection of biological data from lobsters harvested from LCMAs 3, 4 and 5. A communication network was developed with cooperating dealers and fishermen who fish these areas. This network is contacted to identify days and times of vessel landings to provide sampling opportunities. Utilizing this network of contacts allows for the sampling of lobster fishing trips landed in New York from the appropriate LCMAs. A random sample of at least 100 lobsters is collected from the catch before it is culled. For sample sizes under 100, all lobsters are sampled. Sampling protocol adheres to the standards and procedures established in NMFS Fishery Statistics Office Biological Sampling Manual. This program was expanded to collect data from LCMA 6 starting in 2013. In this assessment, port and sea sampling lengths have been combined by statistical area and month in years for which port samples were available.

New Jersey

The New Jersey Division of Fish and Wildlife has conducted at-sea observer sampling aboard commercial lobster trap vessels in LCMAs 4 and 5 since 2008 and has completed a total of 124

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trips through 2019. Sampling is conducted randomly twice a month from May-October and once a month during the rest of the year except during closed periods when sampling does not take place (February and March from 2013-2016; April 30th – May 31st in LCMA 4 since 2017). Biological data collected include carapace length (mm), cull status, sex, egg development stage, v-notch/mutilation condition, presence and condition of eggs, and molt condition.

National Marine Fisheries Service (NMFS)

The Northeast Fisheries Observer Program (NEFOP) has collected data from vessels engaged in the lobster fishery as funding allows since 1991. NEFOP is assigned sea days by the NOAA NMFS Northeast Fisheries Science Center (NEFSC) on a yearly basis as part of the Standardized Bycatch Reporting Methodology since 2012. Because there is no mandate under SBRM to monitor the federal lobster fishery to support the management of lobster itself, number of NEFOP sea days are allocated based on the needs to monitor bycatch of species included in SBRM, including groundfish. Thus, sampling intensity is inconsistent and varies across years. In recent years, NEFOP observer coverage peaked at 550 sea days in 2015 but coverage has since dropped to 45 and 26 sea days in 2017 and 2018 respectively. Inshore and offshore vessels based in ports from Maine to New Jersey are covered by the program. Data collected by NEFOP observers include carapace length (mm), molt stage, shell disease, sex, presence of eggs, v-notch condition, number of claws, kept and discarded catch weights, bycatch data (including finfish lengths and weights), gear and bait characteristics, haul locations, water depth, trip costs, and incidental takes.

The port sampling program for the NMFS Greater Atlantic Regional Fisheries Office has conducted port-sampling for lobster throughout the region since 1983, with sampling ranging from 36 to 79 samples per year in the past decade. Annual sample requests are stratified by region, stock area, gear type, and calendar quarter. In recent years, there has been some effort to allocate NMFS sampling resources to be complimentary to spatial coverage of port sampling by state agencies. Port samplers select vessels for sampling based on current and historical landings data, real-time vessel tracking, and local knowledge of the fisheries. A standard lobster sample consists of 100 length measurements with gender.

Atlantic Offshore Lobstermen's Association (AOLA)

Since 2001, a subset of the fishing industry members of the AOLA has collected at-sea, fishery-dependent data in portions of LCMA 3. From 2001-2008, each participant sampled 10 randomly selected traps from within a pre-designated trawl of approximately 40 traps total. Traps were sampled once per trip, approximately weekly. For each participating vessel, the designated trawl and traps were held constant during the entire sampling period; however, in many cases, the gear were moved to accommodate normal fishing operations. Data collected included: location, average bottom depth, carapace length, sex, egg presence, egg stage, and in some cases v-notch condition. From 2009-present, most participants sampled 200 lobsters once per calendar quarter. Data collected remained as described for the 2001-2008 period, with the addition of number of traps sampled. Over the entire time series 20 vessels participated across 11 NMFS statistical areas. The number and location of vessels participating varied annually.

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Starting in 2013, some AOLA participants transitioned to the data sampling program administered by the Commercial Fisheries Research Foundation (CFRF).

Commercial Fisheries Research Foundation (CFRF)

The CFRF has conducted a fishery-dependent lobster data collection project since June 2013, and provided 2013-2018 data for this assessment. The CFRF project involved 25 vessels over the time series and offered coverage of inshore and offshore SNE, GBK, and offshore GOM. Typically, three sampling sessions were conducted per month from the fisherman's regular commercial catch. For sampling the regular commercial catch, the fisherman decided the day(s) that sampling sessions would be conducted, but the trawl(s) sampled on those days were selected at random. During a sampling session, data are collected from a trawl starting with the first trap hauled until 20 lobster traps had been sampled or 100 lobsters had been sampled (including any remaining lobsters in the trap), whichever comes first.

In addition to commercial trap sampling, each vessel is given three ventless traps to use during the course of this project. To maintain consistency with other ventless trap sampling programs in Rhode Island, Massachusetts, and Maine (see Section 4.2.2.1), the Lobster and Jonah Crab Research Fleet deploys ventless traps with the following configurations: 40" length x 21 " width x 14" height, single parlor, 1" square rubber-coated 12-guage wire, standard mesh netting, cement runners, 4" x 6" disabling door. One ventless trap is deployed at a fixed temperature monitoring station, and the others are deployed as the lobstermen see fit. Ventless trap sampling is not associated with commercial trap sampling, and thus is recorded in a different sampling session. CFRF encourages fishing vessels to record at least one ventless lobster sampling session per month at the bottom temperature monitoring site. As a result, coupled bottom water temperature data with lobster and Jonah crab catch data are available. Only data from the regular catch samples were included in the biosample data (see Section 4.1.4) as the ventless trap catch data are not considered representative of the commercial catch, but these ventless trap data may provide utility in future assessments. Collected data included vessel ID, date, time, and location, depth (feet) sex, size (mm), egg-bearing and v-notch status, shell hardness, shell disease severity, and disposition (kept or discarded).. Data were collected on Samsung tablets using CFRF's On Deck Data application and periodically uploaded to a database at CFRF where they were QA/QC'd and provided to ACCSP.

University of Maryland Eastern Shore

In 2016 and 2017, opportunistic data were taken from two fishing vessels out of Indian River Inlet, Delaware and West Ocean City, Maryland. Both vessels primarily targeted black sea bass with lobster being a bycatch species. The vessels fished out of LCMA5 in NMFS Statistical Area 621. Samples were taken roughly once a month throughout the summer and the fall months, and all lobsters caught during fishing operations were sampled. Both baited and un-baited traps were used, and the traps typically soaked for two weeks. A small subsample of lobsters were caught using ventless traps which were used for various graduate research projects in 2017, but these data were not included in the biosample data (see Section 4.1.4) as they are not considered representative of the commercial catch. In 2016, there were 660 lobsters sampled dockside. In 2017, there were 2,073 lobsters sampled at-sea. Collected data included date, sex, carapace length, egg presence, and v-notch status. Lobsters were also scored for the presence of epizootic shell disease using a regional disease index. The chelae, carapace, and abdomen were scored separately.

4.1.4 Development of Estimates from Biological Data

Biosampling data from port- and sea-sampling are used for multiple model inputs including proportions of landed catch, legal proportions, conservation discard rates, and the landed sex ratio which is used for apportioning the landings by sex. Proportions of landed catch by sex and statistical area are used to calculate the sex ratio of landings by statistical area and the resulting landings are used to weight the landings size composition across statistical areas. The composition of the catch from sea-sampling data is used to calculate the legal proportions and conservation discard rates by size and statistical area, which are also then weighted by landings across statistical area. Additional data necessary to calculate these inputs are legal sizes limits and length-weight relationships. Due to some spatio-temporal limitations of biosampling, it has been necessary to “gap-fill” data sets for calculating these inputs by borrowing data from statistical areas with lobsters of similar size compositions. Gap-filling was triggered in the previous assessment when fewer than ten sampling “trips” occurred. Trips were therefore weighted equally despite some significant protocol differences and data limitations precluding characterizing a sampling trip at a finer and more consistent resolution. In this assessment, effective sample sizes of combined biosampling data were used to trigger gap-filling, discontinuing the need to assume sampling trips carry equal weight for characterizing commercial length data. The process of calculating these inputs is described in Appendix 3.

4.1.4.1 Changes to legal size limits

A complete table showing the minimum and maximum size limits by LCMA is listed in Table 26.

4.1.4.2 Length-weight relationship parameters

The relationship between the length of a lobster’s carapace and the weight of that individual is an important biological characteristic to define for the species, and these data are used in different aspects of the assessment, such as to determine the overall weight of lobsters from trawl survey catch (number and length information). Sex-, and statistical area-specific parameter estimates from NEFSC trawl survey data for these relationships were carried forward from the last assessment (see Section 4.1.4.2 in ASMFC 2015a).

The parameter estimates for all of the relationships are presented in Table 27 and Table 28, and model fits to the data are presented in Figure 67-Figure 69.

4.1.4.3 Size structure of commercial catch

GOMGBK

Size compositions of the commercial landings shifted to larger sizes following the increased minimum size limits implemented in the late 1980s (Table 26, Figure 70). Following implementation of these size limits, there were sharp peaks in landings of the first legal size bin (83mm CL) that then declined with size over the next three size bins (88-98 mm CL). Sizes greater than 102 mm CL (maximum size of 98 mm CL size bin) were infrequent in the catch, particularly after the 1990s when there were decreases in landings of larger females (100-120 mm CL). Otherwise, size compositions have been relatively consistent between sexes and among quarters. At the statistical area level, an inshore-offshore gradient and sub-stock dynamics in size composition can be seen in quarter 3, for example (Figure 71), with smaller, narrower size compositions, similar to the stockwide compositions, in inshore GOM statistical areas (511-514), slightly larger and broader size compositions in transition statistical areas/offshore GOM (e.g., 464, 465, 521, 515, 526), and even broader size compositions including the largest sizes in offshore statistical areas concentrated on Georges Bank (522, 525, 561, 562).

Sex ratios of landings were skewed towards females in quarter 1, closer to 1:1 in quarter 2, skew towards males in quarter 3, and skew back towards females in quarter 4 (Figure 72). Collectively, annual sex ratios were generally close to 1:1, but skewed towards females in the early 1980s, 1990s, and since 2013, and skewed towards males in the late 2000s and early 2010s (Figure 73).

SNE

Shifts in size compositions in response to changing size limits over time can be seen in Figure 74. Size compositions shift to subsequently larger sizes in the 1990s, mid-2000s, and finally in the 2010s. Less defined peaks in landings at the 78-83 mm CL bins in the 1980s shifted to no catch below 83 mm CL and sharp peaks at the 83 mm CL bin accounting for a high proportion of landings in the 1990s and early 2000s. Peaks then shifted to the 88 mm CL bin in mid-2000s and 2010s. Shifts are similar between sexes and quarters, but there have been broader size compositions of males. Sizes greater than 107 mm CL (maximum size of 103 mm CL size bin) were infrequent in the catch. Similar to GOMGBK, an inshore-offshore gradient in size compositions can be seen in quarter 3, for example (Figure 75), with narrower size compositions in inshore statistical areas where landings are coming from inshore areas (e.g., 611, 538, 539) and broader size compositions in statistical areas south of Long Island Sound where landings are coming from more offshore areas.

Seasonal sex ratios of landings were more variable than GOMGBK (Figure 76). Sex ratios were consistently skewed towards females across quarters in the late 1990s. Collectively, annual sex ratios were female skewed through the late 1990s, skewed towards males through the mid-2000s, and have become increasing skewed towards females since the late 2000s (Figure 77).

4.1.4.4 Sampling Intensity

The following summarizes sampling intensity through time according to the threshold sample sizes determined in the development of model inputs from port- and sea-sampling. However, the importance of statistical areas, in terms of total landings, is not directly accounted for in this summary. Current (i.e., 2018) spatial and seasonal port- and sea-sampling intensity relative to landings are further examined in Appendix 4.

GOMGBK

There has been more limited biological sampling in quarters one and two, requiring broader periods of data borrowing for gap-filling, though this sampling has improved through time (Figure 78-Figure 79). Sampling has been more adequate during quarters 3 and 4, particularly from inshore statistical areas where the majority of catch occurs (511-514). There have been occasions of inadequate quarter 1 sampling in these statistical areas in recent years. SAs 561 and 562 had poor sampling in the early 2010s, but improved in the most recent years. There remains a need for increased sampling in SA 522, and increased sea sampling, specifically, in SA 526 and during quarter two in SAs 464 and 465 (Figure 79).

SNE

The lack of early sampling from some statistical areas can be seen in Figure 80 and Figure 81, though these are statistical areas contributing to the relatively low New Jersey south component of landings. There has been more adequate sampling from the statistical areas accounting for larger proportions of the landings (537, 538, and 539), particularly in quarters 2 and 3. Recent declines in sampling can be seen for SA 611. For statistical areas that account for landings on a regular basis, there remains a need for increased sampling in SA 623, and increased sea-sampling, specifically, in SA 616 and during quarter 2 in SAs 622, 613, 614, and 615.

4.2 Fishery-Independent Data Sources

4.2.1 Trawl Surveys

Data used in this assessment were obtained from bottom trawl surveys conducted by the NMFS Northeast Fisheries Science Center (NEFSC) on the continental shelf as well as from inshore bottom trawl surveys conducted by the North East Monitoring and Assessment Program (NEAMAP), and the states of Connecticut, Maine/New Hampshire, Massachusetts, New Jersey, and Rhode Island. Information from long term surveys conducted by the Millstone Power Station and the University of Rhode Island were also included but not used in the models (see Section 4.2.4). NEFSC, NEAMAP, CT, MA, ME/NH and RI conduct trawl surveys during the spring and fall. More detailed information on survey area and timing, years surveyed, sampling design, gear, and methods for each survey is presented in the text below, as well as in Table 29.

4.2.1.1 Trawl Survey Methods

Maine/New Hampshire Trawl Survey

Trawl survey data have historically been limited in Maine and New Hampshire nearshore waters. In the fall of 2000, the Maine/New Hampshire (ME/NH) trawl survey was initiated as a comprehensive inshore survey. The inshore trawl survey is conducted during the spring and fall of each year, same as that of the NMFS offshore surveys. It is a stratified random design modeled after the NMFS and Massachusetts Division of Marine Fisheries (MADMF) surveys. The design includes four depth strata: 5 – 20 fathoms (~9 – 37 m), 21 – 35 fathoms (~38 – 64 m), 36 – 55 fathoms (~66 – 101 m), greater than 56 fathoms (~102 m) (its outer boundary roughly delineated by the 12-mile limit), and 5 regions based on oceanographic, geologic, and biological features. The fourth stratum was added in the spring of 2003; it expands the coverage area to equal that area covered by the NEFSC survey and allows some overlap between this survey and the NMFS Gulf of Maine offshore survey area (Chen et al. 2006). The addition of the fourth stratum slightly reduces the sampling pressure in the shallower strata, which has been of concern to fixed gear fishermen in the past. To randomize the survey area (~4,000 square nautical miles (nm^2)), each depth stratum was divided into 1 nm^2 sampling grids. A target of 120 stations was selected for sampling in each survey resulting in a sampling density of about 1 station per 40 nm^2. This density compares to NEFSC of 1 station per 260 nm^2 and Massachusetts' 1 station per 19 nm^2. The number of stations per stratum was allocated in proportion to each stratum's area. When a station is encountered that cannot be towed, an alternate tow is selected nearby over similar depth.

For a full description of the gear please see Sherman et al. (2005). A standard trawl tow, 20 minutes duration, was made at each station. Shorter tow times were accepted under certain circumstances. Tow speed was maintained at 2.1 to 2.3 knots and tow direction was oriented toward the tidal current whenever possible. All sampling was conducted during the day. After each tow, the net was brought aboard and emptied onto a sorting table. All individuals were identified and sorted by species. All lobster were immediately separated and processed while the rest of the catch was sorted. Total weights (by sex), carapace length (mm), shell condition, presence and stage of eggs, V-notch condition, and trawl damage were recorded for all individuals.

In previous assessments, data have been constrained to the shallowest three depth strata due to the initiation of sampling in the deepest stratum three years after the start of the survey. During this assessment trends were evaluated by depth stratum and showed greater rates of increase moving from shallow to deep water (Figure 82). Additionally, lobster size increased moving from shallow inshore waters to deeper offshore waters (Figure 83). Due to the varying rates of increase in abundance and the less sampled, larger size composition of lobsters captured in the deepest stratum, tracking these trends by including data from depth stratum four in final indices and length compositions for the assessment model was deemed more important than excluding these data to retain three years of data at the beginning of this survey's time series.

Massachusetts

Since 1978, annual spring and autumn bottom trawl surveys of Massachusetts territorial waters have been conducted by the Resource Assessment Project of the MADMF. The objective of this survey is to obtain fishery-independent data on the distribution, relative abundance and size composition of finfish and select invertebrates.

The study utilizes a stratified random sampling design. The survey area is stratified based on five bio-geographic regions and six depth zones. These strata cover both the GOMGBK and SNE stocks, but the fall survey has not had adequate catches to generate indices of abundance for the SNE stock. Trawl sites are allocated in proportion to stratum area and randomly chosen in advance within each sampling stratum. Randomly chosen stations in locations known to be untowable due to hard bottom are reassigned. Sampling intensity is approximately 1 station per 19 nm^2. A minimum of two stations are assigned to each stratum.

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A standard tow of 20-minute duration at 2.5 knots is attempted at each station during daylight hours with a 3/4 size North Atlantic type two seam otter trawl (11.9 m headrope/15.5 m footrope) rigged with a 7.6 cm rubber disc sweep; 19.2 m, 9.5 mm chain bottom legs; 18.3 m, 9.5 mm wire top legs; and 1.8 x 1.0 m, 147 kg wooden trawl doors. The codend contains a 6.4 mm knotless liner to retain small fish. Abbreviated tows no shorter than 13 minute duration are accepted as valid and expanded to the 20 minute standard. The F/V Frances Elizabeth conducted all surveys through fall 1981. The NOAA ship R/V Gloria Michelle has been the survey platform for every survey since spring 1982.

Standard bottom trawl survey techniques are used when processing the catch. The total weight and length-frequency of each species are recorded directly into Fisheries Scientific Computer System (FSCS) data tables. Collections of age and growth material, and biological observations are undertaken during the measuring operation. For lobster, specific data collected include sex, carapace length (mm), and starting in 1995 the egg-bearing status and v-notch status of females.

Rhode Island

The RIDMF seasonal trawl survey was initiated in 1979 to monitor recreationally important finfish stocks in Narragansett Bay, Rhode Island Sound, and Block Island Sound. The survey employs a stratified random design and records aggregate weight by species, frequency, individual length measurements, and various physical data. For lobster, collected data include carapace length, sex, shell hardness, shell disease prevalence, and presence of extruded ova. In 1990, a monthly component was added to the survey, which includes 13 fixed stations in Narragansett Bay. Together, both components of the survey aim to monitor trends in abundance and distribution, to determine population size/age composition, and to evaluate the phenology of estuarine and marine finfish and invertebrate species occurring in Rhode Island waters. Over the years this survey has become an important component of fisheries resource assessment and management at the state and regional levels.

In 2005, the RIDMF replaced the research vessel and survey gear that has been utilized by the survey since its inception. The R/V *Thomas J. Wright* was replaced with a 50’ research vessel, the R/V *John H. Chafee*. During the spring and summer of 2005, a series of paired tow trials were conducted using modern acoustic equipment and new nets designed to match the trawl net used by the NMFS. The results of this experiment were used to calibrate the old and new vessels in order to maintain the continuity of the survey time series. Unfortunately, the new net design was too large for the new research vessel and could not be successfully towed in many of the areas required by the trawl survey. Because of this, a new net was designed in the same dimensions as the net previously used for the survey, which is now used for the trawl survey. By using a similar net design to the previous survey net, the continuity of the survey was maintained (analysis to confirm this is still pending).

In 2012, new doors were installed on the R/V *John H. Chafee.* A rigorous calibration experiment was done to calibrate the new trawl configuration with the new doors to the old trawl configuration with the old doors. The analysis has been conducted and was reported on in the

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previous assessment (ASMFC 2015a). In summary, the findings of the analysis suggested there were not significant differences in the catch of lobster between the old and new door datasets.

A standard tow of 20-minute duration at 2.5 knots is attempted at each station during daylight hours. The net is a two-seam otter trawl (12.2 m headrope/16.8 m footrope) rigged with a 7.9 mm chain link sweep hung 30.5 cm spacing with 13 links per space. The fishing circle of the net is 533.4 cm x 11.4 cm; with 11.4 cm mesh (#42 thread) wings all the way back to the codend. The codend is 5.1 cm mesh (Euro Web 3 mm thread) and contains a 6.4 mm mesh liner to retain small fish. The trawl has Thyboron Type 4 44” doors which are 99 cm in length, 86 cm high (.86 m^2 surface area) and weigh 115 kg a piece. The doors have 36 kg of ballast weight that can be added to each of them. They also are fitted with "Notus Trawlmaster" door spread sensors which provide door spread measurements during the entire tow.

Connecticut

The Connecticut Department of Environmental Protection Marine Fisheries Division has conducted a spring trawl survey in Long Island Sound since 1985 and a fall survey since 1984. Sampling was not conducted during the fall of 2010 due to vessel breakdown. The sampling gear employed is a 14 m otter trawl (9.1 m headrope, 14 m footrope) with 102 mm mesh in the wings and belly, 76 mm mesh in the tail piece, and 51 mm mesh codend towed at 3.5 knots for 30 minutes from a 12.8 m research vessel (1984-89) or the 15.2 m research vessel (1990-present). Forty stations are scheduled to be sampled monthly during a spring survey (April, May, June) and a fall survey (September and October) for a total of 200 samples annually. The trawl survey employs a stratified random sampling design with four depth strata (0-9 m, 9.1-18.2 m, 18.3-27.3 m, 27.4+ m) and three bottom substrate types (sand, mud, and transitional). The sampling area is divided into 1.85 x 3.7 km (1 x 2 nautical mile) sites and includes all trawlable Connecticut and New York waters west of New London and east of Greenwich, CT. Sampling intensity is one station per 68 km^2 (20 nm^2) or less.

Biological data recorded for each tow include total weight (1992-present), carapace length (mm), sex, shell hardness, relative fullness of egg mass, developmental stage of eggs, cull status, and any signs of shell damage (new or old) or disease. From 1992-98, pleopods were taken from a large number of females for cement gland staging to determine length at maturity.

New Jersey

The New Jersey Division of Fish and Wildlife has conducted a groundfish survey along the New Jersey coast since August 1988. The survey area is about 1,800 square miles of coastal waters between Sandy Hook, NJ and Cape Henlopen, DE and from a depth of 18 to 90 ft (5 – 27 m). The area is divided into 15 strata that are bounded by the 30, 60, and 90 ft (9, 18, and 27 m) isobaths. The survey design is stratified random. Since 1990, cruises have been conducted five times a year; in January, April, June, August, and October. For this assessment, data from April and June were combined to represent “spring”. Summer, fall, and winter survey data were excluded because the data are highly variable. Two 20-minute tows are made in each stratum, plus one more in each of the nine larger strata, for a total of 39 tows per cruise in all months except January, when the additional tows are omitted. The trawl gear is a two seam three-in-one trawl (so named because all the tapers are three to one) with 12 cm mesh in the wings and belly and 7.6 cm in the codend with a 6.4 mm liner. The headrope measures 25 m and the footrope 30.5 m. Rubber cookies measuring 2 3/8 inch (60.3 mm) in diameter are used on the trawl bridles, ground wires, and footrope. Five different vessels have been used to conduct the surveys to date.

NMFS, NEFSC

The NMFS Northeast Fisheries Science Center (NEFSC) bottom trawl survey began collecting lobster data in 1967 (fall) and 1968 (spring). The spring survey is generally conducted from March to May. The fall survey is generally conducted in September and October. Lobster data used in this assessment are from both the spring and fall survey beginning with 1982, as lobster survey data prior to 1982 have not been fully audited.

The NEFSC bottom trawl survey utilizes a stratified random sampling design that provides estimates of sampling error or variance. The study area, which now extends from the Scotian Shelf to Cape Hatteras including the Gulf of Maine and Georges Bank is stratified by depth. The stratum depth limits are < 9 m, 9-18 m, >18-27 m, >27-55 m, >55-110 m, >110-185 m, and >185-365 m. Stations are randomly selected within strata with the number of stations in the stratum being proportional to stratum area. The total survey area is 2,232,392 km^2. Approximately 320 hauls are made per survey, equivalent to one station roughly every 885 km^2.

For the assessment, the strata associated with SNE and GOMGBK stocks were adjusted to better align with the statistical areas that define the landings for the stocks. Previously, strata 3520 and 3550 were entirely attributed to the SNE stock and strata 1090-1120 were historically attributed to GBK (Figure 84). However, offshore habitats have become more important to the SNE fishery with SA 537 now providing the majority of landings for the stock. As a significant portion of this statistical area falls in strata previously attributed to GBK, it was appropriate to split these strata along the statistical area boundary so the SNE survey index aligns with the region were the landings were coming from. For consistency, all survey strata in this area at the boundary between SAs 537 and 526 were split. As a result, strata 1090-1120 and 3520 are now split between the stocks and strata 3550, previously attributed to the SNE stock, now lands in the GBK stock region.

Figure 85 and Figure 86 compare the survey indices for the SNE and GOMGBK stocks, respectively, using the previous and updated survey strata designations. In neither case does this change in stratification make marked changes in the survey trends. Indices for the GOMGBK stock are marginally higher with the updated strata set as these strata that are now shared with SNE are of generally lower abundance than much of the remaining stock area. While this change in strata designations does not appear to significantly affect stock trends, it is expected that the updated strata sets will be more appropriate in the future as this area may presumably become more important for the SNE stock.

Most survey cruises between 1967 and 2008 were conducted using the NOAA ship R/V Albatross IV, a 57 m long stern trawler. However some cruises were made on the 47 m stern

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trawler NOAA ship R/V Delaware II. On most spring and autumn survey cruises, a standard, roller rigged #36 Yankee otter trawl was used. The standardized #36 Yankee trawls are rigged for hard-bottom with wire foot rope and 0.5 m roller gear. All trawls were lined with a 1.25 cm stretched mesh liner. BMV oval doors were used on all surveys until 1985 when a change to polyvalent doors was made (catch rates are adjusted for this change). Trawl hauls are made for 30 minutes at a vessel speed of 3.5 knots measured relative to the bottom (as opposed to measured through the water).

Beginning in 2009, the spring and fall trawl survey were conducted from the NOAA ship R/V Henry B. Bigelow; a new, 63 m long research vessel. The standard Bigelow survey bottom trawl is a 3-bridle, 4-seam trawl rigged with a rockhopper sweep. This trawl utilizes 37 m long bridles and 2.2 m^2, 550 kg Poly-Ice Oval trawl doors. The cod-end is lined with a 2.54 cm stretched mesh liner. The rockhopper discs are 40.64 cm diameter in the center section and 35.56 cm in each wing section. Standard trawl hauls are made for 20 minutes on-bottom duration at a vessel speed over ground of 3.0 kts.

The R/V Henry B. Bigelow with a new bottom trawl and protocols replaced the R/V Albatross IV in 2009 for NEFSC spring and fall bottom trawl surveys. Paired tow calibration studies were carried out during 2008 and the data used to estimate length-based calibration factors which convert lobster catches by the Albatross into equivalent catches by the Bigelow, or vice-versa (Jacobson and Miller 2012). From the calibration, the Bigelow appears to be more efficient than the Albatross at catching lobster, particularly for recruits and pre-recruits. Calibration factors $\rho_{\mathrm{L}} = \frac{\mathrm{C}_{\mathrm{Bigelow,L}}}{\mathrm{C}_{\mathrm{Albatross,L}}}$ ranged from about 6.18 (CV 19%) at 50 mm CL to 1.54 (CV 62%) for lobster 210 mm CL (Table 30). Survey catch and catch at length data collected by the Bigelow during 2009-2014 were adjusted to Albatross units $\mathrm{C}_{\mathrm{Albatross,L}} = \frac{\mathrm{C}_{\mathrm{Bigelow,L}}}{\rho_{\mathrm{L}}}$ so that consistent data were available for 1978-2014.

Northeast Area Monitoring and Assessment Program (NEAMAP)

The ASMFC developed NEAMAP in the late 1990s as a cooperative state-federal program modeled after their Southeast Area Monitoring and Assessment Program (SEAMAP). The first survey to be developed under NEAMAP was the NEAMAP Mid-Atlantic/Southern New England (M-A/SNE) Nearshore Trawl Survey, which has been conducted by the Virginia Institute of Marine Science since its inception. Specifically, field sampling for this trawl survey began with a fall pilot cruise in 2006. The first full-scale survey cruise was conducted in the fall of 2007, and spring and fall cruises have occurred each year since 2008. NEAMAP M-A/SNE samples the inshore waters from Cape Cod, Massachusetts south to Cape Hatteras, NC, where samples from the NMFS NEFSC survey are limited due to depth constraints of the NEFSC survey vessel. At each station the net is trawled along the bottom for 20 minutes, at an average speed of 3 knots. The NEAMAP M-A/SNE Survey uses the 400 cm x 12 cm, three-bridle four-seam bottom trawl designed by the Mid-Atlantic / New England Fishery Management Council Trawl Survey Advisory Panel for all sampling operations. This net is paired with a set of Thyboron, Type IV 66" doors. Wingspread, doorspread, headrope height, and sweep bottom contact are monitored using a hydroacoustic monitoring system. The 27.4 m F/V Darana R was used for all surveys.

The NEAMAP M-A/SNE Survey employs a stratified random sampling design stratified by region and depth (6.1 m - 12.2 m and 12.2 m - 18.3 m from Montauk to Cape Hatteras, and 18.3 m - 27.4 m and 27.4 m - 36.6 m in BIS and RIS). NMFS inshore strata definitions were adopted for use by the NEAMAP Survey with minor modifications to align regional boundaries more closely with state borders. Each region / depth stratum combination was subdivided into a grid pattern, with each grid cell (measuring 1.5 minutes Latitude x 1.5 minutes Longitude; 1.8 nm^2) representing a potential sampling site. The target sampling intensity is approximately 1 station per 30 nm^2, which results in sampling 150 sites per cruise. The number of sites sampled in each stratum is determined by proportional allocation, based on the surface area of each stratum. A minimum of two sites are assigned to the smallest of the strata (i.e., those receiving less than two based on proportional allocation). When American lobsters are captured, 25 individuals are sub-sampled for full processing. This includes the collection of individual carapace length (eye notch to back of carapace), individual weight, sex, presence/absence of shell disease, and egg presence and stage (females only) for each of these specimens. If more than 25 lobsters are captured in a single tow, aggregate weight, count, and individual carapace length are measured for the remainder.

Southern strata (south of central New Jersey, strata 8-15) were not sampled in spring 2017 and lobster catches in these strata have been infrequent in other years, so index and length composition data for the assessment models are only from the northern strata (strata 1-7, BIS and RIS).

During preliminary data analyses, it was found that the subsampling protocol for lobster on this multi-species survey causes additional uncertainty in the indices and length compositions. Specifically, sex-specific size compositions and indices can be calculated by using only length information from individuals subsampled for sex or length information from all individuals captured expanded to total catch by sex ratio data from individuals subsampled for sex. Since the subsampling is done when more than 25 individuals are captured during a tow, the additional uncertainty is dependent on lobster density and frequency of encountering aggregations. Figure 87 and Figure 88 show the relative percent difference in annual size compositions calculated with these two methods. The indices of abundance used in the assessment models include lobsters $\geq$ 53mm CL, so the biases in length compositions also result in biases in indices in some years once catch of lobsters <53mm CL are excluded from the data (Figure 89).For this assessment only length information from individuals subsampled for sex was used to develop length compositions and indices of abundance.

4.2.1.2 Survey Trends

All of the bottom trawl survey data in this assessment are random stratified mean numbers per tow with CVs computed using standard formulas instead of the delta mean numbers per tow that were used in previous assessments (see Table 31 and Table 32). Stratified mean numbers were used because they are easier to compute and very similar to delta mean indices used previously, based on comparison of the two techniques.

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Model-based indices (i.e., standardization) were not developed from trawl survey data with associated environmental data that would explain more localized, immediate behavioral changes and resultant changes in survey catchability. Rather, variation in catchability was accounted for with broader climatic variables believed to cause changes in availability (see Section 4.2.4.1).

University of Maine Model

Agencies provided bottom trawl survey data for each sex and survey as mean numbers per tow in two formats for direct use in the assessment models. In particular, survey abundance index data were for lobster 53+ mm and survey size composition data were aggregated into five mm size groups (53-57.9, 58-62.9, 63-67.9,….. 223-227.9 mm CL). Trends in size-specific indices of abundance using the same binning as the length compositions data were also examined and described below, but not used in this format in the assessment models.

4.2.1.2.1 Trawl survey abundance indices

GOMGBK

Trawl survey indices generally show similar trends with the exception of the MA spring indices from the mid-1990s through the 2000s (Figure 90 and Figure 91). The NEFSC and MA spring indices vary at relatively low catch rates at the beginning of their time series then shift to slightly higher catch rates with no trend in the mid to late 1980s through the mid-1990s. The NEFSC indices then increase for the remainder of the time series while the MA indices decline slowly through the 2000s. Similar to the NEFSC indices, the ME/NH indices that start in 2003 also increase throughout their time series (Figure 92). The MA indices begin increasing in 2010, agreeing more closely with the general trend in the other trawl surveys. A notable change across indices occurs in 2011 when all surveys observed at least a 69% increase from 2010. Indices then increase through the remainder of the time series at rates similar to those observed just prior to the sudden increases observed in 2011, with the exception of the NEFSC female index which continues increasing at a greater rate.

There is generally more agreement among trawl survey indices in the fall, though the considerable interannual variability in the MA indices make trends more difficult to discern. The indices with complete time series increase in the early 1980s, vary with no trend through the early 1990s, then decrease through the early 2000s at which time the ME/NH indices start. All indices are stable in the mid-2000s then increase through the late 2010s. Increases of similar magnitude from 2010 to 2011 were observed in some fall indices, but not as consistently as the spring indices. There were relatively large declines across indices in 2019.

Sex ratios among indices are close to 1:1 and, therefore index trends between sexes are similar, with the exception of the NEFSC indices since mid-1990s when sex ratios become increasingly female skewed over time.

Size-specific indices generally show similar trends as the aggregate indices, particularly for the more frequently encountered sublegal size bins (Figure 93-Figure 98). There are also often

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commonalities in interannual variability across size bins, suggesting changes in survey catchability.

Size-specific indices for the ME/NH survey show more stable trends, relative to aggregate indices, or even declining trends across legal size bins. There are generally declining trends of legal size lobsters since the early 2010s. Size-specific indices for the NEFSC trawl survey show similar trends between sexes for smaller sizes. Trends diverge starting with the 78mm CL size bin in the early 2010s with females increasing at greater rates. This divergence occurs earlier, since approximately the mid-1990s, for sizes greater than the first legal size bin (88+ mm CL).

SNE

There is more variability in trends across SNE trawl survey indices (Figure 108-Figure 113), which is not surprising given the greater disparity in overlap and footprint among surveys than occurs in GOMGBK and relatively low densities observed in recent years. A general pattern observed was higher abundance in the 1990s followed by declines to lower abundance in the 2000s and 2010s. Inshore abundance was at intermediate abundance levels in the 1980s (Rhode Island and Connecticut), while offshore abundance (NEFSC) was generally at high, though more variable levels. Declines from 1990s abundance levels occurred slightly earlier in fall indices. Indices decline or become stable at low levels since the late 2000s. These low levels include occurrences of no lobsters being observed throughout the duration of the survey (females during the CT fall survey from 2016-2019 and MA spring survey in 2018, Table 32).

Indices between sexes follow similar trends. Sex ratios vary around 1:1 with no trend in spring surveys, but become skewed towards males in fall surveys. One notable exception to this was a greater rate of increase of female abundance in the 1990s observed by the CT trawl survey that resulted in a sex ratio skewed towards females.

Size-specific indices generally show similar trends as aggregate indices, though the lower catch rates relative to GOMGBK surveys tend to result in more variability in trends at this level (Figure 114-Figure 123). The increase in female abundance observed during the NEFSC spring survey in the late 1990s was more apparent in the 73-83 mm CL bins (Figure 114) and abundance of larger sizes in the fall survey (83+ mm CL) appear more stable than the aggregate indices (Figure 115). The NEAMAP survey observed some increases in abundance in the 73-78 mm CL size bins not seen in other size bins from 2015-2017, particularly males (Figure 116 and Figure 117).The CT survey showed strong divergence towards female-skewed sex ratios in the 73-78 mm CL size bin in the spring survey (Figure 121) that was not apparent in the fall survey (Figure 122).

4.2.1.2.2 Size structure of survey catches

GOMGBK

Size compositions have shifted over time, including abrupt shifts to smaller sizes at the same time the aggregate indices suddenly increased in 2011, particularly in the spring.

The ME/NH trawl survey captures the smallest size structure (Figure 99-Figure 101), the MA trawl survey catches a slightly larger size structure (Figure 105-Figure 107), and the NEFSC trawl survey catches the largest size structure in offshore waters (Figure 102-Figure 104). Catch

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declines steeply in all surveys once individuals reach legal size, and to very small proportions in inshore surveys where sublegal lobsters are more available and account for larger proportions of the catch. The NEFSC captures bimodal size compositions of females, particularly in the spring with peak catches of the largest sublegal lobsters (78-82 mm CL) and legal-sized (88-97 mm CL), but likely mature individuals protected by v-notching and egg-bearing regulations. The ME/NH survey captures a male size structure slightly larger than females in the spring and a female size structure slightly larger than males in the fall, as well as a size structure of both sexes larger than in the spring. The NEFSC captures the largest individuals in the population offshore resulting in a female size structure larger than males in both the spring and fall, as well as similar size structures between seasons. The MA survey captures similar size structure of both sexes during both seasons.

SNE

Size composition trends generally reflect increases since the late 1990s, likely due to both recruitment failure (ASMFC 2010) and decreased exploitation (ASMFC 2015a). There is also increasing interannual variability due to reduced encounter rates in recent years, particularly for females in the MA, RI, and CT surveys. The NEFSC survey catches a slightly larger size composition in the spring than in the fall, but similar size compositions of both sexes within each season (Figure 124-Figure 126). NEAMAP catches a female size composition slightly larger than males in the spring, but similar size compositions in the fall (Figure 127-Figure 129). The MA spring survey catches a similar size composition of both sexes (Figure 130-Figure 131). The RI survey catches a female size structure slightly larger than males in the spring, and the reverse to a slightly larger male size structure in the fall (Figure 132-Figure 134). The CT survey catches a similar size structure between sexes and between seasons (Figure 135-Figure 137). The NJ survey caught a larger female size structure prior to the late 1990s, then caught a slightly larger male size structure (Figure 138-Figure 139).

4.2.1.3 Spatial Analysis of Maine / New Hampshire Trawl Survey

The ME/NH trawl survey has increased disproportionately to the landings and shows a marked increase around 2011. The SAS attributes this increase to both changes in population density and an environmentally-driven change in survey catchability. To better understand this apparent 'regime shift' in the survey, changes in density and trends at the scale of individual survey strata were examined. To get changes in densities by strata between these regimes, densities for each strata and year were calculated, then averaged across years within regime for each strata and calculated the ratio of the densities in the current regime (2011-2018) to the previous regime (2003-2010). Log-linear models were also fit to the mean density by year for each strata to get mean annual growth rates by strata.

Mean strata density in the early period for spring had a median of 17 lobsters per tow and ranged from 2 to 170 with the highest density west of Penobscot Bay in 30-60m depths (Figure 140). In contrast, the current period in spring had a median of 95 lobsters per tow with a range from 14 to 462 and the highest density in 30-60m depths but east of Penobscot Bay. For the spring survey, the relative change between the current and early period was highest east of Penobscot Bay in 60-90m depths, showing a 14-fold increase between the time periods (Figure

141). This area also showed the highest growth rate with catch growing at ~30% per year. With the exception of Penobscot Bay, inshore and western areas generally showed slower growth rates than offshore and eastern areas.

For the fall trawl survey, the early period had median catches of 29 lobsters per tow with a range of 1.5 to 222 with the highest densities occurring in 30-60m depths west of Penobscot Bay, similar to the spring (Figure 142). The current period had a median catch of 116 lobsters with a range of 2.7 to 452 with the highest densities in 30-60m depths east and off of Penobscot Bay. Relative change in density was highest in 60-90m depths in eastern Maine, exhibiting a 6-fold increase between the time periods (Figure 143). Similar to the spring survey, catch rates in the fall survey showed lower growth rates in inshore and western Maine and higher growth rates in offshore and eastern Maine with two strata east of Penobscot Bay in greater than 90m depths showing annual growth approaching 30%.

This geographic pattern of catch from the ME/NH trawl survey generally match observations from Goode et al. (2019) of greater habitat expansion (based on bottom temperatures) toward the northeast versus the southwest. However, the magnitude of change observed in the survey exceeds the change in landings, suggesting that availability or catchability of lobsters also changed over this time period.

4.2.1.4 Lobster abundance and mean size on Georges Bank

Georges Bank was previously assessed as a separate stock until merged with the Gulf of Maine fishery in the 2015 assessment, based on strong evidence for population connectivity between the two regions. Thus, it is worth continuing to track how lobster population dynamics have changed on Georges Bank and how the fishery has responded.

Catch indices for Georges Bank from the NEFSC trawl survey show no strong trend or difference between males and females until around 2000, after which female abundance has been trending upwards while male abundance has trended downwards, approaching time-series lows in the most recent years (Figure 144). For mean observed length in the NEFSC survey females are consistently larger than males in the fall survey, with a couple exceptional years in 1987 and 1998 (Figure 145). However, the mean size of females increases markedly starting around 2000 with mean female sizes nearly 30mm CL larger than males for much of the last two decades and a mean female carapace length above 110mm for most of the past decade. This difference in mean size is not as evident in the spring survey, being similar between the sexes until around 2005 after which, females tend about 10mm CL larger than males. While mean sizes for males are similar between seasons, female size tends to be larger in the fall than the spring, also suggesting that the spring and fall survey are accessing different parts of the population.

4.2.2 Coastwide Ventless Trap Survey (VTS)

The coastwide ventless trap survey (VTS) was initiated in 2006 with the intention of answering the need for a standardized fishery-independent survey designed specifically to monitor lobster relative abundance and distribution. This need was specifically identified in the 2004 Lobster

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Stock Assessment (ASMFC 2006). Of all the possible methods for surveying lobster populations, traps have the fewest associated limitations in relation to habitat factors because they can be used on complex substrate (Smith and Tremblay 2003). However, a number of factors can influence their catchability (see Miller 1990 e.g.), which can complicate interpretation of catch rates. In pilot surveys conducted by MADMF (2004-2005) using a stratification scheme that incorporated depth and substrate type, depth was found to be the driving environmental factor in patterns of catch and size distribution (MADMF unpublished data). Variables impacting catchability are also discussed in Section 2.9.3.

4.2.2.1 Survey Methods

The coastwide VTS employed a random stratified survey design, using NMFS Statistical Area and depth as the primary strata classifications. The SAs included in the survey were 511, 512, 513, and 514 in the Gulf of Maine stock, and 538, 539, and 611 in the Southern New England stock unit. However, sampling in SA 611 was discontinued in 2010. The survey is a cooperative effort between state fisheries agencies and commercial lobstermen, who are contracted to fish the survey gear. A summary of sampling design follows, but greater detail on survey design by state is provided in Appendix 5.

The areal extent of the survey encompassed the state waters portion of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, and New York. For sampling logistics the following areas were excluded from the study area: a) In Maine (SA 511, 512, 513), the estuaries associated with the Kennebec and Penobscot Rivers, b) in New Hampshire (SA 513) Great Bay, the Piscataqua River and Hampton Harbor, c) in Massachusetts SA 514, the eastern-most portion of Cape Cod Bay which contains expansive shallow sandy flats, and in SA 538 the Vineyard Sound and Nantucket Sound areas due to unsuitable lobster habitat and conflicts with mobile gear fleets, d) in Rhode Island, the western portion of Block Island Sound, and e) in New York and Connecticut, only the Long Island Sound portion of SA 611 was sampled, excluding Fishers Island Sound. USGS bathymetry maps were used to identify depth strata. The survey design used three depth strata that span the range of depths in which lobster are typically fished in inshore waters: 1 - 20 m, 21 - 40 m, and 41 - 60 m. A bathymetry map of the study area was overlaid with a one-minute latitude/longitude grid, and each grid cell was assigned a strata based on its bathymetric attributes. A fixed number of sampling stations (grid cells) were randomly selected within each strata in each SA, and new stations were selected each survey year.

In every state except Maine, each station was sampled with one six-pot trawl, in which vented and ventless lobster traps were alternated (3 of each per trawl). Maine deployed the gear either as two three-pot trawls or as one six-pot trawl. In 2015, Maine and New Hampshire transitioned to only ventless pots set as a single three-pot trawl at each station and expanded the number of sites selected for greater coverage. Stations were sampled twice per month with a three night soak time (weather permitting) between baited hauls. There was some variation in months sampled across years and states, however, for this assessment only summer months (June-August) were used.

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Trap deployment, maintenance, and hauling were contracted to commercial fishermen. Fishermen were required to haul survey gear on as close to a three-day soak time as possible in an attempt to standardize trap catchability among sampling trips. All trawls were reset in the same assigned location each time. Survey traps from ME, NH, and RI have dimensions 40” x 21” x 16” a single parlor, and 5” entrance heads; MA traps are only 14” height but otherwise identical.

At-sea samplers (agency staff members) recorded catch in number of lobsters, number of trap hauls, set-over-days, bait type, trap type, and for each lobster; carapace length (to the nearest mm), sex, shell hardness, culls and other shell damage, external gross pathology, mortality, the presence of extruded ova on females, and shell disease symptoms. Trap locations were confirmed with assigned station coordinates after each haul via GPS.

4.2.2.2 Development of Abundance Indices

4.2.2.2.1 Design-Based Calculations

For calculating survey indices for the VTS, only the ventless traps were used and the data from the co-located vented traps were discarded. For the GOM stock, the Massachusetts and Maine surveys were initiated in 2006 but the New Hampshire survey did not start until 2009. The New Hampshire survey was retained in the regional indices because it showed a common dynamic and similar density with the Massachusetts and Maine surveys, indices with and without New Hampshire were similar, and the New Hampshire survey is a continuing data stream. For SNE, both the Massachusetts and Rhode Island surveys started in 2006 but the New York survey started in 2006 and ended in 2009. Due to the shortness of the New York survey, the fact that including the New York survey had a large impact on the combined index, and that the survey is not continuing, the SNE index was calculated using only the Massachusetts and Rhode Island surveys. Because Massachusetts did not run a VTS survey in the GOM or SNE in 2013 and the Massachusetts data were strongly influencing the combined indices, no combined VTS indices were calculated for 2013 for GOM or SNE. Additionally, the survey index was constrained to the months of June, July and August when all agencies were conducting their surveys.

The targeted soak time for the VTS is three days but this is not always consistent. During the last assessment, indices were found to be robust to alternative assumed relationships (i.e., linear and nonlinear) between soak time and catch rates as well as disregarding soak time effects altogether. Thus, only data from traps with extreme soak times of one day or greater than six days were discarded and a linear increase in catch was assumed for all retained traps. Soak time was standardized to three days by dividing catch by soak time to get catch per day and multiplying by three.

Because survey sites were not moved within a survey season, each survey site was treated as an effective replicate and samples within the season as repeated measures. To get the season average for a survey site, the catch was averaged across traps in a trawl, then across trawls within a month, then across months in a season. Calculating the survey indices from the survey site averages then used standard stratified-random equations with the depth and region strata used in the survey design from each state agency:

$$\mathrm{Catch_y} = \frac{\sum_{\mathrm{str}} \frac{\sum_{\mathrm{s}} \mathrm{Catch_{s,str,y}}}{\mathrm{N_{str,y}}} \times \mathrm{A_{str}}}{\sum_{\mathrm{str}} \mathrm{A_{str}}}$$

where $\mathrm{Catch_{y,s,str}}$is the mean catch at site s in stratum str and year y, $\mathrm{N_{y,str}}$is the number of sites in stratum str and year y and $\mathrm{A_{str}}$is the area of a given stratum.

Length compositions for the VTS are calculated in a similar way but by calculating the stratified mean catch for each size bin and then standardizing across bins within a year to sum to one.

Alternative design-based indices for Maine VTS

Design-based VTS indices and length compositions follow stratified random survey designs where strata are associated depth intervals. Strata are divided into 1nm cells and cells are randomly selected for VTS sampling stations. Final locations of stations in Maine are selected in the field to include the desired depth interval represented by the strata. This has been problematic in Maine where coastal bathymetry is particularly complex and mapped strata cells occasionally do not contain the target depth interval associated with the strata. Maine provides the protocol that boats are supposed to search for the depth within a half mile radius, but sometimes the boats must move outside the cell to find locations that match the depth interval, sometimes moving outside the polygon characterization of the stratum itself. As a result, the sampling design remains consistent with sampling effort spread across depth strata. However, accurate digital polygon representation of strata areas is not possible.

We explored the effect of this sampling procedure on resulting survey indices and length compositions by calculating indices and length compositions with two methods. In the first, the stations were assigned to strata based on their spatial coordinates (Spatially-Designated) while, in the second, stations were assigned to strata based on the depth of the station as recorded in the field (Field-Designated). In both cases, the weighted calculations use the respective areas of the strata from the stratification polygons.

A total of 5.6% of stations (142 of 2,537) were located outside of their spatial strata in order to find appropriate depth habitat. Aggregate indices were robust to the different methods, with a mean difference of 0.6% and a maximum difference of 3.7% (Figure 146). Index CVs were ~10.2% for both methods. Calculated length compositions were very robust to methods of assigning stations to strata and not visibly distinguishable (Figure 147). Following discussion, the SAS agreed to use the Field-Designated approach as it was desirable to track changes in depth distributions of lobsters as indicators of changing environmental conditions and habitat preferences and would have minimal impact on the interpretation of temporal trends.

4.2.2.2.2 Model-Based Estimates

The Coastwide Ventless Trap Survey implements a standardized sampling approach to estimate relative abundance indices for lobster. However, certain elements of the survey can vary due to weather delays, gear loss, or other logistical challenges. It has been questioned how variability in these survey elements through time have influenced lobster catch, and ultimately translate

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into impacts on design-based abundance indices from the survey. To address this concern, generalized linear mixed models were constructed to quantify the influence of survey elements (soak time, number of traps per trawl, station, and day of year) on lobster catch per ventless trap, and then standardizing these elements when predicting annual sex and stock-specific relative abundance indices (i.e. model-based indices). Detailed methods and results can be found in Appendix 6. Briefly, SNE model-based and design-based indices indicated similar trends. Both SNE female and male abundance indices have declined since 2006, with the model-based approach declines smoother and less variable over time than those from the design-based approach. Trend differences between sexes from the model approach appeared less than those of the design-based approach; however, the model-based indices were lower in magnitude than the design-based indices. Corroboration in magnitude between model-based and design-based abundance indices for the GOM were stronger than those of SNE. For the GOM, both male and female abundance indices indicated an increase from 2007 through 2012, with abundance variable but still high through 2018 (Appendix 6).

4.2.2.3 Survey indices, spatial patterns and length compositions

Trends in abundance from the design-based calculations are described in the following section. However, the SAS selected the model-based indices of abundance as the indices to use in the assessment models as the standardization models accounted for catchability effects that vary through time and provide a modeled index for the years when the survey did not occur (2013 MA). Comparison of design-based and model-based indices are described in Appendix 6. The length compositions from the design-based calculations were used to characterize the size structure of VTS catch.

GOM

Indices for the GOM at the stock level were similar between sexes and generally increased through the time series, though the rate of increase was greater from 2010-2012, nearly doubling over this period (Figure 148). In addition to the notable increases in 2011 and 2012, there was a notable increase in 2016. Females were more abundant than males throughout the time series. Trends were consistent across frequently encountered size bins (i.e. 5mm bins from 53 through 97), including the abovementioned anomalously high values (Figure 149). This consistency, regardless of size, suggests interannual variability in survey catchability, not necessarily strong year classes moving through the population size structure. The smallest size bin (53-57mm) has declined since a peak in 2016. Similarly, there is a general decline in abundance for both the 58-62 and 63-67 size bin since 2016. The 68-78 mm bins showed stable trends since 2016, however, legal size bins (83+ mm CL) declined over the same period. Massachusetts data for 2019 were not available, so the 2019 data point only represents data from Maine and New Hampshire.

The consistency of trends across size bins is further demonstrated by the consistent size composition data (Figure 150-Figure 152). The survey captures a smaller male size structure and a female size structure more concentrated in the last few sublegal size bins (73-78 mm CL, Figure 150-Figure 151). There is a sharp decline in size composition of both sexes at the first legal size bin (83 mm CL, Figure 150). Some interannual variability in size structure is apparent,

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but there is no discernible trend (Figure 151-Figure 152). The most noticeable deviation was in 2007 when there was an increase in smaller lobsters of both sexes.

At the stratum level, abundance of both sexes have been similar in the shallowest strata, but sex ratios become skewed towards female moving to deeper strata (Figure 153-Figure 154). Indices generally show increases through the late 2000s and early 2010s, but trends stabilize or even decline in recent years. Most notable are the declines in 512 since 2016 in all three depth strata, and similar declines in 514. Densities were similar in Maine and New Hampshire strata and lower in most Massachusetts strata. Trends in mean lengths are generally stable or increasing among strata in statistical areas other than the northeast-most area (SA 511) where trends are generally declining (Figure 155-Figure 156).

SNE

Indices for SNE at the stock level were similar between sexes and generally decreased through the first part of the time series (2006-2014), though the rate of decrease was greater from 2012-2014, declining by greater than 50% over this period (Figure 157). Indices then increased for two years before continuing a declining trend similar to the early part of the time series. In addition to the notable decreases in 2014, there were notable decreases in 2010 and 2019 and, despite being an increase from 2014, 2015 was low relative to subsequent years. Females were more abundant than males throughout the time series except during the first year (2006) when there was a peak in male abundance not observed for females (though it is noted that the survey was not fully implemented in the first year). Trends across more frequently encountered size bins generally showed similar declines during the first part of the time series (2006-2014), but more variability among size bins and between sexes than observed in GOM (Figure 158). During the latter part of the time series there were different trends among size bins with declines among the smaller size bins (53-68 mm CL), stable trends among the next few size bins (73-88 mm CL), and increasing trends among size bins >88 mm CL.

There is also more variability in size compositions between sexes and among years than observed in GOM (Figure 159-Figure 161). Generally, males are equally or more abundant than females at smaller sizes and females are more concentrated in the 73-78 mm size bins, while both sexes show similar steep declines in the 83 mm size bin (Figure 159). The mean size of both sexes was declining through the first part of the time series (Figure 160), but has been steadily increasing since 2012 as lobster larger than 73mm CL have accounted for more catch in recent years (Figure 161).

Similar to GOM, sex ratios are closer to 1:1 in the shallowest strata and become more female skewed moving into deeper in SNE strata (Figure 162). Densities are lower in shallower strata. Index trends in deeper strata are more stable than the declining trends observed in shallow strata. Mean lengths are relatively stable in the early part of the time series among strata, but increase in more recent years with the exception of the deeper stratum in SA 538 which shows a slightly decreasing trend (Figure 163).

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4.2.3 Settlement and Larval Surveys

The youngest life stages for which quantitative data exist is for late-stage larval and newly settled YOY. Ovigerous females hatch eggs in the summer and the larvae follow with a 6-8 week planktonic life phase (Ennis 1995). In SNE, the planktonic phase is sampled by surface plankton nets towed at fixed stations in western Long Island Sound (Giannini 2008) and with plankton nets at the Millstone power station outfall (DNC 2018). After settlement to the bottom, the newly metamorphosed lobsters can be sampled by divers using air lift suction samplers (Wahle and Incze 1997). Settlement was measured in natural cobble substrate (Wahle and Steneck 1991), and settlement strength was defined as the abundance of newly settled lobster (0+ year class: ≤13 mm CL in ME, ≤12 mm CL in MA SA 514, ≤ 13 mm CL in MA SNE, ≤12 mm CL in RI) in cobble nurseries after the end of the settlement season. A standardized survey of this type has been conducted at stations in mid-coast Maine since 1989, Rhode Island since 1990, and Massachusetts since 1995.

Density estimates of newly settled lobster were investigated for evidence of variability in regional settlement strength and for temporal trends that could be used at some point to predict landings in the fishery. This approach has been used successfully for the western Australian rock lobster (*Panulirus cygnus*) fishery (Phillips and Booth 1994). The Australian fishery predicts nearly 75% of their landings based on the long-term relationship between the settlement of the puerulus (the pelagic, postlarval stage) on artificial collectors and the size of the commercial catch four years later.

Observations of settlement patterns in Maine indicate coherent trends among sites in the same region across years (Palma et al. 1999). The similarity in trends in Maine suggests that factors affecting settlement success vary on a regional basis, a finding which enhances the possibility that annual sampling could provide sufficient data for documenting temporal changes in regional year class size when first established and, possibly as they reach fishable size. Earlier studies have demonstrated that annual differences in the abundance of newly settled young-of-year lobsters reliably foretell the number of 1-year-olds in the nurseries a year later (Wahle and Incze 1997, Wahle et al. 2003). The extent to which trends in settlement will eventually affect landings in any given year depends on the survival of juvenile lobsters after settlement, variability in their growth, and the number of year classes that contribute to the size group that recruits into the fishery. The probable mixing of year classes in recruit size classes dampens year-to-year fluctuations in recruitment that would otherwise be caused by annual variation in settlement densities.

For this assessment, larval data were supplied by Connecticut and Millstone Power Station (DNC 2018) and settlement data were provided by Maine, New Hampshire, Massachusetts, and Rhode Island, and for mid-coast Maine (1989-2000) by Richard Wahle, University of Maine, Darling Marine Center, Walpole, ME.

Within the GOM, updated YOY survey data indicate that settlement continues to decline, particularly in the southern-most areas (SA 513W and 514). Since 2013, all areas, except 511, were below the 25th percentile at least two of the past five years (see Table 47). This indicates a potential for declines in recruitment in future years and is a pattern to pay particular attention to in coming years.

In SNE, all YOY surveys are at or below the median, and half are below the 25th percentile for the period of 2007-2018, except MA in 2013 (Table 62). All three surveys were below the 25th percentile in 2017 and 2018, with MA catching no YOY since 2015. The declining pattern of larval production and settlement in Southern New England reinforces concerns about recruitment failure for the stock.

4.2.3.1 Linking Settlement to VTS Trends

Although American lobster landings are currently near time series highs in the GOM (ASMFC 2015a), recent studies have documented a decline in lobster YOY surveys since 2012 throughout the region (ASMFC 2015a; Carloni et al. 2018; Goode et al. 2019). These declines in shallow coastal nursery grounds may be related to the expansion of suitable thermal habitat, whereby lobsters are settling in areas outside of current survey bounds (Goode et al. 2019). This is particularly germane in eastern Maine where the water is well mixed and recent warming has drastically increased the amount of thermally suitable settlement habitat. In the western GOM, there is less evidence for the deep water settlement, though including areas of suitable thermal habitat (> 12˚C) in modeled populations indicates declines may not be as drastic as YOY estimates would suggest, particularly in the eastern GOM (Goode et al. 2019).

A 30-year time series collected off the coast of New Hampshire suggests a disconnect between the abundance of early stage larvae and recruitment in shallow nursery areas (Carloni et al. 2018). Increasing SSB from the NMFS trawl survey correlated well with the increasing stage I larvae sampled during a long term neuston survey. However, postlarvae from the same survey showed a decline, particularly in recent years which correlated well with ALSI YOY indices throughout the western GOM. Increasing SSB and Stage I but decreasing postlarvae and YOY abundance suggests that this issue may be in the larval phase of development. To address potential factors that may influence this dynamic the authors examined wind advection, North Atlantic Oscillation, predation, water temperature, as well as potential important zooplankton food sources. They found a correlation between the abundance of postlarvae and YOY throughout the western GOM and *Calanus finmarchicus*, but not with any of the other co-occuring zooplankters. They hypothesized that development to the postlarval stage may be hindered by lack of sufficient food.

There is evidence that suggests larval mortality has increased in recent years and that thermally suitable habitat has expanded throughout the GOM. It’s still unclear how these dynamics are influencing YOY recruitment on a stock-wide basis, and ongoing studies are currently underway addressing these questions beyond correlation analysis. Based upon current research, at this point, it does however appear that recent broad-scale physical and biological changes in the GOM are adversely affecting recruitment.

After the YOY survey, larger juveniles are sampled from two fisheries independent data sources in the GOM; the Ventless Trap Survey (VTS) and state/federal trawl surveys. Both of these

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surveys are still increasing in abundance on the aggregate (i.e. all sizes and statistical areas combined). Thus, it is still unknown how recent declines in recruitment will translate to future landings, however, Oppenheim et al. (2019) found good agreement with YOY abundance and lobster landings, and projections from their model suggest landings will decline in the coming years to near historic levels in the Gulf of Maine. In this assessment, both VTS and Trawl Survey indices are included in the assessment model (>53mm CL), and one would expect these indices to decline before landings due to selectivity towards pre-recruit juvenile lobsters. In an attempt to better understand links between YOY and subsequent VTS catch by size bin, as well as how temperature may be influencing catch rates in the VTS, the following analyses were performed: 1) Assessed trends in abundance for all statistical areas by size bin, 2) Assessed correlations between YOY abundance and VTS catch by size bin in SAs where declines were evident, 3) assessed how VTS catch correlates with temperature by statistical area.

SAs 511 and 512 are not currently showing long-term declines in any of the size bins represented in the VTS indices. In contrast, SAs 514 and 513 are both beginning to show declines in smaller size bins (i.e. 35-44 & 45-54 mm). Thus the SAS decided to assess relationships between YOY and VTS abundance in 514 and 513 due to the observed declines in smaller size bins. Also, these two areas provide a contrast in both VTS catch and YOY settlement, with 513 showing considerably higher levels for both.

In SA 514, significant correlations were found between YOY abundance and VTS abundance in the 35-45 mm bins lagged by four and five years and 45-54 mm lagged by five and six years for all depth strata combined (Table 33). When excluding the mid and deep water strata the number of significant correlations increased and correlation values were improved (Table 34). Significant correlations were found in the 35-45 mm bin with lags of three, four and five years. Furthermore, in the 45-54mm bin, correlations were found for four, five and six years. All of these lags are within the bounds of the growth matrix used in the assessment.

In 513, one significant correlation was found, which was in the 35-44 mm bin lagged by 4 years (r=0.58, P=0.038), this was similar whether including just stratum one (< 20 m depth stratum) or all strata combined. There are also declines in the 45-54mm bin in 513, yet no significant correlations (P>0.05). It's unclear why "cohorts" could be followed from 3 to 6 years in 514, but only June (four year lag) was significant for 513. It could however, at least in part, be related to the following: YOY recruitment in 514 has been below 0.5 settlers m^2, 13 of the 18 years since 2000, whereas SA 513 has only been below this level a total of four years; in addition, catch in the VTS is lower in 514 compared to 513 and thus overall estimated abundance and recruitment are lower in 514. It's plausible that at high population levels trap saturation and temperature are confounding factors making it difficult to follow cohorts and trends in high level populations.

Temperature affects activity levels of lobsters (McLeese and Wilder 1958, Jury 1999), as well as trap catchability (Miller 1990, Smith and Tremblay 2003, Clark 2015), and although research has been conducted on trap saturation and mechanisms that may be contributing to plateauing catch (Clark et al. 2015, Watson et al. 2018), it is not understood how ventless trap catchability

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is affected by temperature at different densities, and how lobsters of different sizes interact and contribute to overall catch. For instance, if the population of larger size bins is high, but smaller size bins are low, would catchability of larger lobsters increase as smaller lobsters are less abundant and thus competition is decreased? If so this could lead to an overestimate of larger sizes due to increased catchability. These unknowns hinder ability to properly interpret this type of passive sampling, and although dedicated research is needed to better understand some of these questions, correlations between VTS catch and temperature can be assessed with existing data.

To further explore the effect that temperature has on catchability in the coastwide VTS, correlation between catch and temperature was assessed by statistical area and month. Relationships between catch and temperature were assessed at all four inshore statistical areas in the GOM using aggregate (all sizes combined) indices by month and depth stratum. To remove linear trends, both temperature and VTS data sets were detrended. Temperature data were obtained from NERACOOS buoys and used as follows: SA 514=Buoy A, SA 513=Buoy B, and SAs 512 & 511=Buoy I. For each stratum the temperatures from the following buoy depths were used: Stratum 1=1m, Stratum 2= 20 meters and Stratum 3=50 m.

In SA 514, there is a strong correlation between temperature and catch in both the shallow and deep water strata for both sexes (Table 35). SA 513 shows moderate to strong correlations in the mid and deep water for females and only deep water for males (Table 36). SA 512 shows strong correlations for both females and males in all three depth strata (Table 37). SA 511 shows strong correlations for females and males in the shallow stratum, and moderate correlation for males in the deep stratum (Table 38). Although significant correlations were found in all statistical areas, catch in SA 512 appears to be the most highly influenced by temperature.

Fisheries independent surveys such as the trawl survey and the VTS are relied upon to track trends in population. It is apparent VTS catch is highly influenced by temperature in some months and areas. If population levels do decrease, and temperatures continue to increase the underlying trends may be masked by an overall increase in catchability (refer to Section 4.2.4.1). In conclusion, size classes could be followed through the VTS in SA 514 out to six years and in 513 to year four. This suggests that the YOY abundance measured from shallow nursery sites in these two statistical areas is representative of future catch in the VTS, at least to a certain size. This was particularly evident in 514 where correlations were found starting at year three all the way to year six. There is still no evidence of decline in the VTS in SA 512 or 511 even though YOY abundance has been below median levels in many study areas since 2012, these size based indices will be closely monitored in coming years.

Although it is know that increased temperatures lead to increase in activity and catchability, the complexity of trap interactions and the coastal environment make it difficult to interpret VTS abundance trends. It has been demonstrated here that, by removing linear trend, there are still strong correlations between catch and temperature throughout the GOM. A general warming trend and variability in annual monthly temperatures make it difficult to separate population

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trends from temperature trends which provide a level of uncertainty for interpreting VTS data. Trap dynamics are complex and many factors influence catch, some of which is understood and some of which is not. It is important that research is conducted in the near future so that trends in trap based sampling can be better interpreted with regards to temperature, density and trap interactions.

4.2.4 Additional Survey Information Considered

Since 2002, landings and fishery-independent abundance indices for the GOM and GBK stocks have increased to historic high levels while landings and abundance indices for the SNE stock have fallen ten-fold. Other than landings data, long-term data sets characterizing lobster populations are scarce, making it very difficult to determine if this dichotomy among lobster stocks has occurred in past decades on a stock-wide basis. In addition to large-scale state and federal trawl survey data used in this assessment, there are two small-scale but long-term trawl surveys located in the SNE region. These sources include a research trawl program administered by the University of Rhode Island, Graduate School of Oceanography (URI_GSO, J. Collie pers. comm.) at two fixed sites in Narragansett Bay, RI, begun in 1959. The Fox Island site is located half way up Narragansett Bay, while the Whale Rock site is found just outside the bay in Rhode Island Sound. The other program is a standardized trawl survey administered by Dominion Nuclear Connecticut (DNC 2018), at six fixed stations in the vicinity of the Millstone Power Station in northeastern Long Island Sound, begun in 1976.

The longest of these two time series was generated by the URI_GSO program. This survey recorded a period of extremely low abundance at the beginning of the time series in the early 1960s (Figure 164). Abundance increased from the mid-1960s through the late 1970s at the outer site, Whale Rock, but not at Fox Island inside the Bay. Lobster abundance was low at both sites in the early 1980s. Abundance rose and peaked earlier at Fox Island than at Whale Rock and remained at high levels longer. Abundance declined at both sites through the 2000s to the current low abundance levels. The Millstone survey time series begins a decade and a half after the URI_GSO survey, but during the times they overlap, trends in abundance at Millstone are more similar to Fox Island than Whale Rock (Figure 164). For the 42 years when their relative abundance indices overlap, Millstone indices are highly correlated with Fox Island (r = 0.83, df = 42, $P<0.001$), but not with Whale Rock (r = 0.28, df = 42, $P = 0.07$). Fox Island and Millstone Indices for 2012-18 are both below their respective 25th percentiles, while indices at Whale Rock have been below the time series 25th percentile five of the seven years since 2012. Indices from all three sites have been below their time series 25th percentile for the last two years.

In addition to these two long-term SNE region focused trawl surveys, long-term monitoring programs are also available for two areas adjacent to the Millstone nuclear power plant in Connecticut (SNE stock area) and the Seabrook plant in New Hampshire (GOM stock area). Although both datasets are spatially limited, the longevity of these monitoring studies provides corroboration of trawl survey trends as well as useful insight into lobster densities within their respective study areas under similar scientific methodologies that are directly comparable. In CT, Millstone Power Station (DNC 2013) conducts these studies, and in New Hampshire data are compiled for NextEra Energy Seabrook Environmental Monitoring Program by Normandeau

Associates Inc. (NAI 2012). Both power stations conduct ventless lobster trap sampling and lobster larval sampling as part of their annual monitoring programs. Analysis of larval data from the Seabrook monitoring program is detailed in Sections 2.9.2 and 4.2.3.

In the Millstone study, abundance indices of lobster generated by the ventless research trap data (set May-October) have declined below the time series median since 2002 and at or below the 25th percentile since 2010 (Figure 165). Additionally, larval entrainment densities at the Millstone station declined from a median annual value of 0.76 (delta mean density/1000 m^3 of water entrained) for 1984-2001 to 0.26 for 2002-2018, or a 65% decline (Figure 166). These data indicate that the population's production rate of young recruits is falling along with the falling abundance of the surviving spawning stock in the area of the Millstone monitoring program. These data corroborate trends seen in other SNE regional datasets.

The development and progression towards offshore renewable energy has also resulted in multiple surveys conducted to assess before, during, and after impacts of wind farm construction. As part of these before-after-control-impact (BACI) studies, several wind energy areas in southern New England have or will have lobster ventless trap surveys. To assess impacts to the local lobster population near the Block Island Wind Farm, a ventless trap survey was designed to sample the region near the wind farm and theoretically susceptible to impacts (near field) as well as a control area away from the wind farms of similar depth and habitat (Griffin et al. 2019). The survey used 3 12-pot trawls (10 ventless traps, 2 vented) and a 5-night soak. The soak time of 5 nights was implemented to mimic commercial fishing practices in the area. Sampling began in 2013 and has been conducted for six years. Collie and King (2016) implemented a lobster ventless trap survey using a random sampling design within the RI/MA wind lease area. Different than the Coastwide Ventless Trap Survey, the investigators set pots on a targeted 5-night soak and used 10 pots at a station with ventless (V) and vented or standard (S) trap pattern of: V-S-V-S-V-V-S-V-S-V. These differences from the state surveys was based on anticipating fewer lobsters (and needing a longer soak) and being further offshore (i.e. longer trawls provide more total weight and greater ease of recovery). This survey was conducted in 2014, 2015 and 2018. Additional ventless trap surveys have or will be conducted in other wind energy areas within southern New England. These surveys allow for more spatially refined information on the stock's size structure, sex ratio, egg production, and shell disease prevalence.

These data sources were not adopted directly into the analytical assessments primarily due to the limited spatial extent of these surveys, especially because more spatially robust data sets in the same stock areas are readily available. However, all of these data sets are most valuable as supporting evidence for the trends seen in the data that were used in the assessment directly. In addition, the long duration of these surveys gives a greater historic perspective to the changes in the lobster population abundance by stock area, and so provide good context for how the population trends cycle.

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4.2.4.1 Catchability Effects

We developed candidate environmental covariates to potentially explain changes in survey catchability based on temperature. While temperature alone is not expected to explain all changes in catchability, it seems a reasonable proxy for processes linked to both catchability itself and to shifts in spatial distribution where surveys incompletely overlap stock distributions.

Recognizing that lobsters are not homogeneously distributed across survey regions, for surveys with temperature data throughout the survey domain (VTS, ME/NH Trawl , NEFSC Trawl), stratified mean temperatures and mean temperatures weighted by the mean observed lobster density were calculated to get time series of mean temperature experienced by lobsters in the survey domain.

$$\mathrm{T_y} = \sum \frac{\mathrm{T_{s,y}}}{\left(\overline{\mathrm{N}}_{\mathrm{s,y}} * \mathrm{A_s}\right)}$$

Where T_y is the weighted mean temperature in year y, $T_{y,s}$ is the mean temperature in strata s and year y, $\overline{\mathrm{N}}_{\mathrm{Y,S}}$ is the lognormal mean catch of lobsters in strata s and year y, and A_s is the area of strata s. In the case of the ventless trap survey, annual temperatures and weights were calculated monthly as:

$$\mathrm{T_y} = \sum \frac{\mathrm{T_{s,y,m}}}{\left(\overline{\mathrm{N}}_{\mathrm{s,y,m}} * \mathrm{A_s}\right)}$$

Where $\mathrm{T_{s,y,m}}$ is the mean temperature and $\overline{\mathrm{N}}_{\mathrm{s,y,m}}$ is the lognormal mean catch for a stratum, year, and month.

Temperature time series are further transformed to have a mean of one and a specified standard deviation, usually ~0.2, to be used as a catchability covariate for a survey trend.

For surveys without temperature data throughout the survey domain (RI Trawl, CT Trawl), temperature time series from auxiliary data sets were used to generate covariate time series.

4.2.4.1.1 GOM Ventless Trap Survey Catchability Covariates

For the GOM ventless trap survey, temperature time series were calculated from in situ bottom temperatures collected by Maine DMR, Massachusetts DMF, and the eMOLT program (Gulf of Maine Lobster Foundation 2020). Temperature data were not available for some combinations of year, strata and month, in which case temperature data were gap-filled primarily from adjacent strata in the same depth and secondarily by strata from the adjacent depth. Missing VTS lobster catch from Massachusetts in 2013 was patched based on the mean catches from 2012 and 2014. The resulting time series does not show any clear trends or regime shifts (Figure 167; regime shift analysis discussed in Section 2.9.5). However, it does differ from the unweighted time series, particularly in 2006, 2012, and 2013. The interannual anomalies in the unweighted time series better matches the anomalies in the observed survey index (Figure 167) so further investigation into the covariate may be warranted.

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4.2.4.1.2 ME/NH Trawl Catchability Covariates

For the ME/NH bottom trawl surveys, temperature time series were calculated from in situ bottom temperatures collected by Maine DMR, Massachusetts DMF, and the eMOLT program (Gulf of Maine Lobster Foundation 2020). Some gap filling of temperature data was required for the surveys, following the borrow procedure used for the ventless trap survey. The spring temperature time series varies around a slight increasing trend with no clear regime shift (Figure 168). The fall temperature series shows a clearer regime shift between 2009 and 2010 (Figure 169).

4.2.4.1.3 NESFC Trawl Survey Catchability Covariates

For the NEFSC trawl surveys, temperature time series were built from interpolated fields of seasonal temperature, based on in situ bottom temperature observations collected during the NEFSC trawl surveys (Friedland et al. 2018, 2019). By regressing detrended temperature and catch time series against each other, both at the stock level and at the scale of individual strata, it was determined that there was little relationship among interannual anomalies in the two time series. As a result, we consider that much of the observed inter-annual variations are potentially observational noise and calculated a smoothed trendline for each survey period as an alternative for testing in the assessment model. The GOM spring temperatures actually suggest a cooling trend over the course of the time series with a local minima around the mid 1990s (Figure 170). In contrast, the GOM fall temperature series is stable through the 1990s, the decreases below the mean in the 2000s before increasing sharply above the mean after 2010 (Figure 171). The SNE spring temperatures show an increasing trend through the mid-1990s followed by no discernible trend through the remainder of the time series (Figure 172). The SNE fall temperatures show no discernible trend through the 1980s, an increasing trend through the 1990s, and a decreasing trend through the late 2000s followed by an increasing trend since the late 2000s (Figure 173).

4.2.4.1.4 RI Trawl Survey Catchability Covariate

The spring fisheries-independent time series on which the SAS focused were based on feedback from commercial fishers that lobster movement and activity in the spring in SNE may be tied to how warm the area is in the given year, with warmer years perhaps resulting in earlier movement of lobsters and increased detection in the surveys. The RI Spring Trawl Survey was informed with bottom temperatures measured during the University of Rhode Island Graduate School of Oceanography (URIGSO) Trawl survey, with methods on the temperature data collection further described in Collie et al. (2008). The temperature covariate represented annual temperatures as they related to the time series mean (average from 1982-2019 to match the RI Trawl time series length). During this time period, the spring bottom temperature and covariate index showed no signs on trends through time (Figure 174).

4.2.4.1.5 CT Trawl Catchability Covariate

Using the same logic as that for the RI Spring Trawl, the CT Spring trawl survey was informed with a temperature covariate. Subsurface spring (April-May) temperatures measured from the Millstone Power Station were used to show the interannual changes in water temperature for the CT Trawl Survey. The temperature index represented the anomaly around the mean temperature of the time series. Both the temperature indices and the covariate index indicated slight increases through time (Figure 175).

5 STOCK INDICATORS

In addition to standard model-based exploitation and abundance estimates, a number of empirical stock indicators were examined to judge stock status. In order to continue to monitor dynamics specific to the Georges Bank fishery, it is treated separately from the Gulf of Maine in this section. These indicators provide information about the overall health of each stock independent of the assessment model. Four categories of indicators were generated: abundance, mortality, stress, and fishery performance. The annual status of each indicator time series was characterized as positive, neutral, or negative based on its quartile ranking (details below). For all indicators, the terminal five-year average (2014 - 2018) will be used to assess the status relative to the entire time series.

5.1 Stock Indicator Methods

5.1.1 Abundance Indicators

Five indicators were generated to assess relative abundance, total spawning potential, and year class strength of each stock. These include: spawning stock biomass index, recruit abundance, full-recruit abundance, the proportion of survey tows that captured at least one lobster, and an index of larval production or young-of-year (YOY) settlement. Annual abundance indicators were characterized as shown below.

	< 25th percentile	**Between 25th and 75th percentile**	**> 75th percentile**
Spawning stock abundance	Negative	Neutral	Positive
Full recruit abundance	Negative	Neutral	Positive
Recruit abundance	Negative	Neutral	Positive
Proportion positive tows	Negative	Neutral	Positive
Recruitment indices (larval or YOY)	Negative	Neutral	Positive

The spawning stock abundance index reflects the female-specific reproductive potential of the stock in a given year relative to each survey. It represents the annual total weight of mature females (based on maturity ogives, see Section 2.6.1) for each survey, calculated as:

$$\mathrm{SSB} = \sum_{\mathrm{CL}=1}^{\infty} (\#\ \text{females}\ ) * (\text{proportion mature}) * (\text{weight})$$

The full recruit abundance is the mean number per tow of lobsters (sexes combined) that have been legal to harvest throughout the entire time series. Size ranges vary by stock:

GOM - ME/NH, MA, and NEFSC GOM portion) surveys: ≥ 83 mm CL, GBK - NEFSC survey: ≥ 90 mm CL,

SNE - MA, RI, and CT surveys: ≥ 86 mm CL, and NEFSC survey: ≥ 90 mm CL.

The recruit abundance is the mean number per tow of lobsters (sexes combined) that have been below harvestable size throughout the entire time series (71 – 80 mm CL for all surveys). The recruit abundance is intended to represent an approximation of the number of lobster that might be expected to molt into the fishery within one year of the survey.

The proportion of positive tows is used to indicate how broadly distributed the lobster resource is in a given survey area. This is the proportion of survey tows that caught at least one lobster. High proportions of positive tows suggest that lobsters are broadly distributed throughout the survey area and is interpreted as a positive indication of relatively high population abundance. Low proportions of positive tows suggest that the lobster resource has contracted, potentially into areas of complex structure not readily accessible by trawl surveys and is interpreted as an indication of lower population abundance.

YOY indices represent potential recruitment to the population. These indices include an annual estimate of the mean density (delta mean per 1000 m^3 water) of all larval stages (ELIS) or Stage IV larvae (CLIS) or of mean density (mean # per m^2) of newly settled young-of-year (YOY) lobsters (all other locations). YOY size ranges for each survey are: RI ≤ 12 mm CL, MA-SNE ≤ 13 mm CL, MA-GOM ≤ 12 mm CL, NH ≤ 13 mm CL, ME ≤ 13 mm CL. These size ranges are based on temperatures in each area and assumptions about settlement time and opportunity for growth relative to the timing of the surveys. Sustained high levels of larval or YOY density would indicate favorable production. Along with surveys conducted by state agencies, additional data for these indices were provided by R. Wahle (GOM) and by the Dominion Nuclear Power Station (ELIS). There are no available Young-of-Year indicators for GBK.

5.1.2 Mortality Indicator

Exploitation rate is used as an indicator of mortality and is characterized as shown below.

	< 25th percentile	**Between 25th and 75th percentile**	**> 75th percentile**
Relative exploitation rate	Positive	Neutral	Negative

Relative exploitation rate is the landings (in weight) divided by the reference population (all lobsters > 77 mm, converted to weight (see Section 4.1.4.2) from each trawl survey. A separate value was calculated for each survey by assigning the appropriate landings based on statistical area(s) covered by the survey (see Table 9 and Table 10).

5.1.3 Stress indicators

There are two indicators for physiological stress that were developed for this assessment. The first is based on fishery-dependent data and represents the prevalence of shell disease observed in the commercial catch by at-sea observers. The second is based on several available temperature time series, and the number of days the daily mean temperature in each series equaled or exceeded a threshold of 20° C (see Sections 2.1.1 and 2.2).

	< 25th percentile	**Between 25th and 75th percentile**	**> 75th percentile**
Shell disease prevalence	Positive	Neutral	Negative
Days $\geq$ 20° C	Positive	Neutral	Negative

Shell disease is considered to be a physical manifestation of a stressed individual (see Section 2.2). For this indicator, sea sampling data from Quarter 2 (April-June) was used as this generally encompasses the time period prior to the molt and as such is the time frame when shell disease symptoms are at their worst in the population. For consistency across all sampling areas and to minimize subjectivity at identifying and/or determining symptoms, only individuals with moderate and severe disease symptoms (collectively more than 10% of the shell covered with disease) were included (see Section 2.2.1 for details on sampling methodology). The metric is the percent of lobsters examined (by sex) that had moderate or severe disease, averaged across all trips made in Quarter 2. The number of trips included in each year and sampling region are shown in Table 39 and Table 40. At least six lobsters needed to be examined for a particular trip to be included. This minimum resulted in a differing number of trips by sex for some years in Massachusetts (see Table 39 and Table 40), resulting primarily from extremely female-skewed sex ratios in some instances.

Monitoring programs for disease in SNE were initiated in Massachusetts and New York in response to the occurrence of shell disease and began in 2001, and only RI had sampling in place early enough to document initial low levels of disease (RI started sampling in 1996). In GOM monitoring in Massachusetts started in 2001 but was not fully implemented in all portions of Massachusetts GOM until 2003, thus the first two years were excluded. New Hampshire's sampling program was fully implemented in 2002, and in Maine sampling was initiated in 2003. Quartiles were calculated based on all GOM and SNE data combined, with sexes treated separately (Table 41). The use of the entire time series for both stocks was necessary to include both low and high levels of observed disease. This also ensured that assignment and interpretation of positive and negative levels of disease prevalence provided a relative context for assessing the impact of disease coastwide.

Water temperatures above 20° C are associated with increased physiological stress in lobsters (see Section 2.1.1). This temperature threshold was selected as a stress indicator to monitor for changes in the environment that may negatively affect the lobster population. Data from bottom water temperature monitors were preferred but in many areas were not available, so sea surface temperatures were also considered. Only year-round monitors were considered for this indicator, and preference was given to those monitoring locations with longer time series and few data gaps. All locations that were considered are shown in Table 42, and those locations with at least one day $\geq$ 20° C at some point in the time series are identified in the table. Some locations were not included as an indicator due to large periods of missing data. For those with very long time series, only data from 1982 onwards are included in the

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indicators (entire time series are discussed in Section 2.9.4). The temperature indicator is the annual number of days ≥ 20.0° C, and the quartiles are based on the time series for each monitor.

5.1.4 Fisheries Performance Indicators

Seven indicators were used to describe the performance of the fishery in each stock area: effort, total landings, partial landings (from those sources for which effort data were available), gross CPUE (partial landings/traps), price per pound, gross stock revenue (adjusted and un-adjusted) and revenue per trap (adjusted and un-adjusted). For indicators where the price per pound was used, an adjusted value was computed to account for inflation based on the unprocessed fish consumer price index (CPI) with 2018 as the base year (www.bls.gov).

	< 25th percentile	**Between 25th and 75th percentile**	**> 75th percentile**
Number of traps (effort; partial)	Positive	Neutral	Negative
Total stock landings (lbs, all sources)	Negative	Neutral	Positive
Partial landings (lbs, sources with corresponding effort data)	Negative	Neutral	Positive
Gross CPUE (partial landings/traps)	Negative	Neutral	Positive
Price per pound (US Average)	Negative	Neutral	Positive
Revenue (based on total stock landings)	Negative	Neutral	Positive
Revenue per trap (based on gross CPUE)	Negative	Neutral	Positive

The number of traps was used as an indicator of effort and is based on the number of traps reported fished (MA, CT, NY) or for Maine, the average number of traps per boat as estimated from port sampling and the total number of licenses sold from 1982-1995. After 1995, traps in Maine are the number of trap tags issued. Data included here are only for those jurisdictions with complete time series. In the GOM, trap numbers were available from Maine and Massachusetts dating back to 1982. For the SNE stock, data from Massachusetts and New York start in 1981, while data from Connecticut were available starting in 1984, so data from these jurisdictions from 1984 onwards were used. Effort data from New Hampshire start in 2004, and from RI start in 2001, thus were not used due to the short time series available (see Table 13, Table 16, and Table 19 for trap data from all jurisdictions). These data are only a crude proxy for effort as they do not account for how many traps were actually deployed at any given time in the year, the average set-over days (soak time), frequency of hauling, or changes in gear efficiency/design.

Total landings for the stock are landings from all sources (jurisdictions) and represent a common indicator of fishery performance. Partial landings are landings from only those jurisdictions for which effort data (traps) were available. These landings were used in calculations of gross CPUE (partial landings / traps), and revenue per trap (see below).

The average ex-vessel price was queried to provide an estimate of value to the fishermen for each pound of lobster landed

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(https://foss.nmfs.noaa.gov/apexfoss/f?p=215:200:3679366471406::NO:::). The data available for price represent the entire US fishery (not stock-specific). To assess how ex-vessel price has changed relative to inflation, price per pound was adjusted to 2018 US dollars using the Gross Domestic Product Implicit Price Deflator (https://fred.stlouisfed.org/series/GDPDEF#0).

Gross revenue to the fishery was estimated as the product of average US price per pound and total stock-specific landings (raw and adjusted). Finally, the average revenue per trap was estimated using the stock-specific gross CPUE, which includes only landings from those jurisdictions with effort data.

5.2 Stock Indicator Results

The stock indicators should be interpreted somewhat cautiously, and often in relation to other indicators, particularly when only some of the jurisdictions that fish on that stock are included in the time series. While there are more than 35 years of data for most indicators, this time period may not be reflective of the entire productive range of the stock. The strengths of this approach are that the use of quartiles based on the entire time series is objective and the focus on trends is straight-forward and free of modeling assumptions.

5.2.1 GOM

Abundance indicators for recent years were mostly positive or neutral (Table 43-Table 47). Mean (2014-2018) spawning stock abundance indicators were positive in all six surveys (Table 43). Mean full recruit and recruit abundance (2014-2018) were also positive for all six surveys (Table 44-Table 45). The mean (2014-2018) lobster encounter rates were all positive except for the spring MA survey which was neutral (Table 46).

Young-of-year indices were negative in western 513 and 514 and neutral in the other three survey areas (Table 47). At least two of the past five years have been negative in four of the five YOY surveys. This continued (and worsened compared to the 2015 assessment) pattern of reduced settlement indicates a potential for declines in recruitment in future years.

The mortality indicators, expressed as mean exploitation rate for the years of 2014-2018, were positive for all six trawl surveys (Table 48). Annual exploitation rates have been positive since 2015 in all but two instances, the Maine fall 2017 and spring 2018 surveys which were neutral.

The GOM stress indicators suggest that lobsters in the GOM may be starting to experience some stressful conditions, particularly in the southern portion of GOM. Shell disease prevalence has generally increased over time in all of the regions sampled. The mean shell disease prevalence (2014-2018) was neutral for both sexes in all five sampled regions (Table 49). All of the most recent annual values for females were neutral. For males, two of the last five years were neutral in SA 511, and all years were neutral for 512 and both New Hampshire and Maine portions of 513. In Massachusetts 514, annual values were neutral except for 2018 which was negative.

GOM temperature indicators (number of days ≥ 20.0°) were mixed, with two negative bottom temperature indicators and one positive, and two of the four SST indicators falling in the

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negative range (Table 50). The Boothbay SST monitor had a series of years with days ≥ 20° in the 2000s, but from 2014 to 2018 has had no days ≥ 20°. The Western GOM Shelf Buoy B SST monitor was negative for three of the past five years. While this is somewhat concerning, 513 is known to be a relatively stratified region in the GOM, and SST does not reflect conditions on the bottom. Indeed the Buoy B data at 50 m depth, which is below the thermocline, had no days ≥ 20° C . The Scorton's bottom temperature monitor annual values were negative in two of the past five years; this monitor is in the southern-most portion of Cape Cod Bay, which is also the southern-most portion of the GOM inshore stock unit. This region experienced the first ever hypoxic event in the fall of 2019 and should be carefully monitored in the future. While the hypoxic event was likely related to oceanographic conditions specific to Cape Cod Bay, the southern portion of 514 and Cape Cod Bay in particular may act as a canary in a coal mine for changing GOM environmental conditions.

Nearly all of the GOM fishery performance indicators were positive (Table 51). The exceptions were mean effort (number of traps), which was neutral, and mean adjusted price per pound which was negative. Revenue for GOM and the partial revenue per trap were at record highs during the recent time period (2014-2018) and peaked in 2016 (un-adjusted and adjusted values). Total landings also peaked in 2016.

5.2.2 GBK

Abundance indicators for the recent period (2014 - 2018) were positive for three of the four indicators (Table 52-Table 55). The spawning stock abundance index and full recruit abundance index were well above the 75th percentile for both the fall and spring NEFSC Surveys (Table 52-Table 53). The recruit survey abundance for the recent period was neutral for both the spring and fall survey (Table 54); three of five years were negative in the fall survey series, and two of five years were negative in the spring survey series. The distribution of lobster in GBK as measured by the proportion of positive tows was positive, with four of the five most recent years above the 75th percentile in the both the fall and spring survey series (Table 55).

The effective exploitation mortality indicators for the recent period (2014 - 2018) were positive (Table 56). Relative exploitation rates derived from the NEFSC Surveys remained below the 25th percentile in four out of the last five years in fall and for all five years in spring surveys.

GBK stock fishery performance indicators for recent years were nearly all positive (Table 57), including landings and most revenue metrics. The effort indicator (the number of traps reported fished from Massachusetts vessels) was negative. Annual values for traps fished were above the 75th percentile for three of the last five years. While the unadjusted price per pound was positive, the inflation-adjusted price per pound was negative, and has been below the 25th percentile for three of the last five years. However, the inflation-adjusted revenue and revenue per trap values were positive for the time period (2014-2018).

5.2.3 SNE

Abundance indicators for SNE were mostly negative with some classified as neutral (Table 58-Table 62). Average spawning stock abundance from 2014 to 2018 was below the 25th percentile in six of the eight surveys (well-below in CT surveys), and below the median in the fall NEFSC survey (Table 58). The 2014 to 2018 average full recruit abundance was below the median in all eight surveys, and below the 25th percentile for both Connecticut, both Rhode Island, and the spring NEFSC surveys (Table 59). Recruit abundance was very low, with the 2014 to 2018 average for six of the eight surveys below the 25th percentile (Table 60). The mean survey encounter rate (2014-2018) was negative for seven of eight surveys, with the eighth survey (MA fall) only just above the 25th percentile (Table 61). The western LIS postlarval survey was discontinued after 2012. The Rhode Island YOY survey and ELIS larval surveys were both negative, while the Massachusetts YOY survey was neutral but below the median (Table 62).

The mortality indicators based on exploitation rates were mixed across the SNE surveys (Table 63). Exploitation was above the 75th percentile (negative) since 2014 for both CT surveys. The mean exploitation (2014-2018) for Rhode Island and Massachusetts surveys, and for the spring NEFSC survey were neutral, while the fall NEFSC mean exploitation value was positive. The Massachusetts fall mean 2014-2018 value may be biased low due to the 2014 data point; in 2014 there were landings but the fall survey value was 0, resulting in a 0 denominator. A very high value (>5) for the 2014 fall MA value would result in the MA fall 2014-2018 mean value being higher, putting it above the 75th percentile threshold for a negative indicator.

The shell disease prevalence indicators for females and males have been negative for most of the time series in Massachusetts and in Rhode Island (Table 64). Disease prevalence appears to have remained relatively high for both sexes with the exception of WLIS and CLIS. Unfortunately, sampling trips have been extremely limited in recent years for Rhode Island, and for all of 611 (CT and NY) since 2011 (see Table 40), limiting ability to track this indicator in the recent years.

The mean temperature indicator (2014-2018) was negative for all three bottom temperature monitors and for the single sea surface temperature monitor in SNE (Table 65). Three of the last five years for each bottom temperature monitor had days $\geq$ 20 exceeding the 75th percentile of the time series. Unfortunately, the GSO dock sea surface monitor time series was only available through 2015, and data from 2014 were missing, thus its classification should be interpreted cautiously. The large increase in days $\geq$ 20° C at 21 m depth (the Barge monitor) observed in 2012, 2016, and 2018 indicates that these extremely warm water temperatures are no longer limited to just very shallow waters, particularly in extremely warm years.

The fishery performance indicators for SNE were mixed (Table 66). Mean (2014-2018) landings (total and partial) and revenue (adjusted and unadjusted) were negative, as was the inflation-adjusted price per pound. The mean partial gross CPUE and the partial revenue per trap (unadjusted and adjusted) were neutral. Mean effort (traps fished, 2014-2018) and the unadjusted price per pound were positive. Effort has declined over time, and all five of the most recent years were well below the 25th percentile for traps fished. This decline in effort is likely why the gross CPUE and revenue per trap values were somewhat better than expected based on the very low landings; enough traps have been removed from the fishery to result in slightly

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improved efficiency per trap. Total landings and total revenue have been consistently below the 25th percentile since 2011.

6 UNIVERSITY OF MAINE MODEL

6.1 University Of Maine Model Methods

6.1.1 University of Maine model technical description

The UMM for American lobster (Chen et al. 2005) was the primary model used by ASMFC (2009), and the only population dynamics model used in the previous assessment (ASMFC 2015a) and this assessment. It has previously been modified by the Lobster SAS with help from Dr. Chen's laboratory to estimate sex-specific size distributions for new recruits, separate recruitment parameters for females and males in each year, accommodate nonlinear surveys (exponential or saturating relationships), calculate per-recruit models more accurately, estimate growth transition matrices internally from tag data, calculate variances for recruitments and survey trends internally so that data are self-weighted, and model expected recruitments using recruit covariates. It was modified during this assessment to model expected survey indices using catchability covariates. Each of these features were used in the current assessment except 1) the internally estimated growth transition matrix approach because testing during the last assessment found the method was not able to match the observed bimodal distributions of molt increments for lobsters that did and did not molt, and 2) the per-recruit models as these models have been shown in previous assessments to be unreliable for estimating lobster reference points. The program code is C++ using AD-Model Builder libraries.

6.1.2 Descriptors of abundance and fishing pressure

In this assessment, "reference abundance" and "effective exploitation" are used as the primary descriptors of annual abundance and annual fishing pressure when presenting assessment model results. Reference abundance is the number of lobsters 78+ mm CL on January 1 plus the number that will molt and recruit to 78+ mm CL during the year. The 78 mm CL size is the lower end of the 78-82 mm size group which contains the lowest historical minimum legal size (81 mm) for lobsters in both stocks. Effective exploitation is the estimated annual catch in number from the model divided by reference abundance. In other contexts (e.g. stock indicators), reference abundance and effective exploitation are based entirely on survey and landings data.

Effective exploitation and full recruit fishing mortality (full F) have similar trends but full F is higher and more variable. The relationship between the exploitation and fishing mortality measures in stock assessment results is not constant because of variability in size selectivity due to changes in regulations, size structure, and recruitment.

6.1.3 Population dynamics

Female and male lobsters have separate population dynamics (including recruitment, mortality and growth) in all models presented. Five mm size groups are used so that all lobsters leave their original size bin when they molt (tagging data indicate that the smallest molt increment

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for lobsters 53+ mm CL is about 5 mm). The model is length-based and there are 35 size bins (53-57.9, 58-62.9, … , 223+ mm CL). The last bin was a plus group. Size bins are identified by their lower bound so that, for example, the 53 mm size bin contains lobster 53-57 mm CL.

No stock-recruit relationship is included in the model. The total number of recruits for each sex, year and quarter ($R_{s,t,q}$) was:

$$R_{s,t,q} = \phi_q e^{\rho_{s,t} + r_{s,t}}$$

where $\rho_{s,t}$ is the logarithm of expected recruitment for sex s in year t, $r_{s,t}$ is an estimated annual "dev" parameter constrained to average zero, and $\phi_q$is the proportion of total recruitment in quarter q. In this assessment, lobsters were assumed to recruit to the model only at the beginning of summer when the major summer molt occurs (ϕ_3 =0.6615) and at the beginning of fall when the secondary minor molt occurs (ϕ_4 =0.3385). Proportions for winter and spring were zero ($\phi_1 = \phi_2 = 0$).

Expected recruitment can change over time because:

$$\rho_{s,t} = \alpha_s + \sum_j \beta_{s,j} K_{j,t}$$

where α_s and $\beta_{s,j}$ are estimated parameters and $K_{j,t}$ is an observation from recruit covariate j. The recruit covariates are data supplied by the user.

Given recruitment is freely estimated without an explicit stock-recruit relationship, it can be informative to examine how the implicit stock-recruit relationship changes over the assessment time period. Based on juvenile growth matrices from Bergeron (2011), appropriate lags between model-estimated yearly recruitment and spawning stock biomass were determined to be four years for SNE and five years for GOMGBK. For plotting recruitment against SSB, a five-year running average was applied to recruits to better show general trends. To examine changes in productivity or the steepness of the stock-recruit relationship with time, dynamic linear models (DLMs) were fit to a time-varying, state-space Ricker stock-recruit model (Peterman et al. 2003, Tableau et al. 2019). The model uses the linearized Ricker function:

$$\log\left(\frac{R_t}{S_t}\right) = \alpha_t + \beta_t S_t + \varepsilon_t$$

Where R_t is recruitment summed over sexes and quarters in year t, S_t is SSB lagged to year t, α_t is the productivity or steepness parameter, β_t is the density-dependent mortality parameter and ε_t is the year-specific error term. A Kalman filter is then used to estimate α_t as a state-space process that changes dynamically across time.

The size range for new recruits was specified by the user and usually set to the first five size groups. The number of recruits in a single size group:

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$$\mathrm{R_{s,t,q,k} = R_{s,t,q} B_{s,k} \pi_q}$$

where $B_{s,k}$ is the proportion recruiting in each size group based on sex-specific beta distributions spread over the first N size groups (e.g., N=5) specified by the user. The model estimates shape and scale parameters that define the beta distribution for each sex.

The number of lobsters in each size group at the beginning of winter (first quarter) during the first year in the model was:

$$N_{s,t=1,q=1,k} = N_{s,t=1,q=1} p_{s,k}$$

where $N_{s,t,q,k}$ is abundance for sex s, year t, quarter q, size group k and $p_{s,k}$ is the corresponding proportion at the beginning of the first year. The proportions $p_{s,\,k}$ are supplied by the user and usually taken from equilibrium calculations in a preliminary model run with mortality equal to the average level during the first five years of the modeled period.

After the initial quarterly time step in the model and using vector/matrix notation, abundance at size was calculated:

$$\mathbf{N}_{\mathrm{s,t,q}} = \mathbf{P}_{\mathrm{s,t,q-1}} \mathbf{G}_{\mathrm{s,q-1}} + \mathbf{R}_{\mathbf{s,t,q}}$$

where $\mathbf{P}_{s,t,q-1}$ is a vector of survivors at the end of the previous quarterly time step, $\mathbf{G}_{s,q}$ is the sex- and season-specific growth transition matrix, and $\mathbf{R}_{s,t,q}$ is a vector of recruits. Growth transition matrices $\mathbf{G}_{s,q}$ were calculated by simulation outside the assessment model (see Section 2.5, Growth).

Growth occurs instantaneously at the end of quarterly time steps so that the growth transition matrix $G_{s,q-1}$ for quarter q-1 determines the size composition at the beginning of the subsequent quarter q. In this assessment, growth matrices applied at the end of the spring quarter accounted for growth during summer and growth matrices applied at the end of the summer quarter were used to account for growth during fall. The identity matrix was used for growth at the end of the fall and winter quarters because no growth occurs during winter and spring. Survivors in each quarterly time step were calculated:

$$P_{s,t,q,k} = N_{s,t,q,k} e^{-Z_{s,t,q,k}}$$

where $Z_{s,t,q,k}$ is an instantaneous quarterly mortality rate that includes mortality due to fishing and natural causes. As described below, total, fishing and natural mortality rates in the model may vary among years, quarters, sexes, and size groups. In particular:

$$\mathrm{Z_{s,t,q,k} = F_{s,t,q,k} + M_{s,t,q,k}}$$

where $F_{s,t,q,k}$ and $M_{s,t,q,k}$ are instantaneous rates for fishing and natural mortality. Natural mortality is:

$$M_{s,t,q,k} = M_{s,q}\mu_t\sigma_k$$

where $M_{s,q}$ is a parameter (estimable but usually fixed at a user specified value), $\mu_t$is a year specific multiplier and σ_k is size specific multiplier supplied by the user. Fishing mortality is:

$$F_{s,t,q,k} = F_{s,t,q}\ u_{s,t,q,k}$$

where $F_{s,t,q}$ is a fishing mortality parameter estimated in the model and $u_{s,t,q,k}$is size selectivity in the fishery.

Commercial size selectivity in the assessment model relates size composition of the stock to length data from landings in the fishery. Fishery selectivity was modeled based on four contributing factors: 1) legal sizes (minimum and maximum legal size), 2) gear characteristics (changes in size of escape vents due to regulations), 3) conservation activities (discard of v-notched and ovigerous females), and 4) “other” effects such as fishermen behavior, lobster behavior, market preferences, etc. Selectivity due to legal size regulations, gear characteristics and conservation activities are estimated externally based on regulations and sea sampling data (see Appendix 3). Effects due to “other” effects (factor 4) can be estimated in the model as a normal or lognormal distribution with estimable mean and variance but this component of selectivity was ignored in basecase models. Commercial selectivity in the model changes whenever one of the underlying factors changes (e.g. changes in legal size limits). In general, there were differences in commercial selectivity over time, between sexes, and among stock areas.

Based on the considerations above, commercial selectivity at size for each sex, year and quarter $u_{s,t,q,k}$ was computed:

$$u'_{s,t,q,k} = l_{s,t,k}\, g_{s,t,k}\, c_{s,t,q,k}\, o_k$$

$$u_{s,t,q,k} = \frac{u'_{s,t,q,k}}{\max\left(u'_{s,t,q,k}\right)}$$

Where the components for legal sizes ($l_{s,t,k}$) and gear ($g_{s,t,k}$) were the same for each quarter in a year but varied between the sexes and among years. The component for conservation discards ($c_{s,t,q,k}$) varied among quarters and years to model seasonal and annual differences in discard of ovigerous and v-notched females due to the annual reproductive cycle and changes in regulations. The component for other factors was not used for basecase runs in this assessment (o_k=1). The product of each factor was divided by the maximum value of the products so that the final fishery curve had a maximum value of one.

6.1.4 Survey trend predicted values and GOF

The model accommodates sixteen surveys that are defined in terms of size-selectivity patterns. Data for a particular survey may be for either or both sexes and might be collected during one or multiple quarters. Separate survey catchability parameters are used for each sex and quarter in the same survey. However, predicted values and goodness of fit for a survey are always calculated assuming the same size selectivity pattern.

Where survey index residuals are assumed to be log-normal, the catchability parameter would be estimated as:

$$\hat{q}_{j,s,t} = \log\left(\frac{\hat{I}_{j,s,t}}{\widehat{\mathrm{PopN}}_{j,s,t}}\right)$$

And predicted survey observations are estimated as:

$$\hat{I}_{j,s,t} = \exp(\hat{q}_j) * \widehat{\mathrm{PopN}}_t$$

Where $\hat{I}_{j,s,t}$ is the predicted index value for survey j and sex s in year t, $\hat{q}_j$ is the predicted catchability of survey j, $\widehat{\mathrm{PopN}}_t$ is the estimated population abundance in year t.

Starting with the 2015 stock assessment, the UMM was modified to allow for the estimation of density-dependent catchability as:

$$\hat{I}_{j,s,t} = \alpha_j + \exp(\hat{q}_j) * \widehat{\mathrm{PopN}}_t^{\beta_j}$$

Where α_j is an intercept parameter that allows catch to be non-zero at $\widehat{\mathrm{PopN}}=0$ and β_j is a slope parameter for a nonlinear relationship between population abundance and survey catch (Figure 176). In particular, the intercept parameter$\tau<0$ is for surveys that reach expected values of zero before abundance declines to zero. The exponent parameter $\gamma > 1$ accounts for surveys that change faster than abundance (hyperdepletion) and $0< \gamma < 1$ accounts for surveys that change more slowly than abundance (saturation). The intercept parameter was not used in this assessment but exponent parameters were used extensively.

Based on observed dynamics of multiple surveys, it is hypothesized in this assessment that environmental factors are affecting survey catchability in ways that cannot be captured as a density-dependent effect. Thus, the estimation of catchability was further modified as:

$$\hat{I}_{j,s,t} = \alpha_j + \exp(\hat{q}_j) * \left(\widehat{\mathrm{PopN}}_t * \mathrm{EnvCovar}_{j,t}{}^{\gamma_j}\right)^{\beta_j}$$

Where $\mathrm{EnvCovar}_{j,t}$ is the value of the environmental covariate for survey j in year t, and $\gamma_j$is the estimated covariate parameter for survey j. Because $\mathrm{EnvCovar}_j$ is a set of positive numbers with a mean of one, a high value of γ_j acts to decrease catchability in years with covariate values below 1 and increase catchability in years with covariate values above 1. Alternately an estimated γ_j of zero would reduce the covariate to a vector of ones and, thus, have no effect on

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catchability. In this way, the environmental effect on catchability is estimated within the assessment model and evidence for the effect on catchability can be weighed against evidence for changes in underlying population.

Note that where an environmental covariate aliases a process like an expansion in spatial distribution and the expansion corresponds to increases in abundance, the apparent effect of the environmental covariate can be confounded with the estimation of density-dependent parameters if both are estimated.

Size specific survey selectivity relates size composition in the stock to length data from surveys. In this context, size selectivity includes effects due to gear design, overlap between the survey and stock, and size specific differences in capture efficiency. It was calculated:

$$s'_{j,k} = \frac{1}{1+e^{a_j\left(L_k-b_j\right)}}\frac{1}{1+e^{c_j\left(L_k-d_j\right)}}$$

$$s_{j,k} = \frac{s'_{j,k}}{\max\left(s'_{j,k}\right)}$$

where a_j, b_j, c_j and d_j are survey specific selectivity parameters and L_k is the size in mm at the middle of the length group k. Depending on the assumed or estimated values of the parameters, the selectivity curve will be either an ascending, descending or double logistic (i.e., domed) function. The calculated values $s'_{j,k}$ were divided by the maximum value so that the final survey selectivity curve had a maximum value of one.

Goodness of fit for survey data was calculated assuming that the log transformed data were from either a normal or robust (insensitive to outliers) Cauchy distribution (Chen et al. 2000). Log likelihoods were calculated:

$$\Delta = -n_{j,s}\log\left(\sigma_{j,s}\sqrt{2\pi}\right) - 0.5\sum_{t}\left(\frac{\log\left(\hat{I}_{j,s,t}/I_{j,s,t}\right)}{\sigma_{j,s}}\right)^2$$

for the normal distribution and:

$$\Delta = \sum_{t}\ln\left\{\pi\lambda_{j,s}\left[1+\left(\frac{\log\left(\hat{I}_{j,s,t}/I_{j,s,t}\right)}{\lambda_{j,s}}\right)\right]\right\}^{-1}$$

for the Cauchy distribution. In either case, $\sigma_{j,s}$ is the standard deviation calculated either internally from the residuals $\log\left(\hat{I}_{j,s,t}/I_{j,s,t}\right)$ or specified by the user as an arithmetic CV so that $\sigma_{j,s} = \sqrt{\log\left(CV_{j,s}^2 + 1\right)}$. Assumed CVs were "tuned" manually to match the observed variability in residuals from a preliminary run so that the assumed and observed variances were similar. The internal method was used in most cases during this assessment.

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6.1.5 Size composition predicted values and GOF

Predicted values for survey size composition data were calculated:

$$\hat{p}_{j,s,t,k} = \frac{s_{j,k} N_{s,t,q,k}}{\sum_i s_{j,i} N_{s,t,q,i}}$$

Predicted fishery size composition data were calculated in the same manner but using fishery selectivity curves $u_{s,t,q,k}$ in place of survey selectivity curves $s_{j,i}$.

A robust negative log likelihood from Fournier et al. (1990) was used to calculate goodness of fit for survey and fishery size composition data. For a single set of size composition data (i.e. for one sex, one fishery or survey and during one quarter of one year):

$$\Lambda \ = 0.5 \sum_{i=k_{first}}^{k_{last}} \ln\left(2\pi\left(\xi_i + 0.1/N\right)\right)$$

$$+ \sum_{i=k_{first}}^{k_{last}} N \ln(\tau)$$

$$- \sum_{i=k_{first}}^{k_{last}} \ln\left(\frac{-e^{r_k^2}}{2\left(\xi_{,i} + 0.1/N\right)\tau^2} + 0.01\right)$$

where $N = k_{last} - k_{first} + 1$ is the number of size bins in the calculation, $r_k = \hat{p}_k - p_k$ is the raw residual for size group k, $\xi = \hat{p}_k\left(1 - \hat{p}_k\right)$ is a variance for $\hat{p}_k$, and τ is an inverse sample size parameter that scales the variance. In this model, $\tau = 1/S$ where S was an assumed sample size specified by the user. The sample sizes were tuned in preliminary runs as described below.

The choice of the first and last size groups (k_{first} and k_{last}) used in calculating negative log likelihoods for size composition data may affect results because the model includes many size bins that have very low predicted proportions. Two approaches have been used to choose k_{first} and k_{last}. Both approaches treated k_{first} and k_{last} as plus groups so that

$$p^*_{k_{first}} = \sum_{j=1}^{k_{first}} p_j \quad \text{and} \quad p^*_{k_{last}} = \sum_{j=k_{last}}^{35} p_j \quad .$$

The dynamic binning approach used in this assessment for all basecase models chooses k_{first} and k_{last} for each set of length composition data such that the observed proportions $p^*_{k_{first}}$ and $p^*_{k_{last}}$ are ≥ 0.01, an approach borrowed from the Stock Synthesis Model (R. Methot). With dynamic binning, k_{first} and k_{last} may vary from year to year for the same survey, sex and quarter.

The static binning approach used k_{first} and k_{last} values that were specified by the user for the fishery and for each survey. With static binning, one set of k_{first} and k_{last} values were used for all length data from the commercial fishery, another set for all length data from survey one, etc. Static binning was used in previous assessments (ASMFC 2009), but it's use was replaced with the dynamic binning approach in the last assessment (ASMFC 2015a) and this assessment.

The plausibility of user-specified sample sizes for catch-at-length data was evaluated using "effective" sample size (Methot 2000). Effective sample size (n_{eff}) is an estimate of the sample size that corresponds to the goodness of fit observed in preliminary models:

$$n_{eff} = Var(r)N \Big/ \sum_{j=k_{first}}^{k_{last}} \left[\hat{p}_j\left(1-\hat{p}_j\right)\right]$$

Sample sizes (S) assumed in initial model runs were the number of positive tows in a survey during each year or the effective sample size calculated from commercial sampling data. In final runs, assumed sample sizes were tuned so the trends and scale of assumed sample sizes matched the trend and scale of the effective sample sizes based on model fit. Tuning involved fitting a GAM model $n_{eff} \sim s(t)$ to preliminary effective sample size values where s is a scatterplot smoother. Predicted values from the GAM model were then used as sample sizes in likelihood calculations. Effective sample sizes were reduced to a maximum of 400 before fitting the GAM or use in the assessment model.

6.1.6 Landings predicted values and GOF

Numbers of lobsters landed were calculated:

$$L_{s,t,q,k} = \frac{F_{s,t,q,k}}{Z_{s,t,q,k}} N_{s,t,q,k}\left(1-e^{-Z_{s,t,q,k}}\right)$$

Landings in weight were $W_{s.t,q,k} = L_{s.t,q,k}\omega_{s,k}$ and $\omega_{s,k}$ is a sex- and length specific mean weight supplied by the user.

Likelihood calculations compared observed landed weight for each quarter and sex with predicted values $W_{s,t,q} = \sum_k W_{s.t,q,k}$ assuming the data had normally distributed measurement errors with a fixed CV. Thus, the variance used in likelihood calculations was $\kappa W_{s,t,q}$ where κ is the CV. The CV is potentially estimable but was fixed at 10% in this assessment.

6.1.7 Recruitment GOF

The log likelihood for log scale recruit deviation parameters $r_{s,t}$ was calculated assuming that they were normally distributed with mean zero and constant variance:

$$\Delta = -n\log\left(\sigma_s\sqrt{2\pi}\right) - 0.5\sum_t \psi_t \left(\frac{r_{s,t}}{\sigma_s}\right)^2$$

where σ_s is the variance of the $r_{s,t}$ deviation parameters calculated in the model and ψ_t is an annual weight always set to one unless otherwise specified.

6.1.8 Parameter estimation

Parameters were estimated by minimizing the negative log likelihood:

$$\Xi = -\omega_j \Lambda_j$$

where Λ_j is the negative log likelihood for jth data type or model component and ω_j is a weight equal to 1 unless otherwise noted.

6.1.9 Per-recruit model and reference point calculations

Yield (both sexes) and female spawning biomass per-recruit are calculated in the assessment model after it converges with key assumptions based on conditions during the final five years of the modeled period. In particular, commercial selectivity and natural mortality at size, the sex ratio at recruitment, seasonal distribution of recruitment, and ratio of female to male full recruit fishing mortality used in per-recruit calculations are five year average values. However, due to the well documented issues with per-recruit lobster reference points (ASMFC 2015a), these calculations are no longer reported.

6.2 University of Maine Model Configurations

6.2.1 Configuration of basecase assessment models

Table 67 summarizes basecase model configuration for each stock area with some explanations given below. Table 68 and Table 69 summarize survey data used in each model.

6.2.2 Model years pre-1982 and 2019

Model runs were for 1979-2019 but only estimates for 1982-2018 (GOMGBK) and 1984-2018 (SNE) were used in status determination. Data for 2019 were included to stabilize estimates for recent years, but were not used to determine status because complete commercial landings, sea sampling, and survey data for 2019 were not available or were preliminary. Plots with survey estimates, data or residuals include 2019.

6.2.3 Recruitment covariates

Recruitments showed strong temporal trends that were difficult to model assuming constant expected recruitment so step, linear, and polynomial functions were used to model trends in log expected recruitment over time based on recruit covariates (Table 67). In particular, quadratic functions (with covariates year and year^2) were used for SNE while linear functions

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(with the covariate year) were used for GOMGBK. A linear relationship was also tested for SNE, but the quadratic relationship better described the recruitment dynamics.

6.2.4 Natural Mortality

The basecase models implemented the same annual mortality patterns as in the previous assessment (Table 67, see Section 2.3 for more detail). Annual GOMGBK natural mortality from 1979-2019 was M=0.15. Annual SNE natural mortality from 1979-1997 was M=0.15, and M=0.285 from 1998-2019. This shift in SNE attempted to capture effects of recent warm water conditions in the inshore portions of SNE and prospective disease impacts to the stock. Sensitivity results were conducted to assess the influence of this assumption and how other adjustments in natural mortality influenced reference abundance and exploitation.

6.2.5 Landings and commercial size data

Landings data from 1979-2019 are reported as weights of lobster landed by year, quarter, and sex. Landings data for 1979-1982 may be less accurate because the figures were calculated from annual totals in old reports using average proportions by season and sex. Landings in 2019 were assumed to be the same as in 2018 (SNE) or queried from preliminary reports (GOMGBK). Commercial size data were used only for years with adequate sampling (see Appendix 3).

6.2.6 Survey trend and length data

GOMGBK survey data for each sex, season, and survey program were modeled as separate survey indices with their own size selectivity and catchability parameters (see Table 68 for more information). Survey data used for the SNE basecase model (see Table 69 for more information) were the same as those used in ASMFC (2015a); however, there were several differences for these inputs. A significant difference between fisheries-independent data inputs for this assessment was the new occurrences of true zero catch of sex-specific lobster in the trawl surveys. Specifically, from 2016-2019 in the fall CT trawl survey and the 2018 spring MA trawl survey, zero female lobsters were caught. This phenomenon required addressing these true zeros in catch information to allow for estimating the population sizes from the time series data. For these instances, years' relative abundances and length compositions were proxied. Relative abundances were proxied to a value that equated to catching half of a lobster in that given year based on the number of tows conducted. Doing so allowed for the abundance to not be zero, but still providing a difference from catching a single lobster. Length compositions of the previous year with available data were used as a proxy for the years' size distribution for years of true zero catch. Additionally, the NEAMAP trawl survey now only occupied two survey slots in the model as opposed to four in ASMFC (2015a). Per the NEAMAP survey protocols, instances occur over time where lobsters were measured but not sexed. In doing so, this current sampling methodology can result in biased length composition and index estimates over time. Given the importance of sex-specific indices of abundance and length compositions for the stock assessment model, and the uncertainty in this sex-specific information, the NEAMAP trawl survey data were collapsed into season-specific slots, as opposed to season and sex-specific slots in the previous assessment.

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6.2.7 Survey selectivity

Based on preliminary models and familiarity with the survey programs, the GOMGBK basecase model usually assumed that “offshore” NEFSC surveys had domed or ascending logistic size selectivity curves while “inshore” surveys had domed or descending logistic size selectivity curves (Table 68). Ascending logistic selectivity is plausible for offshore surveys because large lobsters tend to be found further offshore in areas covered by the NEFSC surveys. Descending logistic selectivity curves are plausible for inshore surveys because large lobsters are found offshore in areas not covered by inshore programs. Inshore surveys may be domed with an increasing trend for small sizes because capture efficiency for small lobsters increases as they grow large enough to be retained by the gear and move into areas covered by the surveys. The ME/NH trawl survey included an exception to this for males with ascending logistic selectivity, a change from the last assessment which assumed domed selectivity. This is a result of the change from the previous assessment of including depth strata 4 data in indices and length compositions, capturing the depths larger males migrate to and the full extent of male habitat (Figure 83).

Challenges arose when trying to fit length selectivity parameters to the SNE fisheries-independent surveys. In earlier model testing, parameters gravitated towards being estimated at their bounds for several surveys, particularly the NEFSC trawl surveys, with a tendency to allow for greater selectivity at smaller sizes than previously considered (ASMFC 2015a). These challenges, as well as increased proportions of smaller lobsters in these surveys, and lower state survey abundances (e.g. CT trawl survey, MA Spring trawl survey) or proportions of smaller lobsters (RI Spring trawl survey females), led to further theory on survey detectability of lobsters under a warming environment. Previous assessments had assumed single logistic selectivity curves for all surveys, with descending selectivity at size for all surveys except increasing selectivity at size for the NEFSC Trawl surveys. In the basecase model, double logistic selectivity curves were implemented for all surveys except the NEFSC Spring trawl survey to improve fits to survey length compositions, as well as better align with current theories on lobster detectability for the surveys. Further, the NEFSC Fall trawl survey was parameterized with nearly fully selecting all lobsters 53mm+ given the increase in proportion of smaller lobsters and the hypothesis that as coastal waters warm, the smaller sizes traditionally closer to the coast may now be seeking thermal refuge in federal waters. To allow for successful model fitness, multiple surveys’ selectivity parameters were held constant and not estimated (Table 69), as well as the proportions at size of male and female recruit lobsters entering the population each year. The recruitment proportion parameters held constant were derived from stable estimates of previous model fitting.

6.2.8 Survey catchability

In the last assessment there was a focus on surveys with limited geographic coverage that may not measure trends in relative abundance in a linear manner for the entire stock because size distributions and trends in abundance are not the same in all areas. For example, inshore surveys might saturate and increase slowly as lobsters increase in abundance and accumulate offshore, outside the area covered by the survey. Similarly, offshore surveys might increase slowly while abundance is low and lobsters are concentrated inshore, and then increase more

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quickly as abundance increases, the stock occupies offshore habitat areas and large individuals that favor offshore habitats become more common. Abundance might decline more rapidly in nearshore areas than offshore or for the stock as a whole if water temperatures warm and nearshore habitat becomes unsuitable. Where necessary, the relationship between abundance and the survey was assumed to be nonlinear so that $I=QN^{\beta}$ where I is the predicted survey index, Q is a catchability parameter and β is a parameter estimated in the model (Table 68 and Table 69).

During this assessment there was a focus on quantifying the specific process(es) causing changes in catchability. Additionally, occurrences of interannual variability in indices greater than could be expected from true abundance changes alone, given the biology of the species (e.g., 2010 and 2011 GOMGBK spring indices from NEFSC trawl survey), have become more frequent since the last assessment and encouraged the development of catchability covariates to explain interannual changes in addition to true abundance changes. The catchability covariate time series allow for inclusion of environmental variables that explain trends and/or interannual deviations in catchability. Accounting for these environmental effects provides a more accurate representation of abundance trends given the other data sets included in the model (e.g., commercial landings). Covariate time series were developed with stratified mean estimators from survey and auxiliary temperature data (see Section 4.2.4.1). For the GOMBGK VTS covariate, the SAS hypothesized that current summer temperatures affect lobster catchability (e.g., warmer temperatures increase feeding activity and likelihood of “potting”). For GOMGBK trawl survey covariates, given similar shifts observed in the fall temperatures and spring indices of abundance one year later, the SAS hypothesized that fall temperatures affect catchability (I.e., changes in spatial availability) of lobsters starting in the current fall and extend into the following spring (I.e., the fall temperature time series lagged forward one year). Lobsters may be more likely to move from inshore areas to offshore areas covered by trawl surveys during warm years and remain in these areas into the following spring when trawl surveys operate. For SNE trawl survey covariates, temperature in a given spring was hypothesized to influence lobster catch of that same period. Temperatures increase earlier in the year in SNE and lobster movement and activity in the spring may be tied to how warm the area is in the given year, with warmer years perhaps resulting in earlier movement of lobsters and increased detection in the surveys. SNE fall surveys did not have covariates applied given the temperatures during that period are typically warm enough for lobster activity.

During preliminary model fits, it was determined that the model preformed best with both the nonlinear catchability relationships and catchability covariates included. The choice of a saturating ($0 < \beta < 1$) or exponential ($\beta > 1$) catchability relationship was based on the location of the survey relative to the stock, survey trends, availability of catchability covariates, and preliminary model fits.

Early iterations of the model fitting highlighted the need and benefit of using exponential catchability parameterization for several SNE surveys. Specifically, the CT spring and fall trawl survey, MA spring trawl survey, and ventless trap survey were parameterized with nonlinear catchability. Values locked for these surveys were based on those freely estimated from previous model runs. The CT and MA survey parameters reflected strong to weak hyperstability in the surveys, whereas the ventless trap survey highlighted moderate hyperdepletion. Additionally, the spring NEFSC, RI, and CT surveys implemented environmental catchability parameterization using sea temperature time series for their respective regions (see Section 4.2.4.1). All catchability parameters were held constant after iteratively testing their parameters stability via model runs.

6.2.9 Commercial selectivity components

There are three components to commercial selectivity in this assessment: gear selectivity, legal selectivity, and conservation selectivity. Legal selectivity is the proportion of a size group that is legal-size based on analysis of sea sample data (Appendix 3). Gear selectivity is based on the minimum size of escape vents required in traps and is represented as the proportion that enter and are retained based on experimental data (ASMFC 2006, ASMFC 2015a). Conservation selectivity is the size-specific proportion of female lobsters caught that are discarded at sea due to eggs or v-notches based on analysis of sea sample data (Appendix 3). The best estimates available for each component were used in basecase model runs.

6.3 University of Maine Basecase Model Results

6.3.1 GOMGBK Stock

The basecase model converged with a maximum absolute gradient of 0.0002 and an invertible Hessian. Deviance residuals for survey indices were improved with catchability covariate time series to account for temperature effects on catchability and with the nonlinear catchability to account for lack of spatial overlap, but some residual patterning remains, particularly for surveys with less spatial overlap of the exploitable population (MA, NEFSC; Appendix 7: Pages 86-113). There is a trend in positive residuals starting after the sudden shift in trawl survey indices (spring 2011) that the model still cannot reconcile with the observed landings, but this pattern has improved with the nonlinear and covariate dynamics for catchability. As in the last assessment, the model continues having trouble fitting trends in the MA trawl survey which do not show the sharp increases in recent years evident in the other surveys. The model accounts for this by estimating a flat saturation relationship between the population and survey indices, indicating the survey is not tracking abundance trends observed in other data sets, potentially due to lack of spatial overlap between this survey and the stock (Appendix 7: Pages 56, 58-61, 72-75). The catchability relationship of males in the ME/NH and NEFSC trawl surveys flips from an exponential relationship in the spring to a saturating relationship in the fall with more pronounced temperature effects on catchability (Appendix 7: Pages 56-57). Further, the applied catchability offset for these surveys has a nonlinear trend through time with offsets < 1 in the 2000s and offsets >1 in the 2010s.This suggests the nonlinear catchability feature was aliasing fall temperature signals that have strong effects on catchability and interpretation of the underlying abundance trend prior to the addition of the catchability covariate feature. The fall catchability covariates had variable effects on females. Catchability of females in the NEFSC trawl survey was affected similar to males while no effect was estimated for females in the ME/NH trawl survey indicating temperature is not affecting catchability of females inshore in the fall the same way it is affecting males. The spring catchability covariates have a smaller effect on catchability, but show similar trends as the fall covariates, particularly with increased offsets >1 in the 2010s. The nonlinear beta parameters for spring trawl surveys decrease towards 1 relative to a sensitivity model run without catchability covariates indicating that the temperature time series are accounting for one process affecting catchability and a portion of the effects causing non-proportional catchability relationships. The summer catchability covariates accounted for small interannual effects on catchability in the ventless trap survey without trends seen in the bottom trawl surveys.

Generally, fits to length composition data were good and there were no serious residual patterning issues (Appendix 7: Pages 194-199). The most noticeable residual patterns occur for quarter one commercial landings when there is limited biological sampling and relatively low landings. The model also continues to have trouble fitting length data from NEFSC offshore surveys for lobster 100+ mm CL (Appendix 7: Pages 140-143). Switching from a double logistic dome-shaped selectivity to a single logistic ascending selectivity for females in this survey improved fits to larger sizes relative to last assessment at the cost of fit to some of the smaller sizes. The fits to commercial landings data were reasonably good with no serious residual patterning (Appendix 7: Pages 120-123). There were a few large peaks of males landed in quarter two (2012, 2016) that the model underestimated. This is likely due to increases in landings triggered by early molts during warm years that conflict with the static growth matrices.

Recruitment was relatively stable until the mid-1980s and then increased steadily and at an accelerated pace after 2006 (Table 70, Figure 177). The sex ratio of recruits has varied around 1:1 with no trend. Similarly, reference abundance estimates were relatively stable until the late 1980s and then increased steadily and at an accelerated pace after 2008 (Table 70, Figure 177). Female spawning stock biomass declined in the first few years of the model time series, but has increased steadily since and at an accelerated pace since 2008 (Table 70, Figure 177). The early decline appears to be a sort of “burn-in” when the initial population length compositions moved through the population, resulting in the model predicting a similar decline in abundance from the primary source of information on mature females, the NEFSC trawl survey, that was not observed by the survey. This lack of fit disappears after the first few years. The stock-recruit trajectory is generally consistent across the time series with blocks of a few years diverging from the mean trend but no strong evidence of a shift from a linear relationship (Figure 178). Recruitment rate appears marginally lower than the mean between 2002 and 2007 and higher than the mean for two periods; 1990-1996 and 2009-2013 with the terminal years consistent with the mean trend. The state-space trajectory of productivity shows increasing productivity through the 1980s and a relatively constant productivity through the 1990s and early to mid-2000s followed by a shift to higher productivity levels since 2007. This analysis suggests that reproductive success (in terms of survival of offspring and recruitment to the modeled size structure) in the GOMGBK stock has been sufficiently high to allow for an increasing population. It should be noted that the last recruit year of 2018 corresponds to the spawning biomass from 2013, so recruitment trends from the most recent years’ SSB are not included in this analysis.

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Effective exploitation estimates declined from the highest rates in the time series in the mid-1980s to remarkably stable levels since the late 1980s (Table 70, Figure 177). Exploitation of males was generally greater than females. See Appendix 7 for a complete set of plots showing input data, biological assumptions and estimates, model diagnostics, and population estimates.

6.3.2 SNE Stock

The basecase model converged with a maximum absolute gradient of 3.8E^{-5} and an invertible Hessian. Deviance residuals for survey trends showed noticeable patterns that ranged from weak to moderate (Appendix 8: Pages 60-115). All surveys showed similar prediction trajectories in the stock: indices increasing towards the late 1990s and declining thereafter. Fit to the indices varied pending the variability in the time series data, as some of these surveys' signals were nosier than others. The nonlinear catchability aided survey fits, particularly CT trawl survey indices. The environmental catchability effect was most apparent for the CT and NEFSC Spring trawl surveys, allowing for smoother fits to the data through time and accounting for the interannual variability associated with temperature. Such impacts on the RI Spring trawl survey were minimal. Trends in the residuals were most apparent in recent years for surveys, such as CT trawl survey, where catch has continued to decrease through time. Specifying the double logistic selectivity allowed for strong to moderate fits in the survey length compositions. Similar to ASMFC (2015a), the basecase model under predicted large female lobsters (93-123 mm CL) in NEFSC surveys and the NJ spring survey. Despite increasing selectivity of smaller lobsters in the NEFSC surveys, the model still tended to predict larger proportions for smaller (53-73 mm CL) female lobsters than observed.

Model fit was acceptable for commercial landings (Appendix 8: Pages 53, 124-127) and length compositions (Appendix 8: Pages 128-135). Residuals were moderate for few years' quarter and sex-specific landings, with residuals often greatest in quarter three. Predicted annual landings by sexes and combined fit particularly well. Length composition predictions fit well to the observed data, with slight overpredictions in the modal size classes.

Basecase model reference abundance estimates for SNE lobster increased from the early 1980s, peaked during the late 1990s, then declined through the early 2000s to a record low level in 2018 (Table 70 and Figure 180). Summer spawning stock biomass estimates indicated a similar pattern. Basecase estimates for recent recruitment are the lowest on record in the time series, with average recruitment from 2016 to 2018 at 2 million recruits. The stock-recruit trajectory shows clear shifts in recruitment rates over the time series (Figure 181). Recruitment rates were sufficient to allow for an increasing population through the mid 1990s after which recruitment began to decline while the stock biomass continued to increase for a few more years. Around 2000, the stock seems to have settled into a new regime with recruitment rates insufficient to maintain stock biomass and the spawning stock declined through the remainder of the time series. This pattern is consistent with the results from the state-space analysis of steepness (Figure 182). Stock-recruit steepness is consistent and high through 1995, then declines, stabilizing briefly around 2005, before declining further. This analysis suggests that reproductive success (in terms of survival of offspring and recruitment to the modeled size structure) are insufficient to sustain a stable population at current exploitation rates. It should

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be noted that the last recruit year of 2018 corresponds to the spawning biomass from 2013, so recruitment trends from the most recent years' SSB are not included in this analysis.

Effective exploitation was greatest during the period of 1979 to 2002, with a stark decrease in 2003, where exploitation levels have remained low and relatively stable since (Table 70 and Figure 180).

See Appendix 8 for a complete set of plots showing input data, biological assumptions and estimates, model diagnostics, and population estimates from the basecase model.

6.4 Uncertainty

6.4.1 Asymptotic Standard Errors

ADMB calculates asymptotic standard errors of parameter and derived quantity estimates with the delta method. Confidence intervals from standard errors of basecase model estimates were narrow in absolute terms (Table 72) and much narrower than the range of estimates from sensitivity analysis (Table 73 and Table 74). These results indicate that asymptotic standard errors grossly understate true uncertainty in basecase results.

Fishery selectivity, natural mortality and growth parameters were not estimated in the model and this probably contributes to underestimation of uncertainty in model results. A likelihood profile was conducted on the average log recruitment parameters during the last assessment and found a conflict between landings and length composition data stemming from problems with the static growth matrices that resulted in the underestimated uncertainty with asymptotic standard errors. Results showed that landings data are informative for each stock and fit best in models with relatively low abundance and high exploitation estimates. In contrast, length composition data fit best in models with relatively high abundance and low exploitation estimates because low exploitation indices allow more large lobsters to survive and grow to large size so that the fit to size data for large lobsters improves. Basecase model results appear precise because the valley is steep and sharp but the geometry of the valley is due to conflict between landings and length that arises due to difficulties predicting the proportions of large lobsters in size data. Inaccurate growth assumptions are the most likely cause of the problems in fitting size composition data for large lobsters. Thus, the apparent certainty in model results appears to be a geometric side effect of errors in growth assumptions. These results suggest that growth is the most important uncertainty in using the University of Maine assessment model for lobsters. This uncertainty remains in this assessment given the lack of new growth data.

6.4.2 Sensitivity analyses

Many sensitivity runs were conducted for assessment models and compared to the basecase models to understand the impact of certain assumptions or data decisions on the model fitness and results. Sensitivity analyses are particularly important in this assessment because they are the primary measure of uncertainty. As in the previous assessment (ASMFC 2015a), asymptotic variances were implausibly small as uncertainty measures (see Section 6.4.1). In lieu of

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conventional uncertainty calculations, the range of estimates from sensitivity analysis was used to characterize uncertainty in reference abundance and effective exploitation. Thus the range of recent (2016-2018) mean reference abundance and effective exploitation indices in sensitivity analysis tables is the best available information regarding uncertainty. Eleven sensitivity scenarios were shared between both stocks, where others were stock-specific to address explicit questions regarding the populations or fisheries for a given stock. Stock-specific sensitivity analyses for GOMGBK and SNE included ten and six runs, respectively, in addition to the shared set (Table 73 and Table 74). Sensitivity run names used in discussion of results, tables, and figures are bolded and italicized when introduced below.

Similar to ASMFC (2015a), sensitivity runs were conducted for the gear selectivity for both stocks. Gear selectivity for this species is difficult to estimate, but has a large effect on assumed commercial selectivity curves. Model runs were conducted for shifting gear selectivity both up (**Gear Selectivity Shift Right**) and down (**Gear Selectivity Shift Left**) by a size class (5mm). These runs were intended to highlight how assumptions in lobster size selectivity to commercial gear influences population size and exploitation trajectories.

Two GOMGBK-specific runs were used for exploration of the models lack of fit to conflicting trawl survey indices and/or commercial landings identified early in the assessment process due to the sudden shift of trawl indices in 2011 and the accelerated rate of increase observed in some trawl survey indices. The first run increased the emphasis of fitting on the commercial landings time series by increasing the likelihood multiplier from one to ten (**Upweight Landings**). The second run included spring trawl survey indices split into two time series, one before the sudden increase in 2011 and one starting with the sudden increase in 2011 (**Split Spring Trawl Indices**). Splitting the surveys required some index slots to be freed up, so the MA spring trawl survey indices were excluded from this run due to strongly saturated catchability relationship for these indices. Unique selectivity and catchability parameters were estimated for each of the time series (2 sets of parameters for each split survey). The catchability covariates were excluded from this run.

Model sensitivity to recruitment parameterization was evaluated for both stocks to discern how trends in recruitment influence model results. In these sensitivity runs, recruitment was modeled with no trend through time (or at a static level) with annual deviates estimated from the mean (**No Recruit Covariate Trend**), as opposed to the basecase models where expected recruitment was applied as a trend through time and annual deviates estimated from the expected trends. Additionally, GOMGBK recruitment has been a source of uncertainty in recent years as downward trends in settlement and YOY have been detected since the late 2000s and have raised concerns about subsequent declines in recruitment to the exploitable population, though these signals have not been consistent in adult surveys and landings. Two alternative recruitment covariate time series were explored in sensitivity runs, both with the basecase linear increase through 2011, but one with the covariate held constant through the remainder of the time series (**Flattening Recruitment**) and one with the covariate reversing into a linear decline through the remainder of the time series (**Declining Recruitment**). For the SNE stock, a temperature recruit covariate run tested whether the recent decline in recruitment might be

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attributed to recent increases in water temperature in coastal Southern New England (see Section 2.3; **Recruit Trend Days ≥ 20°C**). To examine this, the number of days with sub-surface temperature ≥ 20° C at the Millstone Power Station in southeast Connecticut on Long Island Sound was used as a recruitment covariate.

Various sensitivities were conducted to assess the influence of catchability parameterization on the basecase models for each stock. Numerous surveys were assumed to have strongly nonlinear catchability relationships (saturating or exponential) in basecase models for both stocks. The additional feature of catchability covariates was added in this assessment and provides further flexibility in catchability deviating from linear, constant relationships due to environmental effects. These catchability relationship features are used in interpreting survey trends, tend to increase uncertainty, have the potential to confound each other, and may have affected basecase model estimates. For both stocks, sensitivity runs were conducted without using environmental or nonlinear catchability applications (**No Environmental or Nonlinear Catchability**), as well as only using nonlinear catchability parameterization (**No Environmental Catchability**). As with the SNE basecase model, these values were fixed and not freely estimated in the SNE sensitivity runs. The GOMGBK model included a sensitivity run with catchability covariates only (i.e., no nonlinear catchability applications; **No Nonlinear Catchability**). Finally, two additional GOMGBK runs explored a competing hypothesis that current spring temperatures may affect current spring trawl survey catchability, as hypothesized in SNE. The first run included a spring temperature time series for the NEFSC trawl survey indices instead of the previous year's fall temperature time series (**Spring NEFSC Temperature**). The second run included a spring temperature time series for the ME/NH trawl survey indices instead of the previous year's fall temperature time series (**Spring ME/NH Temperature**).

Scenarios were run to determine the model sensitivity to changes in natural mortality. Natural mortality is important because lobsters are difficult to age, environmental conditions may have increased natural morality in SNE, and because it may have a large effect on assessment results. For both stocks, sensitivity runs were conducted by increasing and decreasing the baseline natural mortality by 0.05. This corresponded to annual natural mortality rates in the GOMGBK stock at 0.1 (**M=0.1**) and 0.2 (**M=0.2**). For the SNE stock, the stepwise increase in 1998 of 1.9 times the base mortality was maintained, corresponding to 0.1 from 1979-1997 and 0.19 from 1998 to 2019 for the lower natural mortality sensitivity run (**M=0.1, 0.19**), and 0.19 from 1979-1997 and 0.38 from 1998 to 2019 for the increased natural mortality sensitivity run (**M=0.2, 0.38**). Varying mortality rates by size was also assessed through sensitivity runs in both stocks (**M Decline with Size, Lorenzen**). The basecase models both held mortality at size constant over size bins. The sensitivity runs assumed that natural mortality decreased exponentially as a function of weight, as described by Lorenzen (1996). Weight-specific mortality rates corresponded to the size bins based on the stock-specific weight-length relationships.

Additional natural mortality sensitivity runs were conducted for the SNE stock. The first examined reallocating seasonal distribution in natural morality (**Summer Allocated M**). As opposed to the basecase model where natural mortality is spread equally across quarters

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within a year, a sensitivity run was made with 80% of the annual natural mortality occurring in the summer, with the rest spread equally across the other three quarters. This was done to better link mortality timing to molting, which occurs in summer and seems likely to be the predominant source of mortality. Another sensitivity run for the SNE model involved using shell disease prevalence to inform interannual natural mortality (**M=Shell Disease Trend**). This sensitivity was chosen to provide a data-informed proxy for stock-wide natural mortality changes through time. This scenario differs from the basecase mortality by using data to inform changes through time, as opposed to a stepwise change in natural mortality in 1997-1998. Shell disease prevalence data for males and females was obtained from the RI trawl survey. Time series of sex-specific shell disease prevalence was log-it transformed and fit with a loess smoother (Figure 183), and then scaled to a base mortality of M=0.15. Thus, annual mortality rates were at a minimum of 0.15 and scaled up based on the relative annual changes in the loess shell disease trends.

As discussed in context of small asymptotic standard errors, growth data continue to be a limitation and primary source of uncertainty in this assessment, including the recent information confirming decreasing size-at-maturity. For the lack of a better alternative growth scenario, the SNE growth matrices were used to illustrate the GOMGBK model’s sensitivity to alternative growth patterns (**SNE Growth**). This scenario is considered an extreme and unlikely “alternative state of nature” for the GOMGBK stock.

Sensitivity runs were run for both stocks using the ventless trap survey design-based (i.e., stratified mean) abundance indices to evaluate the significance of using model-based indices in the basecase model (**VTS Design Based Index**; see Appendix 6 for model-based index methods). Both runs used the same length composition data, except for 2013 where the design-based indices did not have annual data and the model-based indices used the 2013 predicted index values and observed 2013 length composition data.

Two GOMGBK runs evaluated sensitivity to selectivity assumptions that changed relative to the last assessment. The first run assumed dome-shaped selectivity of females in the NEFSC trawl survey by fixing the parameters for this survey to the estimates from the basecase model in ASMFC 2015a (**Domed NEFSC Female Selectivity**). The second run assumed dome-shaped selectivity of males in the ME/NH trawl survey, also by fixing the parameters for this survey to the estimates from the basecase model in ASMFC 2015a (**Domed ME/NH Male Selectivity**).

Another GOMGBK run included only data from the ME/NH trawl survey depth strata 1-3 in indices and length compositions to explore sensitivity of including data from the deepest strata (4) in indices and length compositions in the basecase model of this assessment (**Exclude ME/NH Depth Strata 4**).

The impact of moving to effective sample size thresholds for gap-filling biosample characterization of landings was also conducted by comparing model results to using the ASMFC (2015a) method of using a sampling trip threshold for gap-filling biosample characterization of landings (**Biosample - N=3**). Note that a ten trip threshold was actually used in the last assessment, but was intended to be a three trip threshold; hence a three trip threshold for this sensitivity run. An additional sensitivity run was conducted for SNE with SA 537 landings' biosample characterization changed from LCMA 2 management measures to LCMA 3 management measures (**Biosample - 537 Recharacterization**). With the SNE lobster fishery moving further offshore over time, this sensitivity run was conducted to test whether changing the characterization of 537, one of the largest landings statistical area for the stock, was more appropriate.

Speculation has been raised regarding the influence of Long Island Sound on the stock's historical population trajectories and fishing effort. Specifically, managers have discussed whether Long Island Sound information (i.e. landings, fisheries-dependent sampling, and fisheries-independent surveys) included in the SNE stock is no longer appropriate given changes in lobster habitat in this area, and whether removing this information changes perceptions on stock trajectories and possibly management goals. This theory was tested by removing SA 611 landings and CT trawl survey abundance indices from the assessment data and compared to the basecase model (**Exclude Long Island Sound**). An additional model was conducted excluding only the CT trawl survey abundance indices to still capture the historical removals of lobsters from SA 611, but acknowledging that the frequent low or zero catches of lobsters in the trawl survey may reflect that this area is no longer a functional or habitable component of the stock (**Exclude CT Trawl Survey**).

Recent research on lobster maturity has provided the opportunity to update stock-wide maturity ogives by size. A sensitivity run was conducted for both stocks using the maturity ogives applied in ASMFC (2015a) and comparing the differences in estimated SSB (**Old Maturity Ogive**). Note that given SSB is not parameterized within the model and is arithmetically calculated by estimated abundances at size, the model fits are the same with different SSBs calculated, with this sensitivity designed to simply compare magnitudes and trends in SSB.

6.4.2.1 GOMGBK

Average reference abundance estimates for 2016 - 2018 from sensitivity runs ranged from 5% less than to 33% greater than basecase estimates while average exploitation estimates ranged from 20% less than to 7% greater than basecase estimates (Table 73 and Figure 184). The **SNE Growth** and **Gear Selectivity Shift Right** sensitivity runs had the greatest effect on estimates, both in the same direction (i.e., greater reference abundance and lower exploitation than the basecase). The **SNE Growth** sensitivity run estimated reference abundance and exploitation 33% greater than and 7% less than the basecase model, respectively. SNE growth is slower than GOMGBK growth due to the onset of maturity at smaller sizes, accumulating more lobsters in the smaller, protected size bin (78-82 mm CL) within the reference abundance. The **Gear Selectivity Shift Right** sensitivity run estimated reference abundance and exploitation 18% greater than and 20% less than the basecase model, respectively. Shifting gear selectivity to the right protects more reference abundance and, therefore, results in lower exploitation of similar reference abundance estimates given the same observed landings. Without these runs, average reference abundance estimates ranged from 5% less than to 11% greater than basecase estimates while average exploitation estimates ranged from 3% less than to 7% greater than basecase estimates. The **Gear Selectivity Shift Left** sensitivity run impacted the exploitation estimates early in the time series, but aligned well with the basecase estimates after the minimum size increases from 81 to 83 mm CL from 1987 to 1989. Prior to this year, shifting the gear selectivity to the left made more lobster vulnerable to the fishery. Assuming a lower natural mortality (**M=0.1** and **M Decline with Size, Lorenzen**) results in the model estimating lower recruitment to match the landings once individuals grow to legal sizes. Conversely, assuming a higher natural mortality (**M=0.2**) results in the model estimating greater recruitment to match the landings once individuals grow to legal sizes.

The maturity ogive from the last assessment with 50% maturity at a larger size estimated average quarter three female spawning stock biomass for 2016-2018 27% lower than the basecase model (Appendix 9 Figure 5). The choice of maturity ogive does not affect any other model estimates.

Uncertainty in reference abundance and effective exploitation estimates for the GOMGBK lobster stock is presented in Table 73 as the differences in the various runs when compared to the basecase run. There appears to be less uncertainty in estimated trends than in estimated scale. For comparisons of reference abundance and exploitation trends across sensitivity runs by various categories, please see Appendix 9.

6.4.2.2 SNE

Sensitivity scenarios reflected similar trajectories in reference abundance and effective exploitation compared to the basecase model: increase and decrease in reference abundance pre and post the late 1990s respectively, and the decline in exploitation in 2003 (Figure 185). The greatest increase in recent year reference abundance compared to the basecase model came with increasing annual natural mortality by 0.05 (**M=0.2, 0.38**), and the greatest decrease when applying reduced mortality at size for lobsters (**M=0.1, 0.19** and **M Decline with Size, Lorenzen**). This resulted in the converse in exploitation (Table 74). Using sample sizes of three sampling trips for the biosample borrowing and assignment (**Biosample - N=3**) compared to effective sample size calculations (i.e. the basecase model) resulted in a relative increase in exploitation and decrease in reference abundance. Excluding Long Island Sound information from the model (**Exclude Long Island Sound** and **Exclude CT Trawl Survey**) resulted in lower reference abundance through time compared to the basecase scenario, including terminal years, with a modest increase in terminal year exploitation. For comparisons of reference abundance and exploitation trends across sensitivity runs by various categories, please see Appendix 10.

6.4.3 Retrospective Pattern Analyses

6.4.3.1 Historical retrospective analysis

Basecase reference abundance and effective exploitation estimates in this assessment and estimates from ASMFC (2015a) were compared to evaluate the historical stability of assessment estimates over time. Stability in scale (the level of estimated abundance and exploitation) and trend (changes over time) were evaluated, although only trends are used for status determination. To quantify historical changes in scale, the mean ratio N_{new}/N_{old} was computed where N_{new} is a basecase estimate from this assessment and N_{old} is from ASMFC (2015a). The correlation between N_{new} and N_{old} was used to quantify similarity in historical estimated trends.

6.4.3.2 Analytical retrospective analysis for current basecase models

Basecase models were rerun sequentially omitting one year of data to evaluate the stability of basecase models. The basecase estimates through 2018 were based on data through 2019. Data for 2019 were omitted and the model was run through 2018 to estimate stock size in 2017, and so on. In the last retrospective run, data through 2013 were omitted to estimate stock size in 2012 (7 “peels”).

Mohn’s (2009) rho statistic and standard plots were used to quantify retrospective patterns in reference abundance and effective exploitation estimates from basecase models:

$$\rho = \left(\sum_{r=1}^{7} \frac{x_{2018-r-1,r} - R_{2018-r-1}}{R_{2018-r-1}} \right) \bigg/ 7$$

where $x_{Y-r-1,r}$ is the estimate for the year Y-r-1 in retrospective run r with terminal year Y-r, and R_{Y-r} is the same estimate from the basecase model. Mohn’s rho measures the average relative difference between basecase estimates and terminal estimates for the same year from a retrospective run.

6.4.3.2.1 GOMGBK

Historical retrospective indicates continuity and stability in estimates between assessments. The most noticeable differences were exploitation early in the time series and reference abundance in the last few years of the previous assessment (Table 75 and Figure 186). The model in the last assessment experienced some lack of fit to the quarter three landings in the last few years that resulted in reference abundance increasing at a more rapid rate similar to the trawl survey indices that were in the first few years of the catchability shift.

Plots and Mohn’s rhos indicate mild retrospective patterns in the basecase model, suggesting that the estimated trends and scale for recent years are stable (Table 76 and Figure 187-Figure 188). The reference abundance retrospective pattern did flip relative to the last assessment, with reference abundance being overestimated in this assessment. This pattern appears driven by the divergence between trawl survey indices and landings, with the trawl surveys continually indicating greater abundance than the commercial landings after the catchability shift in 2011. As more commercial landings data and catchability covariate data are added to the time series, the model gains more information on divergence between the trawl survey indices due to temperature effects and the landings.

6.4.3.2.2 SNE

Trends in basecase estimates from this assessment are similar to trends from the previous assessment (Table 75 and Figure 189), with a few caveats. Reference abundance trajectories are nearly the same between the basecase and the last assessment, except the decline in abundance in the 2000s for the basecase model was less steep than the previous assessment.

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Reference abundance in the terminal year (2013) from the previous assessment was estimated at 7.7 million lobsters, whereas this updated assessment indicated that 2013 reference abundance was 11.4 million lobsters (Figure 189). The basecase reference abundance did not reach the previous assessment terminal year levels until approximately 2016-2017. The basecase model terminal year (2018) reference abundance was estimated at 6 million lobsters. Both assessments highlight the decrease in exploitation from 2002 to 2003, with exploitation rates before and after this period comparable (Figure 189). Recruitment trends for combined sexes were similar between the basecase model and last assessment, although greater variability than that observed in reference abundance. Similar to reference abundance, recruitment estimates from the last assessment appeared to be an underestimate for terminal years compared to the same years in the basecase model (Figure 189).

Analytical retrospective runs indicate similar trajectories for reference abundance and exploitation compared to the basecase model, with reference abundance time series more comparable than exploitation. The most noticeable differences were in recent years, from the 2000s onward (Figure 190-Figure 191). Reference abundance in recent years from retrospective runs appeared to be underestimated compared to the basecase model, whereas recent years' exploitation rates from retrospective runs were overestimated compared to the basecase model. Estimates from the last assessment (ASMFC 2015a) indicated stronger coherence and stability across the retrospective runs than this updated basecase model. Both the peels' trends and Mohn's rho values highlight these patterns (Table 76 and Figure 190-Figure 191). The retrospective patterns in the basecase model's estimated scales for recent years are less stable and more uncertain than in the previous assessments (ASMFC 2015a). However, retrospective patterns were directionally the same between the basecase model and those in ASMFC (2015a). The greatest difference is the retrospective patterns are manifested at greater magnitude over the time series than in the previous assessment; differences in peels and the basecase were present throughout the time series, whereas in the ASMFC (2015a) retrospective patterns were greatest in the terminal years.

While the cause for retrospective patterns is not identified, there are several changes in the stock's data that may attribute to this. The occurrence of zero catch in female lobsters in surveys (CT trawl survey 2016-2019, MA trawl survey 2018) corresponded to a precipitous decline in recruitment in 2016-2018 in model runs. For these surveys that have historically described newly recruited lobster trends well, particularly in Long Island Sound, the assessment model is forced to reconcile how recruitment may be entering the population elsewhere. Increased smaller lobsters in the NEFSC trawl surveys, a new phenomenon compared to previous assessments, may be the sign of spatially shifted recruitment. The model is forced to resolve these sources of recruitment for the stock via survey size selectivity fits. These changes in trawl survey information likely highlight the changes in the stock structure as well, with portions of inshore habitat no longer suitable to lobsters, particularly females, and resulting in a greater distribution of smaller lobsters further from shore. Redistribution of lobsters from conventional spatio-temporal patterns coupled with a continued decline in the stock have led to speculation on the current spatio-temporal distribution of the population, and either how the stock should be defined as a result or what components are currently being missed using available survey information. Such retrospective and proportional difference patterns through time have been seen in previous lobster assessments, specifically for GBK when the area was modeled as a separate stock (ASMFC 2009). During the 2009 benchmark assessment, the observed noise in retrospective trends and difference in peels from the GBK basecase model was attributed to diverging abundance trends in the spring and fall surveys on GBK. This issue was resolved in the previous assessment (ASMFC 2015a) with the reclassification of the GOMGBK stock. These issues for GBK in ASMFC (2009) may be analogous to what is occurring for SNE basecase model.

Changes in growth rates through time may also be influencing the stability of the model. Growth matrices impact many attributes of the model, such as the progression of cohorts through time and the size structure of recruit lobsters. Using static growth matrices for this life history trait likely contributes to challenges for model fitness as well as estimates in recruitment and reference abundance. Time-varying growth matrices remains a significant data need for improving modeling efforts.

7 REFERENCE POINTS

7.1 Background and Current Reference Point Definitions

Both per-recruit biological reference points and ad hoc historical reference points have been used for the American lobster stocks historically. Early lobster stock assessments recommended the per-recruit biological reference point $F_{10\%}$, the fishing mortality rate that allows female lobster recruits opportunity, on average, to spawn 10% of the number of eggs that would be spawned in the absence of a fishery. These per-recruit reference points assume equilibrium conditions such as a constant rate of growth and a constant rate of natural mortality which have proved inappropriate for lobster stocks. The UMM has built in capabilities for calculating the per-recruit biological reference points. Per-recruit reference point calculations were provided through the last assessment. During the 2015 assessment, the GOMGBK stock was found to be experiencing overfishing according to an entire suite of per-recruit reference points ($F_{5\%}$, $F_{10\%}$, $F_{15\%}$, $F_{20\%}$, F_{MAX} and $F_{0.1}$), which was considered implausible given the record abundance and recruitment observed in this stock over the last 20 years. For the SNE stock, relatively high assumed natural mortality, early sexual maturation (100% mature prior to recruiting to the fishery), and recent shifts in fishery selectivity towards larger lobsters (via increased minimum size regulations) make it impossible, based on the calculations, to fish hard enough to reduce mean lifetime egg production per-recruit to even 20% of the virgin level, let alone more liberal levels. Additionally, temperature regimes have undergone substantial systematic changes which directly affect natural mortality, rate of maturation, and rate of growth. Climate projections for the Northeast shelf predict that a continuation of environmental variability is a reasonable expectation. Therefore reference points that are based on hypothetical equilibrium conditions become unrealistic and unreliable management tools. An estimate of 100%MSP based on past data has little relevance to current or future conditions. As such per-recruit reference point calculations are not provided in this assessment.

Starting with the 2006 assessment (ASMFC 2006), ad hoc historical reference points were recommended for comparison to recent conditions to determine stock status. Model estimates of recent abundance and instantaneous fishing mortality were compared to percentiles of the modeled time period, except for a few of the earliest years in the 1980s (1982-2003 for GOM and GBK stocks; 1984-2003 for the SNE stock).

In the 2009 assessment (ASMFC 2009) revised reference points were developed which intended to more clearly depict the current and historical status of the lobster stocks. A goal of the 2009 assessment was to alleviate problems created by the use of annual instantaneous fishing mortality rates applied to a model-estimated fishable abundance. Changes in the minimum legal size, gear regulations, and v-notching have changed the selectivity patterns of the various fisheries at differing times and have undermined the reliability of the model estimates of fishable abundance for each stock. This assessment recommended “reference abundance” and “effective exploitation” which are currently the primary descriptors of annual abundance and annual fishing pressure (N and F reference points) to determine stock status. Reference abundance is the number of lobsters 78+ mm carapace length (CL) on January 1 plus the number that will molt and recruit to the 78+ CL group during the year. The 78 mm CL size was chosen because it is the lower end of the model size group that contains the lowest minimum legal size (81 mm) across stocks during the reference period. Effective exploitation is the annual catch in number divided by the reference abundance.

The main disadvantage of effective exploitation rates is that they depend on both recruitment and fishing pressure. In particular, effective exploitation rates will increase or decrease with recruitment and the abundance of lobsters between 78 mm CL and the minimum legal size. An increase in effective exploitation accurately reflects deteriorating conditions for the stock but may be due to low recruitment instead of increased fishing pressure, and vice-versa. Although variability in recruitment may make effective exploitation rates highly variable, status determinations are based on percentile distributions which are much less variable than estimates for individual years. In addition, the relationship between the effective exploitation rate and instantaneous fishing mortality rate will differ between the sexes because management measures differentially affect fishery selectivity and fishable abundance by sex (i.e. discard of v-notched or ovigerous females). The relationship will change over time as new management measures affecting fishery selectivity are introduced or as natural mortality varies. Exploitation rates for combined sexes may exclude important information about stock status for lobster, specifically very high exploitation rates on males. In all cases, however, the effective exploitation rate measures the practical effects of fishing pressure in a consistent manner using a summary statistic that ranges from zero to one.

Point estimates of effective exploitation and reference abundance from the UMM are more reliable as trend indicators than as estimates in absolute terms. For example, a change in effective exploitation from 0.2 to 0.4 would indicate that the variable in question doubled but would not necessarily indicate that either 0.2 or 0.4 was a reasonable estimate of the underlying true values. Uncertainties in estimates and/or reference points stem from several

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sources including growth parameters, natural mortality, and recruitment dynamics at low or high stock sizes.

In view of these uncertainties, the UM model has been used to evaluate stock status relative to trends during the reference period for each stock, but not relative to absolute abundance or exploitation-based reference points (e.g. B_{msy} or $F_{10\%}$). The trend based reference points for lobster have proven robust over a wide range of assumptions about natural mortality and do not depend on the estimated scale of model estimates. However, the disadvantage of using trend based reference points is that there is no guarantee that percentile conditions in the early 1980s through 2003 are equally optimal threshold and target values for lobster stocks. The reference period used in previous assessments has been noted as a relatively short time series that may not reflect an optimal and sustainable production range for each stock. Also, by using a fixed time period, evaluation of status assumes that conditions from the 1980s through 2003 are comparable or relevant to current conditions, where changing environment, or a regime shift likely negates that assumption (see Section 2.9.5).

7.1.1 Current Abundance Reference Points

GOMGBK Stock

A stock is considered below the limit reference point (threshold), and overfished, if model abundance is less than the 25th percentile relative to the 1982-2003 reference period. Immediate action would be required if stock abundance were to fall below the 25th percentile. If the stock abundance is at or above the 75th percentile (green), a stock is considered in favorable condition.

SNE Stock

The SNE stock is considered below the limit reference point (threshold), and overfished, if model abundance is less than the 25th percentile relative to the 1984-2003 reference period. Immediate action would be required if stock abundance were to fall below the 25th percentile. If the stock abundance is at or above the 50th percentile (green), a stock is considered in favorable condition.

7.1.2 Current Exploitation Reference Points

The exploitation reference point is designed to be a conditional target as exploitation has remained relatively stable in all areas over a wide range of abundance during the reference periods. The exploitation reference point is the same for both stocks. A stock is considered above the limit reference point (threshold), and overfishing is occurring, if exploitation is greater than the 75th percentile relative to the reference period (GOMGBK: 1982-2003; SNE: 1984-2003). Immediate action would be required if exploitation were to exceed the 75th percentile. If the stock exploitation is at or below the 25th percentile (green), a stock is considered in favorable condition.

7.2 New Recommended Reference Points

The reference points in recent lobster assessments (ASMFC 2015a, ASMFC 2009, ASMFC 2006) were largely artifacts of the modeled time series (i.e., reference period) during the 2006

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assessment that started in the early 1980s and extended through 2003. Current reference abundance and exploitation in these previous assessments were compared to summary statistics from this fixed reference period to determine stock status. There has been increasing speculation that this historical reference period may not be appropriate for assessing current populations that may have experienced regime shift-like changes since this reference period, given the impacts of environmental changes on lobster population dynamics (see 2.9 Section) and drastic changes in abundance observed. Therefore, a rpart (recursive partitioning and regression trees) analysis (Therneau et al. 2015, R package rpart) of model-estimated reference abundance (78+ mm CL) was conducted to identify regime shifts in the exploitable lobster population and regime-based reference periods for determining status of each stock. Spawning stock biomass was considered as well, but not used due to uncertainty about changes in maturity through time. Consistent with the last stock assessment, the years prior to 1982 for the GOMGBK stock and 1984 for the SNE stock were dropped from the analysis due to greater data uncertainty in these years. The final year estimates (2019) were dropped from both stocks as these were estimated from incomplete/assumed data to stabilize model estimates in 2018. The rpart analysis applies regression models to build binary classification trees that minimize the residual sum of squares within clusters of chronological observations (i.e., annual reference abundance). A k-fold cross-validation procedure is used to test performance of models with various splits in the classification trees. Splits were assessed in terms of cross-validation error and the splits that minimized cross-validation error were included in regime identification (Peabody et al. 2018).

Reference points were tied to regimes and defined based on level and perspective of concern about corresponding stock abundance conditions. In acknowledgment of model uncertainty and interannual variability in stock conditions, the three-year moving average (e.g., $\mu_{2016\text{-}2018}$ for comparison in 2018) is compared to reference points to determine stock status. Perspectives about regimes may change as future environmental and stock conditions are realized, so it is expected that regimes be reevaluated in future stock assessments and reference points be modified accordingly to support adaptive management.

7.2.1 New Recommended Abundance Reference Points

Due to the different abundance trajectories estimated in previous and the current assessments, the difference in regimes detected from these abundance trajectories, and low likelihood of reaching even the most precautionary reference point due to documented changes in natural mortality and recruitment failure in SNE (ASMFC 2010), abundance reference point structures differ between the stock units.

GOMGBK Stock

Three regimes were detected for the GOMGBK stock: a low abundance regime from 1982-1995, a moderate abundance regime from 1996-2008, and a high abundance regime from 2009-2018 (Figure 192 and Figure 193). Though the causes of these regime shifts are likely complex and difficult to tie to any particular metric, the environmental regime shift analysis (Section 2.9.5) does provide some insight on potential drivers of reference abundance. A high abundance regime of Calanus finmarchicus, an important food source for larval lobsters, was detected from 2001-2009 which corresponds with the larval stage of the high reference abundance regime, assuming an approximate eight-year lag. Additionally, regime shifts consistently detected in temperature time series correspond with the shift to the high reference abundance regime which could indicate expansion of suitable habitat for lobster recruiting to the reference abundance and implications on other processes (e.g., reduced competition).

Three abundance reference points are defined based on the detected reference abundance regimes, including one to assess the stock condition from an economics perspective and two to assess the status of the stock from a biological perspective. These reference points should be interpreted according to the categories defined in ASMFC (2008): a target reference point indicates a desirable state of a fishery, a limit reference point indicates an undesirable state of a fishery which management action should be taken to avoid, and a threshold reference point indicates a 'red area' where continuity of resource production is in danger and immediate action is needed. Both limit and threshold reference points are provided here to differentiate between the degree of management action recommended if abundance falls below these reference points.

The first abundance reference point (Fishery/Industry Target) is a target calculated as the 25th percentile of annual abundance estimates during the high abundance regime. Abundance at or above this target is considered ideal, but, given the unprecedentedly high abundance levels and information on the environment's influence on lobster population dynamics, these abundances are not necessarily biologically-sustainable in the face of the changing environment. Abundance falling below this target does not trigger biological concern that the stock's ability to replenish itself is jeopardized, but rather that economic conditions of the lobster industry may degrade. Abundance falling below this target is also potentially within the realm of "carrying capacity corrections" to the current record abundance levels, as one might expect that a population overshooting carrying capacity might take some time to self-correct and/or stabilize into the 'new' environmental regime. Economic analyses and advice were outside the scope of this stock assessment and the expertise of the SAS, so the SAS strongly recommends that an economics analysis be commissioned as part of a post-assessment management document to provide robust advice on appropriate action to stabilize the fishery and prevent economic harm if or when abundance falls below the target.

The second abundance reference point (Abundance Limit) is a limit calculated as the median of annual abundance estimates during the moderate abundance regime. Abundance levels equal to or above this limit and less than the Fishery/Industry Target do not necessarily indicate concern about the biological condition of the stock, but abundance trajectories that fall below the Fishery/Industry Target and continue trending down towards this limit should be monitored closely with the annual Data Update Process (see Section 7.5)to determine if more research (e.g., an expedited stock assessment) or management actions are necessary to reverse this trend. Abundance that falls below the Abundance Limit indicates concern that the stock's ability to replenish itself is diminished and will continue to diminish if no action is taken. The stock is considered depleted if the three-year average abundance falls below this limit and management action to halt the decline in reference abundance is recommended.

The third abundance reference point (Abundance Threshold) is a threshold calculated as the average of the three highest annual abundance estimates during the low abundance regime. The use of a three-year average is to smooth uncertainty and interannual variability in model estimates and represents the boundary between moderate and low abundance regimes. This threshold indicates significant concern about the stock's ability to replenish itself and potential for stock collapse. The stock is considered significantly depleted if the three-year average abundance falls below this threshold. Significant management action to halt the decline of abundance and increase reproductive capacity and recruitment to the stock, such as a moratorium, is recommended if abundance falls below this threshold. Though stock abundance has been observed to expand from these abundance levels early in the model time series, there is increased uncertainty about recovery potential at these levels as environmental conditions change and regime shifts affect population dynamics, so this provides a precautionary approach for avoiding abundance levels with low recovery potential.

Accordingly, the Fishery/Industry Target, Abundance Limit, and Abundance Threshold for the GOMGBK stock are 212 million lobsters, 125 million lobsters, and 89 million lobsters, respectively. Both the Fishery/Industry Target and Abundance Limit are greater than the previous assessment reference abundance target (75th percentile of the annual reference abundance estimates during the 1982-2003 reference period, Table 77 and Figure 196). The Abundance Threshold is less than the previous assessment reference abundance target, but greater than the previous assessment reference abundance threshold (25th percentile of the annual reference abundance estimates during the 1982-2003 reference period).

SNE Stock

Two regimes were detected for the SNE stock: a high abundance regime from 1984-2002 and a low abundance regime from 2003-2018 (Figure 194 and Figure 195). The greatest support for drivers of these regimes comes from the Millstone temperature data in eastern Long Island Sound. The regime shift analysis detected a shift to more stressful conditions in 1999 (Section 2.9) which has been documented to cause increased mortality of lobsters in Long Island Sound (Section 2.3), a major contributor to overall SNE abundance at the time. This shift to stressful conditions and resultant increase in mortality was also the basis of an increased natural mortality rate in the assessment model starting in 1998, which was supported by the data sets included in the model. Despite the reference abundance starting to decline at approximately the same time as the temperature regime shift, the regime shift in reference abundance is not detected until four years after the temperature regime shift. This is because the reference abundance during these four years is still high, similar to the period of increasing abundance just before the temperature regime shift.

Only one abundance reference point, the Abundance Threshold as described for the GOMGBK stock, is provided for the SNE stock due to the continued downward abundance trajectory and evidence that recruitment failure has persisted. This reference point structure is similar to other ASMFC-managed species experiencing similar effects due to changing environmental conditions such as northern shrimp and weakfish.

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The Abundance Threshold is calculated as the average of the three highest annual abundance estimates during the low abundance regime. The use of a three-year average is to smooth uncertainty and interannual variability in model estimates and represents the boundary between moderate and low abundance regimes. This threshold indicates significant concern about the stock's ability to replenish itself and potential for stock collapse. The stock is considered significantly depleted if three-year average abundance falls below this threshold. Significant management action to halt the decline of abundance and increase reproductive capacity and abundance, such as a moratorium, is recommended if abundance falls below this threshold. Though the stock has been observed to expand from these abundance levels early in the model time series, deleterious environmental conditions currently affecting the SNE stock will impede recovery, thus drastic measures will be needed to provide the stock with a chance to recover or stabilize.

Accordingly, the Abundance Threshold for the SNE stock is 20 million lobsters. The Abundance Threshold is less than the previous assessment reference abundance target (50th percentile of the annual reference abundance estimates during the 1984-2003 reference period) and the previous assessment reference abundance threshold (25th percentile of the annual reference abundance estimates during the 1984-2003 reference period, Table 77 and Figure 197).

7.2.2 New Recommended Exploitation Reference Points

Exploitation reference points are defined to assess the status of the stock from a perspective on fishing mortality (i.e., overfishing vs. not overfishing). Changes in exploitation have conveniently matched well with changes in reference abundance, though have coincided with different reference abundance patterns between the stocks. The GOMGBK stock experienced higher exploitation during the low abundance regime when less restrictive management measures were in place. Exploitation decreased during the moderate abundance regime and remained relatively stable into the recent high abundance regime. The SNE stock also experienced higher exploitation in early years when less restrictive management measures were in place, but this coincided with the high abundance regime. Exploitation declined sharply at the beginning of the low abundance regime and remained relatively stable throughout this regime. These trajectories demonstrate the impact of management measures on exploitation and the SAS believes exploitation is unlikely to increase without liberalizing current management measures.

Given divergent reference abundance histories despite these similar exploitation histories, the SAS believes abundance reference points offer the most robust metric to assess stock status and trigger the need for management action. This aside, exploitation reference points are provided as an extra safeguard against sudden increases in exploitation that may not be explained by decreasing reference abundance.

For both stocks, the 75th and 25th percentiles of annual exploitation estimates during the current abundance regime (high abundance regime from 2009-2018 for GOMGBK and low abundance regime from 2003-2018 for SNE) were defined as the exploitation threshold and exploitation target, respectively. The stock is experiencing overfishing if the three-year average exploitation exceeds the threshold. Given the observed interannual variability in exploitation

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estimates around what are otherwise very stable exploitation patterns in recent regimes, the SAS recommends initiating additional research if the three-year average exploitation exceeds the threshold to better understand the cause of increased exploitation and determine if management action is necessary. The stocks fishing mortality status is considered favorable if the three-year average exploitation is less than or equal to the target.

The exploitation threshold and exploitation target for the GOMGBK stock are 0.475 and 0.461, respectively. The range between the target and threshold has narrowed relative to the last assessment, with both the current target and threshold being less than the previous assessment exploitation threshold (75th percentile of the annual exploitation estimates during the 1982-2003 reference period, Table 78 and Figure 198), and greater than the previous assessment exploitation target (25th percentile of the annual exploitation estimates during the 1982-2003 reference period). The exploitation threshold and exploitation target for the SNE stock are 0.2895 and 0.2569, respectively. The target and threshold have shifted to much lower values relative to the last assessment due to the steep decline in exploitation during the first year of the low abundance regime (Table 78 and Figure 199).

7.3 Stock Status

7.3.1 GOMGBK Stock Status

The GOMGBK stock is not depleted as the three-year average abundance from 2016-2018 was 256 million lobsters (Table 77, Figure 200 and Figure 202), greater than the Abundance Threshold (89 million lobsters) and Abundance Limit (125 million lobsters). Further, stock abundance is favorable as it is at an all-time high above the Fishery/Industry Target (212 million lobsters) and the SAS does not believe any management action is necessary at this time. The GOMGBK stock is not experiencing overfishing as the three-year average exploitation from 2016-2018 was 0.459 (Table 78, Figure 201 and Figure 202), less than the exploitation threshold (0.475). Exploitation is also below the target (0.461) and is considered favorable.

In general, both UMM estimates and model-free stock indicators suggest that abundance and spawning stock biomass are high in GOMGBK and the stock appears to be healthy at present. However, assessment results suggest careful consideration of key issues:

1. The model results indicate a dramatic overall stock abundance increase since the late 1980s, with more rapid rate of increase since 2005 and again after 2010. However, it is important to recognize that spatial dynamics and changes by statistical area are not consistent, and environmental influence on the population and on survey catchability are not consistent throughout the entire stock range. It will remain important to pay attention to spatial dynamics, both between the inshore areas and at larger GOM vs GBK scale.

2. The lobster distribution, as described by survey encounter rate, was positive over the last 5 years. In particular the federal survey has demonstrated a dramatic increasing trend in percent positive occurrence over the time series, indicating that lobster in GOMGBK were generally more available in offshore areas compared to the early part of the time series. Continued exploration of the influence of environmental conditions on

lobster distribution and catchability is warranted, especially if stock trends change. Should indices decline, it will be important to determine whether the change reflects changes in catchability, an actual change in the population, or both.

3. Exploitation rate is below the reference point threshold and target. Exploitation levels have varied, largely without trend since the early 1990s. Model free exploitation indicators for the GOM and GBK sub-stock areas are all positive. One of the more remarkable patterns presented in this assessment (and previous assessments) is the stability of exploitation rates while stock abundance has increased over time. This suggests that the fishery is efficient at removing the harvestable component of the resource, and is generally a recruit-dependent fishery. This complicates interpretation of trends in exploitation, as it may not be a good indicator of the relative impact of fishing on the population. Additionally, the exploitation indicator might be biased low because of the increased catchability observed in surveys (see Section 6.3.1), making it look like abundance is outpacing landings more rapidly than in reality.

4. Model free indicators show that the average spawning stock, full recruit and recruit abundance are nearly all above the 75th percentile. In contrast, the YOY indicator is neutral or negative, similar to the last assessment. All five regions in the GOM reported the mean 2014-2018 settlement was below the median for the time series, and two of those were below the 25th percentile. While recent research suggests that increases in available habitat might be diluting settlers in some areas (Goode et al. 2019), those habitat changes are less relevant in southern/western GOM where YOY index trends are particularly poor.

5. Effort (# traps – MA) in the GBK sub-stock is negative, even though LCMA 3 is going through a trap reduction plan. This is supported by the temporal trend in number of trips occurring on GBK (see Section 3.2.2). This is possibly related to shifting effort from SNE canyons and offshore GOM to GBK sub-stock area. This trend is a potential concern and work is needed to better understand fishing effort. Effort in general is difficult to track because of the lack of good data. Increased availability of data on the number of traps fished and especially the number of trap hauls from all jurisdictions is required to better understand effort in this fishery.

6. While disease remains low and days $\geq$ 20 degrees remain infrequent in the GOMGBK, the increasing trend over time in both metrics suggests an increase in stressful conditions, particularly in the southwest portion of the stock. These trends should be monitored closely.

7.3.2 SNE Stock Status

The SNE stock is significantly depleted as the three-year average abundance from 2016-2018 was 7 million lobsters (Table 77, Figure 203 and Figure 205), less than the Abundance Threshold (20 million lobsters). Stock abundance is at an all-time low and the SAS believes significant management action is necessary to provide the best chance of stabilizing or improving abundance and reproductive capacity. The SNE stock is not experiencing overfishing as the

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three-year average exploitation from 2016-2018 was 0.2742 (Table 78, Figure 204 and Figure 205), less than the exploitation threshold (0.2895). However, the exploitation exceeds the target (0.2569) and is not considered favorable.

In general, UMM estimates and non-model based stock indicators suggest that the stock is at record low abundance and the continued downward trajectory in reference abundance, recruits, and SSB is concerning. Most inshore abundance indicators are negative, with 0s showing up in some surveys for the first time ever in the time series. YOY indicators for Rhode Island and Millstone are negative and neutral for MA; however, zero YOYs were observed in four of the last five years in the MA survey. The continued low YOY and low recruit indices indicate SNE is still experiencing recruitment failure. The stock has not rebuilt since the last assessment and is in very poor condition. Assessment results suggest careful consideration of key issues:

1. Recruitment indices indicate that the stock is not rebuilding and is in recruitment failure. Since 2014, eleven of the fifteen annual values for Rhode Island, Massachusetts, and Millstone YOY indices were below their time series' 25th percentile.

2. The lobster distribution, as described by survey encounter rate, was negative in seven of the eight indices for the 2014-2018 period, and the eighth indicator is well below the median. The contraction of the SNE stock has continued and is becoming apparent in the offshore portion as well as the inshore.

3. The total SNE landings have been below the time series median for more than a decade, and below the 25th percentile for the past 8 years. Landings have continued to decline, and the 2018 landings were a time series low.

4. Disease remains high in Rhode Island and Massachusetts, and all four temperature indicators are negative. The stressful environment may be having both lethal and sublethal effects.

5. There is evidence from the model-based SSB-recruit relationship that mechanisms have negatively impacted recruitment in the stock, resulting in a decreasing recruitment rate (see Section 6.3.2). This will likely pose significant challenges to rebuilding the stock. Substantive measures are suggested that are specifically aimed to improve recruitment success via increased abundance of adults.

7.4 Projections

7.4.1 Projection Methods

To perform stock projections, a population simulator that was developed since the 2015 benchmark assessment to support lobster assessment and management was used. The length-aggregated simulator uses the same data structures and calculations of the assessment model (i.e., same length bins, quarterly time steps, selectivities, growth models, etc.) and directly accepts the outputs (abundance, length composition, parameters), from the assessment model.

It has been tested to reproduce the default projections from the assessment model but is more flexible for specifying future scenarios. One growth model is specified for a model run but users can specify multiple projection time series for fishing and natural mortality, recruitment, and selectivity. The simulator produces projections for all resulting combinations (i.e., 10 fishing mortality scenarios, 20 recruitment scenarios and 2 selectivity scenarios results in 400 simulation runs) which can then be examined individually or aggregated as desired.

For both stocks, three sets of projections were examined:

- Basecase projections: Stock projections based on the new basecase models, projected ahead 10 years.
- Sensitivity projections: Stock projections based on each sensitivity run, projected ahead 10 years.
- Prior Projections: Stock projections with the basecase from the previous assessment, projected ahead to 2019 and compared to the new basecase model.

For each simulation, the population is initialized with the abundance and length composition from the terminal year of the model run. Quarterly fishing mortalities for projection runs are calculated based on stochastic draws from the mean and standard deviation of estimated fishing mortality rates from the current stock regime. For each set of projections, three different recruitment scenarios were examined, based on the assessment model recruitment estimates for the current regime (SNE: 2003-2017, GOMGBK: 2009-2017). Recruit estimates for the last two years in the model were excluded as these estimates appeared unstable and are poorly informed.

- No Trend which assumes there is no trend in recruitment in the current regime: Estimated recruitment from current regime are log-transformed with random draws from the resulting mean and standard deviation.
- Current Trend which assumes that there is a recruitment trend in the current regime that will inform the projection: Estimated recruitment from current regime is log-transformed and fit to a linear model. The trend is projected forward with random draws from the distribution of the model residuals.
- Covariate Trend which uses the trend in the recruit covariate to inform future recruitment: A linear model is fit to the recruit covariate trend for the current regime and projected forward with random draws from the distribution of residuals of the covariate fit to the estimated recruits.

For the Basecase and Prior Projections, 100 fishing mortality projections and 200 recruit projections for each of the three recruitment scenarios were generated. A set of projections for SNE were also run with no fishing mortality to project potential population changes in the

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absence of fishing. Yearly mean and 95% confidence intervals for recruitment, reference abundance, and catch for each recruit scenario were then calculated.

For the sensitivity runs, each sensitivity run was projected with 20 fishing mortality projections and 200 recruit projections for each of the three recruitment scenarios. Yearly means for recruitment, reference abundance, and catch were then calculated for each recruit scenario and sensitivity run.

7.4.2 Projection Results

GOM Projection Results

The Current and Covariate Trend recruit projection models both show an increasing trend in recruitment for 2009 – 2017 with the basecase model with the Current Trend finding only a slightly positive recruitment in recent years. The basecase model estimates an anomalously high recruitment event in 2018, which is not used in the recruitment projection (Figure 206) but is included for initiating the projection models in 2019. This anomaly is evident in the reference abundance and landings projections (Figure 207 and Figure 208 , respectively), influencing both projections for the first few years.

Sensitivity Projections are fairly consistent for the No Trend projection with more spread evident among the Current Trend projections, suggesting some uncertainty in the recruitment trends in the recent years. The Covariate Trend projections are consistent with the exception of three Sensitivity Projections that represent model runs with no recruit covariates, a flat recruit covariate, and a declining recruit covariate, all of which give much lower projected recruitment. There is a fair spread in the initial projections of reference abundance and catch, indicating some uncertainty in the 2018 recruitment estimate that influences initial conditions of the projection (Figure 210 and Figure 211).

Recruitment estimates from the prior assessment are marginally but consistently higher than the current estimate, diverging around 2011 (Figure 212). Visually, the No Trend projection appears to better match the recent estimates than either the Current Trend or the Covariate trend projections with the exception of the 2018 recruitment estimate. Accordingly, the projections for recruit abundance and landings initiate at higher values than the observed landings in recent years (Figure 213 and Figure 214, respectively). The No Trend projection comes closest to converging with reference abundance estimates in the last year of the projection but no recruitment projection appears to be converging with observed landings.

There is a general contrast in the performance of the projections between the SNE and GOMGBK and what they may indicate about the underlying trajectories of the stocks and performance of the assessment model. In the SNE stock, there is a clear recruitment trajectory that is consistent between assessments, though different in magnitude, and a general agreement between recruit trends and recruit covariates. The No Trend scenario seems least appropriate. In contrast, there is general disagreement among all three recruit scenarios for the GOMGBK stock with the No Trend scenario perhaps performing best and the Covariate Trend performing worst. This suggests a change in the recruitment trend in recent years and that the

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form of the recruit covariate may be creating some minor bias in the terminal years of the assessment model and may need to be re-examined for appropriateness in future assessments.

SNE Projection Results

Given that estimated recruitment in SNE has declined during the current regime, the SNE recruit projection from the No Trend scenario produces a distinctly different projection than the Current Trend and Covariate Trend scenarios (Figure 215). Mean recruit for the No Trend scenario is comparable to estimated recruitment from 2009-2012 while the Current Trend and Covariate Trend scenarios both project continued declines in recruitment beyond the terminal year of the assessment. As a result, the No Trend scenario would project an increase in abundance (Figure 216) and landings (Figure 217), reaching pre-2010 values within about five years while the Current Trend and Covariate Trend scenarios both project continued decreases in abundance and landings.

Mean recruitment from Sensitivity Projections tend to agree with the Basecase Projections with moderate variations in recruitment across Sensitivity Projections for the No Trend recruit projections and less absolute variations in the Current Trend and Covariate Trend (Figure 218). Two exceptions are Covariate Trends that project higher recruitment, associated with sensitivity runs that assume no recruit covariate and that use the Millstone temperature time series for the recruit covariate. These recruitment projections produce abundance and landings projections that are comparable to the Basecase Projections (Figure 219 and Figure 220, respectively), with the exception of the two Covariate Trend projections noted above.

The SNE recruitment estimates from the prior assessment are lower than the recruit estimates from the current assessment model in recent years, diverging around 2010 (Figure 221). As a result, projections from the prior assessment start below the current estimated recruitment. The No Trend recruitment scenario exhibits a different trend than the current basecase trend, increasing above current estimated levels by the end of the time series. The Current Trend and Covariate Trend exhibit similar downward trends, converging at current recruitment estimates at the end of the time series. The recruit projections produce comparable trends in reference abundance and landings (Figure 222 and Figure 223, respectively).

The final set of SNE projections explore the capacity of the stock to rebound in the absence of fishing pressure. It is important to recognize that there is no stock/recruit relationship included in the simulation so the projections represent the direct effect of reduced fishing mortality and do not include any potential benefit from increased egg production. As a result, recruitment trends are similar to those reported for the Basecase Projection (Figure 224). In the absence of mortality, reference abundance would be projected to increase with recruit abundance exceeding the maximum abundance for the current regime (Figure 225). However, increases in abundance in the Current Trend and Covariate Trend are limited due to the projected continuing decline in recruitment.

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7.5 Recommended Data Update Process

To support management using the new recommended reference point definitions and responses resulting from this assessment, the SAS also recommends that an annual Data Update process be established to monitor changes to stock abundance. As described in the previous sections, this process would allow managers to more closely track the trajectories of stock abundance between stock assessments and allow for more timely reactions to any concerning trends.

The SAS recommends that on an annual basis, each state and federal agency submit updated survey indices to ASMFC staff. These data would be processed following the procedures used in this assessment to update the indicator time series through the most recent year. Data from the most recent year to be submitted annually by each state and federal agency should include:

- Trawl survey indicators, including recruit abundance (71-80 mm lobsters) and survey encounter rate)
- Ventless trap survey sex-specific model-based abundances indices (53mm+)
- YOY settlement indicator

The product of the annual Data Update process would be a brief memo and presentation to the Management Board reviewing these updated indicators and the Ventless Trap survey results during each ASMFC Annual Meeting (October). The intention of this process is not to reevaluate stock status by comparing these data points to established reference points, but rather to provide the Board with additional information on the condition of the stocks and trend of these indices between assessments. This information could be used to provide support for additional research or consideration of changes to management.

The SAS recommends that the annual deadline for data submission for the Data Update should align with the due date of annual compliance reports (August 1).

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8 RESEARCH RECOMMENDATIONS

8.1 Timing of Future Stock Assessments

The SAS recommends the next benchmark stock assessment be completed in five years. As indicated, the ecosystem is rapidly changing within the Northeast U.S. Continental Shelf, and these changes have implications for both stocks' conditions and statuses. While at record highs, the GOMGBK stock must be monitored closely to avoid declines under continued warming waters; a stock assessment in this time frame will provide information necessary to increase proactiveness toward stock and fishery resiliency. With the recruitment failure in SNE, a stock assessment in five years will also allow assessment of the stock's trajectory under a continually changing environment, and perhaps response to future management actions. While many advancements in lobster science have been made and described herein, additional aspects could be improved upon, and this benchmark assessment time frame would allow for the SAS to improve the assessment with new tools and information.

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8.2 Research Recommendations

FISHERY-DEPENDENT MONITORING

a. ***Port and Sea Sampling (High priority)***

Accurate and comparable landings data are the principal data needed to assess the impact of fishing on lobster populations. The quality of landings data has not been consistent spatially or temporally. Limited funding, and in some cases, elimination of sea sampling and port sampling programs will negatively affect the ability to characterize catch and conservation discards, limiting the ability of the model to accurately describe landings and stock conditions. It is imperative that funding for critical monitoring programs continues, particularly for offshore areas from which a large portion of current landings originate in SNE. The CFRF Lobster and Jonah crab Research Fleet has improved these data needs and will continue to be imperative in describing landings for future stock assessments. Programmatically, sea sampling should be increased in Long Island Sound (SA 611), and in the statistical areas in federal waters, particularly those fished by the LCMA 3 fleet, via a NMFS-implemented lobster-targeted sea sampling program. These fishery-dependent programs are essential for accurate lobster assessments and must have dedicated funding.

b. ***Commercial Data Reporting***

Spatial Resolution (High Priority)

Spatial resolution and compliance of reporting have made it a challenge to understand how commercial harvest has varied through time. These data are paramount in understanding how landings align between statistical area and LCMAs. While this remains to be a major data need for the stock assessment, progress is anticipated to be made with Addendum 26, which will improve spatial resolution by implementing 10-minute square resolution reporting, require reporting the number of vertical lines used, and require 100% of lobster fishers to report in the near future. Vessel tracking is still in the pilot program phase, but, if found feasible and cost effective, is recommended for federal vessels. Once in place, the new spatial data should be analyzed for comparison to current spatial understanding of harvest.

Lobster versus Jonah Crab Effort (High Priority)

The growing Jonah crab fishery in SNE continues to complicate how to differentiate directed lobster versus Jonah crab effort. This phenomenon complicates understanding which species are targeted in a given trip. Truesdale et al. (2019) has begun data collection for differentiating via semi-structured interviews with fishers, but more data must be collected from sea sampling trips and reported landings to better differentiate the two fisheries’ activities.

Bait Usage (Low Priority)

Shortage of Atlantic herring due to reduced herring recruitment and quotas has raised concerns on bait availability for the lobster fishery, particularly for the GOM. However, fishers across both stocks use a variety of baits based on availability and prices. Bait use information collected as part of sea sampling trips and trip reports would provide better guidance on what is currently being used and could be included in future economic analyses of the lobster industry.

c. *CPUE Indices (Low Priority*)

In SNE, lobsters appear to be shifting offshore and into deeper waters (Rheuban et al. 2017, Mazur et al. 2020, Tanaka et al. 2020); these regions have traditionally been minimally sampled, and existing surveys in the region may not fully be capturing this new redistribution in lobsters. This contraction or movement in and lack of survey overlap to the population is likely attributing to difficulties in modeling the population. CFRF ventless trap data should be explored to determine if a post-stratified CPUE index can be constructed to inform a metric of abundance trends in offshore waters.

<u>FISHERT-INDEPENDENT MONITORING</u>

a. *Ventless Trap Survey* (*High Priority*)

Calibration work to determine how catch in the ventless trap surveys relates to catch in the bottom trawl surveys remains an important and unaddressed topic of research. It is likely that at low densities, when trawl survey indices have dropped to near zero, ventless trap surveys will still catch lobsters due to the attractive nature of the gear and the ability to fish the gear over all habitat types. Conversely, it is possible that trawl surveys may be able to detect very high levels of lobster abundance, if trap saturation limits the capacity of the ventless traps. Ventless traps may be limited in their ability to differentiate between moderately high and extremely high abundance, and calibration with bottom trawl surveys may help to clarify how q might change with changes in lobster density. Currently, inference on these dynamics are limited to the estimated non-linear q values from the UMM, which for some surveys are sensitive and variable. A prospective starting place may be to examine the overlapping data between ventless trap and trawl catch rates in Long Island Sound (Dominion Nuclear Power Station) and Rhode Island state waters.

b. *Early Benthic Phase Lobsters (Medium Priority)*

To date, many indices for the lobster assessment have focused on spawning stock biomass, recruits, or young of the year. However, few annual abundance indices exist for early-benthic (≤ 40-50mm) and these trends have been largely unexamined by the SAS. Examination of available datasets and survey protocols (for consistency between surveys) should be undertaken, and if possible, such indices could be incorporated as model-free indicators in future assessments. These may better describe changes in lobster abundance in nursery habitats across a broader portion of their life cycle.

c. *NEAMAP Trawl Survey Protocols (High Priority)*

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The SAS recommends that the NEAMAP Trawl Survey sampling protocol be modified for all lobsters caught to be sorted by sex. If a subsample is necessary, subsamples be taken by sex for additional biological data (size, egg presence and stage, vnotch, etc.) This modification would align the biological sampling methodology with other trawl surveys used in the assessment, and perhaps allow the survey to not be collapsed by sex into survey slots.

REPRODUCTIVE BIOLOGY

a. Maturity (Medium Priority)

Recent work has demonstrated that size at maturity changes over time (Waller et al. 2019, Haarr et al 2018), which has direct implications for estimating spawning stock biomass and lobster growth rates. Extensive efforts made since the previous assessment have updated maturity data in statistical areas from which significant landings originate (see Appendix 1 and Appendix 2) resulting in more accurate spawning stock biomass estimates. Future maturity work should focus on additional statistical areas with large landings contributions. Exploration of non-invasive techniques to assess maturity are also desirable, allowing for more frequent and efficient updates to maturity estimates. Methods to allow for time-varying maturity in the assessment model should also be explored, to better capture the influence of a changing environment on lobster population dynamics. Finally, it is extremely important for the newly updated maturity data to be applied towards updating the growth matrix underlying the assessment model.

b. Mating Success (Medium Priority)

Depleted stock conditions in SNE and the female-skewed sex ratio observed in the GBK sub-stock raise questions about the mating and reproductive success in these systems. Low population abundance may cause a mate-finding Allee effect (Stephens et al. 1999, Gascoigne et al. 2009), and contributing to the dramatically reduced recruits per spawner relationship observed in SNE (Section 6.3.2). More research to characterize reproductive success (mating activity and subsequent larval production) under the current population and environmental conditions in SNE will be important to understanding the rebuilding potential of the stock. In the GBK sub-stock, there is limited information to describe the timing of events such as spawning, egg hatch, and molting; additional data from the CFRF fleet could improve understanding of reproductive cycles in this region. Further research incorporating the timing of these events and a characterization of the operational sex ratio during the molting/mating season should be initiated to increase understanding of reproductive dynamics in the GBK region. This will help to determine what role the GBK sub-stock plays in terms of source/sink dynamics of the overall GOMGBK stock, and whether the skewed sex ratios are negatively influencing reproductive output in the region.

AGE AND GROWTH

a. *Time Varying Growth (High Priority)*

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Growth of American lobster has been found to change through time (McMahan et al. 2016), yet the ability to incorporate this dynamic in the assessment model currently is unavailable. Accounting for interannual changes in the growth matrix, including those in increment, probability, and seasonality, is imperative for model convergence. This issue was faced in ASMFC (2015a) when an early molt occurred in 2012 in GOM, leading to discrepancies in observed landings and predicted abundance. Data suggests that changes in growth may also be occurring for the SNE stock, where alterations in molt probability and increment with size in recent years could be causing challenges for describing recruitment size composition and survey's size selectivity. Modification to the assessment model is needed to allow for time varying growth matrices to be used to reflect changing growth in the stocks.

b. *Expansion of Growth Matrices (High Priority)*

The UMM currently has lobsters recruit into the population between 53 and 77mm. However, many of the processes driving recruitment are not captured by the input or model abundances given they happen at sizes less than 53mm. Exploration of expanding the model size structure to smaller sizes could allow to better capture changes in recruitment for the population by incorporating < 53mm lobster abundances from the surveys currently used, as well as incorporating additional surveys that currently are not model inputs for the assessment, such as those from the young of year settlement surveys. Due to decreased recruitment in SNE and some areas in GOMGBK, available survey data should be evaluated to determine whether current data sources for small sizes are sufficient for expanding the size structure and growth matrices.

ENVIRONMENTAL INFLUENCE ON LOBSTER LIFE HISTORY PROCESSES

a. *Temperature-Molt Dynamics (High Priority)*

Sea temperatures have direct impacts on the molting dynamics of American lobster (Section 2.1). Growth is directly influenced by water temperatures, with evidence in SNE suggesting increased temperatures have resulted in increased molt frequency and decreased molt increments (DNC 2013). Interannually varying and long-term increases in temperature through time suggest the molting dynamics have also changed over the last several decades. Understanding how the timing for molting, molt increments, and probability by size vary with temperature for all stocks would allow for more accurate and realistic depictions of growth via updated annual growth matrices. The work of Groner et al. (2018) should be expanded by using the Millstone data to specifically analyze how molt frequency and increment has changed seasonally and interannually.

b. *Larval Ecology (High Priority)*

Recent work has highlighted the importance of coastal oceanography and *Calanus finmarchicus* on the early life history of American lobster, with implications for their settlement and future recruitment (Carloni et al. 2018). The importance of ocean temperature and secondary productivity have also been correlated to adult abundances (Mazur et al. 2020), and major

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changes through time for these variables and the GOMGBK stock seem to co-occur (Section 2.9.5.1.1). To date, many of these analyses are based on a larval dataset with small spatial coverage in a relatively shallow area and are correlative in nature. This warrants spatial expansion of larval surveys and further testing particularly in areas like the eastern GOM and GBK that lack any studies of this nature. Studies that explore greater spatial coverage of larval sampling and examine lobster larval diets, in situ development time in current conditions, larval interactions with well-mixed versus stratified water columns, and varying growth and mortality with temperature would allow for greater context on these variables' influence on recruitment.

c. *Deepwater Settlement (High Priority)*

Settlement and YOY trends from inshore sampling sites have continued to reflect poor conditions despite record abundance levels for older, larger lobsters in the GOMGBK stock, a trend that has continued since the last assessment five years ago. Following work by Goode et al. (2019) indicating settlement trends might not be as poor as the inshore sites reflect if deeper, newly suitable settlement habitat was sampled and accounted for, there is a need to determine settlement success in habitat not currently sampled and its contribution to overall stock productivity. Industry supported work in the eastern and western regions of the Maine coast show evidence of settlement, but research needs to explore the levels of detectability, impact of stratification, and interannual temperature effects on the indices. The CFRF fleet provides another potential platform to sample presence/absence of deep-water settlement, but specifically designed fishery-independent monitoring is needed to characterize trends through time. Additionally, it will be important to understand whether there are differences in growth and survival in these deeper habitats, particularly relative to the desire to expand the growth matrix into smaller size ranges for modeling purposes.

POPULATION DYNAMICS AND ASSESSMENT MODELING

a. *SNE Recruitment Failure (High Priority)*

Many variables are attributed to the decline in the SNE stock, such as warming waters, predation pressure increases, and disease prevalence. However, the direct cause of the precipitous declines in recruitment under less variable spawning stock biomass is largely unknown. Research designed to understand the causes driving recruitment failure is vital for any efforts toward rebuilding the SNE stock. In addition, being able to predict similar conditions in GOMGBK could allow management the opportunity to respond differently. Such research could address: egg production and mating success, larval survival and connectivity to the early benthic phase, benthic habitat changes in historical SNE nursery grounds, predator-prey dynamics, and disease impacts (both lethal and sublethal).

b. *Index Modeling (Moderate Priority)*

Further expand VAST work that currently integrates survey indices into sex-specific stock-wide indices (Hodgdon et al. In Press) to construct accompanying stock and sex-specific time series of size composition.

c. ***Supporting Models (Moderate Priority)***

For SNE, less data-intensive or data-limited models should be explored to compare recent trajectories of Reference Abundance and Exploitation to those produced by the UMM.

d. ***Modeling Program (High Priority)***

Other software programs, such as Template Model Builder, should be evaluated as a new platform to host the UMM and allow more flexible, efficient coding capabilities across SAS members.

STOCK CONNECTIVITY

a. Stock Structure Working Group (High Priority)

There are a couple of ongoing studies that the SAS is aware of, and presumably others, to inform a re-assessment of stock boundaries that were not ready in time for this assessment. The SAS recommends that a workshop on stock boundaries be convened prior to the initiation of the next assessment to review results of any new research and re-evaluate appropriate stock boundaries. Inclusion of Canadian researchers at this workshop would be beneficial to share data and knowledge on this shared resource. Several research topics relevant to evaluation of stock boundaries are listed below, but this list could be expanded upon.

b. ***Spatial Analyses of Fisheries-Independent Data (High Priority)***

NEFSC trawl survey data remains one of the richest data sources to understand abundance and distribution patterns through time for lobsters by size and sex. While preliminary data analyses have been conducted, formal analyses should be performed and described for the Management Board and/or scientific peer-review. Deeper investigations should also be conducted for the ME/NH Trawl Survey. The Ecosystem Monitoring (EcoMon) Program's larval lobster information should also be considered. Integrating the former into analyses with the NEFSC Trawl may provide greater insight into coastal-offshore movement patterns with temperature. While EcoMon sampling techniques and seasonality may not best describe lobster larvae abundance and phenology, efforts to investigate its use in stock definitions remain worthwhile.

c. ***Tagging Studies (Medium Priority)***

Ongoing tagging work to examine the movement of lobsters between GOM and GBK will be completed shortly and presented to the TC for incorporation into future discussions regarding stock boundaries. Additional tagging efforts that target specific areas, lobster demographics, and seasons that were not covered in this work would fill remaining gaps. Similar tagging studies in SNE would also be useful, as much of current understanding of lobster movement for this stock is based on information from decades before rapid warming.

d. ***Larval Transport (Medium Priority)***

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Transport modeling of lobster larvae has improved understanding in specific regions, such as inshore southern Massachusetts and coastal Maine-Massachusetts connectivity. However, there are several regions for which further research could greatly inform stock boundaries and connectivity. For example, determining whether larvae released in the offshore regions of GOM or GBK remain within that region or are transported to other stocks, especially to SNE locations, will identify the role offshore regions play in recruitment dynamics. Similar modeling exercises focusing on the fate of larvae released from offshore SNE can determine whether the offshore shift of the SNE stock is resulting in a larval sink, or whether there is a linkage to viable settlement habitat. Transport modeling work would benefit from a component that couples predicted destinations to an examination of habitat suitability for settlement success, and sampling to ground-truth results.

e. ***Genetics*** **(*Low Priority*)**

Additional genetics information would provide further insight on stock structure and on potential environmentally driven changes. For example, western Long Island Sound lobsters were genetically distinct from those in other areas of LIS (Crivello et al. 2005b), raising the possibility that this is the result of selective forces producing lobsters adapted to the stressful environment of WLIS. Additional work to test this hypothesis and to examine in detail what might promote survival in that habitat could clarify whether lobsters in SNE might be able to adapt to the new, warmer environment. Benestan et al (2016) similarly suggested future work should incorporate environmental variables to understand localized selective pressures and their influence on lobster population structure. Comparisons of lobsters from disparate areas, such as SNE and GBK canyons, GOM and Canadian deep waters, and the northern and southern portions of the SNE stock may shed additional light on connectivity and potential for localized adaptations. Work that links adult movements, ocean currents and larval dispersal, and genetic population structure should be explored in order to characterize source/sink dynamics and identify whether sub-populations exist that disproportionately influence recruitment.

NATURAL MORTALITY

a. ***Reevaluate Baseline Natural Mortality Rate (High Priority)***

Natural mortality has been estimated by a variety of methods such as life history approaches, cohort analysis and tagging. Estimates of M range from 0.02 to 0.35 (Fogarty and Idoine 1988, ASMFC 2000). Early stock assessments assumed M=0.1 (NEFSC 1992, 1993). Subsequent assessments utilized M=0.15 for assessment models and partitioned M into hardshell (0.10) and softshell (molting) (0.05) for egg per recruit reference points (NEFSC, 1966, ASMFC 2000). Besides the question regarding how well the current value used for M reflects the actual M experienced by the stocks, there are additional questions such as how has M changed through time, and how the interactive abiotic stressors that results from changing climate may exacerbate or mitigate mortality during all life stages. Further, while scientifically many acknowledge size varying mortality for lobsters, there is little data to support or quantify this and thus the assessment model currently uses the same mortality rate for all lobsters. Intensive hypothesis-driven sensitivity analyses should be conducted to evaluate the base mortality rate for both stocks by season and year. Canadian tagging data should be examined to determine how natural mortality rates derived from these data compare to the assumptions used currently in the model and sensitivity analyses. Exploration of additional time series representing natural mortality hypotheses (e.g. sea temperature, shell disease prevalence, predators) should be continued to either inform time-varying natural mortality or correlate to rates produced in sensitivity analyses.

b. *Tagging Studies (Medium Priority)*

A tagging study specifically designed to quantify natural mortality should be conducted for both stocks. Traditional tagging studies designed to document movement or growth often do not allow for generating sound estimates of natural mortality. A directed study on natural mortality would provide empirical data needed to understand total and size-specific rates.

c. *Predation Studies (High Priority)*

Lobsters are subject to a suite of predators, and the abundance of many of these predators have fluctuated substantially through time. As such, it is often suspected that a given predator’s role in lobster natural mortality has changed through time. Predation laboratory studies and gut content analyses would provide greater guidance on individual species’ roles in lobster natural mortality. With this information, predation-indices as a function of predator annual abundances and their contribution to stock-specific lobster mortality would be immensely valuable, particularly in SNE.

d. *Shell Disease (Medium Priority)*

Many studies have aimed at describing epizootic shell disease, including its pathology, environmental correlates (e.g. warm sea temperatures), and demographics. The relative difference in mortality rates for lobsters with and without shell disease has been examined (Hoenig et al. 2017), but the existing datasets have limitations relative to scaling mortality estimates up to regional or population-level estimates. The true impact of shell disease on the population remains uncertain. Studies designed specifically to generate robust estimates of mortality for diseased lobsters that can be scaled up to the stock are necessary to understand the direct effect of this disease on mortality. Additionally, more work is needed to understand the impact(s) of sublethal effects of shell disease and other diseases on vital population rates (growth, reproduction, etc.). Sensitivity analyses for the SNE model included using shell disease time series data to inform interannual changes in natural mortality (Section 6.4.2), but indices representing the totality of the stock would provide more sound inferences on disease’s contribution to natural mortality.

<u>MANAGEMENT AND ECONOMIC ANALYSES</u>

a. *Management Strategy Evaluation (High Priority)*

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Since the previous assessment, a projection tool was developed to assess how certain management actions may impact lobster populations. However, the projection tool lacks the ability to refit the model iteratively with new years' simulated data to best understand the feedback of a given suite of management measures. Developing a true management strategy evaluation tool that can iteratively project and refit the operating model would best inform future management discussions on rebuilding the SNE stock or providing resiliency for the GOM stock and fishery. Development of consensus statements by the Board with input from industry about management objectives will be critical to evaluating the results of any projection tool.

b. *Economic Reference Points (High Priority)*

The SAS developed new reference points using change point analyses to propose when management action should be taken for the different stocks recognizing there are different levels of productivity with changing environmental conditions. To trigger management action, previous target reference points for the GOMGBK, based on historical abundances prior to 2003, required a substantial population decline to occur and the downward trend to reach that level would likely be challenging to reverse in changing environmental conditions. Recognizing that the GOMGBK stock is currently in a high productivity regime and experiencing record high abundances that may not be sustainable, the SAS proposed the Abundance Limit level based on the medium productivity regime, but was concerned that significant adverse economic impacts would be experienced before the population reached that Abundance Limit. The SAS proposed a new reference point to address this issue based on the high productivity regime but did not incorporate economic information that should be used to inform this Fishery/Industry Target. Economic analyses considering landings, ex-vessel value, costs, associated economic multipliers, number of active participants, and other factors are imperative to truly discern how declines in the population would impact the GOMGBK industry. The SAS strongly recommends a thorough economics analysis be conducted by a panel of experts to more properly inform economic-based reference points, and ultimately provide resiliency to both the GOMGBK stock and fishery.

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10 TABLES

Table 1. A summary of management measures by LCMA, current as of June 2020.

Management Measure	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	OCC
Min Gauge Size	3 $^{1}/_{4}$”	3$^{3}/_{8}$”	3 $^{17/32}$ ”	3$^{3}/_{8}$”	3$^{3}/_{8}$”	3$^{3}/_{8}$”	3$^{3}/_{8}$”
Vent Rect.	1$^{15}/_{16}$ x 5$^{3}/_{4}$”	2 x 5$^{3}/_{4}$”	2 $^{1}/_{16}$ x 5$^{3}/_{4}$”	2 x 5$^{3}/_{4}$”	2 x 5$^{3}/_{4}$”	2 x 5$^{3}/_{4}$”	2 x 5$^{3}/_{4}$”
Vent Cir.	2 $^{7}/_{16}$”	2 $^{5}/_{8}$”	2 $^{11}/_{16}$”	2 $^{5}/_{8}$”	2 $^{5}/_{8}$”	2 $^{5}/_{8}$”	2 $^{5}/_{8}$”
V-notch requirement	Mandatory for all eggers	Mandatory for all legal size eggers	Mandatory for all eggers above 42°30’	Mandatory for all eggers in federal waters. No v-notching in state waters.	Mandatory for all eggers	None	None
V-Notch Definition[1] (possession)	Zero Tolerance	$^{1}/_{8}$” with or w/out setal hairs[1]	$^{1}/_{8}$” with or w/out setal hairs[1]	$^{1}/_{8}$” with or w/out setal hairs[1]	$^{1}/_{8}$” with or w/out setal hairs[1]	$^{1}/_{8}$” with or w/out setal hairs[1]	State Permitted fisherman in state waters $^{1}/_{4}$” without setal hairs Federal Permit holders $^{1}/_{8}$” with or w/out setal hairs[1]
Max. Gauge (male & female)	5”	5 ¼”	6 $^{3}/_{4}$”	5 ¼”	5 ¼”	5 ¼”	State Waters none Federal Waters 6 $^{3}/_{4}$”
Season Closure				April 30-May 31[2]	February 1-March 31[3]	Sept 8-Nov 28[4]	February 1-April 30

[1] A v-notched lobster is defined as any female lobster that bears a notch or indentation in the base of the flipper that is at least as deep as 1/8”, with or without setal hairs. It also means any female which is mutilated in a manner that could hide, obscure, or obliterate such a mark.

[2] Pots must be removed from the water by April 30 and un-baited lobster traps may be set one week prior to the season reopening.

[3] During the February 1 – March 31 closure, trap fishermen will have a two week period to remove lobster traps from the water and may set lobster traps one week prior to the end of the closed season.

[4] Two week gear removal and a 2 week grace period for gear removal at beginning of closure. No lobster traps may be baited more than 1 week prior to season reopening.

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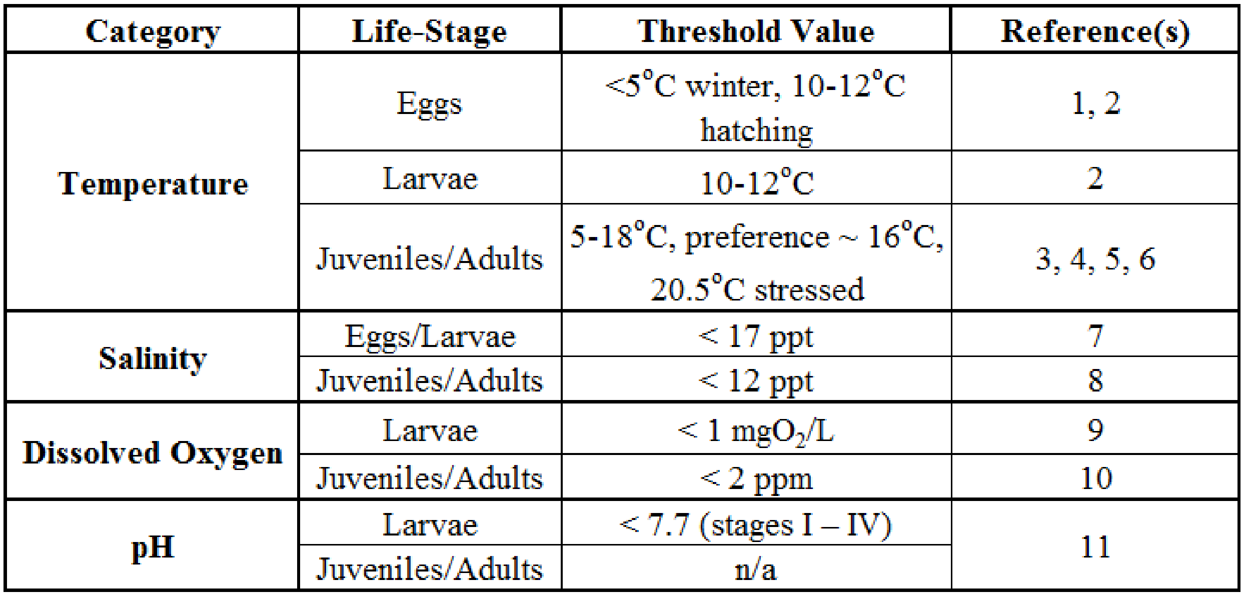
Table 2. A summary of key biological threshold values for *H. americanus*.



Category	Life-Stage	Threshold Value	Reference(s)
Temperature	Eggs	<5°C winter, 10-12°C hatching	1, 2
	Larvae	10-12°C	2
	Juveniles/Adults	5-18°C, preference ~ 16°C, 20.5°C stressed	3, 4, 5, 6
Salinity	Eggs/Larvae	< 17 ppt	7
	Juveniles/Adults	< 12 ppt	8
Dissolved Oxygen	Larvae	< 1 mgO_2/L	9
	Juveniles/Adults	< 2 ppm	10
pH	Larvae	< 7.7 (stages I – IV)	11
	Juveniles/Adults	n/a	

References: (1) Waddy and Aiken 1995; (2) MacKenzie 1988; (3) Reynolds and Casterlin 1979; (4) Crossin et al. 1998; (5) Dove et al. 2005; (6) Powers et al. 2004; (7) Charmantier et al. 2001; (8) Jury et al. 1994; (9) Ennis 1995; (10) Howell and Simpson 1994; (11) Keppel et al. 2012.

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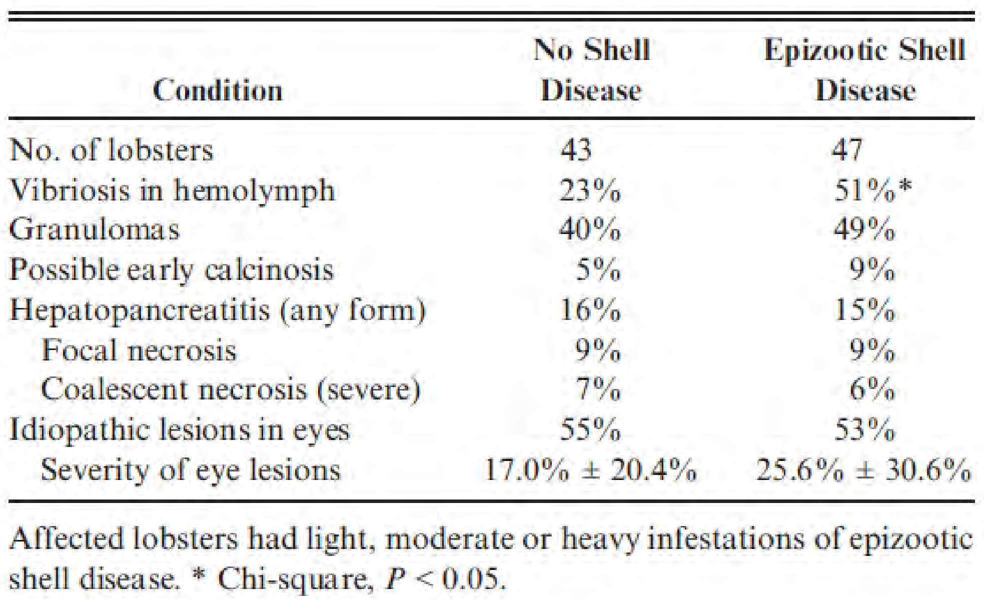
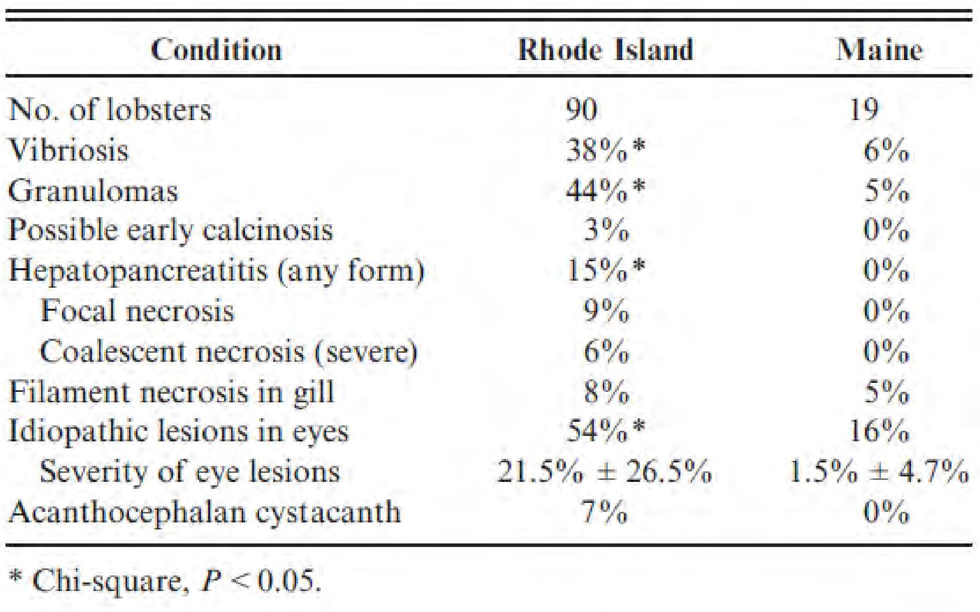
Table 3. Presence of idiopathic conditions in lobsters from Rhode Island with epizootic shell disease compared with those without the syndrome. Source: Shields et al 2012.



Condition	No Shell Disease	Epizootic Shell Disease
No. of lobsters	43	47
Vibriosis in hemolymph	23%	51%*
Granulomas	40%	49%
Possible early calcinosis	5%	9%
Hepatopancreatitis (any form)	16%	15%
Focal necrosis	9%	9%
Coalescent necrosis (severe)	7%	6%
Idiopathic lesions in eyes	55%	53%
Severity of eye lesions	17.0% ± 20.4%	25.6% ± 30.6%

Affected lobsters had light, moderate or heavy infestations of epizootic shell disease. * Chi-square, $P < 0.05$.

Table 4. Presence of idiopathic conditions in lobsters from Rhode Island and Maine. Source: Shields et al 2012



Condition	Rhode Island	Maine
No. of lobsters	90	19
Vibriosis	38%*	6%
Granulomas	44%*	5%
Possible early calcinosis	3%	0%
Hepatopancreatitis (any form)	15%*	0%
Focal necrosis	9%	0%
Coalescent necrosis (severe)	6%	0%
Filament necrosis in gill	8%	5%
Idiopathic lesions in eyes	54%*	16%
Severity of eye lesions	21.5% ± 26.5%	1.5% ± 4.7%
Acanthocephalan cystacanth	7%	0%

* Chi-square, $P < 0.05$.

Table 5. Annual days with average temperature ≥ 20° C recorded at Millstone Power Station (DNC 2018 and personal communication). Daily averages are computed from continuous 15-min readings taken at the intakes 1-2 m off bottom (4.6-7.6 m depth).

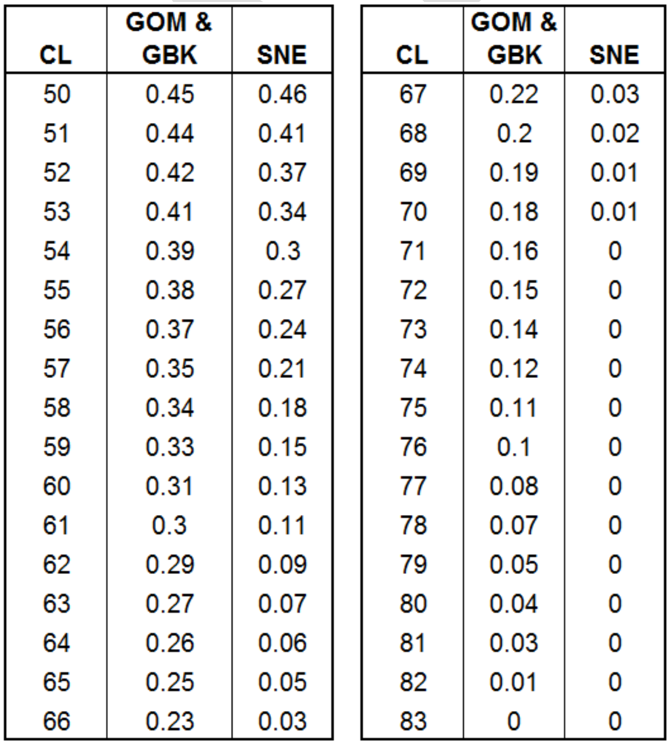
Year	Total Days in Year	# Days ≥20° C	Deviation from Avg Days≥20° C 1979-2018	Recruitment covariate weight factor (1+(dev from avg/avg))
1976	366	9		
1977	365	35		
1978	365	20		
1979	365	48	-7.45	0.87
1980	366	44	-11.45	0.79
1981	365	59	3.55	1.06
1982	365	42	-13.45	0.76
1983	365	32	-23.45	0.58
1984	366	35	-20.45	0.63
1985	365	52	-3.45	0.94
1986	365	35	-20.45	0.63
1987	365	33	-22.45	0.60
1988	366	17	-38.45	0.31
1989	365	42	-13.45	0.76
1990	365	47	-8.45	0.85
1991	365	54	-1.45	0.97
1992	366	14	-41.45	0.25
1993	365	50	-5.45	0.90
1994	365	44	-11.45	0.79
1995	365	60	4.55	1.08
1996	366	13	-42.45	0.23
1997	365	7	-48.45	0.13
1998	365	55	-0.45	0.99
1999	365	76	20.55	1.37
2000	366	71	15.55	1.28
2001	365	66	10.55	1.19
2002	365	76	20.55	1.37
2003	365	63	7.55	1.14
2004	366	57	1.55	1.03
2005	365	65	9.55	1.17
2006	365	69	13.55	1.24
2007	365	69	13.55	1.24
2008	366	73	17.55	1.32
2009	365	44	-11.45	0.79
2010	365	75	19.55	1.35
2011	365	63	7.55	1.14
2012	366	94	38.55	1.70
2013	365	77	21.55	1.39
2014	365	78	22.55	1.41
2015	365	90	34.55	1.62
2016	366	85	29.55	1.53
2017	365	53	-2.45	0.96
2018	365	91	35.55	1.64

Average 1979 - 2018	55.45		1.00

Table 6. Parameters for logistic molt probability curves for American lobster. GBK parameters are from Fogarty and Idoine (1988). Parameters for GOM and SNE are from ASMFC (2009). Parameters for the GOM&GBK area are from fitting logistic curves to average curves for GOM and GBK using average numbers caught per tow during NMFS spring and fall bottom trawl surveys in the two areas as weights for each length group.

Stock Area	α	β
GBK females	-6.867	0.058
GBK males	-6.886	0.052
GOM females	-8.081	0.07654
GOM&GBK females	-6.571	0.05901
GOM&GBK males	-6.834	0.06046
SNE female	-9.720	0.1032

Table 7. Assumed double molting probabilities for lobsters used in calculating growth matrices for the University of Maine stock assessment model.



CL	GOM & GBK	SNE
50	0.45	0.46
51	0.44	0.41
52	0.42	0.37
53	0.41	0.34
54	0.39	0.3
55	0.38	0.27
56	0.37	0.24
57	0.35	0.21
58	0.34	0.18
59	0.33	0.15
60	0.31	0.13
61	0.3	0.11
62	0.29	0.09
63	0.27	0.07
64	0.26	0.06
65	0.25	0.05
66	0.23	0.03
67	0.22	0.03
68	0.2	0.02
69	0.19	0.01
70	0.18	0.01
71	0.16	0
72	0.15	0
73	0.14	0
74	0.12	0
75	0.11	0
76	0.1	0
77	0.08	0
78	0.07	0
79	0.05	0
80	0.04	0
81	0.03	0
82	0.01	0
83	0	0

Table 8. Sample size, pre-molt size range and mean molt increment model parameters used to estimate lobster growth for the GOM, GBK and combined GOM&GBK stock areas. Used in this assessment and in ASMFC (2006; 2009).

Sex	N	Size range	Inflection	Asymptotic increment	Residual standard deviation	Intercept	Slope
GOM&GBK							
Female	554	50-151	76	13	2.1	-3.90	0.22
Male	438	50-171	86	15	2.5	-4.51	0.23
SNE							
Female	1255	50-102	na	9	2.3	na	na
Male	955	51-98	na	11	2.3	na	na

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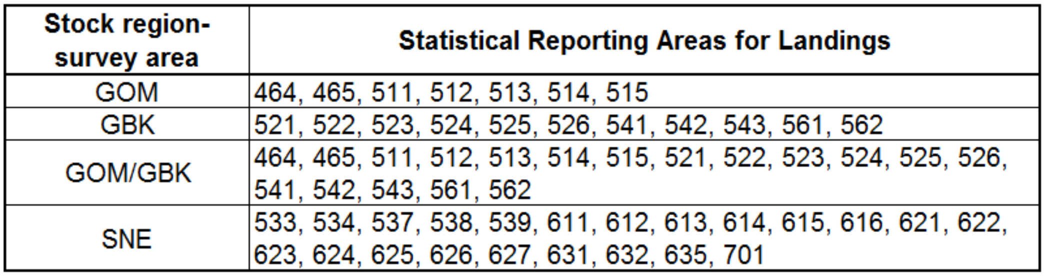
Table 9. Assignment of surveys to stocks used in stock indicators and modeling.

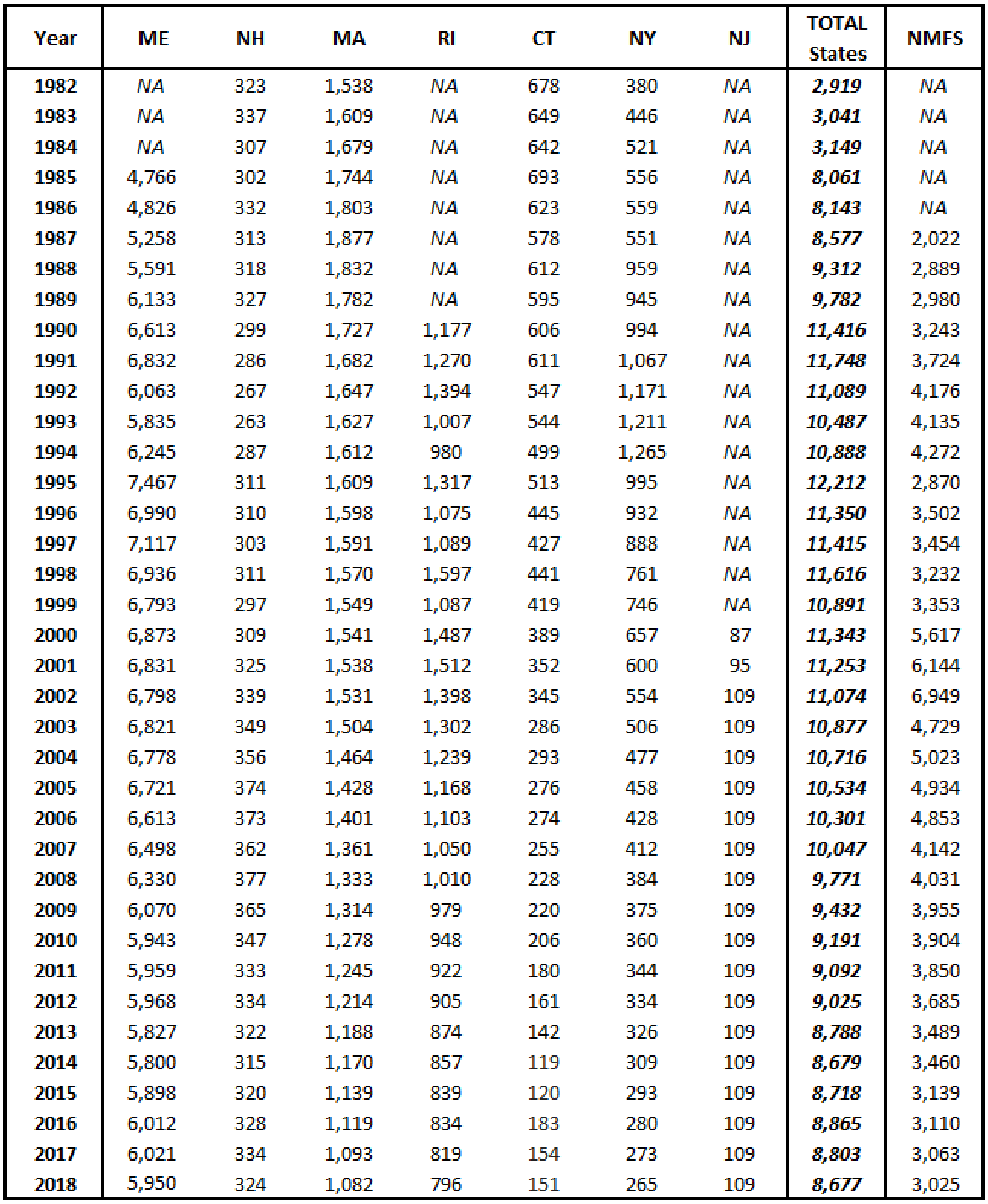
Stock	Survey	Strata
GOM	NEFSC - Spring, Fall	Strata 01260-01300, 01340, 01351, 01360-01400, 03590-03610, 03640-03660
	ME/NH - Spring, Fall	Strata 1-4
	MA - Spring, Fall	Strata 25-29, 31-36
	Ventless Trap (ME, NH, MA) - Summer	ME 0-60m, NH 0-60m, MA 0-60m
GBK	NEFSC - Spring, Fall	Strata 01090-01120 (partial for each), 01130-01250, 03520 (partial), 03550
GOMGBK	NEFSC - Spring, Fall	Strata 01090-01120 (partial for each), 01130-01300, 01340, 01351, 01360-01400, 03590-03610, 03640-03660, 03520 (partial), 03550
	ME/NH - Spring, Fall	Strata 1-4
	MA - Spring, Fall	Strata 25-29, 31-36
	Ventless Trap (ME, NH, MA) - Summer	ME 0-60m, NH 0-60m, MA 0.60m
SNE	NEFSC - Spring, Fall	Strata 01010-01080, 01090-01250 (partial for each), 01610-01760, 0320-03440 offshore, 03450, 03460, 03480, 03520 (partial)
	NEAMAP - Spring, Fall	Strata 1-7, BIS, and RIS
	MA - Spring	Strata 11-16
	RI - Spring, Fall	Strata 1-11
	CT - Spring, Fall	See CTDEP (2004) p. 63 and Fig 2.1
	NJ - Spring	Strata 1-15
	Ventless Trap (MA, RI) - Summer	MA 0-40m, RI 0-40m

Table 10. Assignment of statistical areas for landings data to stock regions used in modeling.



Stock region-survey area	Statistical Reporting Areas for Landings
GOM	464, 465, 511, 512, 513, 514, 515
GBK	521, 522, 523, 524, 525, 526, 541, 542, 543, 561, 562
GOM/GBK	464, 465, 511, 512, 513, 514, 515, 521, 522, 523, 524, 525, 526, 541, 542, 543, 561, 562
SNE	533, 534, 537, 538, 539, 611, 612, 613, 614, 615, 616, 621, 622, 623, 624, 625, 626, 627, 631, 632, 635, 701

Table 11. The number of commercial lobster licenses issued by each state to fish within state waters, and number of Federal licenses issued by NMFS. Totals represent the total of all state licenses. Note that numbers from each state may include vessels that also have a Federal lobster license. NA indicates data were not available.



Year	ME	NH	MA	RI	CT	NY	NJ	TOTAL States	NMFS
1982	*NA*	323	1,538	*NA*	678	380	*NA*	***2,919***	*NA*
1983	*NA*	337	1,609	*NA*	649	446	*NA*	***3,041***	*NA*
1984	*NA*	307	1,679	*NA*	642	521	*NA*	***3,149***	*NA*
1985	4,766	302	1,744	*NA*	693	556	*NA*	***8,061***	*NA*
1986	4,826	332	1,803	*NA*	623	559	*NA*	***8,143***	*NA*
1987	5,258	313	1,877	*NA*	578	551	*NA*	***8,577***	2,022
1988	5,591	318	1,832	*NA*	612	959	*NA*	***9,312***	2,889
1989	6,133	327	1,782	*NA*	595	945	*NA*	***9,782***	2,980
1990	6,613	299	1,727	1,177	606	994	*NA*	***11,416***	3,243
1991	6,832	286	1,682	1,270	611	1,067	*NA*	***11,748***	3,724
1992	6,063	267	1,647	1,394	547	1,171	*NA*	***11,089***	4,176
1993	5,835	263	1,627	1,007	544	1,211	*NA*	***10,487***	4,135
1994	6,245	287	1,612	980	499	1,265	*NA*	***10,888***	4,272
1995	7,467	311	1,609	1,317	513	995	*NA*	***12,212***	2,870
1996	6,990	310	1,598	1,075	445	932	*NA*	***11,350***	3,502
1997	7,117	303	1,591	1,089	427	888	*NA*	***11,415***	3,454
1998	6,936	311	1,570	1,597	441	761	*NA*	***11,616***	3,232
1999	6,793	297	1,549	1,087	419	746	*NA*	***10,891***	3,353
2000	6,873	309	1,541	1,487	389	657	87	***11,343***	5,617
2001	6,831	325	1,538	1,512	352	600	95	***11,253***	6,144
2002	6,798	339	1,531	1,398	345	554	109	***11,074***	6,949
2003	6,821	349	1,504	1,302	286	506	109	***10,877***	4,729
2004	6,778	356	1,464	1,239	293	477	109	***10,716***	5,023
2005	6,721	374	1,428	1,168	276	458	109	***10,534***	4,934
2006	6,613	373	1,401	1,103	274	428	109	***10,301***	4,853
2007	6,498	362	1,361	1,050	255	412	109	***10,047***	4,142
2008	6,330	377	1,333	1,010	228	384	109	***9,771***	4,031
2009	6,070	365	1,314	979	220	375	109	***9,432***	3,955
2010	5,943	347	1,278	948	206	360	109	***9,191***	3,904
2011	5,959	333	1,245	922	180	344	109	***9,092***	3,850
2012	5,968	334	1,214	905	161	334	109	***9,025***	3,685
2013	5,827	322	1,188	874	142	326	109	***8,788***	3,489
2014	5,800	315	1,170	857	119	309	109	***8,679***	3,460
2015	5,898	320	1,139	839	120	293	109	***8,718***	3,139
2016	6,012	328	1,119	834	183	280	109	***8,865***	3,110
2017	6,021	334	1,093	819	154	273	109	***8,803***	3,063
2018	5,950	324	1,082	796	151	265	109	***8,677***	3,025

Table 12. Gulf of Maine landings (metric tons) from ME, NH, and MA, and the total from these three states. ** Total does not include confidential data from other states, which are not shown here.

	ME	NH	MA	TOTAL**
1982	10,310	366	3,992	14,669
1983	9,836	594	4,638	15,069
1984	8,866	712	4,219	13,797
1985	9,129	539	4,890	14,558
1986	8,935	427	4,454	13,816
1987	8,957	570	4,425	13,952
1988	9,861	508	4,328	14,696
1989	10,600	649	5,459	16,708
1990	12,732	752	5,756	19,240
1991	13,965	817	5,417	20,200
1992	12,170	694	4,870	17,734
1993	13,574	673	4,551	18,799
1994	17,667	596	5,400	23,663
1995	16,877	710	5,308	22,896
1996	16,367	628	5,092	22,088
1997	21,329	544	4,715	26,589
1998	21,336	460	3,932	25,727
1999	24,265	525	5,110	29,900
2000	25,923	658	5,144	31,725
2001	22,053	780	3,673	26,506
2002	28,860	781	4,110	33,751
2003	24,934	682	3,467	29,084
2004	32,466	968	3,558	36,991
2005	31,175	622	3,189	34,987
2006	32,961	680	3,553	37,194
2007	29,024	725	3,267	33,016
2008	31,711	831	3,656	36,198
2009	36,797	1,049	4,052	41,899
2010	43,654	1,225	4,153	49,033
2011	47,606	1,381	4,458	53,445
2012	57,815	1,559	4,772	64,146
2013	57,972	1,211	5,098	64,281
2014	56,393	1,580	5,144	63,118
2015	55,639	1,684	5,652	62,975
2016	60,154	1,986	6,251	68,391
2017	50,759	1,597	5,479	57,835
2018	54,868	1,857	5,684	62,408

1982-2013 mean	23,429	747	4,460	28,636
2014-2018 mean	55,563	1,741	5,642	62,945
% change	137	133	27	120

Table 13. **The number of traps reported fished (NH & MA) or the number of trap tags issued (ME estimated traps 1982-1996 and trap tags sold 1996-2018) in the GOM stock. *NA* = data not available.**

	ME	NH	MA
1982	2,143,000	*NA*	247,415
1983	2,340,000	*NA*	259,642
1984	2,175,000	*NA*	275,165
1985	1,766,000	*NA*	313,758
1986	1,595,000	*NA*	331,713
1987	1,909,000	*NA*	356,169
1988	2,053,000	*NA*	356,689
1989	2,001,000	*NA*	351,584
1990	2,130,000	*NA*	378,703
1991	2,015,000	*NA*	399,010
1992	2,012,000	*NA*	388,415
1993	1,806,000	*NA*	370,641
1994	2,785,000	*NA*	373,641
1995	2,408,000	*NA*	377,305
1996	2,450,926	*NA*	389,492
1997	2,588,955	*NA*	383,506
1998	2,837,270	*NA*	389,933
1999	3,050,598	*NA*	379,970
2000	2,775,582	*NA*	384,606
2001	2,966,143	*NA*	376,587
2002	3,091,555	*NA*	393,879
2003	3,207,012	*NA*	382,655
2004	3,236,925	67,895	358,537
2005	3,286,272	72,880	344,029
2006	3,293,028	73,127	341,931
2007	3,274,512	72,089	338,314
2008	3,186,575	70,840	323,970
2009	3,106,428	70,647	310,449
2010	3,030,989	71,415	316,669
2011	2,994,771	70,783	309,620
2012	2,986,200	73,516	300,552
2013	2,946,494	70,089	286,189
2014	2,924,623	65,694	282,803
2015	2,937,032	66,851	291,491
2016	2,873,796	69,344	297,303
2017	2,883,271	70,211	315,538
2018	2,849,783	67,663	304,643

Table 14. The number of trips that landed lobsters by state in the Gulf of Maine. *NA* = data not available.

	ME	NH	MA
2000	*NA*	*NA*	*NA*
2001	*NA*	*NA*	*NA*
2002	*NA*	*NA*	*NA*
2003	*NA*	*NA*	*NA*
2004	*NA*	*NA*	*NA*
2005	*NA*	*NA*	*NA*
2006	*NA*	*NA*	*NA*
2007	*NA*	12,184	*NA*
2008	269,558	11,175	*NA*
2009	265,720	11,256	*NA*
2010	280,005	10,752	43,267
2011	272,974	9,226	42,951
2012	281,108	9,533	43,231
2013	283,908	9,420	41,061
2014	266,395	9,482	39,732
2015	270,324	9,505	41,722
2016	293,919	10,310	43,028
2017	276,754	9,495	40,746
2018	264,825	8,901	38,482

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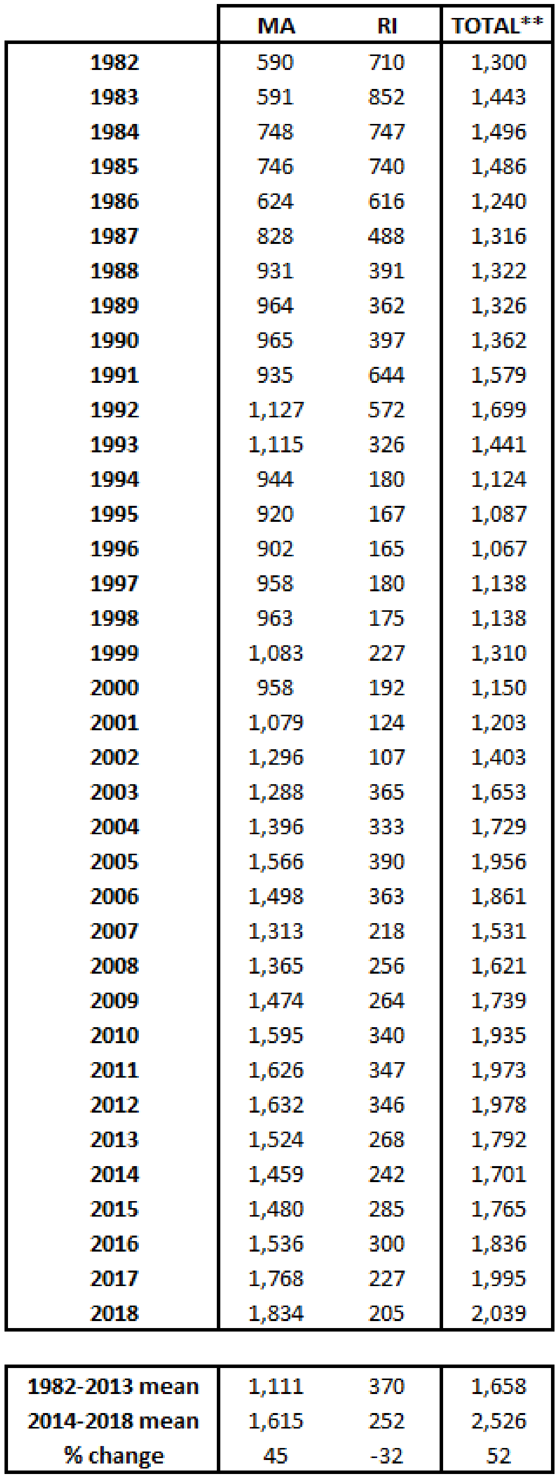
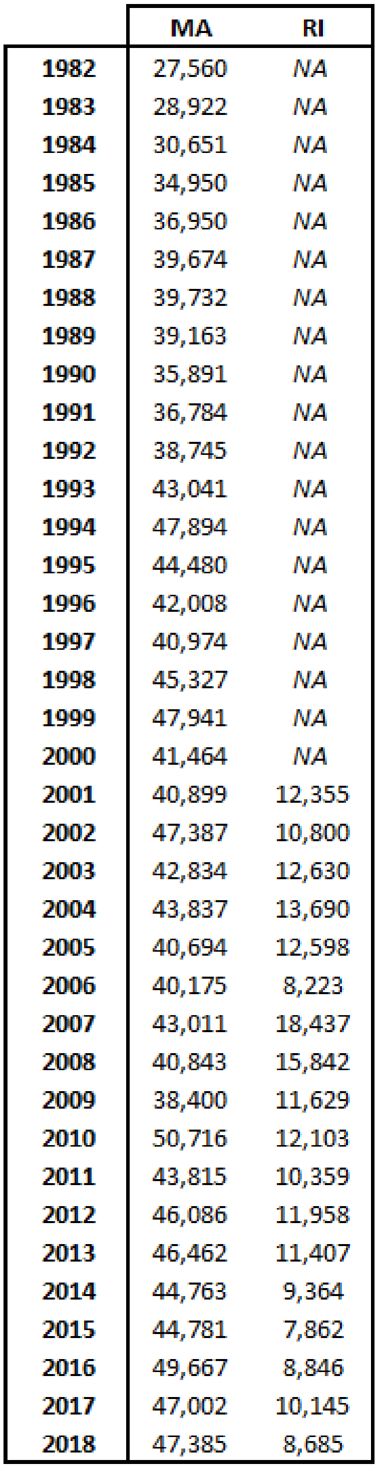
Table 15. Georges Bank landings (metric tons) from MA and RI and the total from these two states. ** Total does not include confidential data from other states, which are not shown here.



	MA	RI	TOTAL**
1982	590	710	1,300
1983	591	852	1,443
1984	748	747	1,496
1985	746	740	1,486
1986	624	616	1,240
1987	828	488	1,316
1988	931	391	1,322
1989	964	362	1,326
1990	965	397	1,362
1991	935	644	1,579
1992	1,127	572	1,699
1993	1,115	326	1,441
1994	944	180	1,124
1995	920	167	1,087
1996	902	165	1,067
1997	958	180	1,138
1998	963	175	1,138
1999	1,083	227	1,310
2000	958	192	1,150
2001	1,079	124	1,203
2002	1,296	107	1,403
2003	1,288	365	1,653
2004	1,396	333	1,729
2005	1,566	390	1,956
2006	1,498	363	1,861
2007	1,313	218	1,531
2008	1,365	256	1,621
2009	1,474	264	1,739
2010	1,595	340	1,935
2011	1,626	347	1,973
2012	1,632	346	1,978
2013	1,524	268	1,792
2014	1,459	242	1,701
2015	1,480	285	1,765
2016	1,536	300	1,836
2017	1,768	227	1,995
2018	1,834	205	2,039

1982-2013 mean	1,111	370	1,658
2014-2018 mean	1,615	252	2,526
% change	45	-32	52

Table 16. The number of traps reported fished in the Georges Bank stock from MA and RI. Data from RI were not available (NA) prior to 2001.



	MA	RI
1982	27,560	*NA*
1983	28,922	*NA*
1984	30,651	*NA*
1985	34,950	*NA*
1986	36,950	*NA*
1987	39,674	*NA*
1988	39,732	*NA*
1989	39,163	*NA*
1990	35,891	*NA*
1991	36,784	*NA*
1992	38,745	*NA*
1993	43,041	*NA*
1994	47,894	*NA*
1995	44,480	*NA*
1996	42,008	*NA*
1997	40,974	*NA*
1998	45,327	*NA*
1999	47,941	*NA*
2000	41,464	*NA*
2001	40,899	12,355
2002	47,387	10,800
2003	42,834	12,630
2004	43,837	13,690
2005	40,694	12,598
2006	40,175	8,223
2007	43,011	18,437
2008	40,843	15,842
2009	38,400	11,629
2010	50,716	12,103
2011	43,815	10,359
2012	46,086	11,958
2013	46,462	11,407
2014	44,763	9,364
2015	44,781	7,862
2016	49,667	8,846
2017	47,002	10,145
2018	47,385	8,685

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Table 17. The number of trips that landed lobsters by state for Georges Bank. *NA* = data not available.

	MA	RI
2000	*NA*	*NA*
2001	*NA*	*NA*
2002	*NA*	*NA*
2003	*NA*	*NA*
2004	*NA*	*NA*
2005	*NA*	*NA*
2006	*NA*	*NA*
2007	*NA*	347
2008	*NA*	233
2009	*NA*	216
2010	3,189	209
2011	3,156	219
2012	3,116	189
2013	3,169	177
2014	3,172	119
2015	2,969	117
2016	2,686	112
2017	2,652	137
2018	2,681	99

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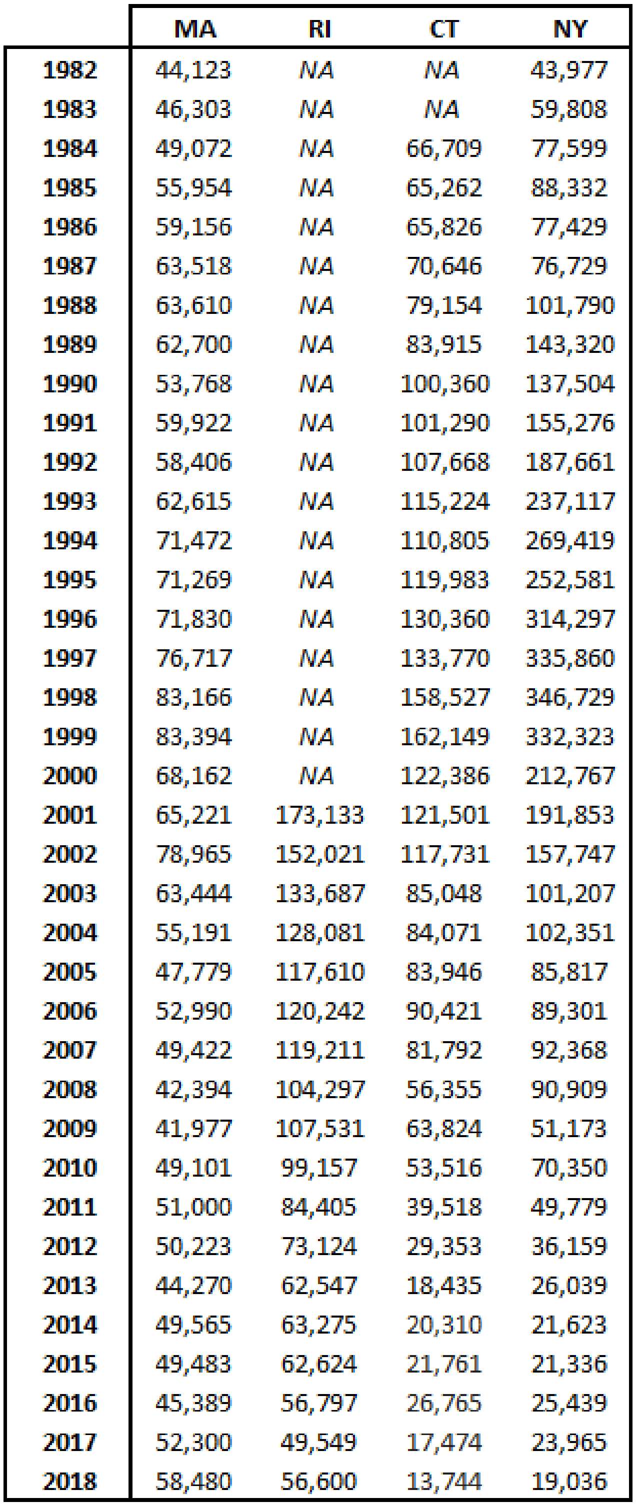
Table 18. Southern New England landings (metric tons) by state and the total from these states. ** Total does not include confidential data from other states, which are not shown here.

	MA	RI	CT	NY	NJ south	TOTAL**
1982	527	788	399	508	457	2,680
1983	608	1,468	750	548	414	3,788
1984	678	1,638	815	593	530	4,254
1985	579	1,592	626	563	600	3,960
1986	590	1,955	569	643	627	4,383
1987	578	1,924	713	520	722	4,457
1988	628	1,768	872	713	771	4,752
1989	674	2,263	942	1,064	997	5,940
1990	795	2,895	1,200	1,549	1,066	7,506
1991	905	2,721	1,213	1,419	799	7,056
1992	792	2,496	1,149	1,203	573	6,213
1993	843	2,499	987	1,210	445	5,984
1994	994	2,757	974	1,794	271	6,790
1995	985	2,553	1,153	3,018	301	8,009
1996	952	2,521	1,310	4,268	313	9,363
1997	1,136	2,760	1,572	4,027	406	9,902
1998	1,078	2,674	1,684	3,582	338	9,356
1999	1,007	3,473	1,177	2,927	447	9,031
2000	697	2,941	629	1,308	456	6,031
2001	681	1,896	600	931	324	4,431
2002	689	1,633	482	653	243	3,700
2003	380	1,244	303	429	191	2,548
2004	342	1,021	290	531	211	2,395
2005	366	1,018	322	556	213	2,475
2006	423	1,256	358	590	270	2,898
2007	358	780	247	407	363	2,155
2008	341	951	189	320	363	2,165
2009	403	947	186	331	388	2,255
2010	346	913	196	368	366	2,189
2011	249	811	89	156	341	1,645
2012	305	772	112	125	450	1,763
2013	315	665	58	112	334	1,484
2014	332	810	64	101	295	1,603
2015	355	705	93	67	248	1,468
2016	397	661	115	99	205	1,477
2017	345	595	59	69	217	1,285
2018	358	575	37	56	217	1,243

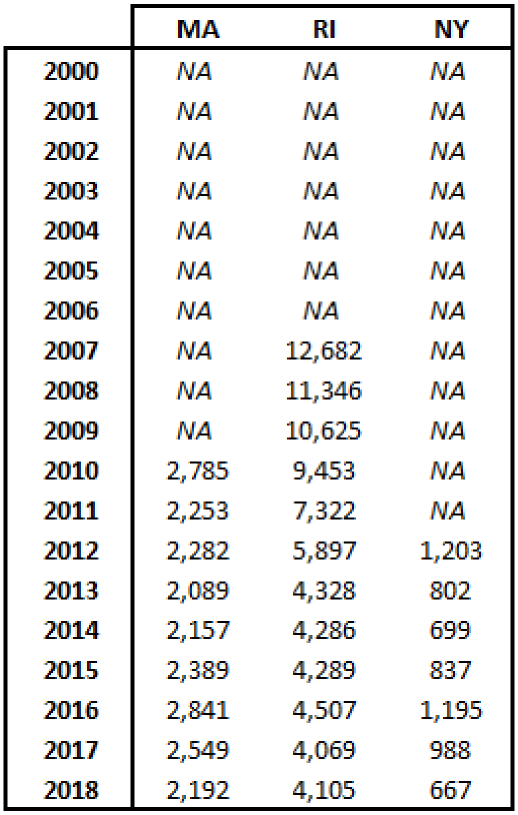
1982-2013 mean	595	1,647	609	1,010	426	4,287
2014-2018 mean	357	669	74	78	236	1,415
% change	-40	-59	-88	-92	-45	-67

Table 19. The number of traps reported fished in the Southern New England stock. Traps data for RI prior to 2001, and for CT prior to 1984 were not available (NA).



	MA	RI	CT	NY
1982	44,123	*NA*	*NA*	43,977
1983	46,303	*NA*	*NA*	59,808
1984	49,072	*NA*	66,709	77,599
1985	55,954	*NA*	65,262	88,332
1986	59,156	*NA*	65,826	77,429
1987	63,518	*NA*	70,646	76,729
1988	63,610	*NA*	79,154	101,790
1989	62,700	*NA*	83,915	143,320
1990	53,768	*NA*	100,360	137,504
1991	59,922	*NA*	101,290	155,276
1992	58,406	*NA*	107,668	187,661
1993	62,615	*NA*	115,224	237,117
1994	71,472	*NA*	110,805	269,419
1995	71,269	*NA*	119,983	252,581
1996	71,830	*NA*	130,360	314,297
1997	76,717	*NA*	133,770	335,860
1998	83,166	*NA*	158,527	346,729
1999	83,394	*NA*	162,149	332,323
2000	68,162	*NA*	122,386	212,767
2001	65,221	173,133	121,501	191,853
2002	78,965	152,021	117,731	157,747
2003	63,444	133,687	85,048	101,207
2004	55,191	128,081	84,071	102,351
2005	47,779	117,610	83,946	85,817
2006	52,990	120,242	90,421	89,301
2007	49,422	119,211	81,792	92,368
2008	42,394	104,297	56,355	90,909
2009	41,977	107,531	63,824	51,173
2010	49,101	99,157	53,516	70,350
2011	51,000	84,405	39,518	49,779
2012	50,223	73,124	29,353	36,159
2013	44,270	62,547	18,435	26,039
2014	49,565	63,275	20,310	21,623
2015	49,483	62,624	21,761	21,336
2016	45,389	56,797	26,765	25,439
2017	52,300	49,549	17,474	23,965
2018	58,480	56,600	13,744	19,036

Table 20. The number of trips that landed lobsters in Southern New England. *NA* = data not available.



	MA	RI	NY
2000	*NA*	*NA*	*NA*
2001	*NA*	*NA*	*NA*
2002	*NA*	*NA*	*NA*
2003	*NA*	*NA*	*NA*
2004	*NA*	*NA*	*NA*
2005	*NA*	*NA*	*NA*
2006	*NA*	*NA*	*NA*
2007	*NA*	12,682	*NA*
2008	*NA*	11,346	*NA*
2009	*NA*	10,625	*NA*
2010	2,785	9,453	*NA*
2011	2,253	7,322	*NA*
2012	2,282	5,897	1,203
2013	2,089	4,328	802
2014	2,157	4,286	699
2015	2,389	4,289	837
2016	2,841	4,507	1,195
2017	2,549	4,069	988
2018	2,192	4,105	667

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Table 21. Discard estimates and CVs by stock for the otter trawl fishery.

Otter Trawl							
	SNE		GBK		GOM		Total
Year	Discard (mt)	CV	Discard (mt)	CV	Discard (mt)	CV	Discards (mt)
1989	150.7	0.38	39.1	0.31	39.2	0.45	229.0
1990	68.8	0.60	129.7	0.55	192.2	0.32	390.6
1991	462.3	0.27	102.4	0.41	202.7	0.26	767.3
1992	530.3	0.62	142.0	0.52	109.8	0.32	782.1
1993	250.3	0.39	65.2	0.34	41.3	0.49	356.9
1994	239.4	0.45	60.2	0.20	24.0	0.91	323.6
1995	102.7	0.34	152.8	0.32	176.0	0.38	431.5
1996	107.9	0.30	90.0	1.26	220.9	0.20	418.9
1997	81.3	0.81	105.0	0.37	65.4	2.14	251.7
1998	48.2	0.89	235.8	0.77	240.6	1.73	524.7
1999	20.0	0.46	253.3	0.56	166.4	0.28	439.7
2000	112.9	3.55	160.0	0.23	170.1	0.28	443.0
2001	16.6	0.48	297.3	0.22	80.8	0.20	394.7
2002	61.0	0.98	261.1	0.24	167.3	0.12	489.4
2003	5.7	1.02	270.0	0.16	210.4	0.16	486.1
2004	70.8	0.32	297.2	0.07	296.3	0.11	664.3
2005	84.2	0.16	293.7	0.05	203.1	0.09	580.9
2006	32.0	0.87	278.7	0.09	151.8	0.17	462.5
2007	34.4	0.27	268.3	0.07	73.2	0.13	375.8
2008	81.6	0.35	275.1	0.06	62.5	0.14	419.2
2009	76.9	0.18	332.0	0.08	99.0	0.09	507.9
2010	61.7	0.28	317.6	0.07	150.3	0.07	529.5
2011	87.4	0.43	427.3	0.05	206.2	0.04	720.9
2012	41.9	0.24	495.8	0.06	299.2	0.05	836.9
2013	36.9	0.21	481.0	0.08	201.4	0.07	719.3
2014	27.1	0.15	485.5	0.12	177.0	0.06	689.6
2015	34.8	0.26	353.7	0.12	161.6	0.10	550.1
2016	41.5	0.29	287.5	0.12	194.9	0.13	523.9
2017	34.9	0.26	210.6	0.16	241.5	0.11	487.0
2018	18.1	0.16	181.7	0.17	233.4	0.10	433.3
2019	15.5	0.11	237.8	0.12	241.1	0.07	494.3

Table 22. Discard estimates and CVs by stock for the sea scallop dredge fishery.

Scallop Dredge							
	SNE		GBK		GOM		Total
Year	Discard (mt)	CV	Discard (mt)	CV	Discard (mt)	CV	Discards (mt)
1989	0.0	-	0.0	-	0.0	-	0.0
1990	0.0	-	0.0	-	0.0	-	0.0
1991	10.7	-	78.0	-	0.0	-	88.6
1992	138.7	0.95	23.6	1.55	0.6	-	162.9
1993	18.6	0.71	24.9	0.32	0.0	-	43.4
1994	4.5	0.32	6.1	2.09	13.8	-	24.4
1995	7.2	0.35	17.4	0.86	11.9	-	36.6
1996	9.6	0.26	8.6	0.41	3.4	0.80	21.6
1997	6.4	0.37	20.6	0.79	0.9	-	27.9
1998	6.5	1.06	42.4	0.53	1.7	-	50.5
1999	3.9	0.38	44.4	0.19	0.0	-	48.3
2000	3.9	0.42	10.8	0.24	0.0	-	14.7
2001	2.6	0.23	1.7	0.36	0.0	-	4.3
2002	4.2	0.19	14.8	0.27	0.0	-	19.1
2003	5.8	0.24	37.4	1.00	0.0	-	43.1
2004	2.3	0.13	5.6	0.28	0.7	0.87	8.7
2005	3.2	0.23	15.7	0.21	0.4	0.59	19.3
2006	4.4	0.55	28.9	0.16	0.0	-	33.2
2007	2.1	0.35	34.9	0.17	0.2	-	37.2
2008	1.1	0.23	20.3	0.26	5.5	-	26.9
2009	1.6	0.23	22.6	0.20	3.5	-	27.6
2010	3.0	0.17	4.1	0.23	0.0	-	7.1
2011	3.3	0.24	32.1	0.29	67.8	-	103.2
2012	2.5	0.17	69.5	0.17	0.0	-	72.0
2013	3.4	0.54	39.4	0.14	2.5	0.47	45.3
2014	2.6	0.16	30.6	0.16	5.5	0.34	38.6
2015	1.3	0.23	12.3	0.20	8.4	0.34	22.0
2016	1.8	0.17	15.3	0.21	3.8	1.05	20.9
2017	1.3	0.19	30.8	0.16	0.4	1.40	32.5
2018	0.9	0.23	25.1	0.17	2.6	1.04	28.6
2019	2.0	0.28	27.6	0.20	20.6	0.97	50.3

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Table 23. Discard estimates and CVs by stock for the sink gillnet fishery.

	Sink Gillnet						
	SNE		GBK		GOM		Total Discards (mt)
Year	Discard (mt)	CV	Discard (mt)	CV	Discard (mt)	CV	
1989	0.0	-	0.6	1.82	42.7	0.30	43.4
1990	0.0	-	0.6	1.42	107.9	0.37	108.4
1991	6.4	-	1.4	0.26	50.2	0.13	58.0
1992	2.1	0.91	0.8	0.40	58.2	0.09	61.0
1993	6.8	0.35	0.7	0.78	77.6	0.13	85.1
1994	0.4	0.30	1.0	1.29	43.6	1.03	44.9
1995	1.7	0.52	4.1	0.63	96.9	0.34	102.7
1996	2.1	0.29	5.4	0.48	114.6	0.89	122.2
1997	4.9	0.28	5.4	0.43	96.9	0.43	107.2
1998	4.7	0.29	2.0	0.47	52.0	0.33	58.7
1999	3.9	0.50	4.0	0.72	28.8	0.38	36.6
2000	1.1	0.74	8.4	0.28	131.5	0.27	141.0
2001	0.3	0.66	18.7	0.44	95.1	0.24	114.1
2002	8.3	0.43	26.4	0.45	60.1	0.21	94.7
2003	7.2	0.31	34.9	0.28	162.2	0.15	204.2
2004	4.3	0.25	52.9	0.22	207.9	0.13	265.1
2005	13.6	0.16	26.3	0.13	252.2	0.21	292.2
2006	3.3	0.39	19.7	0.28	98.2	0.45	121.1
2007	14.0	0.43	39.2	0.27	104.7	0.33	157.9
2008	10.6	0.46	20.4	0.16	102.9	0.34	133.8
2009	8.5	0.73	141.2	1.73	122.3	0.27	272.0
2010	11.9	0.19	22.8	0.14	152.3	0.07	187.1
2011	26.6	0.17	16.2	0.08	168.4	0.05	211.2
2012	27.9	0.38	13.1	0.10	145.6	0.05	186.6
2013	17.7	0.21	16.8	0.06	113.7	0.08	148.1
2014	10.2	0.18	19.3	0.07	125.2	0.06	154.6
2015	7.6	0.24	10.0	0.09	132.9	0.09	150.5
2016	2.9	0.20	14.6	0.24	136.6	0.11	154.1
2017	2.6	0.19	11.9	0.33	158.3	0.13	172.9
2018	1.4	0.31	27.9	0.55	131.7	0.19	161.0
2019	1.2	0.23	20.3	0.69	125.1	0.11	146.5

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Table 24. Recreational lobster landings (pounds) and percent of total statewide lobster landings.*NH expanded values from a 5% randomly selected subset of recreational license holders.

Year	NH Rec lbs	NH Rec % Total lbs	MA Rec lbs	MA Rec % Total lbs	NY Rec lbs	NY Rec % Total lbs	DE Rec lbs
1969	4,247*						
1970	5,208*						
1971	3,386*						
1972	2,658*						
1973	2,138*						
1974	2,025*						
1975	4,502*						
1976	3,381*						
1977	3,013*						
1978	3,314*						
1979	5,160*						
1980	7,011*						
1981	8,997*						
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989	4,094*	0.29%					
1990	3,809*	0.23%					
1991	1,738*	0.10%					
1992	4,788*	0.31%					
1993	8580*	0.50%					
1994	4,707*	0.28%					
1995	8,751*	0.47%					
1996	5,814*	0.35%					
1997	4541*	0.32%					
1998	6,637*	0.55%					
1999	7,388*	0.53%					
2000	4,528*	0.26%	376,458	2.45%			
2001	4,929*	0.24%	337,546	2.74%	8,788	0.43%	
2002	4,669*	0.23%	321,365	2.34%	9,029	0.62%	
2003	3,986*	0.20%	280,762	2.42%	8,129	0.85%	
2004	4,376*	0.15%	287,919	2.41%	10,709	0.89%	
2005	6,229*	0.24%	283,598	2.45%	10,032	0.81%	
2006	3,859	0.15%	275,416	2.23%	14,057	1.06%	
2007	7,036	0.28%	272,943	2.45%	13,293	1.44%	
2008	5,708	0.22%	266,149	2.20%	7,636	1.06%	
2009	6,034	0.20%	255,531	1.92%	9,051	1.22%	
2010	6,482	0.18%	244,021	1.78%	7,391	0.90%	
2011	5,118	0.13%	226,211	1.59%	5,329	1.52%	
2012	6,813	0.16%	225,922	1.50%	3,455	1.24%	
2013	6,707	0.18%	221,528	1.43%	2,488	0.99%	
2014	4,897	0.11%	210,961	1.36%	2,461	1.09%	
2015	7,379	0.16%	220,864	1.32%	3,257	2.16%	
2016	8,281	0.14%			3,316	1.49%	0
2017	6,797	0.12%			1,933	1.25%	0
2018	5,526	0.09%			2,317	1.86%	0
2019	5,678				2,245	1.94%	0

Table 25. Recreational lobster licenses and trap tags and percent of statewide totals.

Year	ME Rec Lic	ME Rec % Total Lic	ME Rec Tags	ME Rec % Total Tag	RI Rec Lic	RI Rec % Total Lic	NJ Rec Lic	NJ Rec % Total Lic
1997	162	2.2%	771	0.03%				
1998	199	2.8%	955	0.03%				
1999	303	4.3%	1,452	0.05%				
2000	570	7.7%	2,784	0.10%				
2001	866	11.3%	4,209	0.14%				
2002	1,275	15.8%	6,486	0.21%				
2003	2,018	22.8%	9,713	0.30%				
2004	1,982	22.6%	9,438	0.29%				
2005	1,996	22.9%	9,635	0.29%				
2006	2,086	24.0%	10,087	0.31%				
2007	2,147	24.8%	10,451	0.32%				
2008	2,177	25.6%	10,486	0.33%				
2009	2,045	25.2%	9,863	0.32%				
2010	1,917	24.4%	9,276	0.31%	885	93.35%		
2011	1,964	24.8%	9,555	0.32%				
2012	1,931	24.4%	9,379	0.31%	721	79.67%		
2013	1,777	23.4%	8,748	0.30%	620	70.94%		
2014	1,758	23.3%	8,614	0.29%	552	64.41%		
2015	1,923	24.6%	9,417	0.32%	508	60.55%		
2016	2,087	25.8%	9,894	0.34%	532	63.79%	29	26.61%
2017	2,187	26.6%	10,203	0.35%	541	66.06%	36	33.03%
2018	2,182	26.8%	10,288	0.36%	504	63.32%	53	48.62%
2019					490		32	

Table 26. Minimum and maximum legal size (CL, mm) by LCMA used for legal selectivity. Cells in bold marked with an asterisk indicate maximum size for females only with no maximum size for males.

Year	Minimum Size							Maximum Size						
	1	2	3	4	5	6	OCC	1	2	3	4	5	6	OCC
1981	81	81	81	81	81	81	81	128	NA	NA	NA	NA	NA	NA
1982	81	81	81	81	81	81	81	128	NA	NA	NA	NA	NA	NA
1983	81	81	81	81	81	81	81	128	NA	NA	NA	NA	NA	NA
1984	81	81	81	81	81	81	81	128	NA	NA	NA	NA	NA	NA
1985	81	81	81	81	81	81	81	128	NA	NA	NA	NA	NA	NA
1986	81	81	81	81	81	81	81	128	NA	NA	NA	NA	NA	NA
1987	81	81	81	81	81	81	81	128	NA	NA	NA	NA	NA	NA
1988	82	82	82	82	82	82	81	128	NA	NA	NA	NA	NA	NA
1989	83	83	83	83	83	83	82	128	NA	NA	NA	NA	NA	NA
1990	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1991	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1992	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1993	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1994	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1995	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1996	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1997	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1998	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
1999	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
2000	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
2001	83	83	83	83	83	83	83	128	NA	NA	NA	NA	NA	NA
2002	83	84	84	84	84	83	84	128	**_133*_**	NA	**_133*_**	**_133*_**	NA	NA
2003	83	85	85	85	85	83	85	128	**_133*_**	NA	**_133*_**	**_133*_**	NA	NA
2004	83	86	86	86	86	83	86	128	**_133*_**	NA	**_133*_**	**_133*_**	NA	NA
2005	83	86	86	86	86	83	87	128	**_133*_**	NA	**_133*_**	**_133*_**	NA	NA
2006	83	86	88	86	86	84	87	128	**_133*_**	NA	**_133*_**	**_133*_**	NA	NA
2007	83	86	88	86	86	84	88	128	**_133*_**	NA	**_133*_**	**_133*_**	NA	NA
2008	83	86	89	86	86	84	89	128	133	174	133	133	133	NA
2009	83	86	89	86	86	84	86	128	133	174	133	133	133	NA
2010	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2011	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2012	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2013	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2014	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2015	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2016	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2017	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2018	83	86	89	86	86	86	86	128	133	171	133	133	133	171
2019	83	86	89	86	86	86	86	128	133	171	133	133	133	171

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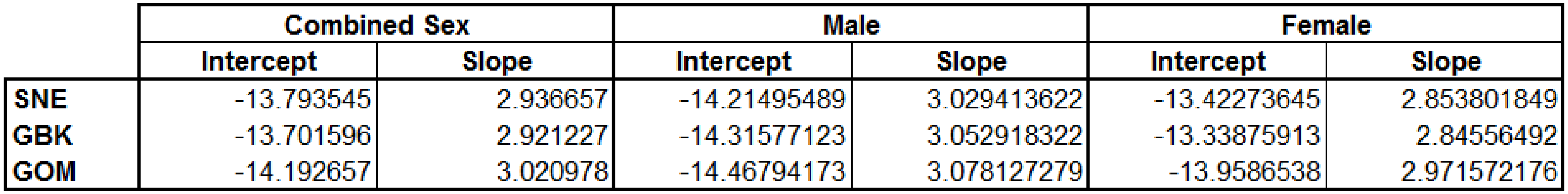
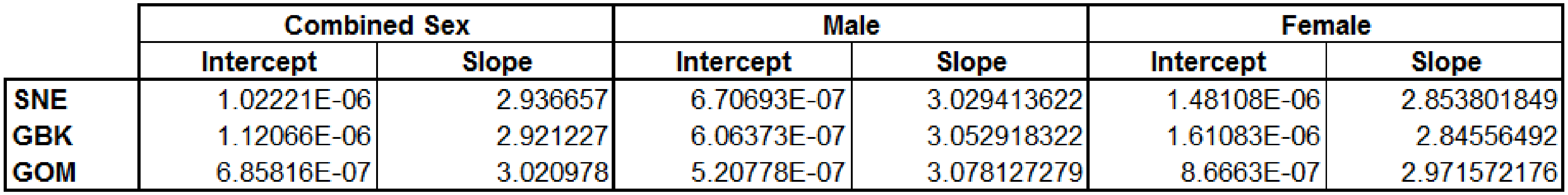
Table 27. Parameter estimates for the length-weight analysis on log transformed data. Note, all parameter estimates were significantly different from 0. SNE = Southern New England; GBK = Georges Bank; GOM = Gulf of Maine.



	Combined Sex		Male		Female	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
SNE	-13.793545	2.936657	-14.21495489	3.029413622	-13.42273645	2.853801849
GBK	-13.701596	2.921227	-14.31577123	3.052918322	-13.33875913	2.84556492
GOM	-14.192657	3.020978	-14.46794173	3.078127279	-13.9586538	2.971572176

Table 28. Back transformed parameter estimates for the length-weight equation. Note, all parameter estimates were significantly different from 0. SNE = Southern New England; GBK = Georges Bank; GOM = Gulf of Maine.



	Combined Sex		Male		Female	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
SNE	1.02221E-06	2.936657	6.70693E-07	3.029413622	1.48108E-06	2.853801849
GBK	1.12066E-06	2.921227	6.06373E-07	3.052918322	1.61083E-06	2.84556492
GOM	6.85816E-07	3.020978	5.20778E-07	3.078127279	8.6663E-07	2.971572176

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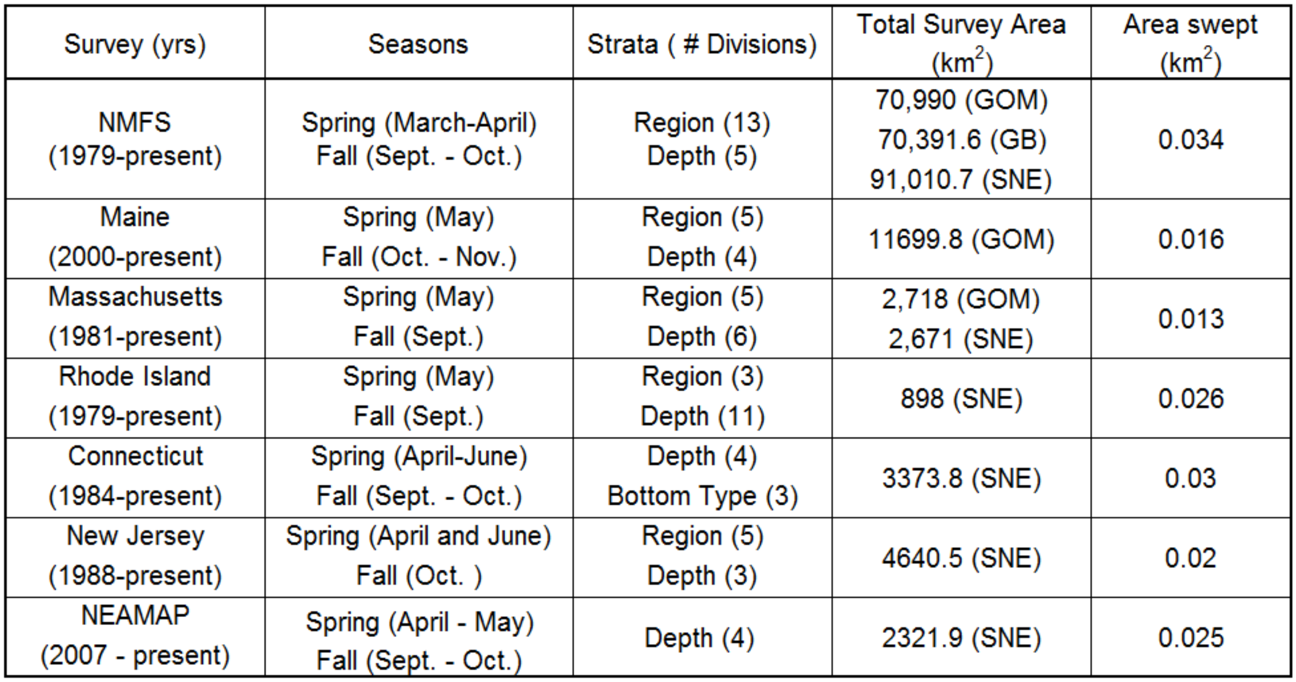
Table 29. Sampling seasons, strata, and survey coverage (total survey area and actual area swept) for fishery-independent trawl surveys incorporated into assessment models.



Survey (yrs)	Seasons	Strata (# Divisions)	Total Survey Area (km^2)	Area swept (km^2)
NMFS (1979-present)	Spring (March-April) Fall (Sept. - Oct.)	Region (13) Depth (5)	70,990 (GOM) 70,391.6 (GB) 91,010.7 (SNE)	0.034
Maine (2000-present)	Spring (May) Fall (Oct. - Nov.)	Region (5) Depth (4)	11699.8 (GOM)	0.016
Massachusetts (1981-present)	Spring (May) Fall (Sept.)	Region (5) Depth (6)	2,718 (GOM) 2,671 (SNE)	0.013
Rhode Island (1979-present)	Spring (May) Fall (Sept.)	Region (3) Depth (11)	898 (SNE)	0.026
Connecticut (1984-present)	Spring (April-June) Fall (Sept. - Oct.)	Depth (4) Bottom Type (3)	3373.8 (SNE)	0.03
New Jersey (1988-present)	Spring (April and June) Fall (Oct.)	Region (5) Depth (3)	4640.5 (SNE)	0.02
NEAMAP (2007 - present)	Spring (April - May) Fall (Sept. - Oct.)	Depth (4)	2321.9 (SNE)	0.025

Table 30. Size-based calibration coefficients (r) and CVs for lobsters in NEFSC bottom trawl surveys (Jacobson and Miller (2012).

.

CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV
2.6	17.272	0.48	6.1	3.784	0.13	9.6	1.45	0.07	13.1	1.185	0.08	16.6	1.237	0.18	20.1	1.564	0.52
2.7	16.735	0.47	6.2	3.64	0.12	9.7	1.443	0.07	13.2	1.186	0.08	16.7	1.247	0.18	20.2	1.562	0.53
2.8	16.198	0.45	6.3	3.504	0.12	9.8	1.436	0.07	13.3	1.188	0.09	16.8	1.259	0.19	20.3	1.559	0.54
2.9	15.661	0.44	6.4	3.376	0.12	9.9	1.431	0.07	13.4	1.191	0.09	16.9	1.271	0.19	20.4	1.556	0.56
3	15.127	0.43	6.5	3.255	0.11	10	1.426	0.07	13.5	1.195	0.09	17	1.285	0.2	20.5	1.552	0.57
3.1	14.594	0.41	6.6	3.141	0.11	10.1	1.422	0.07	13.6	1.198	0.09	17.1	1.299	0.2	20.6	1.548	0.58
3.2	14.065	0.4	6.7	3.032	0.11	10.2	1.418	0.07	13.7	1.202	0.09	17.2	1.314	0.21	20.7	1.544	0.6
3.3	13.539	0.38	6.8	2.928	0.11	10.3	1.413	0.07	13.8	1.206	0.09	17.3	1.329	0.22	20.8	1.54	0.61
3.4	13.018	0.37	6.9	2.828	0.1	10.4	1.409	0.07	13.9	1.21	0.1	17.4	1.345	0.23	20.9	1.536	0.62
3.5	12.502	0.36	7	2.733	0.1	10.5	1.403	0.07	14	1.213	0.1	17.5	1.36	0.23			
3.6	11.994	0.34	7.1	2.641	0.1	10.6	1.397	0.07	14.1	1.216	0.1	17.6	1.376	0.24			
3.7	11.493	0.33	7.2	2.553	0.1	10.7	1.39	0.07	14.2	1.218	0.1	17.7	1.391	0.25			
3.8	11.002	0.32	7.3	2.468	0.1	10.8	1.383	0.07	14.3	1.22	0.1	17.8	1.407	0.26			
3.9	10.521	0.3	7.4	2.386	0.09	10.9	1.374	0.07	14.4	1.221	0.11	17.9	1.422	0.27			
4	10.051	0.29	7.5	2.308	0.09	11	1.364	0.07	14.5	1.222	0.11	18	1.436	0.28			
4.1	9.594	0.28	7.6	2.233	0.09	11.1	1.354	0.07	14.6	1.221	0.11	18.1	1.45	0.28			
4.2	9.151	0.27	7.7	2.16	0.09	11.2	1.343	0.07	14.7	1.22	0.11	18.2	1.463	0.29			
4.3	8.722	0.26	7.8	2.091	0.09	11.3	1.331	0.07	14.8	1.219	0.12	18.3	1.476	0.3			
4.4	8.309	0.25	7.9	2.026	0.09	11.4	1.319	0.07	14.9	1.217	0.12	18.4	1.487	0.31			
4.5	7.911	0.24	8	1.963	0.09	11.5	1.306	0.07	15	1.214	0.12	18.5	1.499	0.32			
4.6	7.53	0.23	8.1	1.905	0.08	11.6	1.293	0.07	15.1	1.212	0.12	18.6	1.509	0.34			
4.7	7.167	0.22	8.2	1.849	0.08	11.7	1.28	0.07	15.2	1.209	0.13	18.7	1.519	0.35			
4.8	6.821	0.21	8.3	1.798	0.08	11.8	1.267	0.07	15.3	1.206	0.13	18.8	1.528	0.36			
4.9	6.492	0.2	8.4	1.75	0.08	11.9	1.255	0.07	15.4	1.203	0.13	18.9	1.536	0.37			
5	6.181	0.19	8.5	1.706	0.08	12	1.243	0.07	15.5	1.201	0.13	19	1.543	0.38			
5.1	5.887	0.18	8.6	1.666	0.08	12.1	1.232	0.07	15.6	1.199	0.14	19.1	1.549	0.39			
5.2	5.611	0.17	8.7	1.629	0.08	12.2	1.222	0.07	15.7	1.198	0.14	19.2	1.555	0.4			
5.3	5.351	0.17	8.8	1.597	0.08	12.3	1.213	0.08	15.8	1.198	0.14	19.3	1.559	0.42			
5.4	5.107	0.16	8.9	1.568	0.08	12.4	1.205	0.08	15.9	1.199	0.15	19.4	1.563	0.43			
5.5	4.878	0.16	9	1.542	0.07	12.5	1.199	0.08	16	1.2	0.15	19.5	1.565	0.44			
5.6	4.664	0.15	9.1	1.52	0.07	12.6	1.193	0.08	16.1	1.203	0.15	19.6	1.567	0.45			
5.7	4.464	0.14	9.2	1.501	0.07	12.7	1.189	0.08	16.2	1.207	0.16	19.7	1.568	0.47			
5.8	4.276	0.14	9.3	1.485	0.07	12.8	1.186	0.08	16.3	1.213	0.16	19.8	1.568	0.48			
5.9	4.101	0.13	9.4	1.471	0.07	12.9	1.185	0.08	16.4	1.219	0.17	19.9	1.567	0.49			
6	3.938	0.13	9.5	1.46	0.07	13	1.184	0.08	16.5	1.227	0.17	20	1.566	0.5			

Table 31. Gulf of Maine and Georges Bank. Coefficients of variation (CV) for the NMFS NEFSC, Maine/New Hampshire, and Massachusetts bottom trawl surveys by season and lobster sex. Blanks indicate no data.

Year	Spring Trawl Survey - Females			Spring Trawl Survey - Males			Fall Trawl Survey - Females			Fall Trawl Survey - Males		
	NEFSC	ME/NH	MA	NEFSC	ME/NH	MA	NEFSC	ME/NH	MA	NEFSC	ME/NH	MA
1979	0.293		0.463	0.285		0.418	0.167		0.434	0.164		0.487
1980	0.207		0.256	0.232		0.413	0.189		0.162	0.175		0.122
1981	0.267		0.368	0.336		0.352	0.151		0.355	0.229		0.332
1982	0.256		0.549	0.252		0.527	0.252		0.326	0.219		0.333
1983	0.213		0.282	0.226		0.276	0.185		0.394	0.240		0.337
1984	0.360		0.201	0.293		0.184	0.183		0.439	0.189		0.475
1985	0.602		0.308	0.324		0.310	0.198		0.575	0.182		0.506
1986	0.228		0.248	0.363		0.189	0.178		0.281	0.165		0.226
1987	0.250		0.271	0.315		0.298	0.287		0.342	0.291		0.323
1988	0.172		0.213	0.192		0.261	0.296		0.757	0.241		0.746
1989	0.307		0.281	0.426		0.368	0.222		0.708	0.241		0.612
1990	0.235		0.287	0.441		0.351	0.188		0.501	0.220		0.460
1991	0.258		0.230	0.311		0.240	0.282		0.414	0.301		0.361
1992	0.224		0.232	0.252		0.219	0.240		0.359	0.252		0.313
1993	0.286		0.171	0.337		0.197	0.213		0.273	0.227		0.278
1994	0.177		0.303	0.256		0.246	0.239		0.297	0.288		0.264
1995	0.206		0.311	0.234		0.221	0.302		0.436	0.464		0.384
1996	0.226		0.214	0.193		0.196	0.233		0.335	0.215		0.280
1997	0.187		0.296	0.286		0.236	0.160		0.347	0.209		0.340
1998	0.154		0.395	0.237		0.288	0.219		0.673	0.179		0.631
1999	0.224		0.336	0.220		0.258	0.148		0.307	0.184		0.304
2000	0.296		0.166	0.354		0.181	0.213		0.352	0.231		0.272
2001	0.222		0.202	0.231		0.149	0.235		0.316	0.249		0.286
2002	0.155		0.257	0.209		0.218	0.146		0.274	0.180		0.202
2003	0.220	0.169	0.208	0.242	0.170	0.187	0.241	0.138	0.276	0.327	0.132	0.167
2004	0.119	0.181	0.237	0.174	0.162	0.199	0.347	0.177	0.541	0.489	0.201	0.352
2005	0.183	0.185	0.215	0.228	0.182	0.166	0.146	0.189	0.309	0.209	0.182	0.290
2006	0.176	0.225	0.209	0.243	0.234	0.187	0.159	0.153	0.383	0.260	0.148	0.382
2007	0.257	0.130	0.218	0.188	0.125	0.192	0.190	0.175	0.355	0.304	0.160	0.303
2008	0.212	0.278	0.194	0.297	0.273	0.162	0.162	0.158	0.394	0.180	0.205	0.406
2009	0.193	0.171	0.191	0.318	0.187	0.126	0.149	0.163	0.296	0.266	0.133	0.226
2010	0.114	0.104	0.159	0.191	0.104	0.131	0.141	0.122	0.305	0.187	0.151	0.289
2011	0.135	0.164	0.167	0.171	0.132	0.179	0.125	0.111	0.282	0.190	0.113	0.241
2012	0.096	0.100	0.171	0.120	0.104	0.183	0.110	0.099	0.218	0.150	0.103	0.180
2013	0.233	0.134	0.142	0.262	0.129	0.136	0.148	0.104	0.178	0.088	0.101	0.163
2014	0.120	0.216	0.172	0.207	0.132	0.141	0.128	0.098	0.238	0.306	0.096	0.202
2015	0.134	0.059	0.118	0.185	0.065	0.124	0.144	0.093	0.277	0.181	0.091	0.275
2016	0.088	0.065	0.142	0.125	0.060	0.156	0.128	0.063	0.191	0.152	0.069	0.181
2017	0.191	0.119	0.283	0.263	0.112	0.225	0.130	0.072	0.271	0.173	0.067	0.238
2018	0.321	0.112	0.222	0.517	0.101	0.166	0.172	0.062	0.323	0.088	0.065	0.277
2019	0.112	0.076	0.432	0.170	0.080	0.227	0.162	0.097	0.203	0.301	0.089	0.234

Table 32. Southern New England. Coefficients of variation (CV) for the NMFS NEFSC, Northeast Area Monitoring Assessment Program (NEAMAP), Massachusetts, Rhode Island, Connecticut, and New Jersey bottom trawl surveys by season and lobster sex. Blanks indicate no data and NAs indicate occurrences of no catch during the survey.

Year	Spring Trawl Survey - Females						Spring Trawl Survey - Males						Fall Trawl Survey - Females				Fall Trawl Survey - Males			
	NEFSC	NEAMAP	MA	RI	CT	NJ	NEFSC	NEAMAP	MA	RI	CT	NJ	NEFSC	NEAMAP	RI	CT	NEFSC	NEAMAP	RI	CT
1979	0.398		0.389				0.443		0.230				0.184				0.181			
1980	0.310		0.304				0.236		0.306				0.268				0.323			
1981	0.408		0.325				0.543		0.303				0.539				0.628			
1982	0.420		0.274	0.327			0.450		0.242	0.261			0.293		0.310		0.275		0.279	
1983	0.355		0.322	0.335			0.535		0.365	0.234			0.273		0.373		0.347		0.305	
1984	0.470		0.236	0.397	0.282		0.545		0.221	0.402	0.321		0.574		0.386	0.260	0.569		0.414	0.318
1985	0.880		0.312	0.370	0.315		0.790		0.214	0.462	0.340		0.483		0.313	0.244	0.441		0.313	0.229
1986	0.440		0.205	0.272	0.182		0.603		0.243	0.337	0.162		0.469		0.377	0.196	0.544		0.525	0.191
1987	1.175		0.291	0.395	0.193		1.124		0.290	0.496	0.200		0.295		0.388	0.209	0.267		0.329	0.204
1988	0.646		0.332	0.315	0.179		0.758		0.253	0.255	0.200		0.427		0.481	0.311	0.555		0.516	0.314
1989	0.356		0.308	0.449	0.222	0.403	0.568		0.409	0.547	0.216	0.330	0.347		0.372	0.282	0.278		0.344	0.238
1990	0.487		0.305	0.375	0.220	0.460	0.424		0.341	0.407	0.175	0.474	0.430		0.342	0.223	0.553		0.490	0.173
1991	0.491		0.229	0.271	0.169	0.449	0.481		0.259	0.249	0.199	0.294	0.265		0.358	0.197	0.307		0.279	0.201
1992	0.305		0.288	0.403	0.207	0.445	0.341		0.230	0.336	0.223	0.489	0.385		0.332	0.225	0.351		0.304	0.212
1993	0.655		0.272	0.497	0.210	0.439	0.490		0.143	0.465	0.187	0.486	0.446		0.803	0.209	0.382		0.792	0.175
1994	0.621		0.191	0.346	0.225	0.351	0.508		0.200	0.242	0.211	0.347	0.309		0.391	0.171	0.210		0.373	0.160
1995	0.726		0.370	0.308	0.230	0.327	0.748		0.283	0.276	0.177	0.313	0.260		0.392	0.229	0.236		0.240	0.259
1996	0.639		0.264	0.273	0.232	0.233	0.546		0.278	0.259	0.196	0.421	0.513		0.434	0.227	0.471		0.305	0.170
1997	0.955		0.292	0.424	0.206	0.367	0.802		0.250	0.398	0.206	0.491	0.471		0.396	0.219	0.445		0.318	0.188
1998	0.564		0.354	0.395	0.188	0.416	0.495		0.274	0.307	0.164	0.550	0.439		0.467	0.209	0.400		0.374	0.163
1999	0.753		0.357	0.303	0.186	0.437	0.623		0.420	0.205	0.162	0.466	0.233		0.443	0.201	0.245		0.464	0.167
2000	0.576		0.240	0.287	0.196	0.555	0.696		0.312	0.258	0.168	0.268	0.453		0.668	0.196	0.315		0.492	0.189
2001	0.631		0.264	0.282	0.174	0.336	0.416		0.236	0.277	0.146	0.440	0.478		0.391	0.170	0.440		0.329	0.197
2002	0.474		0.197	0.311	0.195	0.344	0.397		0.234	0.342	0.160	0.542	0.268		0.587	0.178	0.245		0.351	0.199
2003	0.576		0.321	0.277	0.164	0.577	0.954		0.348	0.279	0.158	0.588	0.288		0.451	0.245	0.197		0.377	0.168
2004	0.297		0.383	0.374	0.214	0.511	0.324		0.298	0.300	0.188	0.753	0.464		0.340	0.222	0.574		0.287	0.163
2005	0.636		0.361	0.306	0.204	0.504	0.622		0.295	0.341	0.189	0.663	0.367		0.720	0.242	0.277		0.526	0.166
2006	0.521		0.380	0.402	0.344	0.422	0.515		0.257	0.285	0.229	0.645	0.437		0.528	0.360	0.256		0.271	0.307
2007	0.546		0.318	0.417	0.247	0.429	0.416		0.206	0.305	0.186	0.509	0.361	0.626	0.373	0.249	0.270	0.456	0.367	0.231
2008	0.611	0.492	0.235	0.320	0.151	0.635	0.402	0.499	0.225	0.294	0.132	0.459	0.381	0.698	0.382	0.284	0.326	0.772	0.348	0.261
2009	0.265	0.359	0.264	0.376	0.183	0.745	0.355	0.302	0.179	0.306	0.175	0.745	0.206	0.367	0.406	0.206	0.222	0.350	0.324	0.212
2010	0.525	0.436	0.259	0.446	0.290	0.475	0.519	0.370	0.302	0.305	0.222	0.349	0.168	0.467	0.418		0.164	0.262	0.423	
2011	0.388	0.564	0.306	0.344	0.240	0.579	0.371	0.321	0.318	0.340	0.204	0.590	0.187	0.405	0.506	0.480	0.189	0.325	0.474	0.285
2012	0.338	0.312	0.316	0.510	0.184	0.523	0.442	0.221	0.197	0.401	0.190	0.571	0.360	0.555	0.492	0.416	0.291	0.667	0.487	0.372
2013	0.540	0.364	0.158	0.466	0.267	0.548	0.548	0.326	0.188	0.600	0.256	0.448	0.244	0.399	0.699	0.377	0.216	0.338	0.699	0.452
2014	0.551	0.281	0.671	0.738	0.276	0.698	0.573	0.277	0.306	1.000	0.291	0.444	0.195	0.451	0.498	0.582	0.230	0.370	0.370	0.483
2015	0.762	0.253	0.411	0.482	0.318	0.544	0.879	0.279	0.286	0.699	0.250	0.631	0.170	0.707	0.534	0.448	0.158	0.609	0.416	0.703
2016	0.764	0.464	0.349	0.456	0.269	0.640	0.750	0.414	0.318	0.422	0.247	0.632	0.307	0.362	0.690	**NA***	0.221	0.379	0.625	0.703
2017	0.403	0.272	0.267	0.493	0.741	0.685	0.607	0.353	0.205	0.596	0.722	0.438		0.614	0.534	**NA***		0.589	0.463	0.703
2018	0.575	0.470	**NA***	0.699	0.574	0.882	0.412	0.307	0.361	0.699	0.607	1.000	0.224	0.391	0.796	**NA***	0.300	0.524	0.764	1.000
2019	0.477	0.605	0.514	0.650	0.704	0.723	0.691	0.483	0.411	0.576	0.377	0.479	0.197	0.574	0.680	**NA***	0.243	0.463	0.666	**NA***

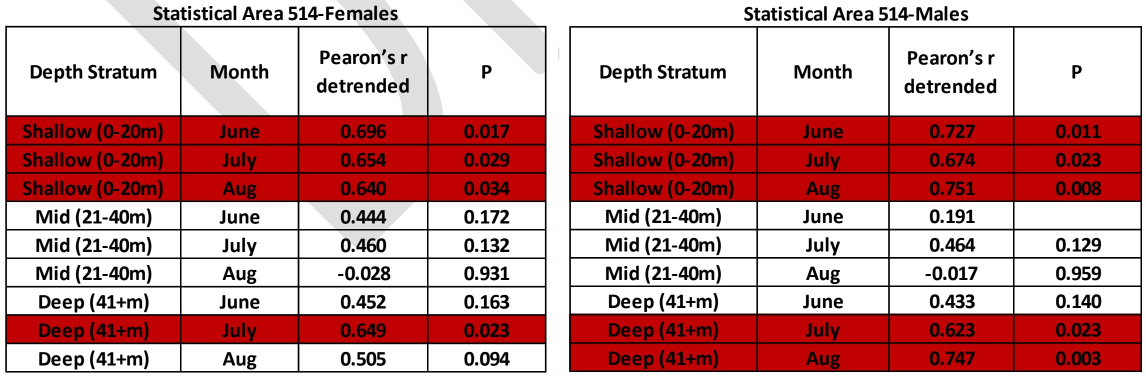
Table 33. Correlation statistics between YOY abundance and VTS catch for all three depth strata combined, by month with lags of four, five and six years. Table only depicts significant correlations, non-significant correlations were left out of the table.

Size Bin (mm)	Lag (# of years)	Month	Pearson's r	P
35-45	4	July	0.58	0.048
35-45	4	August	0.58	0.048
35-45	5	June	0.63	0.040
45-54	5	July	0.58	0.047
45-54	6	June	0.65	0.031

Table 34. Correlation statistics between YOY abundance and VTS catch for depth stratum one, by month with lags of three, four, five and six years. Table only depicts significant correlations (*P*<0.05), non-significant correlations were left out of the table.

Size Bin (mm)	Lag (# of years)	Month	Pearson's r	P
35-45	3	August	0.68	0.014
35-45	4	July	0.66	0.019
35-45	4	August	0.68	0.015
35-45	5	June	0.70	0.015
35-45	5	August	0.64	0.024
45-54	4	August	0.74	0.006
45-54	5	June	0.72	0.013
45-54	5	July	0.60	0.039
45-54	5	August	0.61	0.036
45-54	6	June	0.64	0.035

Table 35. Correlation statistics (detrended) in SA 514 between temperature and catch from the Coastwide Ventless Trap Survey. Bright red indicates moderate correlation and darker red color indicates strong correlations.



Statistical Area 514-Females

Depth Stratum	Month	Pearon's r detrended	P
🟥 Shallow (0-20m)	June	0.696	0.017
🟥 Shallow (0-20m)	July	0.654	0.029
🟥 Shallow (0-20m)	Aug	0.640	0.034
Mid (21-40m)	June	0.444	0.172
Mid (21-40m)	July	0.460	0.132
Mid (21-40m)	Aug	-0.028	0.931
Deep (41+m)	June	0.452	0.163
🟥 Deep (41+m)	July	0.649	0.023
Deep (41+m)	Aug	0.505	0.094

Statistical Area 514-Males

Depth Stratum	Month	Pearon's r detrended	P
🟥 Shallow (0-20m)	June	0.727	0.011
🟥 Shallow (0-20m)	July	0.674	0.023
🟥 Shallow (0-20m)	Aug	0.751	0.008
Mid (21-40m)	June	0.191	
Mid (21-40m)	July	0.464	0.129
Mid (21-40m)	Aug	-0.017	0.959
Deep (41+m)	June	0.433	0.140
🟥 Deep (41+m)	July	0.623	0.023
🟥 Deep (41+m)	Aug	0.747	0.003

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Table 36. Correlation statistics (detrended) in SA 513 between temperature and catch from the Coastwide Ventless Trap Survey. Bright red indicates moderate correlation and darker red color indicates strong correlations.

Statistical Area 513-Females

Depth Stratum	Month	Pearon's r detrended	P
Shallow (0-20m)	June	-0.309	0.304
Shallow (0-20m)	July	0.2486	0.4128
Shallow (0-20m)	Aug	0.4389	0.1338
Mid (21-40m)	June	0.7935	0.0021
Mid (21-40m)	July	0.4056	0.1908
Mid (21-40m)	Aug	0.3011	0.3416
Deep (41+m)	June	0.4652	0.1092
Deep (41+m)	July	0.5797	0.0378
Deep (41+m)	Aug	0.5655	0.044

Statistical Area 513-Males

Depth Stratum	Month	Pearon's r detrended	P
Shallow (0-20m)	June	-0.4401	0.1323
Shallow (0-20m)	July	0.2248	0.4602
Shallow (0-20m)	Aug	0.4059	0.1688
Mid (21-40m)	June	0.073	0.8216
Mid (21-40m)	July	0.4109	0.1845
Mid (21-40m)	Aug	0.5354	0.0728
Deep (41+m)	June	0.4327	0.1397
Deep (41+m)	July	0.6228	0.023
Deep (41+m)	Aug	0.7466	0.0034

Table 37. Correlation statistics (detrended) in SA 512 between temperature and catch from the Coastwide Ventless Trap Survey. Bright red indicates moderate correlation and darker red color indicates strong correlations.

Statistical Area 512-Females

Depth Stratum	Month	Pearon's r detrended	P
Shallow (0-20m)	June	0.6043	0.0287
Shallow (0-20m)	July	0.5007	0.0813
Shallow (0-20m)	Aug	0.7	0.0077
Mid (21-40m)	June	0.5154	0.0714
Mid (21-40m)	July	0.4449	0.1277
Mid (21-40m)	Aug	0.7586	0.0026
Deep (41+m)	June	0.5154	0.0714
Deep (41+m)	July	0.4449	0.1227
Deep (41+m)	Aug	0.7586	0.0026

Statistical Area 512-Males

Depth Stratum	Month	Pearon's r detrended	P
Shallow (0-20m)	June	0.5913	0.0333
Shallow (0-20m)	July	0.5113	0.0741
Shallow (0-20m)	Aug	0.7453	0.0035
Mid (21-40m)	June	0.642	0.0332
Mid (21-40m)	July	0.5584	0.0592
Mid (21-40m)	Aug	0.8108	0.0014
Deep (41+m)	June	0.6659	0.013
Deep (41+m)	July	0.6702	0.0122
Deep (41+m)	Aug	0.7924	0.0012

Table 38. Correlation statistics (detrended) in SA 512 between temperature and catch from the Coastwide Ventless Trap Survey. Bright red indicates moderate correlation and darker red color indicates strong correlations.

Statistical Area 511-Females

Depth Stratum	Month	Pearon's r detrended	P
Shallow (0-20m)	June	0.6116	0.0263
Shallow (0-20m)	July	0.5275	0.0639
Shallow (0-20m)	Aug	0.6954	0.0083
Mid (21-40m)	June	0.5013	0.1159
Mid (21-40m)	July	-0.0759	0.8147
Mid (21-40m)	Aug	0.2578	0.4185
Deep (41+m)	June	0.3691	0.2146
Deep (41+m)	July	0.1417	0.6443
Deep (41+m)	Aug	0.3614	0.2251

Statistical Area 511-Males

Depth Stratum	Month	Pearon's r detrended	P
Shallow (0-20m)	June	0.7038	0.0073
Shallow (0-20m)	July	0.436	0.1364
Shallow (0-20m)	Aug	0.5306	0.0621
Mid (21-40m)	June	0.2883	0.3899
Mid (21-40m)	July	0.3498	0.265
Mid (21-40m)	Aug	0.5425	0.0684
Deep (41+m)	June	0.3699	0.2135
Deep (41+m)	July	0.1851	0.545
Deep (41+m)	Aug	0.5975	0.0311

Table 39. The number of sampling trips included in the mean percent with shell disease calculation for GOM areas. Males and females are only listed separately when the number of trips differed (this was the result of establishing a threshold minimum of 6 lobsters sampled for the trip's data to be included).

	ME			NH	MA	
	511	512	513	513	514	
	both	both	both	both	Males	Females
2001	0	0	0	0	0	0
2002	0	0	0	9	0	0
2003	6	50	17	9	14	14
2004	6	22	22	8	14	14
2005	5	18	26	5	12	12
2006	10	21	19	6	11	11
2007	8	23	22	6	12	13
2008	5	22	21	7	14	14
2009	6	20	21	7	14	14
2010	5	21	18	7	12	13
2011	6	19	20	7	11	12
2012	7	17	22	6	13	13
2013	6	18	23	6	13	13
2014	6	18	20	7	14	14
2015	6	18	22	7	13	13
2016	8	17	24	5	11	11
2017	5	17	21	5	13	13
2018	6	18	22	6	13	13

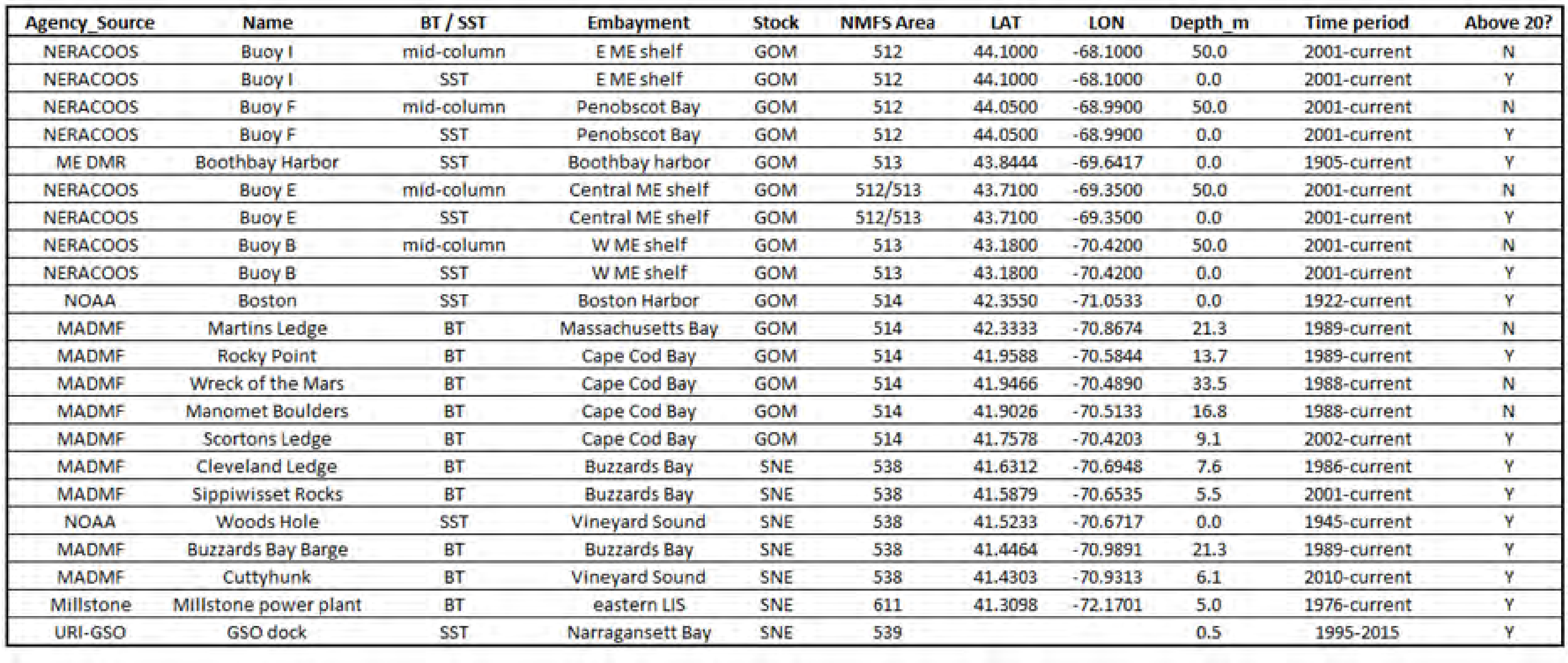
Table 40. The number of sampling trips included in the mean percent with shell disease calculation for SNE areas. Males and females are only listed separately when the number of trips differed (this was the result of establishing a threshold minimum of 6 lobsters sampled for the trip's data to be included).

	MA 537/538		RI 537/539	611 (CT & NY combined)		
				WLIS	CLIS	ELIS
	Males	Females	both	both	both	both
1996	0	0	8	0	0	0
1997	0	0	6	0	0	0
1998	0	0	6	0	0	0
1999	0	0	6	0	0	0
2000	0	0	6	0	0	0
2001	4	4	6	10	7	6
2002	4	4	6	11	3	7
2003	4	4	5	5	7	5
2004	3	4	7	10	7	3
2005	2	4	6	6	6	2
2006	3	4	6	3	0	1
2007	3	4	6	5	5	1
2008	4	4	6	3	3	0
2009	2	4	10	2	4	3
2010	1	3	10	4	2	3
2011	1	3	8	3	0	0
2012	3	5	4	1	0	1
2013	3	3	0	0	1	0
2014	2	3	2	0	0	0
2015	1	3	1	0	0	0
2016	5	5	1	2	1	0
2017	3	5	0	1	0	0
2018	4	4	0	0	0	1

Table 41. Quartiles for shell disease indicators, based on combined GOM and SNE data.

	Females	Males
25th	0.03	0.02
median	0.83	0.71
75th	14.48	6.11

Table 42. Temperature monitors considered for inclusion in the temperature stress indicator. The “Above 20?” column indicates whether there were any days in the available data that exceeded 20.0° C.



Agency_Source	Name	BT / SST	Embayment	Stock	NMFS Area	LAT	LON	Depth_m	Time period	Above 20?
NERACOOS	Buoy I	mid-column	E ME shelf	GOM	512	44.1000	-68.1000	50.0	2001-current	N
NERACOOS	Buoy I	SST	E ME shelf	GOM	512	44.1000	-68.1000	0.0	2001-current	Y
NERACOOS	Buoy F	mid-column	Penobscot Bay	GOM	512	44.0500	-68.9900	50.0	2001-current	N
NERACOOS	Buoy F	SST	Penobscot Bay	GOM	512	44.0500	-68.9900	0.0	2001-current	Y
ME DMR	Boothbay Harbor	SST	Boothbay harbor	GOM	513	43.8444	-69.6417	0.0	1905-current	Y
NERACOOS	Buoy E	mid-column	Central ME shelf	GOM	512/513	43.7100	-69.3500	50.0	2001-current	N
NERACOOS	Buoy E	SST	Central ME shelf	GOM	512/513	43.7100	-69.3500	0.0	2001-current	Y
NERACOOS	Buoy B	mid-column	W ME shelf	GOM	513	43.1800	-70.4200	50.0	2001-current	N
NERACOOS	Buoy B	SST	W ME shelf	GOM	513	43.1800	-70.4200	0.0	2001-current	Y
NOAA	Boston	SST	Boston Harbor	GOM	514	42.3550	-71.0533	0.0	1922-current	Y
MADMF	Martins Ledge	BT	Massachusetts Bay	GOM	514	42.3333	-70.8674	21.3	1989-current	N
MADMF	Rocky Point	BT	Cape Cod Bay	GOM	514	41.9588	-70.5844	13.7	1989-current	Y
MADMF	Wreck of the Mars	BT	Cape Cod Bay	GOM	514	41.9466	-70.4890	33.5	1988-current	N
MADMF	Manomet Boulders	BT	Cape Cod Bay	GOM	514	41.9026	-70.5133	16.8	1988-current	N
MADMF	Scortons Ledge	BT	Cape Cod Bay	GOM	514	41.7578	-70.4203	9.1	2002-current	Y
MADMF	Cleveland Ledge	BT	Buzzards Bay	SNE	538	41.6312	-70.6948	7.6	1986-current	Y
MADMF	Sippiwisset Rocks	BT	Buzzards Bay	SNE	538	41.5879	-70.6535	5.5	2001-current	Y
NOAA	Woods Hole	SST	Vineyard Sound	SNE	538	41.5233	-70.6717	0.0	1945-current	Y
MADMF	Buzzards Bay Barge	BT	Buzzards Bay	SNE	538	41.4464	-70.9891	21.3	1989-current	Y
MADMF	Cuttyhunk	BT	Vineyard Sound	SNE	538	41.4303	-70.9313	6.1	2010-current	Y
Millstone	Millstone power plant	BT	eastern LIS	SNE	611	41.3098	-72.1701	5.0	1976-current	Y
URI-GSO	GSO dock	SST	Narragansett Bay	SNE	539			0.5	1995-2015	Y

Table 43. GOM abundance indicators: spawning stock abundance.

SPAWNING STOCK ABUNDANCE						
Mean weight (g) per tow of mature females						
Survey	*NESFC*		*ME/NH*		*MA 514*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*
1981	175.32	400.28			502.65	430.53
1982	39.45	113.58			626.48	151.21
1983	206.03	234.21			844.76	67.08
1984	234.64	443.81			593.77	126.47
1985	499.62	2771.23			919.56	93.81
1986	267.97	502.99			231.88	112.97
1987	85.35	497.40			194.34	148.62
1988	186.56	244.92			200.58	88.14
1989	325.69	247.15			293.61	230.26
1990	216.65	516.20			1048.72	241.94
1991	247.11	430.56			335.80	165.54
1992	193.95	453.31			512.83	212.89
1993	284.34	484.30			120.59	229.72
1994	430.32	720.67			783.17	285.01
1995	464.96	390.15			520.26	171.71
1996	734.25	872.53			569.39	156.53
1997	568.34	1083.76			235.18	114.78
1998	381.81	1182.44			282.79	170.21
1999	1444.07	807.41			365.53	282.12
2000	585.66	1281.05	4430.55		533.40	236.55
2001	511.25	1498.42	2446.85	690.89	165.74	235.85
2002	1789.42	2022.04	4638.64	1436.34	324.34	175.73
2003	985.93	2343.63	3949.63	1226.05	129.67	72.99
2004	685.89	2773.35	3610.67	907.07	120.27	259.35
2005	465.35	1670.29	4805.25	1990.08	248.23	489.12
2006	681.87	1810.96	3698.94	1327.93	240.27	410.97
2007	445.78	1536.47	3163.24	1437.85	176.95	139.94
2008	805.10	1894.91	4080.36	1107.00	559.70	300.35
2009	1787.92	1864.92	6906.45	1747.30	630.52	219.83
2010	2850.60	2476.79	5793.51	1886.61	1424.75	211.52
2011	2317.94	2089.39	6169.40	2013.80	1268.44	267.51
2012	3215.29	3516.38	4174.85	2287.55	889.87	124.81
2013	3299.56	2499.71	5363.14	2007.92	1135.54	300.86
2014	4979.28	3083.09	5891.58	3010.73	768.88	382.81
2015	3553.44	3665.39	8488.62	2233.05	1947.04	418.46
2016	3692.26	5142.42	7691.01	2613.49	3712.66	1119.26
2017	3274.69	6566.80	4629.68	2530.74	2309.44	564.30
2018	2093.20	3555.09	5242.34	2005.07	2782.55	550.68
2014-2018 mean	3518.57	4402.56	6388.65	2478.62	2304.11	607.10

25th	272.06	487.57	4015.00	1355.03	242.26	149.27
median	539.79	1389.74	4638.64	1938.34	526.83	224.78
75th	1789.05	2443.50	5842.54	2178.24	878.60	296.52

Table 44. GOM abundance indicators: full recruit abundance.

FULL RECRUIT ABUNDANCE (SURVEY)						
Abundance of lobsters > 82 mm CL (sexes combined)						
Survey	*NEFSC*		*ME/NH*		*MA 514*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*
1981	0.316	0.475			1.913	1.834
1982	0.060	0.278			2.817	0.571
1983	0.287	0.259			3.070	0.516
1984	0.391	0.431			4.146	0.496
1985	0.747	2.293			3.977	0.505
1986	0.625	0.721			1.709	0.537
1987	0.216	0.587			0.521	0.550
1988	0.192	0.363			1.513	0.557
1989	0.515	0.377			2.271	0.797
1990	0.351	0.575			4.934	0.969
1991	0.492	0.608			3.177	0.687
1992	0.296	0.489			2.341	0.867
1993	0.540	0.642			0.626	1.007
1994	0.692	0.925			3.164	0.758
1995	1.347	0.623			2.506	0.592
1996	1.212	1.336			2.501	0.335
1997	0.940	1.361			1.691	0.628
1998	0.607	1.288			0.885	0.484
1999	2.086	0.679			1.920	0.719
2000	0.836	1.802	16.322		2.200	0.976
2001	0.851	2.025	10.590	3.250	0.718	0.524
2002	2.526	2.381	14.607	5.180	1.031	0.430
2003	1.530	3.174	14.395	3.452	0.430	0.220
2004	1.613	3.409	13.679	3.524	0.330	0.779
2005	0.837	2.185	19.818	6.935	0.600	0.972
2006	1.107	2.214	14.210	6.054	1.023	0.674
2007	0.689	1.991	12.547	5.333	0.472	0.353
2008	1.226	2.565	19.351	4.082	1.559	0.668
2009	2.491	2.204	29.727	7.382	1.722	0.539
2010	4.189	3.519	22.976	7.291	2.286	0.395
2011	4.272	2.893	24.447	9.045	3.805	0.547
2012	4.621	4.579	16.890	10.569	3.169	0.308
2013	4.501	3.287	20.796	9.988	3.722	0.868
2014	7.911	3.717	25.711	11.424	2.928	0.770
2015	4.775	5.430	37.607	9.923	5.691	1.251
2016	4.642	6.554	31.537	12.303	7.385	2.422
2017	4.819	7.022	19.245	10.078	6.127	1.640
2018	2.293	4.185	22.345	6.748	6.725	1.263
2014-2018 mean	4.888	5.382	27.289	10.095	5.771	1.469

25th	0.521	0.612	14.501	5.218	1.152	0.518
median	0.895	1.896	19.351	7.113	2.278	0.648
75th	2.441	3.104	23.711	9.972	3.175	0.868

Table 45. GOM abundance indicators: recruit abundance.

RECRUIT ABUNDANCE (SURVEY)						
Abundance of lobsters 71 - 80 mm CL (sexes combined)						
Survey	*NEFSC*		*ME/NH*		*MA 514*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*
1981	0.065	0.127			4.800	6.431
1982	0.353	0.274			3.893	2.772
1983	0.848	0.283			9.714	1.772
1984	0.263	0.193			6.131	2.166
1985	1.312	0.194			9.498	4.442
1986	1.063	0.225			3.828	2.992
1987	0.578	0.469			1.169	2.424
1988	1.040	0.520			4.137	2.496
1989	1.265	0.000			7.529	4.452
1990	1.822	0.409			15.363	6.123
1991	1.503	0.577			7.554	2.743
1992	1.153	0.516			9.007	4.324
1993	0.980	0.220			3.196	5.138
1994	2.330	0.187			13.867	7.542
1995	1.537	1.553			12.181	4.547
1996	4.144	0.662			11.961	3.106
1997	1.749	1.898			6.480	4.590
1998	1.997	1.536			7.542	4.524
1999	2.716	1.210			8.730	4.252
2000	2.561	3.556	24.093		8.890	4.247
2001	1.347	1.171	17.811	9.280	1.586	4.312
2002	1.488	1.434	22.413	22.002	4.999	3.408
2003	0.397	1.203	18.316	10.647	0.667	1.962
2004	2.132	0.782	12.293	7.546	1.295	2.467
2005	0.764	0.582	25.895	18.507	2.124	4.398
2006	1.163	2.300	18.304	18.066	5.295	6.094
2007	0.762	1.457	16.819	15.912	1.583	0.767
2008	2.139	0.998	31.607	17.878	6.145	2.537
2009	2.343	1.990	32.665	24.717	8.907	3.202
2010	2.957	1.427	37.354	17.663	9.529	2.201
2011	5.402	3.997	46.092	39.254	14.981	5.243
2012	3.225	4.694	37.120	36.547	11.349	3.030
2013	6.560	3.989	37.859	34.504	12.158	4.818
2014	8.461	3.823	41.947	50.793	7.051	3.353
2015	7.847	5.683	67.994	38.513	17.862	7.091
2016	9.373	5.668	60.069	50.832	17.409	13.582
2017	8.904	4.817	48.130	48.424	13.628	7.853
2018	5.516	4.917	55.839	42.769	25.618	5.247
2014-2018 mean	8.020	4.982	54.796	46.266	16.313	7.425

25th	1.045	0.424	20.364	17.717	4.303	2.751
median	1.643	1.187	32.665	23.359	7.548	4.282
75th	2.897	2.222	44.019	39.069	11.808	5.058

Table 46. GOM abundance indicators: survey encounter rate.

SURVEY LOBSTER ENCOUNTER RATE						
Proportion of postive tows						
Survey	*NEFSC*		*ME/NH*		*MA 514*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*
1981	0.250	0.438			0.725	0.857
1982	0.185	0.364			0.698	0.500
1983	0.328	0.265			0.756	0.756
1984	0.359	0.281			0.756	0.756
1985	0.492	0.381			0.674	0.707
1986	0.471	0.333			0.829	0.684
1987	0.242	0.426			0.543	0.848
1988	0.304	0.306			0.583	0.762
1989	0.359	0.190			0.952	0.783
1990	0.324	0.424			0.946	0.857
1991	0.319	0.415			0.943	0.872
1992	0.246	0.403			0.774	0.927
1993	0.388	0.412			0.816	0.971
1994	0.400	0.449			0.930	1.000
1995	0.357	0.408			0.927	0.932
1996	0.543	0.538			0.955	0.911
1997	0.348	0.638			0.861	0.930
1998	0.400	0.516			0.686	0.757
1999	0.425	0.507			0.909	0.727
2000	0.420	0.612	0.936		0.977	0.932
2001	0.400	0.565	0.863	0.877	0.717	0.932
2002	0.530	0.750	0.945	0.938	0.732	0.913
2003	0.439	0.686	0.854	0.922	0.550	0.818
2004	0.313	0.866	0.860	0.891	0.564	0.844
2005	0.362	0.768	0.907	0.953	0.674	0.951
2006	0.600	0.724	0.932	0.933	0.881	0.909
2007	0.429	0.721	0.849	0.966	0.542	0.511
2008	0.493	0.841	0.864	0.924	0.750	0.826
2009	0.628	0.820	0.923	0.978	0.867	0.889
2010	0.750	0.851	0.959	0.979	0.977	0.872
2011	0.743	0.833	0.959	0.990	0.854	0.891
2012	0.778	0.864	0.977	0.980	0.950	0.909
2013	0.733	0.867	0.929	1.000	0.955	0.957
2014	0.709	0.903	0.989	1.000	0.957	0.787
2015	0.687	0.928	0.963	1.000	0.951	0.977
2016	0.753	0.938	0.964	1.000	0.974	0.957
2017	0.773	0.864	0.941	0.992	0.977	0.841
2018	0.714	0.857	0.958	0.983	0.902	0.844
2014-2018 mean	0.727	0.898	0.963	0.995	0.952	0.881

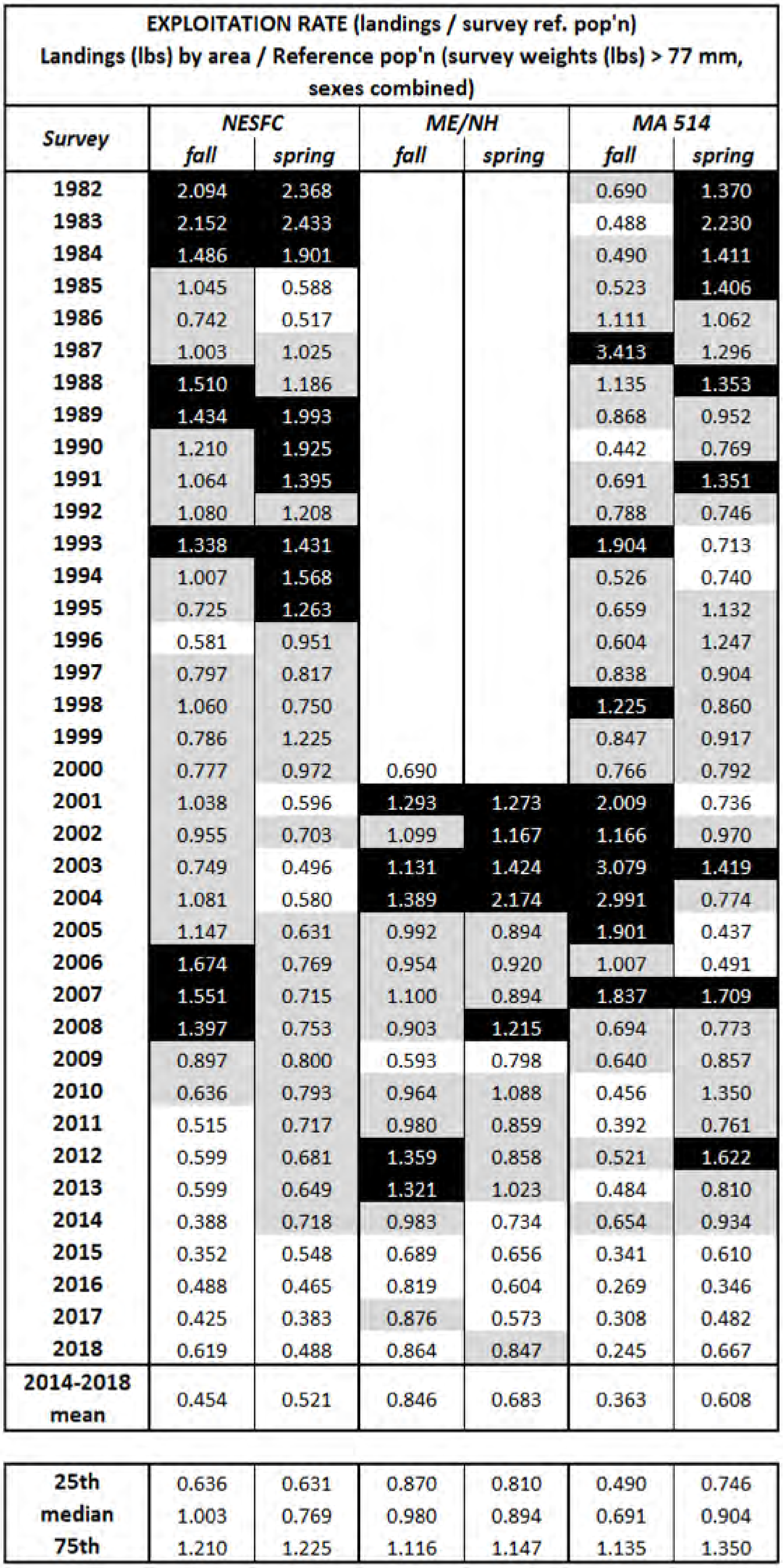
25th	0.350	0.413	0.885	0.934	0.719	0.784
median	0.423	0.589	0.936	0.979	0.858	0.865
75th	0.621	0.839	0.959	0.991	0.949	0.929

Table 47. GOM abundance indicators: YOY indices.

	YOUNG-OF-YEAR INDICES				
	YOY	YOY	YOY	YOY	YOY
Survey	*ME* *511*	*ME* *512*	*ME* *513 East*	*ME* *513 West*	*MA* *514*
1981					
1982					
1983					
1984					
1985					
1986					
1987					
1988					
1989			1.640		
1990			0.770		
1991			1.540		
1992			1.300		
1993			0.450		
1994			1.610		
1995		0.020	0.660		0.559
1996		0.050	0.470		0.000
1997		0.050	0.460		0.167
1998		0.000	0.140		0.021
1999		0.040	0.650		0.354
2000	0.000	0.100	0.130	0.294	0.188
2001	0.240	0.430	2.080	1.350	0.378
2002	0.128	0.290	1.380	0.953	0.889
2003	0.218	0.270	1.750	1.285	0.684
2004	0.165	0.360	1.750	1.068	1.198
2005	1.628	1.360	1.770	0.916	0.817
2006	0.488	1.130	0.840	1.085	0.322
2007	0.848	1.340	2.010	1.417	1.217
2008	0.415	0.830	1.080	0.898	0.241
2009	0.688	0.480	1.250	0.412	0.130
2010	0.285	0.720	0.800	0.618	0.446
2011	0.410	1.100	2.330	0.974	0.539
2012	0.535	0.730	1.060	0.243	0.077
2013	0.095	0.200	0.480	0.119	0.038
2014	0.160	0.430	0.833	0.282	0.094
2015	0.145	0.220	0.430	0.051	0.000
2016	0.063	0.211	0.467	0.052	0.056
2017	0.160	0.360	0.700	0.235	0.092
2018	0.268	0.322	0.708	0.155	0.019
2014-2018 mean	0.159	0.309	0.628	0.155	0.052

25th	0.153	0.175	0.523	0.239	0.071
median	0.240	0.341	0.837	0.618	0.214
75th	0.451	0.723	1.593	1.021	0.544

Table 48. GOM mortality indicator: relative exploitation.



EXPLOITATION RATE (landings / survey ref. pop'n)
Landings (lbs) by area / Reference pop'n (survey weights (lbs) > 77 mm, sexes combined)

Survey	*NESFC*		*ME/NH*		*MA 514*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*
1982	2.094	2.368			0.690	1.370
1983	2.152	2.433			0.488	2.230
1984	1.486	1.901			0.490	1.411
1985	1.045	0.588			0.523	1.406
1986	0.742	0.517			1.111	1.062
1987	1.003	1.025			3.413	1.296
1988	1.510	1.186			1.135	1.353
1989	1.434	1.993			0.868	0.952
1990	1.210	1.925			0.442	0.769
1991	1.064	1.395			0.691	1.351
1992	1.080	1.208			0.788	0.746
1993	1.338	1.431			1.904	0.713
1994	1.007	1.568			0.526	0.740
1995	0.725	1.263			0.659	1.132
1996	0.581	0.951			0.604	1.247
1997	0.797	0.817			0.838	0.904
1998	1.060	0.750			1.225	0.860
1999	0.786	1.225			0.847	0.917
2000	0.777	0.972	0.690		0.766	0.792
2001	1.038	0.596	1.293	1.273	2.009	0.736
2002	0.955	0.703	1.099	1.167	1.166	0.970
2003	0.749	0.496	1.131	1.424	3.079	1.419
2004	1.081	0.580	1.389	2.174	2.991	0.774
2005	1.147	0.631	0.992	0.894	1.901	0.437
2006	1.674	0.769	0.954	0.920	1.007	0.491
2007	1.551	0.715	1.100	0.894	1.837	1.709
2008	1.397	0.753	0.903	1.215	0.694	0.773
2009	0.897	0.800	0.593	0.798	0.640	0.857
2010	0.636	0.793	0.964	1.088	0.456	1.350
2011	0.515	0.717	0.980	0.859	0.392	0.761
2012	0.599	0.681	1.359	0.858	0.521	1.622
2013	0.599	0.649	1.321	1.023	0.484	0.810
2014	0.388	0.718	0.983	0.734	0.654	0.934
2015	0.352	0.548	0.689	0.656	0.341	0.610
2016	0.488	0.465	0.819	0.604	0.269	0.346
2017	0.425	0.383	0.876	0.573	0.308	0.482
2018	0.619	0.488	0.864	0.847	0.245	0.667
2014-2018 mean	0.454	0.521	0.846	0.683	0.363	0.608

25th	0.636	0.631	0.870	0.810	0.490	0.746
median	1.003	0.769	0.980	0.894	0.691	0.904
75th	1.210	1.225	1.116	1.147	1.135	1.350

Table 49. GOM stress indicator: shell disease prevalence (percent of the observed catch) in females (left) and males (right).

	ME			NH	MA
	511	**512**	**513**	**513**	**514**
2001					
2002				0.52	
2003	0.05	0.03	0.01	1.18	3.10
2004	0.00	0.00	0.20	0.32	2.85
2005	0.00	0.00	0.00	0.86	2.83
2006	0.00	0.00	0.07	0.00	3.03
2007	0.00	0.03	0.09	0.14	2.58
2008	0.00	0.02	0.03	1.20	1.55
2009	0.00	0.01	0.09	0.08	0.58
2010	0.00	0.00	0.33	0.20	1.86
2011	0.00	0.02	0.35	0.43	4.27
2012	0.03	0.05	0.39	0.51	3.54
2013	0.04	0.20	1.36	0.84	9.06
2014	0.22	0.15	1.06	3.09	9.58
2015	0.28	0.27	0.49	1.91	4.60
2016	0.09	0.20	0.69	2.10	3.92
2017	0.22	0.31	2.34	4.21	5.62
2018	0.15	0.22	1.01	5.57	6.85
2014-2018 mean	0.19	0.23	1.12	3.37	6.11

	ME			NH	MA
	511	**512**	**513**	**513**	**514**
2001					
2002				0.00	
2003	0.00	0.00	0.08	0.82	5.04
2004	0.00	0.03	0.11	0.14	2.56
2005	0.00	0.00	0.10	0.00	1.41
2006	0.04	0.00	0.16	0.47	0.73
2007	0.00	0.00	0.43	0.11	2.08
2008	0.00	0.00	0.00	0.88	0.73
2009	0.00	0.01	0.21	0.35	1.41
2010	0.00	0.00	0.03	0.22	0.97
2011	0.00	0.02	0.30	0.39	9.41
2012	0.02	0.03	0.36	0.20	2.43
2013	0.05	0.28	0.71	1.45	3.51
2014	0.22	0.51	1.22	4.50	6.07
2015	0.00	0.11	1.10	1.57	3.44
2016	0.00	0.04	0.23	1.49	2.18
2017	0.00	0.22	1.33	1.73	4.88
2018	0.38	0.11	0.64	3.34	6.20
2014-2018 mean	0.12	0.20	0.91	2.53	4.55

DRAF

Table 50. GOM stress indicators: number of days ≥ 20.0° C (left: bottom water, right: sea surface temperature). ** The Buoy B data are from 50 m depth in the water column (below the thermocline), not actual bottom temperature.

	514 Scortons (9.1 m)	514 Rocky Pt (13.7 m)	513 Buoy B (50 m)**	513 Boothbay SST	513 Buoy B SST	512/513 Buoy E SST	512 Buoy F SST
1982				0			
1983				0			
1984				0			
1985				0			
1986				0			
1987				0			
1988				0			
1989		0		0			
1990		0		0			
1991		0		0			
1992		0		0			
1993		0		0			
1994		0		0			
1995		2		0			
1996		0		0			
1997		0		0			
1998		0		0			
1999		0		0			
2000		0		0			
2001		0		1			
2002	2	0	0	12	4	0	0
2003	☒	0	0	2	0	0	0
2004	☒	0	0	☒	0	0	0
2005	☒	0	0	20	0	0	0
2006	☒	0	0	36	7	0	0
2007	☒	☒	0	5	6	0	0
2008	☒	0	0	2	6	0	0
2009	0	0	0	0	8	1	0
2010	0	☒	0	1	11	0	0
2011	0	0	0	3	7	0	0
2012	0	0	0	☒	30	0	0
2013	5	0	0	☒	8	0	1
2014	1	0	0	0	6	0	0
2015	1	0	0	0	16	0	0
2016	3	0	0	0	14	0	0
2017	0	0	0	0	5	0	0
2018	11	1	0	0	23	3	0
2014-2018 mean	3.2	0.2	0	0	12.8	0.6	0

25th	0	0	0	0	5	0	0
median	1	0	0	0	7	0	0
75th	2.5	0	0	0.75	11	0	0

Table 51. GOM fishery performance indicators.

	EFFORT	TOTAL GOM LANDINGS	PARTIAL LANDINGS	PARTIAL GROSS CPUE	PRICE PER POUND (US average)		GOM REVENUE		PARTIAL REVENUE PER TRAP	
Description	**Traps**	**Pounds (all sources)**	**Pounds from jurisdictions with effort data**	**Landings / Traps**	**Un-adjusted**	**Adjusted to Unprocessed Fish CPI**	**Un-adjusted**	**Adjusted to Unprocessed Fish CPI**	**Un-adjusted**	**Adjusted to Unprocessed Fish CPI**
Jurisdiction	***ME & MA***	***All GOM***	***ME & MA***	***ME & MA***	***All stocks***	***All stocks***	***All GOM***	***All GOM***	***ME & MA***	***ME & MA***
1982	2,390,415	32,339,298	31,531,898	13.2	$2.31	$5.19	$74,644,183	$167,749,344	$30	$68
1983	2,599,642	33,221,334	31,910,774	12.3	$2.42	$5.24	$80,408,123	$173,930,577	$30	$64
1984	2,450,165	30,417,633	28,846,342	11.8	$2.69	$5.62	$81,834,767	$170,835,061	$32	$66
1985	2,079,758	32,094,306	30,906,225	14.9	$2.49	$5.04	$79,902,535	$161,681,956	$37	$75
1986	1,926,713	30,459,295	29,518,195	15.3	$2.62	$5.19	$79,761,794	$158,203,610	$40	$80
1987	2,265,169	30,758,952	29,502,782	13.0	$3.09	$5.99	$95,192,407	$184,267,177	$40	$78
1988	2,409,689	32,398,809	31,279,909	13.0	$2.99	$5.58	$96,725,009	$180,858,372	$39	$72
1989	2,352,584	36,833,842	35,403,495	15.0	$2.80	$5.04	$103,155,806	$185,594,306	$42	$76
1990	2,508,703	42,417,483	40,759,133	16.2	$2.48	$4.30	$105,227,291	$182,475,805	$40	$70
1991	2,414,010	44,561,185	42,730,989	17.7	$2.59	$4.34	$115,421,043	$193,616,632	$46	$77
1992	2,400,415	39,097,274	37,567,982	15.7	$2.90	$4.76	$113,577,196	$186,284,080	$45	$75
1993	2,176,641	41,445,728	39,959,800	18.4	$2.77	$4.43	$114,600,373	$183,607,953	$51	$81
1994	3,158,641	52,167,577	50,853,369	16.1	$2.96	$4.65	$154,540,009	$242,423,977	$48	$75
1995	2,785,305	50,476,397	48,911,325	17.6	$3.06	$4.71	$154,683,136	$237,659,760	$54	$83
1996	2,840,418	48,694,981	47,309,440	16.7	$3.39	$5.11	$164,871,538	$248,762,452	$56	$85
1997	2,972,461	58,617,713	57,417,747	19.3	$3.29	$4.88	$192,781,996	$285,941,368	$64	$94
1998	3,227,203	56,718,508	55,704,780	17.3	$3.18	$4.67	$180,510,570	$264,761,265	$55	$81
1999	3,430,568	65,917,304	64,760,803	18.9	$3.69	$5.34	$243,529,356	$352,112,315	$70	$101
2000	3,160,188	69,958,725	68,491,852	21.7	$3.61	$5.11	$252,876,383	$357,629,312	$78	$111
2001	3,342,730	58,434,874	56,714,244	17.0	$3.50	$4.85	$204,796,782	$283,402,135	$59	$82
2002	3,485,434	74,408,863	72,686,394	20.9	$3.54	$4.82	$263,197,057	$358,552,227	$74	$100
2003	3,589,667	64,133,003	62,615,223	17.4	$3.96	$5.29	$253,654,705	$339,271,734	$69	$92
2004	3,595,462	81,626,937	79,417,673	22.1	$4.18	$5.45	$341,396,629	$444,660,722	$92	$120
2005	3,630,301	77,206,666	75,761,371	20.9	$4.75	$6.01	$367,099,588	$463,688,442	$99	$125
2006	3,634,959	82,180,681	80,499,503	22.1	$4.21	$5.16	$345,753,320	$423,880,489	$93	$114
2007	3,612,826	72,886,377	71,189,236	19.7	$4.54	$5.42	$330,789,425	$394,929,112	$89	$107
2008	3,510,545	79,923,716	77,970,463	22.2	$3.69	$4.33	$295,197,266	$345,684,213	$82	$96
2009	3,416,877	92,543,480	90,057,338	26.4	$3.08	$3.58	$285,109,788	$331,362,260	$81	$94
2010	3,347,658	108,264,068	105,396,910	31.5	$3.44	$3.95	$372,057,287	$427,447,732	$108	$124
2011	3,304,391	118,028,748	114,781,425	34.7	$3.35	$3.77	$395,125,028	$444,656,984	$116	$131
2012	3,286,752	141,656,903	137,979,552	42.0	$2.86	$3.16	$405,662,899	$447,917,275	$120	$133
2013	3,232,683	141,815,997	139,046,939	43.0	$3.06	$3.32	$434,120,712	$471,083,450	$132	$143
2014	3,207,426	139,243,469	135,666,309	42.3	$3.83	$4.08	$533,511,177	$568,428,296	$162	$173
2015	3,228,523	138,971,065	135,124,413	41.9	$4.23	$4.46	$588,034,155	$620,038,526	$177	$187
2016	3,171,099	150,919,162	146,397,215	46.2	$4.20	$4.39	$634,604,818	$662,297,324	$194	$203
2017	3,198,809	127,722,833	123,982,663	38.8	$4.14	$4.24	$529,146,557	$542,037,873	$161	$164
2018	3,154,426	137,773,040	133,493,722	42.3	$4.27	$4.27	$588,209,704	$588,209,704	$181	$181
2014-2018 mean	**3,192,057**	**138,925,914**	**134,932,864**	**42.3**	**$4.14**	**$4.29**	**$574,701,282**	**$596,202,344**	**$175**	**$181**

25th	2,450,165	41,445,728	39,959,800	16.1	$2.86	$4.33	$113,577,196	$185,594,306	$45	$77
median	3,171,099	64,133,003	62,615,223	18.9	$3.29	$4.82	$243,529,356	$331,362,260	$69	$94
75th	3,347,658	92,543,480	90,057,338	26.4	$3.83	$5.19	$367,099,588	$444,656,984	$99	$124

Table 52. GBK abundance indicator: SSB.

SPAWNING STOCK ABUNDANCE		
Mean weight (g) per tow of mature females		
Survey	*NESFC*	
	fall	*spring*
1981	707.14	69.71
1982	670.07	123.96
1983	643.84	152.05
1984	397.33	45.17
1985	504.87	39.00
1986	491.96	307.05
1987	537.31	113.27
1988	695.27	307.49
1989	933.18	161.43
1990	761.64	103.62
1991	848.03	164.32
1992	817.25	213.11
1993	626.81	126.03
1994	774.61	41.77
1995	939.85	71.74
1996	1051.09	482.61
1997	754.00	62.46
1998	993.56	64.67
1999	1363.68	395.66
2000	945.69	132.57
2001	1756.38	313.41
2002	2183.80	341.90
2003	1030.19	842.92
2004	1557.16	298.95
2005	1404.20	491.00
2006	2123.43	465.72
2007	1859.53	728.26
2008	3074.33	1827.61
2009	3703.99	1336.34
2010	2120.51	1126.52
2011	4681.76	1113.11
2012	2696.38	1510.08
2013	2530.26	1369.39
2014	3012.69	1833.98
2015	3743.71	1509.13
2016	3020.98	2138.96
2017	6627.18	3749.60
2018	9630.86	725.09
2014-2018 mean	5207.09	1991.35

25th	755.91	124.47
median	1040.64	310.45
75th	2443.64	1045.56

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Table 53. GBK abundance indicator: full recruit abundance.

FULL RECRUIT ABUNDANCE (SURVEY)		
Abundance of lobsters ≥ 90 mm CL (sexes combined)		
Survey	*NEFSC*	
	fall	*spring*
1981	0.813	0.129
1982	0.819	0.250
1983	0.747	0.255
1984	0.687	0.075
1985	0.678	0.178
1986	0.821	0.400
1987	0.530	0.158
1988	0.918	0.471
1989	1.104	0.272
1990	0.755	0.114
1991	1.035	0.234
1992	0.831	0.396
1993	0.694	0.313
1994	0.888	0.088
1995	0.781	0.104
1996	0.955	0.541
1997	1.093	0.090
1998	0.856	0.090
1999	1.322	0.580
2000	1.021	0.267
2001	1.646	0.471
2002	2.124	0.578
2003	0.874	0.893
2004	1.555	0.335
2005	1.281	0.533
2006	1.555	0.540
2007	1.623	0.721
2008	2.571	1.520
2009	2.670	1.122
2010	1.514	1.264
2011	3.606	1.071
2012	2.095	1.562
2013	2.285	0.978
2014	2.310	1.856
2015	3.504	1.371
2016	2.697	2.188
2017	5.699	4.292
2018	7.722	0.876
2014-2018 mean	4.386	2.116

25th	0.824	0.238
median	1.099	0.471
75th	2.117	0.957

Table 54. GBK abundance indicator: recruit abundance.

RECRUIT ABUNDANCE (SURVEY)		
Abundance of lobsters 71 - 80 mm CL (sexes combined)		
	NEFSC	
Survey	***fall***	***spring***
1981	0.286	0.073
1982	0.433	0.155
1983	0.292	0.167
1984	0.407	0.046
1985	0.167	0.220
1986	0.600	0.495
1987	0.442	0.315
1988	0.405	0.242
1989	0.117	0.169
1990	0.326	0.320
1991	0.298	0.170
1992	0.566	0.128
1993	0.289	0.684
1994	0.125	0.080
1995	0.197	0.028
1996	0.378	0.012
1997	0.647	0.000
1998	0.361	0.012
1999	0.238	0.031
2000	0.445	0.268
2001	0.571	0.429
2002	0.489	0.091
2003	0.328	0.227
2004	0.277	0.074
2005	0.129	0.072
2006	0.098	0.221
2007	0.189	0.054
2008	0.126	0.134
2009	0.220	0.139
2010	0.050	0.105
2011	0.299	0.024
2012	0.096	0.082
2013	0.131	0.066
2014	0.103	0.067
2015	0.097	0.041
2016	0.104	0.111
2017	0.370	0.155
2018	0.138	0.035
2014-2018 mean	0.162	0.082

25th	0.129	0.057
median	0.288	0.108
75th	0.398	0.207

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Table 55. GBK abundance indicator: survey encounter rate.

SURVEY LOBSTER ENCOUNTER RATE

Proportion of postive tows

Survey	*NEFSC*	
	fall	*spring*
1981	0.524	0.247
1982	0.432	0.227
1983	0.378	0.179
1984	0.354	0.122
1985	0.346	0.192
1986	0.359	0.272
1987	0.354	0.174
1988	0.395	0.342
1989	0.377	0.147
1990	0.432	0.182
1991	0.455	0.179
1992	0.486	0.261
1993	0.364	0.224
1994	0.384	0.114
1995	0.418	0.143
1996	0.388	0.162
1997	0.470	0.103
1998	0.397	0.101
1999	0.564	0.156
2000	0.403	0.215
2001	0.494	0.213
2002	0.550	0.286
2003	0.438	0.273
2004	0.531	0.184
2005	0.577	0.165
2006	0.538	0.225
2007	0.461	0.261
2008	0.548	0.294
2009	0.541	0.337
2010	0.628	0.381
2011	0.686	0.279
2012	0.560	0.349
2013	0.648	0.317
2014	0.611	0.370
2015	0.586	0.264
2016	0.549	0.448
2017	0.613	0.396
2018	0.585	0.293
2014-2018 mean	0.589	0.354

25th	0.396	0.175
median	0.478	0.226
75th	0.558	0.291

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Table 56. GBK mortality indicator: relative exploitation.

EXPLOITATION RATE (landings / survey ref. pop'n) Landings (lbs) by area / Reference pop'n (survey weights (lbs) > 77 mm, sexes combined)		
Survey	*NESFC*	
	fall	*spring*
1982	1.090	1.111
1983	1.212	1.235
1984	1.374	2.590
1985	1.437	2.273
1986	1.110	0.903
1987	1.258	1.084
1988	1.299	0.885
1989	0.934	0.664
1990	1.074	1.178
1991	1.241	1.546
1992	1.288	1.151
1993	1.358	0.817
1994	1.174	1.066
1995	1.117	2.196
1996	0.950	0.966
1997	0.809	1.172
1998	0.879	2.854
1999	0.950	0.992
2000	0.758	0.749
2001	0.723	0.774
2002	0.617	0.653
2003	0.913	0.626
2004	1.338	0.843
2005	1.495	1.618
2006	1.448	1.180
2007	1.061	0.812
2008	0.818	0.488
2009	0.684	0.439
2010	0.992	0.580
2011	0.800	0.602
2012	0.708	0.536
2013	0.937	0.541
2014	0.812	0.436
2015	0.667	0.416
2016	0.691	0.409
2017	0.594	0.269
2018	0.391	0.346
2014-2018 mean	0.631	0.375

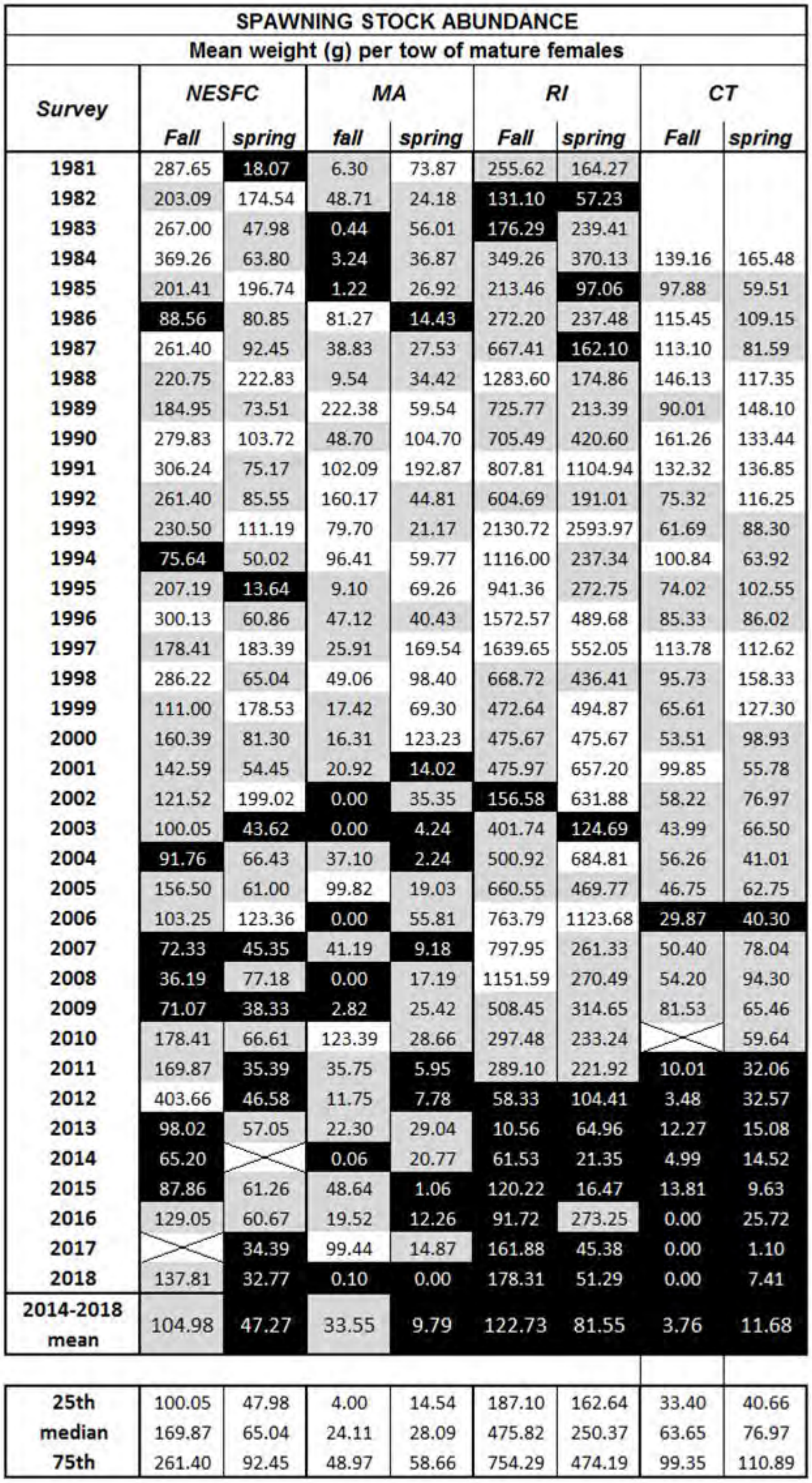
25th	0.800	0.580
median	0.950	0.843
75th	1.241	1.172

Table 57. GBK fishery performance indicators.

	PARTIAL EFFORT	TOTAL GBK LANDINGS	PARTIAL LANDINGS	PARTIAL GROSS CPUE	PRICE PER POUND (US average)		GBK REVENUE		PARTIAL REVENUE PER TRAP	
Description	**Traps**	**Pounds (all sources)**	**Pounds from jurisdictions with effort data**	**Landings / Traps**	**Un-adjusted**	**Adjusted to Unprocessed Fish CPI**	**Un-adjusted**	**Adjusted to Unprocessed Fish CPI**	**Un-adjusted**	**Adjusted to Unprocessed Fish CPI**
Jurisdiction	***MA***	***All GBK***	***MA***	***MA***	***All stocks***	***All stocks***	***All GBK***	***All GBK***	***MA***	***MA***
1982	27,560	2,869,149	1,301,273	47.2	$2.31	$5.19	$6,622,447	$14,882,755	$109	$245
1983	28,922	3,190,486	1,301,843	45.0	$2.42	$5.24	$7,722,176	$16,703,817	$109	$236
1984	30,651	3,297,839	1,650,155	53.8	$2.69	$5.62	$8,872,416	$18,521,708	$145	$302
1985	34,950	3,281,605	1,644,547	47.1	$2.49	$5.04	$8,169,940	$16,531,790	$117	$237
1986	36,950	2,739,725	1,375,295	37.2	$2.62	$5.19	$7,174,341	$14,229,955	$97	$193
1987	39,674	2,901,600	1,826,275	46.0	$3.09	$5.99	$8,979,834	$17,382,570	$142	$276
1988	39,732	3,123,131	2,052,972	51.7	$2.99	$5.58	$9,323,950	$17,434,110	$154	$288
1989	39,163	2,923,821	2,126,030	54.3	$2.80	$5.04	$8,188,370	$14,732,227	$152	$274
1990	35,891	3,019,812	2,128,150	59.3	$2.48	$4.30	$7,491,408	$12,990,933	$147	$255
1991	36,784	3,480,944	2,061,698	56.0	$2.59	$4.34	$9,016,235	$15,124,566	$145	$244
1992	38,745	3,745,881	2,485,009	64.1	$2.90	$4.76	$10,881,748	$17,847,741	$186	$306
1993	43,041	3,384,968	2,457,898	57.1	$2.77	$4.43	$9,359,675	$14,995,683	$158	$253
1994	47,894	2,813,716	2,080,429	43.4	$2.96	$4.65	$8,335,287	$13,075,407	$129	$202
1995	44,480	2,666,353	2,029,253	45.6	$3.06	$4.71	$8,170,945	$12,554,082	$140	$215
1996	42,008	2,600,327	1,989,099	47.4	$3.39	$5.11	$8,804,191	$13,283,991	$160	$242
1997	40,974	2,724,839	2,112,082	51.5	$3.29	$4.88	$8,961,454	$13,291,959	$170	$251
1998	45,327	2,691,913	2,123,457	46.8	$3.18	$4.67	$8,567,200	$12,565,817	$149	$219
1999	47,941	3,112,706	2,388,034	49.8	$3.69	$5.34	$11,499,790	$16,627,227	$184	$266
2000	41,464	2,801,346	2,111,323	50.9	$3.61	$5.11	$10,125,887	$14,320,491	$184	$260
2001	40,899	2,966,042	2,378,304	58.2	$3.50	$4.85	$10,395,092	$14,384,949	$204	$282
2002	47,387	3,404,579	2,857,929	60.3	$3.54	$4.82	$12,042,585	$16,405,562	$213	$291
2003	42,834	4,101,791	2,838,611	66.3	$3.96	$5.29	$16,223,137	$21,698,994	$262	$351
2004	43,837	4,557,555	3,078,390	70.2	$4.18	$5.45	$19,061,526	$24,827,169	$294	$383
2005	40,694	5,508,854	3,453,503	84.9	$4.75	$6.01	$26,193,308	$33,085,121	$404	$510
2006	40,175	5,222,485	3,301,837	82.2	$4.21	$5.16	$21,972,214	$26,937,103	$346	$424
2007	43,011	4,285,054	2,895,336	67.3	$4.54	$5.42	$19,447,402	$23,218,231	$306	$365
2008	40,843	4,324,559	3,008,869	73.7	$3.69	$4.33	$15,972,706	$18,704,483	$272	$319
2009	38,400	4,510,717	3,250,594	84.7	$3.08	$3.58	$13,896,708	$16,151,127	$261	$303
2010	50,716	5,225,069	3,516,530	69.3	$3.44	$3.95	$17,956,328	$20,629,597	$238	$274
2011	43,815	5,227,993	3,585,291	81.8	$3.35	$3.77	$17,501,761	$19,695,742	$274	$308
2012	46,086	5,139,369	3,598,202	78.1	$2.86	$3.16	$14,717,613	$16,250,618	$224	$247
2013	46,462	5,090,271	3,359,516	72.3	$3.06	$3.32	$15,582,106	$16,908,828	$221	$240
2014	44,763	4,640,107	3,216,039	71.8	$3.83	$4.08	$17,778,563	$18,942,130	$275	$293
2015	44,781	4,903,572	3,263,265	72.9	$4.23	$4.46	$20,748,694	$21,877,963	$308	$325
2016	49,667	5,451,157	3,386,620	68.2	$4.20	$4.39	$22,921,745	$23,921,990	$287	$299
2017	47,002	6,391,343	3,897,737	82.9	$4.14	$4.24	$26,478,875	$27,123,966	$344	$352
2018	47,385	6,460,893	4,043,723	85.3	$4.27	$4.27	$27,584,204	$27,584,204	$364	$364
2014-2018 mean	**46,720**	**5,569,414**	**3,561,477**	**76.2**	**$4.14**	**$4.29**	**$23,102,416**	**$23,890,051**	**$316**	**$327**

25th	39,163	2,923,821	2,061,698	49.8	$2.86	$4.33	$8,804,191	$14,732,227	$147	$245
median	42,008	3,404,579	2,457,898	59.3	$3.29	$4.82	$10,881,748	$16,703,817	$186	$276
75th	45,327	4,903,572	3,263,265	72.3	$3.83	$5.19	$17,778,563	$20,629,597	$274	$308

Table 58. SNE abundance indicators: spawning stock abundance.

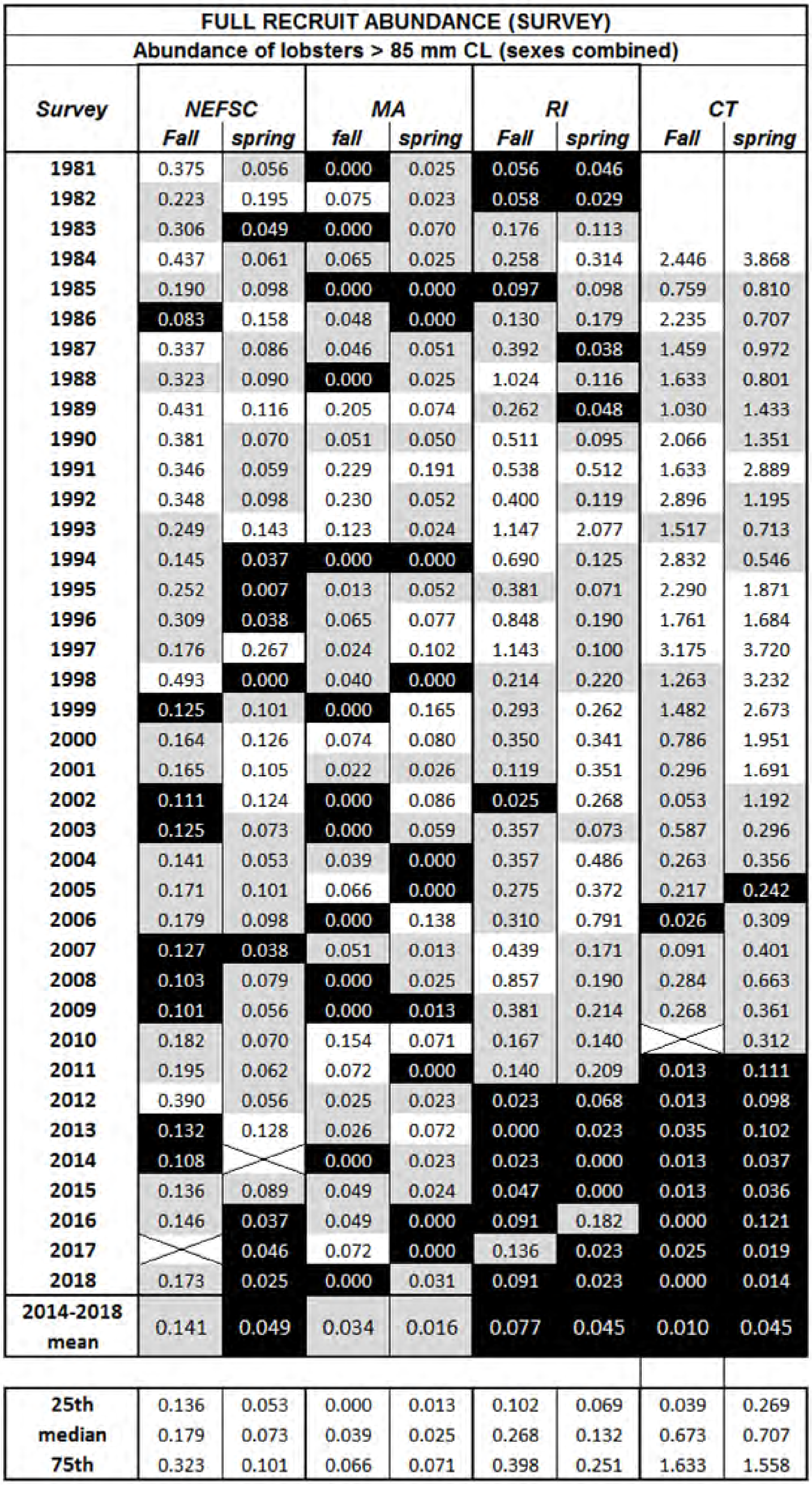


SPAWNING STOCK ABUNDANCE

Mean weight (g) per tow of mature females

Survey	NESFC		MA		RI		CT	
	Fall	spring	fall	spring	Fall	spring	Fall	spring
1981	287.65	18.07	6.30	73.87	255.62	164.27		
1982	203.09	174.54	48.71	24.18	131.10	57.23		
1983	267.00	47.98	0.44	56.01	176.29	239.41		
1984	369.26	63.80	3.24	36.87	349.26	370.13	139.16	165.48
1985	201.41	196.74	1.22	26.92	213.46	97.06	97.88	59.51
1986	88.56	80.85	81.27	14.43	272.20	237.48	115.45	109.15
1987	261.40	92.45	38.83	27.53	667.41	162.10	113.10	81.59
1988	220.75	222.83	9.54	34.42	1283.60	174.86	146.13	117.35
1989	184.95	73.51	222.38	59.54	725.77	213.39	90.01	148.10
1990	279.83	103.72	48.70	104.70	705.49	420.60	161.26	133.44
1991	306.24	75.17	102.09	192.87	807.81	1104.94	132.32	136.85
1992	261.40	85.55	160.17	44.81	604.69	191.01	75.32	116.25
1993	230.50	111.19	79.70	21.17	2130.72	2593.97	61.69	88.30
1994	75.64	50.02	96.41	59.77	1116.00	237.34	100.84	63.92
1995	207.19	13.64	9.10	69.26	941.36	272.75	74.02	102.55
1996	300.13	60.86	47.12	40.43	1572.57	489.68	85.33	86.02
1997	178.41	183.39	25.91	169.54	1639.65	552.05	113.78	112.62
1998	286.22	65.04	49.06	98.40	668.72	436.41	95.73	158.33
1999	111.00	178.53	17.42	69.30	472.64	494.87	65.61	127.30
2000	160.39	81.30	16.31	123.23	475.67	475.67	53.51	98.93
2001	142.59	54.45	20.92	14.02	475.97	657.20	99.85	55.78
2002	121.52	199.02	0.00	35.35	156.58	631.88	58.22	76.97
2003	100.05	43.62	0.00	4.24	401.74	124.69	43.99	66.50
2004	91.76	66.43	37.10	2.24	500.92	684.81	56.26	41.01
2005	156.50	61.00	99.82	19.03	660.55	469.77	46.75	62.75
2006	103.25	123.36	0.00	55.81	763.79	1123.68	29.87	40.30
2007	72.33	45.35	41.19	9.18	797.95	261.33	50.40	78.04
2008	36.19	77.18	0.00	17.19	1151.59	270.49	54.20	94.30
2009	71.07	38.33	2.82	25.42	508.45	314.65	81.53	65.46
2010	178.41	66.61	123.39	28.66	297.48	233.24	☒	59.64
2011	169.87	35.39	35.75	5.95	289.10	221.92	10.01	32.06
2012	403.66	46.58	11.75	7.78	58.33	104.41	3.48	32.57
2013	98.02	57.05	22.30	29.04	10.56	64.96	12.27	15.08
2014	65.20	☒	0.06	20.77	61.53	21.35	4.99	14.52
2015	87.86	61.26	48.64	1.06	120.22	16.47	13.81	9.63
2016	129.05	60.67	19.52	12.26	91.72	273.25	0.00	25.72
2017	☒	34.39	99.44	14.87	161.88	45.38	0.00	1.10
2018	137.81	32.77	0.10	0.00	178.31	51.29	0.00	7.41
2014-2018 mean	104.98	47.27	33.55	9.79	122.73	81.55	3.76	11.68
25th	100.05	47.98	4.00	14.54	187.10	162.64	33.40	40.66
median	169.87	65.04	24.11	28.09	475.82	250.37	63.65	76.97
75th	261.40	92.45	48.97	58.66	754.29	474.19	99.35	110.89

Table 59. SNE abundance indicators: full recruit abundance.



FULL RECRUIT ABUNDANCE (SURVEY)

Abundance of lobsters > 85 mm CL (sexes combined)

Survey	NEFSC		MA		RI		CT	
	Fall	spring	fall	spring	Fall	spring	Fall	spring
1981	0.375	0.056	0.000	0.025	0.056	0.046		
1982	0.223	0.195	0.075	0.023	0.058	0.029		
1983	0.306	0.049	0.000	0.070	0.176	0.113		
1984	0.437	0.061	0.065	0.025	0.258	0.314	2.446	3.868
1985	0.190	0.098	0.000	0.000	0.097	0.098	0.759	0.810
1986	0.083	0.158	0.048	0.000	0.130	0.179	2.235	0.707
1987	0.337	0.086	0.046	0.051	0.392	0.038	1.459	0.972
1988	0.323	0.090	0.000	0.025	1.024	0.116	1.633	0.801
1989	0.431	0.116	0.205	0.074	0.262	0.048	1.030	1.433
1990	0.381	0.070	0.051	0.050	0.511	0.095	2.066	1.351
1991	0.346	0.059	0.229	0.191	0.538	0.512	1.633	2.889
1992	0.348	0.098	0.230	0.052	0.400	0.119	2.896	1.195
1993	0.249	0.143	0.123	0.024	1.147	2.077	1.517	0.713
1994	0.145	0.037	0.000	0.000	0.690	0.125	2.832	0.546
1995	0.252	0.007	0.013	0.052	0.381	0.071	2.290	1.871
1996	0.309	0.038	0.065	0.077	0.848	0.190	1.761	1.684
1997	0.176	0.267	0.024	0.102	1.143	0.100	3.175	3.720
1998	0.493	0.000	0.040	0.000	0.214	0.220	1.263	3.232
1999	0.125	0.101	0.000	0.165	0.293	0.262	1.482	2.673
2000	0.164	0.126	0.074	0.080	0.350	0.341	0.786	1.951
2001	0.165	0.105	0.022	0.026	0.119	0.351	0.296	1.691
2002	0.111	0.124	0.000	0.086	0.025	0.268	0.053	1.192
2003	0.125	0.073	0.000	0.059	0.357	0.073	0.587	0.296
2004	0.141	0.053	0.039	0.000	0.357	0.486	0.263	0.356
2005	0.171	0.101	0.066	0.000	0.275	0.372	0.217	0.242
2006	0.179	0.098	0.000	0.138	0.310	0.791	0.026	0.309
2007	0.127	0.038	0.051	0.013	0.439	0.171	0.091	0.401
2008	0.103	0.079	0.000	0.025	0.857	0.190	0.284	0.663
2009	0.101	0.056	0.000	0.013	0.381	0.214	0.268	0.361
2010	0.182	0.070	0.154	0.071	0.167	0.140		0.312
2011	0.195	0.062	0.072	0.000	0.140	0.209	0.013	0.111
2012	0.390	0.056	0.025	0.023	0.023	0.068	0.013	0.098
2013	0.132	0.128	0.026	0.072	0.000	0.023	0.035	0.102
2014	0.108		0.000	0.023	0.023	0.000	0.013	0.037
2015	0.136	0.089	0.049	0.024	0.047	0.000	0.013	0.036
2016	0.146	0.037	0.049	0.000	0.091	0.182	0.000	0.121
2017		0.046	0.072	0.000	0.136	0.023	0.025	0.019
2018	0.173	0.025	0.000	0.031	0.091	0.023	0.000	0.014
2014-2018 mean	0.141	0.049	0.034	0.016	0.077	0.045	0.010	0.045

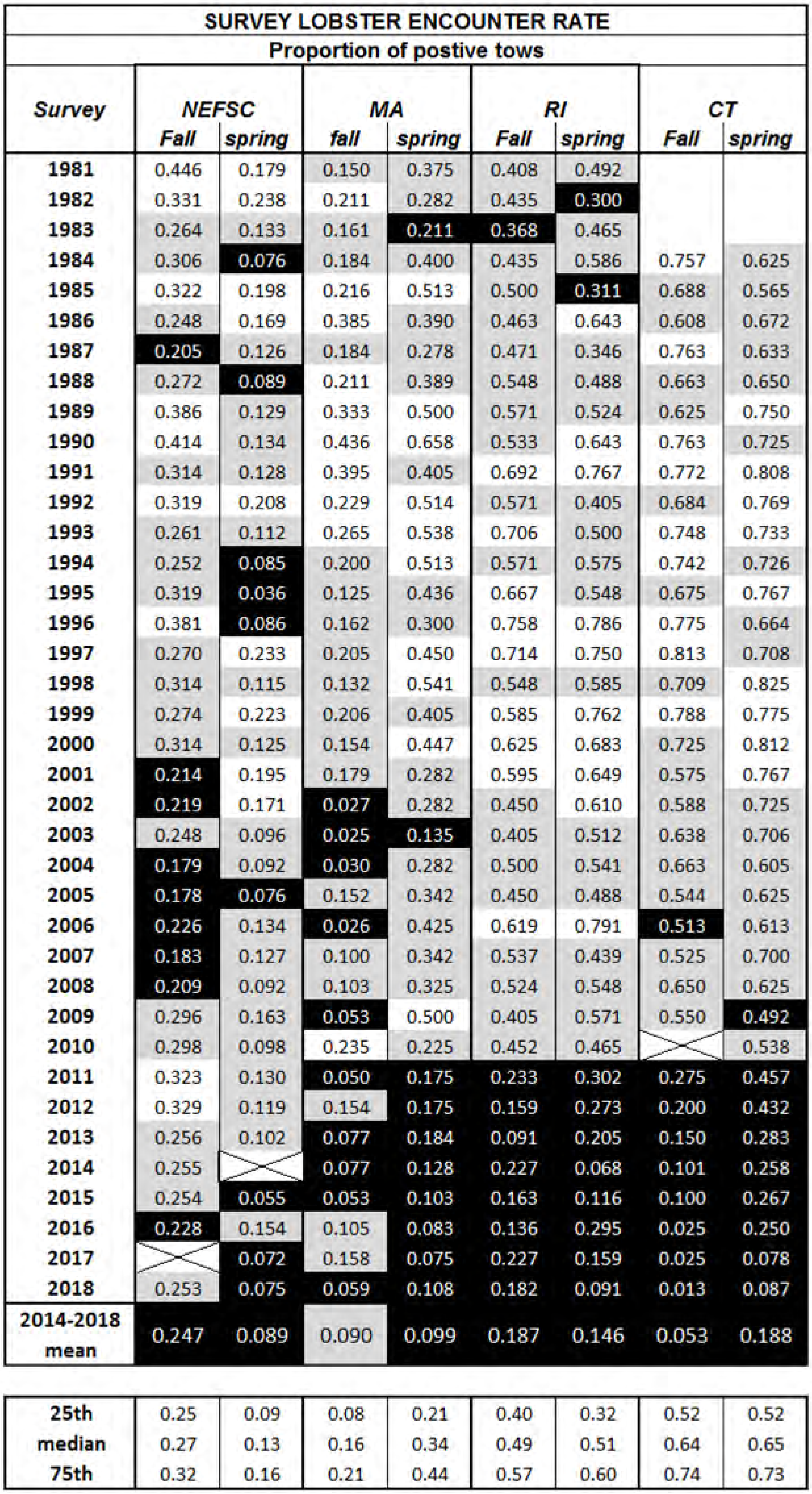
25th	0.136	0.053	0.000	0.013	0.102	0.069	0.039	0.269
median	0.179	0.073	0.039	0.025	0.268	0.132	0.673	0.707
75th	0.323	0.101	0.066	0.071	0.398	0.251	1.633	1.558

Table 60. SNE abundance indicators: recruit abundance.

RECRUIT ABUNDANCE (SURVEY)								
Abundance of lobsters 71 - 80 mm CL (sexes combined)								
Survey	*NEFSC*		*MA*		*RI*		*CT*	
	Fall	*spring*	*fall*	*spring*	*Fall*	*spring*	*Fall*	*spring*
1981	0.983	0.127	0.066	0.657	1.310	0.892		
1982	0.653	0.713	0.039	0.101	0.638	0.257		
1983	0.783	0.324	0.044	0.095	0.426	0.944		
1984	0.529	0.145	0.013	0.422	1.355	1.029	7.957	10.885
1985	0.829	1.710	0.088	0.333	0.968	0.279	4.270	3.209
1986	0.359	0.208	0.193	0.168	1.278	0.911	6.542	2.933
1987	0.534	0.739	0.168	0.266	3.137	0.788	7.427	3.271
1988	0.672	0.434	0.160	0.238	4.048	0.465	5.437	1.995
1989	1.339	0.124	0.420	0.139	3.262	0.905	5.843	5.332
1990	0.855	0.620	0.315	2.338	2.689	2.167	8.271	7.570
1991	0.597	0.397	0.868	1.231	3.103	4.767	11.414	11.564
1992	0.940	0.140	0.554	0.097	1.971	0.619	11.774	11.363
1993	0.424	0.734	0.517	0.249	8.294	7.808	16.833	8.400
1994	0.391	0.218	0.420	0.947	3.881	1.000	12.706	5.480
1995	0.622	0.007	0.028	1.127	4.500	1.333	12.669	13.123
1996	1.672	0.313	0.320	0.398	6.545	1.595	12.079	12.317
1997	1.187	1.321	0.123	1.437	6.095	2.575	27.692	16.876
1998	1.096	0.799	0.110	1.112	3.238	1.634	13.967	26.200
1999	0.444	2.048	0.194	0.734	2.073	1.714	14.148	26.959
2000	1.154	0.622	0.134	0.552	1.825	1.537	8.270	13.371
2001	0.375	0.388	0.027	0.182	2.167	2.973	7.414	10.803
2002	0.468	1.340	0.000	0.336	0.725	2.683	2.748	8.108
2003	0.422	0.448	0.000	0.070	0.929	0.293	4.083	3.516
2004	0.289	0.271	0.000	0.052	1.476	1.865	3.366	2.377
2005	0.206	0.134	0.000	0.079	2.525	1.070	1.539	2.258
2006	0.255	0.279	0.034	0.086	2.238	3.628	1.402	2.166
2007	0.360	0.235	0.000	0.074	2.683	0.683	1.217	2.918
2008	0.266	0.275	0.013	0.158	2.952	0.643	1.342	2.514
2009	0.167	0.102	0.047	0.161	1.357	1.143	1.433	1.332
2010	0.314	0.144	0.189	0.054	1.214	0.442		1.386
2011	0.276	0.082	0.000	0.186	1.023	0.419	0.200	0.452
2012	0.361	0.085	0.213	0.065	0.182	0.295	0.085	0.481
2013	0.266	0.070	0.037	0.108	0.023	0.159	0.060	0.239
2014	0.327		0.000	0.043	0.136	0.023	0.051	0.167
2015	0.183	0.010	0.298	0.074	0.372	0.047	0.081	0.161
2016	0.405	0.390	0.134	0.049	0.250	0.568	0.000	0.204
2017		0.059	0.162	0.129	0.409	0.136	0.000	0.047
2018	0.265	0.080	0.013	0.023	0.682	0.182	0.013	0.000
2014-2018 mean	0.295	0.135	0.121	0.063	0.370	0.191	0.029	0.116

25th	0.314	0.127	0.016	0.081	0.776	0.424	1.248	1.359
median	0.424	0.275	0.099	0.164	1.651	0.908	4.853	3.209
75th	0.783	0.620	0.194	0.416	3.065	1.624	10.628	10.844

Table 61. SNE abundance indicators: survey encounter rate.



SURVEY LOBSTER ENCOUNTER RATE

Proportion of postive tows

Survey	NEFSC		MA		RI		CT	
	Fall	spring	fall	spring	Fall	spring	Fall	spring
1981	0.446	0.179	0.150	0.375	0.408	0.492		
1982	0.331	0.238	0.211	0.282	0.435	0.300		
1983	0.264	0.133	0.161	0.211	0.368	0.465		
1984	0.306	0.076	0.184	0.400	0.435	0.586	0.757	0.625
1985	0.322	0.198	0.216	0.513	0.500	0.311	0.688	0.565
1986	0.248	0.169	0.385	0.390	0.463	0.643	0.608	0.672
1987	0.205	0.126	0.184	0.278	0.471	0.346	0.763	0.633
1988	0.272	0.089	0.211	0.389	0.548	0.488	0.663	0.650
1989	0.386	0.129	0.333	0.500	0.571	0.524	0.625	0.750
1990	0.414	0.134	0.436	0.658	0.533	0.643	0.763	0.725
1991	0.314	0.128	0.395	0.405	0.692	0.767	0.772	0.808
1992	0.319	0.208	0.229	0.514	0.571	0.405	0.684	0.769
1993	0.261	0.112	0.265	0.538	0.706	0.500	0.748	0.733
1994	0.252	0.085	0.200	0.513	0.571	0.575	0.742	0.726
1995	0.319	0.036	0.125	0.436	0.667	0.548	0.675	0.767
1996	0.381	0.086	0.162	0.300	0.758	0.786	0.775	0.664
1997	0.270	0.233	0.205	0.450	0.714	0.750	0.813	0.708
1998	0.314	0.115	0.132	0.541	0.548	0.585	0.709	0.825
1999	0.274	0.223	0.206	0.405	0.585	0.762	0.788	0.775
2000	0.314	0.125	0.154	0.447	0.625	0.683	0.725	0.812
2001	0.214	0.195	0.179	0.282	0.595	0.649	0.575	0.767
2002	0.219	0.171	0.027	0.282	0.450	0.610	0.588	0.725
2003	0.248	0.096	0.025	0.135	0.405	0.512	0.638	0.706
2004	0.179	0.092	0.030	0.282	0.500	0.541	0.663	0.605
2005	0.178	0.076	0.152	0.342	0.450	0.488	0.544	0.625
2006	0.226	0.134	0.026	0.425	0.619	0.791	0.513	0.613
2007	0.183	0.127	0.100	0.342	0.537	0.439	0.525	0.700
2008	0.209	0.092	0.103	0.325	0.524	0.548	0.650	0.625
2009	0.296	0.163	0.053	0.500	0.405	0.571	0.550	0.492
2010	0.298	0.098	0.235	0.225	0.452	0.465		0.538
2011	0.323	0.130	0.050	0.175	0.233	0.302	0.275	0.457
2012	0.329	0.119	0.154	0.175	0.159	0.273	0.200	0.432
2013	0.256	0.102	0.077	0.184	0.091	0.205	0.150	0.283
2014	0.255		0.077	0.128	0.227	0.068	0.101	0.258
2015	0.254	0.055	0.053	0.103	0.163	0.116	0.100	0.267
2016	0.228	0.154	0.105	0.083	0.136	0.295	0.025	0.250
2017		0.072	0.158	0.075	0.227	0.159	0.025	0.078
2018	0.253	0.075	0.059	0.108	0.182	0.091	0.013	0.087
2014-2018 mean	0.247	0.089	0.090	0.099	0.187	0.146	0.053	0.188

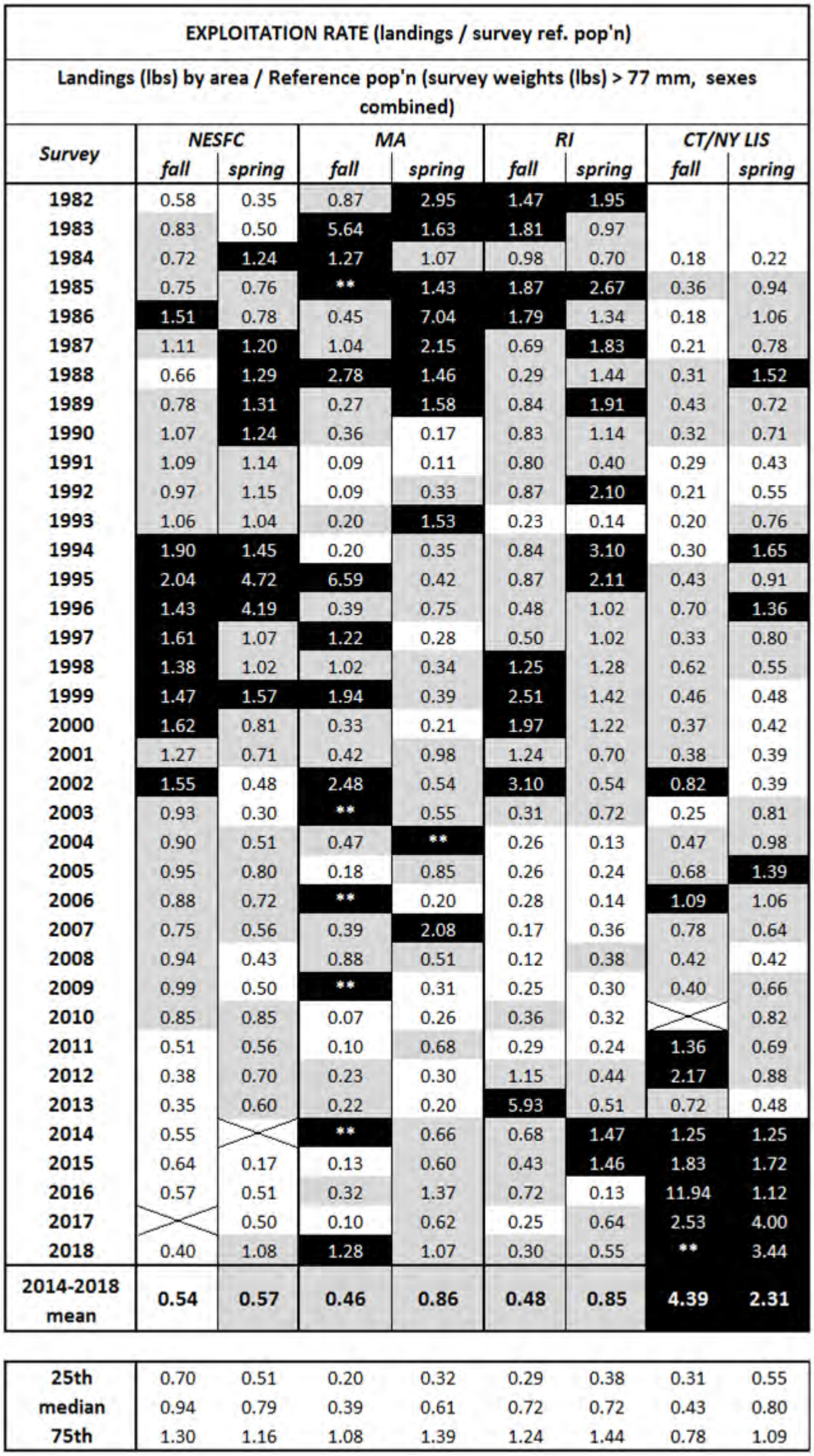
25th	0.25	0.09	0.08	0.21	0.40	0.32	0.52	0.52
median	0.27	0.13	0.16	0.34	0.49	0.51	0.64	0.65
75th	0.32	0.16	0.21	0.44	0.57	0.60	0.74	0.73

Table 62. SNE abundance indicators: YOY indices.

YOUNG-OF-YEAR INDICES				
	YOY	YOY	Larvae	Postlarvae
Survey	*MA*	*RI*	*CT / ELIS* *Summer*	*CT_NY / WLIS* *Summer*
1981				
1982				
1983				14.480
1984			0.429	6.890
1985			0.527	66.750
1986			0.898	4.580
1987			0.775	18.980
1988			0.739	49.270
1989			0.739	5.880
1990		1.127	0.806	19.660
1991		1.449	0.546	9.970
1992		0.634	1.435	14.120
1993		0.513	1.186	26.230
1994		1.208	0.975	96.520
1995	0.167	0.340	1.463	18.200
1996	0.000	0.151	0.305	12.070
1997	0.083	0.958	0.209	13.692
1998	0.200	0.543	0.547	4.850
1999	0.033	0.908	2.830	39.703
2000	0.333	0.278	0.777	14.279
2001	0.100	0.722	0.319	9.460
2002	0.100	0.248	0.638	1.988
2003	0.034	0.702	0.251	2.600
2004	0.034	0.396	0.453	6.100
2005	0.134	0.535	0.490	6.900
2006	0.168	0.444	0.709	1.700
2007	0.100	0.538	0.372	18.100
2008	0.000	0.139	0.374	8.100
2009	0.033	0.056	0.193	7.620
2010	0.000	0.083	0.350	9.910
2011	0.034	0.000	0.262	5.900
2012	0.000	0.089	0.124	2.770
2013	0.134	0.194	0.159	
2014	0.066	0.222	0.059	
2015	0.000	0.167	0.190	
2016	0.000	0.028	0.447	
2017	0.000	0.028	0.100	
2018	0.000	0.028	0.165	
2014-2018 mean	0.013	0.094	0.192	

25th	0.000	0.139	0.257	5.950
median	0.034	0.340	0.453	9.940
75th	0.109	0.634	0.757	18.175

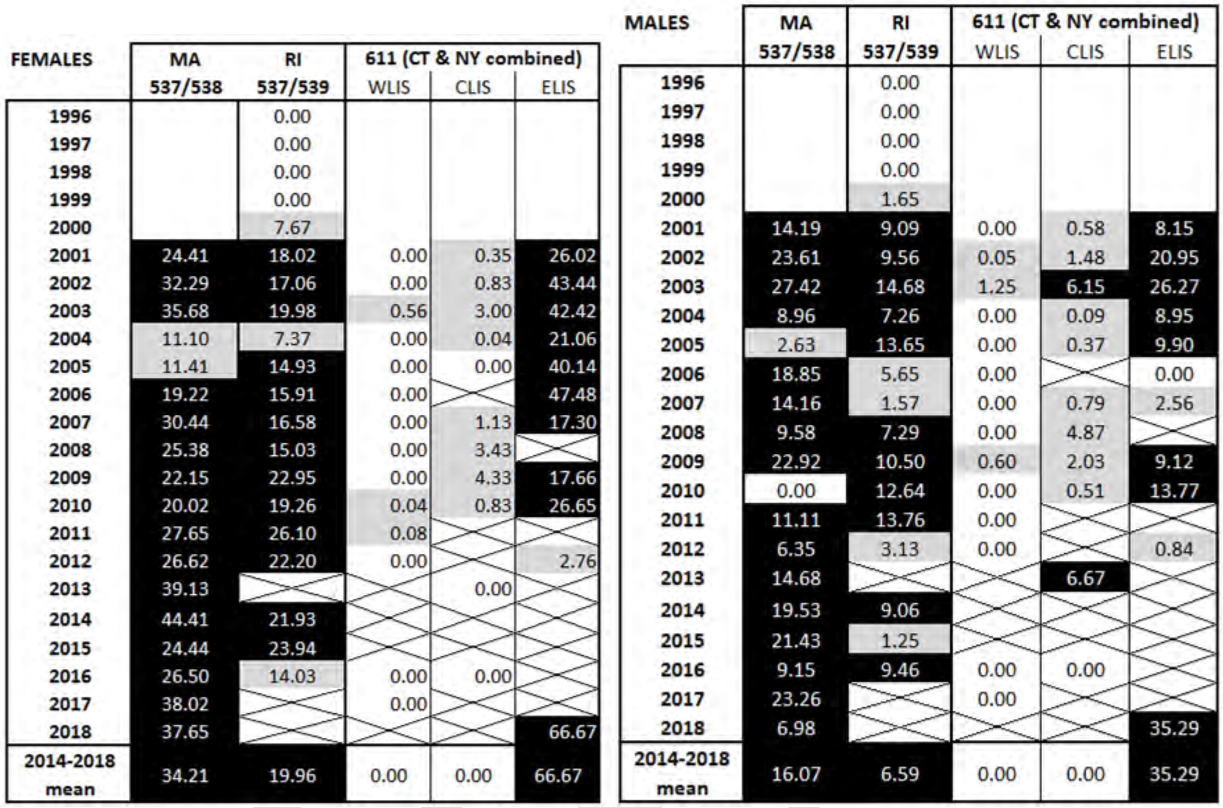
Table 63. SNE mortality indicator: relative exploitation. ** indicates the survey index was 0 but there were landings that year.



EXPLOITATION RATE (landings / survey ref. pop'n)								
Landings (lbs) by area / Reference pop'n (survey weights (lbs) > 77 mm, sexes combined)								
Survey	*NESFC*		*MA*		*RI*		*CT/NY LIS*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*	*fall*	*spring*
1982	0.58	0.35	0.87	2.95	1.47	1.95		
1983	0.83	0.50	5.64	1.63	1.81	0.97		
1984	0.72	1.24	1.27	1.07	0.98	0.70	0.18	0.22
1985	0.75	0.76	**	1.43	1.87	2.67	0.36	0.94
1986	1.51	0.78	0.45	7.04	1.79	1.34	0.18	1.06
1987	1.11	1.20	1.04	2.15	0.69	1.83	0.21	0.78
1988	0.66	1.29	2.78	1.46	0.29	1.44	0.31	1.52
1989	0.78	1.31	0.27	1.58	0.84	1.91	0.43	0.72
1990	1.07	1.24	0.36	0.17	0.83	1.14	0.32	0.71
1991	1.09	1.14	0.09	0.11	0.80	0.40	0.29	0.43
1992	0.97	1.15	0.09	0.33	0.87	2.10	0.21	0.55
1993	1.06	1.04	0.20	1.53	0.23	0.14	0.20	0.76
1994	1.90	1.45	0.20	0.35	0.84	3.10	0.30	1.65
1995	2.04	4.72	6.59	0.42	0.87	2.11	0.43	0.91
1996	1.43	4.19	0.39	0.75	0.48	1.02	0.70	1.36
1997	1.61	1.07	1.22	0.28	0.50	1.02	0.33	0.80
1998	1.38	1.02	1.02	0.34	1.25	1.28	0.62	0.55
1999	1.47	1.57	1.94	0.39	2.51	1.42	0.46	0.48
2000	1.62	0.81	0.33	0.21	1.97	1.22	0.37	0.42
2001	1.27	0.71	0.42	0.98	1.24	0.70	0.38	0.39
2002	1.55	0.48	2.48	0.54	3.10	0.54	0.82	0.39
2003	0.93	0.30	**	0.55	0.31	0.72	0.25	0.81
2004	0.90	0.51	0.47	**	0.26	0.13	0.47	0.98
2005	0.95	0.80	0.18	0.85	0.26	0.24	0.68	1.39
2006	0.88	0.72	**	0.20	0.28	0.14	1.09	1.06
2007	0.75	0.56	0.39	2.08	0.17	0.36	0.78	0.64
2008	0.94	0.43	0.88	0.51	0.12	0.38	0.42	0.42
2009	0.99	0.50	**	0.31	0.25	0.30	0.40	0.66
2010	0.85	0.85	0.07	0.26	0.36	0.32		0.82
2011	0.51	0.56	0.10	0.68	0.29	0.24	1.36	0.69
2012	0.38	0.70	0.23	0.30	1.15	0.44	2.17	0.88
2013	0.35	0.60	0.22	0.20	5.93	0.51	0.72	0.48
2014	0.55		**	0.66	0.68	1.47	1.25	1.25
2015	0.64	0.17	0.13	0.60	0.43	1.46	1.83	1.72
2016	0.57	0.51	0.32	1.37	0.72	0.13	11.94	1.12
2017		0.50	0.10	0.62	0.25	0.64	2.53	4.00
2018	0.40	1.08	1.28	1.07	0.30	0.55	**	3.44
2014-2018 mean	**0.54**	**0.57**	**0.46**	**0.86**	**0.48**	**0.85**	**4.39**	**2.31**

25th	0.70	0.51	0.20	0.32	0.29	0.38	0.31	0.55
median	0.94	0.79	0.39	0.61	0.72	0.72	0.43	0.80
75th	1.30	1.16	1.08	1.39	1.24	1.44	0.78	1.09

Table 64. SNE stress indicators: shell disease prevalence (percent of the observed catch) in females (left) and males (right).



FEMALES	MA	RI	611 (CT & NY combined)		
	537/538	537/539	WLIS	CLIS	ELIS
1996		0.00			
1997		0.00			
1998		0.00			
1999		0.00			
2000		7.67			
2001	24.41	18.02	0.00	0.35	26.02
2002	32.29	17.06	0.00	0.83	43.44
2003	35.68	19.98	0.56	3.00	42.42
2004	11.10	7.37	0.00	0.04	21.06
2005	11.41	14.93	0.00	0.00	40.14
2006	19.22	15.91	0.00	☒	47.48
2007	30.44	16.58	0.00	1.13	17.30
2008	25.38	15.03	0.00	3.43	☒
2009	22.15	22.95	0.00	4.33	17.66
2010	20.02	19.26	0.04	0.83	26.65
2011	27.65	26.10	0.08	☒	☒
2012	26.62	22.20	0.00	☒	2.76
2013	39.13	☒	☒	0.00	☒
2014	44.41	21.93	☒	☒	☒
2015	24.44	23.94	☒	☒	☒
2016	26.50	14.03	0.00	0.00	☒
2017	38.02	☒	0.00	☒	☒
2018	37.65	☒	☒	☒	66.67
2014-2018 mean	34.21	19.96	0.00	0.00	66.67

MALES	MA	RI	611 (CT & NY combined)		
	537/538	537/539	WLIS	CLIS	ELIS
1996		0.00			
1997		0.00			
1998		0.00			
1999		0.00			
2000		1.65			
2001	14.19	9.09	0.00	0.58	8.15
2002	23.61	9.56	0.05	1.48	20.95
2003	27.42	14.68	1.25	6.15	26.27
2004	8.96	7.26	0.00	0.09	8.95
2005	2.63	13.65	0.00	0.37	9.90
2006	18.85	5.65	0.00	☒	0.00
2007	14.16	1.57	0.00	0.79	2.56
2008	9.58	7.29	0.00	4.87	☒
2009	22.92	10.50	0.60	2.03	9.12
2010	0.00	12.64	0.00	0.51	13.77
2011	11.11	13.76	0.00	☒	☒
2012	6.35	3.13	0.00	☒	0.84
2013	14.68	☒	☒	6.67	☒
2014	19.53	9.06	☒	☒	☒
2015	21.43	1.25	☒	☒	☒
2016	9.15	9.46	0.00	0.00	☒
2017	23.26	☒	0.00	☒	☒
2018	6.98	☒	☒	☒	35.29
2014-2018 mean	16.07	6.59	0.00	0.00	35.29

Table 65. SNE stress indicators: number of days > 20.0° C.

	611 Millstone (5 m)	538 Barge (21.3 m)	538 Cleveland (7.6 m)	539 GSO dock SST
1982	42			
1983	32			
1984	35			
1985	52			
1986	35		40	
1987	33		56	
1988	17		68	
1989	42	0	84	
1990	47	0	66	
1991	54	0	83	
1992	14	0	70	
1993	50	0	81	
1994	44	0	70	
1995	60	0	74	59
1996	13	0	68	45
1997	7	0	84	51
1998	55	0	73	46
1999	76	4	91	74
2000	71	0	90	71
2001	66	0	100	74
2002	76	0	97	76
2003	63	0	85	58
2004	57	0	☒	☒
2005	65	0	☒	☒
2006	69	0	68	43
2007	69	0	86	☒
2008	73	0	93	66
2009	44	0	68	53
2010	75	8	92	49
2011	63	4	97	83
2012	94	30	92	79
2013	77	2	88	67
2014	78	0	93	☒
2015	90	16	95	87
2016	85	35	100	☒
2017	53	0	90	☒
2018	91	34	90	☒
2014-2018 mean	79.4	17	93.6	87

25th	42	0	70	51
median	57	0	85	66
75th	73	1.5	92	74

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Table 66. SNE fishery performance indicators.

	EFFORT	TOTAL SNE LANDINGS	PARTIAL LANDINGS	PARTIAL GROSS CPUE	PRICE PER POUND (US average)		SNE REVENUE		PARTIAL REVENUE PER TRAP	
Description	Traps	Pounds (all sources)	Pounds from jurisdictions with effort data	Landings / Traps	Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI
Jurisdiction	*MA, CT, NY*	*All SNE*	*MA, CT, NY*	*MA, CT, NY*	*All stocks*	*All stocks*	*All SNE*	*All SNE*	*MA, CT, NY*	*MA, CT, NY*
1982		5,907,392	3,162,701		2.308	$5.19	$13,635,189	$30,642,630		
1983		8,350,549	4,201,282		2.420	$5.24	$20,211,469	$43,719,370		
1984	193,380	9,379,399	4,600,200	23.8	2.690	$5.62	$25,234,078	$52,677,676	$64	$134
1985	209,548	8,731,336	3,899,064	18.6	2.490	$5.04	$21,737,684	$43,985,979	$46	$94
1986	202,411	9,663,791	3,971,263	19.6	2.619	$5.19	$25,305,947	$50,193,106	$51	$102
1987	210,893	9,826,717	3,993,434	18.9	3.095	$5.99	$30,411,597	$58,868,761	$59	$113
1988	244,554	10,475,605	4,878,090	19.9	2.985	$5.58	$31,274,390	$58,477,485	$60	$111
1989	289,935	13,094,869	5,906,831	20.4	2.801	$5.04	$36,673,116	$65,980,984	$57	$103
1990	291,632	16,546,977	7,813,987	26.8	2.481	$4.30	$41,048,961	$71,183,455	$66	$115
1991	316,488	15,556,196	7,796,341	24.6	2.590	$4.34	$40,293,192	$67,591,073	$64	$107
1992	353,735	13,696,536	6,932,034	19.6	2.905	$4.76	$39,788,303	$65,258,940	$57	$93
1993	414,956	13,192,396	6,703,489	16.2	2.765	$4.43	$36,477,910	$58,443,391	$45	$72
1994	451,696	14,968,496	8,292,592	18.4	2.962	$4.65	$44,342,322	$69,558,959	$54	$85
1995	443,833	17,656,959	11,365,906	25.6	3.064	$4.71	$54,109,128	$83,134,870	$78	$121
1996	516,487	20,642,701	14,393,821	27.9	3.386	$5.11	$69,892,088	$105,454,995	$94	$142
1997	546,347	21,830,516	14,849,109	27.2	3.289	$4.88	$71,796,223	$106,490,807	$89	$133
1998	588,422	20,626,357	13,985,884	23.8	3.183	$4.67	$65,644,806	$96,283,568	$76	$111
1999	577,866	19,909,909	11,267,825	19.5	3.694	$5.34	$73,556,516	$106,353,318	$72	$104
2000	403,315	13,295,342	5,805,415	14.4	3.615	$5.11	$48,058,023	$67,965,847	$52	$74
2001	378,575	9,769,408	4,876,276	12.9	3.505	$4.85	$34,238,859	$47,380,460	$45	$62
2002	354,443	8,157,082	4,021,913	11.3	3.537	$4.82	$28,853,014	$39,306,337	$40	$55
2003	249,699	5,617,159	2,452,149	9.8	3.955	$5.29	$22,216,626	$29,715,487	$39	$52
2004	241,613	5,280,696	2,565,694	10.6	4.182	$5.45	$22,085,989	$28,766,459	$44	$58
2005	217,542	5,455,832	2,742,502	12.6	4.755	$6.01	$25,941,201	$32,766,681	$60	$76
2006	232,712	6,388,386	3,023,281	13.0	4.207	$5.16	$26,877,432	$32,950,715	$55	$67
2007	223,582	4,751,414	2,230,561	10.0	4.538	$5.42	$21,563,943	$25,745,167	$45	$54
2008	189,658	4,773,425	1,875,051	9.9	3.693	$4.33	$17,630,588	$20,645,909	$37	$43
2009	156,974	4,972,270	2,028,766	12.9	3.081	$3.58	$15,318,668	$17,803,768	$40	$46
2010	172,967	4,831,217	2,005,737	11.6	3.437	$3.95	$16,602,825	$19,074,589	$40	$46
2011	140,297	3,628,285	1,087,633	7.8	3.348	$3.77	$12,146,414	$13,669,060	$26	$29
2012	115,735	3,905,360	1,192,830	10.3	2.864	$3.16	$11,183,781	$12,348,698	$30	$33
2013	88,744	3,281,982	1,069,346	12.0	3.061	$3.32	$10,046,656	$10,902,068	$37	$40
2014	91,498	3,533,813	1,096,295	12.0	3.831	$4.08	$13,539,798	$14,425,948	$46	$49
2015	92,580	3,235,777	1,133,755	12.2	4.231	$4.46	$13,691,682	$14,436,866	$52	$55
2016	97,593	3,255,705	1,348,011	13.8	4.205	$4.39	$13,690,017	$14,287,413	$58	$61
2017	93,739	2,831,845	1,043,036	11.1	4.143	$4.24	$11,732,130	$12,017,954	$46	$47
2018	91,260	2,740,962	993,942	10.9	4.269	$4.27	$11,702,292	$11,702,292	$46	$46
2014-2018 mean	**93,334**	**3,119,620**	**1,123,008**	**12.0**	**$4.14**	**$4.29**	**$12,871,183.72**	**$13,374,094.53**	**$50**	**$52**

25th	164,970	4,773,425	2,005,737	11.5	$2.86	$4.33	15,318,668	19,074,589	45	50
median	232,712	8,350,549	3,971,263	13.8	$3.29	$4.82	25,305,947	43,719,370	52	72
75th	366,509	13,295,342	6,703,489	19.8	$3.83	$5.19	39,788,303	65,980,984	60	106

Table 67. Configuration of basecase models for lobster in this assessment by stock area.

Item	GOMGBK	SNE
Model years	1979-2019 with quarterly time steps	
Sexes	Separate population dynamics (recruitment, growth, and mortality)	
Sizes	35 bins each 5 mm starting at 53 mm CL (i.e., 53-57, 58-62,….,223+ mm CL)	
Recruitment	Log recruitment, independent normal	
Log expected recruitment	Linear in year	Quadratic in year
Variance of recruitment	Calculated internally from recruitment deviation parameters	
Seasonal recruitment	Winter 0%, Spring 0%, Summer 66%, Fall 34%	
Recruitment size distribution	Sex-specific beta distribution with estimated shape and scale parameters over first 5 size bins	
Spawning season	Summer	
Age-at-recruitment for SR plots	5 years	
Natural mortality rate	M=0.15 year^{-1} all size groups, quarters, and years	1979-1997: M=0.15 year^{-1}; 1998-2018: M=0.285 year^{-1}
Maturity-at-length	Updated in this assessment; see Section 2.6.1	
CL-weight parameters	Area and sex-specific; see Section 4.1.4.2	
Growth transition matrix	Occurs in summer and fall only; See Section 2.5	
Initial abundance	Sex-specific parameters estimated in model	
Total landings data	Weight by quarter and sex	
Total landings error	Normal with CV=10%	
Landings length composition data	See Section 4.1.4 and Appendix 3	
Survey length composition data	See Sections 4.2.1.2.2 and 4.2.2.3	
Plus group for length composition GOF	Dynamic binning (accumulate from above and below until proportions in first and last size bin $\geq$ 0.01	
Length composition error	Robust likelihood from Fournier et al. 1990	
Assumed sample sizes	Year-specific. Tuned to match trend and scale of effective sample size from goodness of fit in preliminary run. Always $\leq$ 400.	
Commercial selectivity	Components for legal size regulations, gear regulations, and conservation discards for v-notches and ovigerous females specified (see Appendix 3). Other component not used.	
Survey index data and configurations	See Table 68-Table 69	See Table 68-Table 69
Survey index error	Cauchy distributed with constant log scale variance fixed.	
Priors	None	
Likelihood weights	1 for all data and recruitment	

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Table 68. Survey data, selectivity and catchability configuration in the basecase model for GOMGBK.

Bin Number	Agency	Gear	Season	Sex	Name in Plots	Years	N Years	Catchability Relationship	Catchability Covariate	Selectivity	N Parameters Estimated	Notes
1	MA DMF	Bottom Trawl	Spring	Female	MaFQ2	1979-2019	41	Saturation	NA	Domed	3	Ascending L50 fixed
2	MA DMF	Bottom Trawl	Fall	Female	MaFQ4	1979-2019	41	Saturation	NA	Domed	2	Ascending slope and L50 fixed
3	MA DMF	Bottom Trawl	Spring	Male	MaMQ2	1979-2019	41	Saturation	NA	Domed	3	Ascending L50 fixed
4	MA DMF	Bottom Trawl	Fall	Male	MaMQ4	1979-2019	41	Saturation	NA	Domed	2	Ascending slope and L50 fixed
5	ME DMR	Bottom Trawl	Spring	Female	MeFQ2	2003-2019	17	Exponential	Previous Fall	Domed	3	Ascending L50 fixed
6	ME DMR	Bottom Trawl	Fall	Female	MeFQ4	2003-2019	17	Exponential	Fall	Domed	2	Descending slope and L50 fixed
7	ME DMR	Bottom Trawl	Spring	Male	MeMQ2	2003-2019	17	Exponential	Previous Fall	Ascending	2	
8	ME DMR	Bottom Trawl	Fall	Male	MeMQ4	2003-2019	17	Saturation	Fall	Ascending	2	
9	NEFSC	Bottom Trawl	Spring	Female	NefscFQ2	1979-2019	41	Exponential	Previous Fall	Ascending	2	
10	NEFSC	Bottom Trawl	Fall	Female	NefscFQ4	1979-2019	41	Exponential	Fall	Ascending	2	
11	NEFSC	Bottom Trawl	Spring	Male	NefscMQ2	1979-2019	41	Exponential	Previous Fall	Ascending	2	
12	NEFSC	Bottom Trawl	Fall	Male	NefscMQ4	1979-2019	41	Saturation	Fall	Ascending	2	
13	MA DMF, NH F&G, ME DMR	Ventless Trap	Summer	Female	VtsFQ3_stand	2006-2019	14	Linear	Summer	Domed	3	Ascending L50 fixed
14	MA DMF, NH F&G, ME DMR	Ventless Trap	Summer	Male	VtsMQ3_stand	2006-2019	14	Linear	Summer	Domed	3	Ascending L50 fixed
15	Not used											
16	Not used											

Table 69. Survey data, selectivity and catchability configuration in the basecase model for SNE.

Bin Number	Agency	Gear	Season	Sex	Name in Plots	Years	N Years	Catchability Relationship	Catchability Covariate	Selectivity	N Parameters Estimated	Notes
1	CT DEEP	Bottom Trawl	Spring	Female and Male	CTQ2	1984-2019	36	Exponential	Spring Temperature	Domed	2	Slopes fixed
2	CT DEEP	Bottom Trawl	Fall	Female and Male	CTQ4	1984-2009, 2011-2019	35	Exponential	NA	Domed	2	L50's fixed
3	MA DMF	Bottom Trawl	Spring	Female and Male	MAQ2	1979-2019	41	Saturation	NA	Descending	2	Descending slope and L50 fixed
4	NEAMAP	Bottom Trawl	Spring	Female and Male	NEAMAPQ2	2008-2019	12	Linear	NA	Domed	2	L50's fixed
5	NEAMAP	Bottom Trawl	Fall	Female and Male	NEAMAPQ4	2007-2019	13	Linear	NA	Domed	2	L50's fixed
6	NEFSC	Bottom Trawl	Fall	Female	NefscFQ4	1979-2016, 2018-2019	40	Linear	NA	Ascending	0	Fixed parameters after iterative testing
7	NEFSC	Bottom Trawl	Fall	Male	NefscMQ2	1979-2016, 2018-2019	40	Linear	NA	Ascending	0	Fixed parameters after iterative testing
8	NEFSC	Bottom Trawl	Spring	Female and Male	NefscQ2	1979-2019	41	Linear	Spring Temperature	Ascending	0	Fixed parameters after iterative testing
9	NJ DEP	Bottom Trawl	Spring	Female and Male	NJ	1989-2019	31	Linear	NA	Domed	2	L50's fixed
10	RI DMF	Bottom Trawl	Spring	Female	RIFQ2	1982-2019	38	Linear	Spring Temperature	Domed	2	Descending slope and L50 fixed
11	RI DMF	Bottom Trawl	Fall	Female	RIFQ4	1982-2019	38	Linear	NA	Domed	1	Asending slope estimated
12	RI DMF	Bottom Trawl	Spring	Male	RIMQ2	1982-2019	38	Linear	Spring Temperature	Domed	1	Descending L50 estimated
13	RI DMF	Bottom Trawl	Fall	Male	RIMQ4	1982-2019	38	Linear	NA	Domed	2	L50's fixed
14	MA DMF, RI DMF	Ventless Trap	Summer	Female and Male	VTSQ3_model	2006-2019	14	Saturation	NA	Domed	2	L50's fixed
15	Not used											
16	Not used											

Table 70. Annual recruitment, reference abundance, effective exploitation and summer spawning biomass estimates generated by the GOMGBK basecase model (1979-2018).

Year	Female				Male			Both Sexes		
	Recruitment (millions)	Reference Abundance (millions)	Effective Exploitation	Spawning Biomass (Summer, mt)	Recruitment (millions)	Reference Abundance (millions)	Effective Exploitation	Recruitment (millions)	Reference Abundance (millions)	Effective Exploitation
1979	24	29	0.38	11,832	30	25	0.50	54	54	0.43
1980	21	29	0.41	10,704	27	25	0.57	48	54	0.48
1981	21	30	0.43	9,807	21	27	0.48	43	57	0.45
1982	23	30	0.47	9,158	14	31	0.57	37	61	0.52
1983	26	29	0.49	7,845	24	27	0.54	50	56	0.51
1984	22	29	0.50	7,373	25	24	0.54	46	53	0.52
1985	17	30	0.53	7,297	21	25	0.55	38	55	0.54
1986	23	27	0.51	6,623	22	26	0.56	45	54	0.53
1987	35	26	0.44	6,677	24	26	0.53	59	52	0.49
1988	34	29	0.41	7,631	39	27	0.48	73	56	0.44
1989	20	37	0.44	9,396	34	32	0.48	53	69	0.46
1990	34	41	0.41	10,063	15	38	0.48	49	79	0.45
1991	41	40	0.41	11,512	45	39	0.53	86	79	0.47
1992	40	43	0.51	12,397	24	36	0.54	64	79	0.52
1993	28	45	0.45	11,269	48	38	0.47	76	83	0.46
1994	56	49	0.49	12,568	30	42	0.50	86	91	0.50
1995	30	48	0.45	12,337	66	45	0.45	96	93	0.45
1996	71	54	0.40	14,174	31	53	0.58	103	106	0.49
1997	68	60	0.43	17,166	29	54	0.56	96	114	0.49
1998	28	71	0.44	19,318	53	49	0.54	81	121	0.48
1999	50	77	0.47	20,968	64	46	0.49	114	123	0.48
2000	32	68	0.46	20,480	36	55	0.42	68	123	0.44
2001	55	61	0.36	19,539	54	66	0.57	110	128	0.47
2002	74	64	0.45	21,510	29	59	0.50	103	123	0.47
2003	21	67	0.36	19,890	85	58	0.47	106	125	0.41
2004	71	79	0.46	22,910	39	62	0.50	110	140	0.48
2005	50	70	0.50	20,809	61	69	0.49	111	138	0.49
2006	51	68	0.40	17,498	53	70	0.54	103	138	0.47
2007	77	75	0.44	22,172	85	67	0.51	162	142	0.47
2008	78	76	0.39	21,440	62	73	0.49	140	149	0.44
2009	80	90	0.40	25,751	96	83	0.50	176	173	0.45
2010	98	102	0.41	27,904	75	90	0.53	173	192	0.47
2011	116	112	0.45	32,633	107	96	0.50	223	207	0.48
2012	69	121	0.46	32,164	103	105	0.54	173	225	0.50
2013	81	129	0.42	35,215	69	112	0.52	150	240	0.46
2014	117	126	0.49	38,349	87	116	0.49	205	243	0.49
2015	101	116	0.43	32,470	108	112	0.50	209	227	0.46
2016	118	131	0.46	34,848	88	112	0.49	206	243	0.48
2017	91	138	0.44	37,292	96	119	0.48	187	257	0.46
2018	173	144	0.42	39,445	199	123	0.47	373	267	0.44

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Table 71. Annual recruitment, reference abundance, effective exploitation and summer spawning biomass estimates generated by the SNE basecase model (1979-2018).

Year	Female				Male			Both Sexes		
	Recruitment (millions)	Reference Abundance (millions)	Effective Exploitation	Spawning Biomass (Summer, mt)	Recruitment (millions)	Reference Abundance (millions)	Effective Exploitation	Recruitment (millions)	Reference Abundance (millions)	Effective Exploitation
1979	8	7	0.36	2,457	6	5	0.47	14	13	0.41
1980	9	7	0.38	2,262	4	5	0.53	14	12	0.44
1981	8	7	0.37	2,284	8	6	0.51	17	13	0.43
1982	6	9	0.34	2,624	4	6	0.42	10	15	0.37
1983	6	11	0.37	3,021	8	8	0.51	15	19	0.43
1984	19	11	0.44	3,131	7	8	0.53	26	19	0.47
1985	17	10	0.42	2,998	5	8	0.48	23	18	0.45
1986	10	12	0.45	3,494	11	9	0.55	21	21	0.50
1987	13	16	0.33	4,230	10	8	0.49	23	24	0.38
1988	17	19	0.35	5,373	13	11	0.42	30	30	0.37
1989	12	19	0.33	5,515	6	13	0.43	19	32	0.37
1990	10	20	0.38	5,659	10	15	0.40	20	35	0.39
1991	15	20	0.41	5,463	10	14	0.49	25	34	0.44
1992	22	19	0.42	5,449	15	13	0.51	37	32	0.46
1993	20	18	0.37	5,366	9	13	0.40	29	31	0.38
1994	27	21	0.34	5,834	14	16	0.45	41	37	0.39
1995	13	25	0.33	7,138	12	16	0.48	25	41	0.38
1996	22	29	0.40	8,205	17	17	0.45	39	46	0.42
1997	22	29	0.43	8,008	18	18	0.44	40	47	0.44
1998	19	26	0.35	6,780	11	21	0.37	30	47	0.36
1999	14	24	0.35	6,272	12	20	0.40	26	44	0.37
2000	13	22	0.40	5,604	9	16	0.45	22	38	0.42
2001	8	18	0.38	4,803	4	13	0.41	13	31	0.39
2002	7	15	0.36	3,956	11	11	0.43	18	25	0.39
2003	12	12	0.20	3,429	5	8	0.29	17	21	0.24
2004	9	12	0.29	3,675	6	10	0.30	14	21	0.30
2005	8	10	0.23	3,218	6	9	0.30	14	19	0.26
2006	11	11	0.23	3,176	6	8	0.38	17	19	0.29
2007	5	10	0.30	3,260	5	7	0.31	10	18	0.30
2008	5	10	0.23	2,836	5	7	0.27	11	17	0.24
2009	6	9	0.23	2,731	3	7	0.28	9	17	0.25
2010	5	8	0.25	2,507	4	7	0.33	10	15	0.29
2011	6	7	0.25	2,261	4	6	0.27	10	13	0.26
2012	5	7	0.26	1,884	3	5	0.33	8	12	0.29
2013	5	6	0.21	1,954	2	5	0.33	7	11	0.26
2014	2	7	0.26	1,945	3	4	0.28	5	11	0.27
2015	3	6	0.24	1,750	2	4	0.28	5	10	0.25
2016	2	5	0.27	1,517	2	4	0.32	4	9	0.29
2017	1	4	0.28	1,241	2	3	0.24	3	7	0.26
2018	1	3	0.29	966	1	3	0.25	2	6	0.27

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Table 72. Asymptotic confidence intervals with 95% coverage for mean reference abundance and effective exploitation during 2016-2018 from basecase University of Maine assessment models in this assessment. Confidence intervals are the estimate ± 1.96 σ using standard errors σ from lobster6f6.std output files for each stock area.

Quantity	GOMGBK			SNE		
	LCI	MLE	UCI	LCI	MLE	UCI
Reference Abundance	247	256	264	7.22	7.44	7.66
Exploitation	0.455	0.459	0.464	0.268	0.274	0.280

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Table 73. Mean terminal year (2016-2018) effective exploitation and reference abundance estimates for GOMGBK lobster (sexes combined) from the basecase and sensitivity analysis runs. The basecase run is in the top row. “Relative to mean” is the ratio of the estimate shown to the mean in all years from the same model run. “Compare to basecase” is the percent change from the basecase terminal year estimates for the sensitivity scenarios.

Model Scenario	Refernce Exploitation			Reference Abundance (millions)		
	2016-2018 Mean	Relative to Mean	Compare to Basecase	2016-2018 Mean	Relative to Mean	Compare to Basecase
Basecase	0.46	0.97	0%	256	2.02	0%
VTS Design Based Index	0.46	0.97	0%	256	2.01	0%
Split Spring Trawl Indices	0.46	0.97	1%	258	2.01	1%
Exclude ME/NH Depth Strata 4	0.46	0.97	0%	260	2.05	2%
Domed NEFSC Female Selectivity	0.46	0.95	0%	255	2.02	0%
Domed ME/NH Male Selectivity	0.46	0.97	0%	256	2.02	0%
No Environmental or Nonlinear Catchability	0.46	0.97	0%	262	2.06	3%
No Environmental Catchability	0.46	0.97	0%	254	2.00	0%
No Nonlinear Catchability	0.46	0.97	0%	257	2.03	1%
Spring ME/NH Temperature	0.46	0.97	0%	256	2.02	0%
Spring NEFSC Temperature	0.46	0.97	0%	257	2.03	0%
Biosample - N=3	0.46	0.97	0%	259	2.04	2%
Upweight Landings	0.45	0.94	-3%	253	2.06	-1%
Gear Selectivity Shift Left	0.46	0.92	0%	272	2.14	6%
Gear Selectivity Shift Right	0.37	0.96	-20%	302	2.09	18%
SNE Growth	0.43	1.00	-7%	340	2.17	33%
M Decline with Size, Lorenzen	0.49	0.96	7%	244	2.04	-5%
M=0.1	0.48	0.94	4%	247	2.03	-3%
M=0.2	0.45	1.00	-3%	269	2.01	5%
No Recruit Covariate Trend	0.47	0.97	1%	284	2.18	11%
Flattening Recruitment	0.46	0.97	0%	247	1.95	-3%
Declining Recruitment	0.47	0.98	1%	264	2.07	3%
Old Maturity Ogive	0.46	0.97	0%	256	2.02	0%
Summary Across Runs						
Minimum	0.37	0.92	-20%	243.51	1.95	-5%
Maximum	0.49	1.00	7%	339.78	2.18	33%

Table 74. Mean terminal year (2016-2018) effective exploitation and reference abundance estimates for SNE lobster (sexes combined) from the basecase and sensitivity analysis runs. The basecase run is in the top row. "Relative to mean" is the ratio of the estimate shown to the mean in all years from the same model run. "Compare to basecase" is the percent change from the basecase terminal year estimates for the sensitivity scenarios.

Model Scenario	Refernce Exploitation			Reference Abundance (millions)		
	2016-2018 Mean	Relative to Mean	Compare to Basecase	2016-2018 Mean	Relative to Mean	Compare to Basecase
Basecase	0.27	0.77	0%	7.4	0.32	0%
Gear Selectivity Shift Left	0.29	0.83	6%	7.3	0.31	-3%
Gear Selectivity Shift Right	0.27	0.94	0%	7.4	0.28	-1%
Biosample - N=3	0.32	0.89	16%	6.9	0.30	-7%
Biosample - 537 Recharacterization	0.28	0.80	2%	7.5	0.32	0%
Exclude Long Island Sound	0.29	0.82	6%	6.6	0.41	-11%
Exclude CT Trawl Survey	0.30	0.83	8%	7.7	0.34	3%
No Environmental Catchability	0.29	0.83	7%	7.1	0.31	-4%
No Environmental or Nonlinear Catchability	0.27	0.77	-1%	7.8	0.34	5%
No Recruit Covariate Trend	0.29	0.82	5%	7.2	0.31	-3%
Recruit Trend Days > 20°C	0.28	0.81	2%	7.4	0.31	-1%
M=0.1, 0.19	0.33	0.84	19%	6.5	0.31	-13%
M=0.2, 0.38	0.22	0.70	-18%	9.2	0.37	24%
M=Shell Disease Trend	0.31	0.86	13%	6.8	0.30	-9%
Summer Allocated M	0.32	0.89	18%	7.0	0.31	-6%
M Decline with Size, Lorenzen	0.33	0.84	20%	6.3	0.31	-15%
VTS Design Based Index	0.29	0.81	5%	7.6	0.32	2%
Old Maturity Ogive	0.27	0.77	0%	7.4	0.32	0%
Summary Across Runs						
Minimum	0.22	0.70	-18%	6.34	0.28	-15%
Maximum	0.33	0.94	20%	9.22	0.41	24%

Table 75. Historical retrospective results for comparison of basecase reference abundance estimates for 1982-2013 in ASMFC (2015a) and this assessment. The mean ratio N_{new}/N_{old} is the average ratio of the new and old estimates in each year.

Stock	Quantity	N_{new}/N_{old}	R^2
GOMGBK	Reference Abundance	0.99	0.98
	Exploitation	1.00	0.71
SNE	Reference Abundance	1.02	0.98
	Exploitation	1.04	0.89

Table 76. Mohn's rho (ρ) retrospective scores for basecase models in this assessment.

Stock	**Reference Abundance**	**Effective Exploitation**
GOMGBK	0.04	0.01
SNE	-0.20	0.17

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Table 77. Current (2016-2018) reference abundance estimates (millions), current target and threshold abundance (millions), and new recommended abundance reference points for both stocks.

Quantity	GOMGBK	SNE
Current (2016-2018 average)	256	7
Current Target	119	32
Current Threshold	58	25
Fishery/Industry Target	212	NA
Abundance Limit	125	NA
Abundance Threshold	89	20

Table 78. Current (2016-2018) exploitation, current target and threshold exploitation, and new recommended target and threshold exploitation for both stocks.

Quantity	GOMGBK	SNE
Current (2016-2018 average)	0.459	0.274
Current Target	0.457	0.379
Current Threshold	0.510	0.437
Recommended Target	0.461	0.257
Recommended Threshold	0.475	0.290

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11 FIGURES

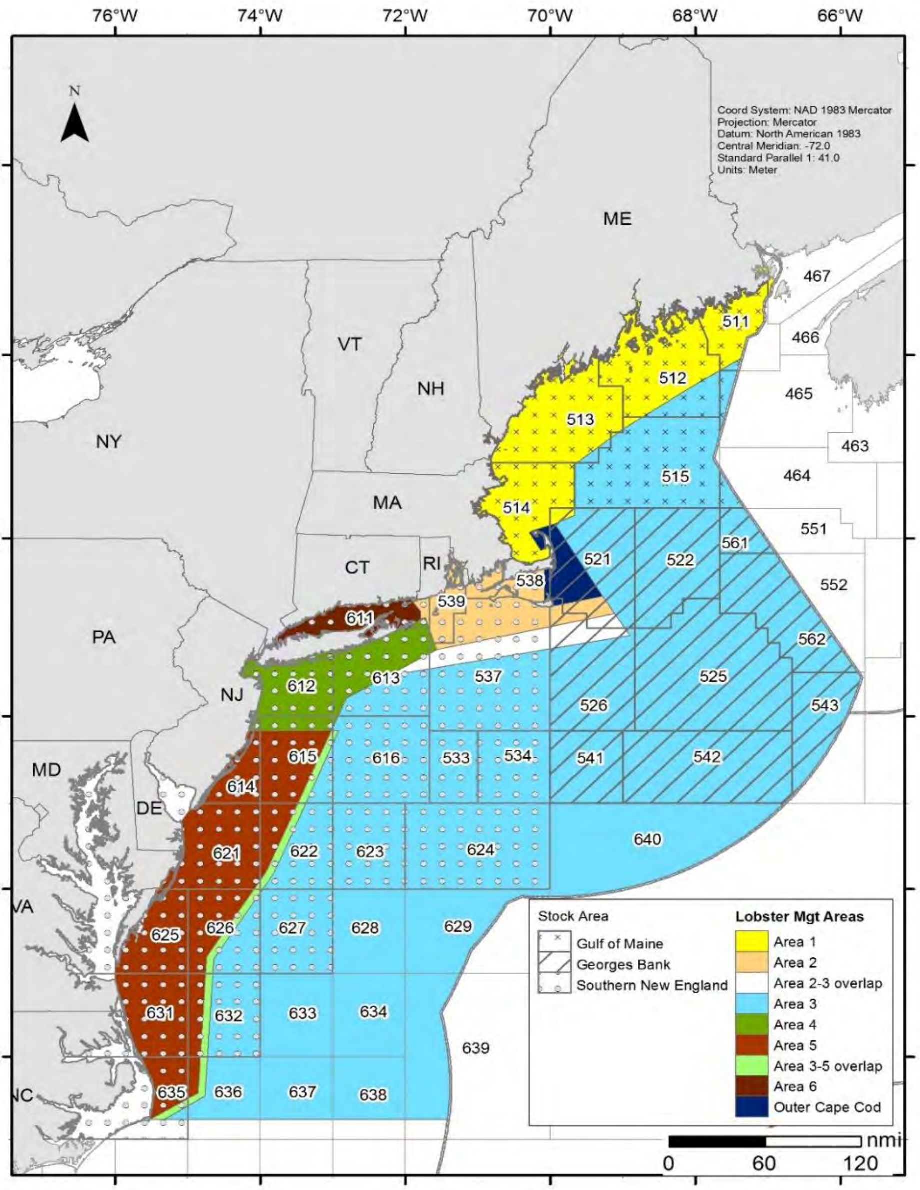

Figure 1. NMFS statistical areas, U.S. American lobster, *Homarus americanus*, Stock Areas, and Lobster Conservation Management Areas (LCMA's).

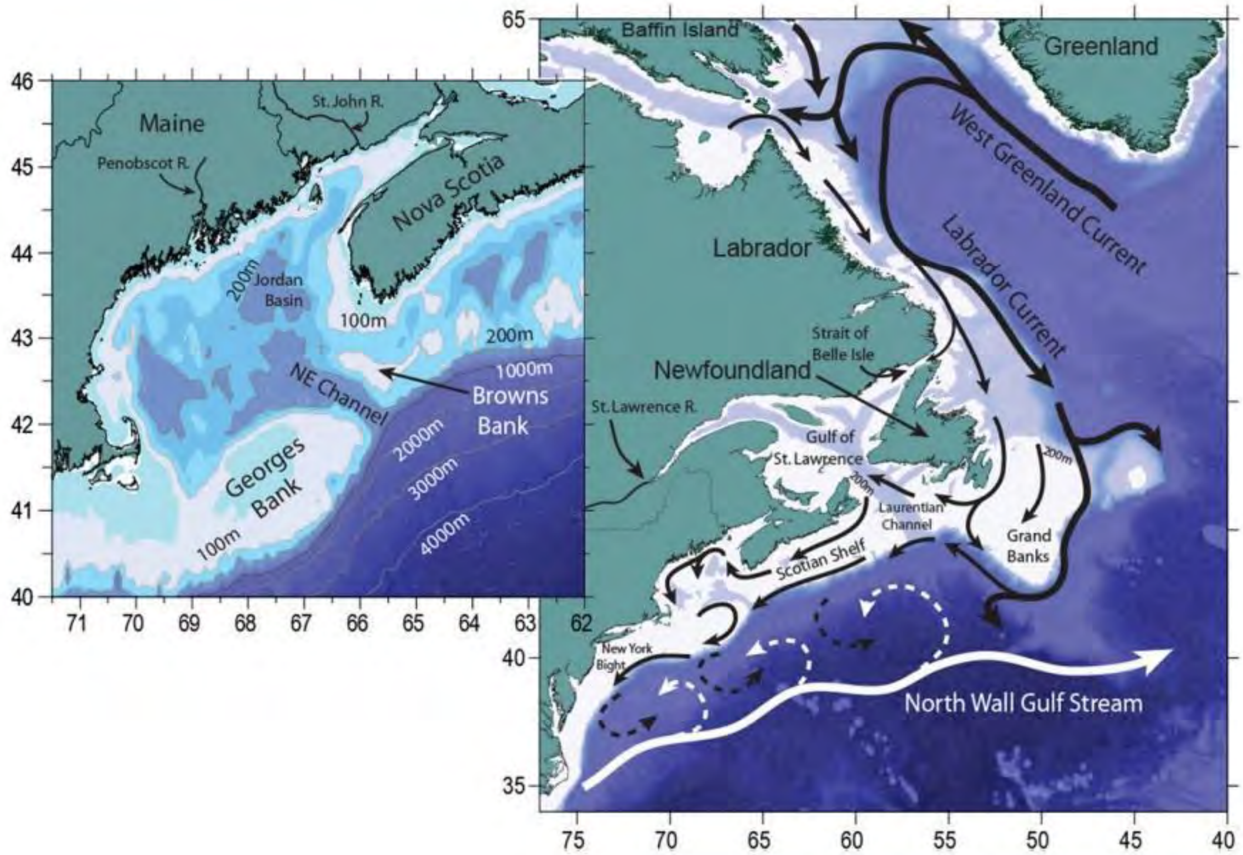

Figure 2. Maps of Gulf of Maine and Georges Banks (left) and larger northwest Atlantic current paths (Townsend et al., 2010).

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Figure 3. Finer scale circulation of Georges Bank and the Gulf of Maine. The EMCC and WMCC are delineated with the bifurcation near Penobscot Bay (Pettigrew et al. 2005).

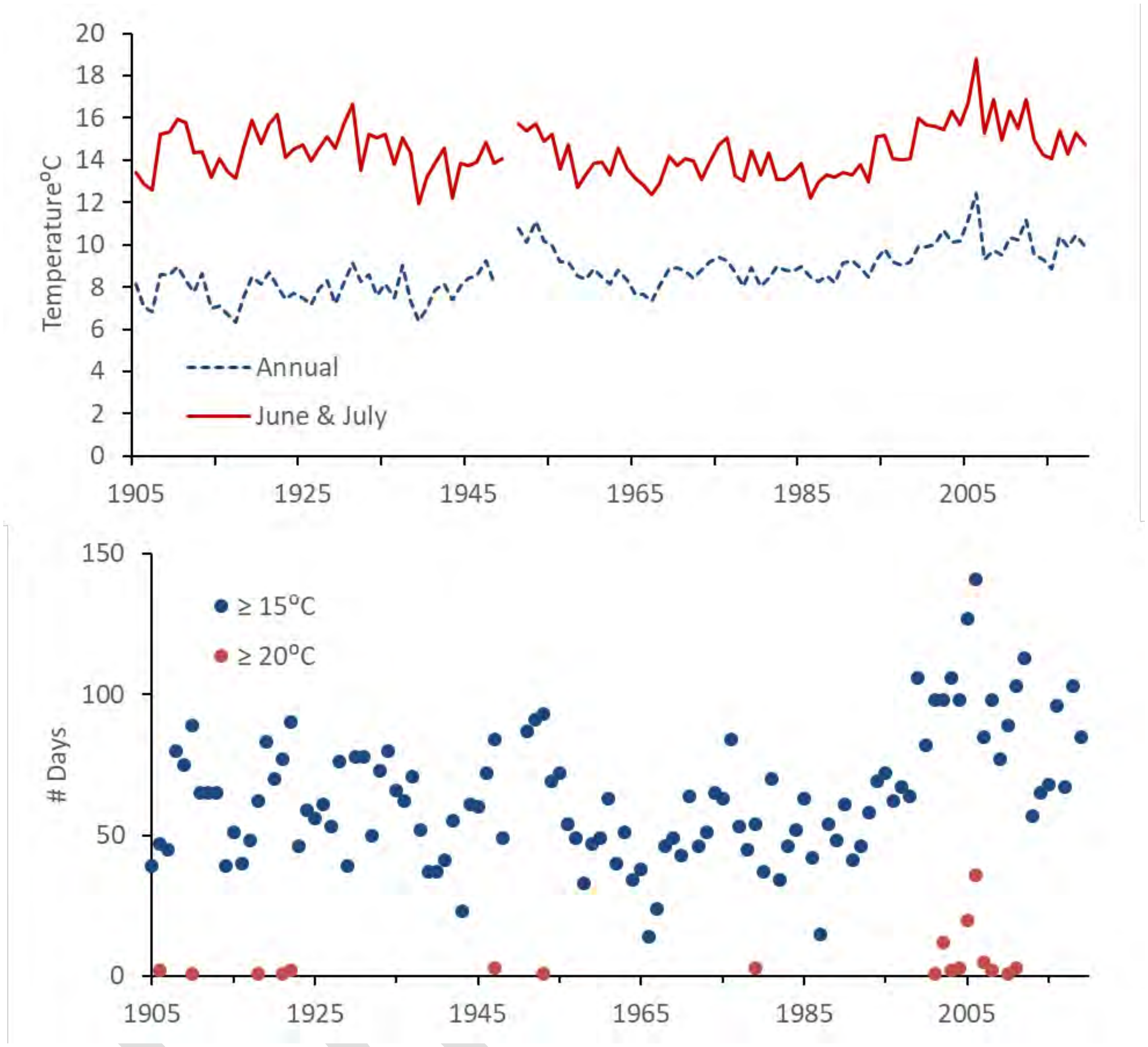

Figure 4. Long-term 1905-2018 Boothbay Harbor, Maine average sea surface temperatures (top) annually (dotted blue) and June-July only (solid red). Number of days per year ≥ 15 (blue) and 20ºC (red) from the same data are also presented (bottom).

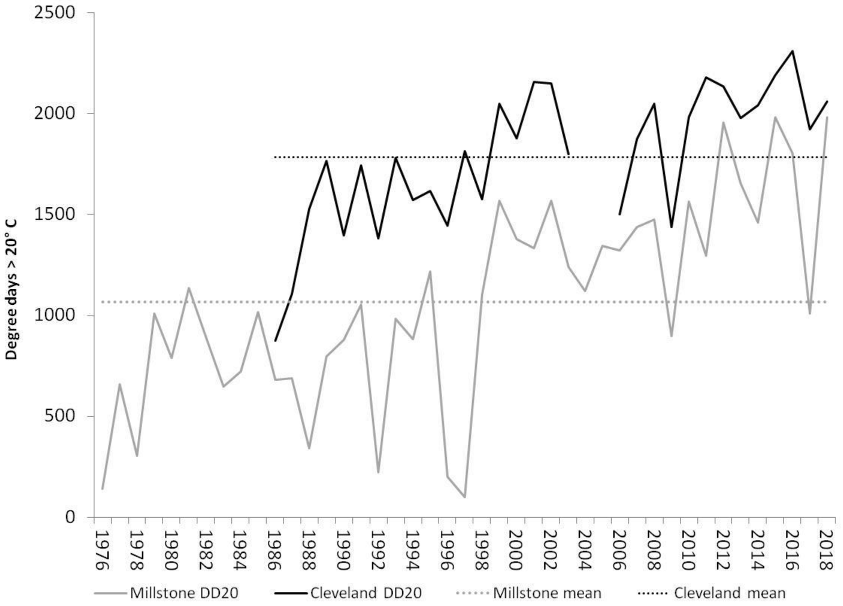

Figure 5. The annual number of degree days greater than 20.0° C from the Millstone (Dominion Nuclear Power Station) and Cleveland Ledge (MADMF) bottom temperature monitoring locations. Degree days over 20° is the sum of all daily temperature values over 20.0° C. The dashed lines represent the time series mean degree days over 20°.

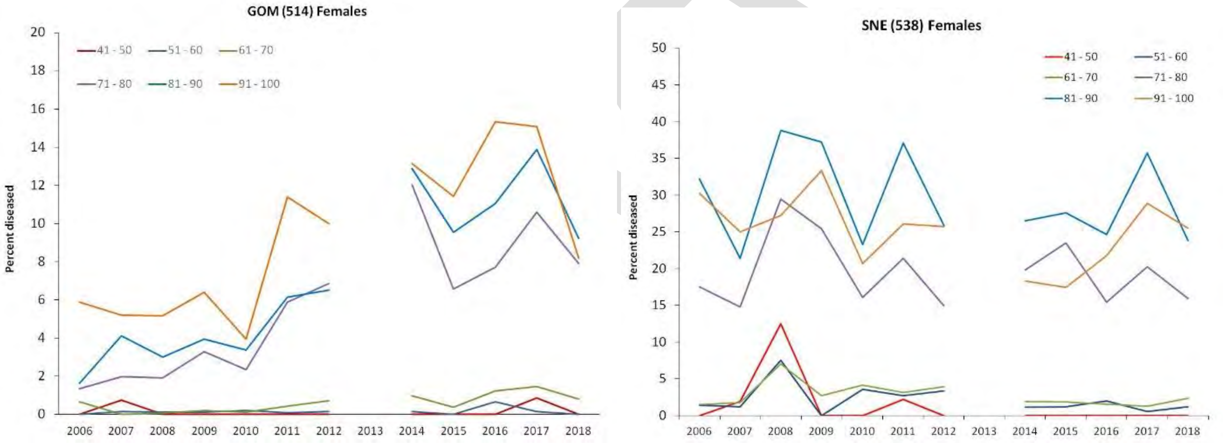

Figure 6. Percent of female lobsters with shell disease in the MA VTS from 2006 – 2018, by 10 mm size bin. **A)** MA VTS survey area 514 (GOM stock). **B)** MA VTS survey area 538 (SNE stock). Note the y-axis range differs.

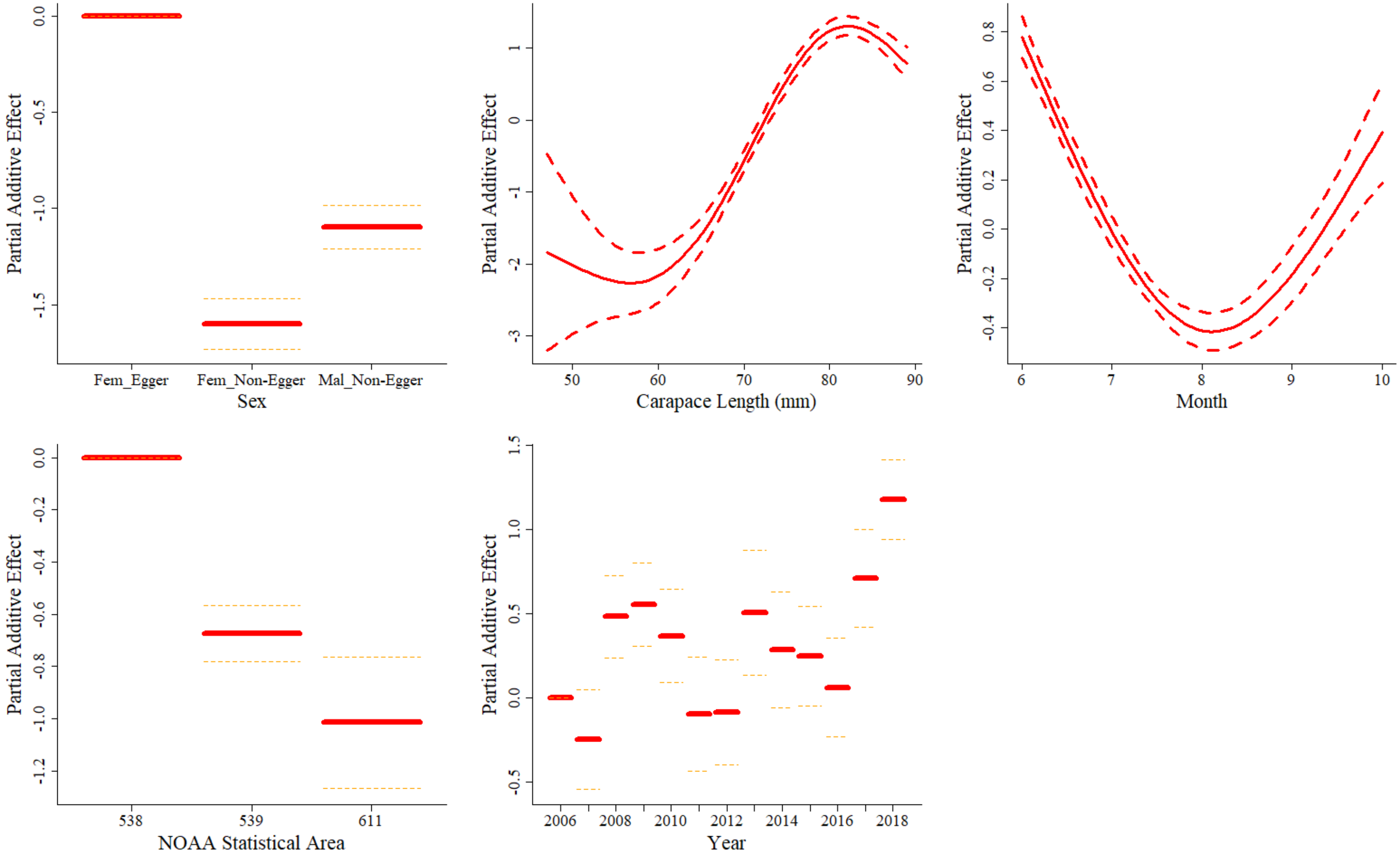

Figure 7. Estimated effects of covariates on severe shell disease prevalence in SNE. Positive additive effects represent a positive influence on shell disease prevalence, whereas negative values indicate a negative influence on shell disease prevalence. Sex characterization was described as either Male (Mal_Non-Egger), Female without eggs (Fem_Non-Egger), or female with eggs (Fem-Egger).

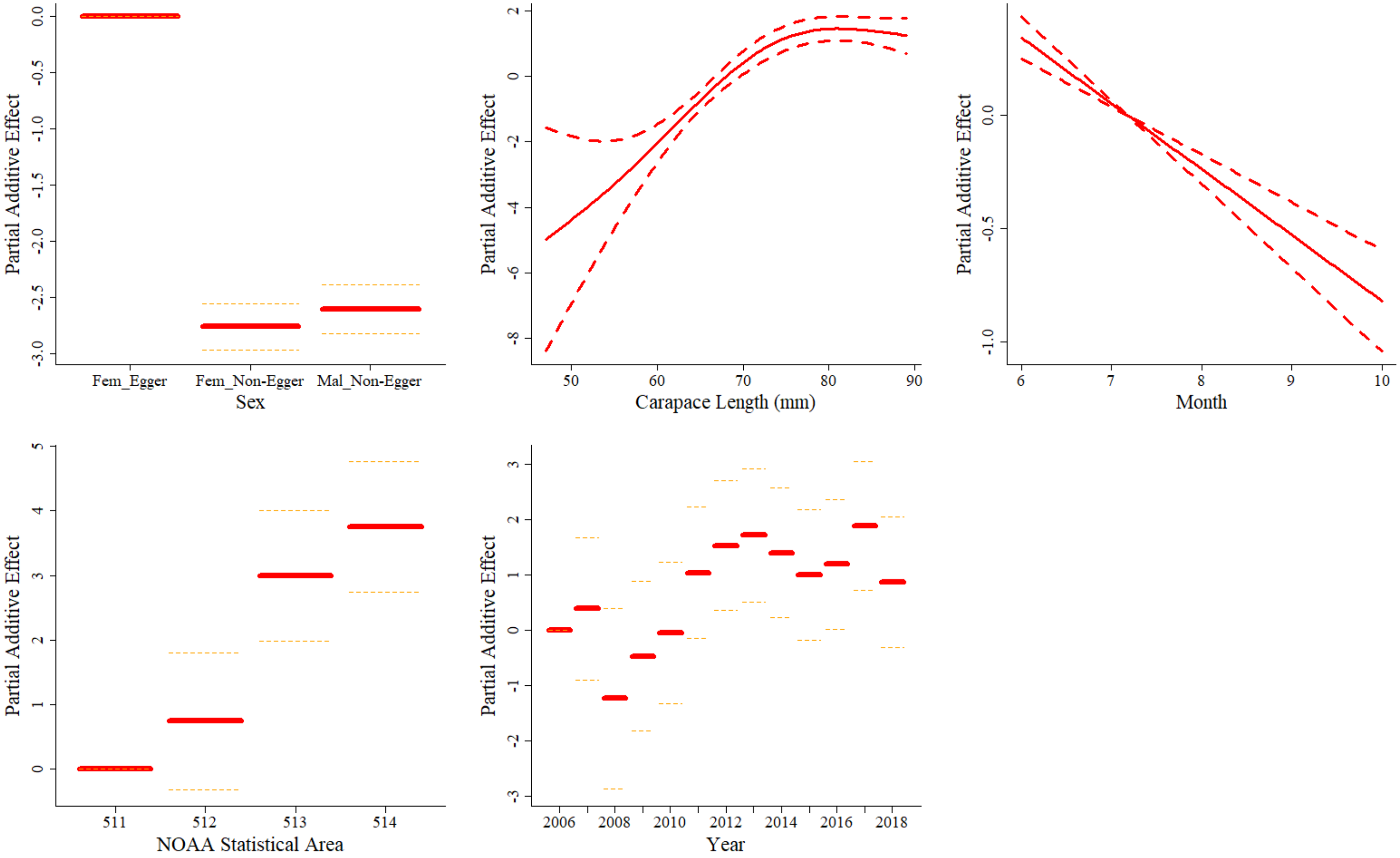

Figure 8. Estimated effects of covariates on severe shell disease prevalence in GOM. Positive additive effects represent a positive influence on shell disease prevalence, whereas negative values indicate a negative influence on shell disease prevalence. Sex characterization was described as either Male (Mal_Non-Egger), Female without eggs (Fem_Non-Egger), or female with eggs (Fem-Egger).

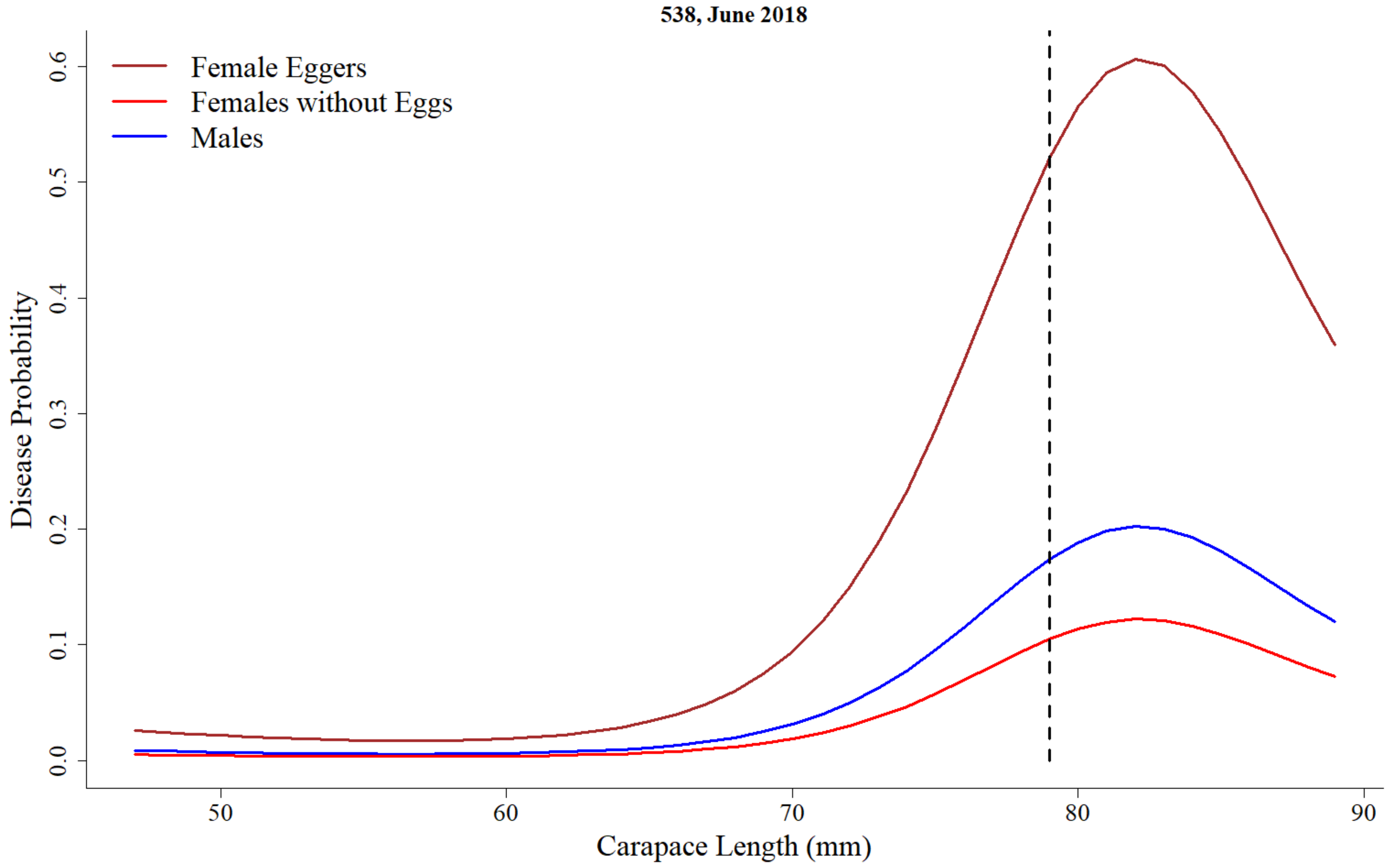

Figure 9. Predicting disease probabilities for lobsters of varying sizes in June 2017 for SA 514 using the SNE model. Colored lines present the difference in prevalence across the three sex categories. The response variable is the probability of a lobster being severely diseased. The vertical dashed line represents the SNE stock-wide L_{50} Maturity (79mm).

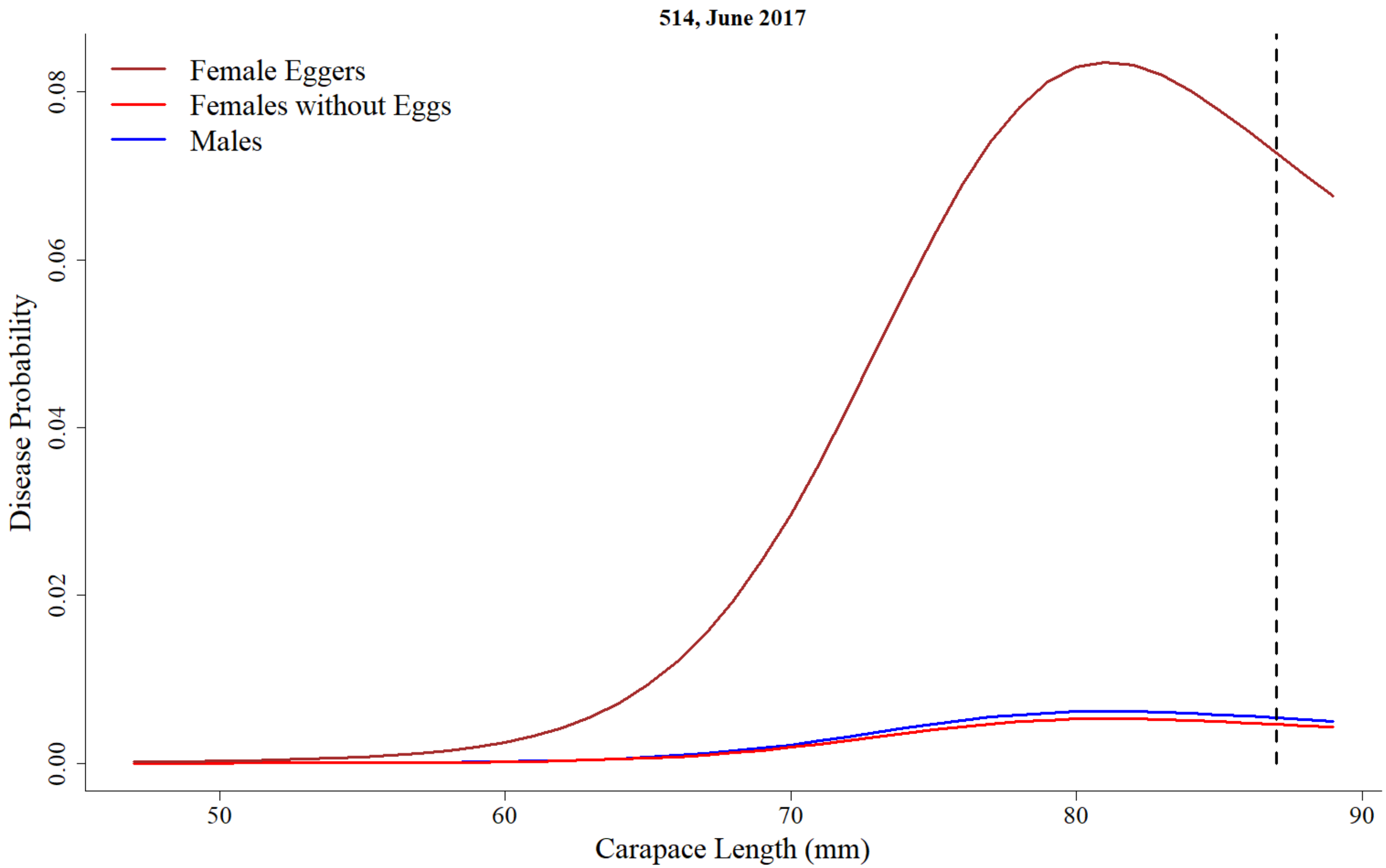

Figure 10. Predicting disease probabilities for lobsters of varying sizes in June 2018 for SA 538 using the GOM model. Colored lines present the difference in prevalence across the three sex categories. The response variable is the probability of a lobster being severely diseased. The vertical dashed line represents the GOM stock-wide L_{50} Maturity (87mm).

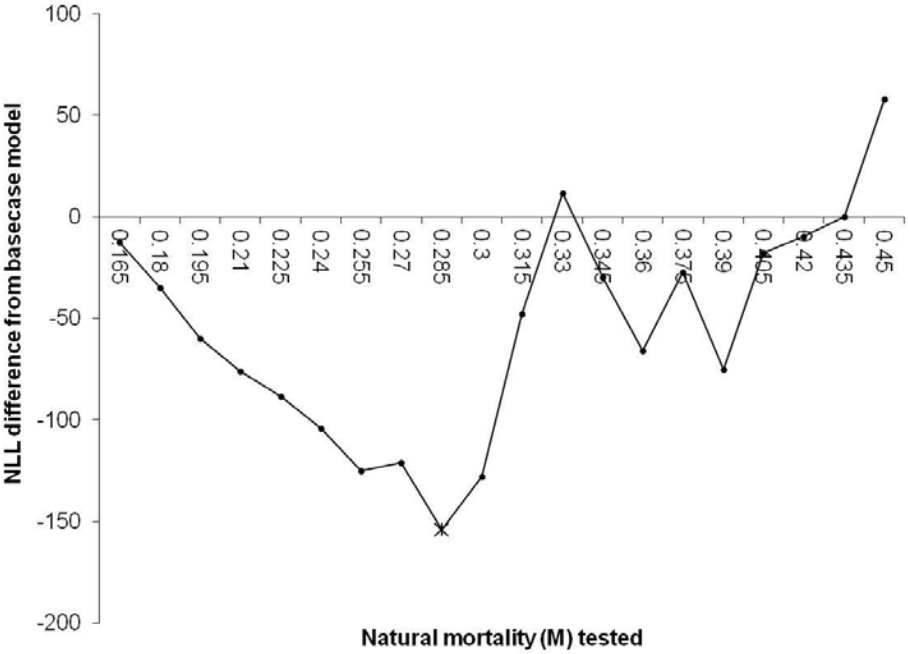

Figure 11. Difference in fit of alternative UMM model runs from ASMFC (2009) assuming different natural mortality during 1998 - 2007.

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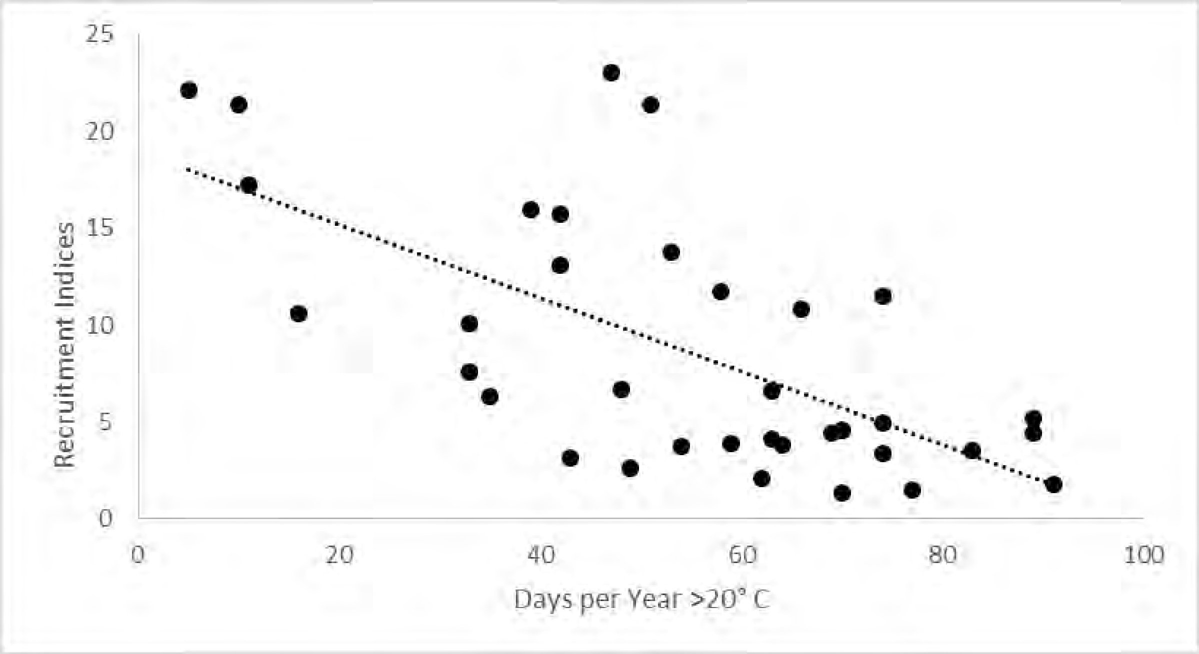

Figure 12. Annual relative abundance of recruit-size lobsters versus the annual number of days with average temperature > 20° C. Recruit lobster abundance is the averaged catch index in four fall research surveys. Daily water temperature is the mean of continuous temperature recorded at the submerged intakes of Millstone Power Station.

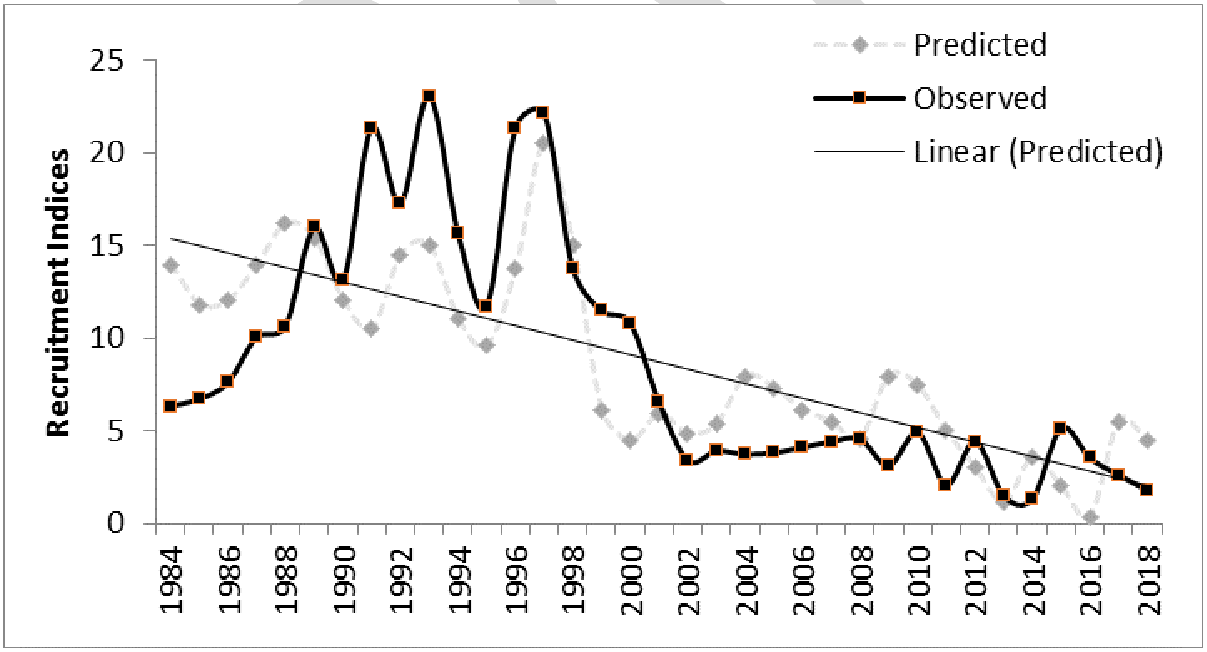

Figure 13. Rate of decline in predicted and observed recruitment based on the number of day > 20° C, 1984 - 2018. Recruit lobster abundance is the averaged catch index in four fall research surveys (MA, RI, CT, NMFS SNE surveys). Daily water temperature is the mean of continuous temperature recorded at the submerged intakes of Millstone Power Station.

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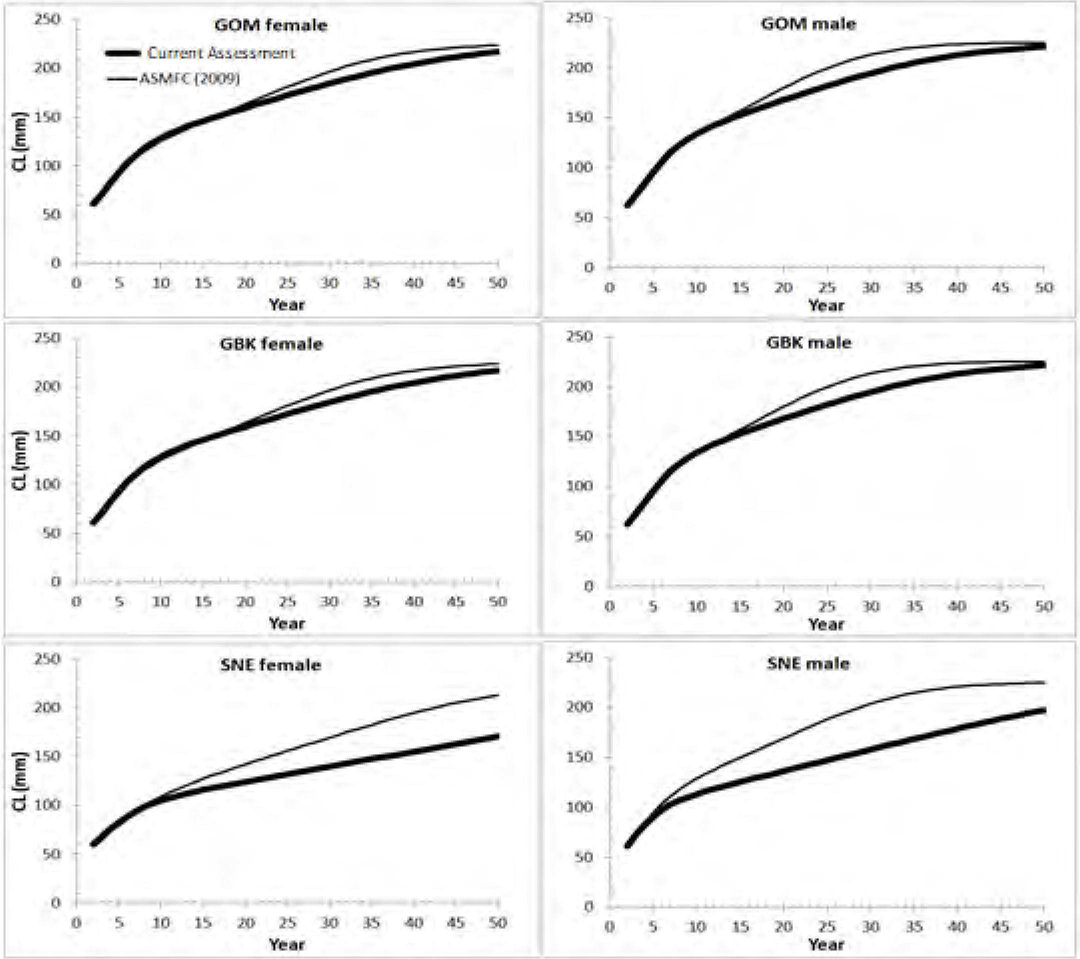

Figure 14. Mean length at age of female and male lobsters in the three areas from growth transition matrices developed in the last assessment (ASMFC 2015a) and used in the current assessment.

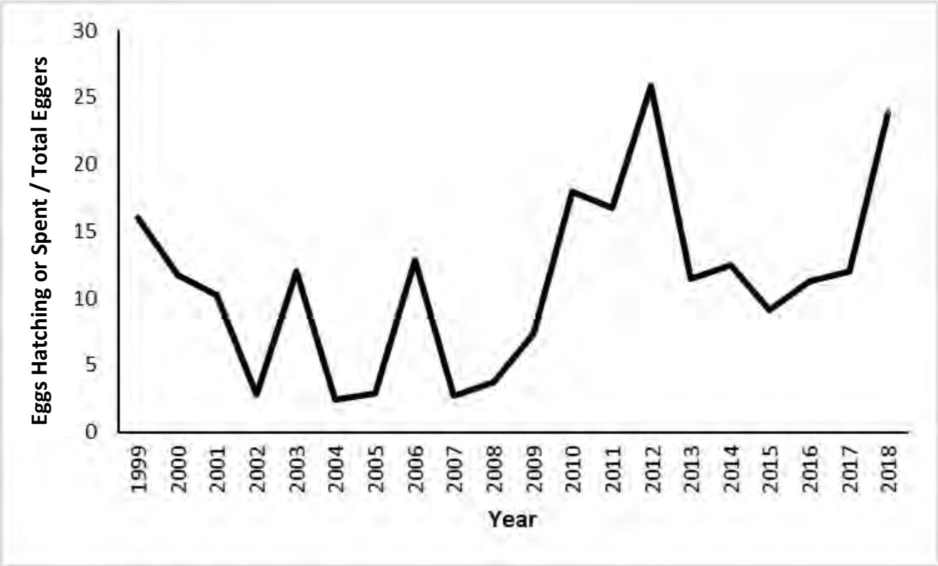

Figure 15. Percentage of egg bearing lobsters with eggs hatching or spent in June, in the Eastern Gulf of Maine (511 and 512 combined).

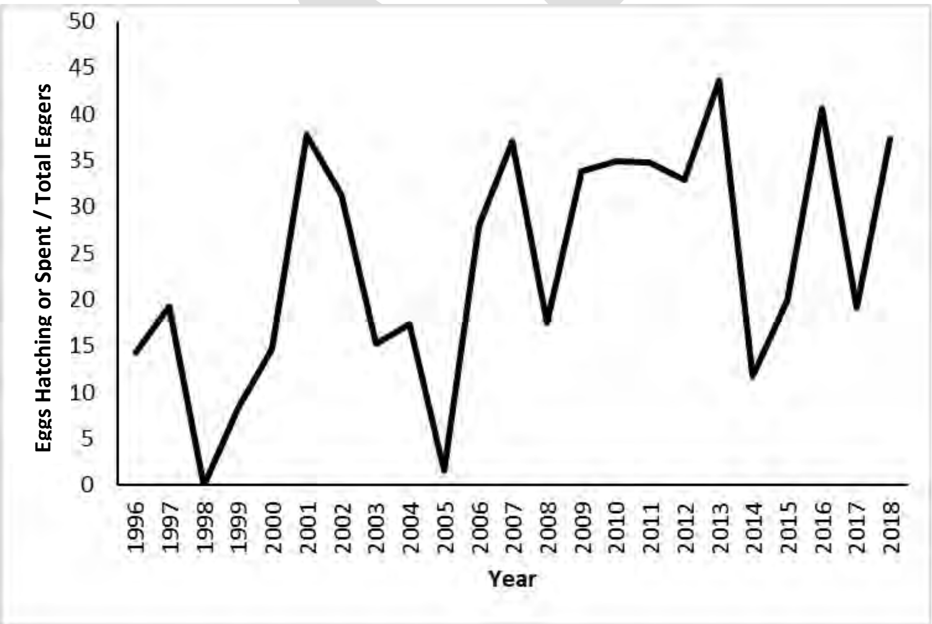

Figure 16. Percentage of egg bearing lobsters with eggs hatching or spent in June, in the Western Gulf of Maine (Maine SA 513).

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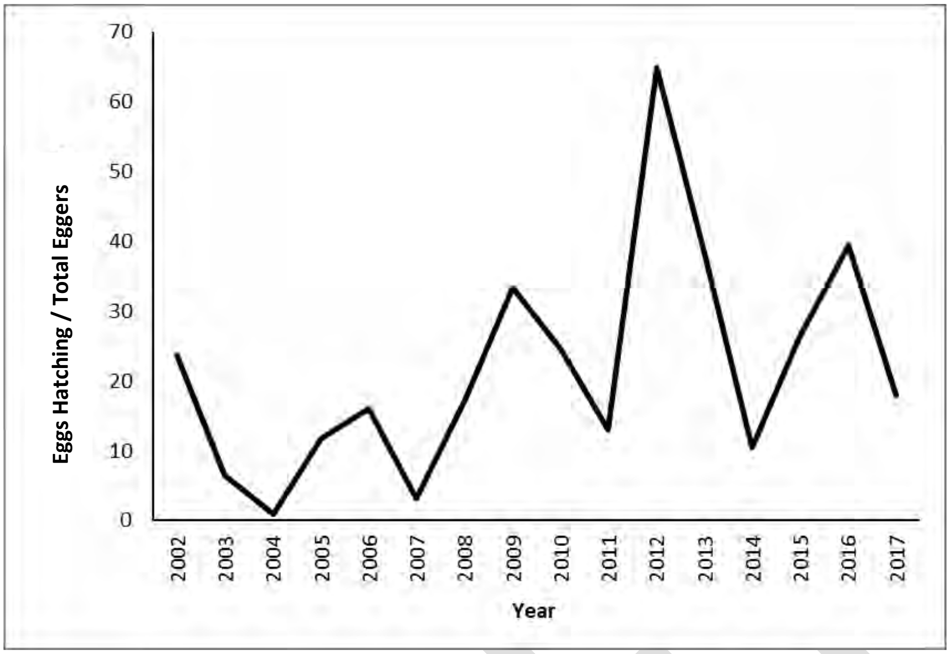

Figure 17. Percentage of egg bearing lobsters with eggs in the process of hatching in June in New Hampshire waters in the Western Gulf of Maine (New Hampshire SA 513).

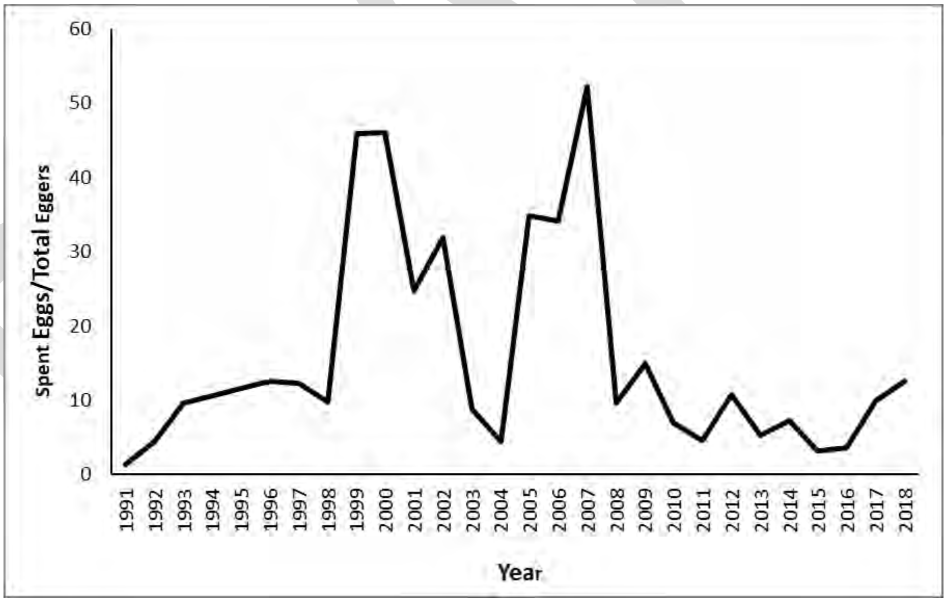

Figure 18. Percentage of egg bearing lobsters with spent eggs in June in Massachusetts waters located in the Western Gulf of Maine (SA 514)

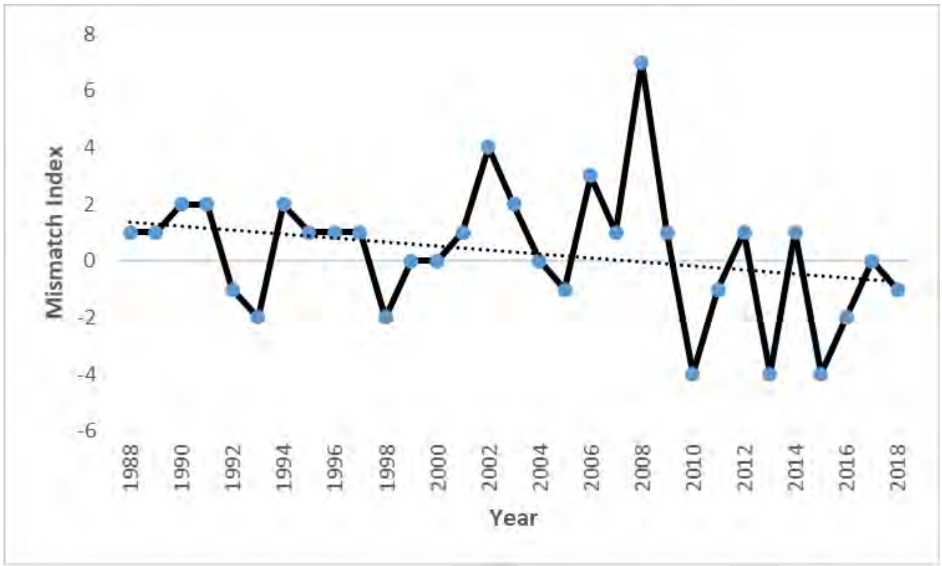

Figure 19. The difference between peak stage I lobster larvae and end of season *C. finmarchicus*. Positive numbers indicate peak stage I occurred before the end of the season, whereas negative numbers indicate the *C. finmarchicus* season ended before peak stage I. There is a significant downward trend towards negative numbers over the time series suggesting a mismatch between stage I lobster larvae and a potentially important food source (Figure from Carloni et. al., in prep).

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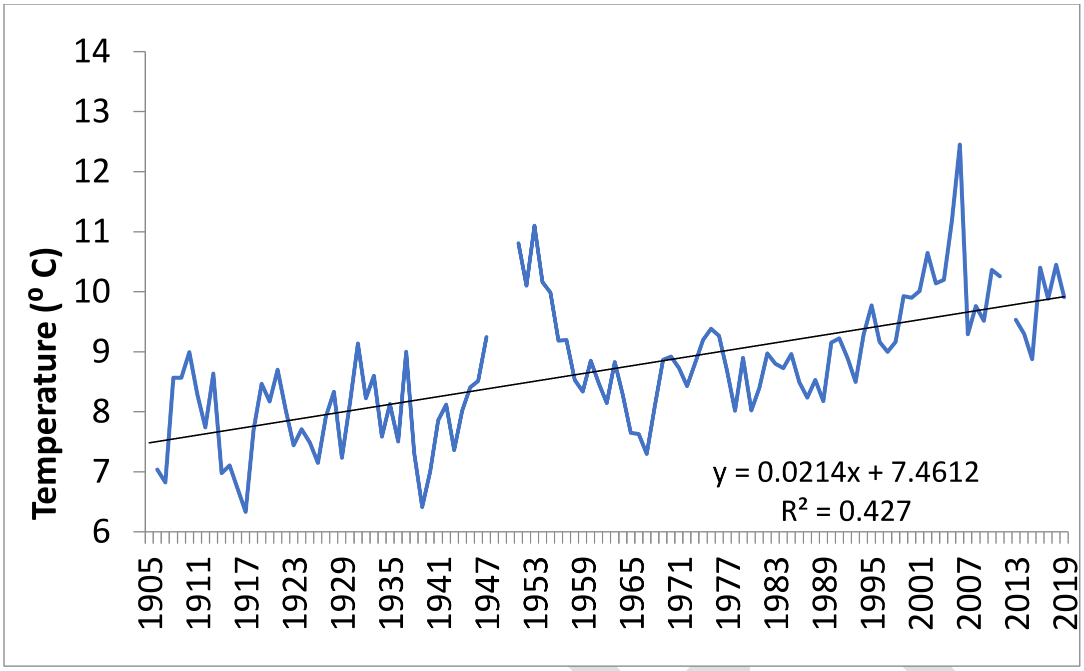

Figure 20. Mean annual sea surface temperature (SST) from Boothbay Harbor, M from 1906 to 2019.

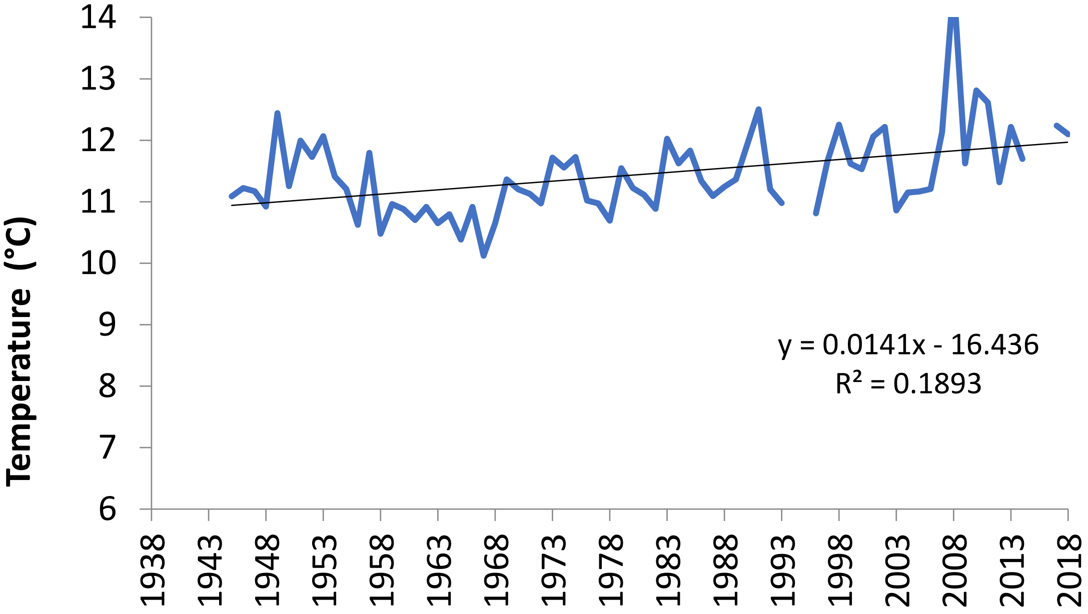

Figure 21. Mean annual sea surface temperature (SST) from Woods Hole, MA from 1945 to 2018.

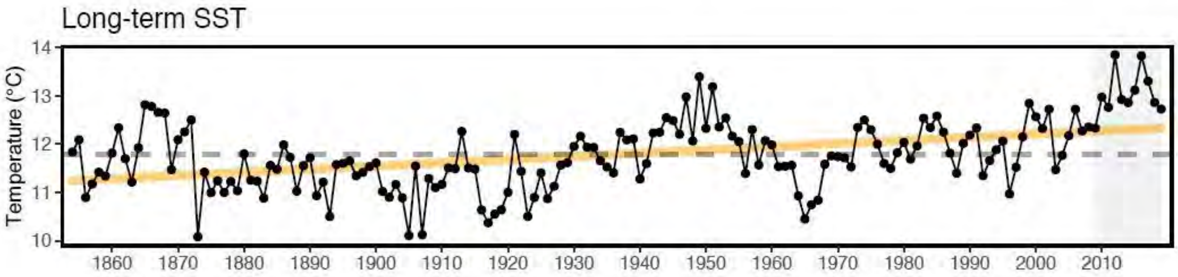

Figure 22. Mean annual sea surface temperature (SST) over the Northwest Atlantic shelf. (Source: Gaichas et al., 2020)

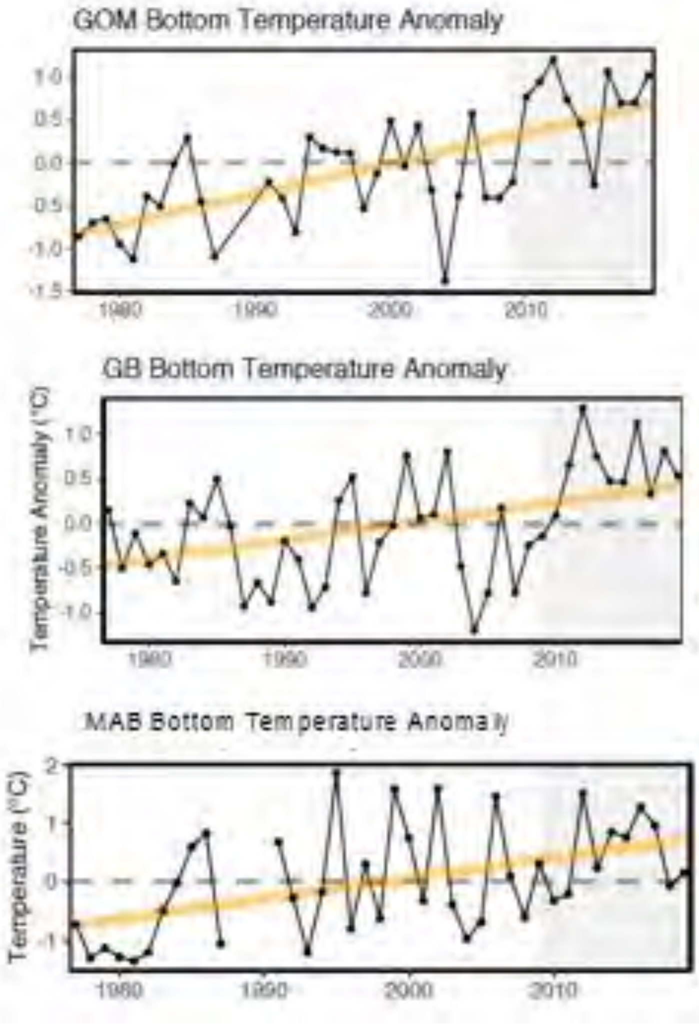

Figure 23. Mid-Atlantic Bight (MAB), Georges Bank (GB), and Gulf of Maine (GOM) bottom temperature anomolies. Yellow line indicates significant increasing trend at $p < 0.05$. (Source: Gaichas et al., 2020A and Gaichas et al., 2020B).

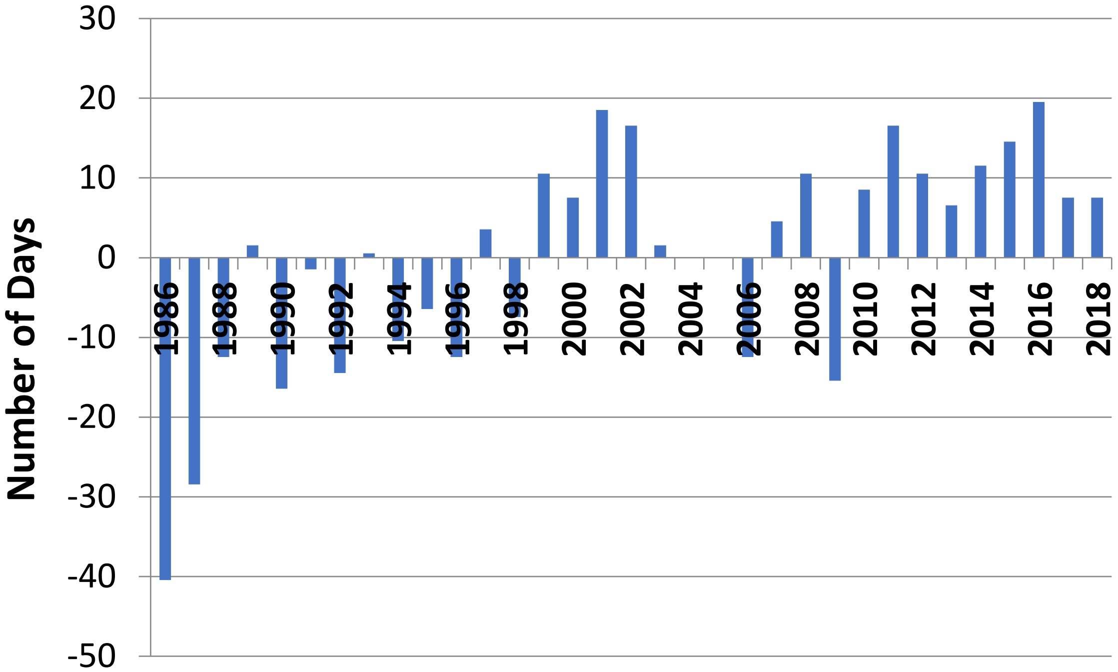

Figure 24. Bottom temperature anomolies from mean number of days above 20 °C at Cleveland Ledge (8 m) - Buzzards Bay, MA. Mean number of days = 80.5, missing data 2004 – 2005.

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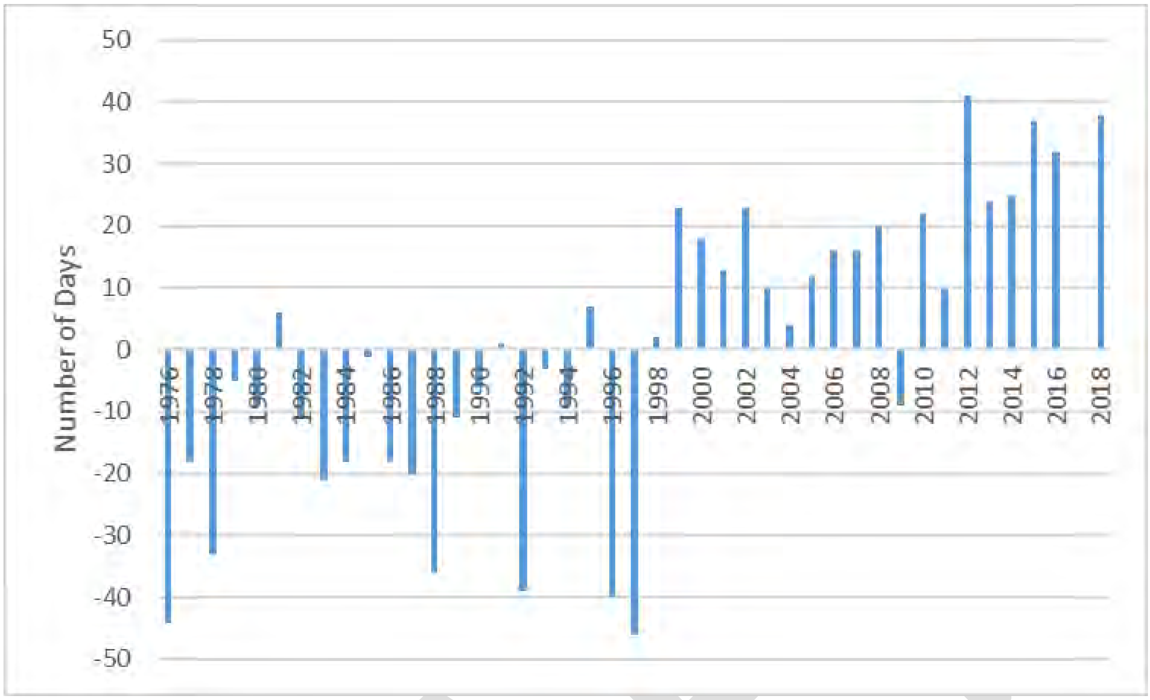

Figure 25. Bottom temperature anomolies from mean number of days ≥ 20 °C at Dominion Nuclear Power Stationn (5 m) - Niantic Bay, CT. Mean number of days = 55.45 (personal communication J. Swenarton, DNPS).

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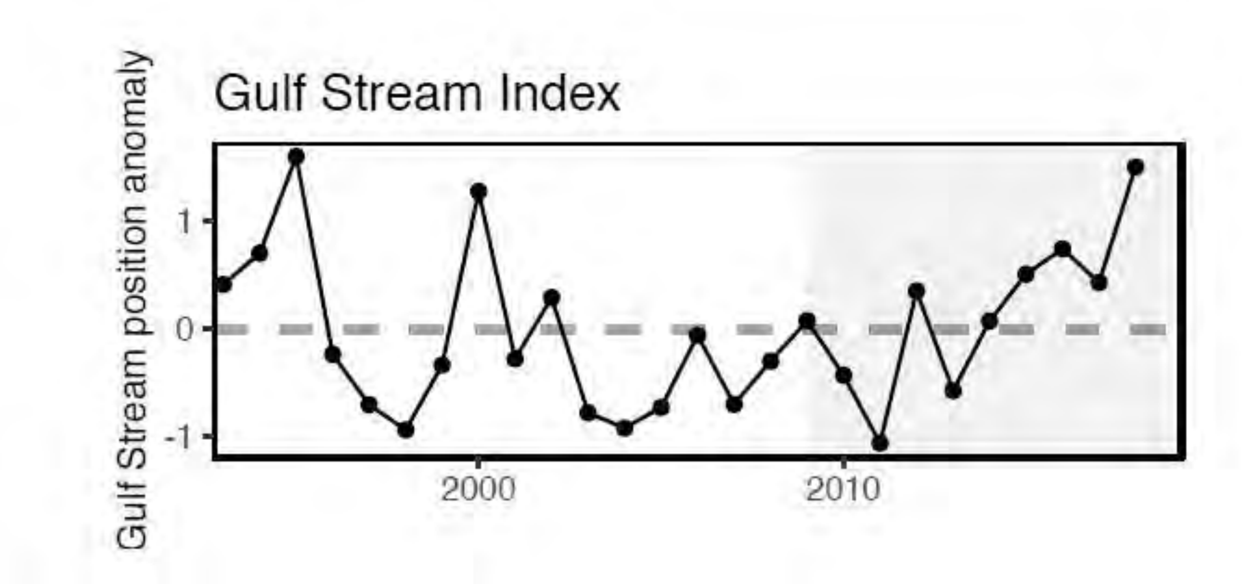

Figure 26. Gulf Stream Index which represents the position of the Gulf Stream. Positive Values are more northerly. Dashed line is the time series mean (Gaichas et al., 2020)

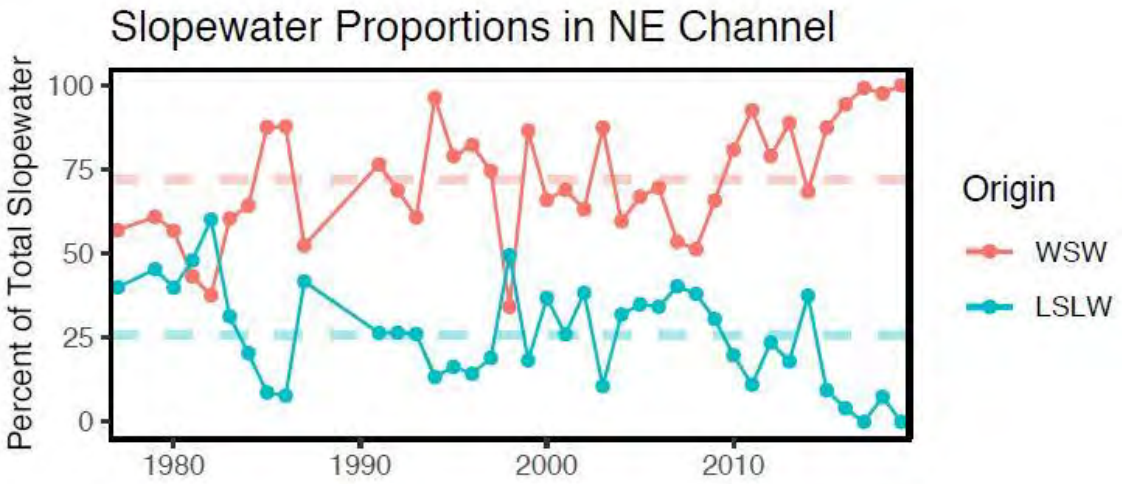

Figure 27. Proportion of Warm Slope Water (WSW) from the Gulf Stream and Labrador Slope Water (LSLW) entering GOM through the Northeast Channel. Dashed line is time series mean. (Gaichas et al., 2020)

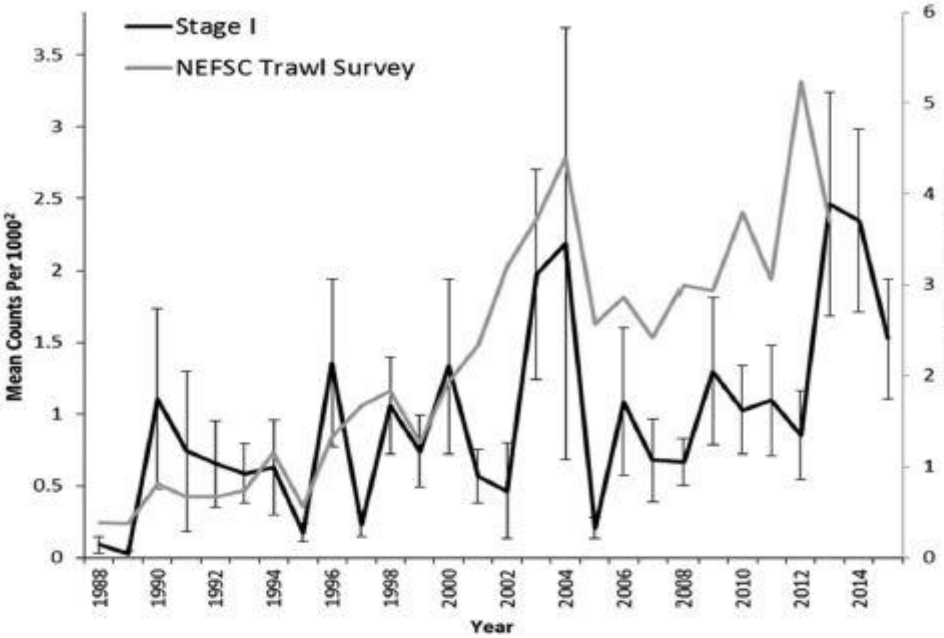

Figure 28. Seabrook Station Environmental Monitoring neuston-sampled stage I larvae (SE) and Northeast Fisheries Science Center spring trawl survey for mature female lobsters. The two indices are significantly correlated (*r* = 0.56, *P* = 0.002). (Carloni et al., 2018)

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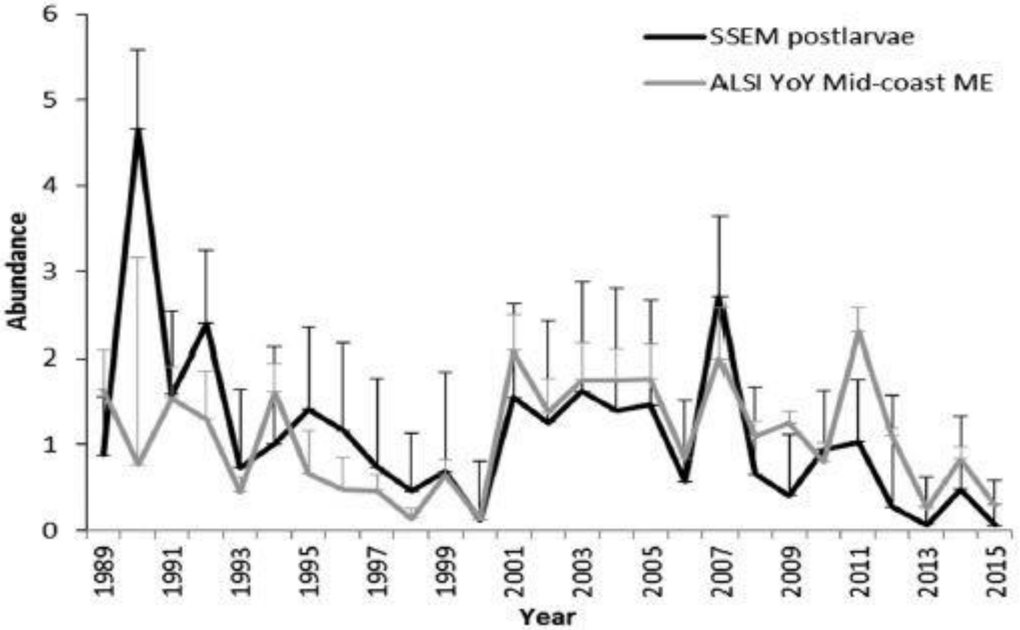

Figure 29. Parallel time series indicating the spatial coherence of Seabrook Station Environmental Monitoring neuston-sampled lobster postlarvae (SE) and young-of-the year (YOY) (SE) from mid-coast Maine. Only positive error bars are displayed. These two indices were significantly correlated over the 27 yr time series (*r* = 0.52, *P* = 0.006). Units of abundance for postlarvae, n 1000 m^{-2}; for YOY, n m^{-2}.. (Carloni et al., 2018)

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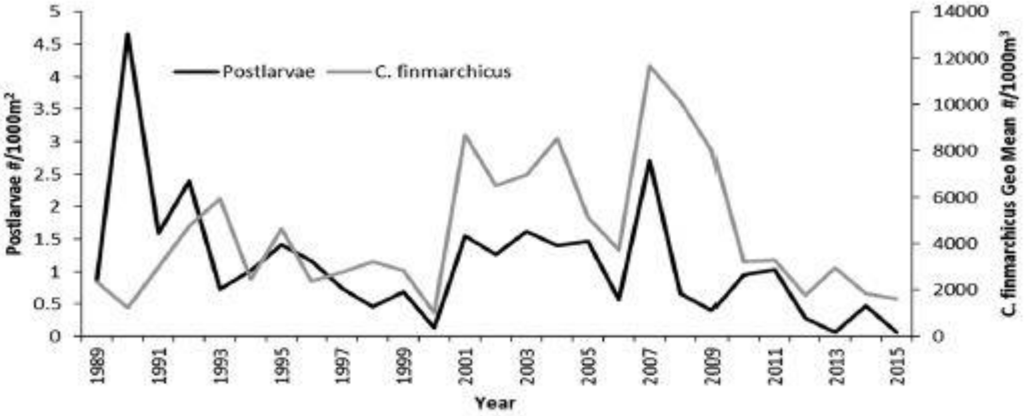

Figure 30. Parallel time series of neuston net-sampled lobster postlarvae and plankton net-sampled *Calanus finmarchicus* from Seabrook Station Environmental Monitoring (SSEM). The two indices were significantly correlated over the 27-year time series (*r* = 0.55, *P* = 0.0038). (Carloni et al., 2018)

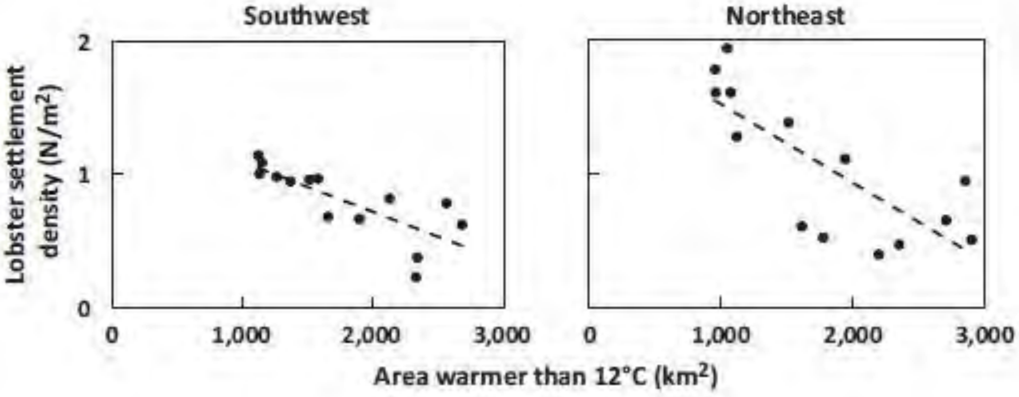

Figure 31. Regression between thermal habitat area and YOY lobster densities in the southwestern and northeastern GOM. Southwestern GOM: *Y* = −3.74 × 10−4*x* + 1.47, *N* = 14, *R*2 = 0.60, *p* = .001. Northeastern GOM: *Y* = −5.86 × 10−4*x* + 2.11, *N* = 14, *R*2 = 0.61, *p* = .001. Three-year moving block average values were used). (Goode et al. 2019)

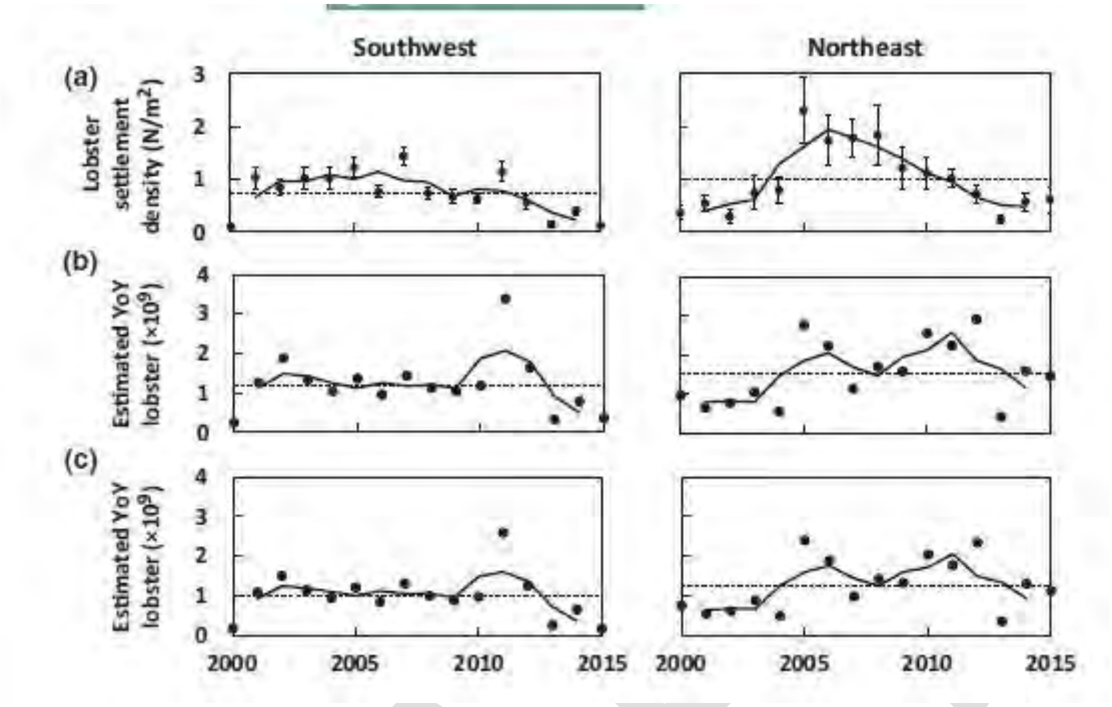

Figure 32. Effects of expanded habitat for lobster settlement. (a) YOY densities ≤10 m from 2000 to 2015 in the southwestern and northeastern GOM. (b) Abundance of YOY extrapolated uniformly distributed over suitable thermal habitats ≤50 m. (c) Abundance of YOY extrapolated over suitable thermal habitats ≤100 m taking into account depth-dependent scaling of inshore (≤10 m) YOY densities and rocky habitat availability. Solid line denotes the 3-year moving block average. Dashed line denotes time-series average. (Goode et al. 2019)

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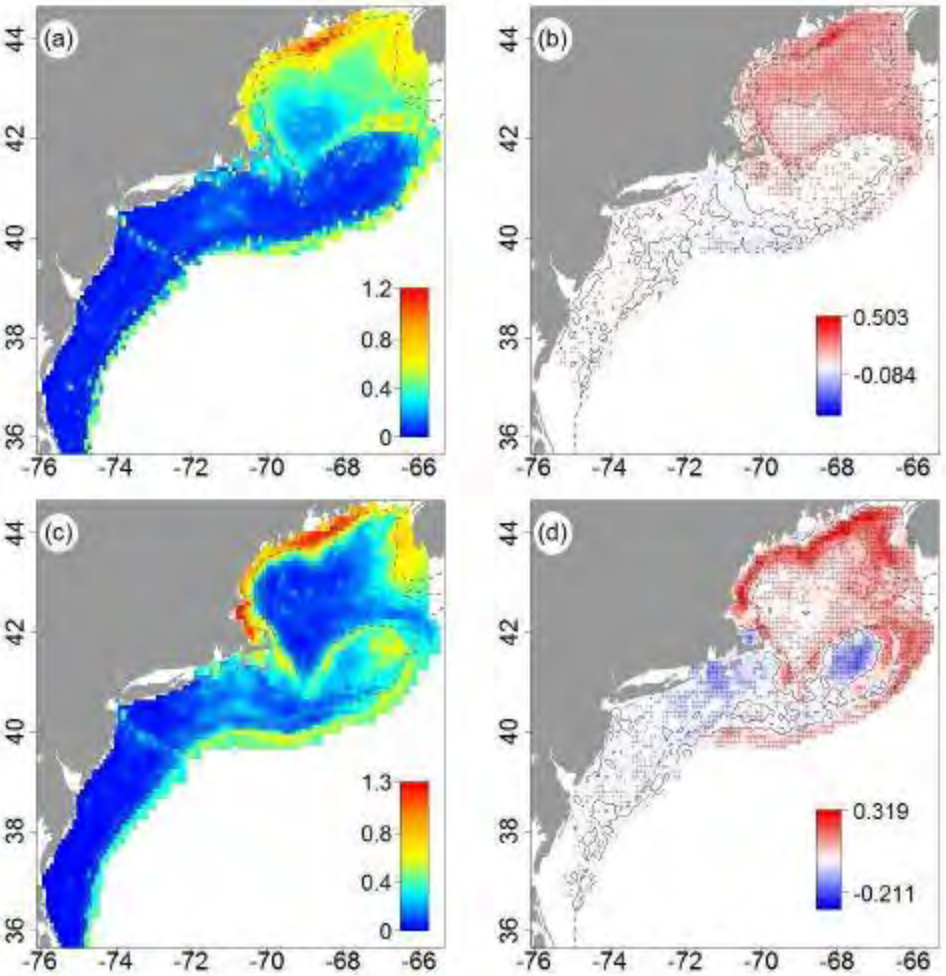

Figure 33. Mean predicted biomass for spring (a) and fall (c) annual rates of change (Sen slope) in biomass (b and d, spring and fall, respectively). Black crosses in rate of change panels indicate significant slopes ($P<0.01$). (Source: Mazur et al. 2020)

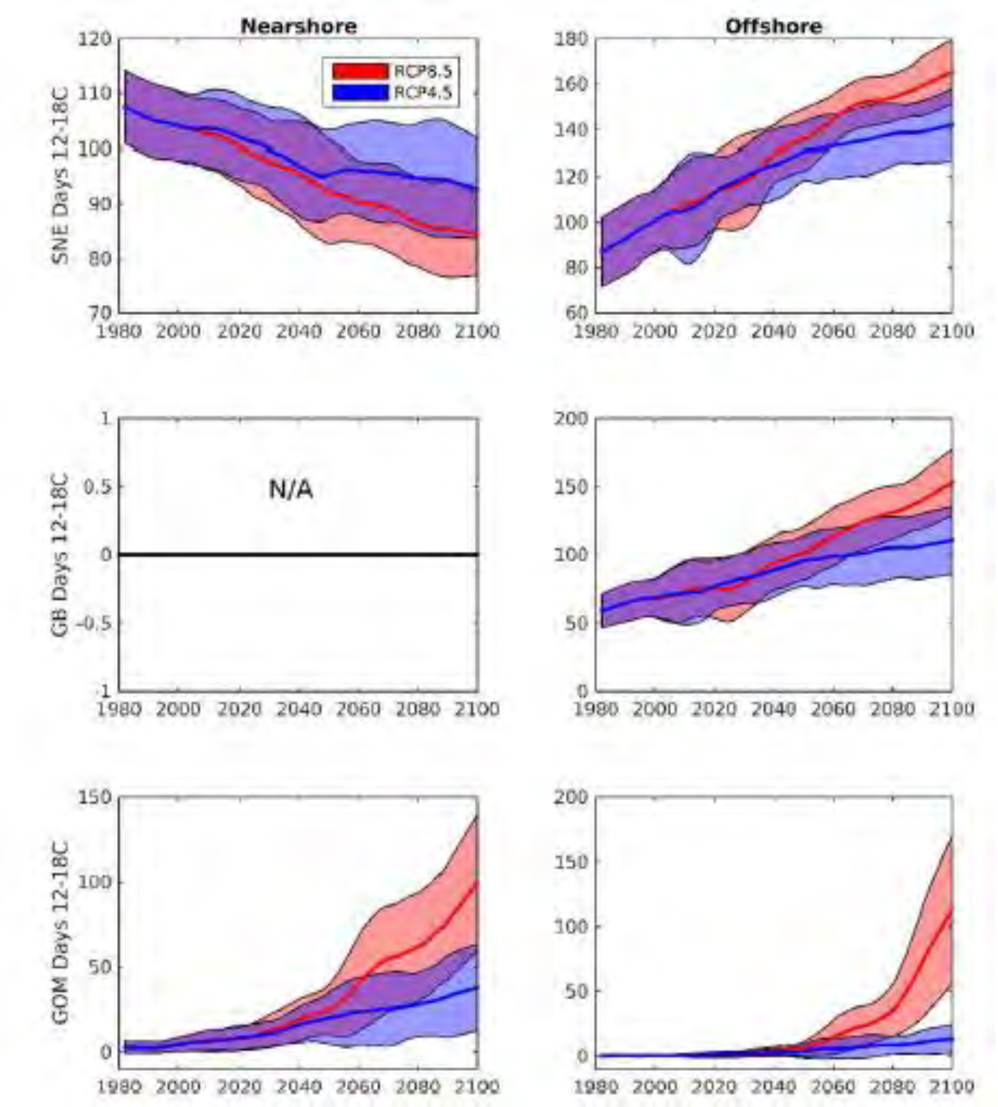

Figure 34. Nearshore and offshore number of days annually between 12 and 18^{o} C under two climate scenarios (RCP8.5 (red) and RCP4.5 (blue)) for southern New England (SNE), Georges Bank (GB), and the Gulf of Maine (GOM). There is no nearshore region in GB (panel left blank). The thick lines are the model ensemble mean, and shading shows ± 1 standard deviation. Model projections have been smoothed using 20 year locally weighted scatterplot (LOWESS) smoothing. (Source: Rhueban et al., 2018)

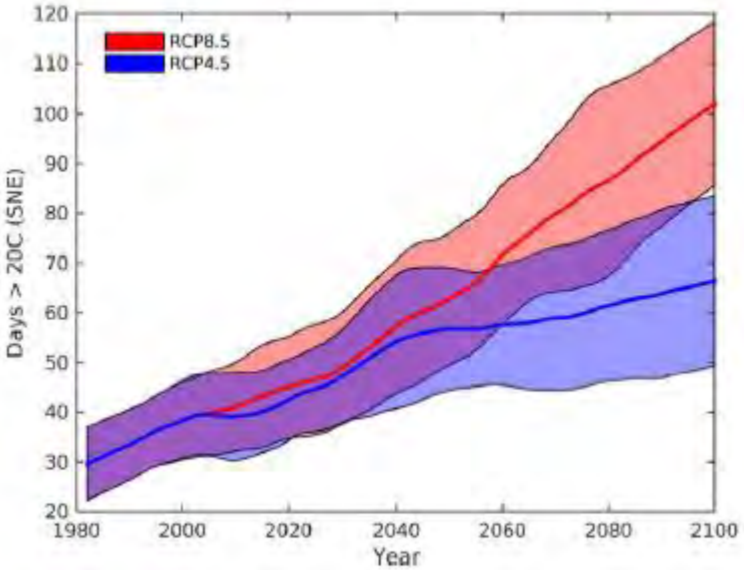

Figure 35. SNE Nearshore number of days annually >20^0 C under two climate scenarios (RCP8.5 (red) and RCP4.5 (blue)). The thick lines are the model ensemble mean, and shading shows standard deviation. Model projections have been smoothed using 20 year locally weighted scatterplot (LOWESS) smoothing. (Source: Rhueban et al., 2018)

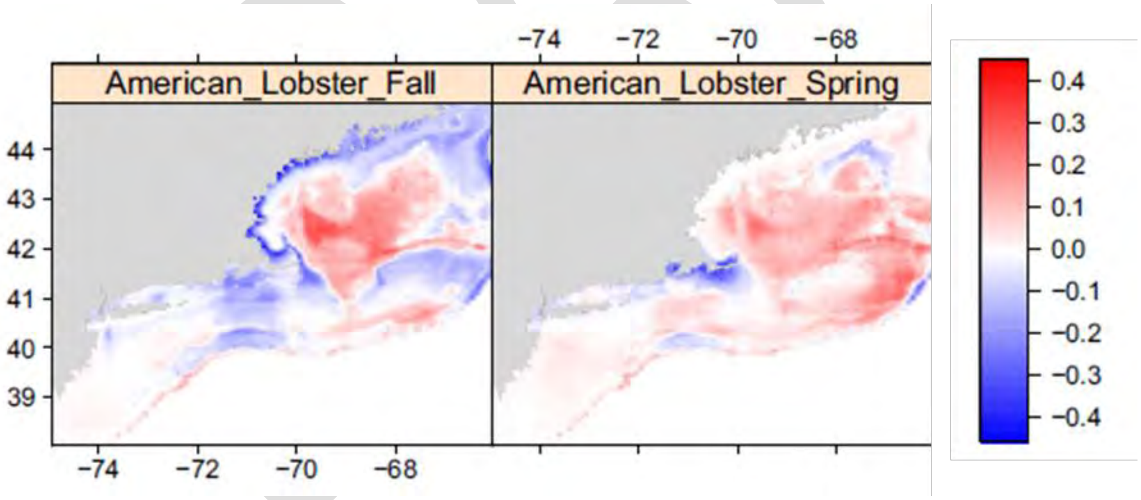

Figure 36. Temporal change in lobster habitat suitability (probability of presence) over the future 80 years of changes in bottom temperature and salinity. The color ramp corresponds to a linear trend in habitat suitability with red areas having a positive change and blue areas having a negative change. (Source: Tanaka et al., 2020)

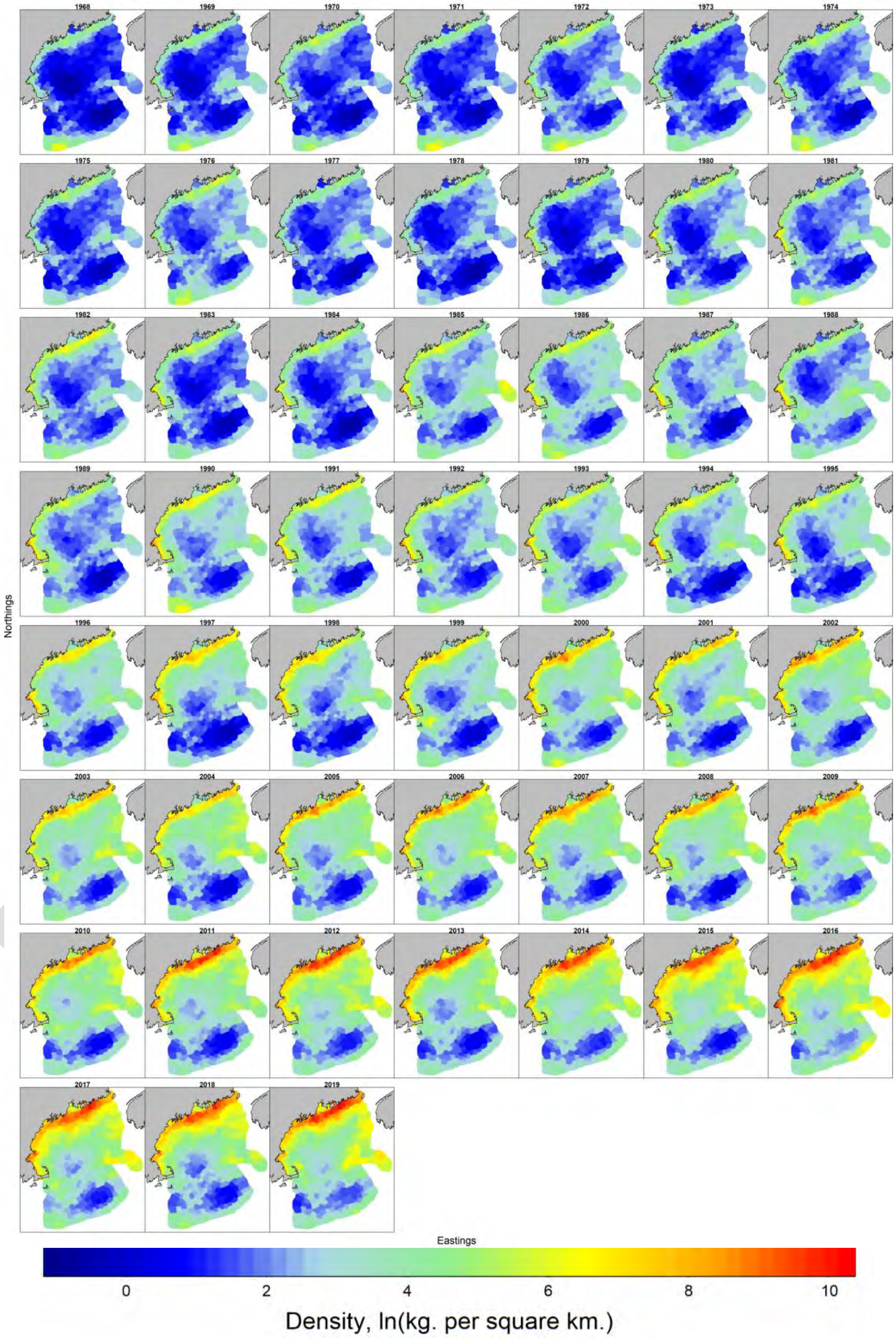

Figure 37. VAST predicted biomass of spring female lobsters in the GOMGBK through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

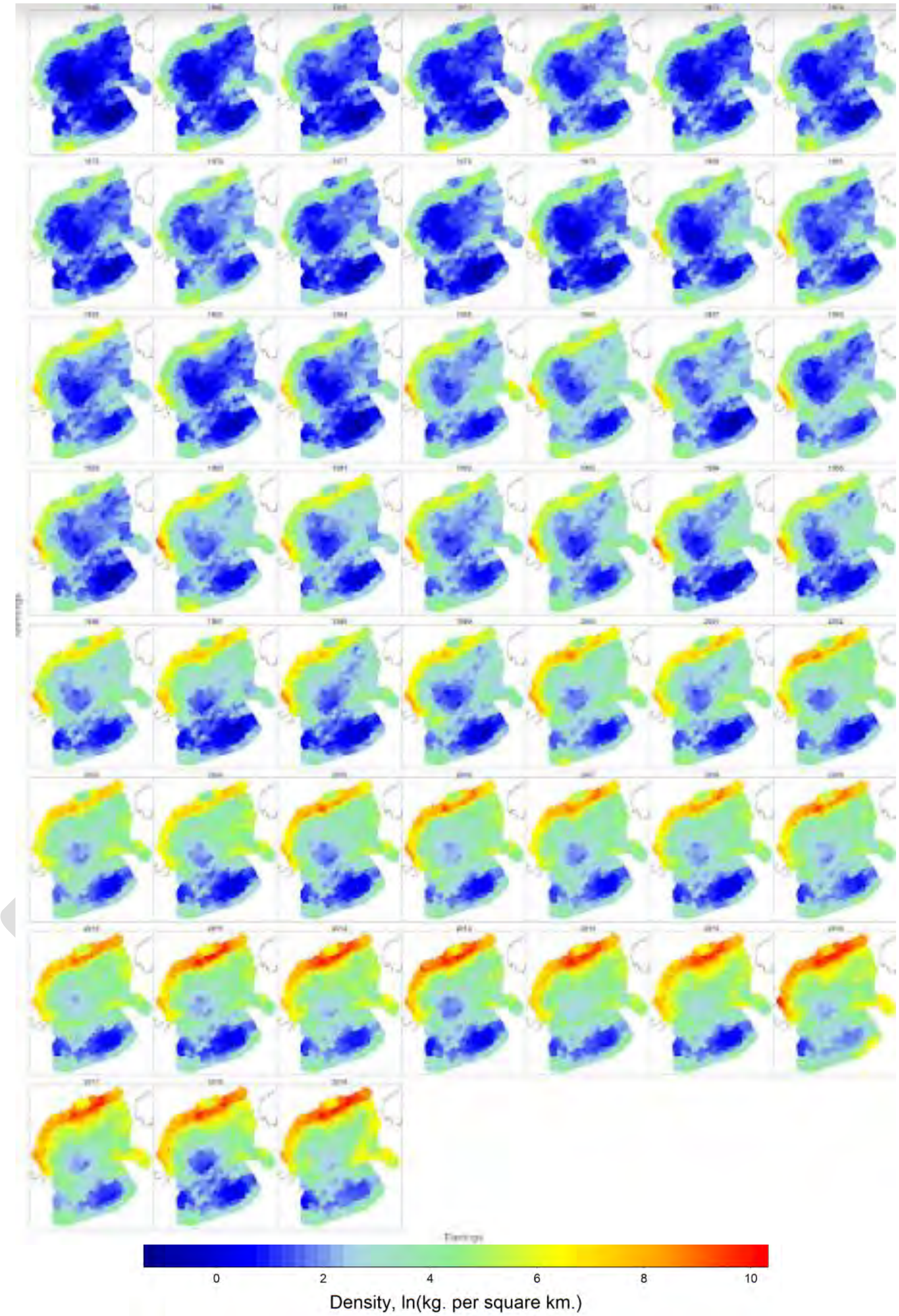

Figure 38. VAST predicted biomass of spring mal lobsters in the GOMGBK through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

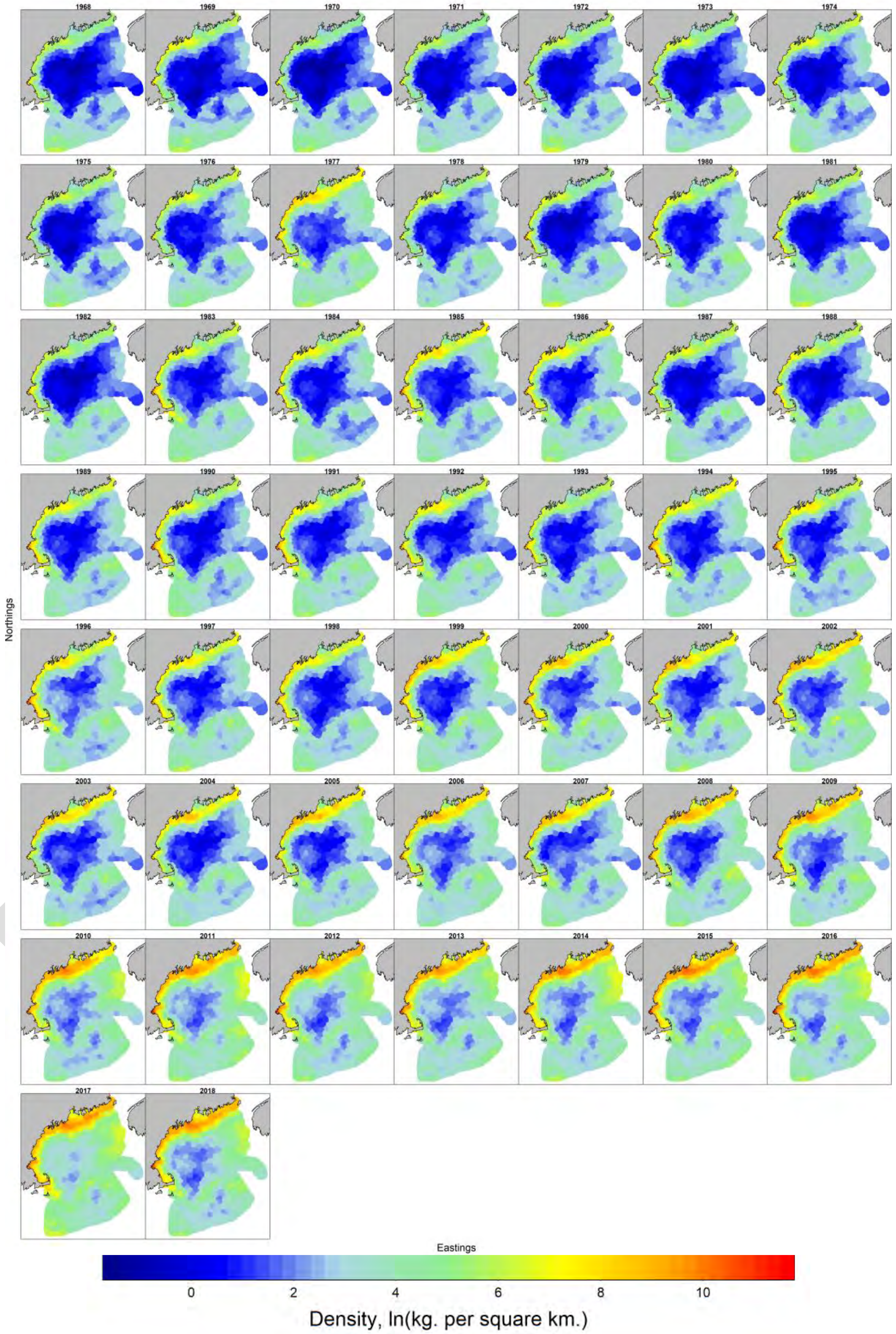

Figure 39. VAST predicted biomass of fall female lobsters in the GOMGBK through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

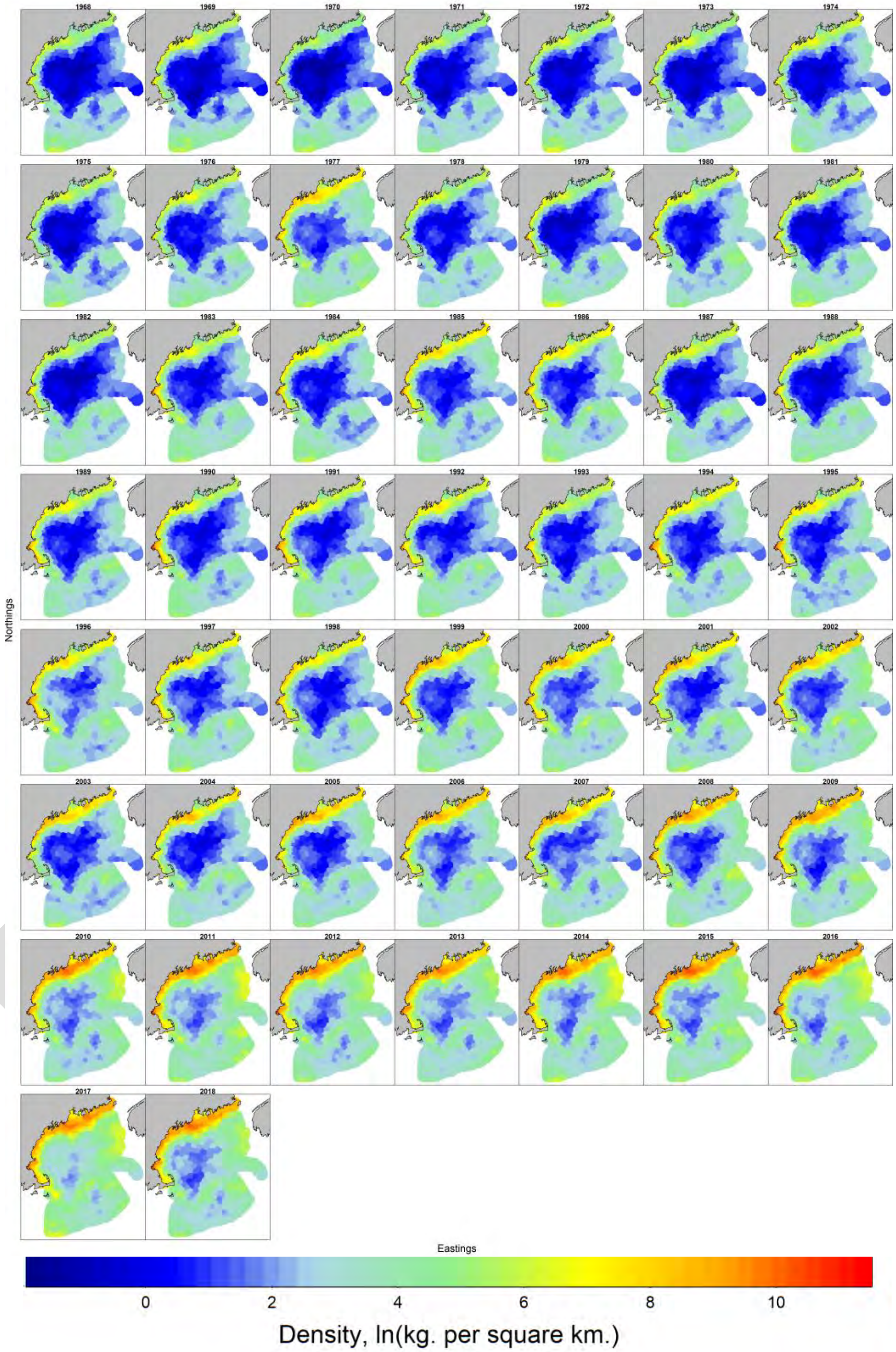

Figure 40. VAST predicted biomass of fall male lobsters in the GOMGBK through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

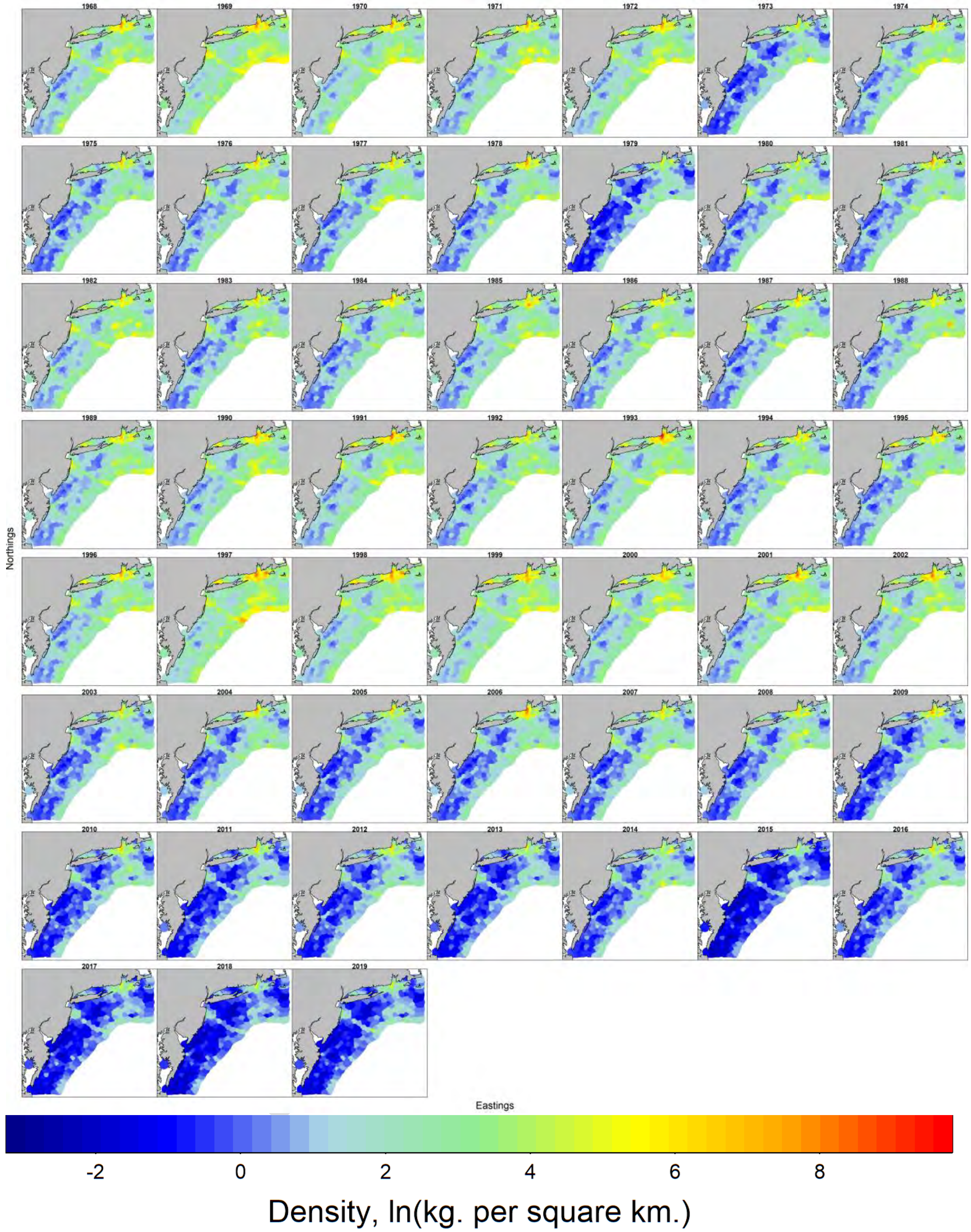

Figure 41. VAST predicted biomass of spring female lobsters in SNE through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

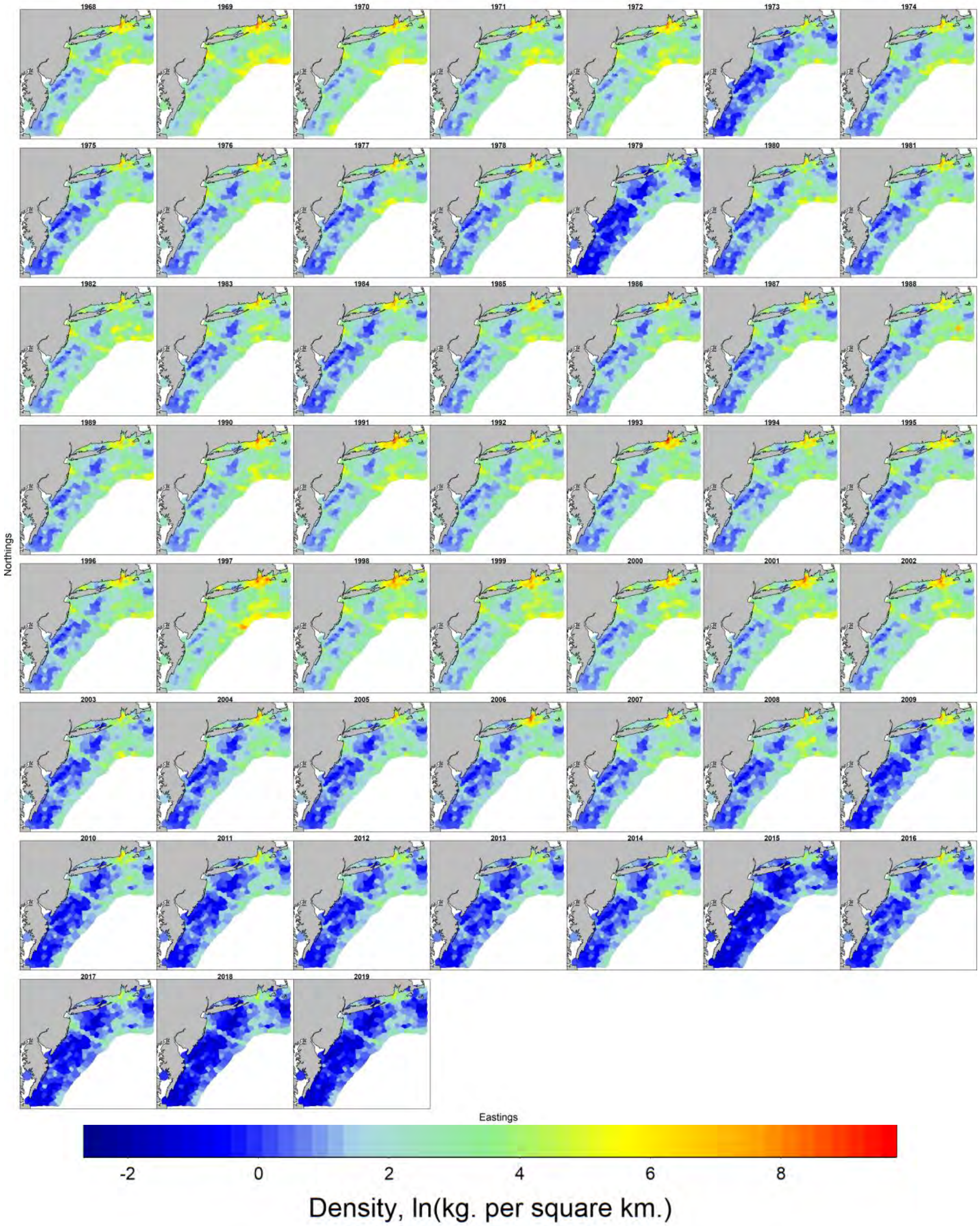

Figure 42. VAST predicted biomass of spring male lobsters in SNE through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

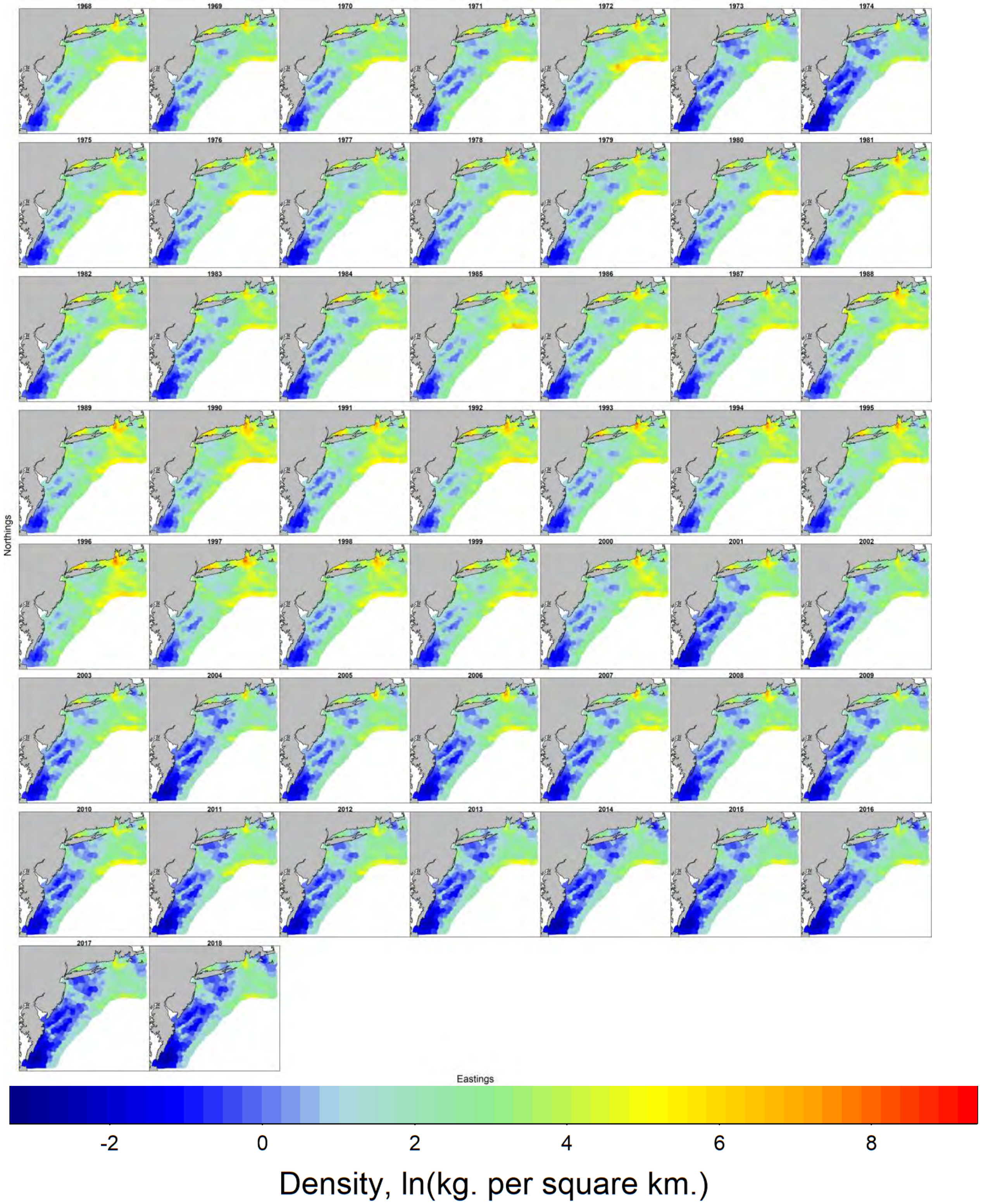

Figure 43. VAST predicted biomass of fall female lobsters in SNE through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

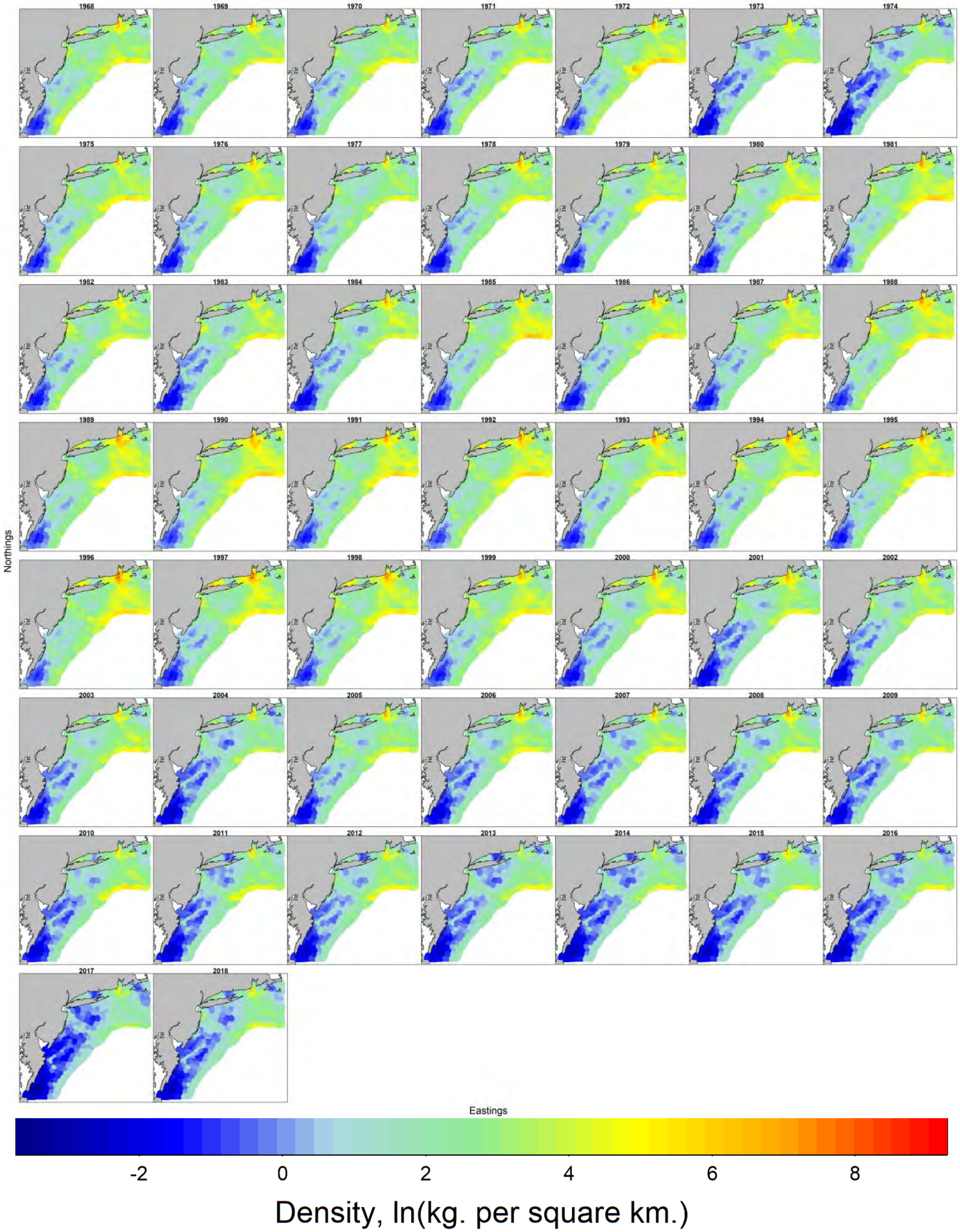

Figure 44. VAST predicted biomass of fall male lobsters in SNE through time. Paneled plots represent individual years from 1968 to 2019. Annual maps progress by column and then row.

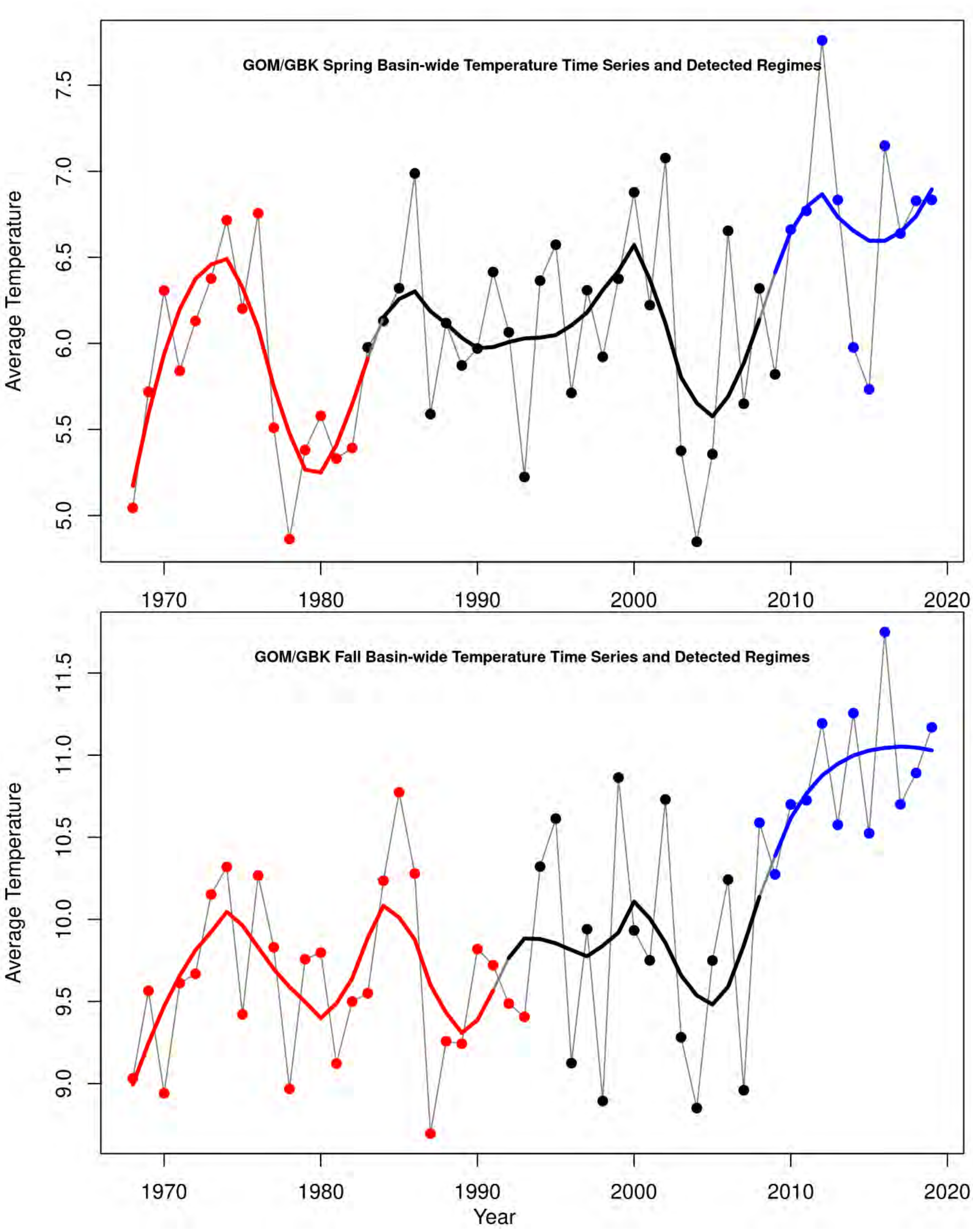

Figure 45. Stock-wide seasonal temperature time series for the Gulf of Maine and Georges Bank for the spring (top) and fall (bottom) including both raw and smoothed time series. Colors identify different candidate regimes.

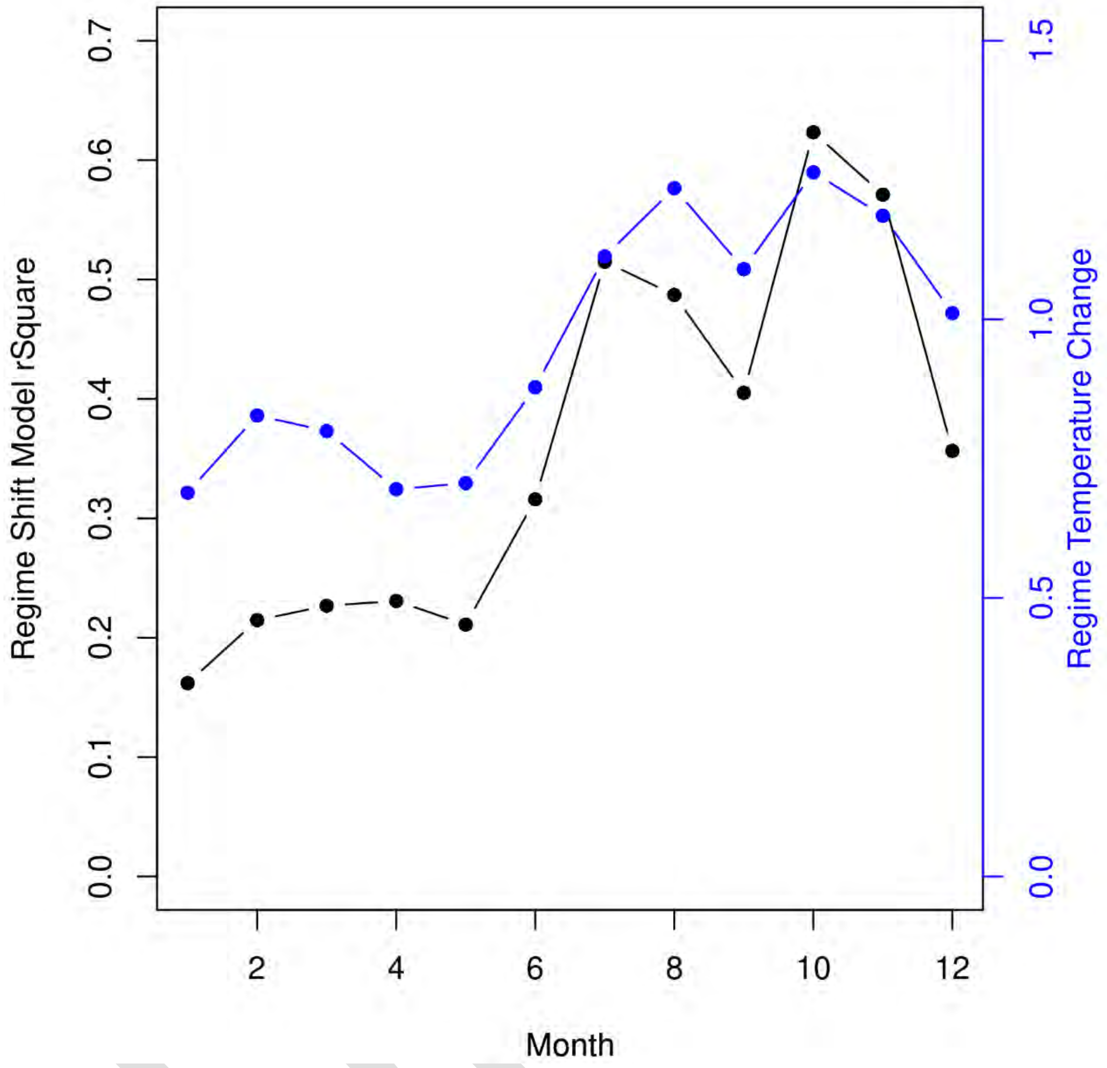

Figure 46. Variance explained and temperature differences by candidate regime shifts for coastal Gulf of Maine from NERACOOS buoys.

D

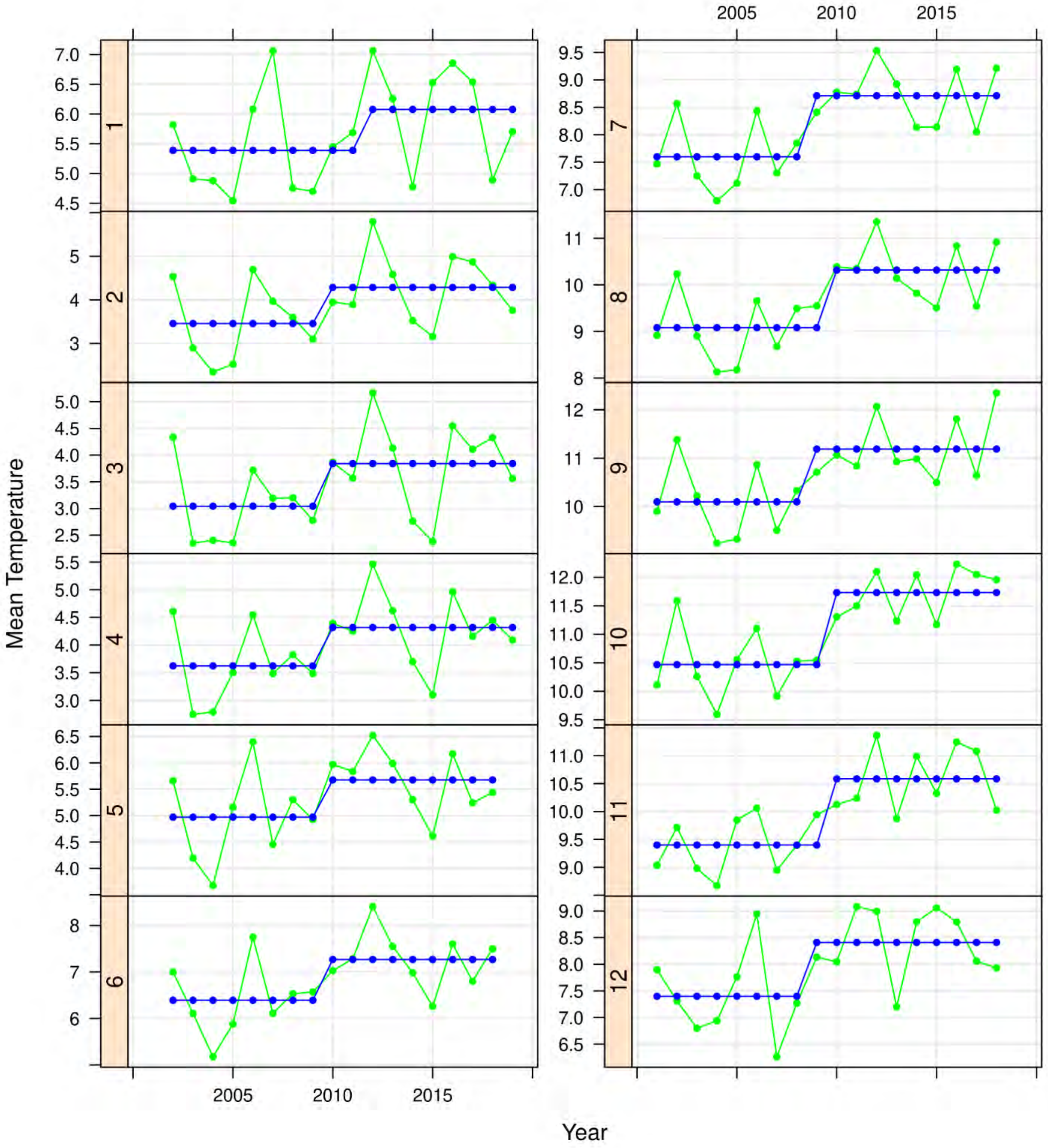

Figure 47. Monthly temperature time series (green) and candidate regime shifts (blue) for coastal Gulf of Maine from NERACOOS buoys.

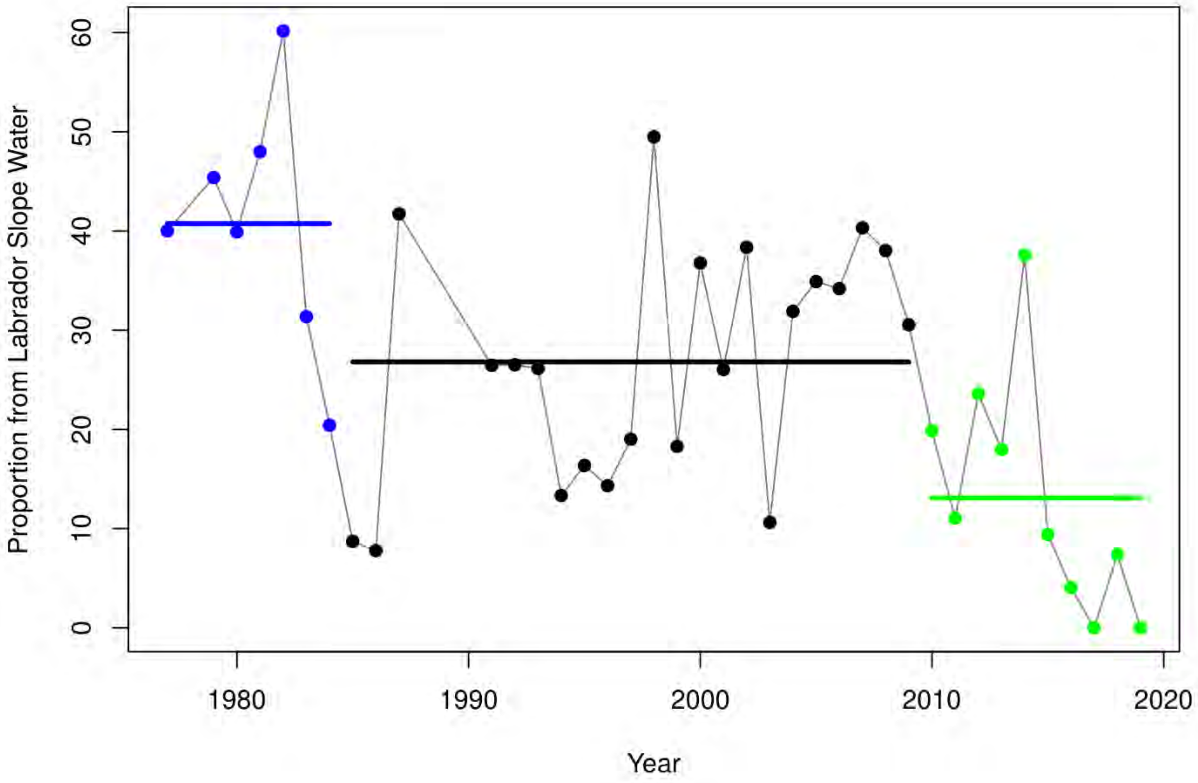

Figure 48. Proportion of water entering the Gulf of Maine through the Northeast Channel that originated as Labrador Slope Water. Colors indicate different candidate regimes with horizontal lines indicating mean values during the regime.

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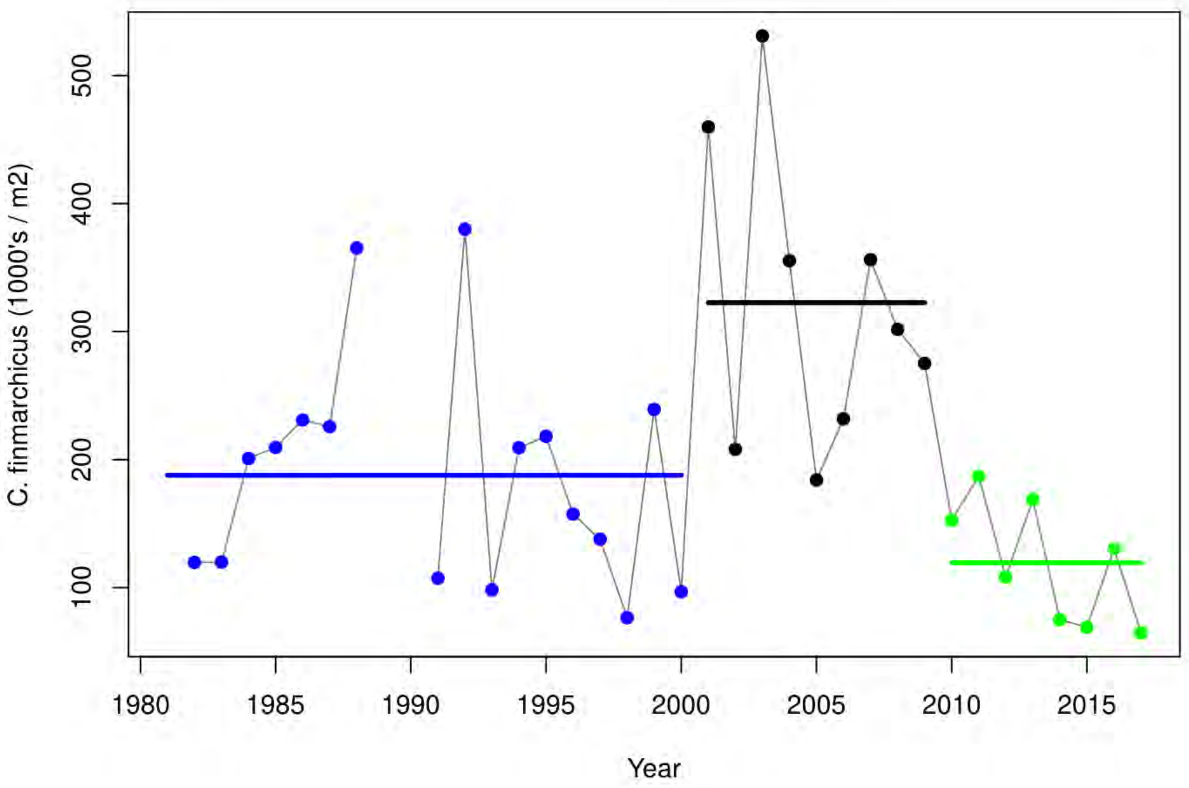

Figure 49. Mean density of *Calanus finmarchicus* in NEFSC EcoMon plankton tows in the Gulf of Maine. Colors indicate different candidate regimes with horizontal lines indicating mean values during the regime.

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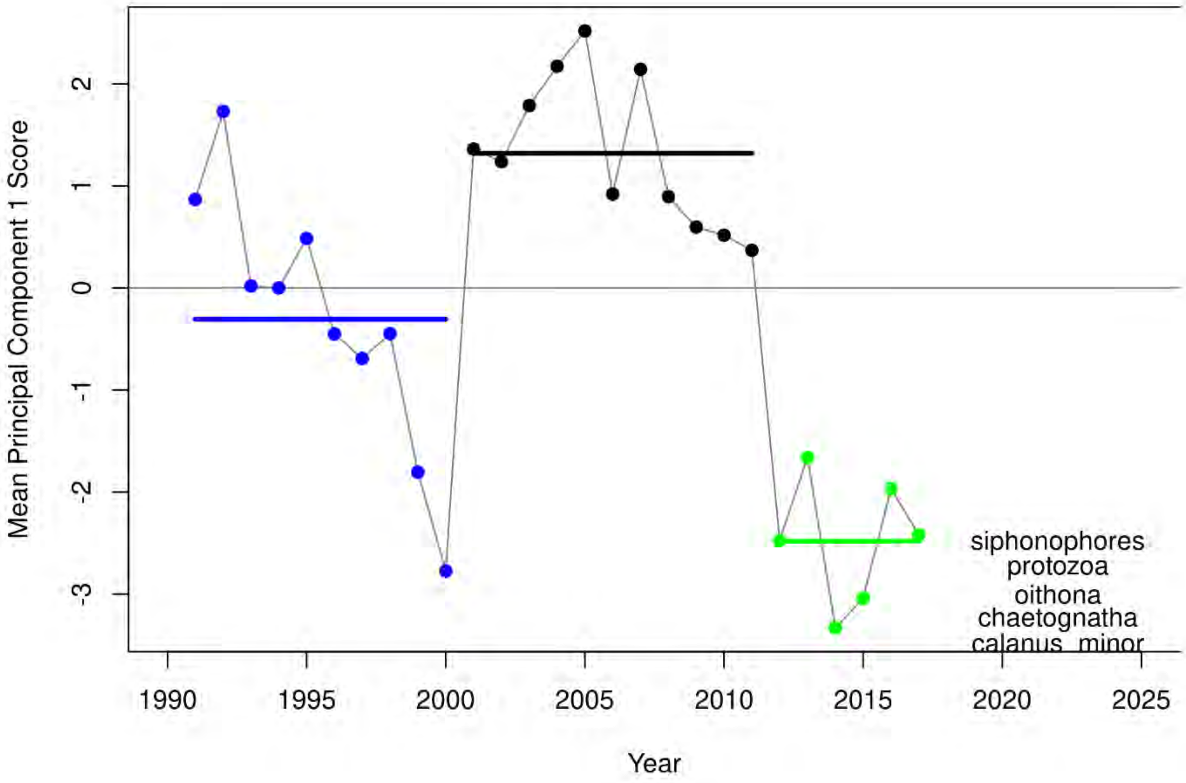

Figure 50. Yearly mean values of zooplankton community first principal component from NEFSC Fall EcoMon plankton surveys. Colors indicate different candidate regimes with horizontal lines indicating mean values during the regime. Low PCA scores are associated with higher densities of the indicated species groups.

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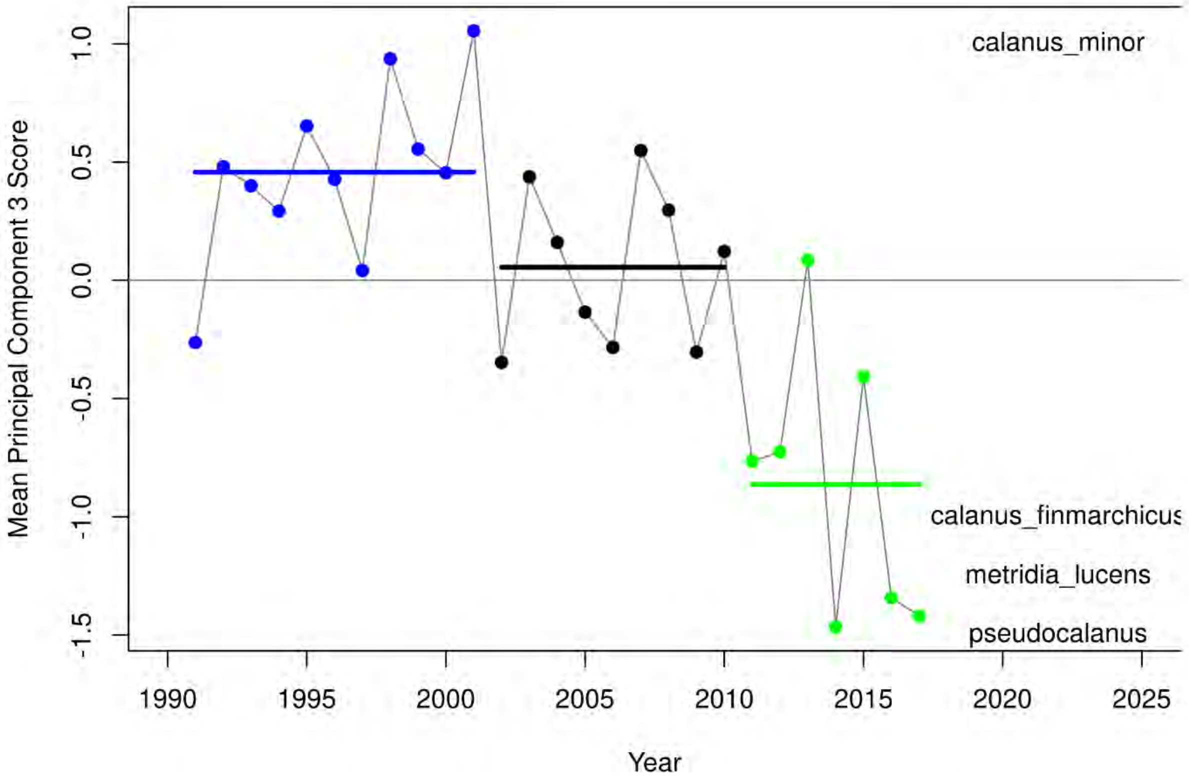

Figure 51. Yearly mean values of zooplankton community third principal component from NEFSC Fall EcoMon plankton surveys. Colors indicate different candidate regimes with horizontal lines indicating mean values during the regime. High PCA scores are associated high densities of *C. minor* with low scores associated with high densities of *C. finmarchicus*, *M. lucens* and *Pseudocalanus*.

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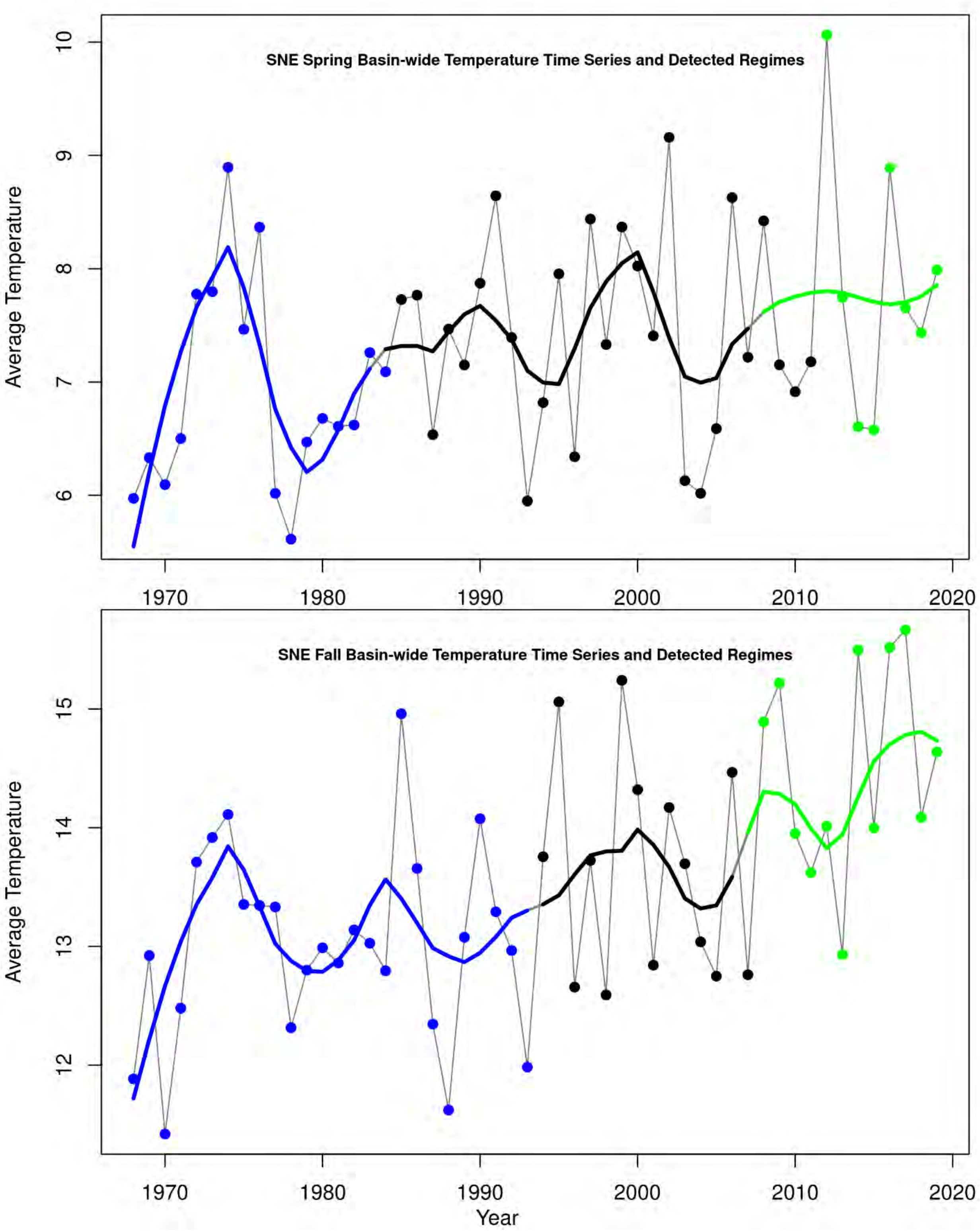

Figure 52. Stock-wide seasonal temperature time series for the Gulf of Maine and Georges Bank for the spring (top) and fall (bottom) including both raw and smoothed time series. Colors identify different candidate regimes.

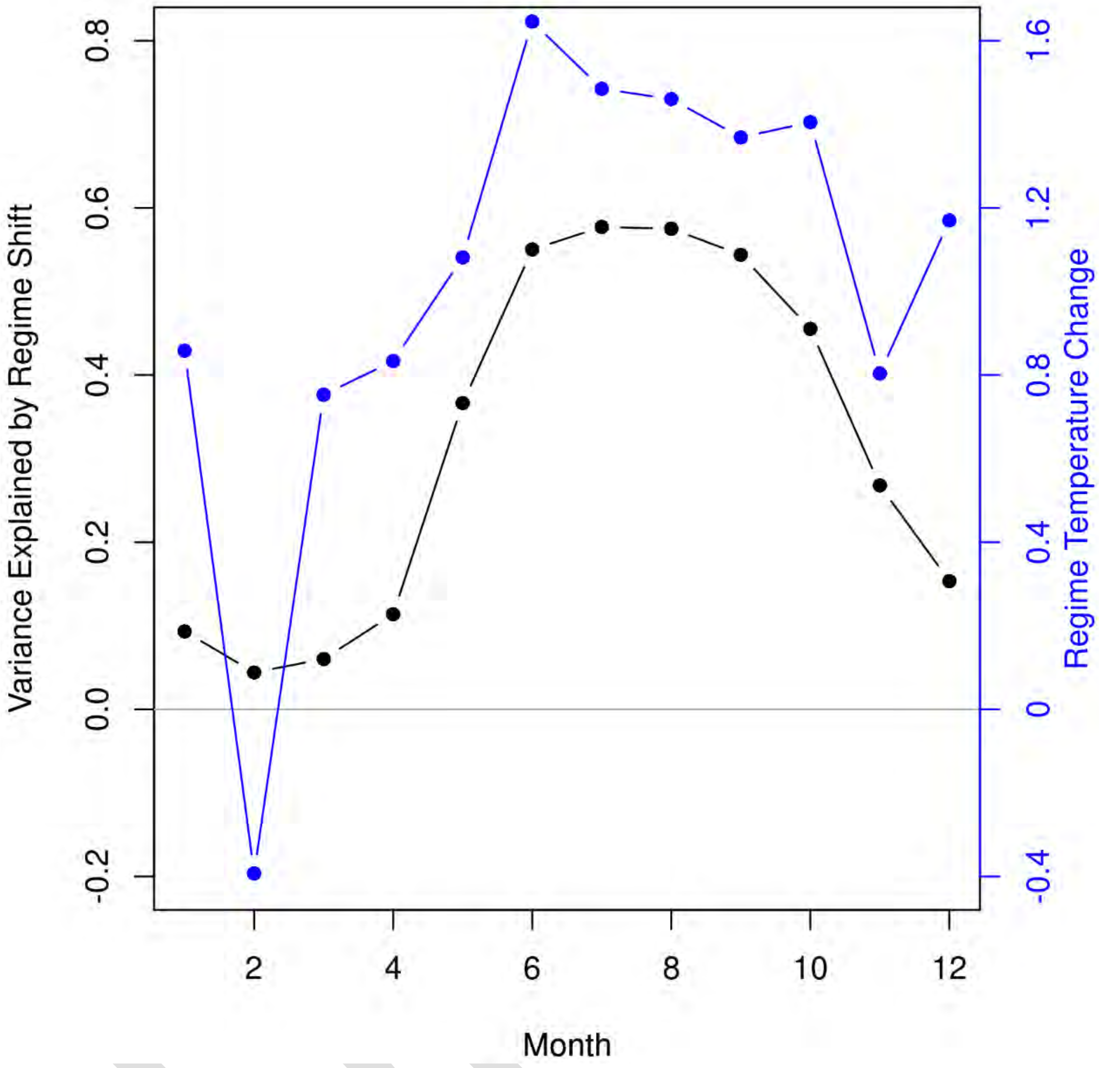

Figure 53. Variance explained and temperature differences by candidate regime shifts for Buzzards Bay, Massachusetts.

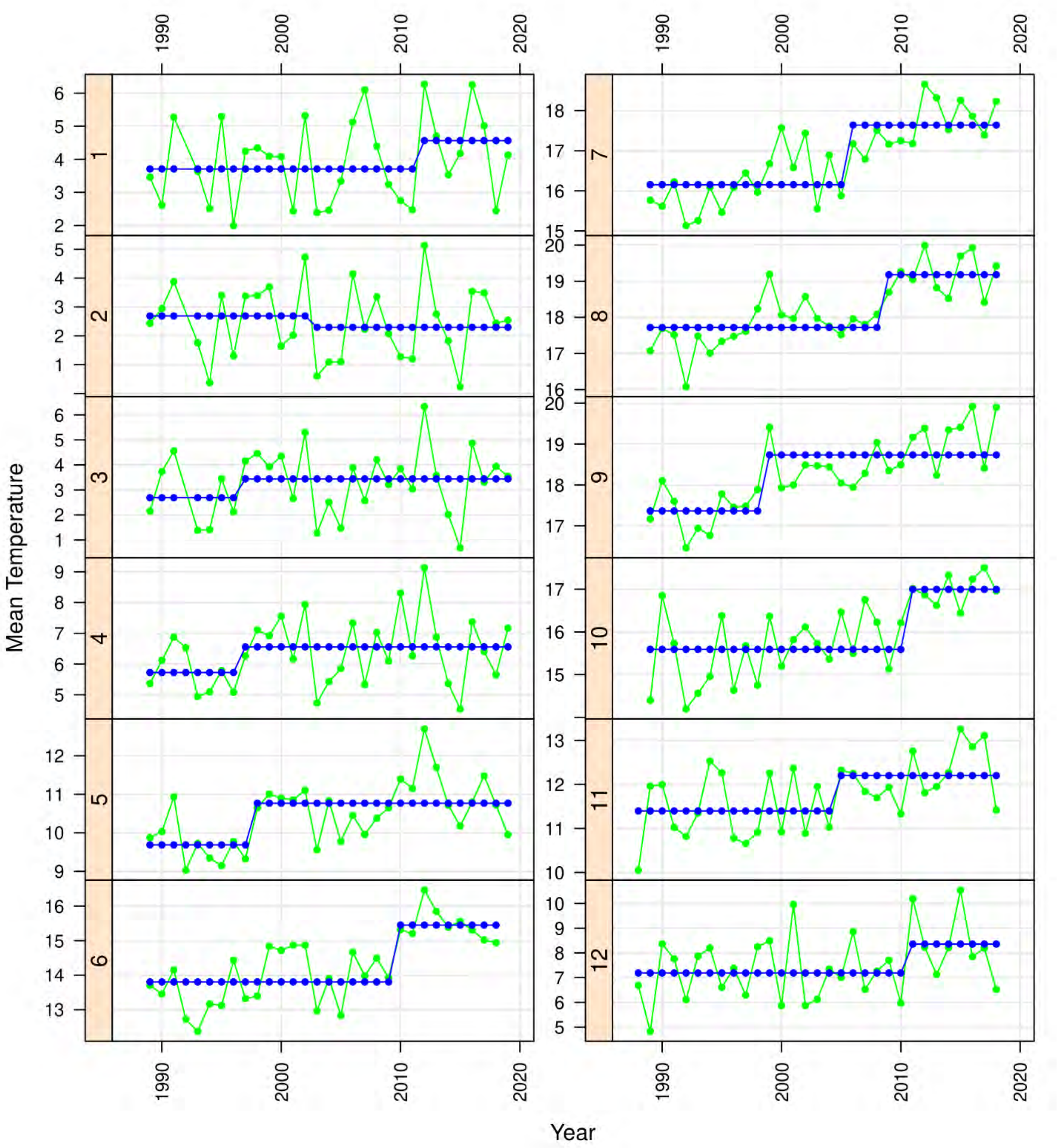

Figure 54. Monthly temperature time series (green) and candidate regime shifts (blue) for Buzzards Bay, Massachusetts.

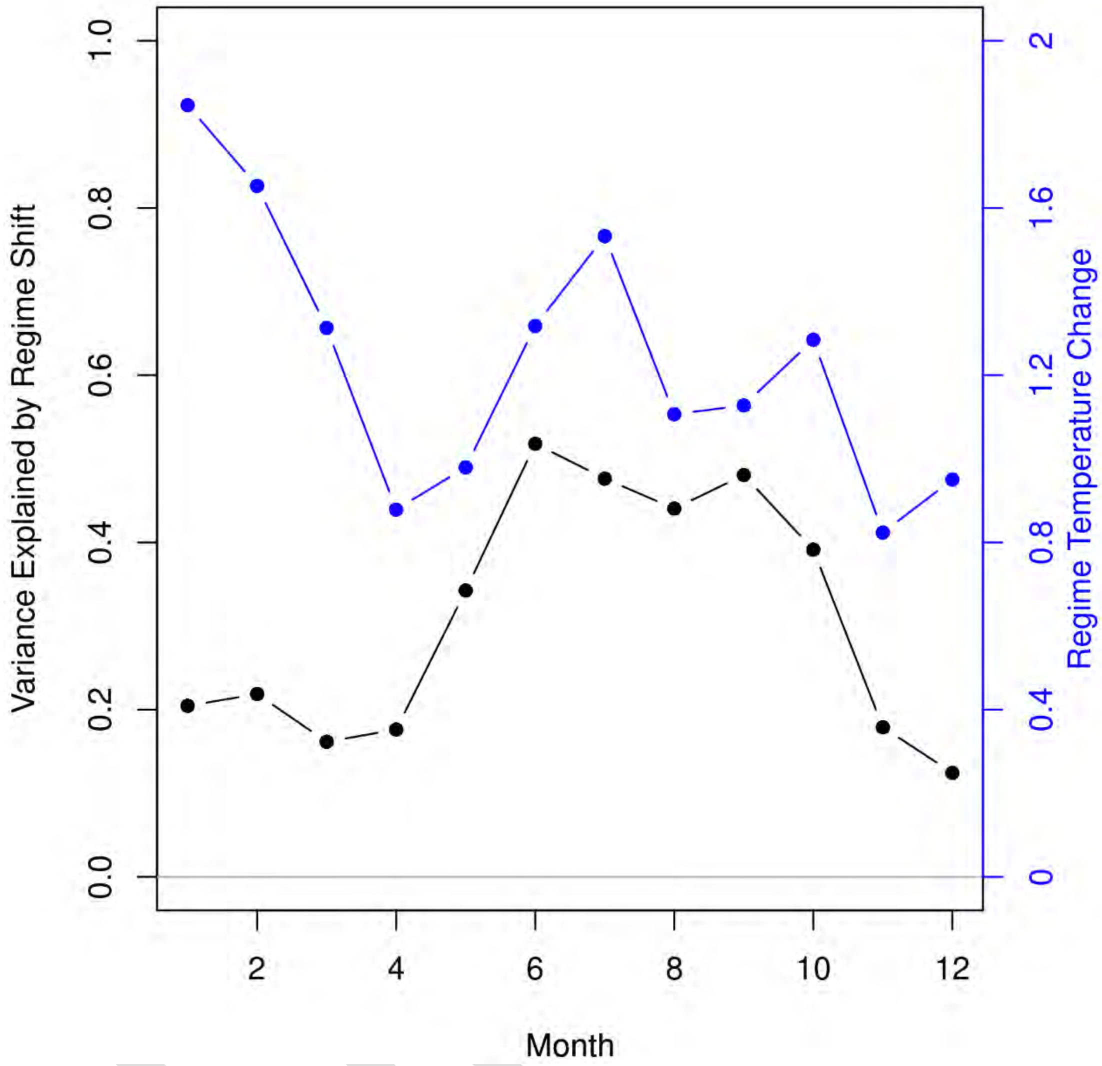

Figure 55. Variance explained and temperature differences by candidate regime shifts for Millstone, CT.

D

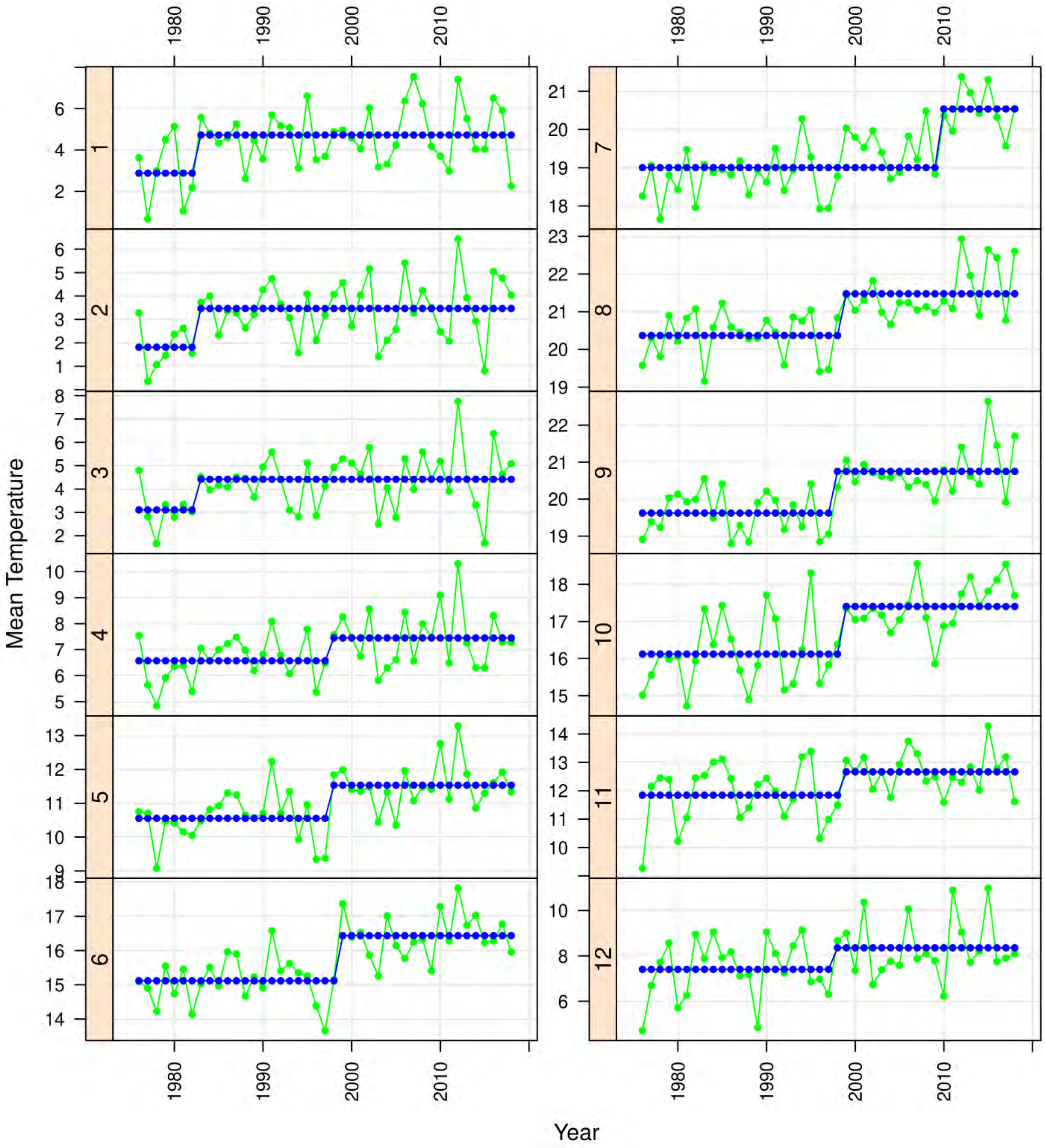

Figure 56. Monthly temperature time series (green) and candidate regime shifts (blue) for Millstone, CT.

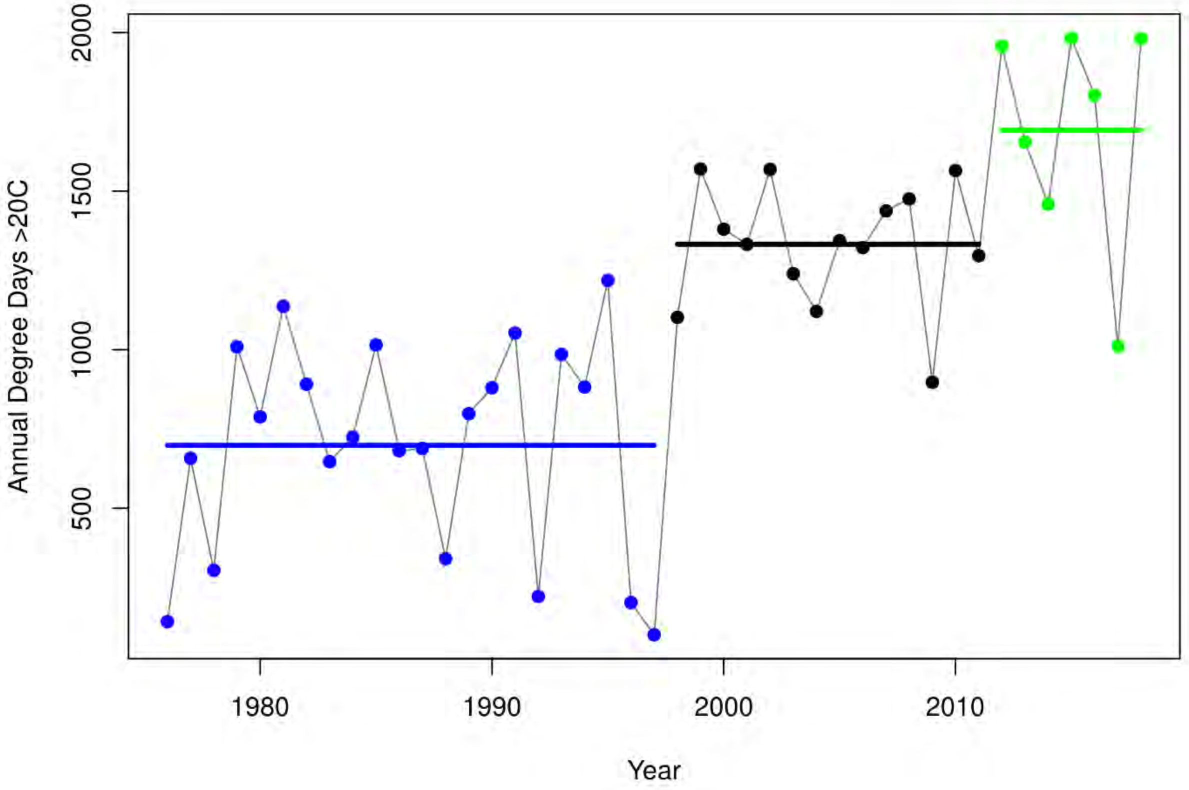

Figure 57. Number of degree days ≥ 20C from Millstone with candidate regime shifts.

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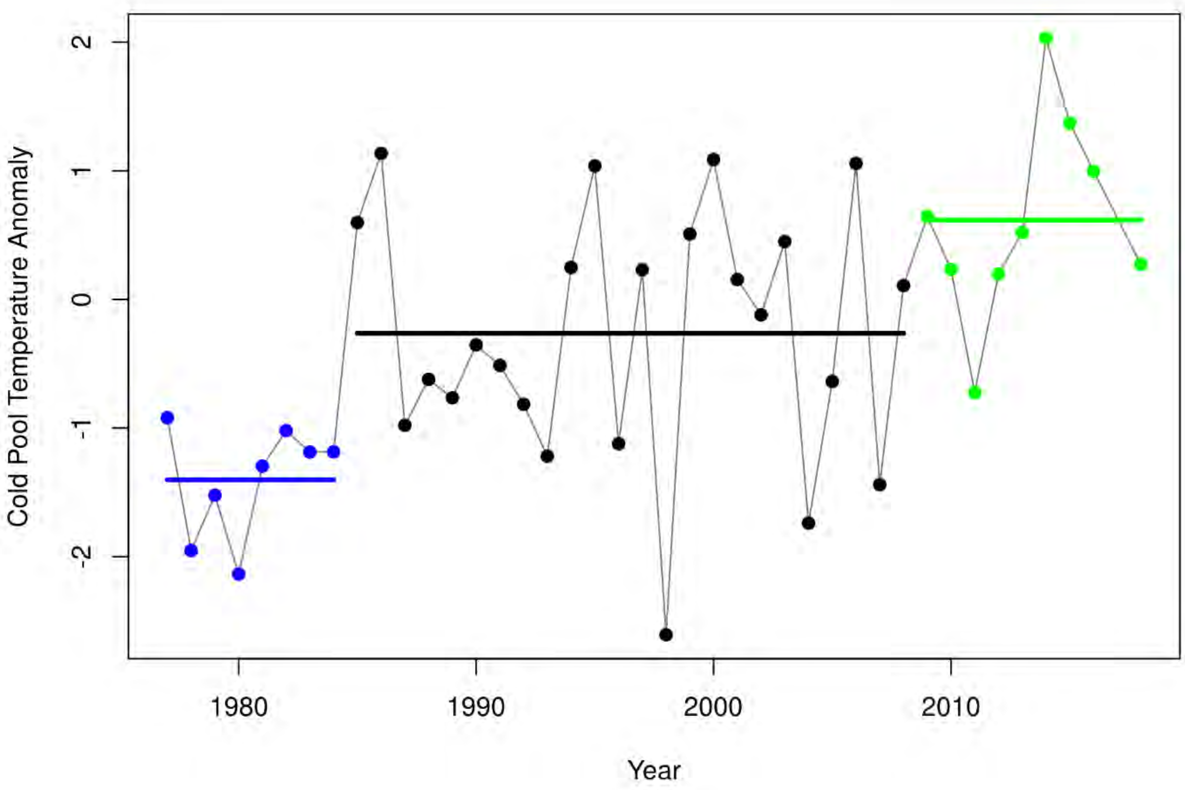

Figure 58. Temperature anomalies for the Mid Atlantic Cold Pool with candidate regime shifts.

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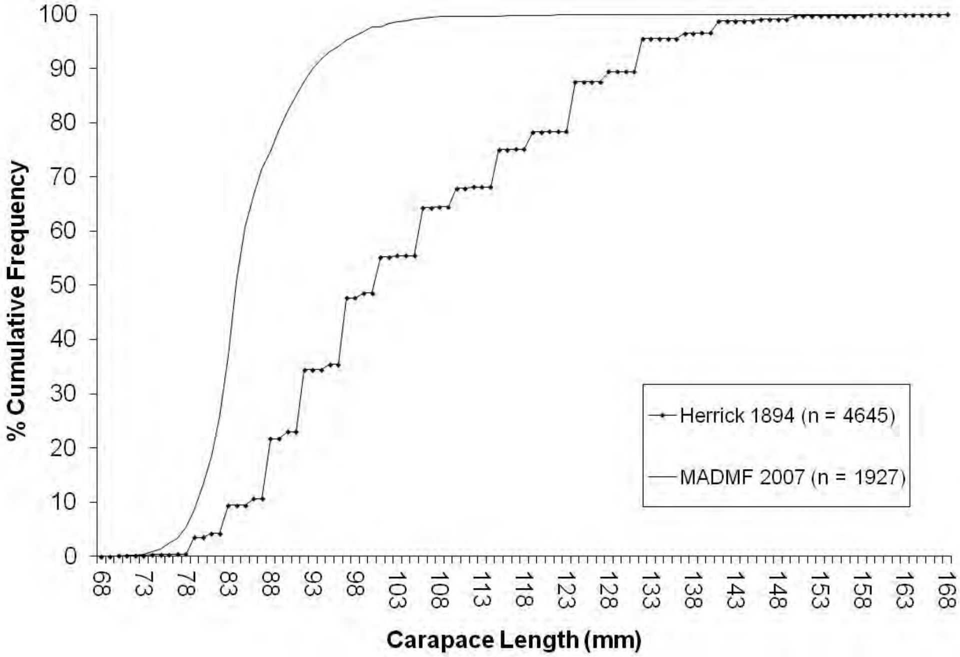

Figure 59. Comparison of cumulative length distribution of egg-bearing female lobsters from Buzzards Bay, MA (2007)/Cox Ledge, MA (1894).

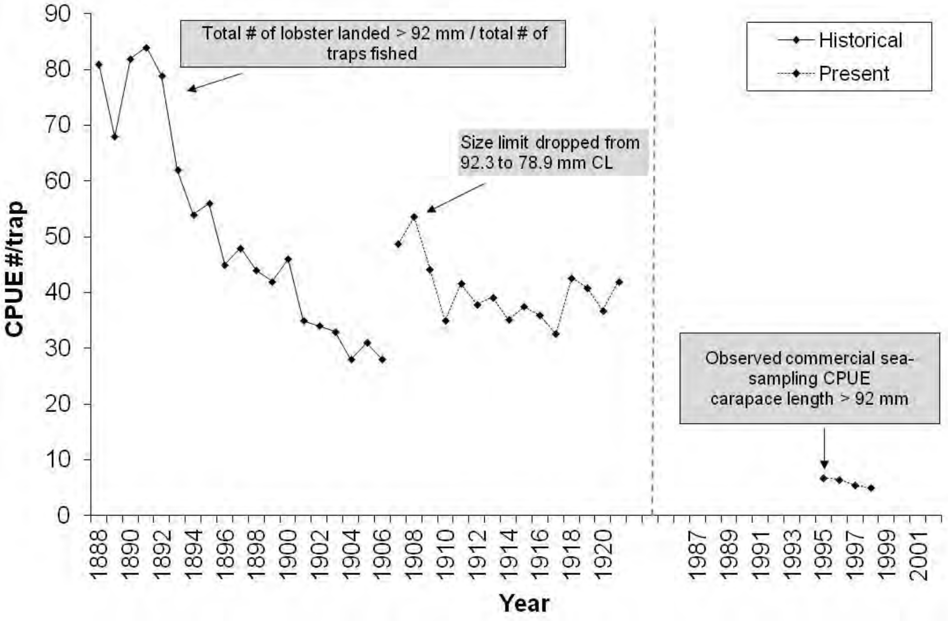

Figure 60. Annual CPUE (total # landed / total # traps) of lobsters >92 mm, 1880-1921, and 1995-1998 in Massachusetts coastal waters. Vertical dashed line indicates break in x-axis time line.

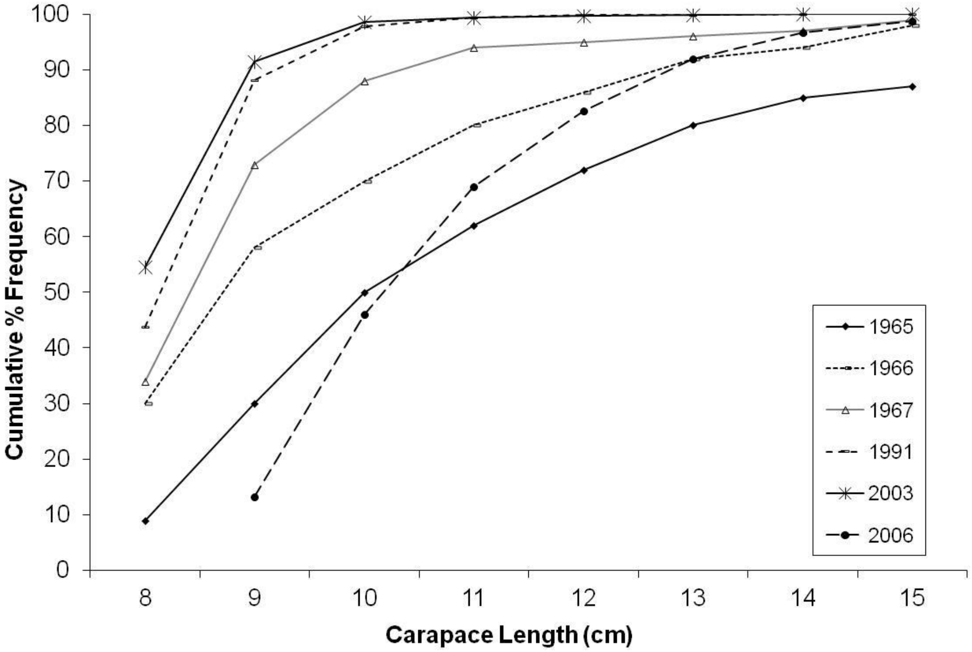

Figure 61. Comparison of cumulative length distribution of egg-bearing female lobsters from the Hudson Canyon from the 1960s, 1990s, and 2000s.

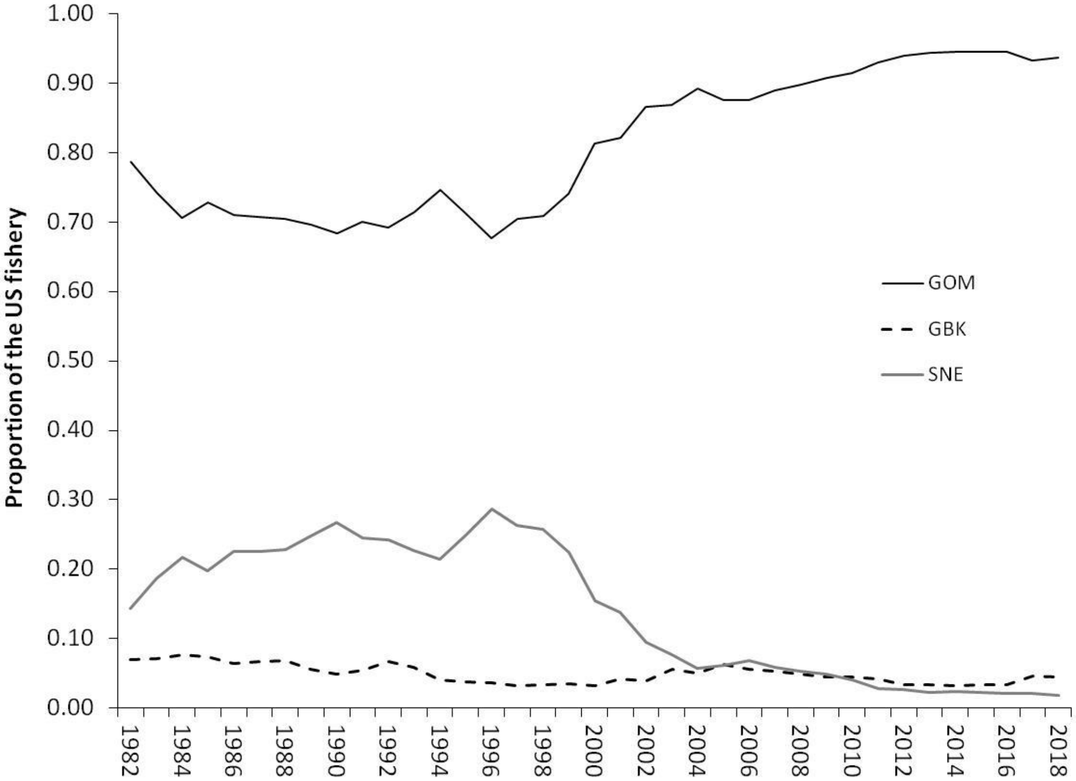

Figure 62. Proportion of the total US landings from the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE).

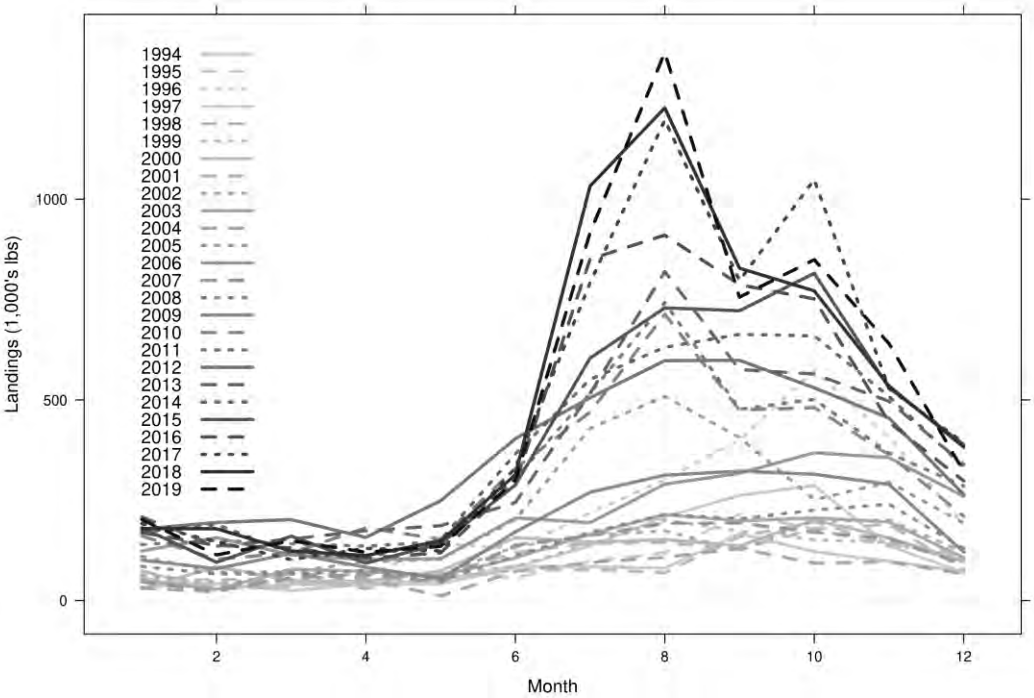

Figure 63. Monthly landings by year for the Georges Bank region. The observed sudden increase in landings in summer and fall months occurs around 2005.

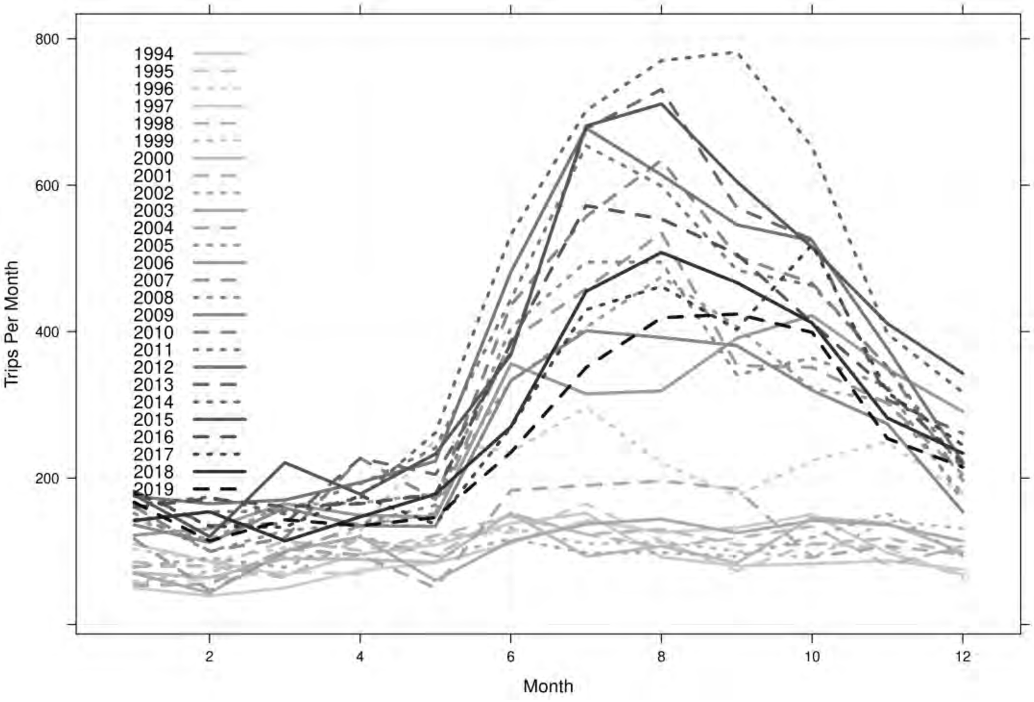

Figure 64. Number of monthly trips reported for the Georges Bank region by year. The shift in apparent fishing effort in the summer and fall months occurs around 2005.

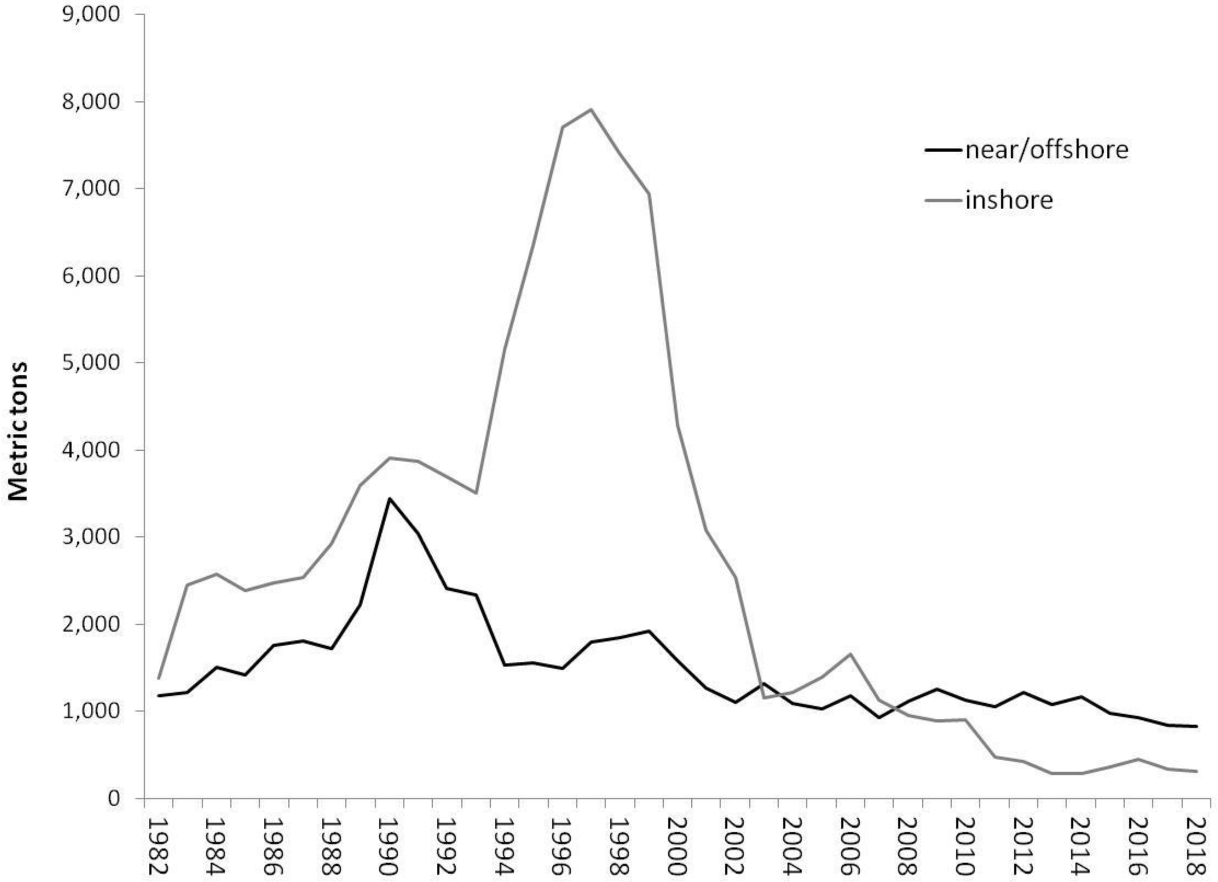

Figure 65. Commercial lobster landings in the Southern New England stock unit 1982 to 2018 from inshore (SA 538, 539, 611; grey) and offshore/nearshore (SA 537, 612, 613, 614, 615, 616; black) regions.

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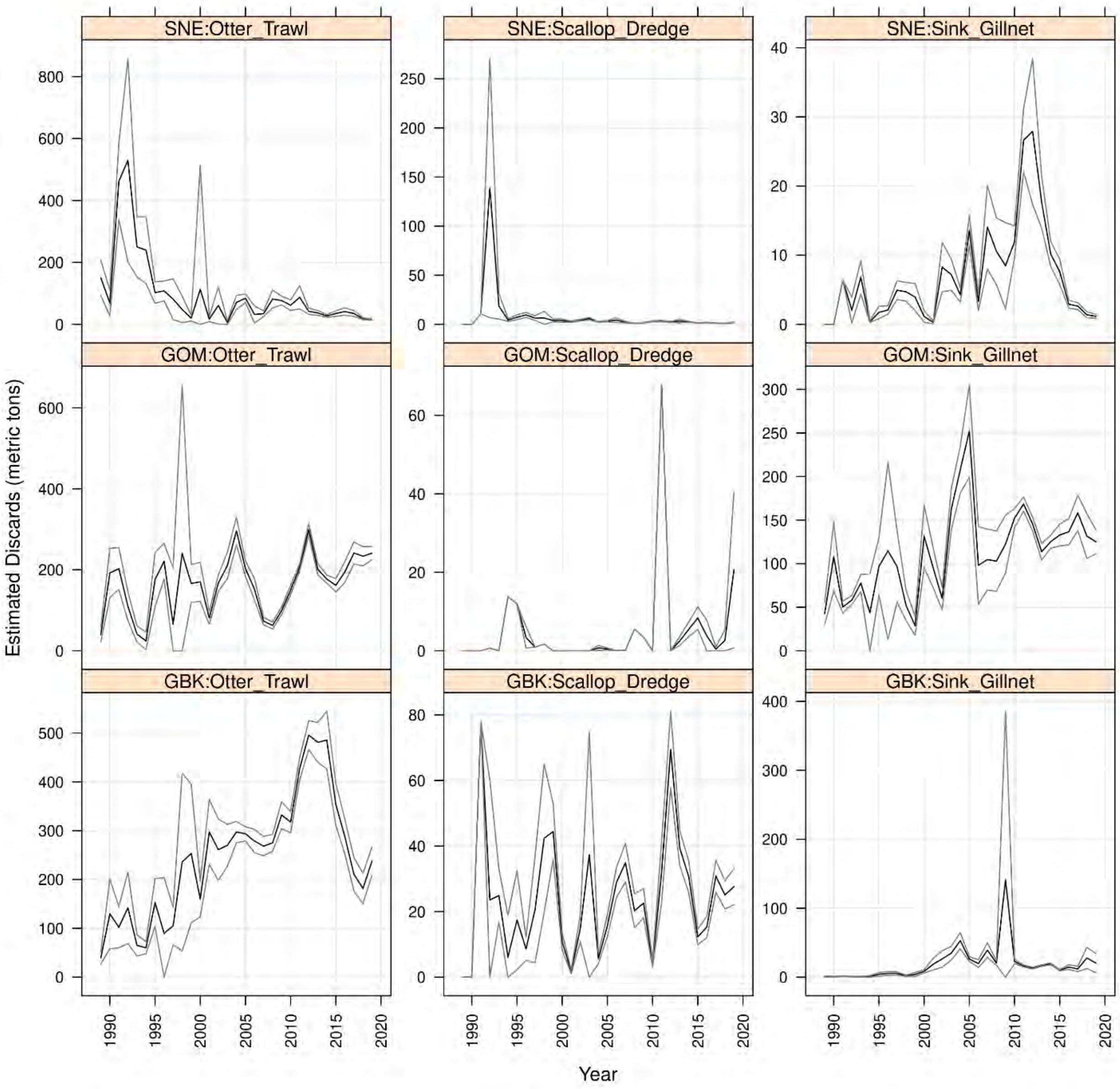


Figure 66. Discard estimates and CV's by fishery and stock since 1990.

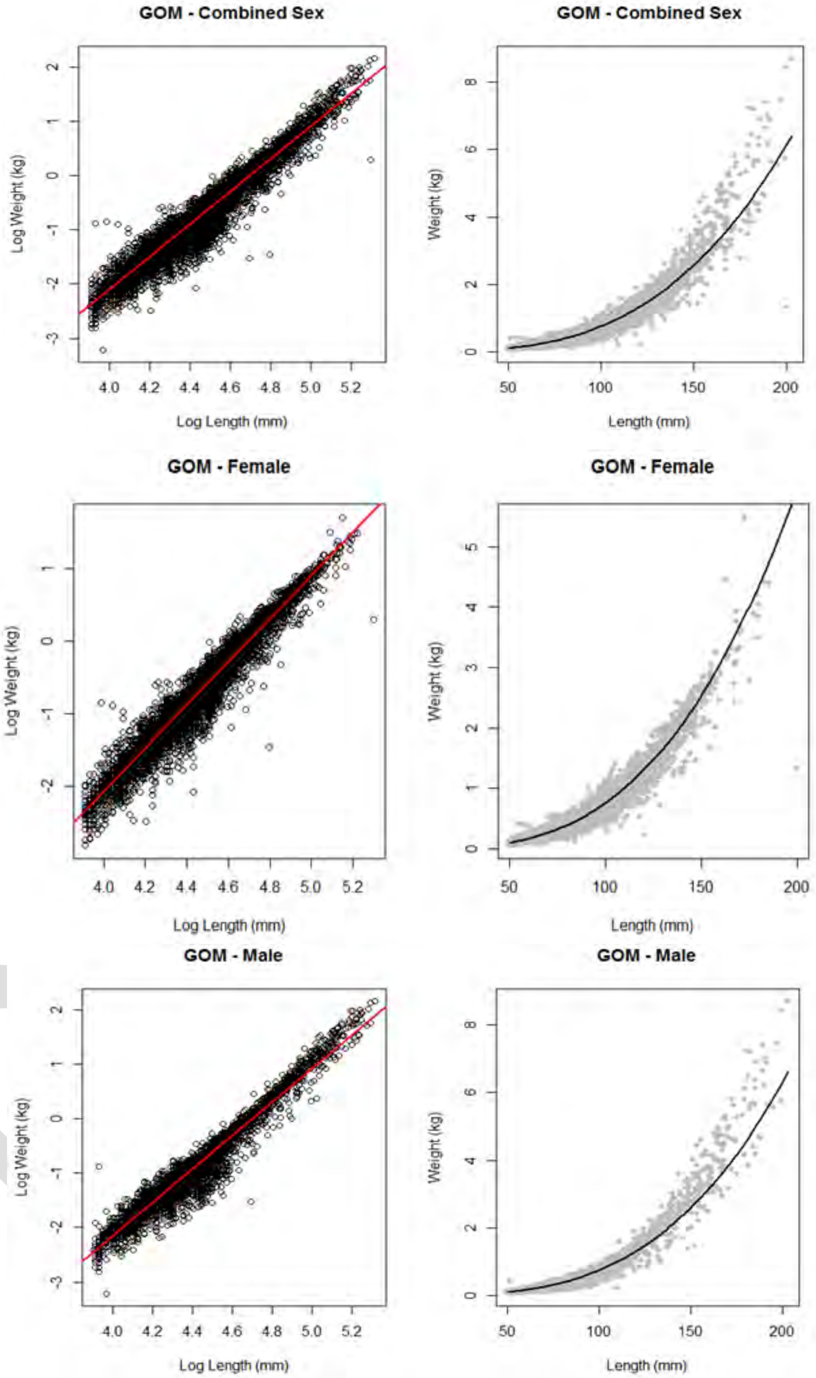


Figure 67. Model fits to the combined sex, female, and male data for Gulf of Maine. Left hand panel shows the linear regression fit to the log transformed observed data. Right hand panel shows the back transformed parameter fit to the untransformed data.

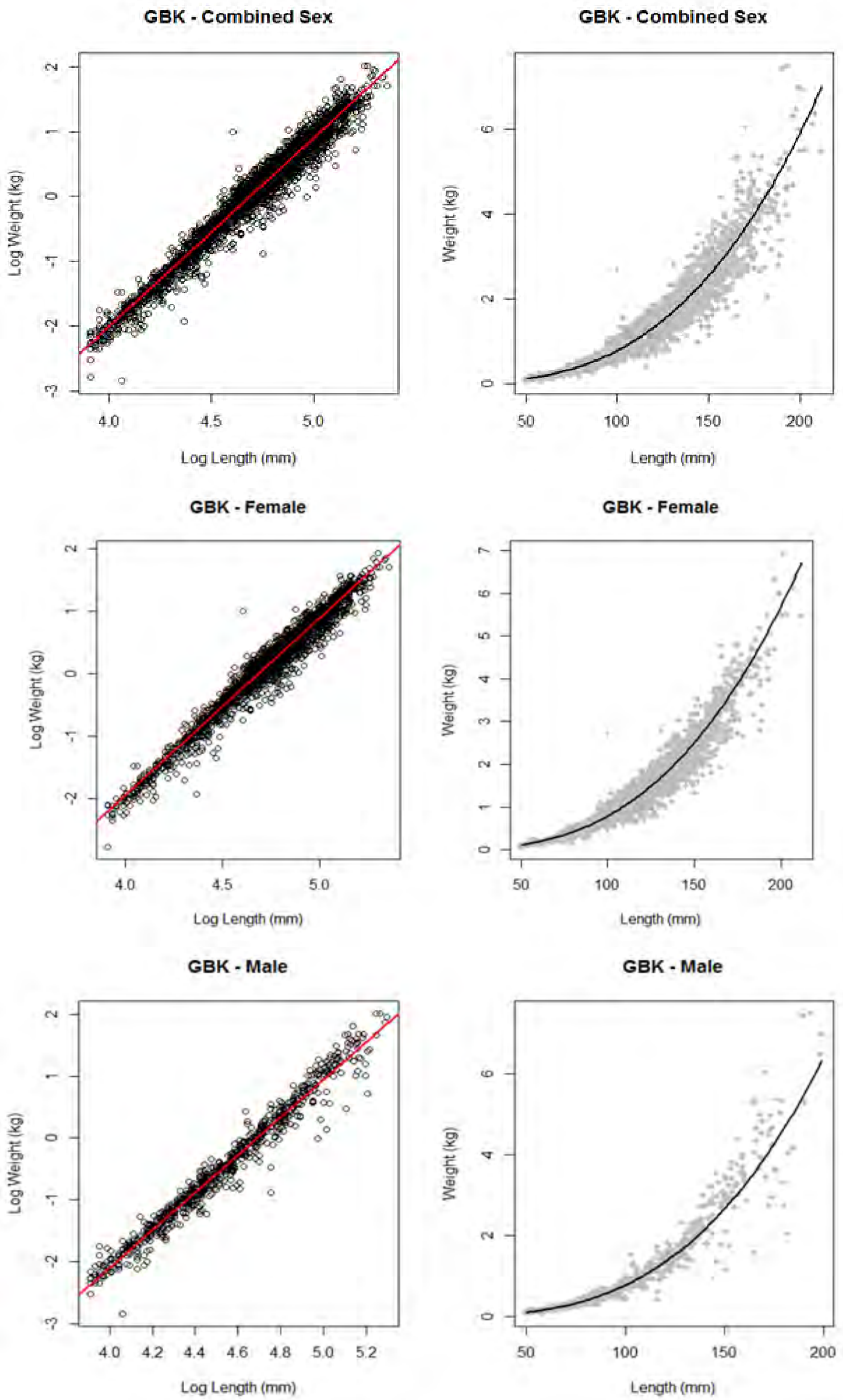


Figure 68. Model fits to the combined sex, female, and male data for Georges Bank. Left hand panel shows the linear regression fit to the log transformed observed data. Right hand panel shows the back transformed parameter fit to the untransformed data.

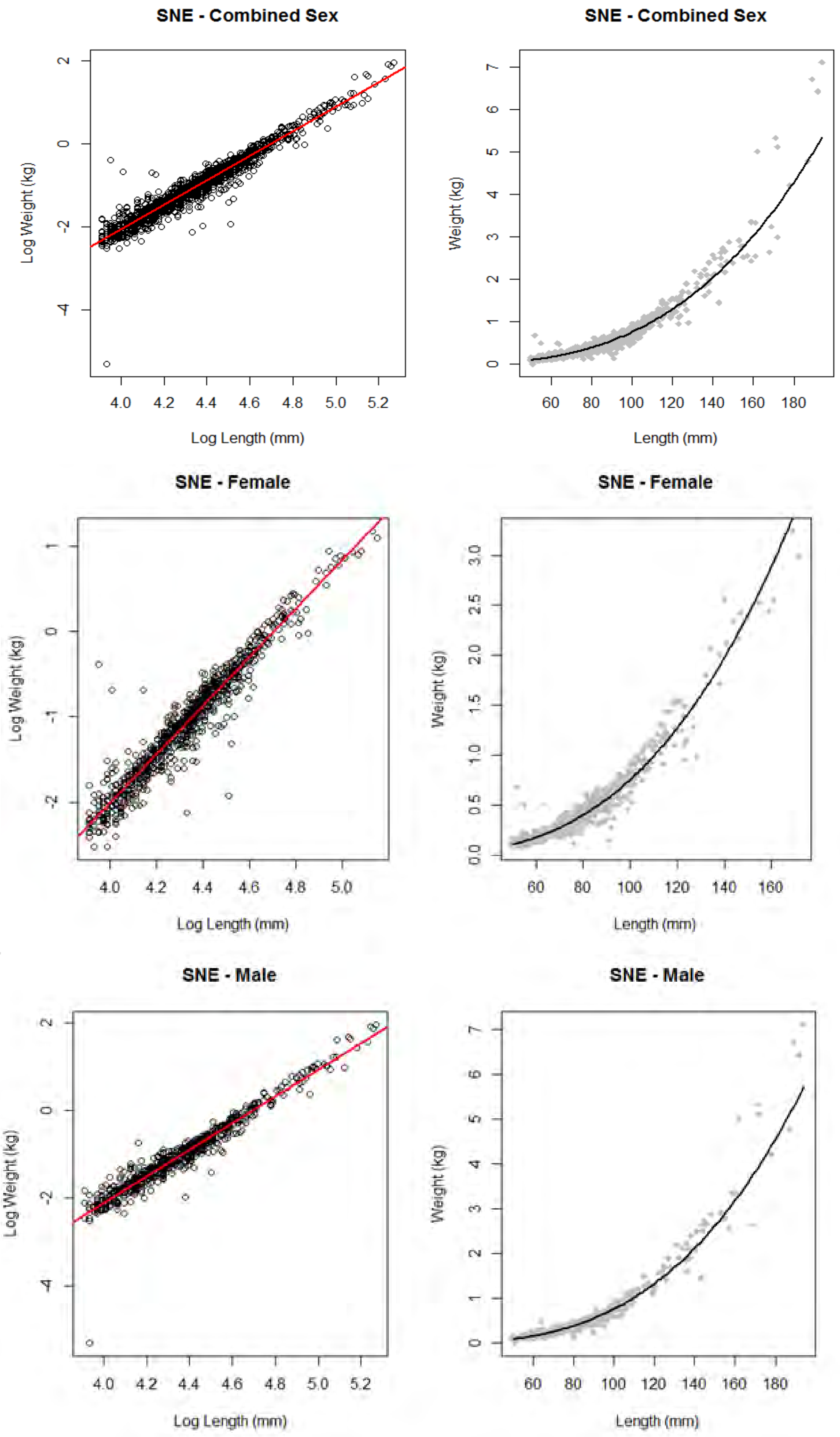


Figure 69. Model fits to the combined sex, female, and male data for Southern New England. Left hand panel shows the linear regression fit to the log transformed observed data. Right hand panel shows the back transformed parameter fit to the untransformed data.

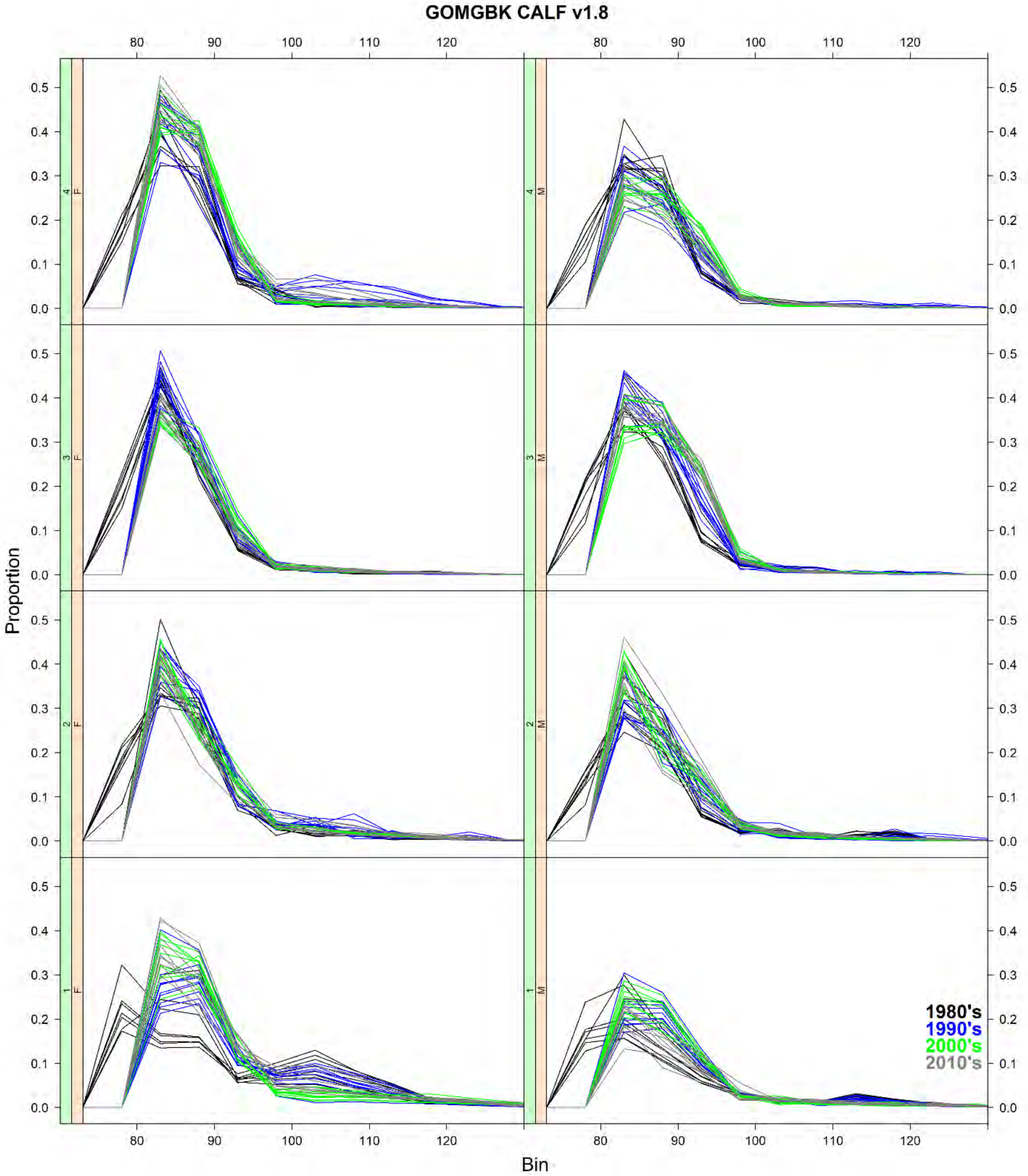


Figure 70. Annual GOMGBK commercial landings size compositions by quarter (light green panel title) and sex (beige panel title) with decadal color coding.

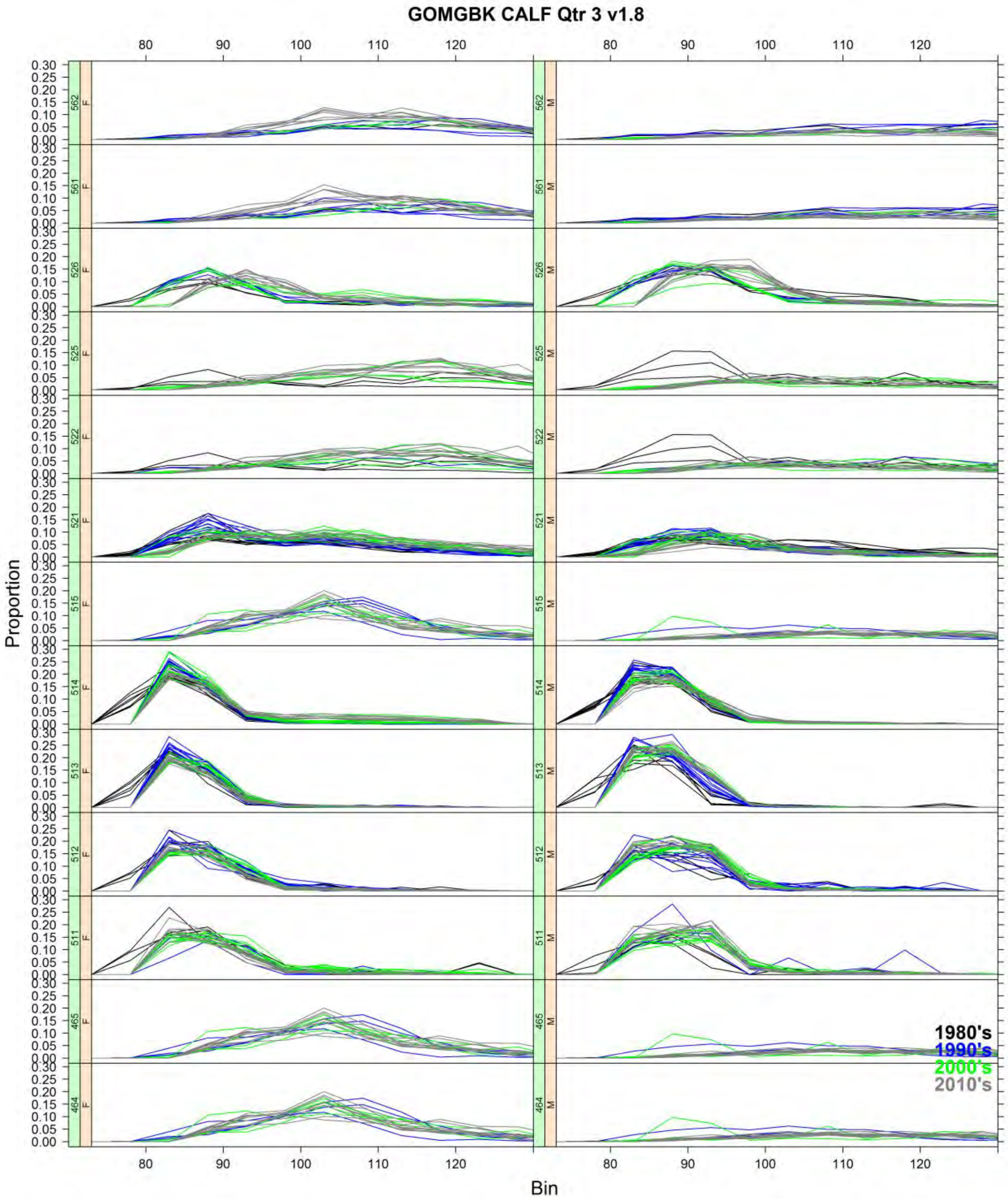


Figure 71. Quarter 3 GOMGBK commercial landings size compositions by statistical area (light green panel title) and sex (beige panel title) with decadal color coding.

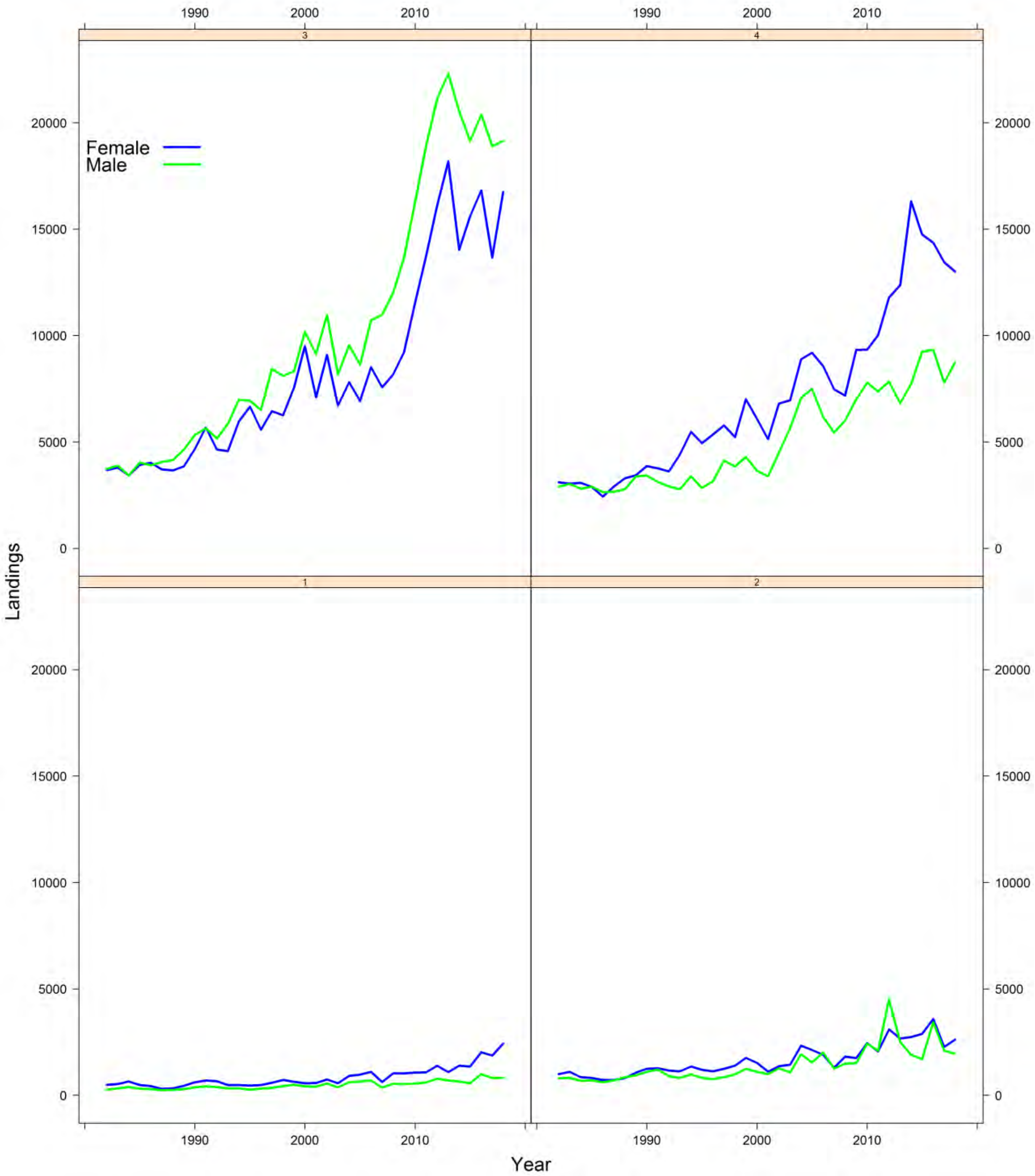


Figure 72. GOMGBK commercial landings by quarter (beige panel title) and sex.

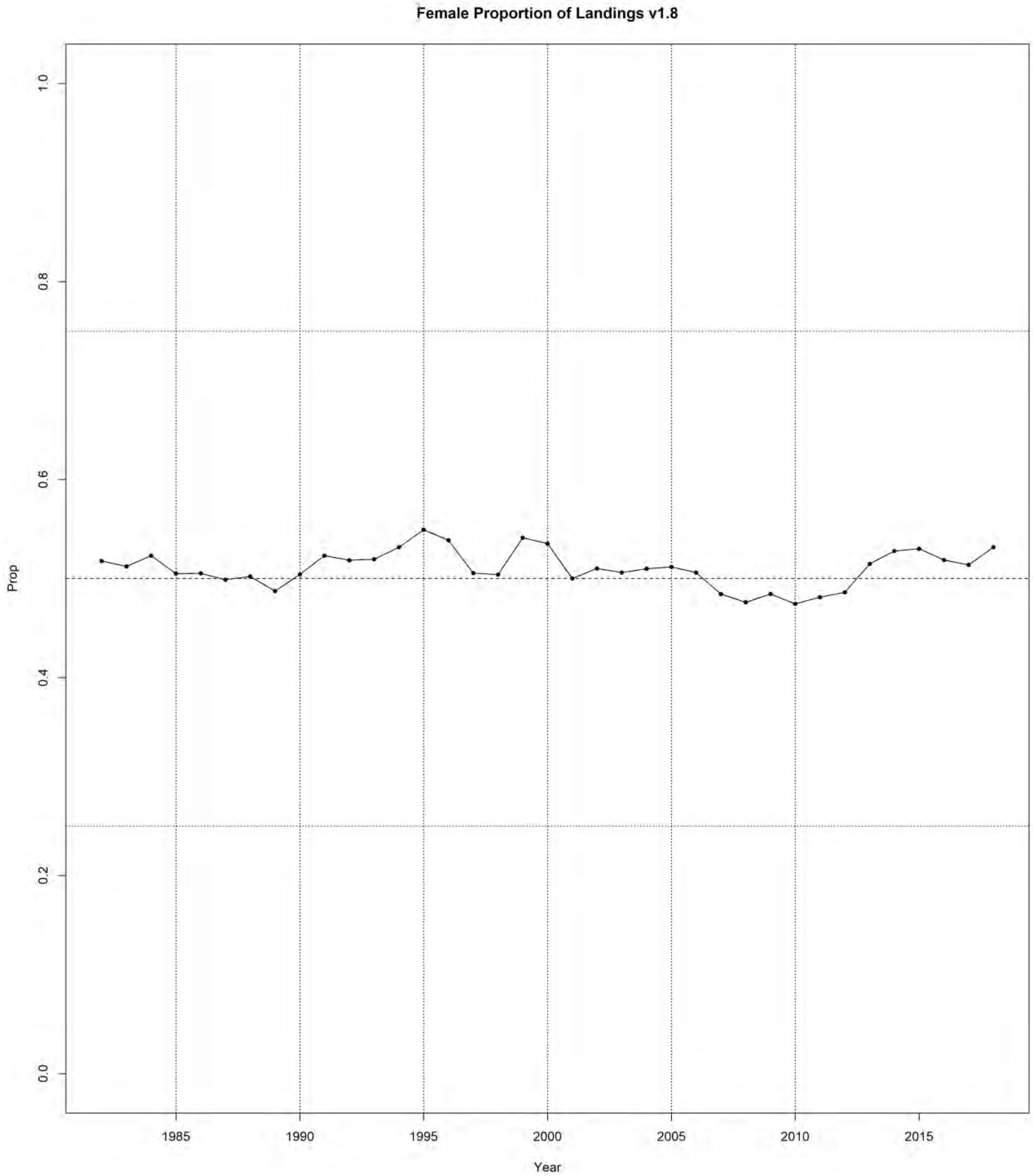


Figure 73. Proportion female of annual GOMGBK commercial landings.

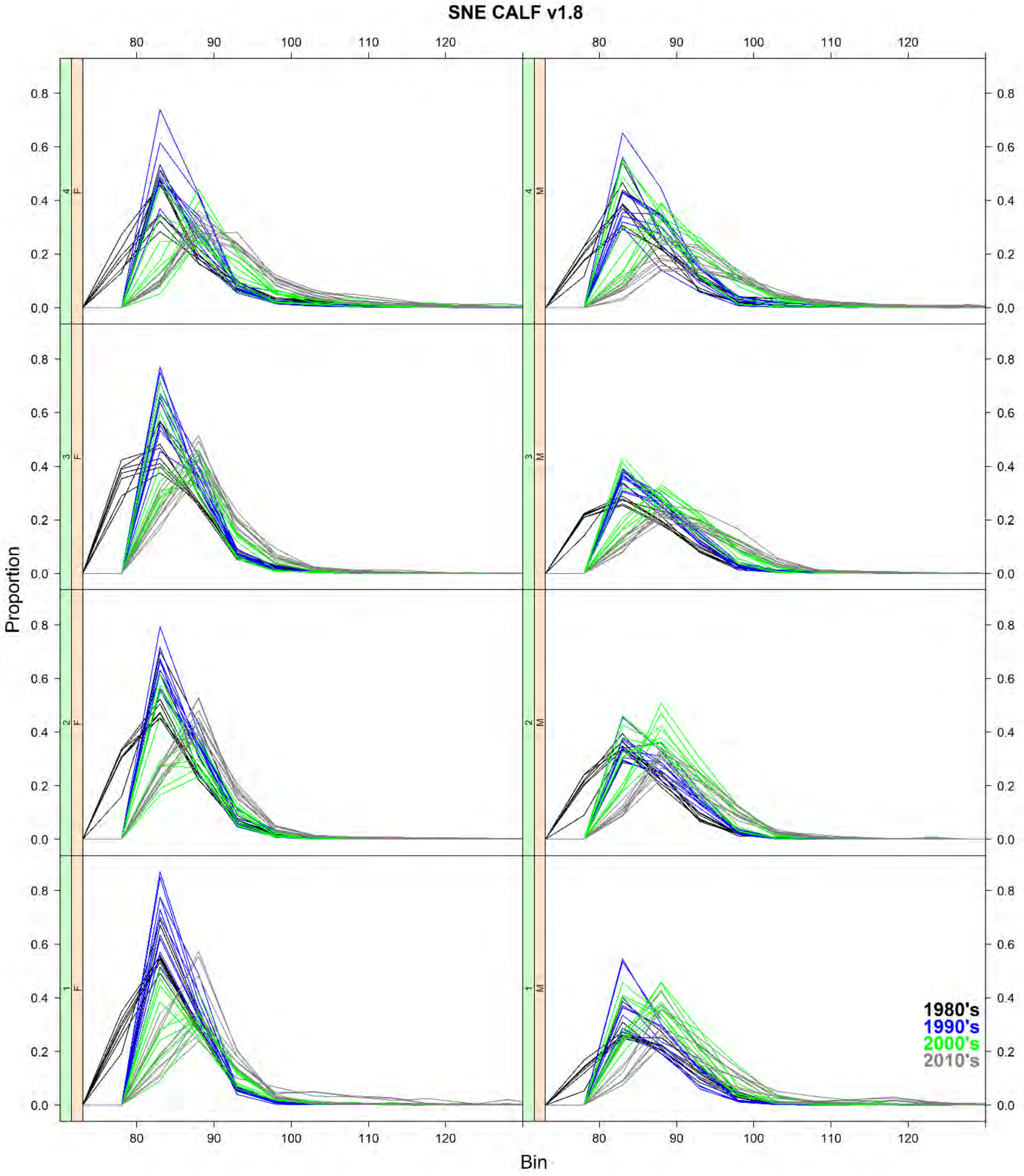


Figure 74. Annual SNE commercial landings size compositions by quarter (light green panel title) and sex (beige panel title) with decadal color coding.

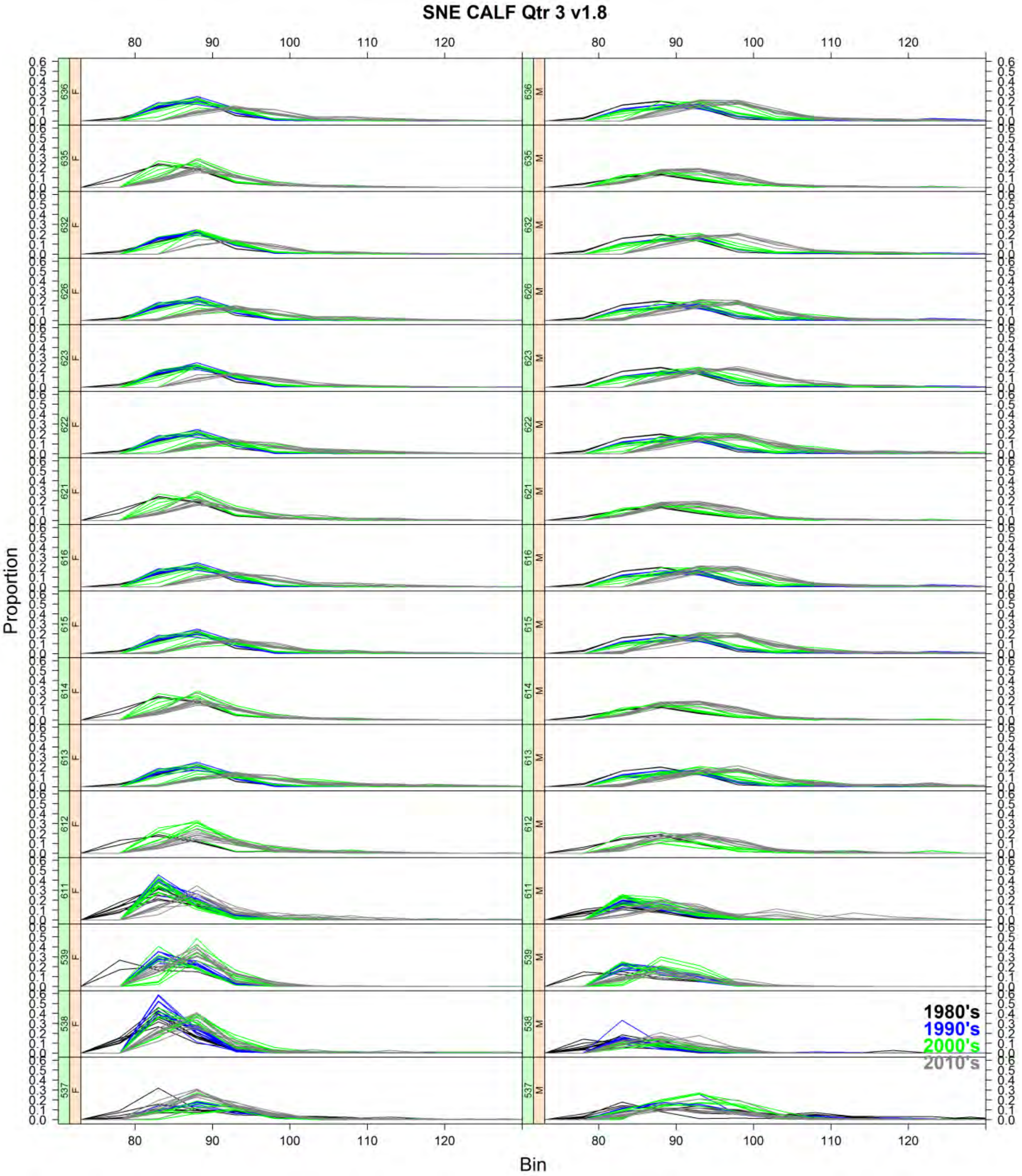


Figure 75. Quarter 3 SNE commercial landings size compositions by statistical area (light green panel title) and sex (beige panel title) with decadal color coding.

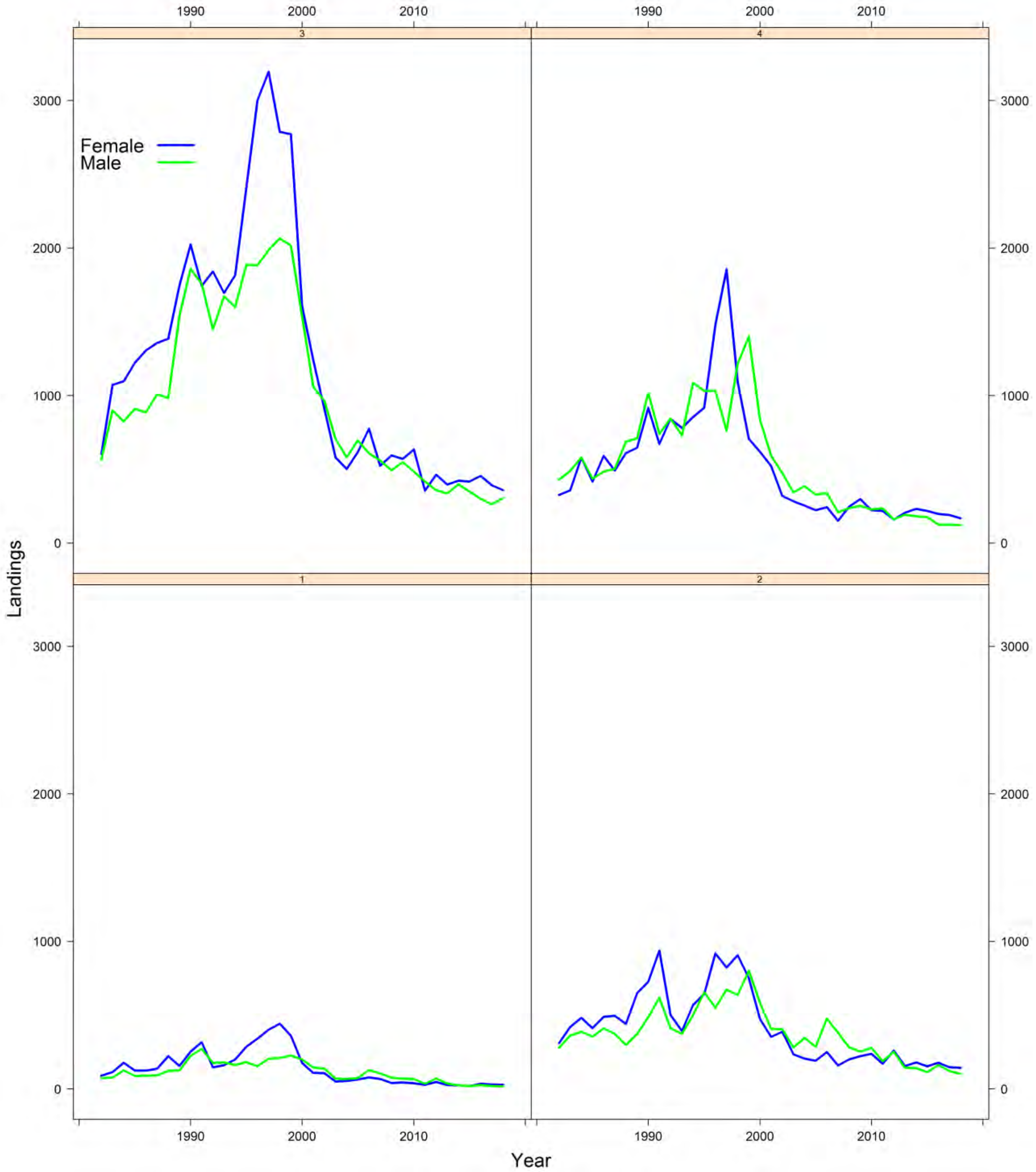


Figure 76. SNE commercial landings by quarter (beige panel title) and sex.

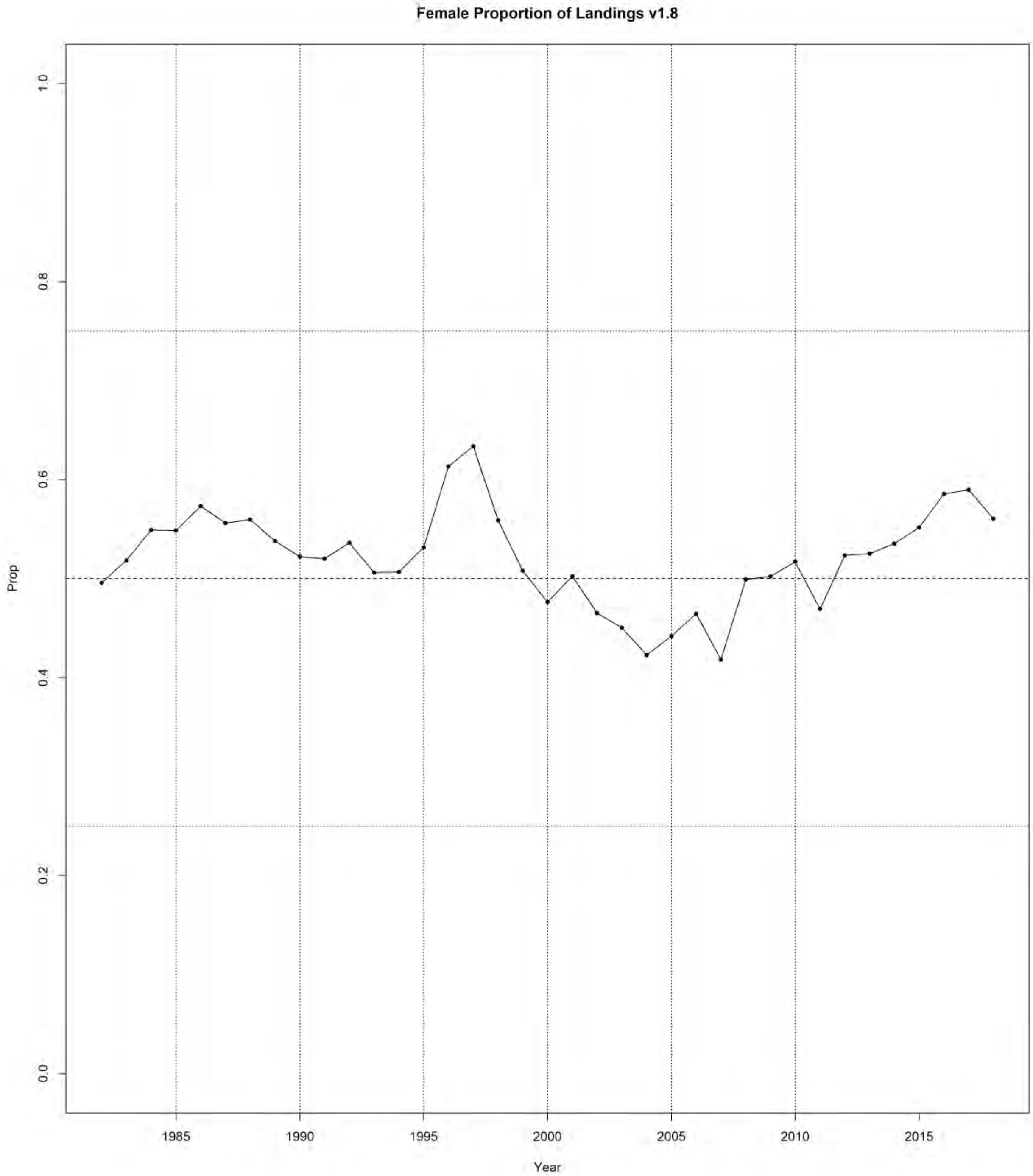


Figure 77. Proportion female of annual SNE commercial landings.

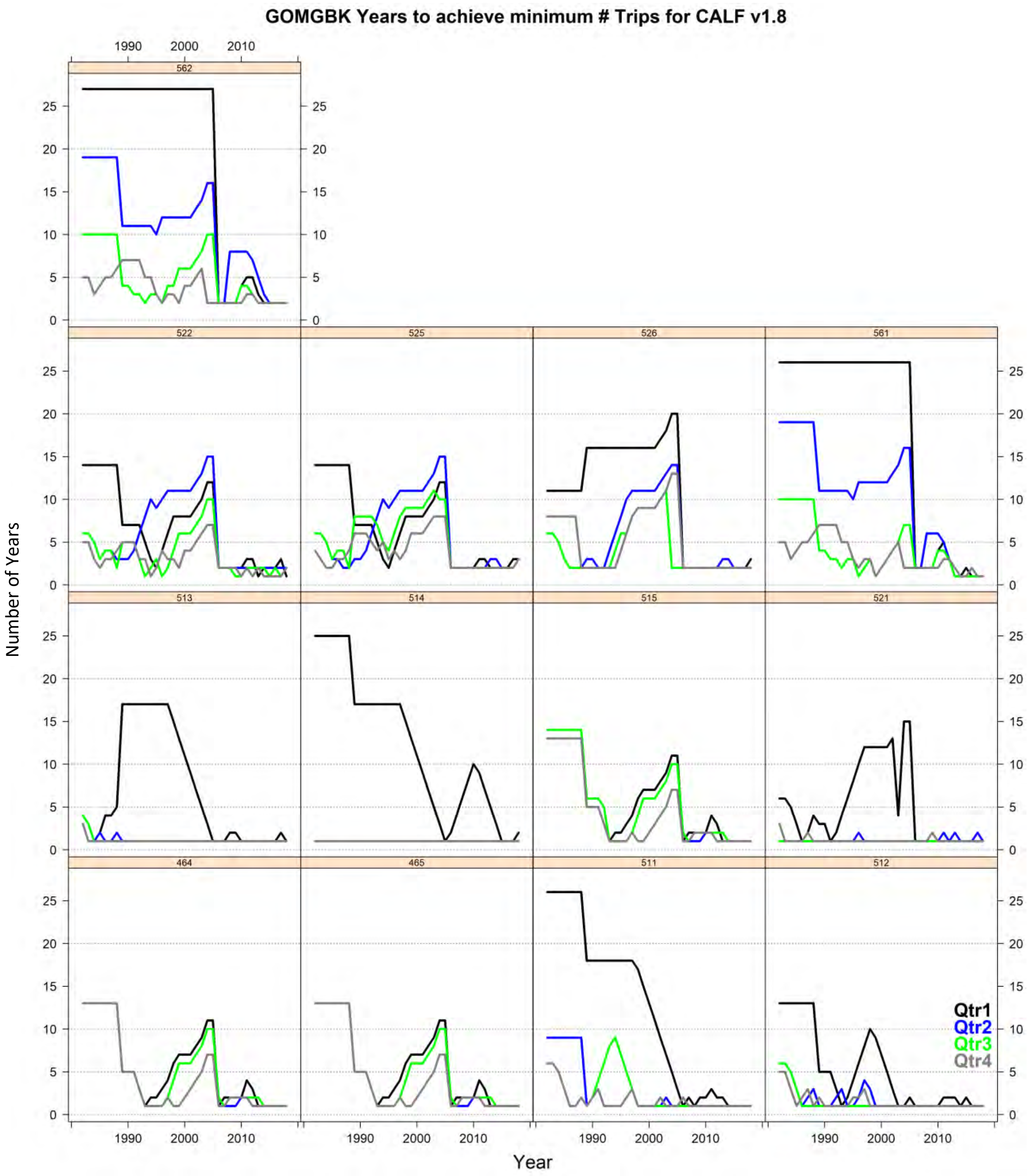


Figure 78. Number of years required to pool combined port- and sea- sampling data across by GOMGBK statistical area (beige panel title) and quarter for characterizing respective commercial landings size composition and sex ratio.

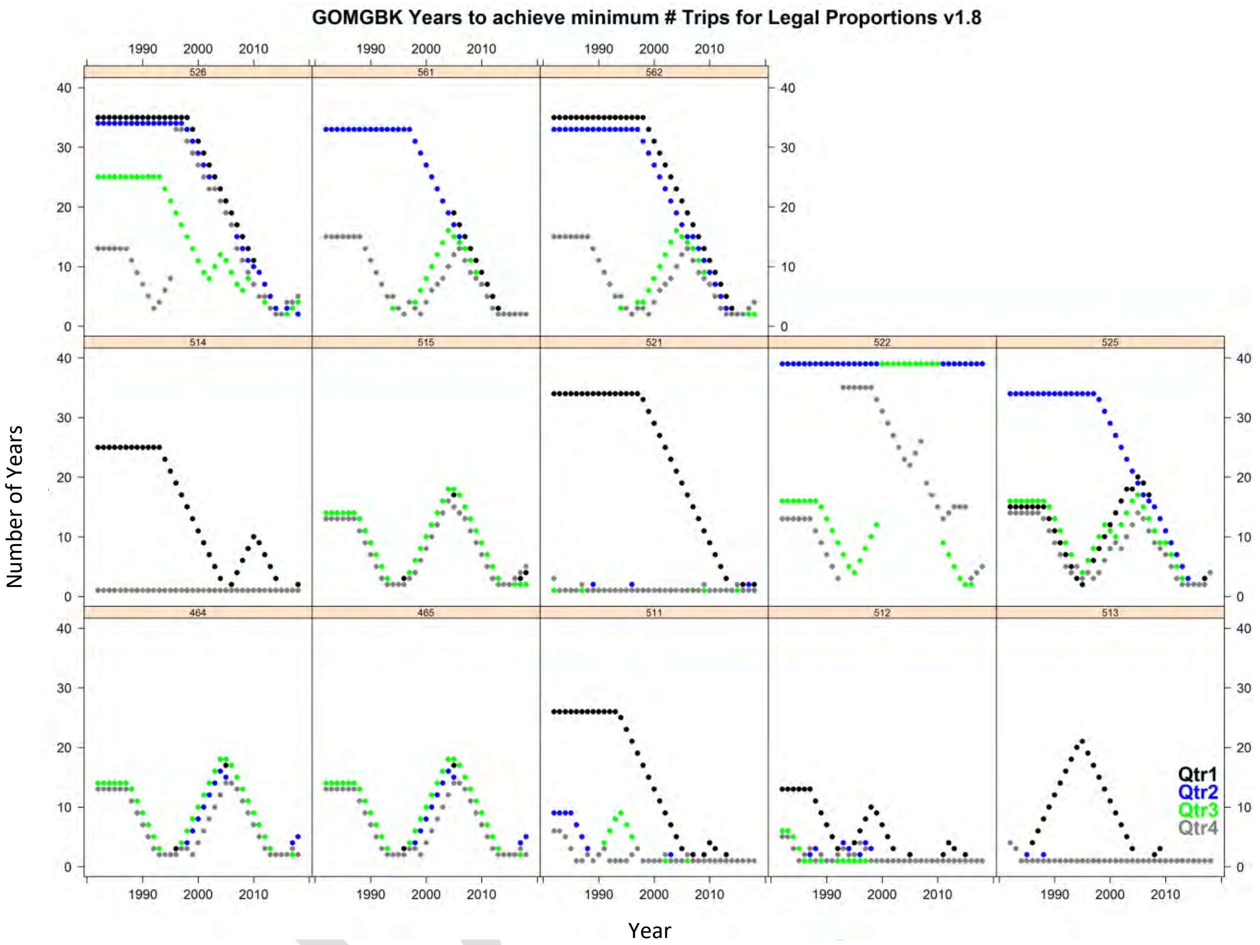


Figure 79. Number of years required to pool sea- sampling data across by GOMGBK statistical area (beige panel title) and quarter for characterizing respective commercial landings size composition and sex ratio.

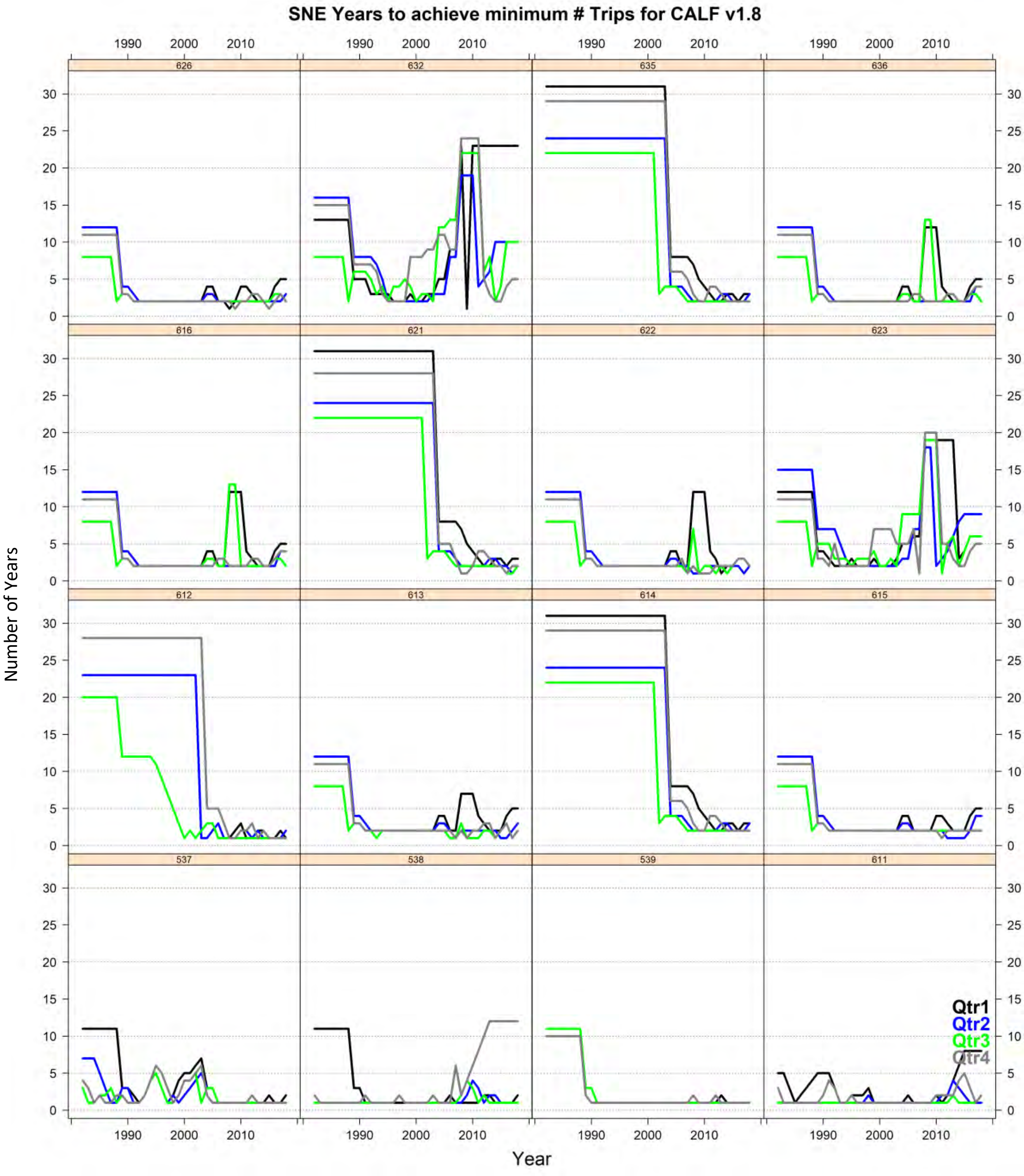


Figure 80. Number of years required to pool combined port- and sea- sampling data across by SNE statistical area (beige panel title) and quarter for characterizing respective commercial landings size composition and sex ratio.

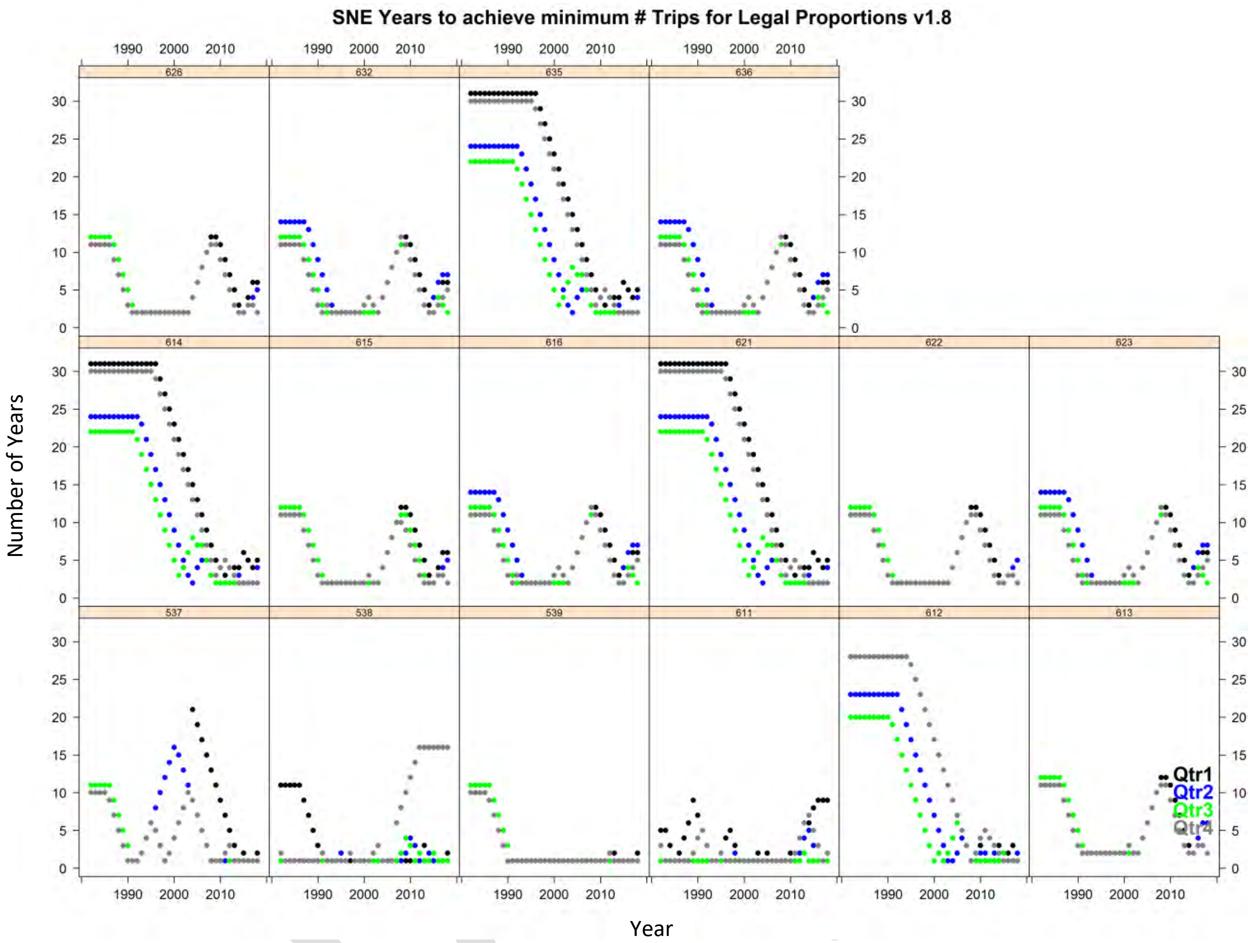


Figure 81. Number of years required to pool sea- sampling data across by SNE statistical area (beige panel title) and quarter for characterizing respective commercial landings size composition and sex ratio.

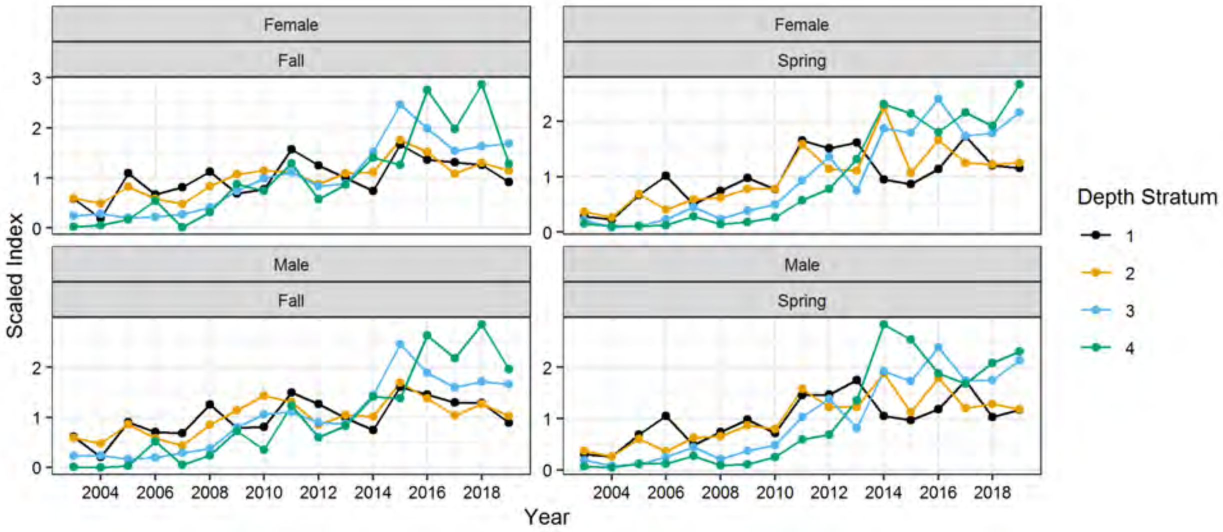


Figure 82. ME/NH Trawl Survey seasonal indices of 53+ mm CL lobsters by depth stratum. Indices are scaled to their time series mean to show relative trends.

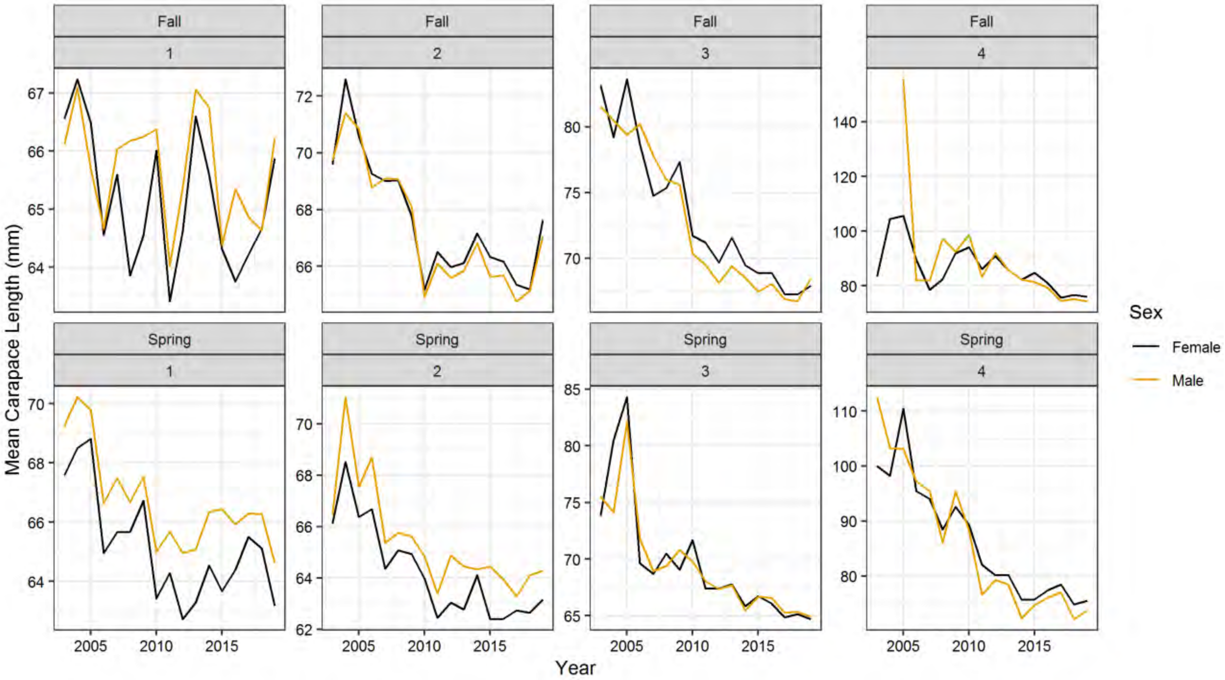


Figure 83. Seasonal mean CL of ME/NH Trawl Survey 53+ mm CL lobster catch by depth stratum.

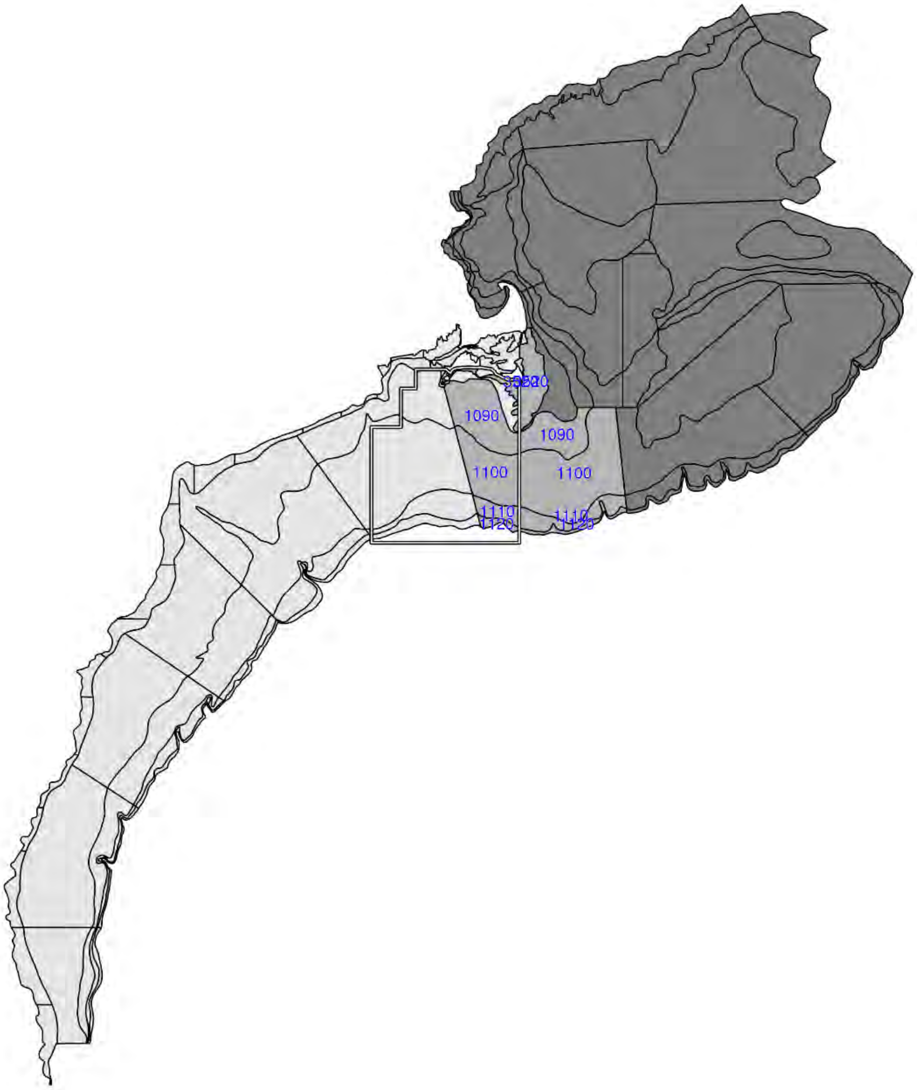


Figure 84. NEFSC survey strata as assigned to the SNE and GOMGBK stock areas. Labeled strata, shaded in medium gray, were affected by change in stock definition. The boundary of SA 537 is shown as the double black line for reference purposes.

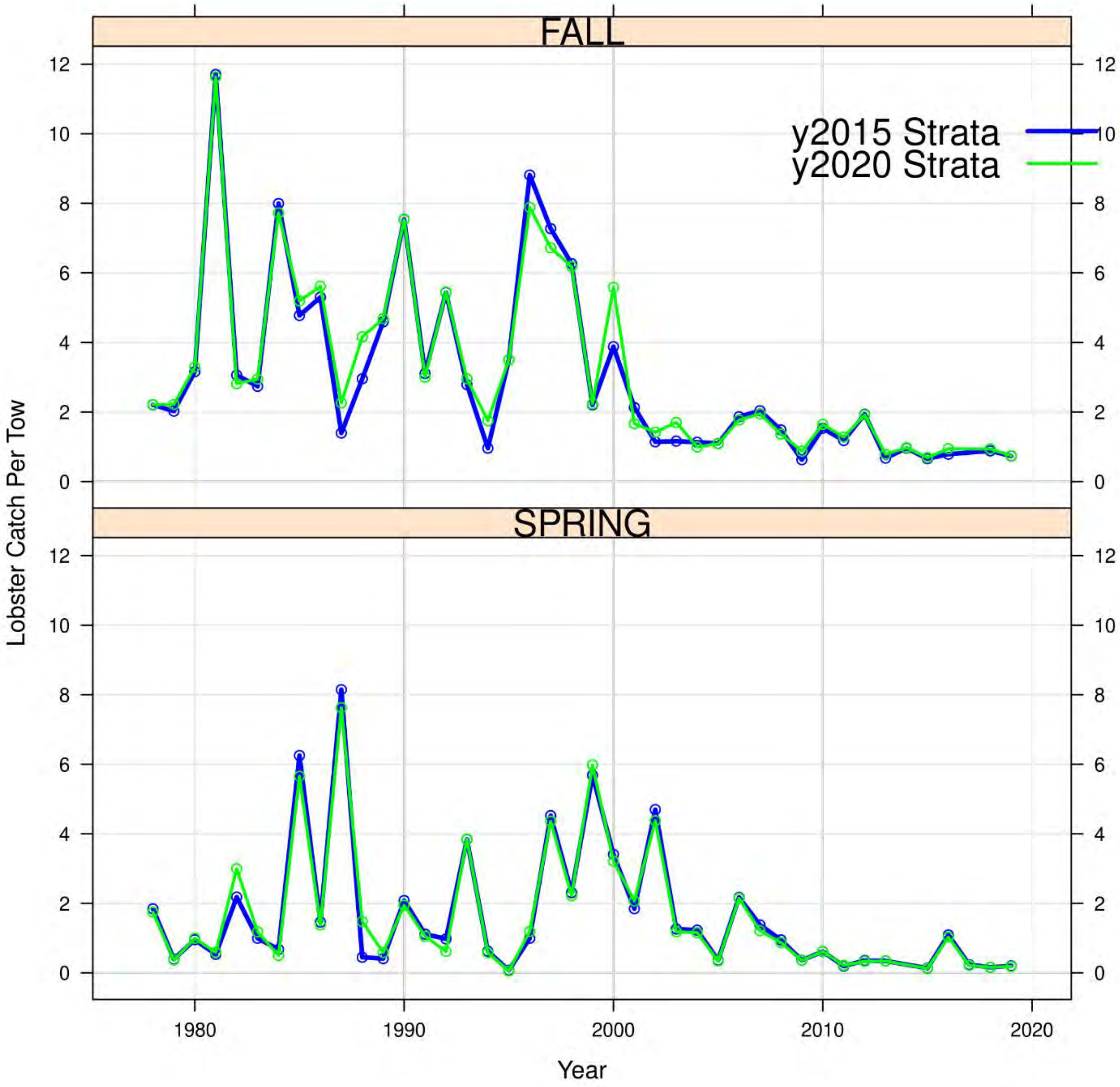


Figure 85. Aggregate SNE abundance indices for the NEFSC trawl survey based on the sampling strata used in the previous and current assessment.

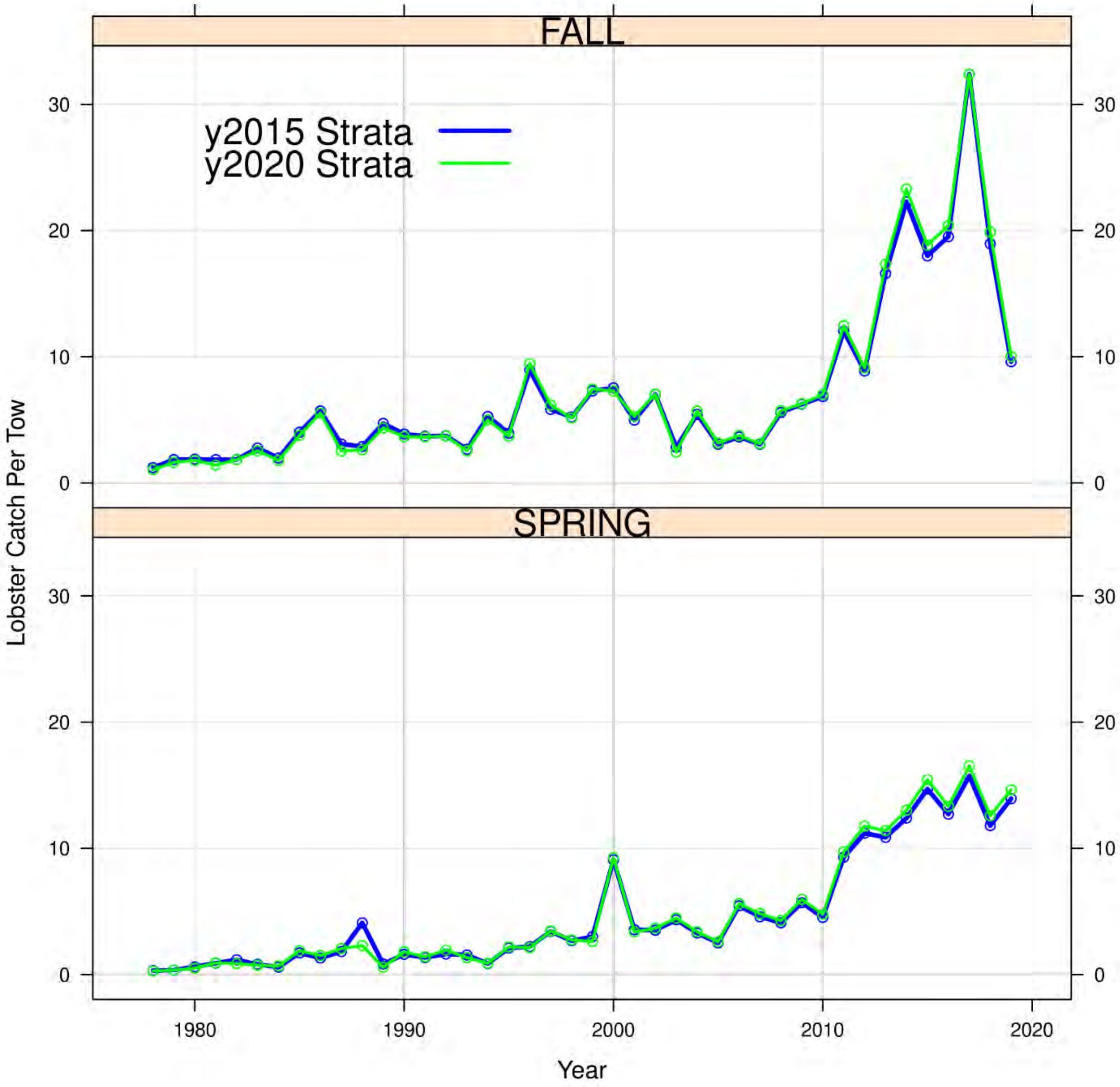


Figure 86. Aggregate GOMGBK abundance indices for the NEFSC trawl survey based on the sampling strata used in the previous and current assessment.

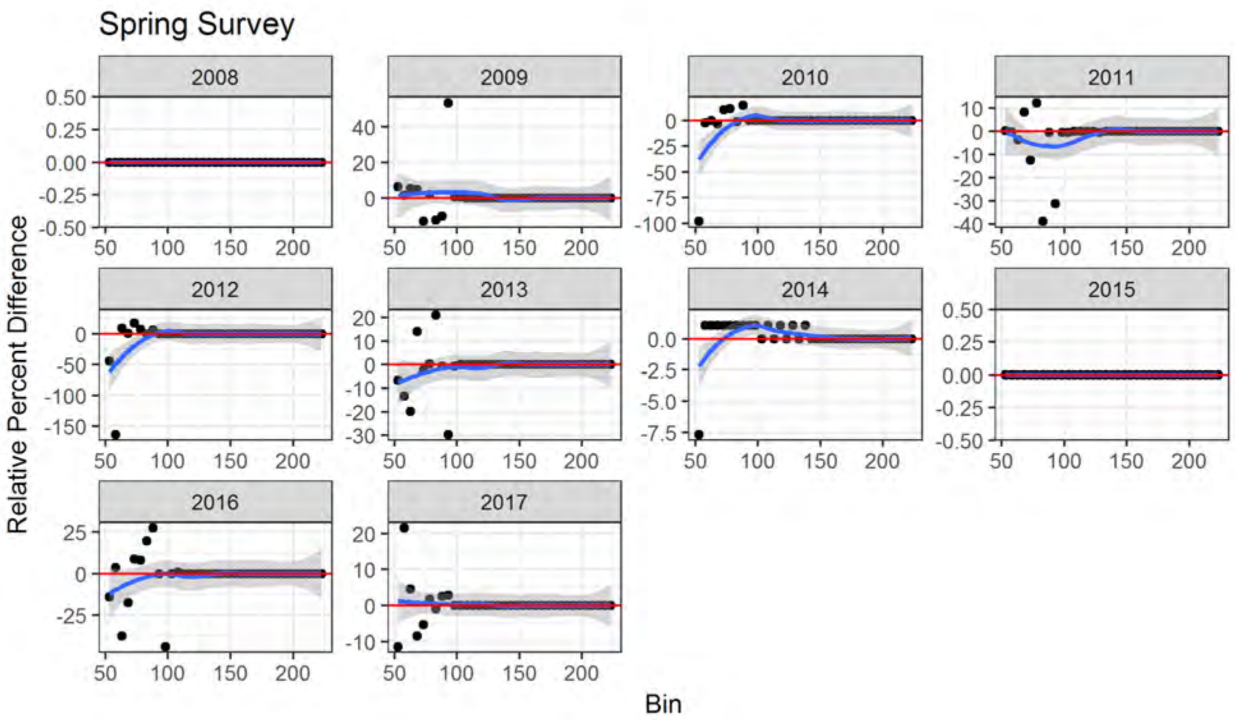


Figure 87. Relative percent difference (black dots) between length composition estimates using all lobsters sampled and only lobsters sampled for sex during the Spring NEAMAP Trawl Survey. Red lines show no difference and blue lines are smoothed trend lines with 95% confidence intervals (shaded grey areas).

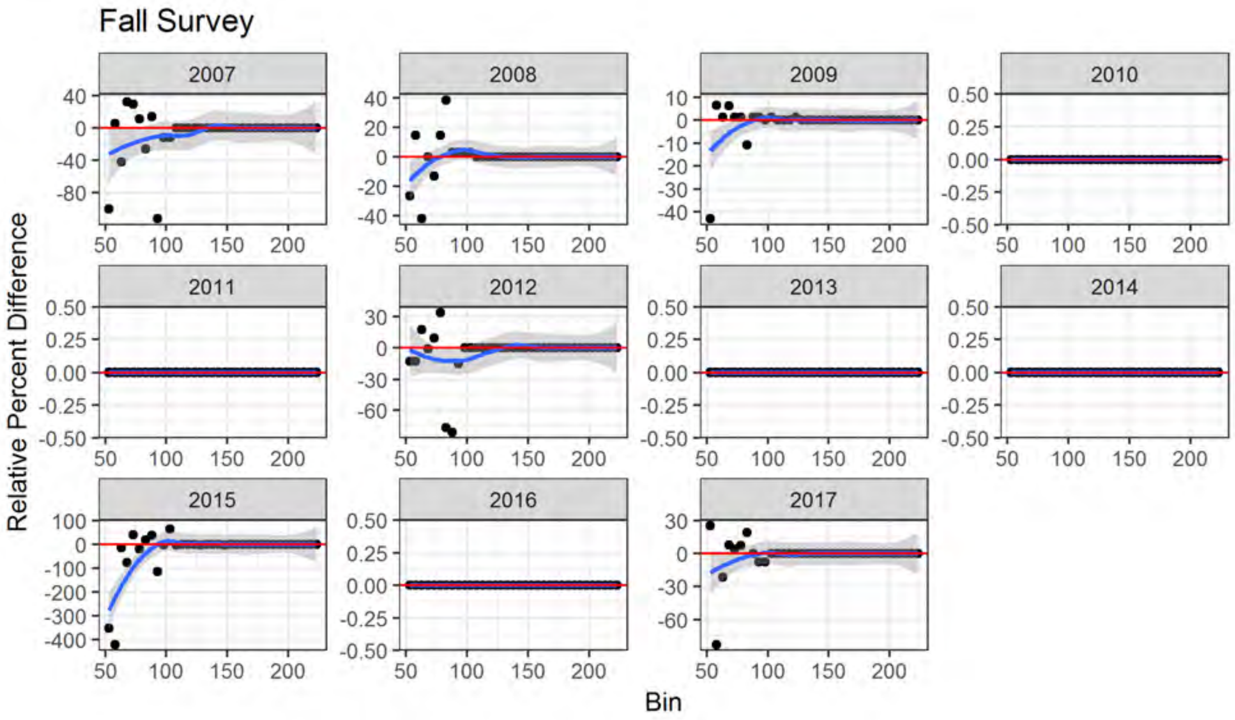


Figure 88. Relative percent difference (black dots) between length composition estimates using all lobsters sampled and only lobsters sampled for sex during the Fall NEAMAP Trawl Survey. Red lines show no difference and blue lines are smoothed trend lines with 95% confidence intervals (shaded grey areas).

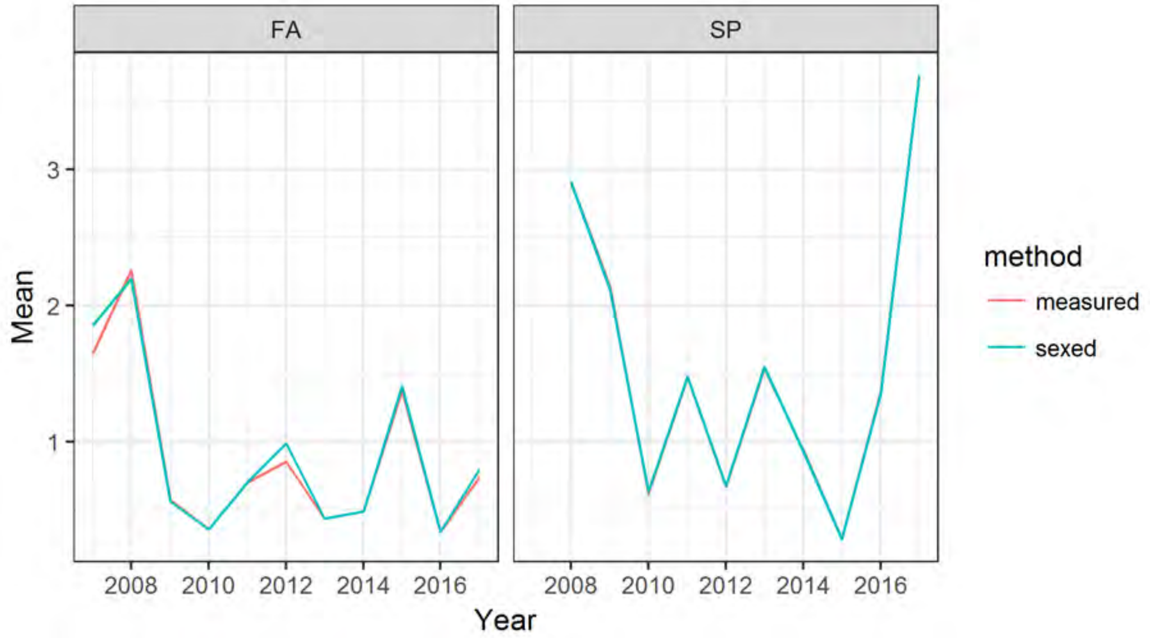


Figure 89. Fall (left) and Spring (right) NEAMAP Trawl Survey indices of abundance developed from length compositions using all lobsters sampled (red lines) and only lobsters subsampled for sex (blue lines).

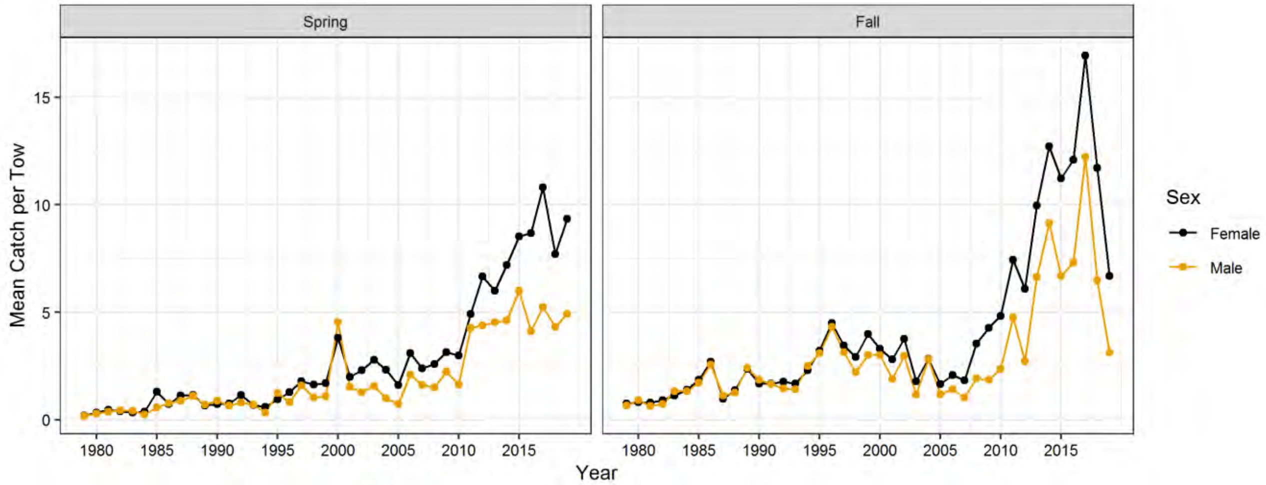


Figure 90. NEFSC Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters from GOMGBK strata.

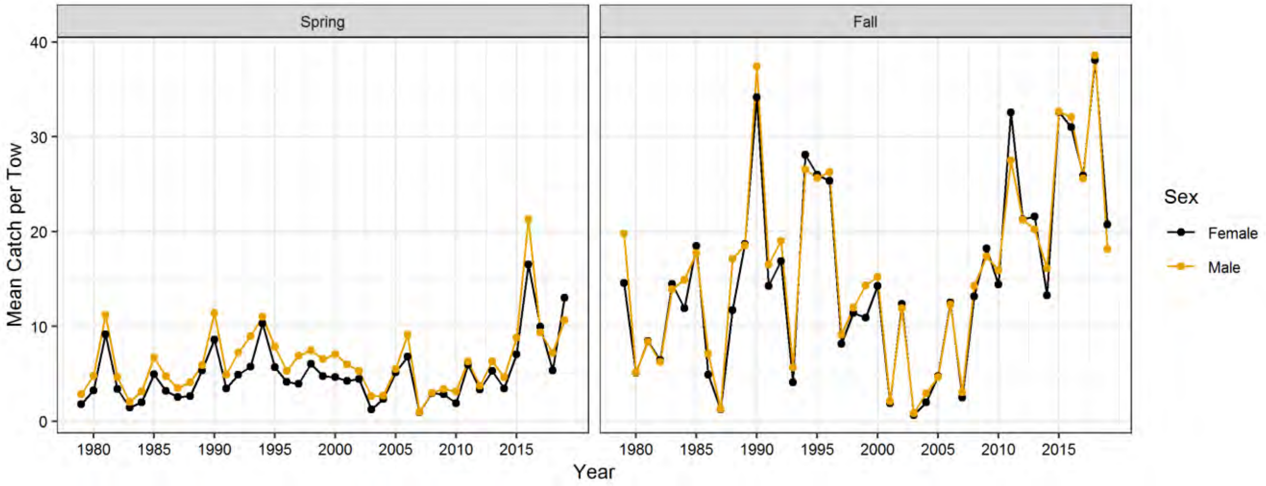


Figure 91. MA Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters from GOMGBK strata.

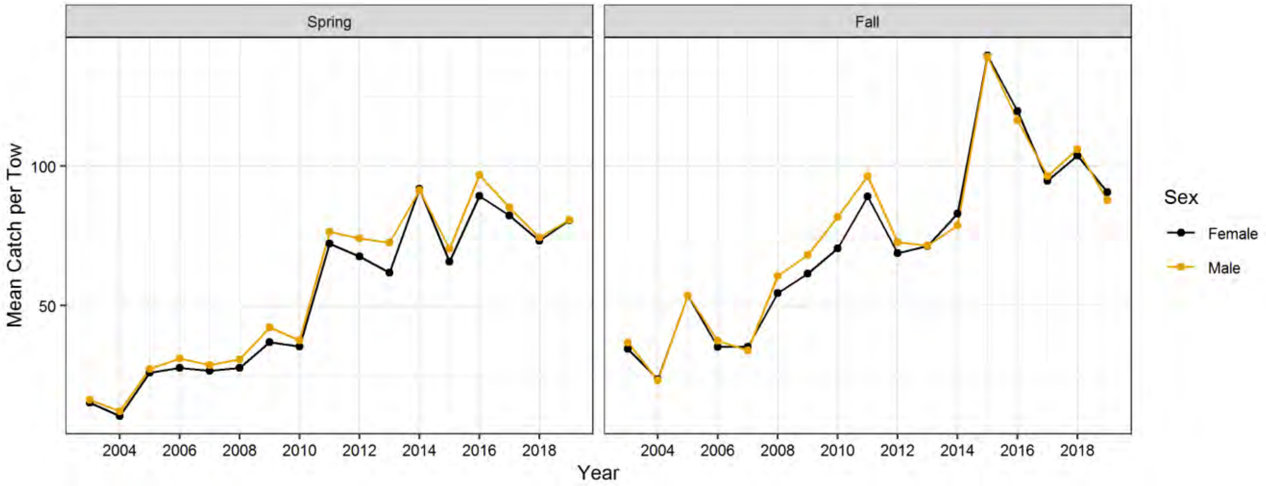


Figure 92. ME/NH Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters.

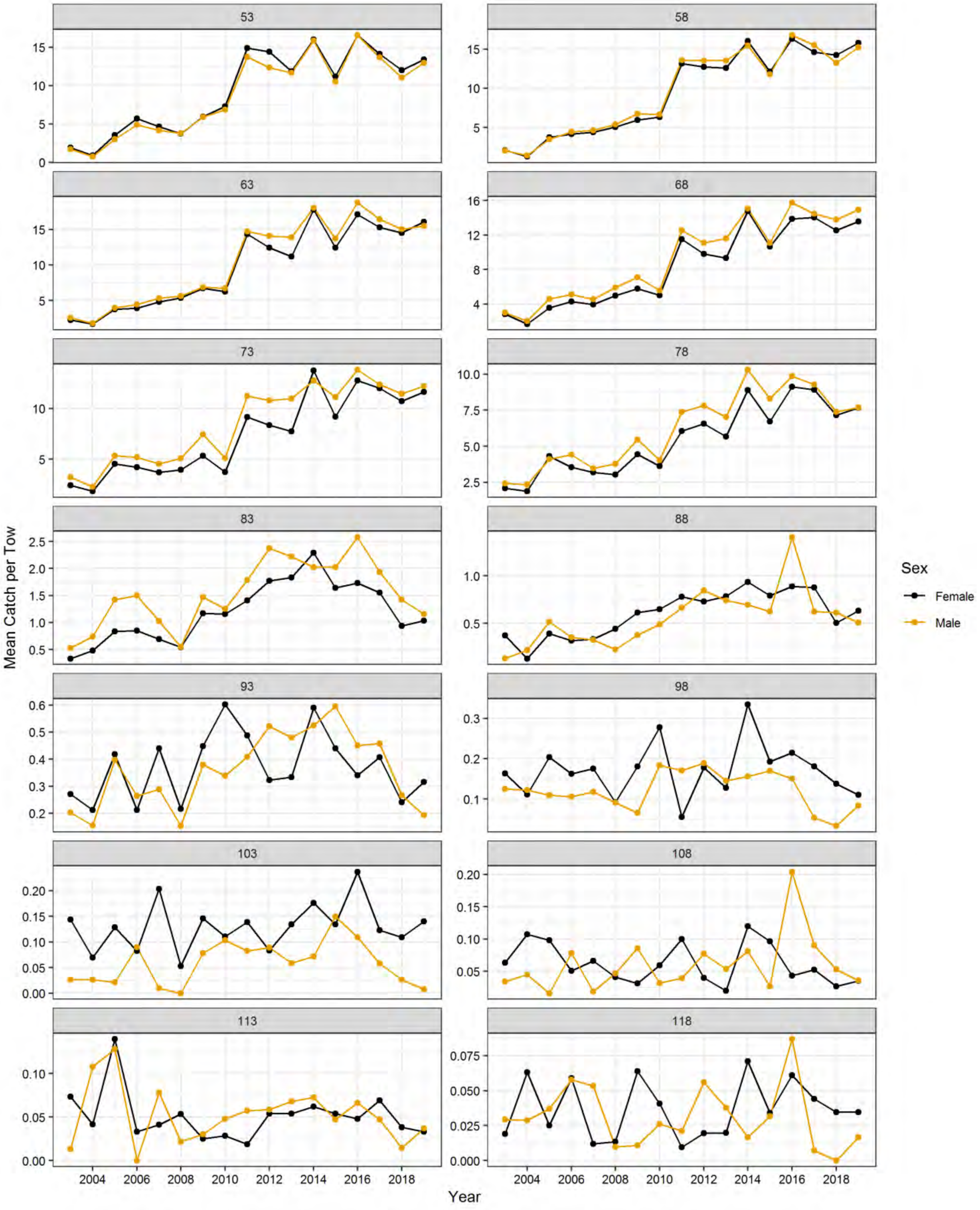


Figure 93. Spring ME/NH Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.

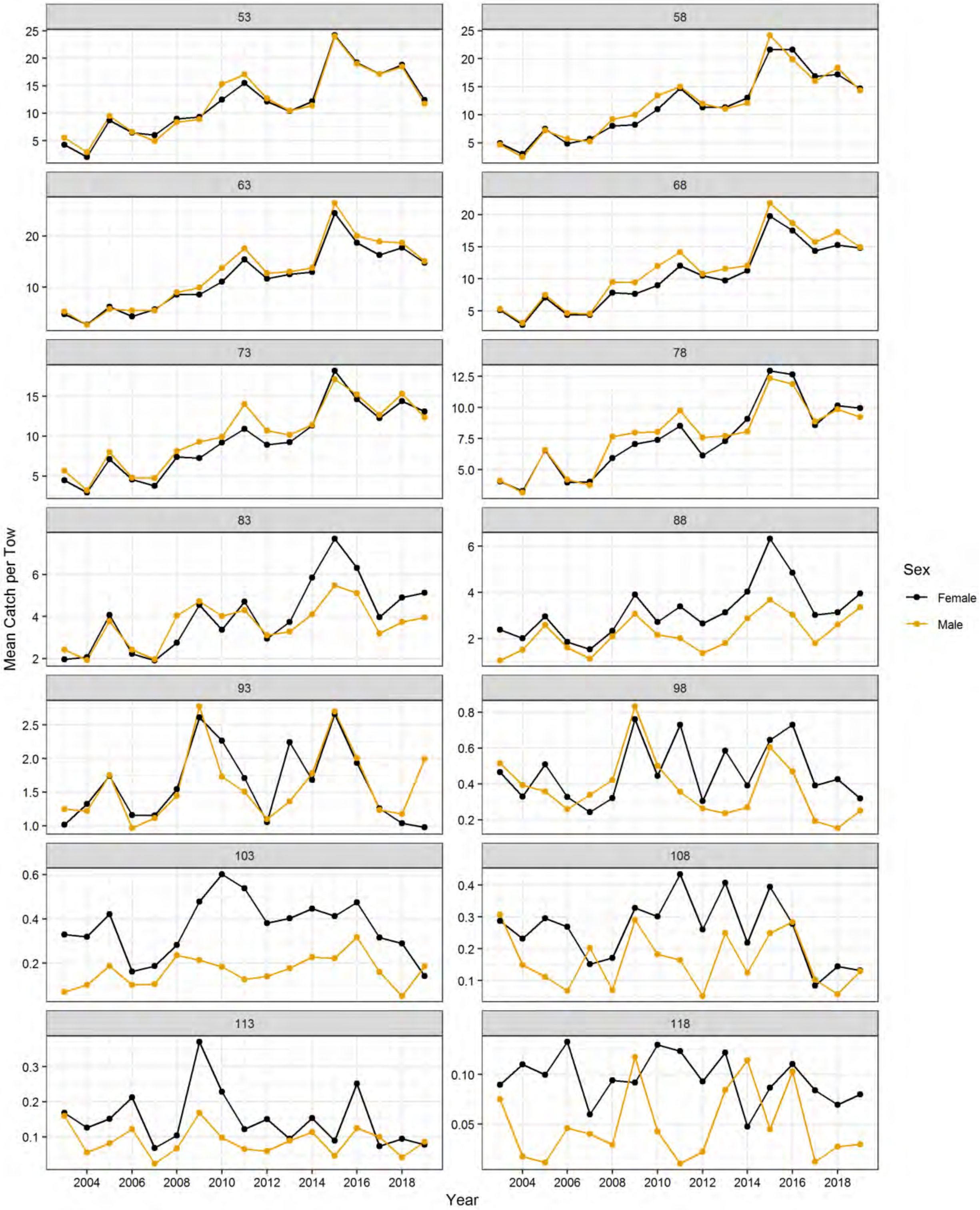


Figure 94. Fall ME/NH Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.

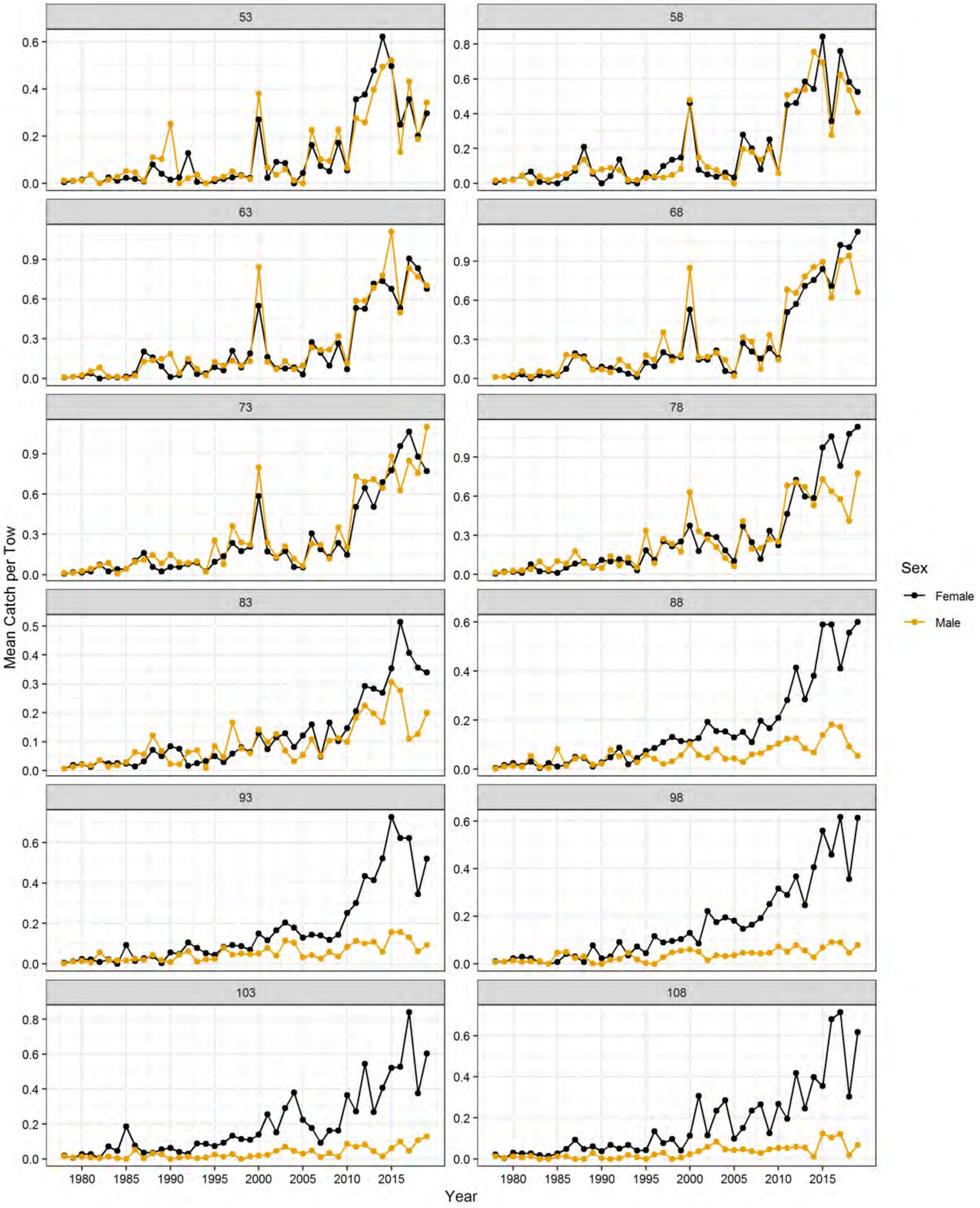
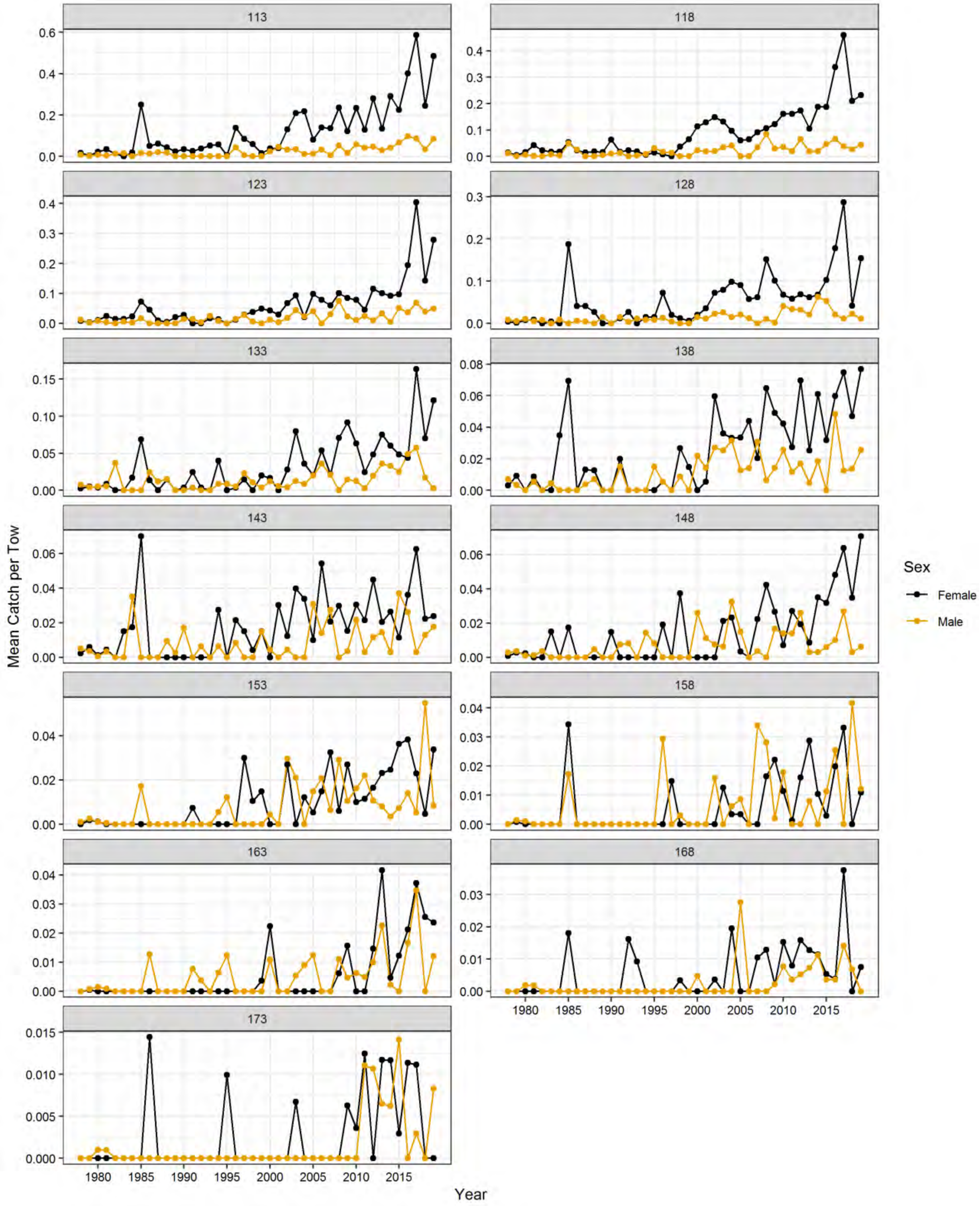


Figure 95. Spring NEFSC Trawl Survey mean catch per tow of lobsters from GOMGBK strata by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 173 mm size bin (173-177 mm CL; see continued trends below) as catches of larger sizes are relatively infrequent and variable.



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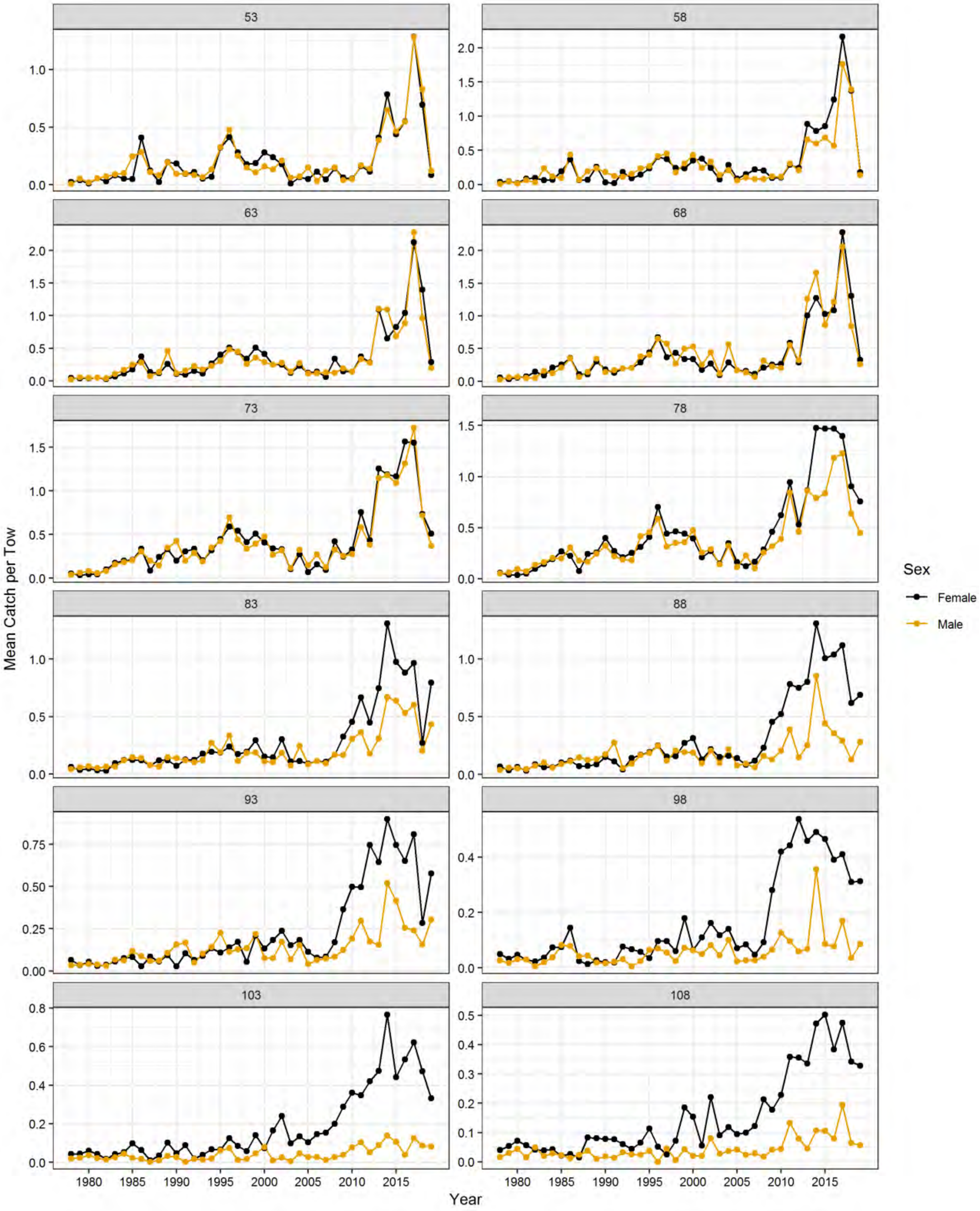
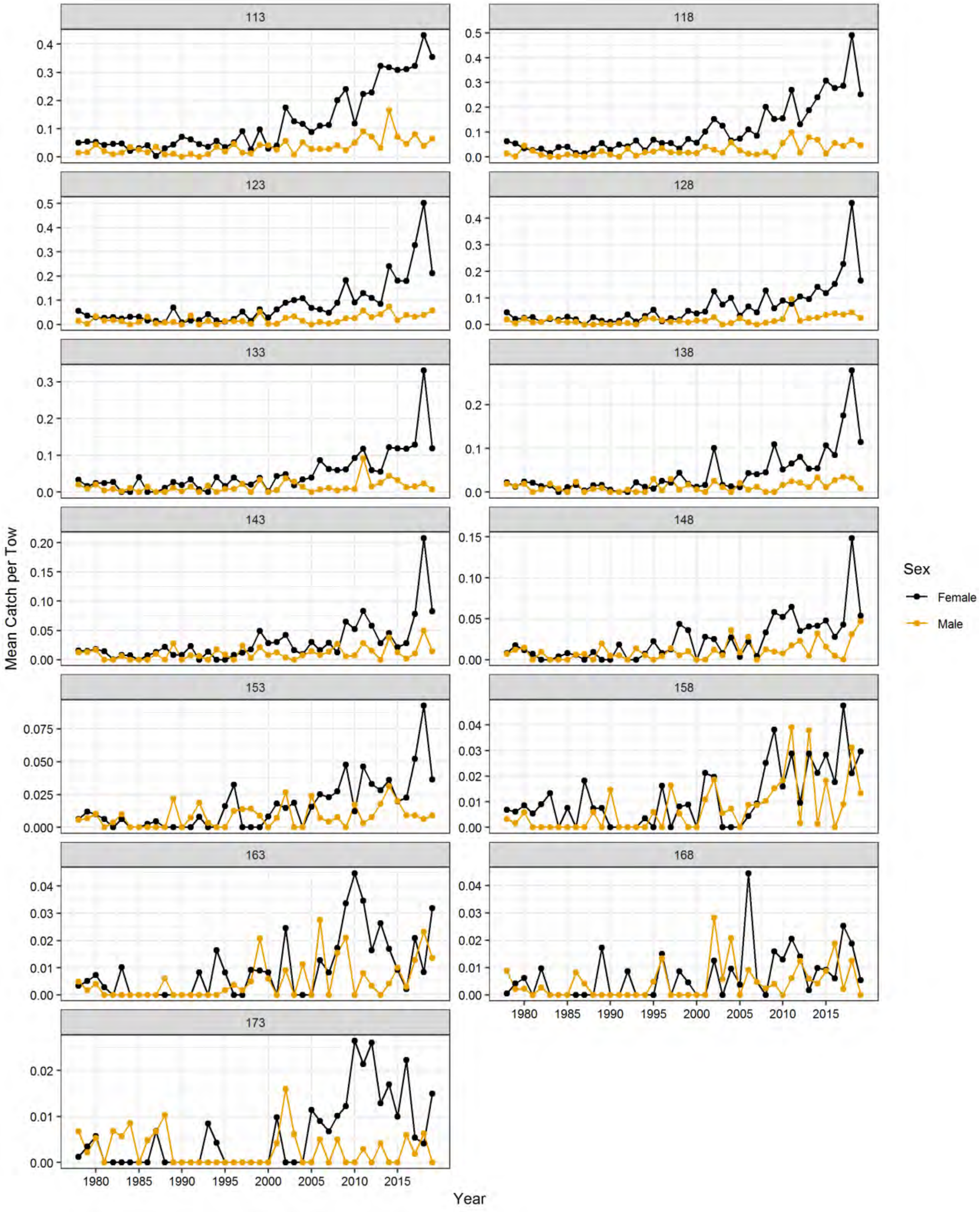


Figure 96. Fall NEFSC Trawl Survey mean catch per tow of lobsters from GOMGBK strata by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 173 mm size bin (173-177 mm CL; see continued trends below) as catches of larger sizes are relatively infrequent and variable.



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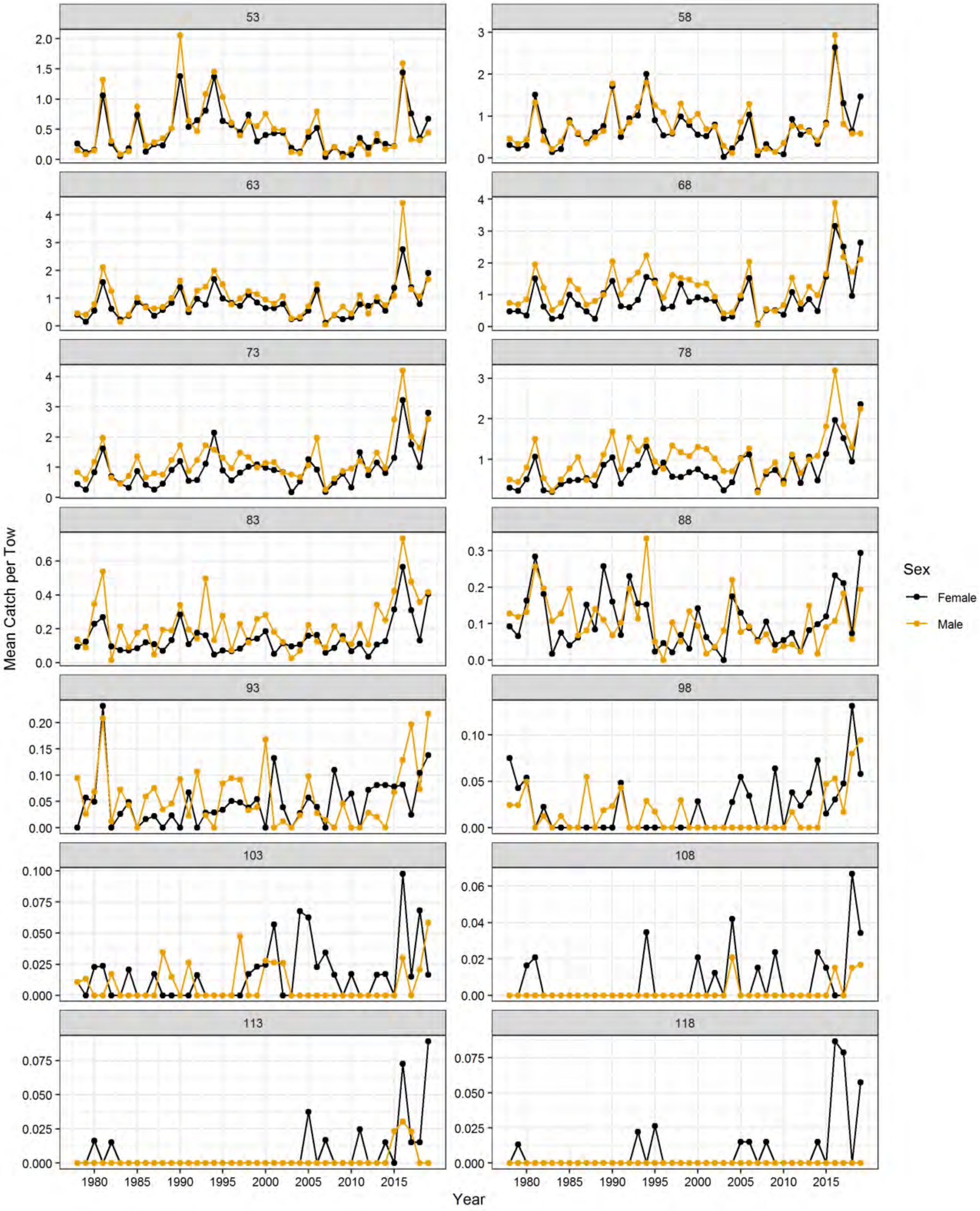

Figure 97. Spring MA Trawl Survey mean catch per tow of lobsters from GOMGBK strata by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.

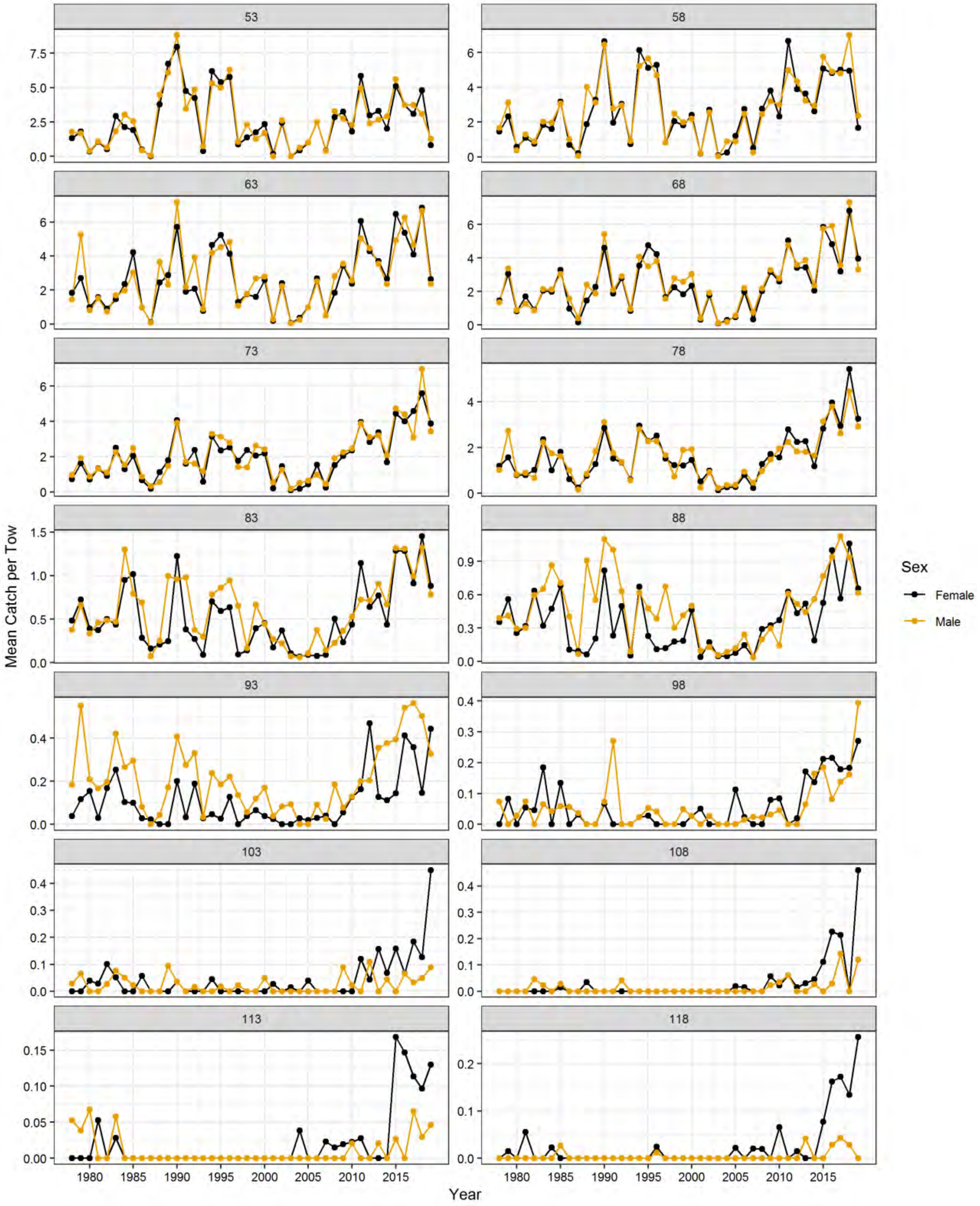

Figure 98. Fall MA Trawl Survey mean catch per tow of lobsters from GOMGBK strata by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.

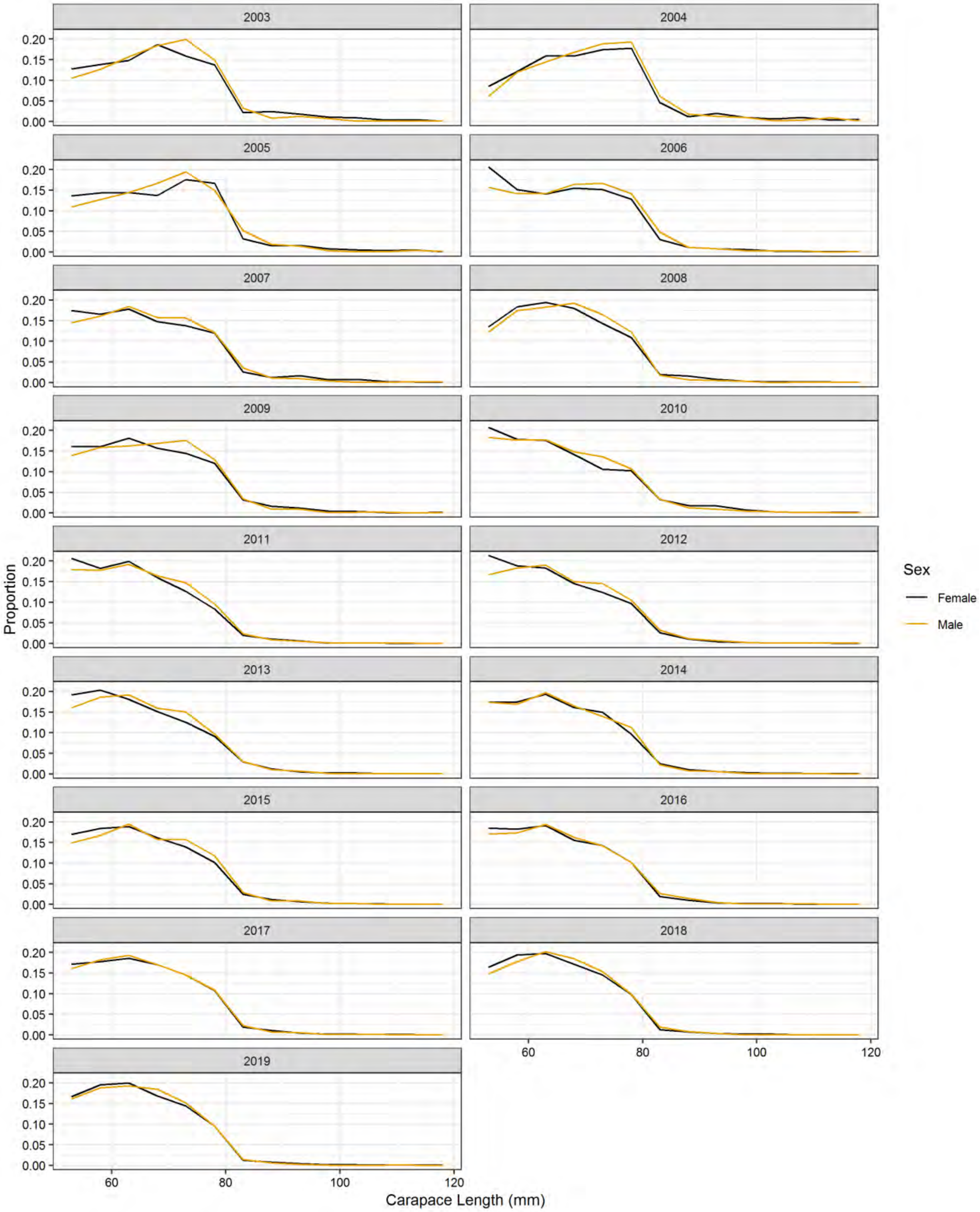

Figure 99. Spring ME/NH Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.

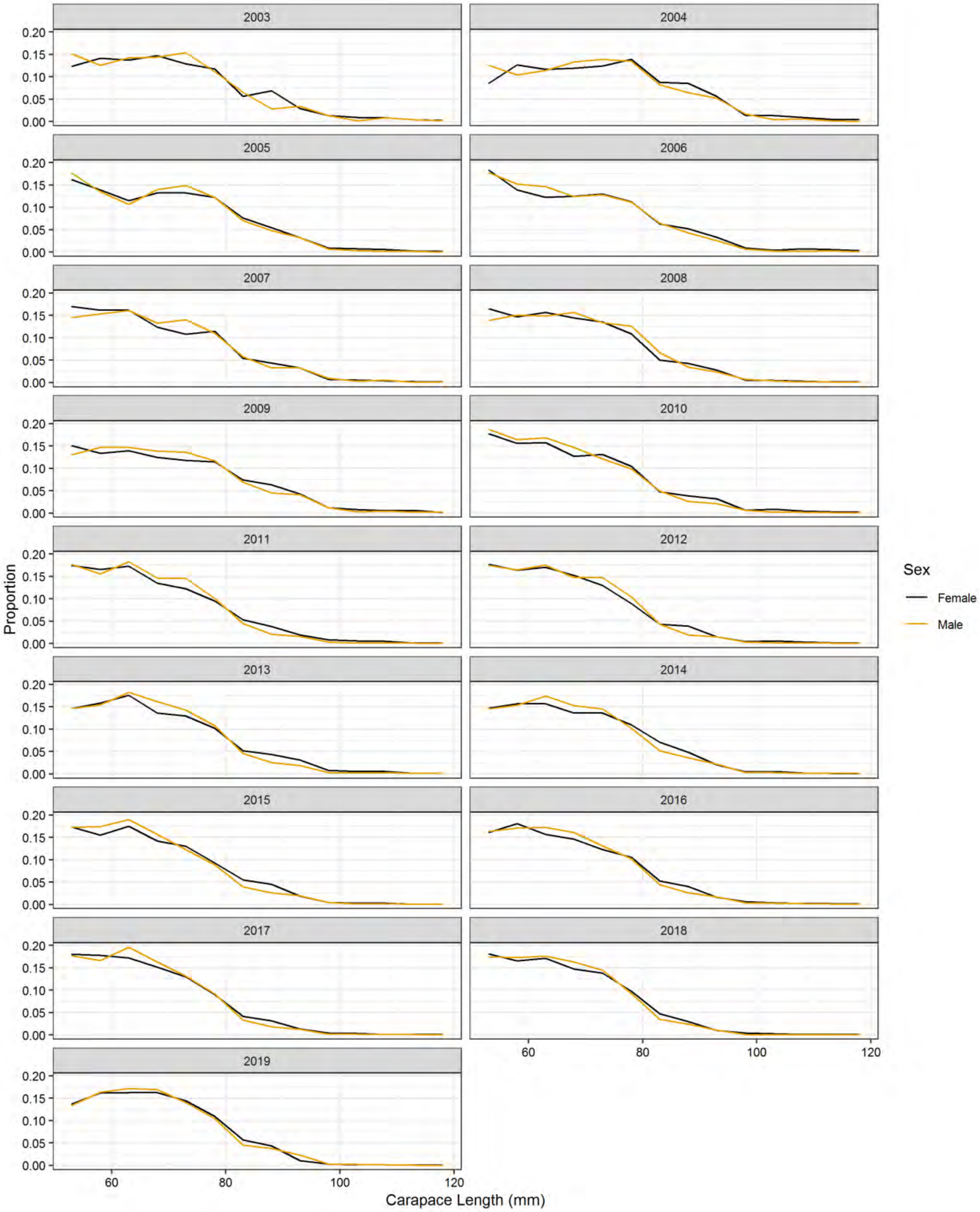

Figure 100. Fall ME/NH Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.

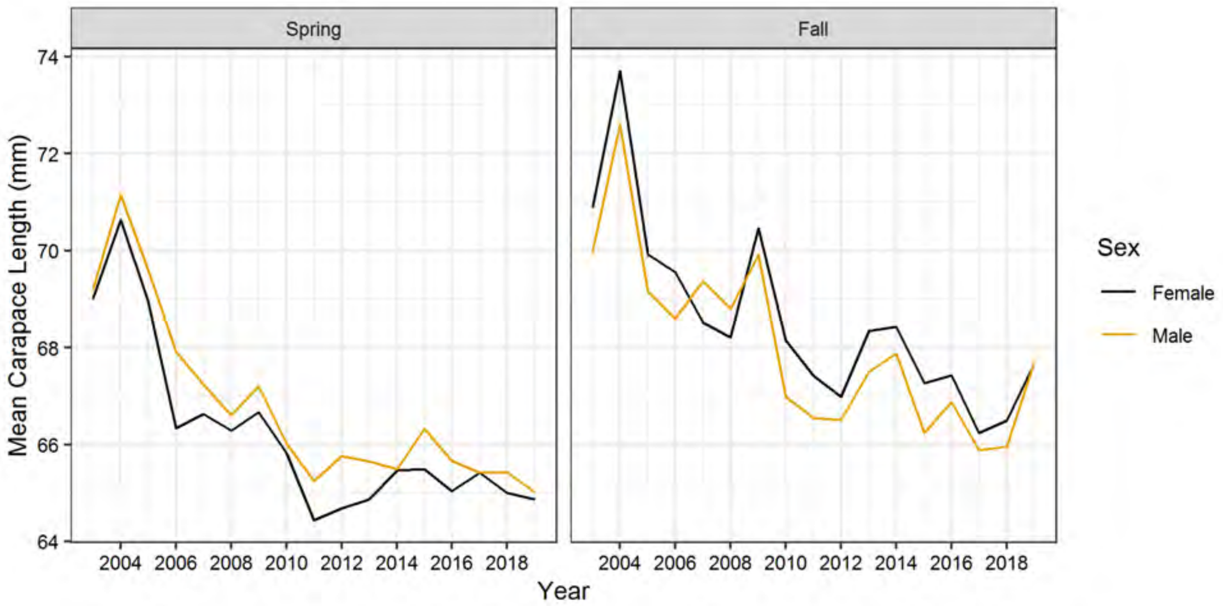

Figure 101. Seasonal mean CL of ME/NH Trawl Survey 53+ mm CL lobster catch.

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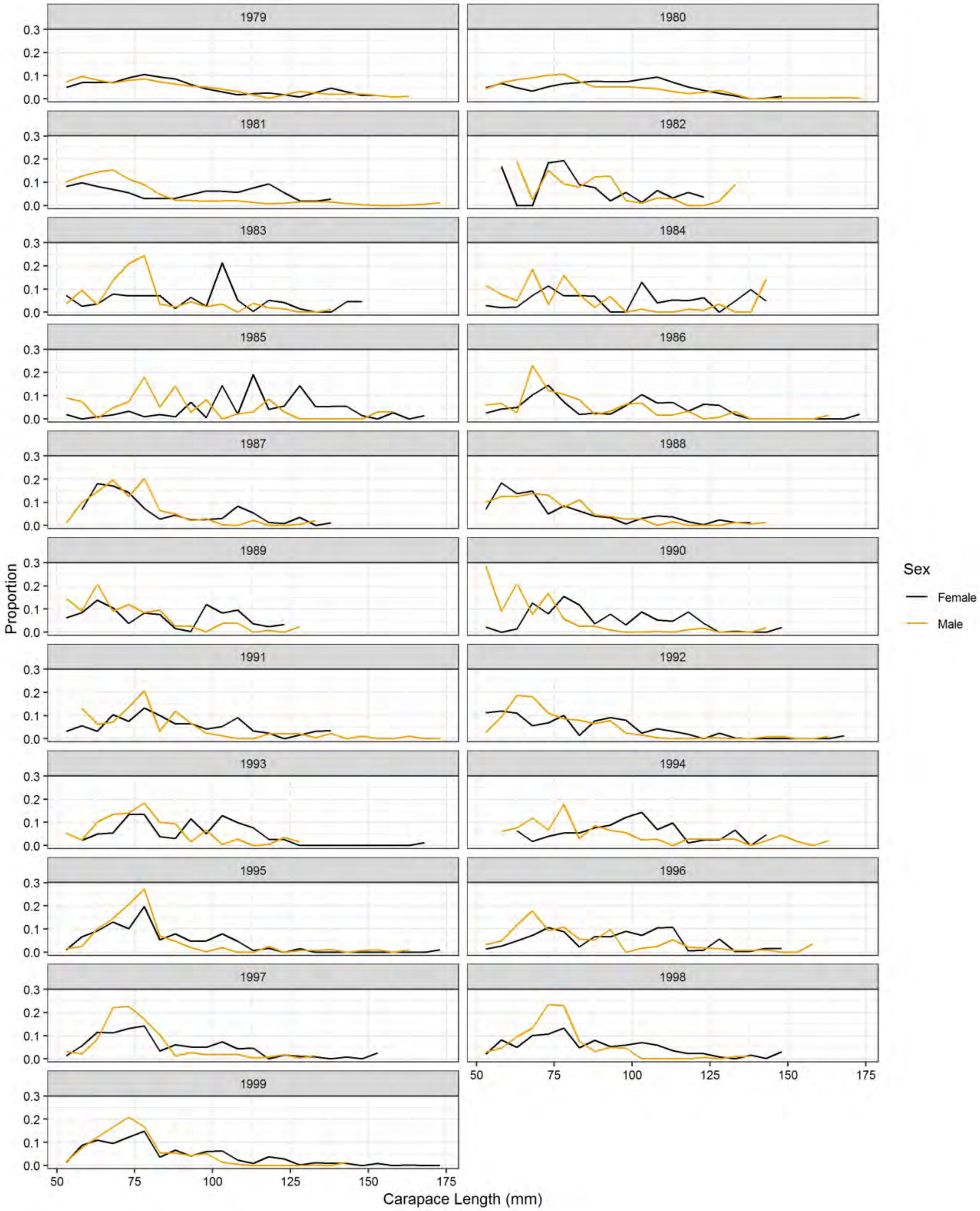
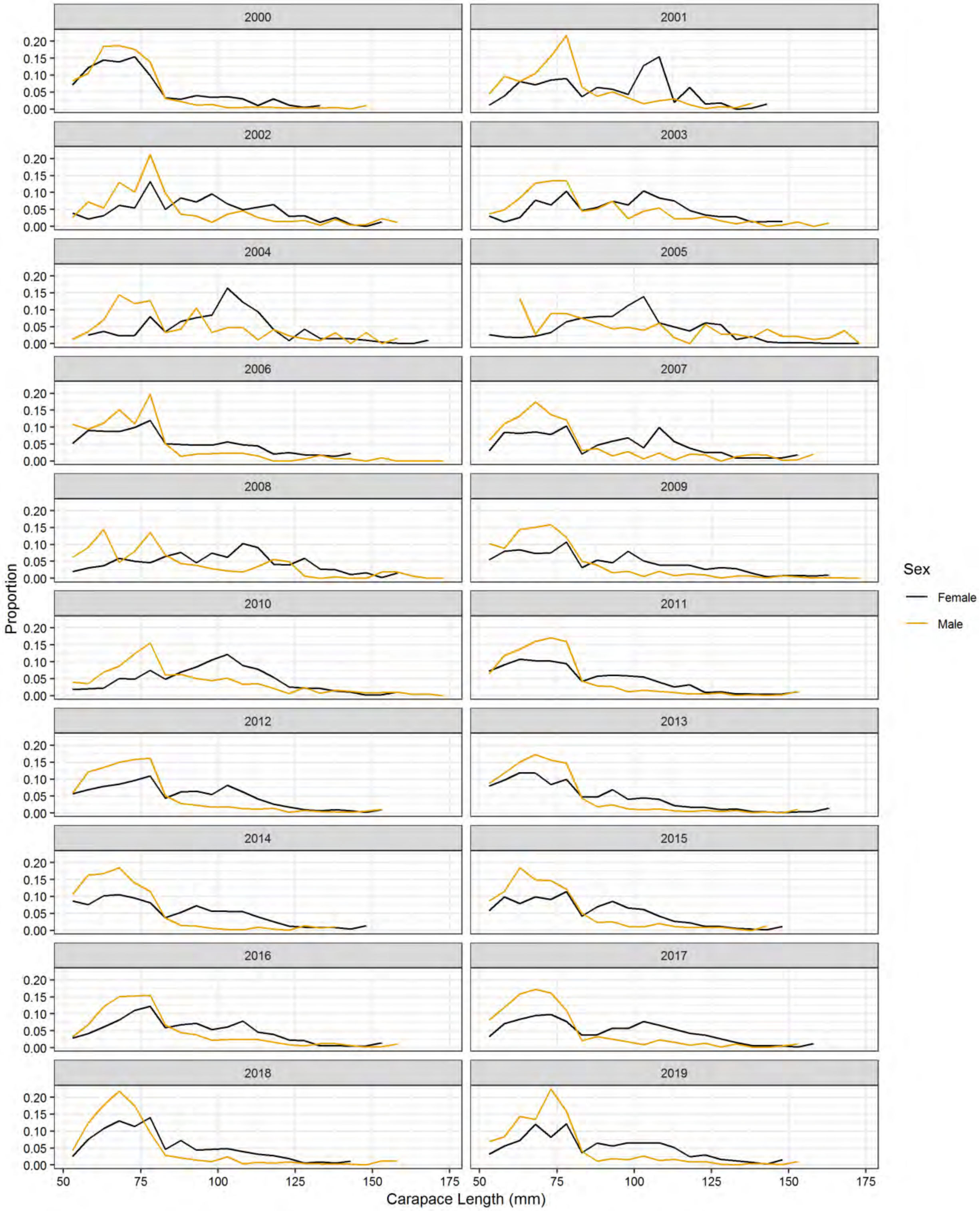


Figure 102. Spring NEFSC Trawl Survey 53+ mm CL lobster catch size compositions from GOMGBK strata. Size bins are truncated at the 173 mm size bin (173-177 mm CL) as catches of larger sizes are relatively infrequent and variable.



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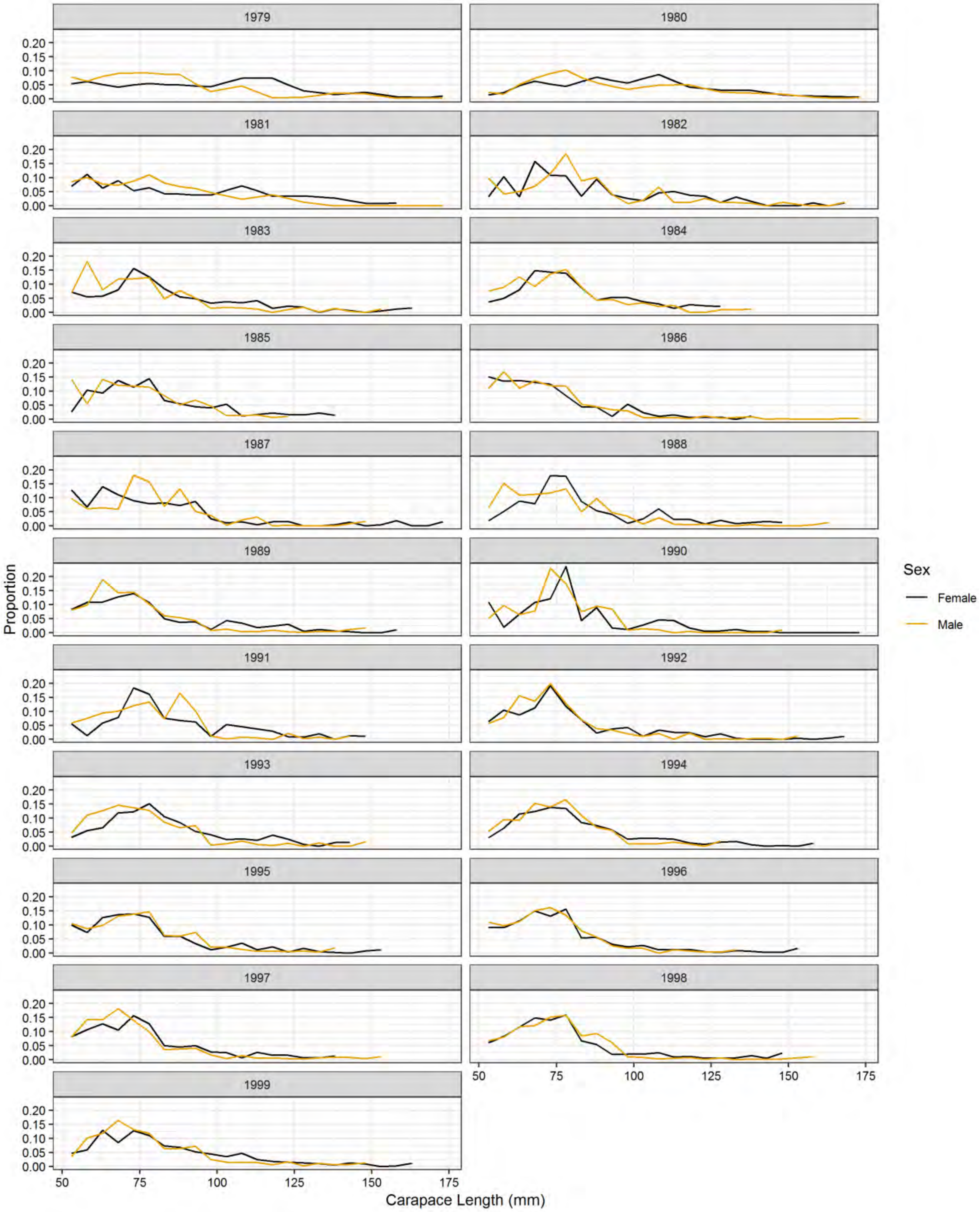
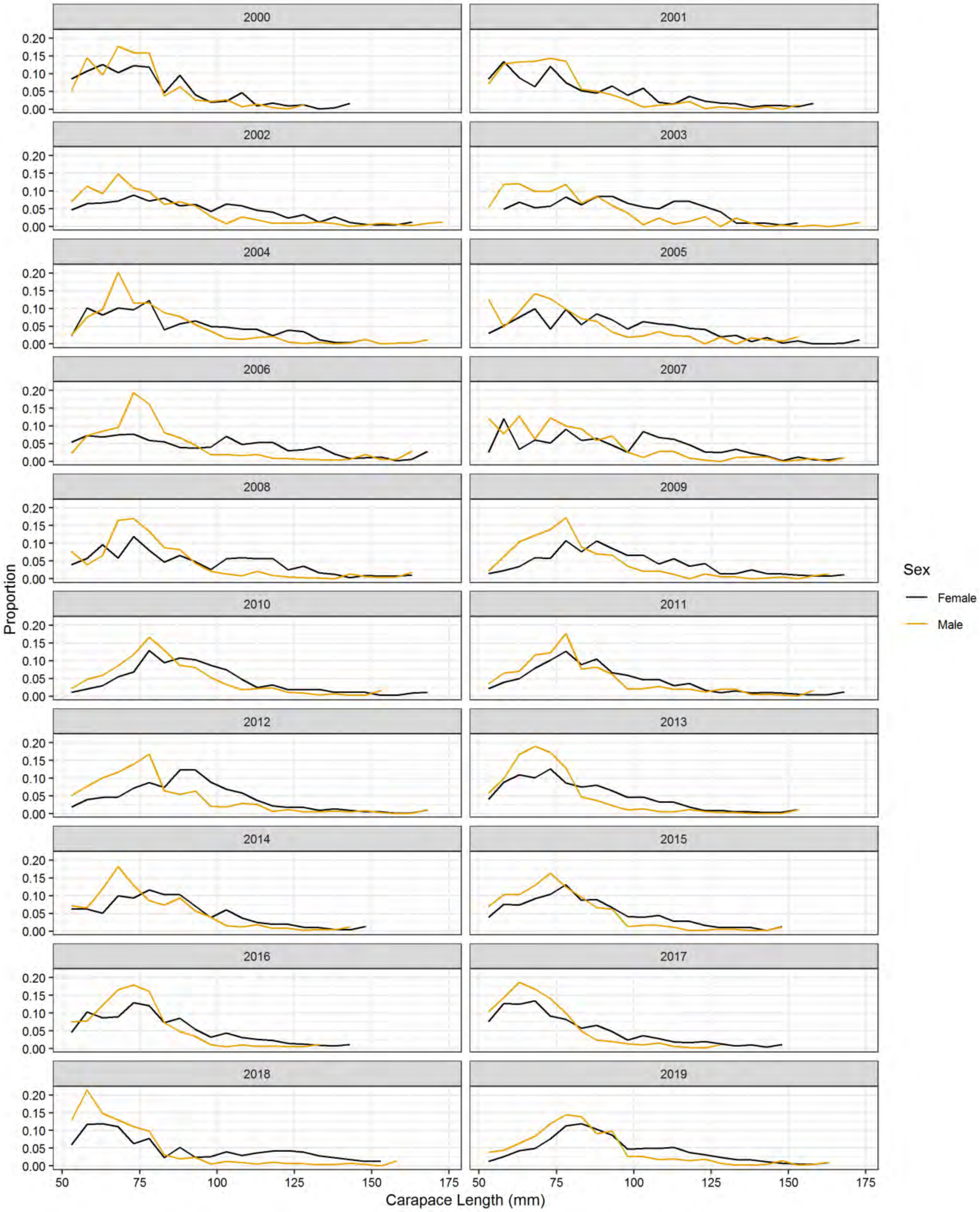


Figure 103. Fall NEFSC Trawl Survey 53+ mm CL lobster catch size compositions from GOMGBK strata. Size bins are truncated at the 173 mm size bin (173-177 mm CL) as catches of larger sizes are relatively infrequent and variable.



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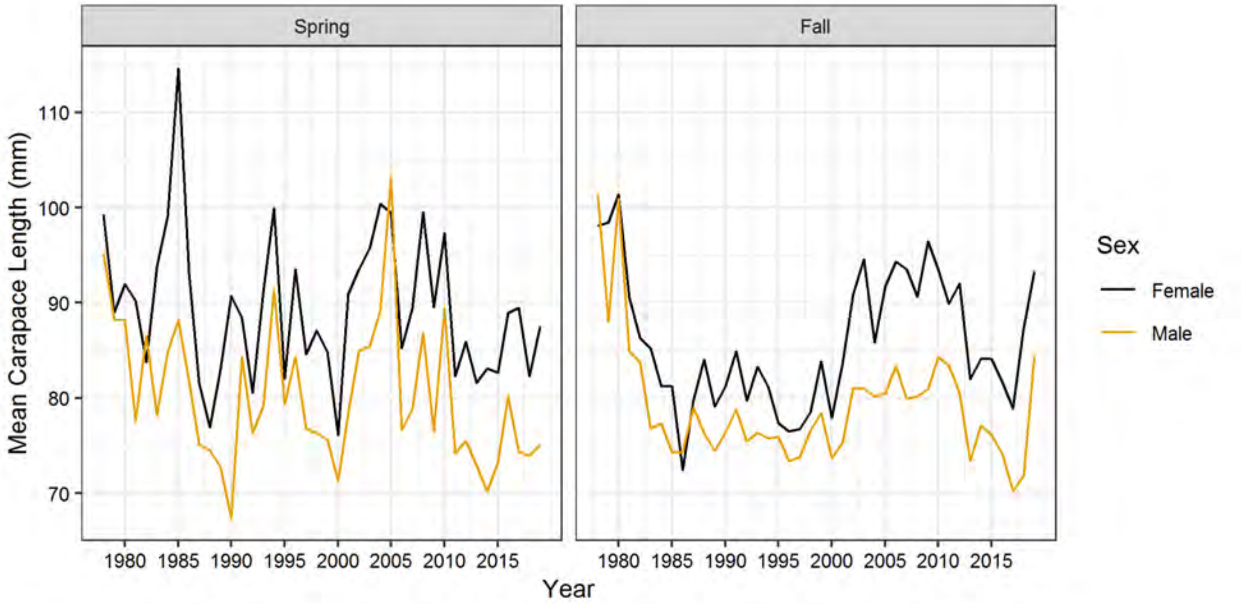

Figure 104. Seasonal mean CL of NEFSC Trawl Survey 53+ mm CL lobster catch from GOMGBK strata.

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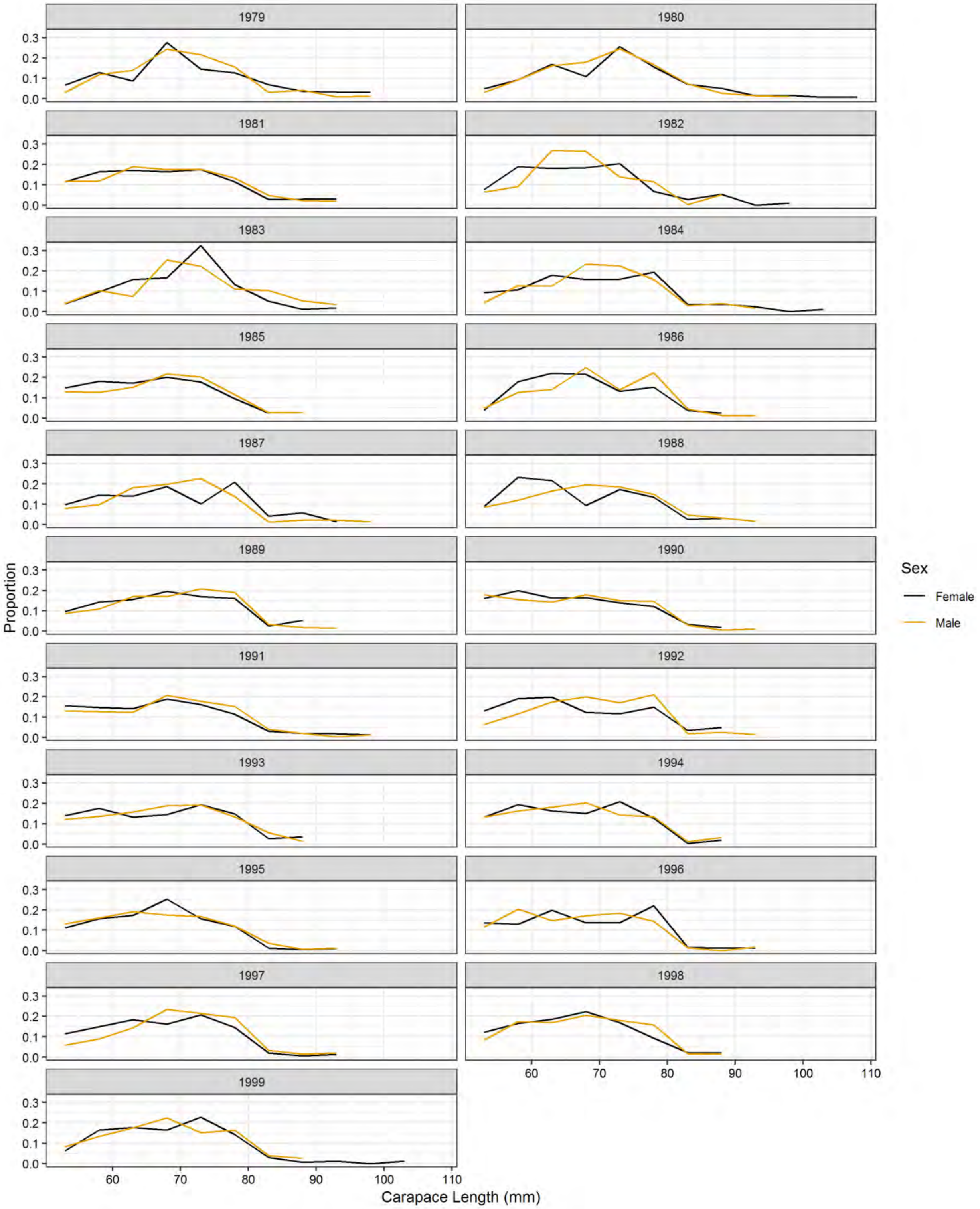
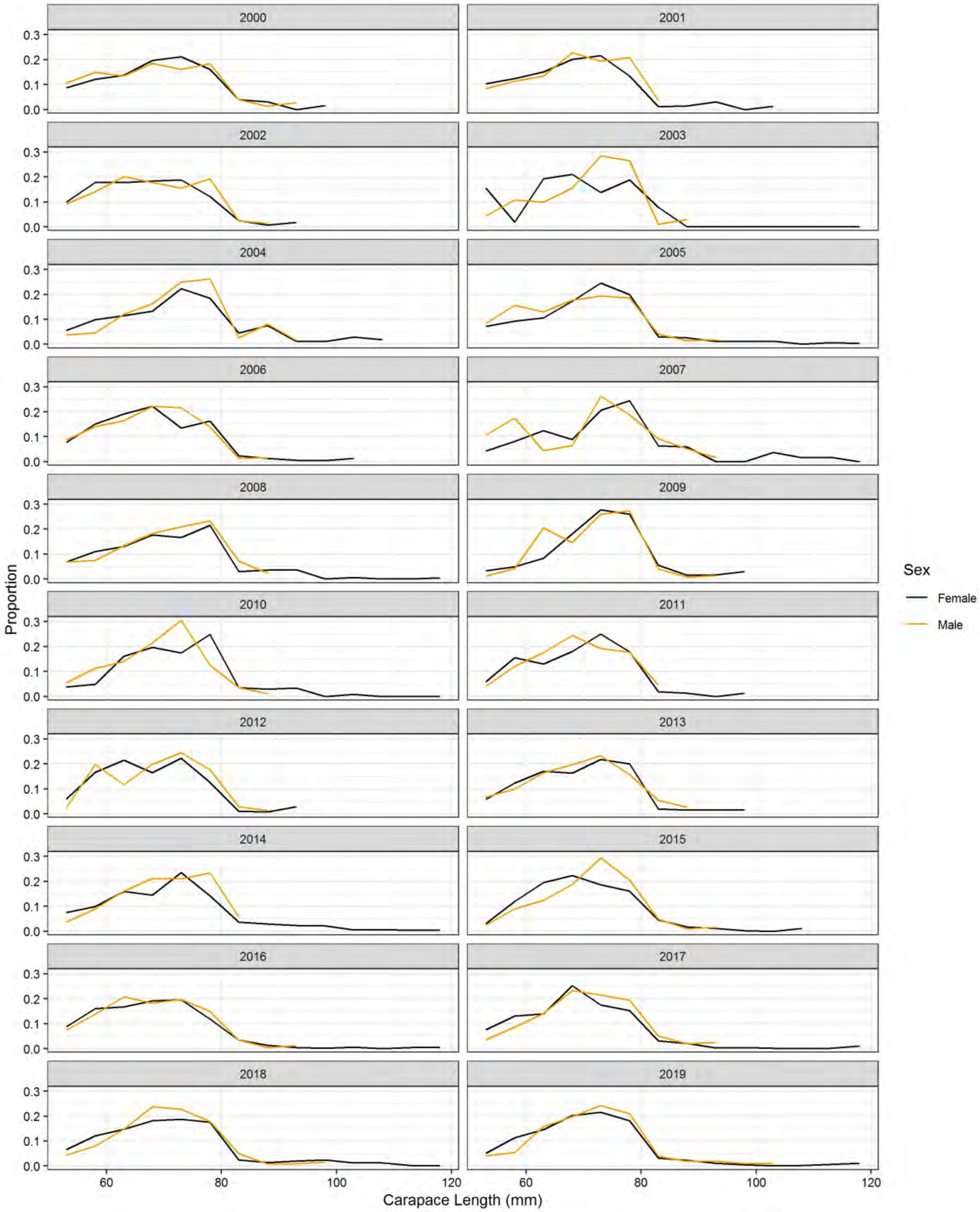


Figure 105. Spring MA Trawl Survey 53+ mm CL lobster catch size compositions from GOMGBK strata. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.



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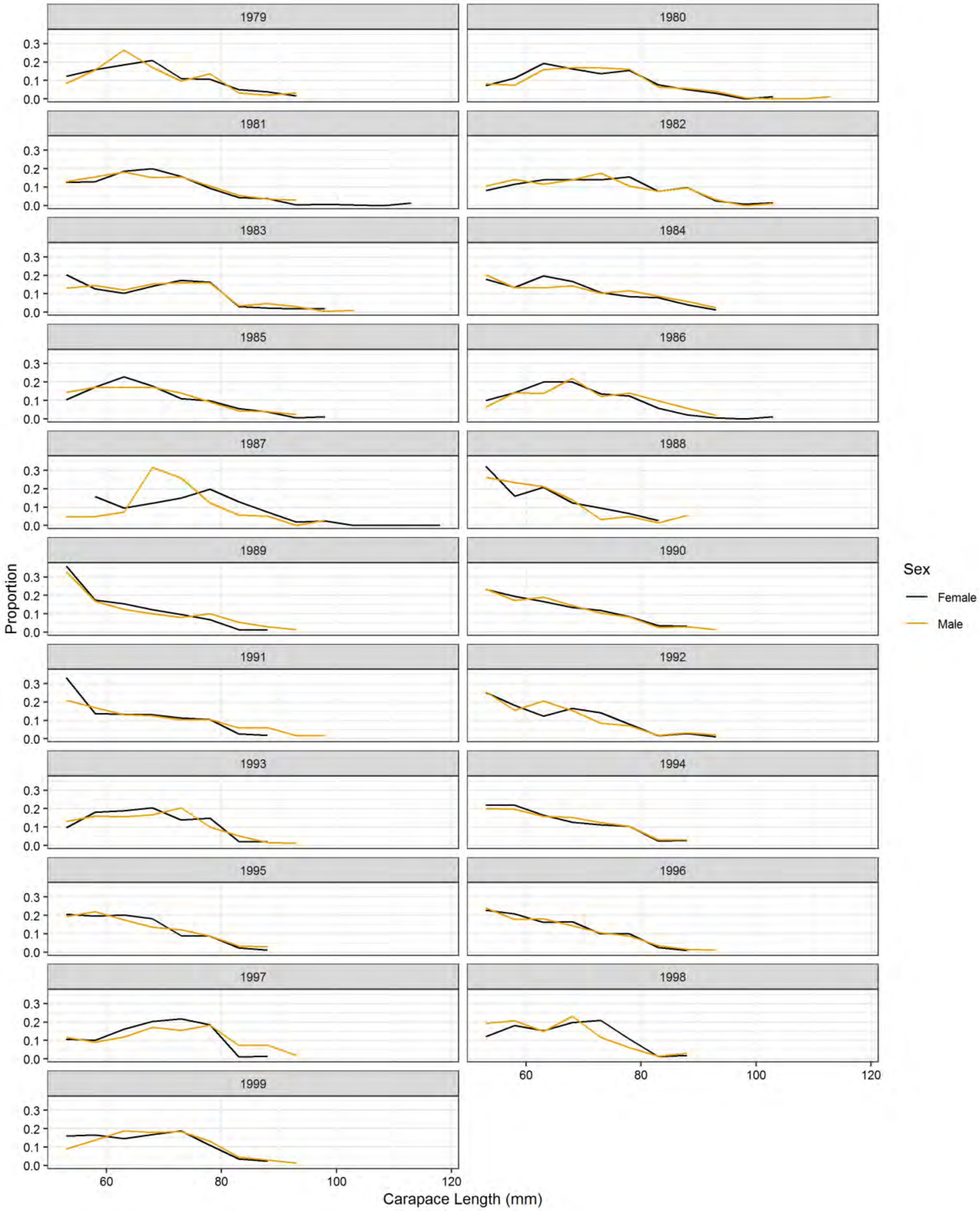
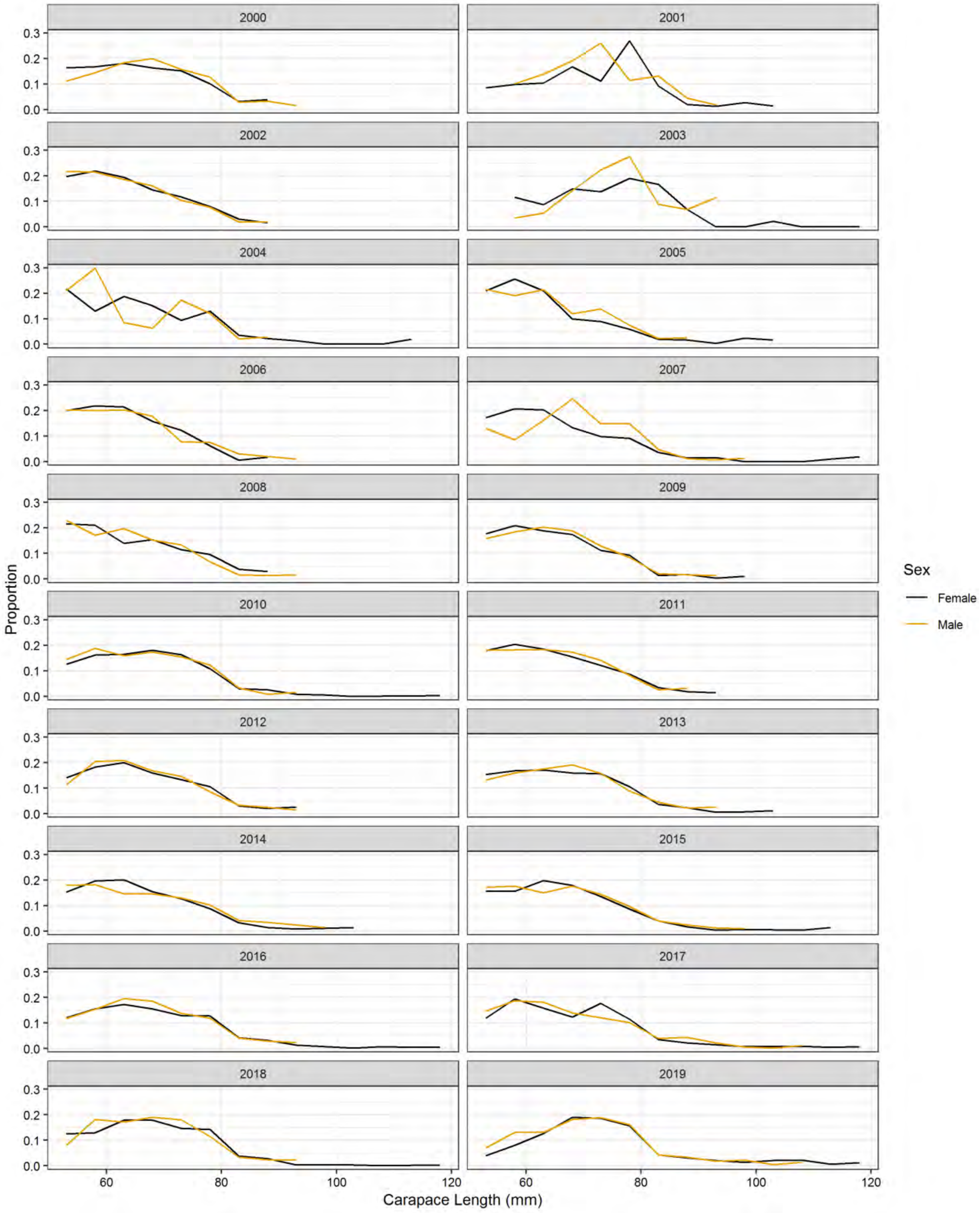


Figure 106. Fall MA Trawl Survey 53+ mm CL lobster catch size compositions from GOMGBK strata. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.



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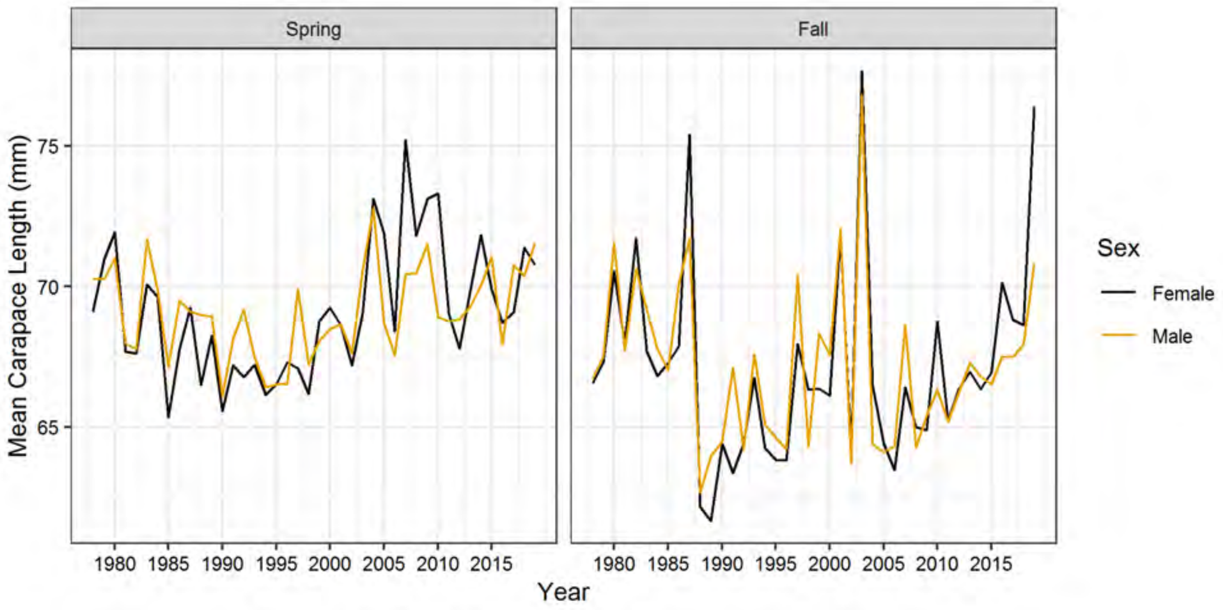

Figure 107. Seasonal mean CL of MA Trawl Survey 53+ mm CL lobster catch from GOMGBK strata.

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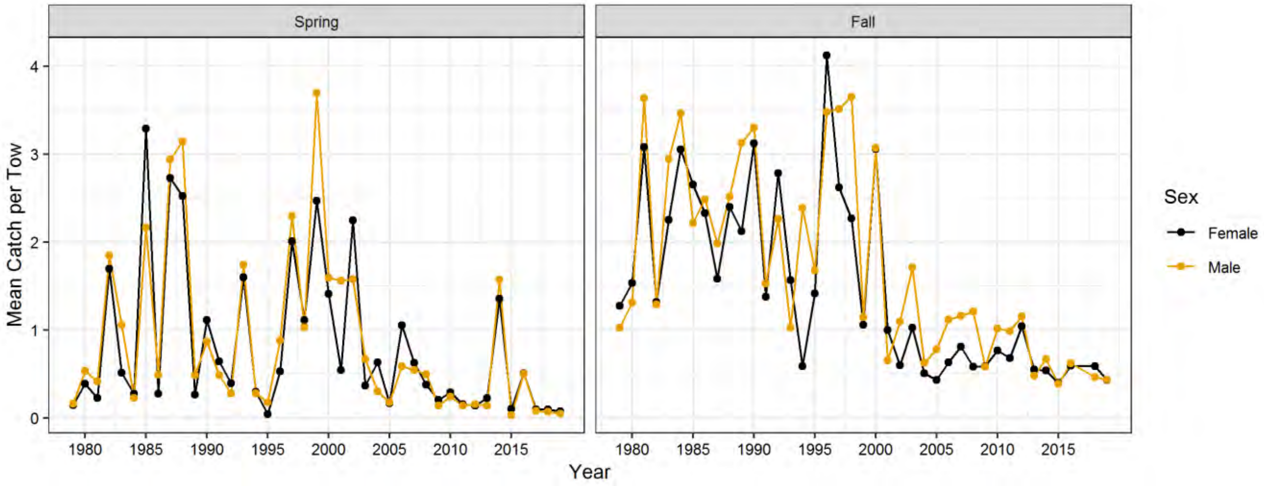


Figure 108. NEFSC Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters from SNE strata.

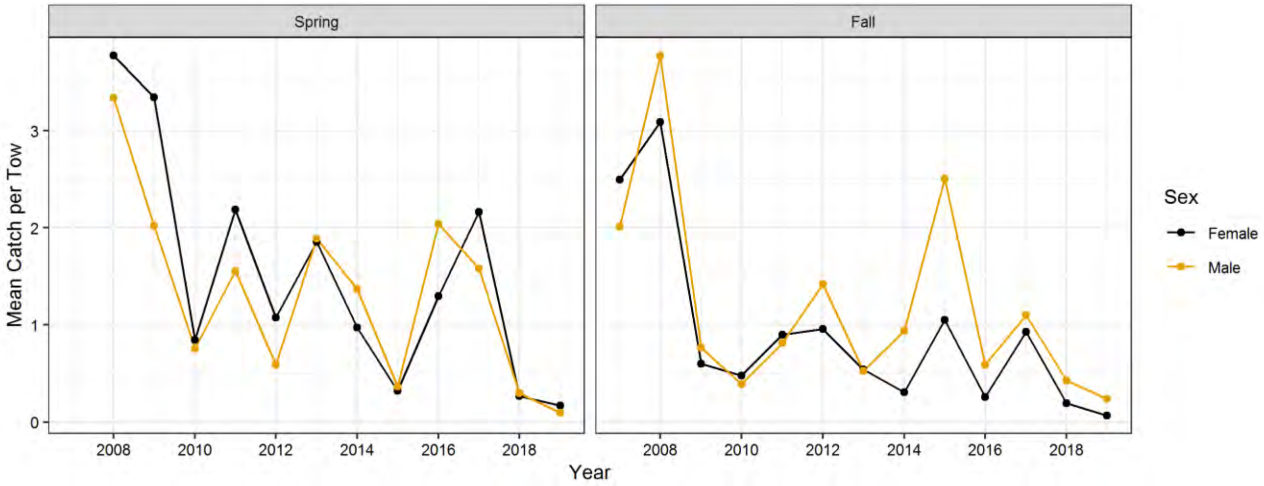


Figure 109. NEAMAP Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters.

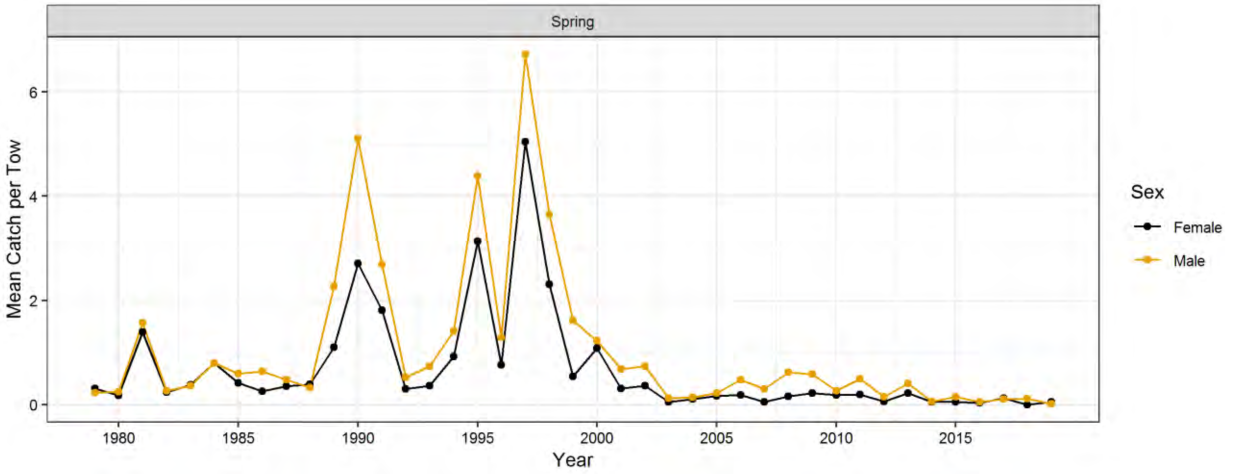


Figure 110. Spring MA Trawl Survey mean catch per tow of 53+ mm CL lobsters from SNE strata.

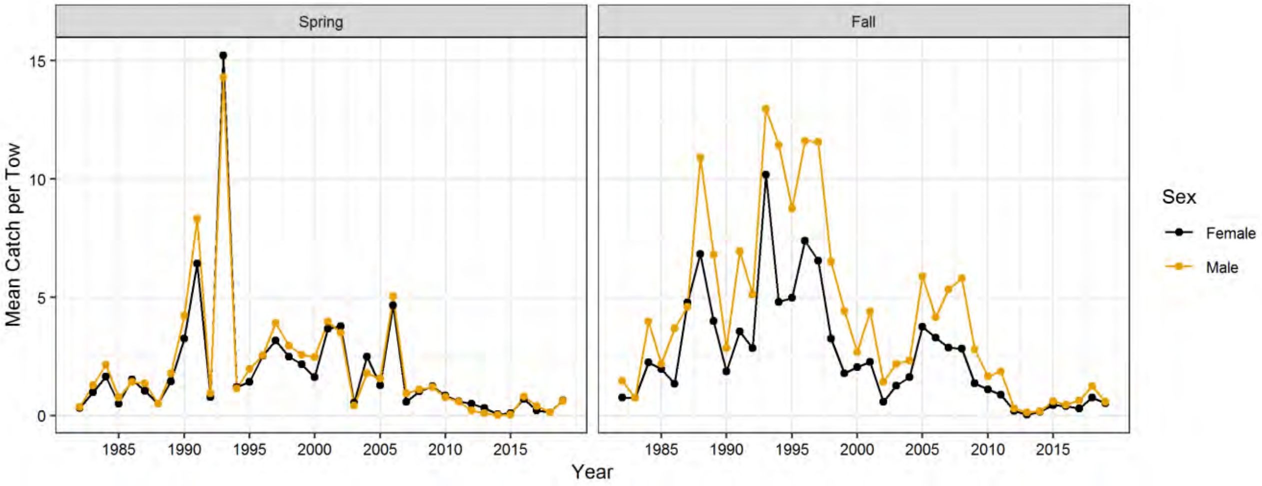


Figure 111. RI Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters.

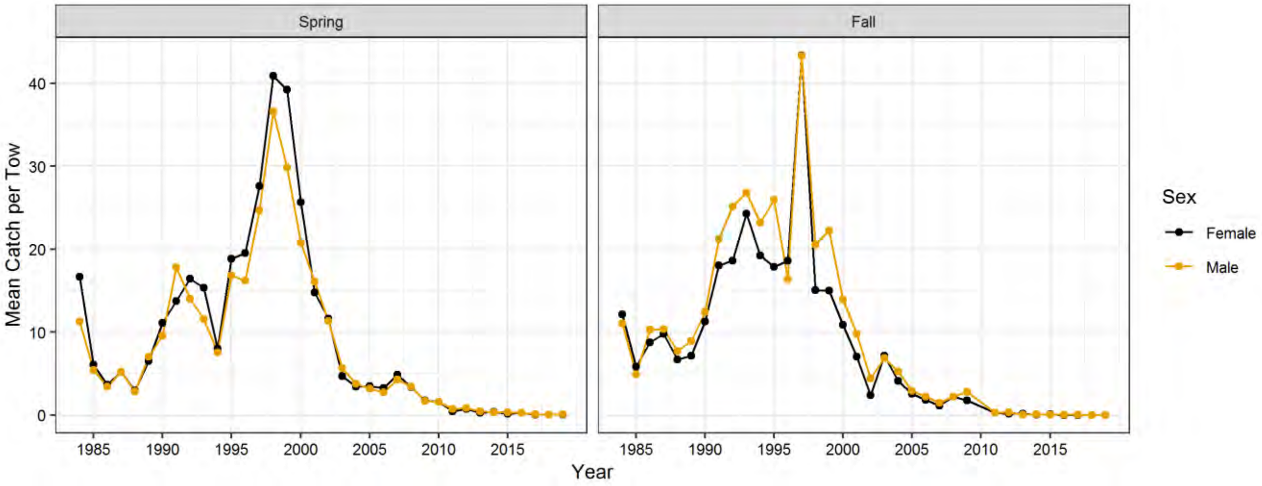


Figure 112. CT Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters.

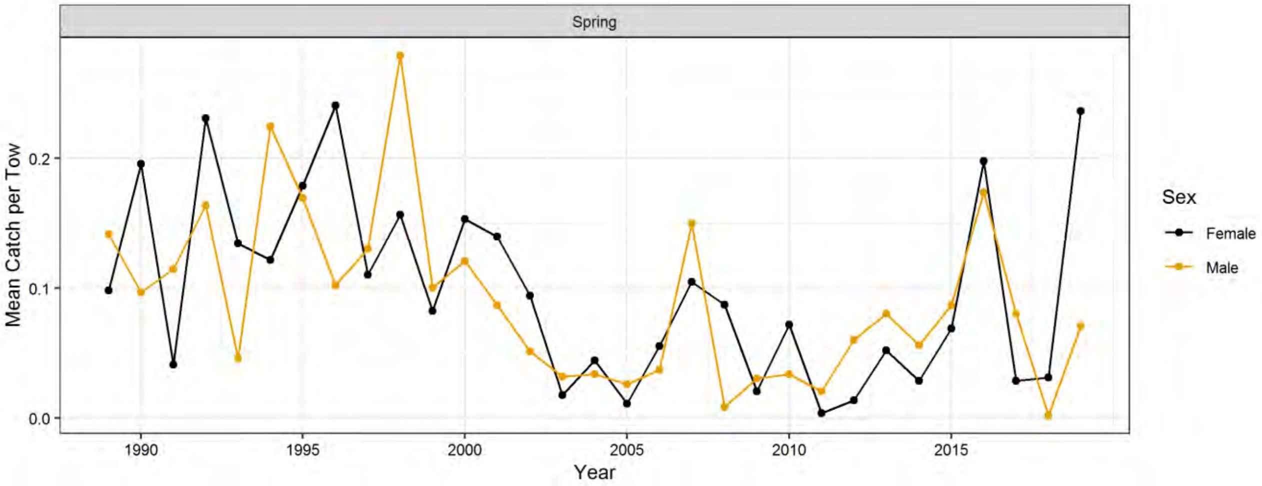


Figure 113. Spring NJ Trawl Survey seasonal mean catch per tow of 53+ mm CL lobsters.

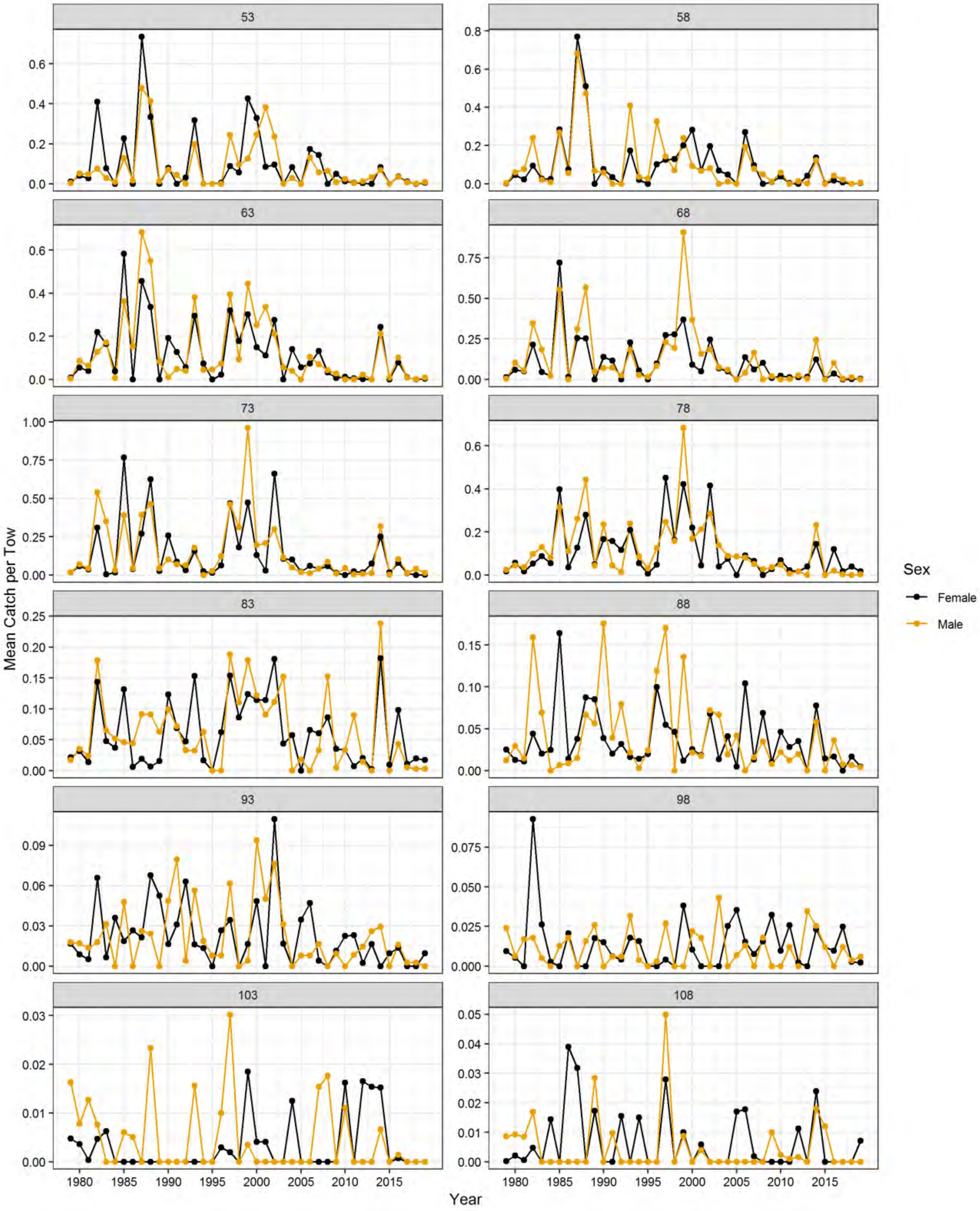


Figure 114. Spring NEFSC Trawl Survey mean catch per tow of lobsters from SNE strata by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 108 mm size bin (108-112 mm CL) as catches of larger sizes are relatively infrequent and variable.

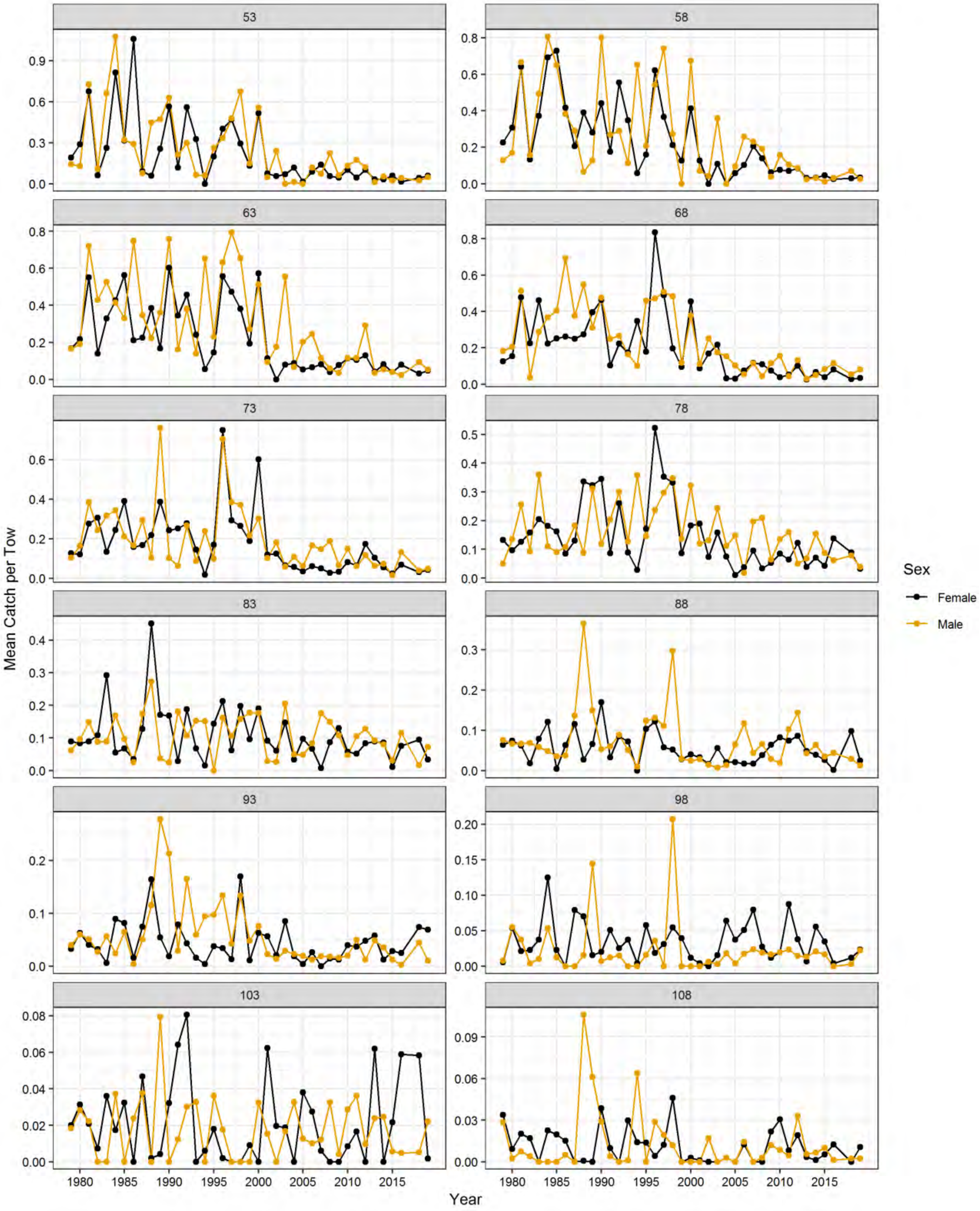


Figure 115. Fall NEFSC Trawl Survey mean catch per tow of lobsters from SNE strata by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 108 mm size bin (108-112 mm CL) as catches of larger sizes are relatively infrequent and variable.

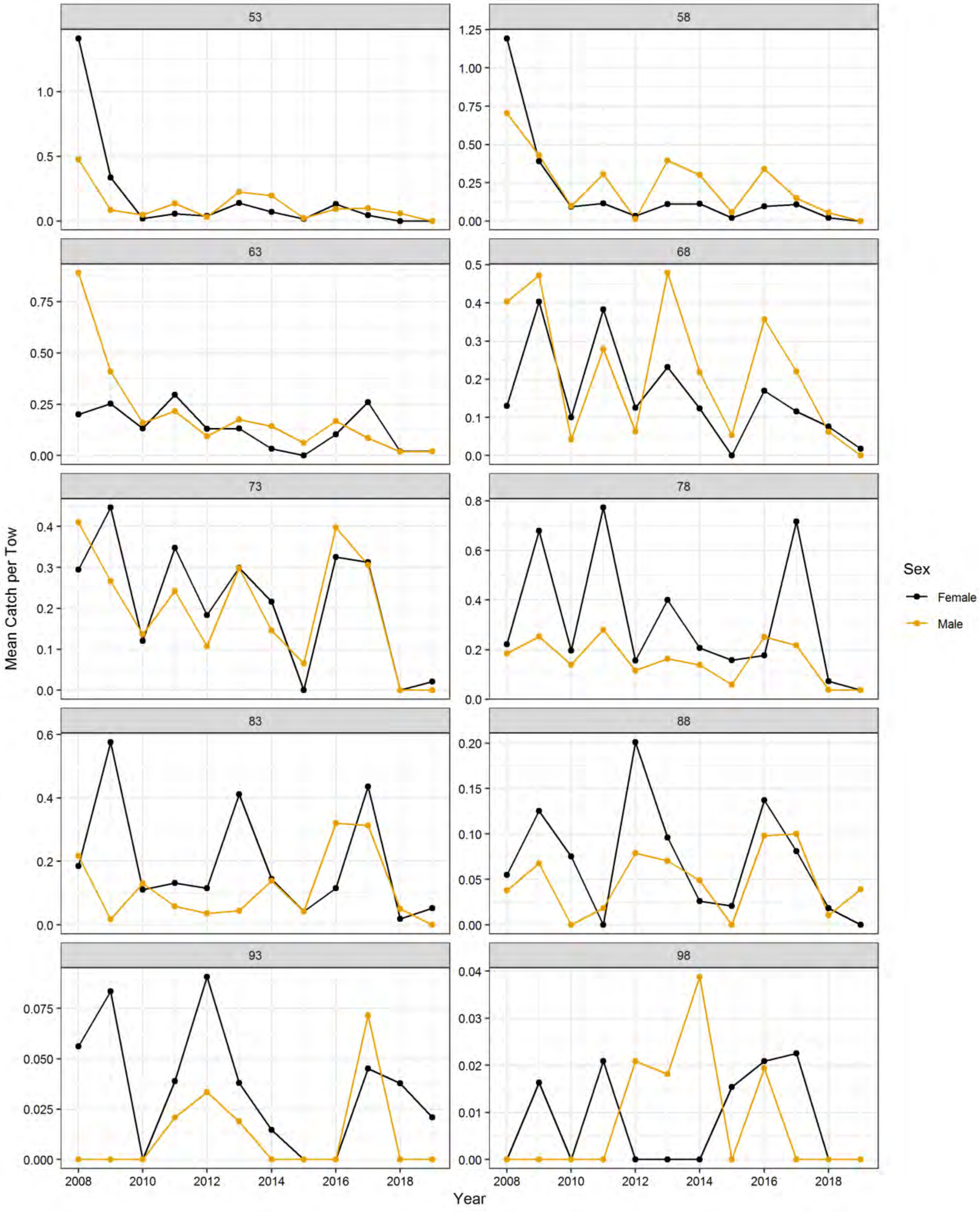


Figure 116. Spring NEAMAP Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

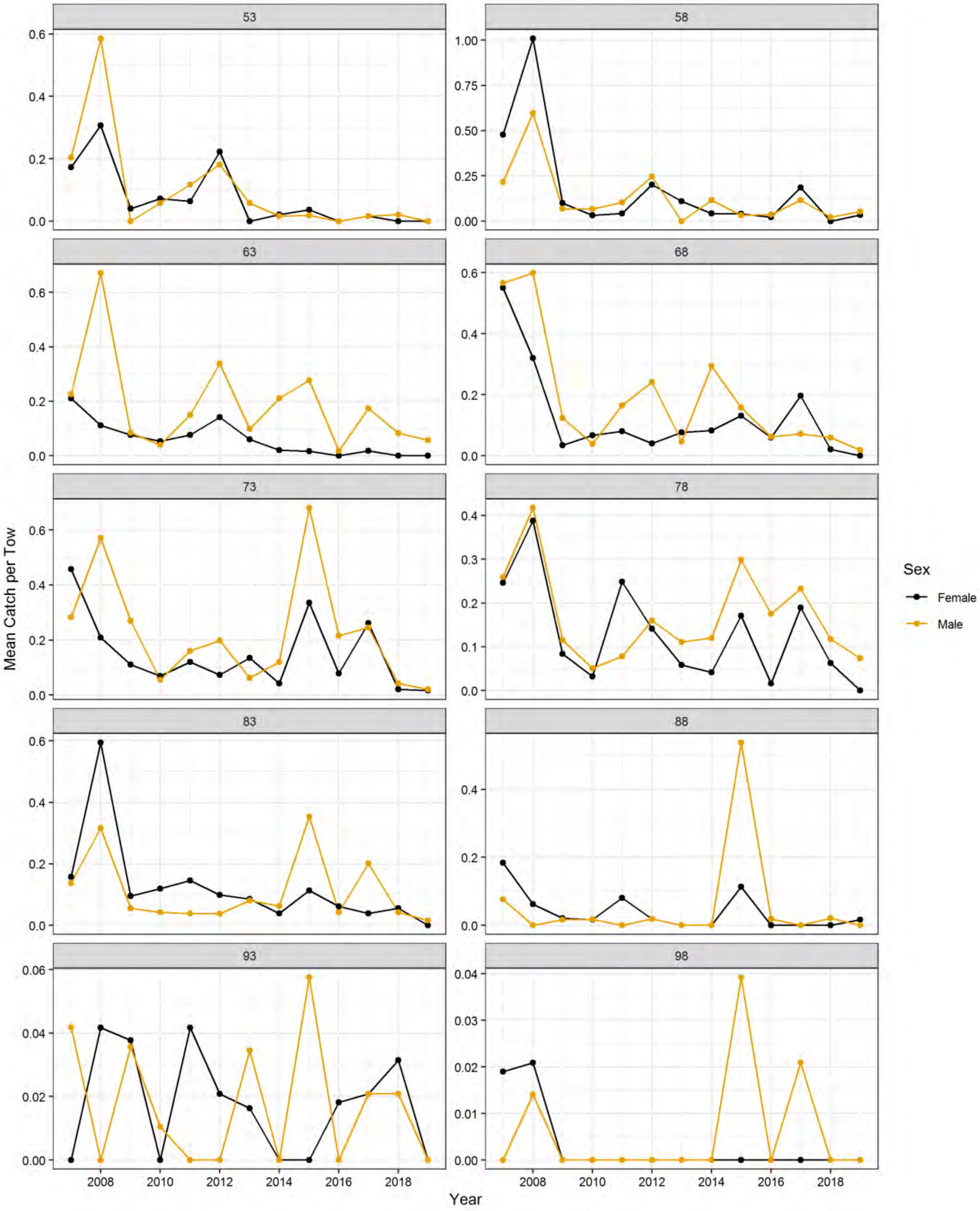


Figure 117. Fall NEAMAP Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

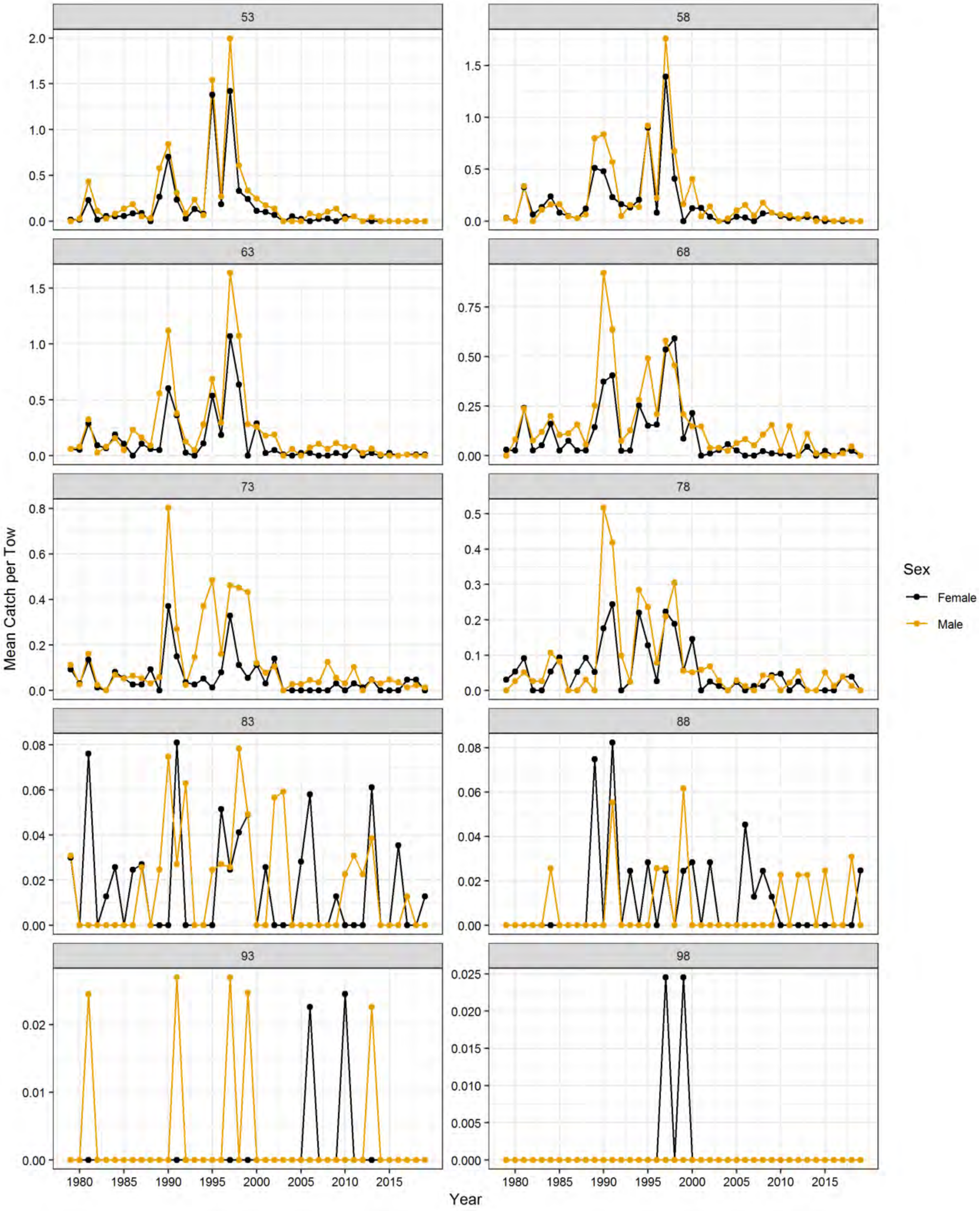


Figure 118. Spring MA Trawl Survey mean catch per tow of lobsters from SNE strata by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

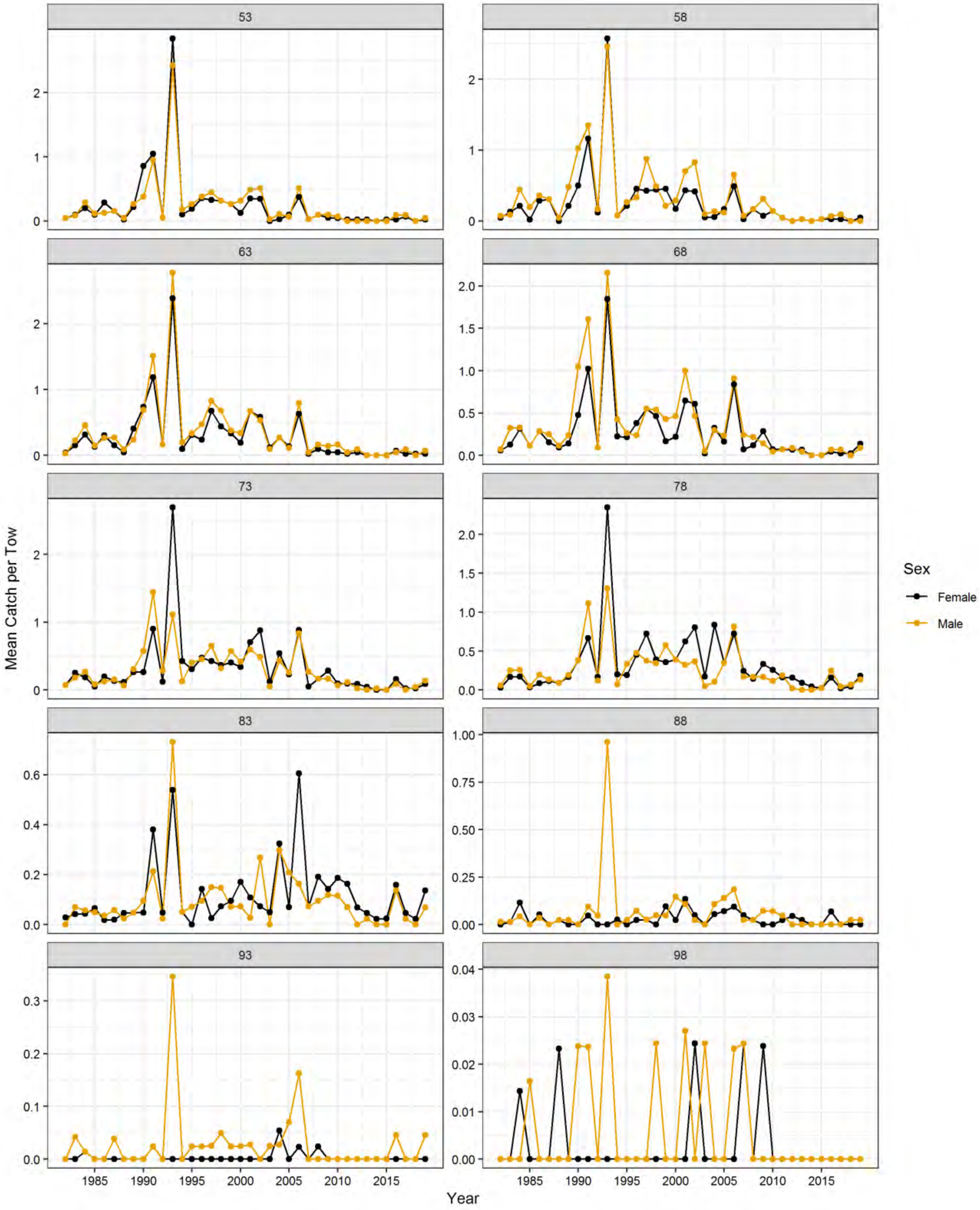


Figure 119. Spring RI Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

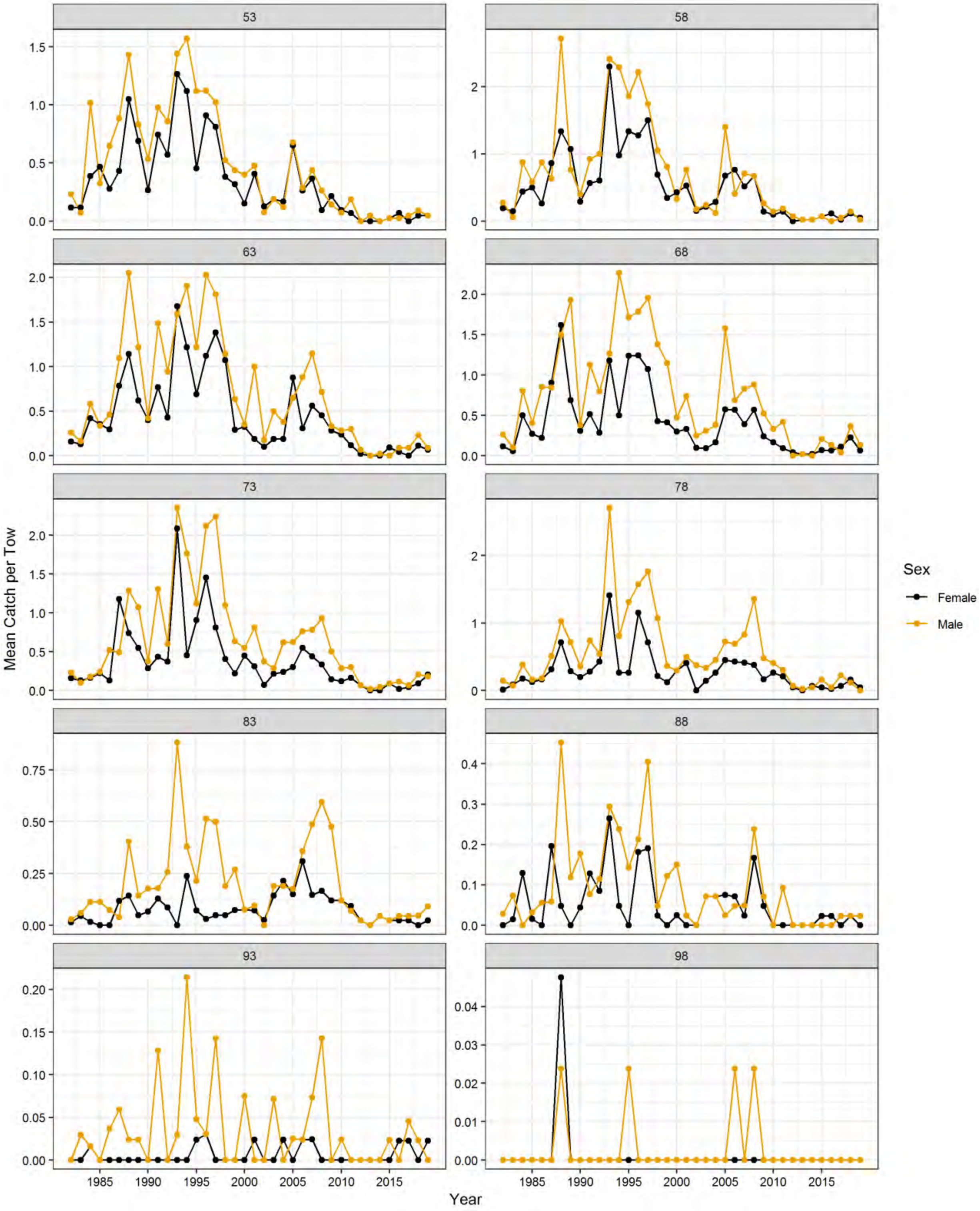


Figure 120. Fall RI Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

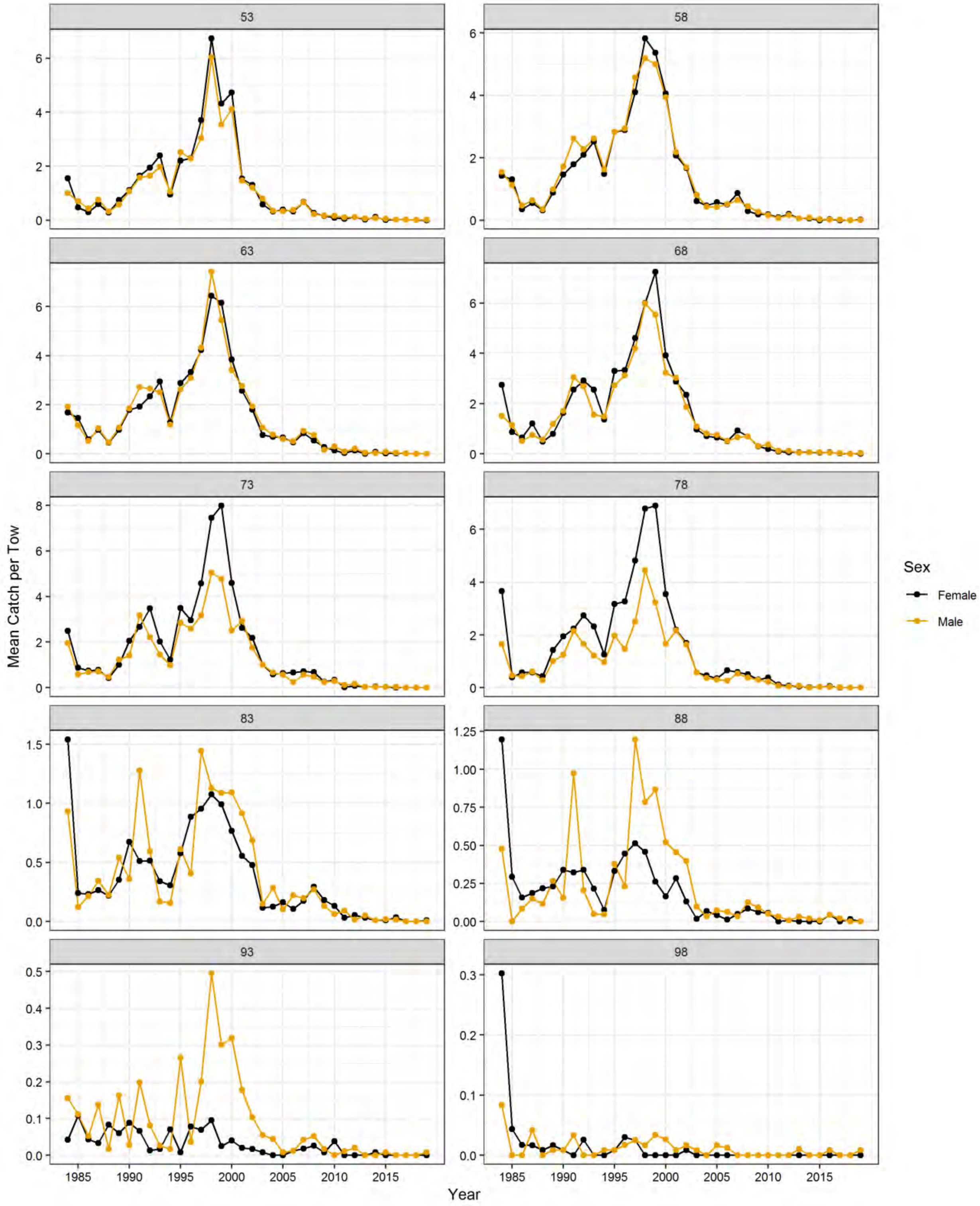


Figure 121. Spring CT Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

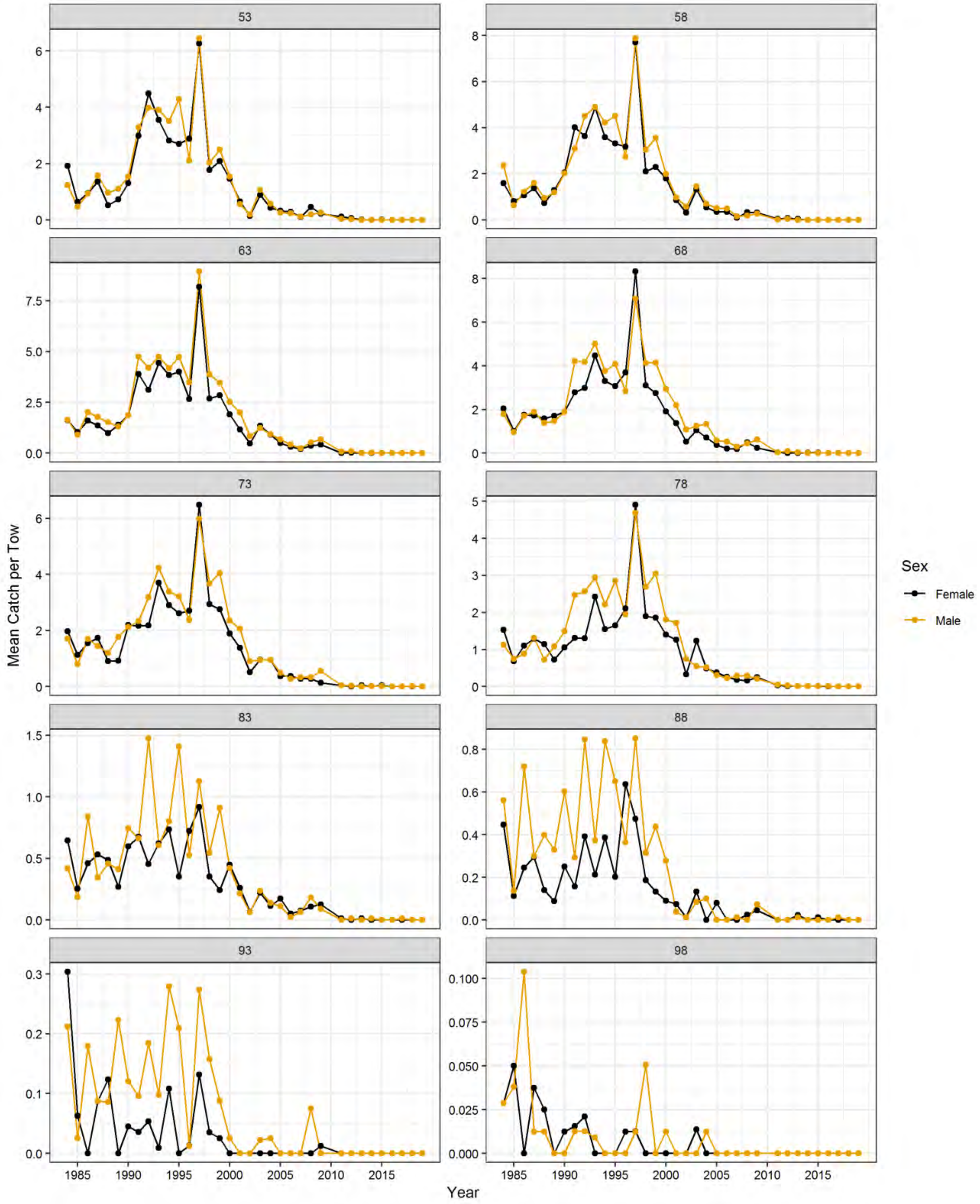


Figure 122. Fall CT Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

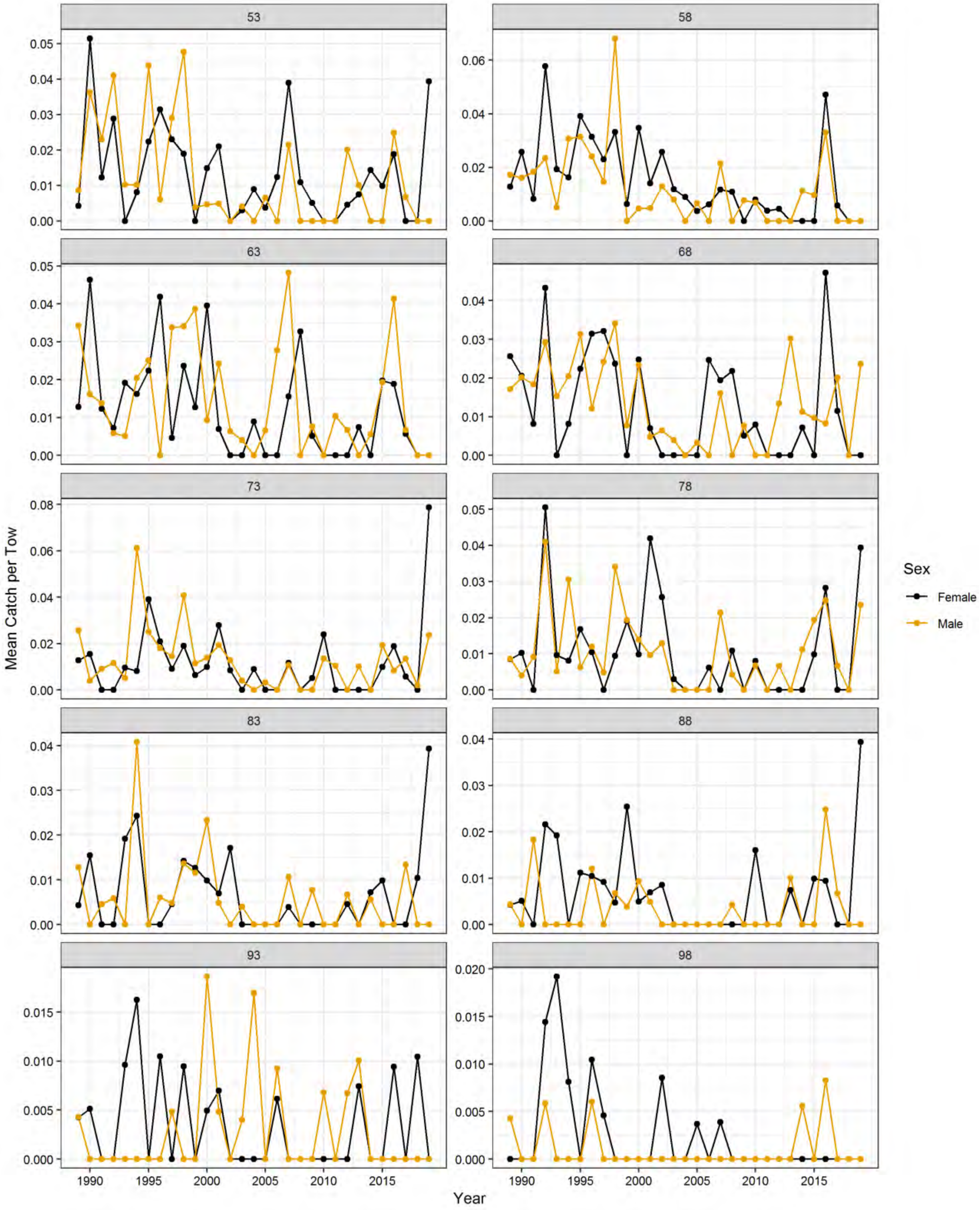


Figure 123. Spring NJ Trawl Survey mean catch per tow of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

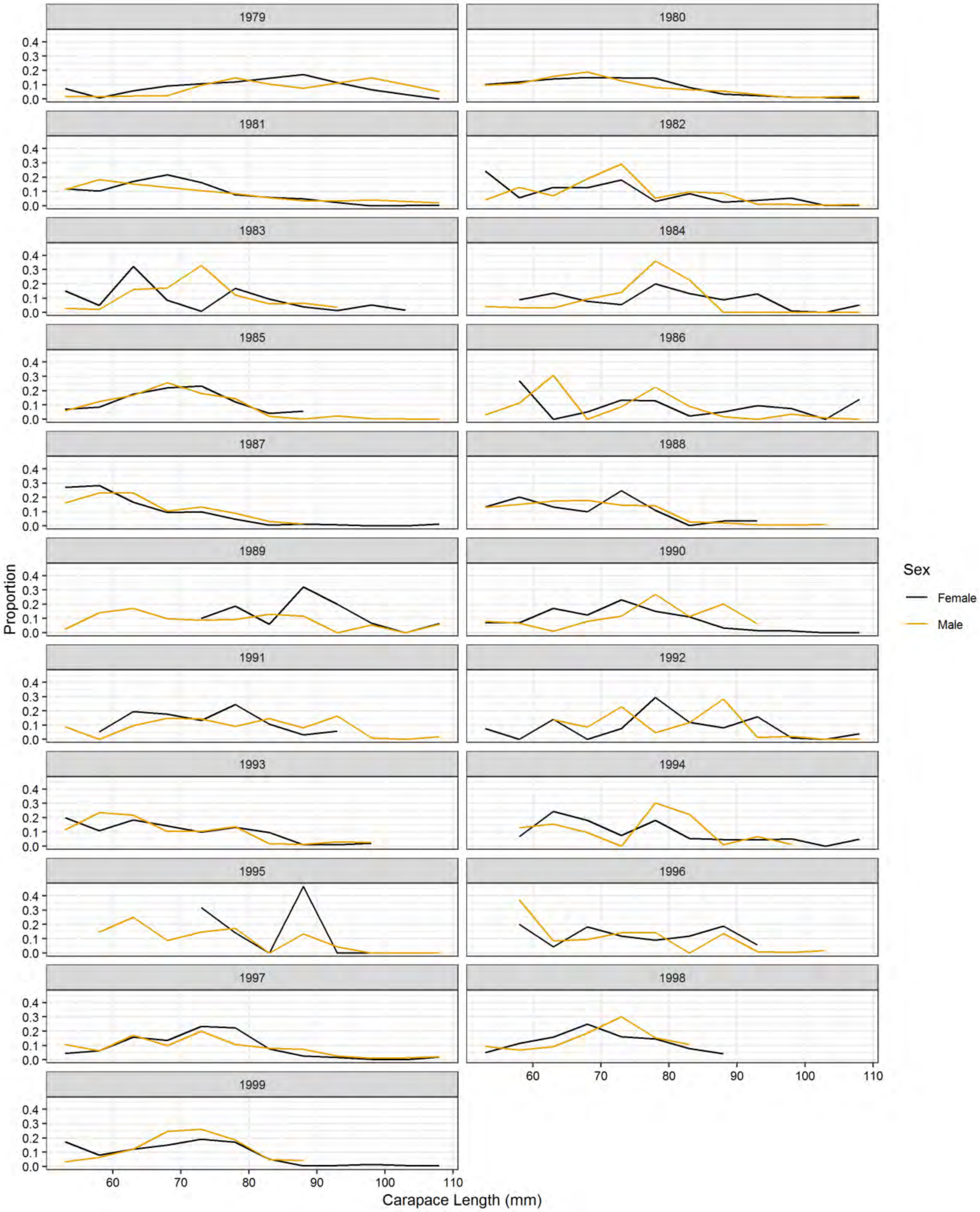
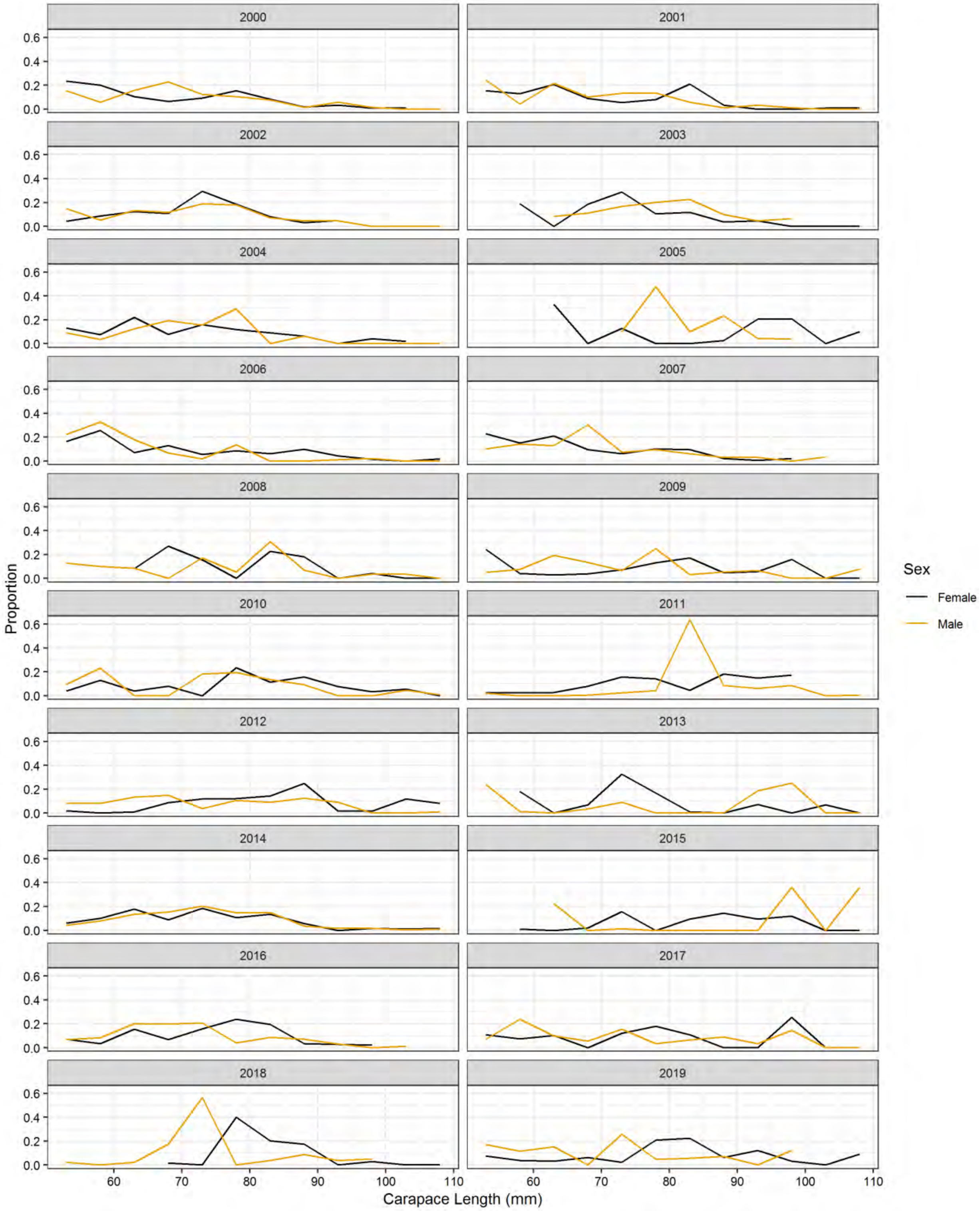


Figure 124. Spring NEFSC Trawl Survey 53+ mm CL lobster catch size compositions from SNE strata. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.



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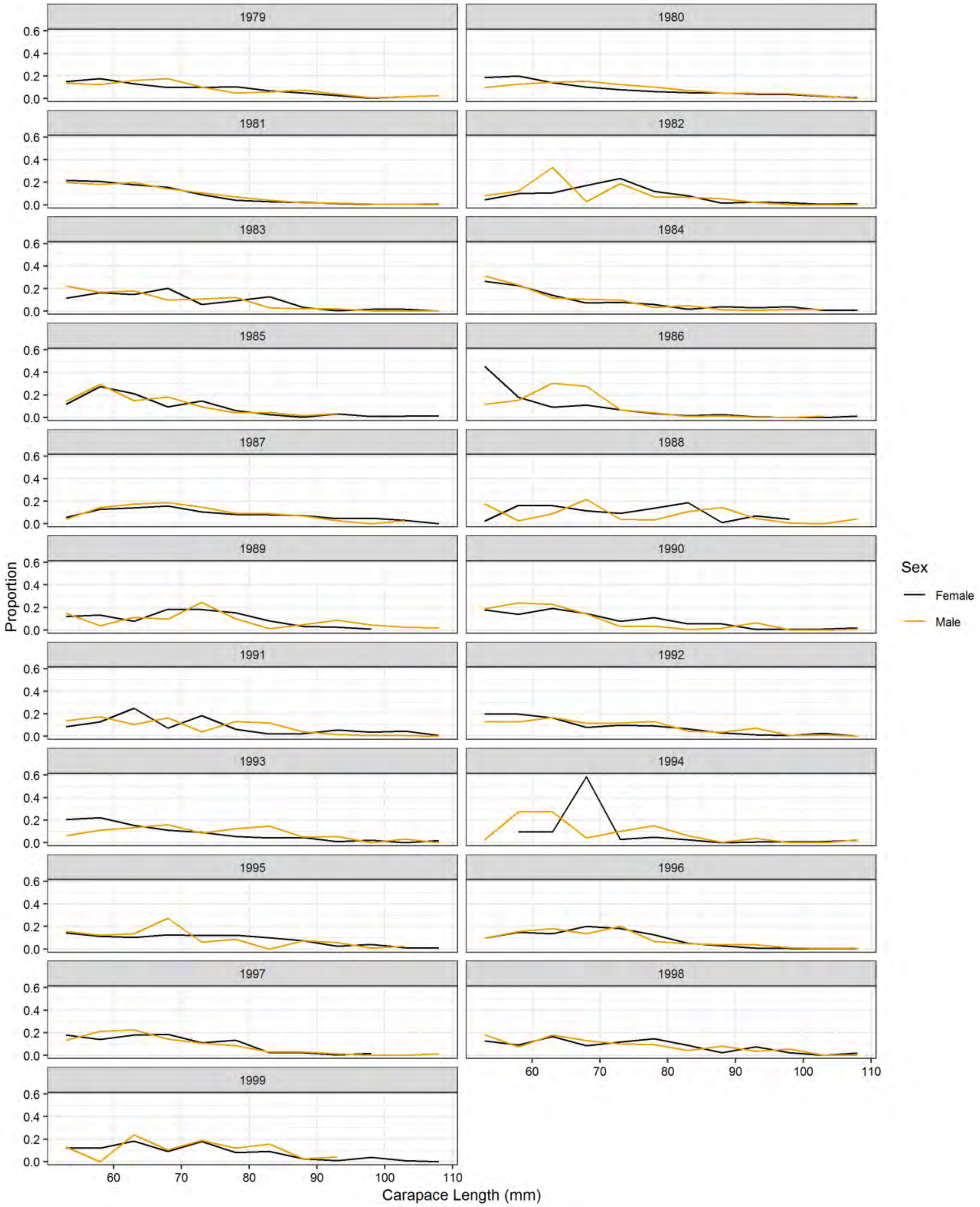
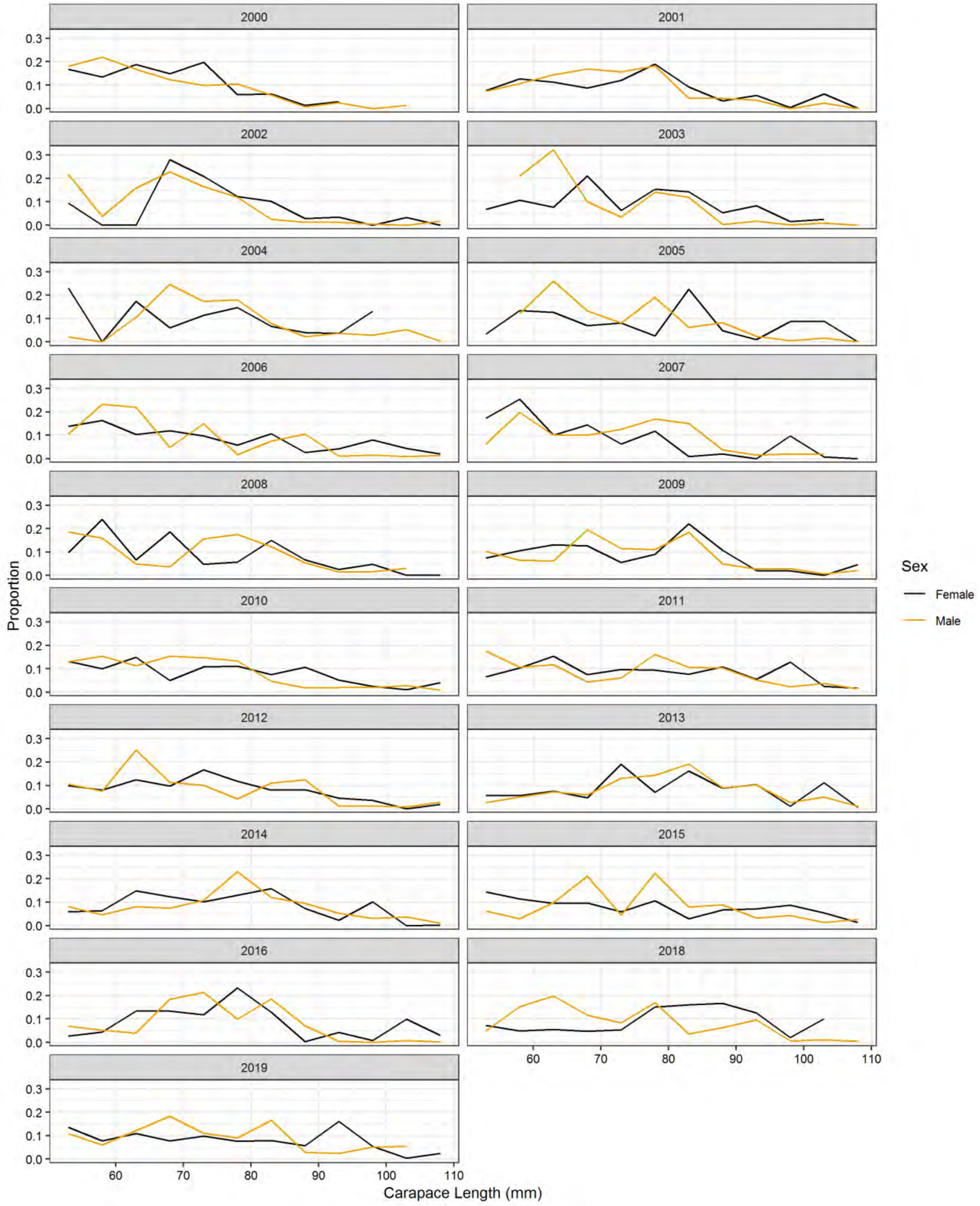


Figure 125. Fall NEFSC Trawl Survey 53+ mm CL lobster catch size compositions from SNE strata. Size bins are truncated at the 118 mm size bin (118-122 mm CL) as catches of larger sizes are relatively infrequent and variable.



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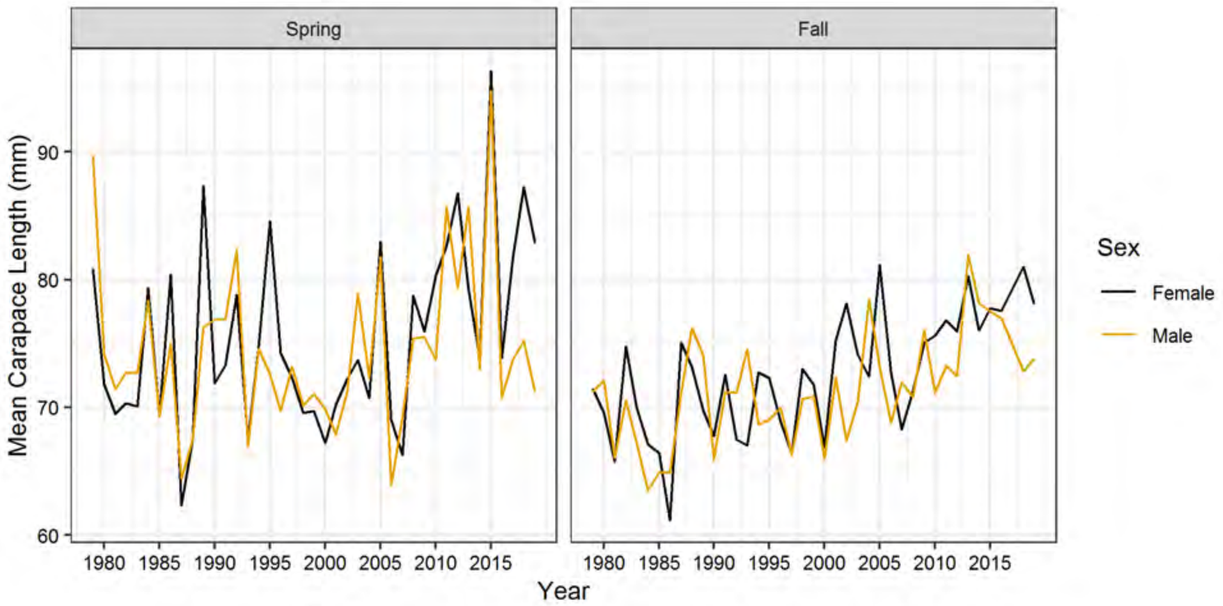

Figure 126. Seasonal mean CL of NEFSC Trawl Survey 53+ mm CL lobster catch from SNE strata.

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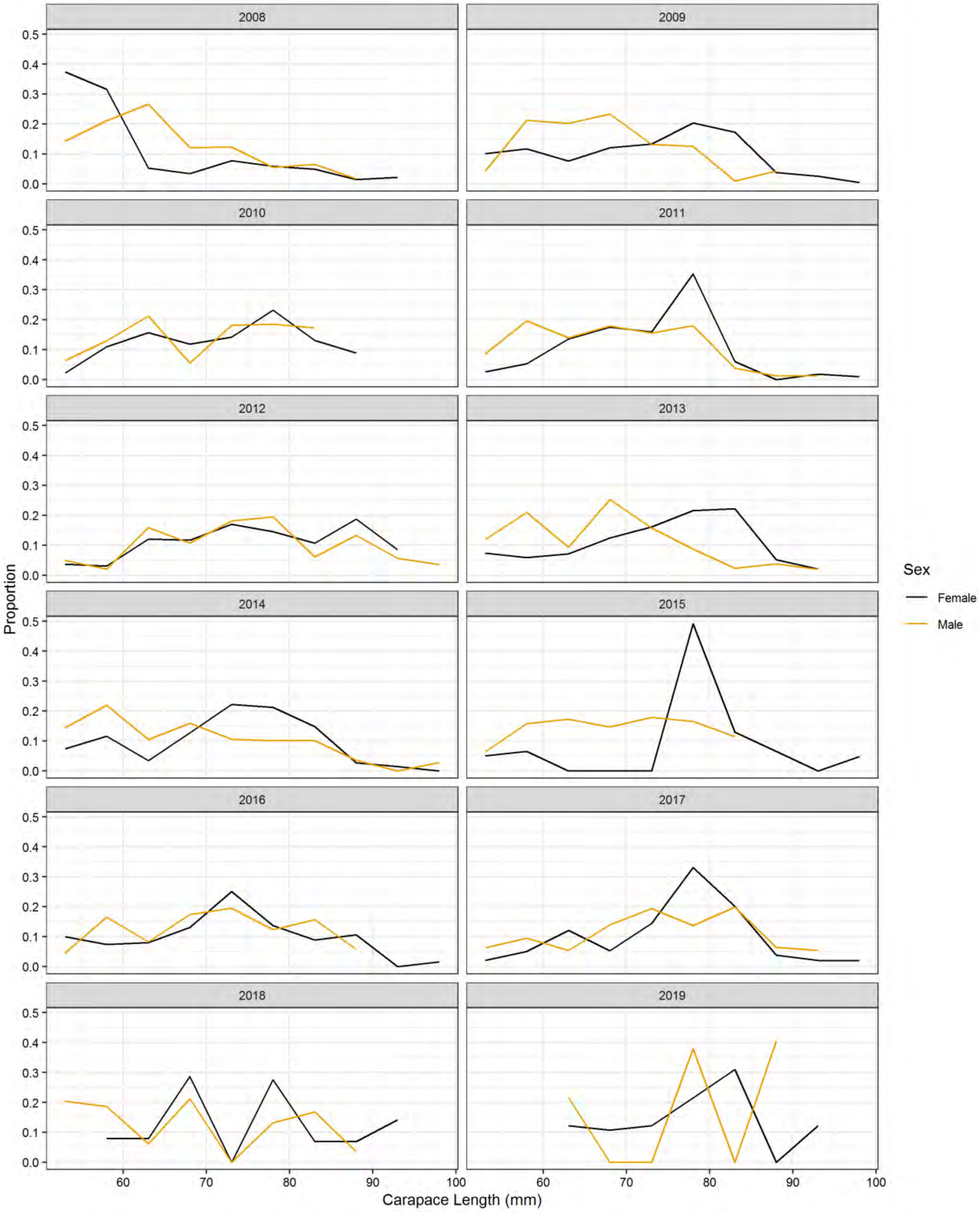

Figure 127. Spring NEAMAP Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

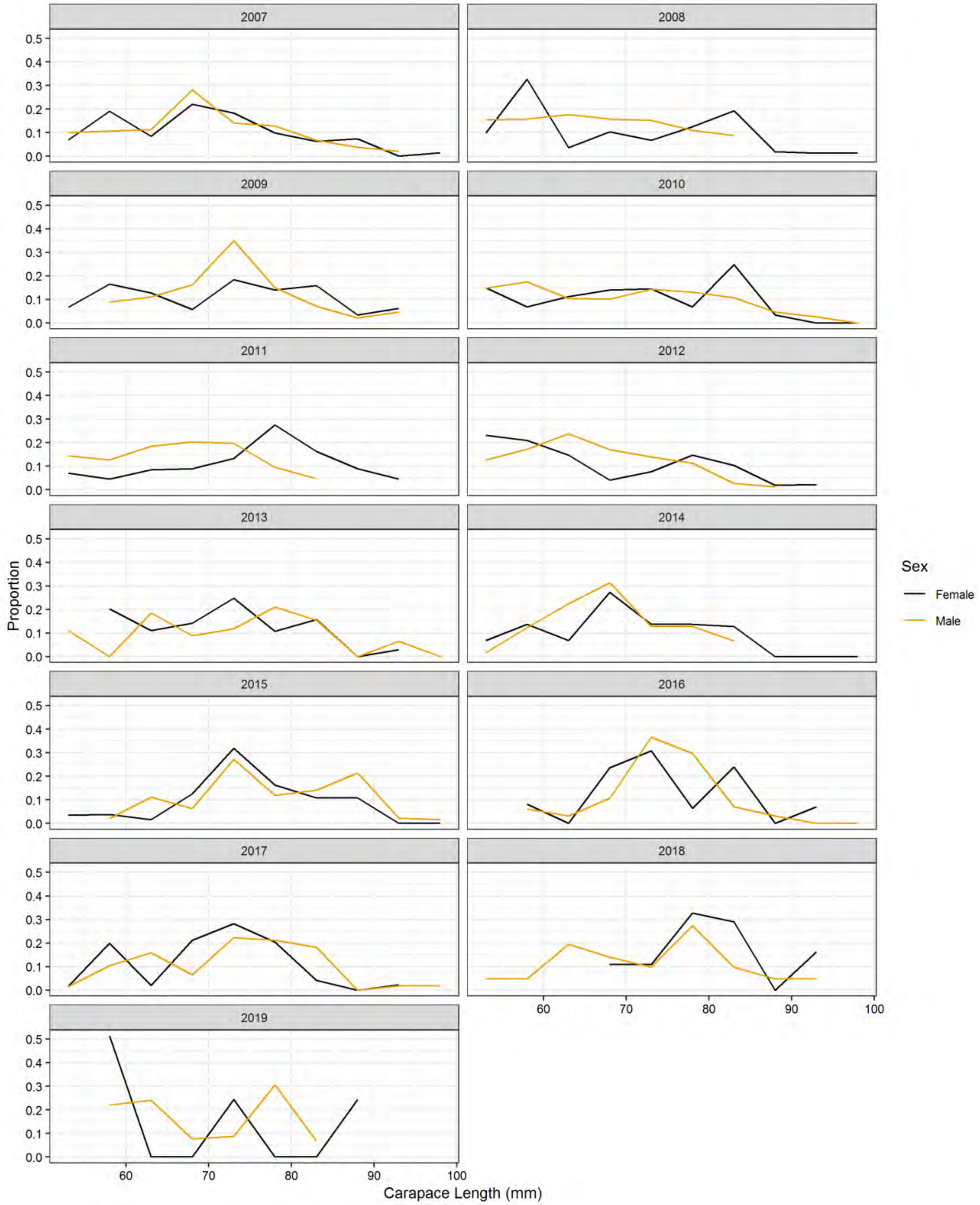

Figure 128. Fall NEAMAP Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

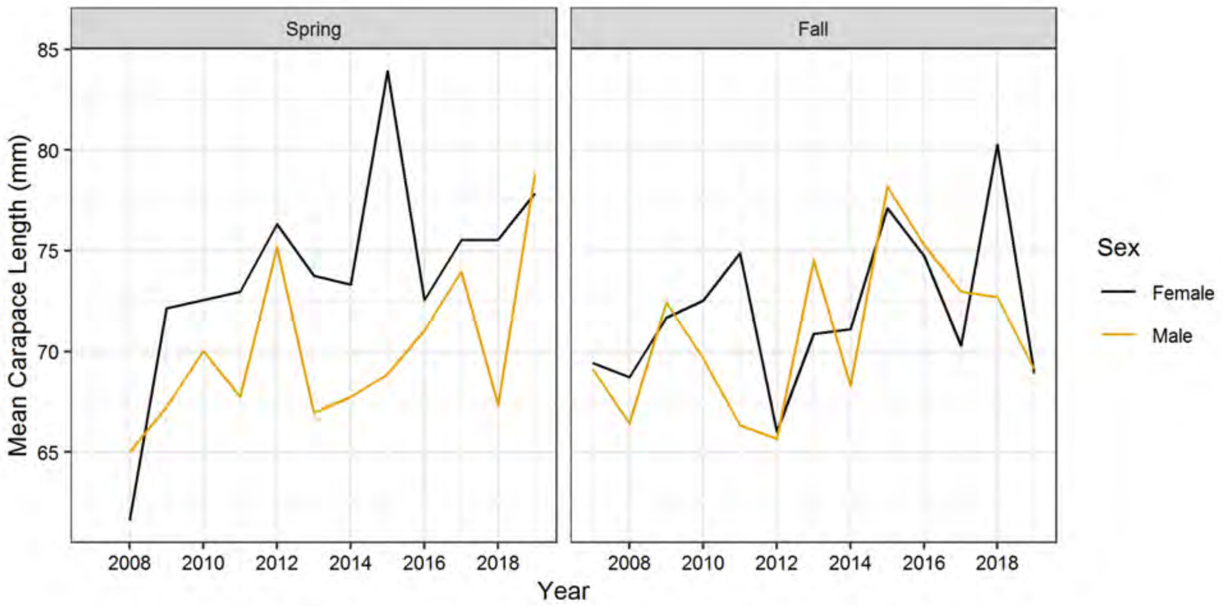

Figure 129. Seasonal mean CL of NEAMAP Trawl Survey 53+ mm CL lobster catch.

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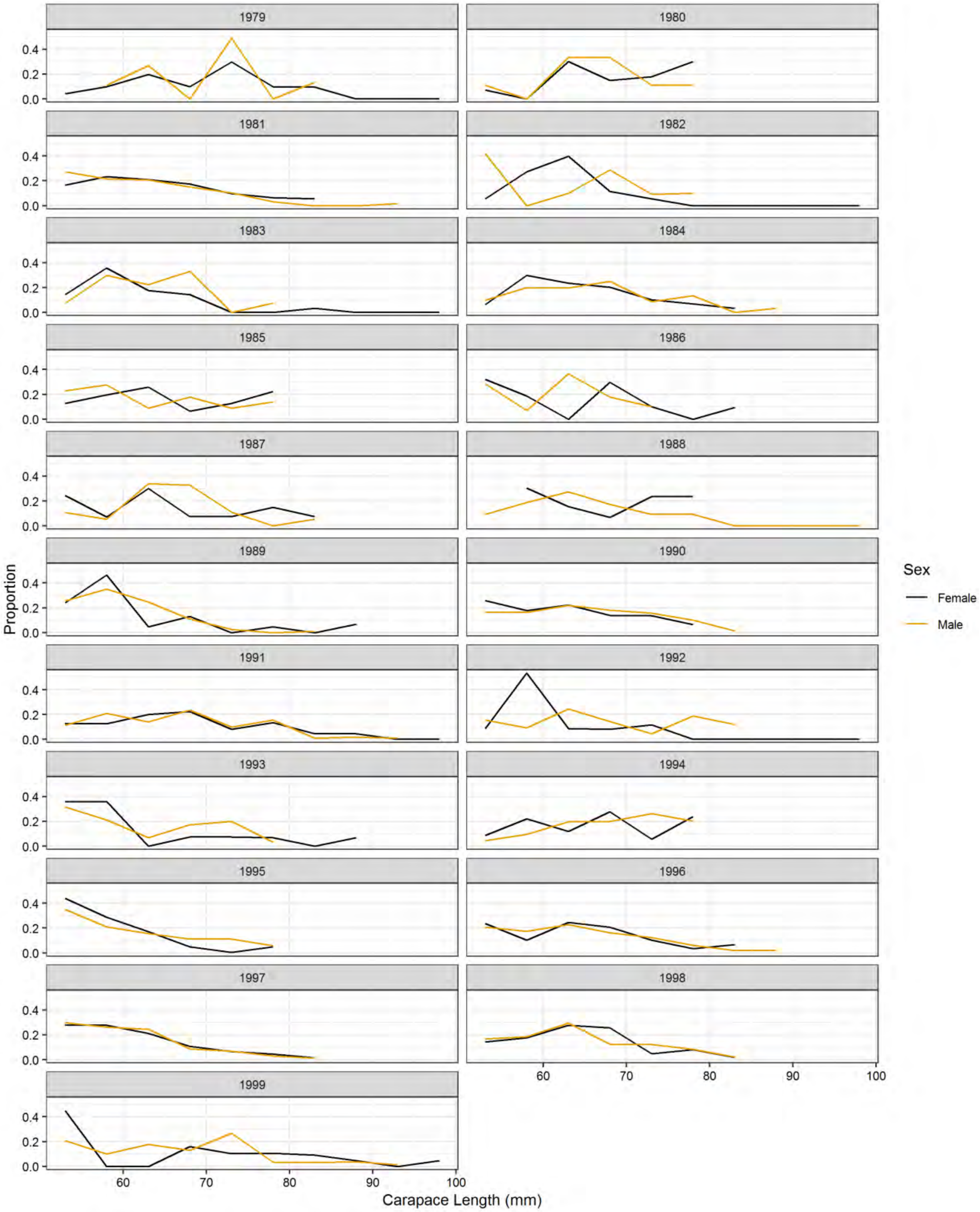
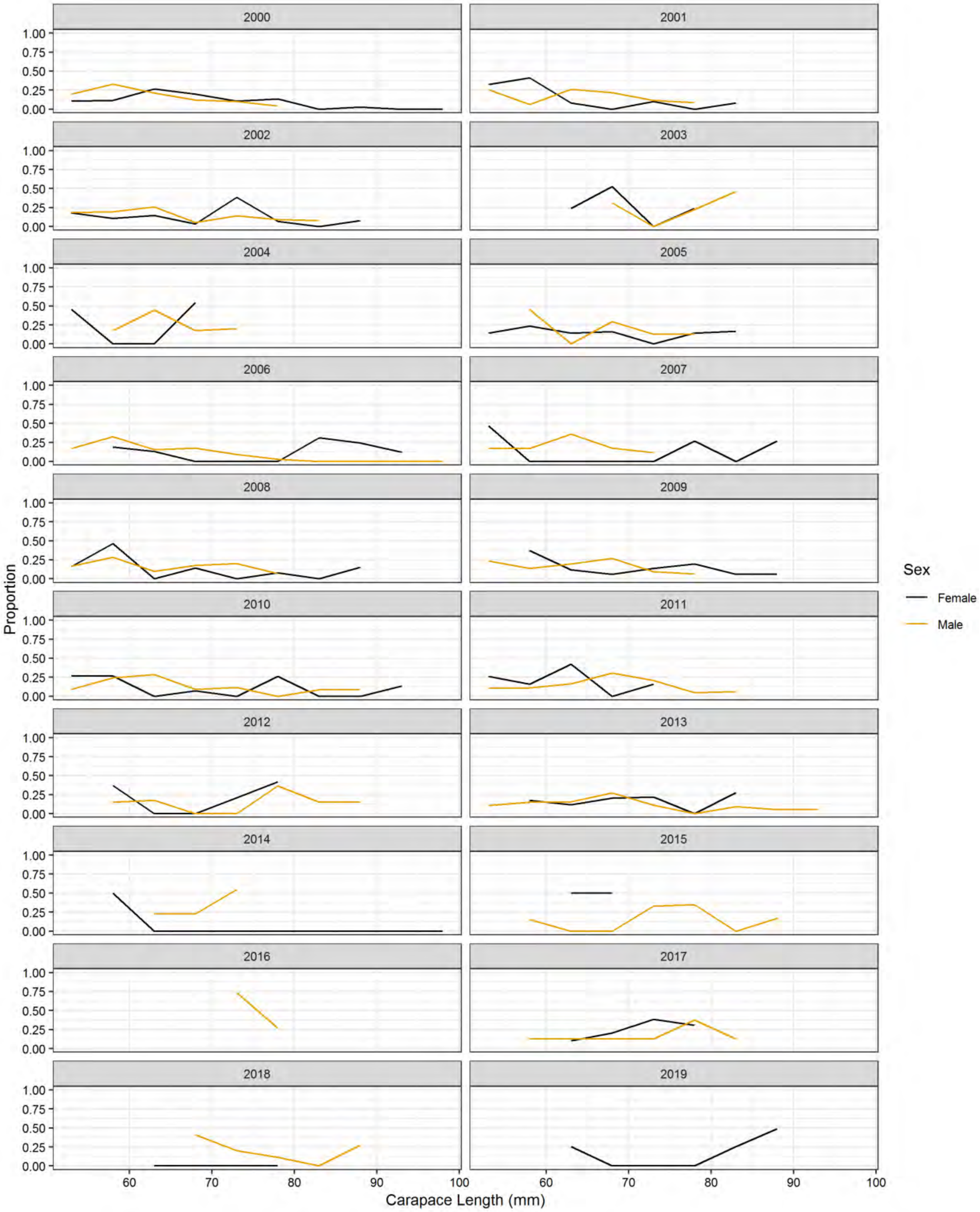


Figure 130. Spring MA Trawl Survey 53+ mm CL lobster catch size compositions from SNE strata. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.



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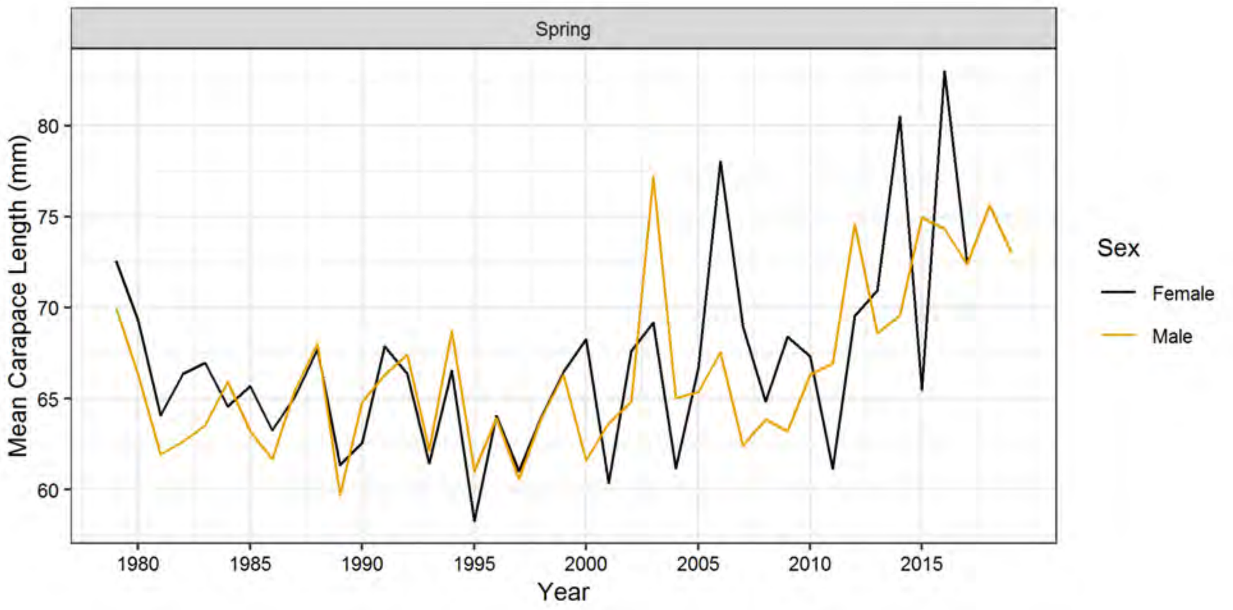

Figure 131. Mean CL of Spring MA Trawl Survey 53+ mm CL lobster catch from SNE strata.

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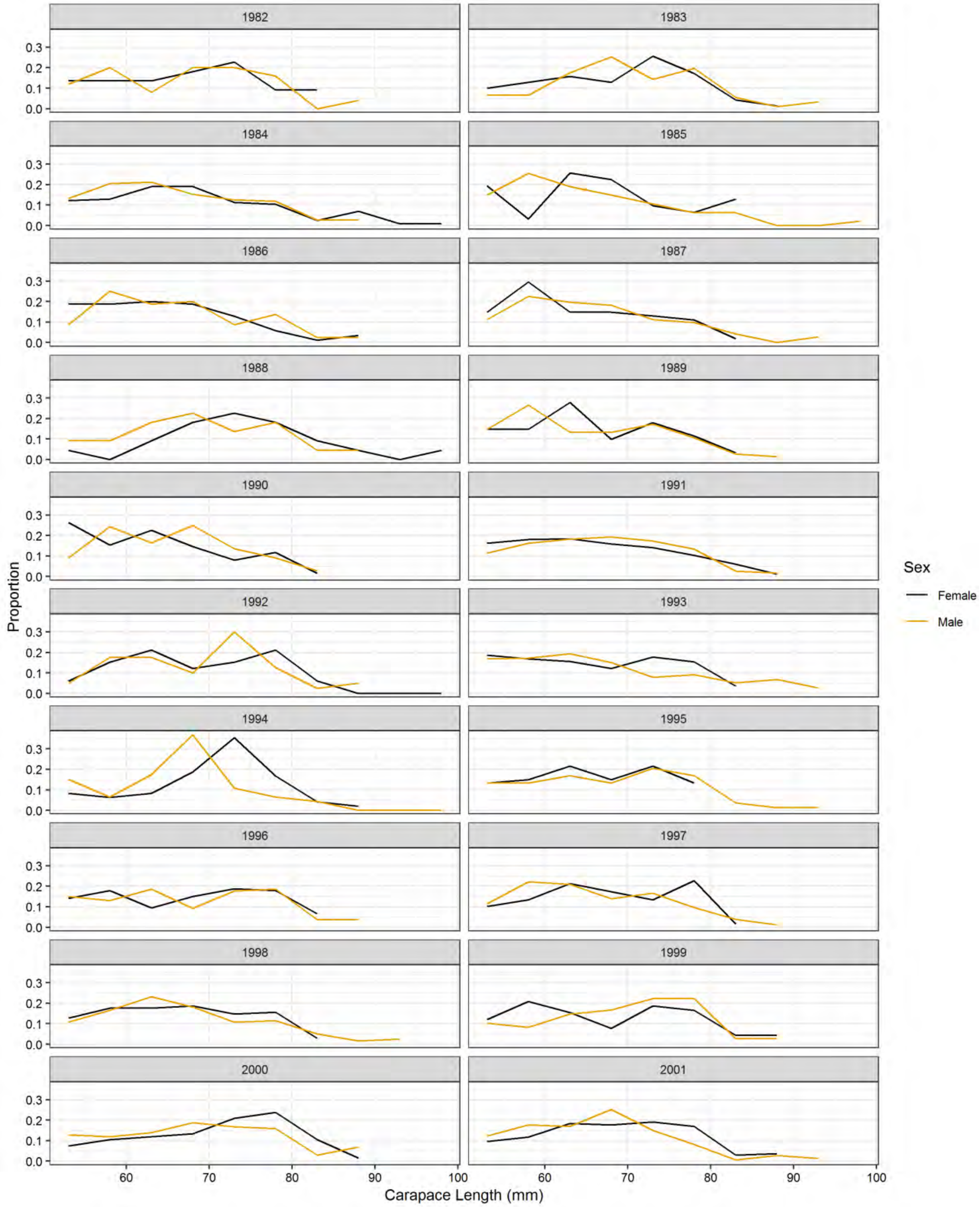
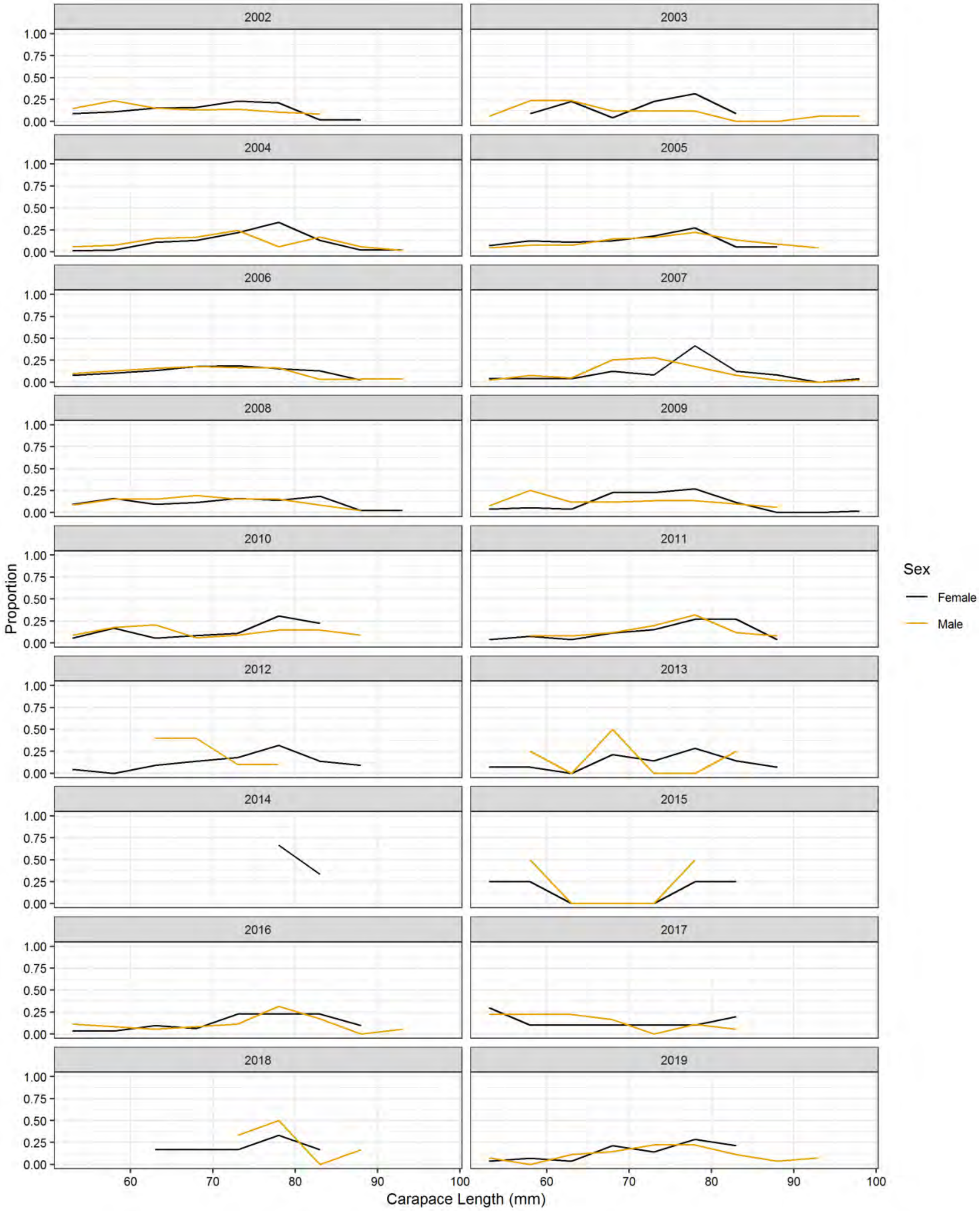


Figure 132. Spring RI Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.



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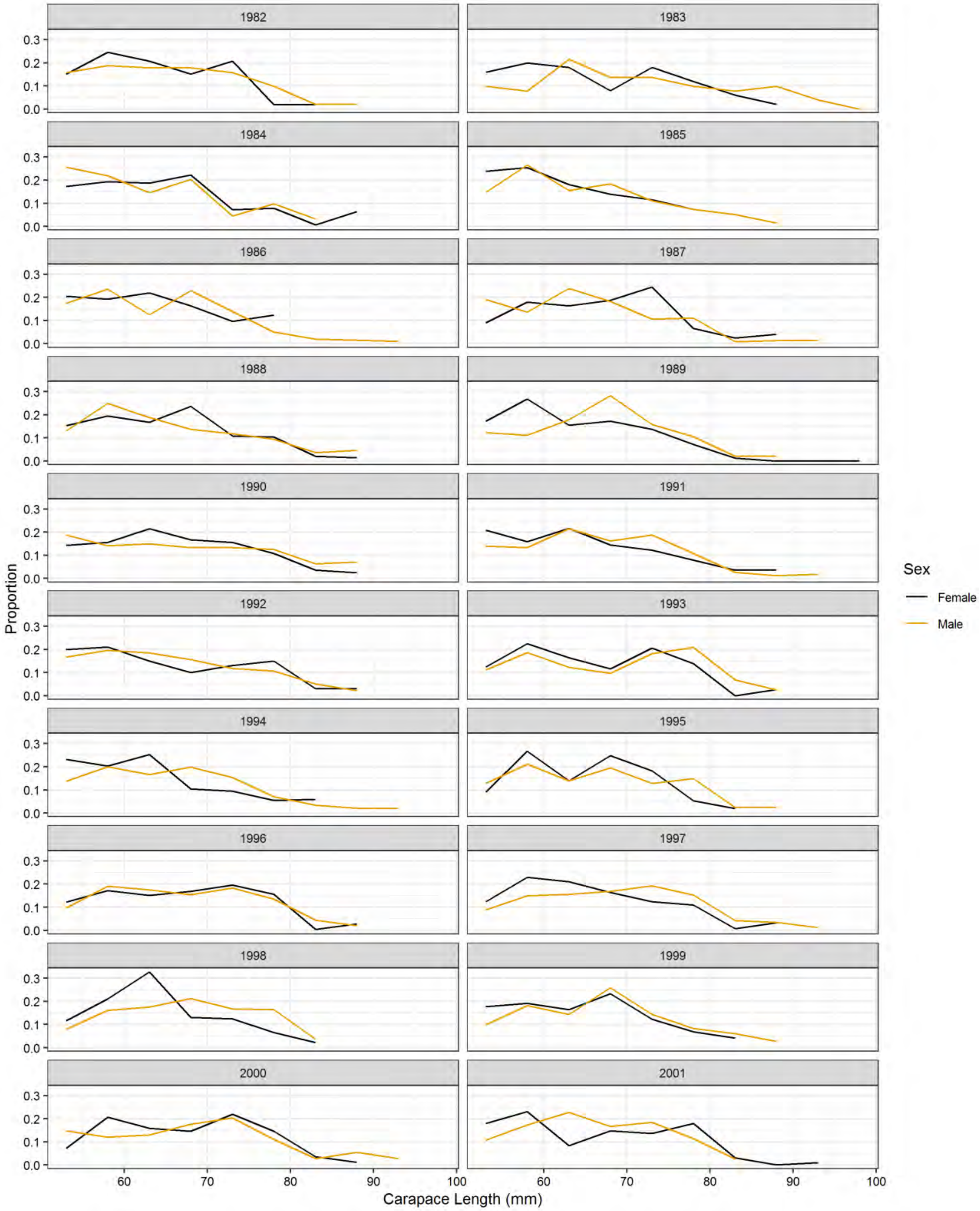
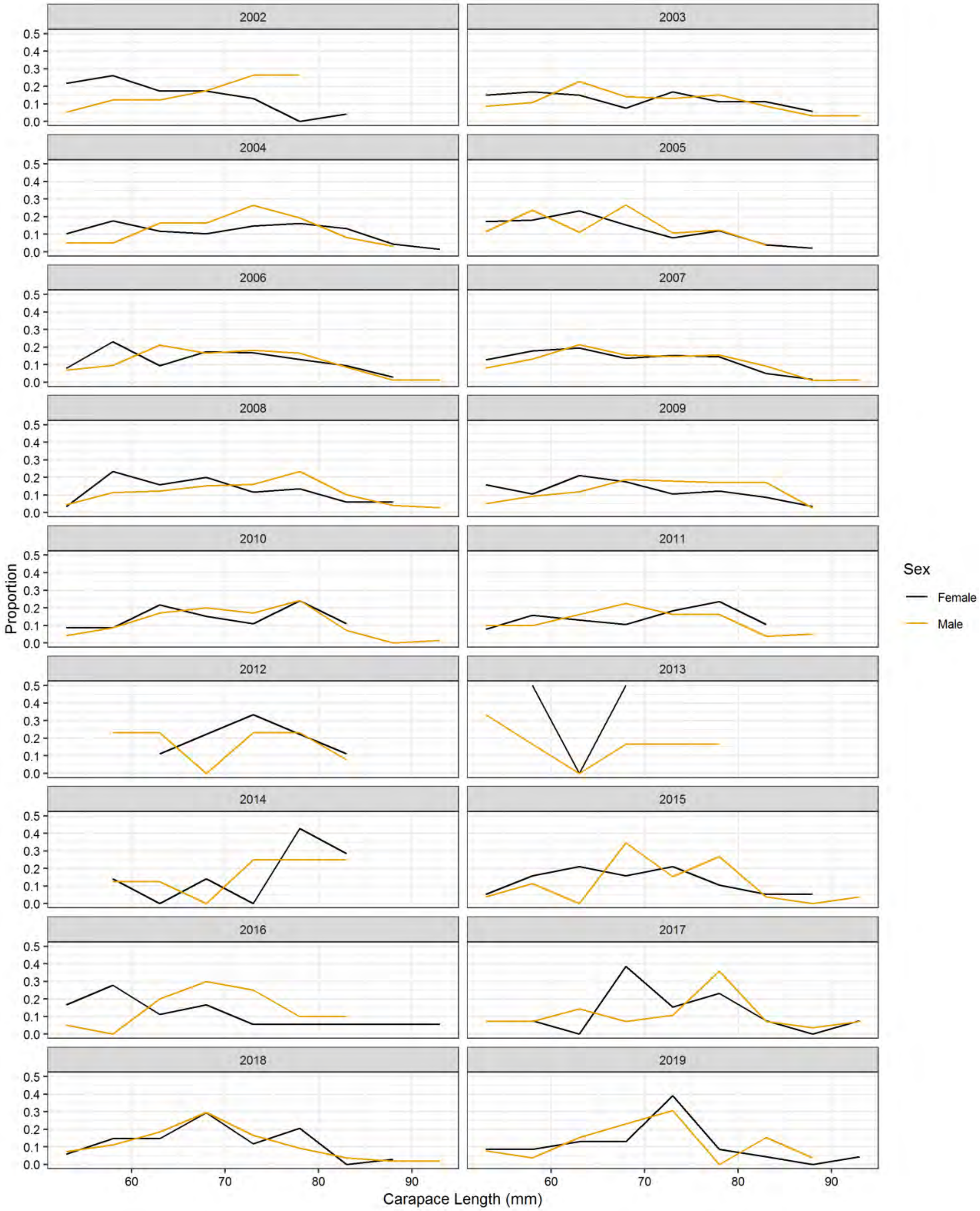


Figure 133. Fall RI Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.



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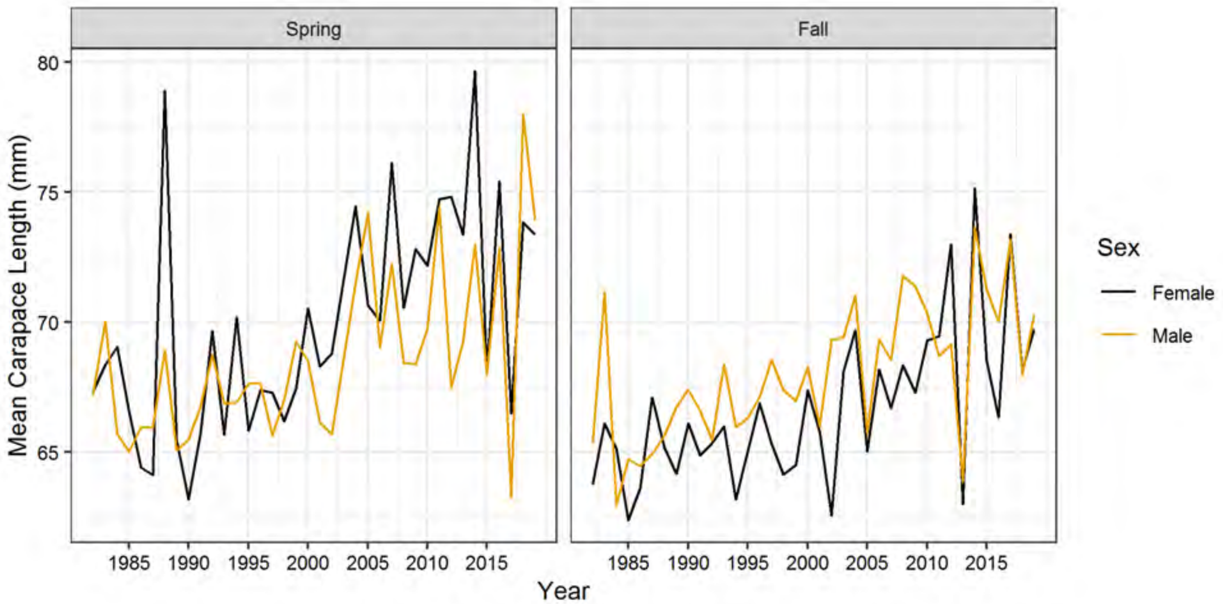

Figure 134. Seasonal mean CL of RI Trawl Survey 53+ mm CL lobster catch.

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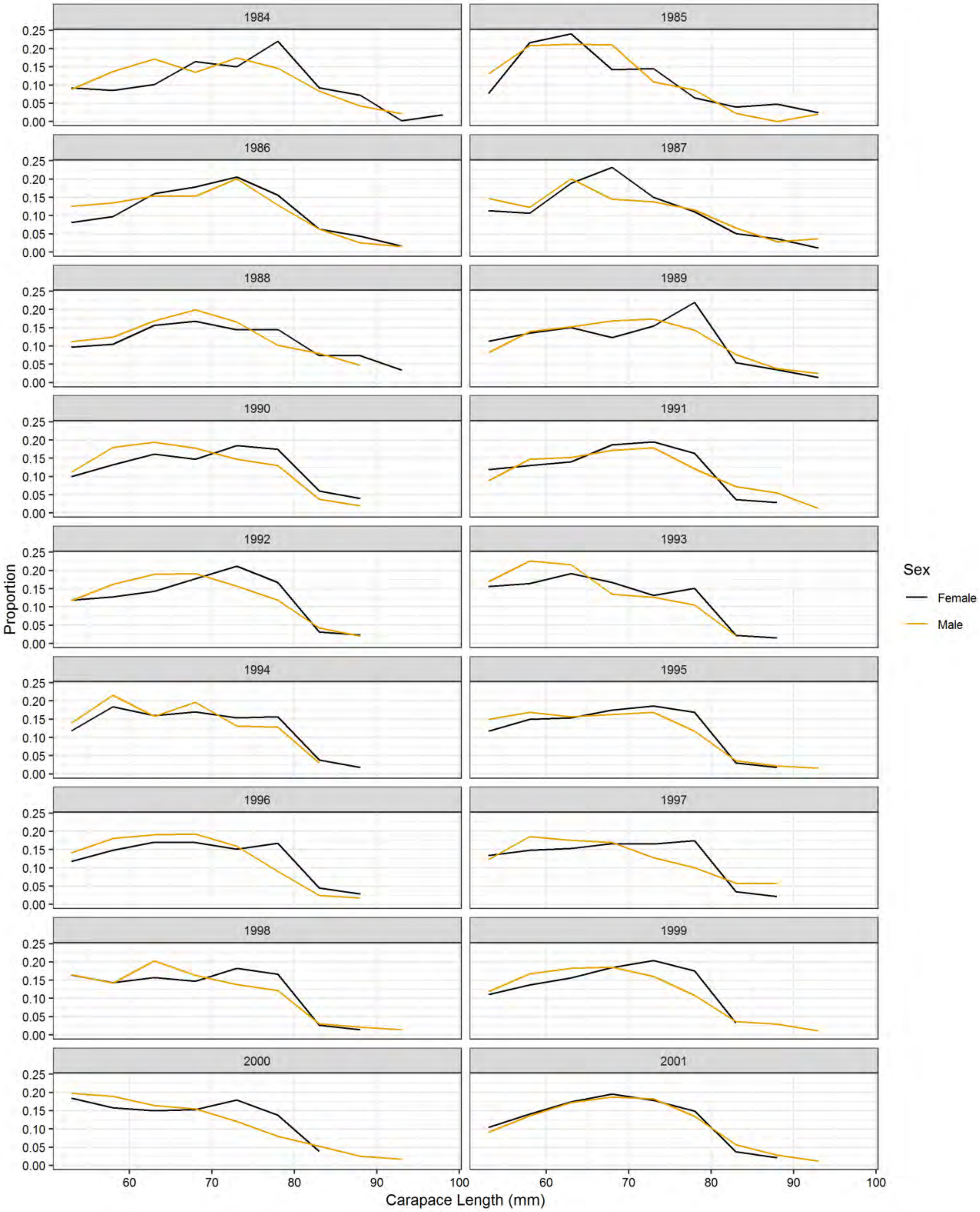
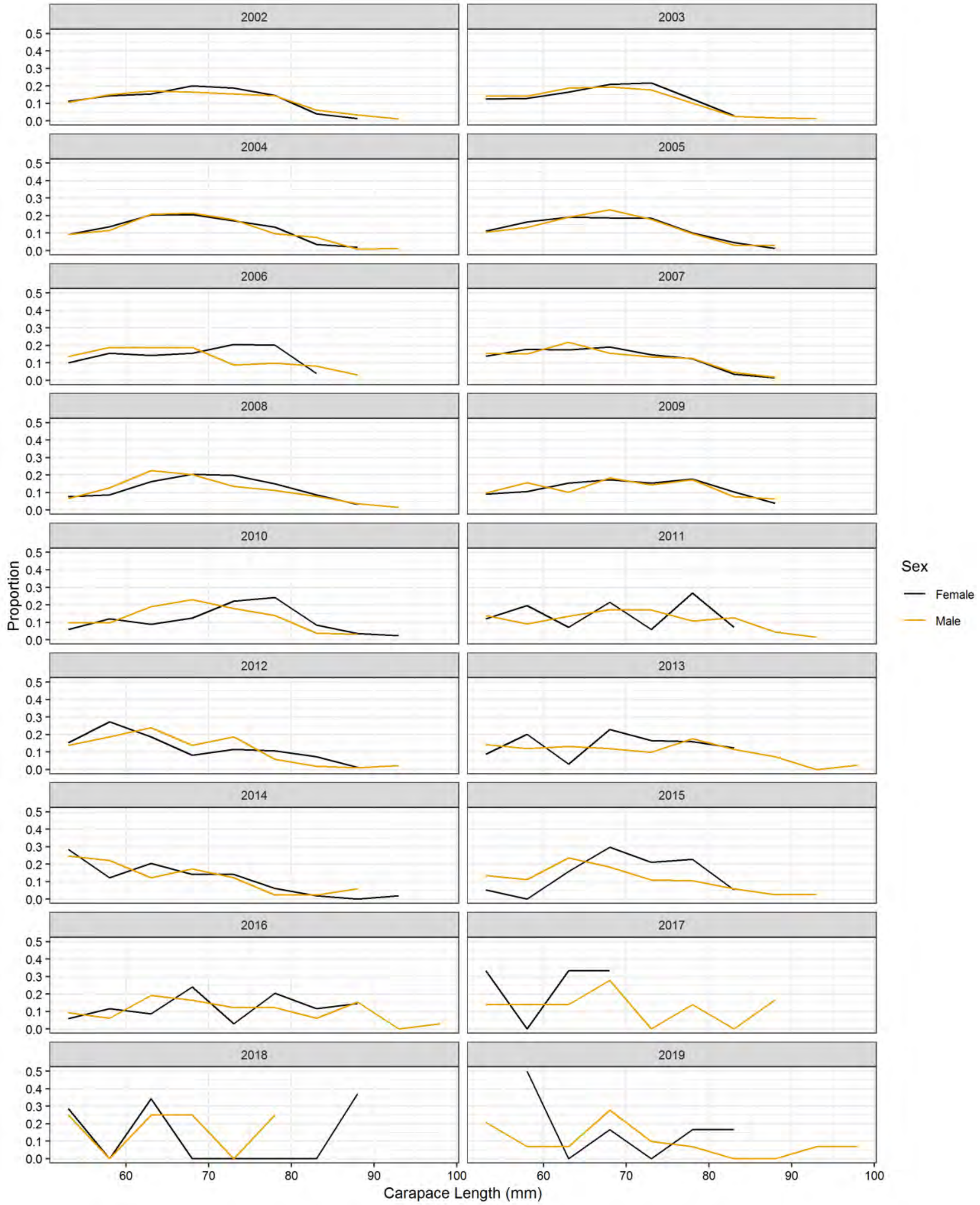


Figure 135. Spring CT Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.



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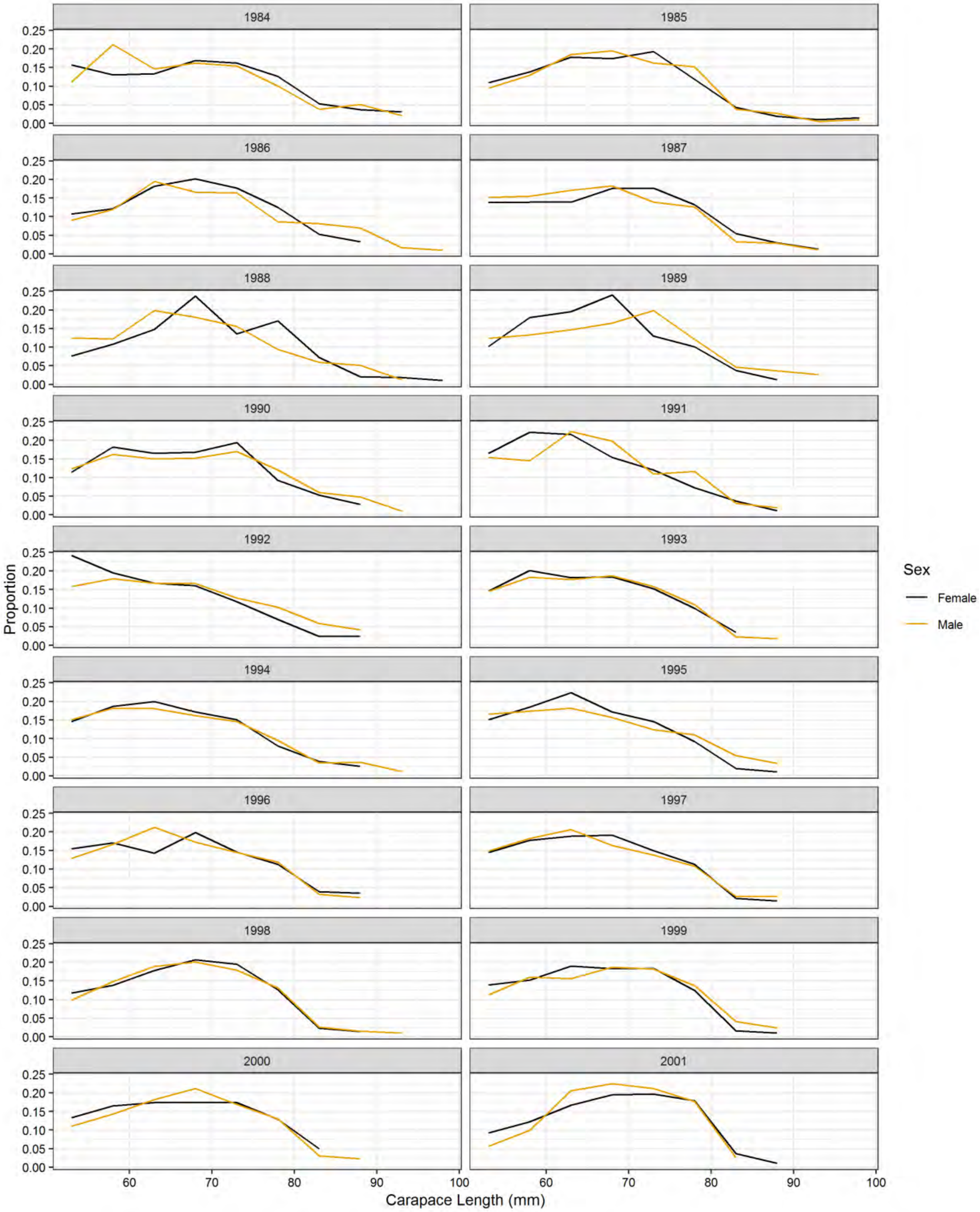

Figure 136. Fall CT Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

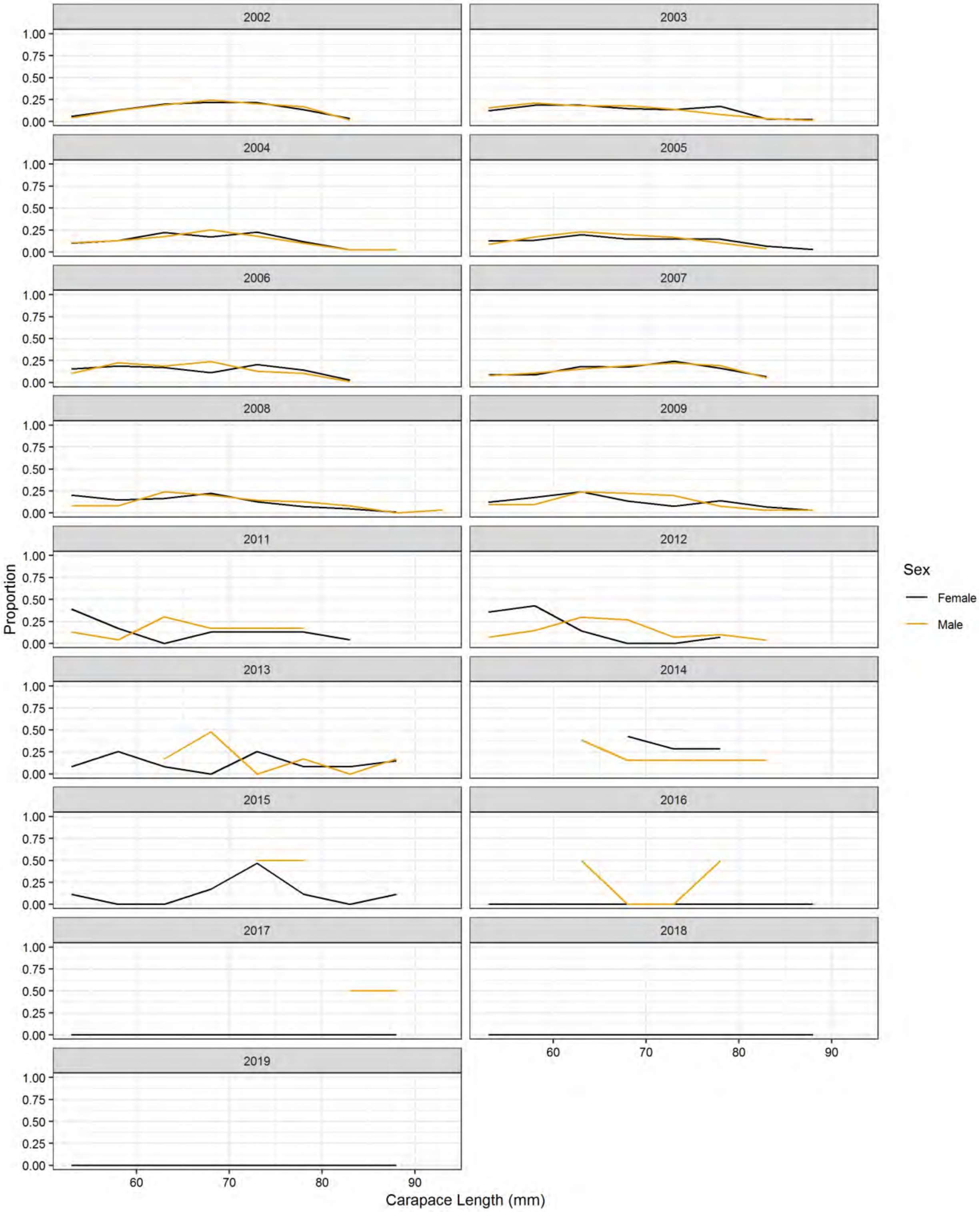

Figure 136. Continued.

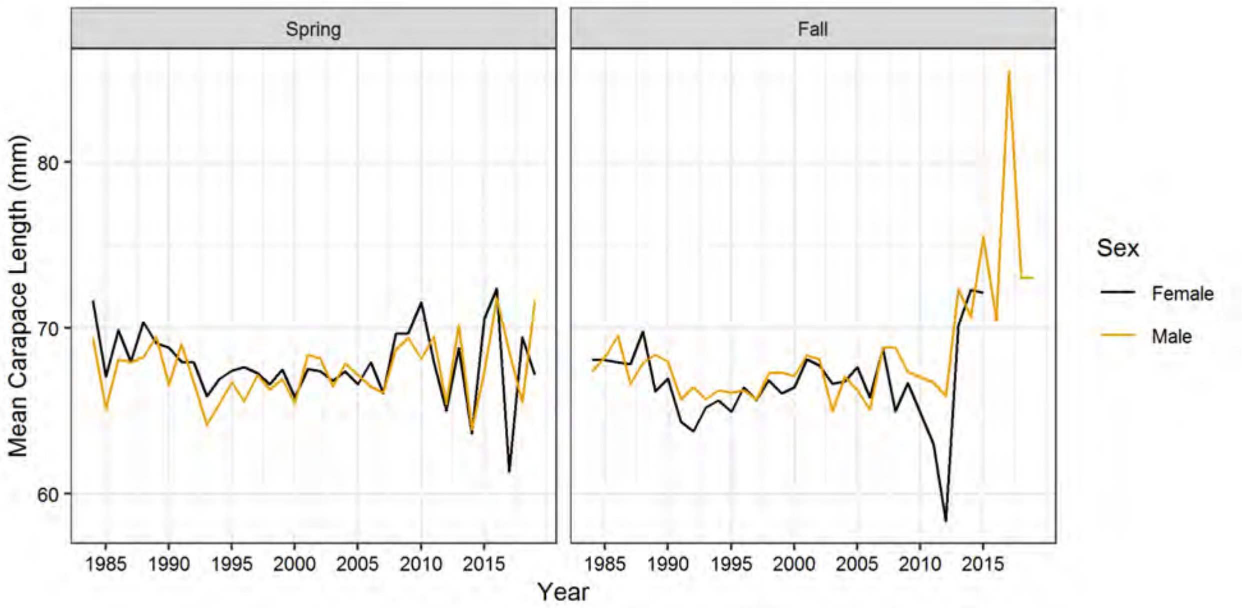

Figure 137. Seasonal mean CL of CT Trawl Survey 53+ mm CL lobster catch.

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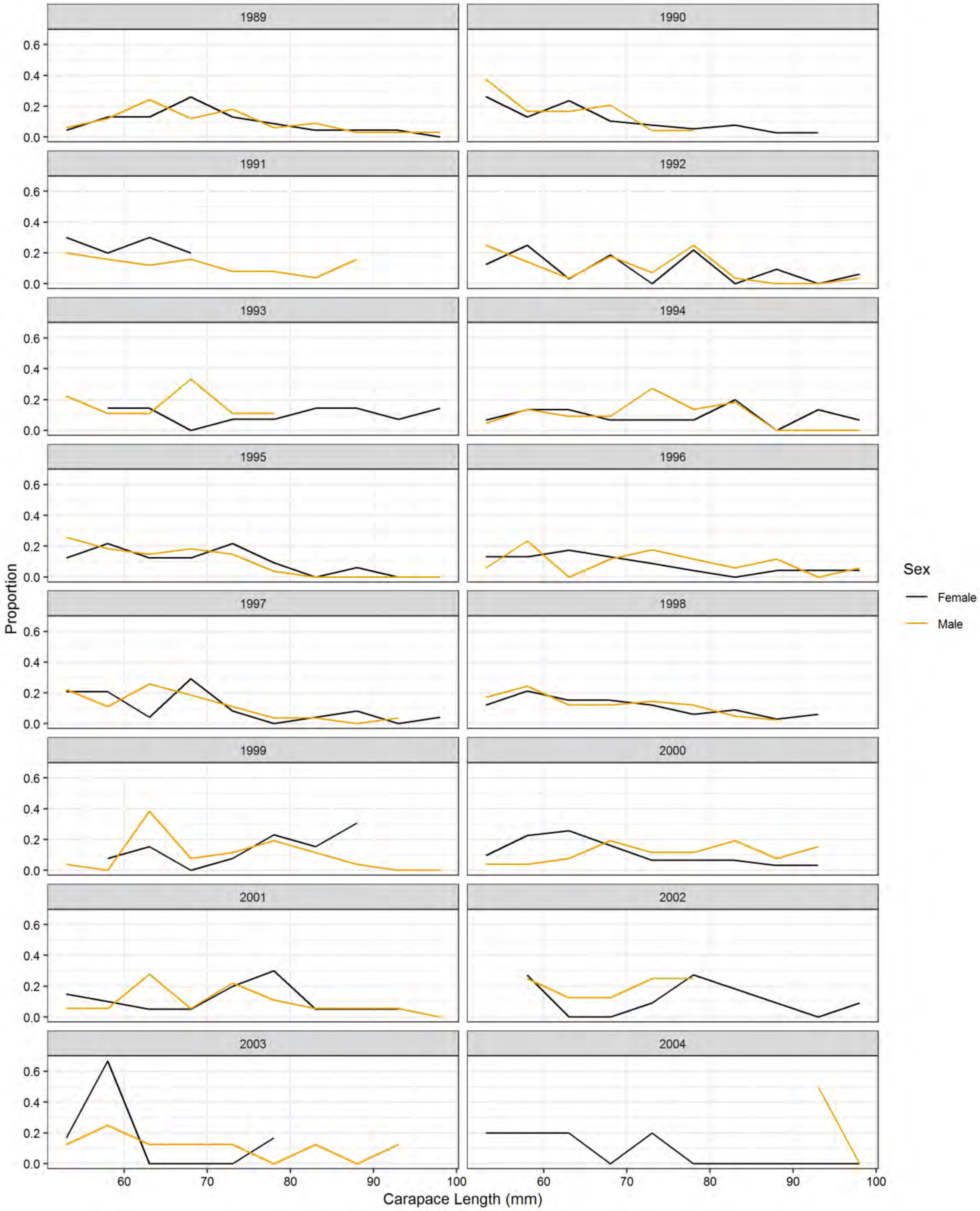

Figure 138. Spring NJ Trawl Survey 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

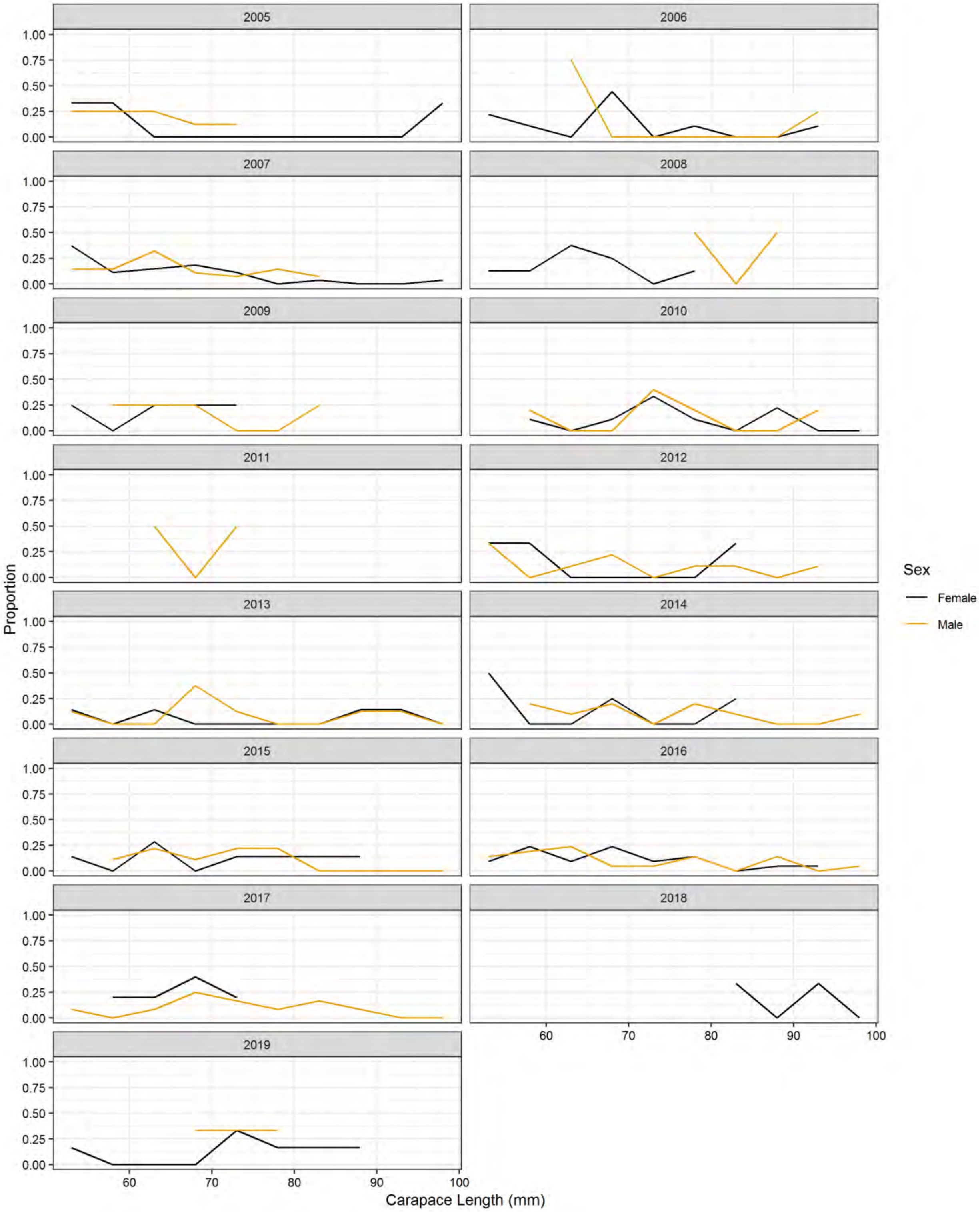

Figure 138. Continued.

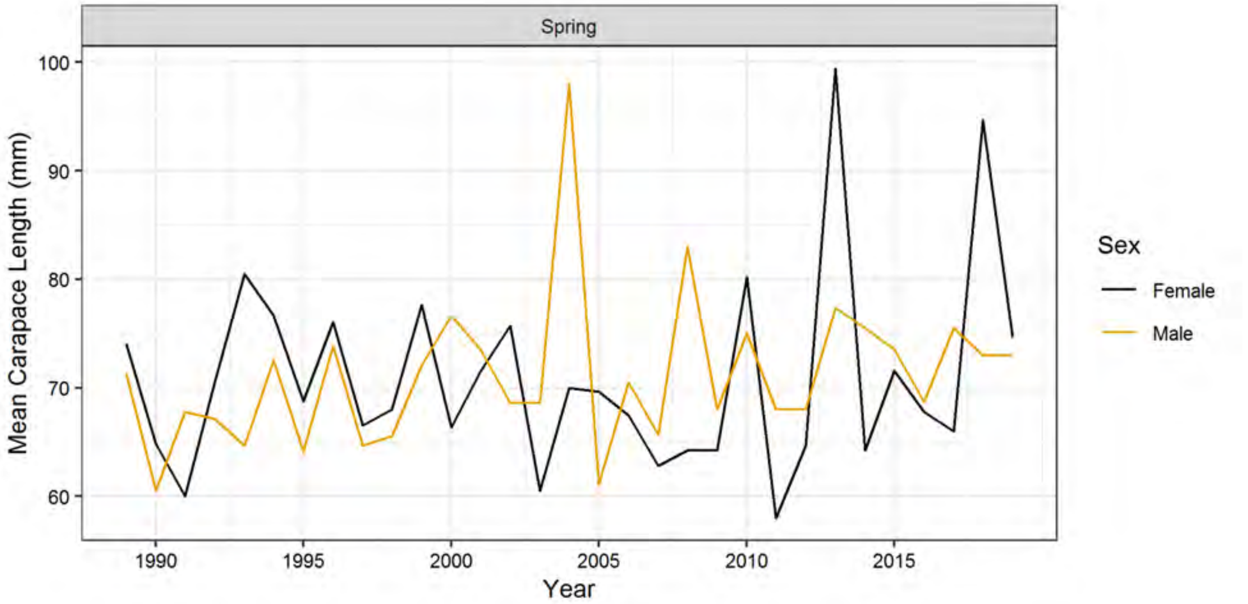

Figure 139. Mean CL of Spring NJ Trawl Survey 53+ mm CL lobster catch.

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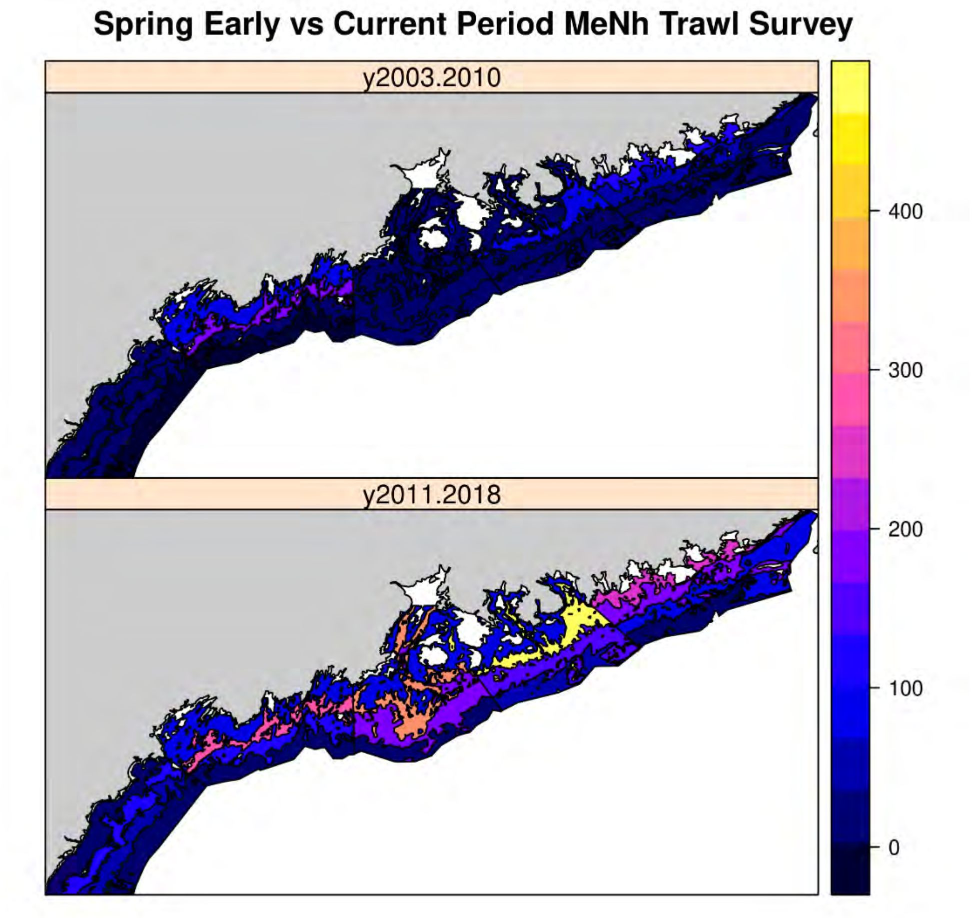

Figure 140. Mean catch per tow for the spring Maine / New Hampshire trawl survey for the early (2003-2010) and current (2011-2018) period of the time series.

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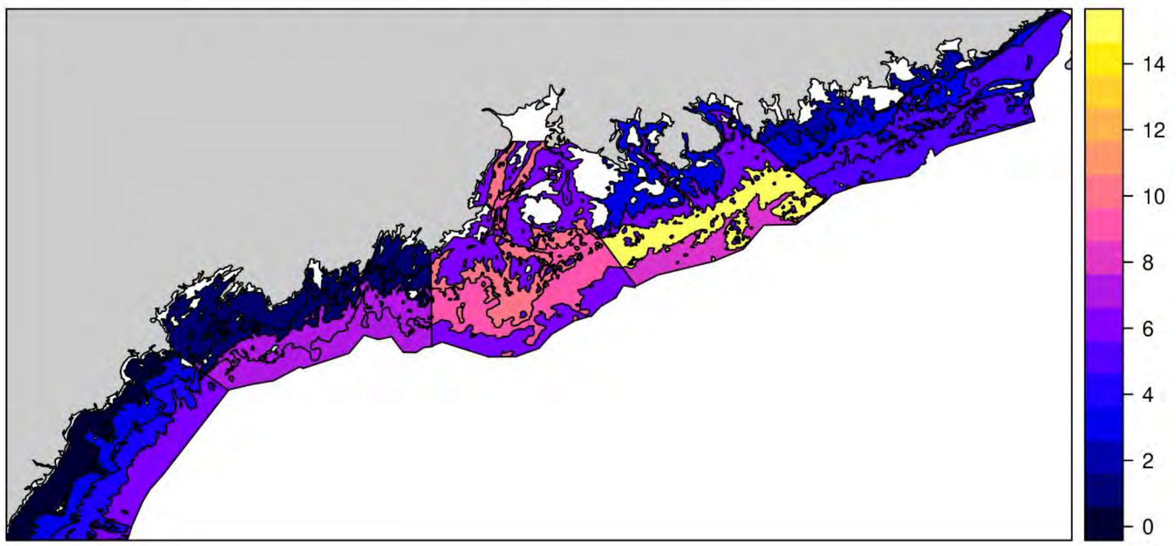
Spring change in catch density as ratio of Current to Early period, MeNh Trawl Survey



Spring trawl survey estimated annual growth rate 2000 - 2018

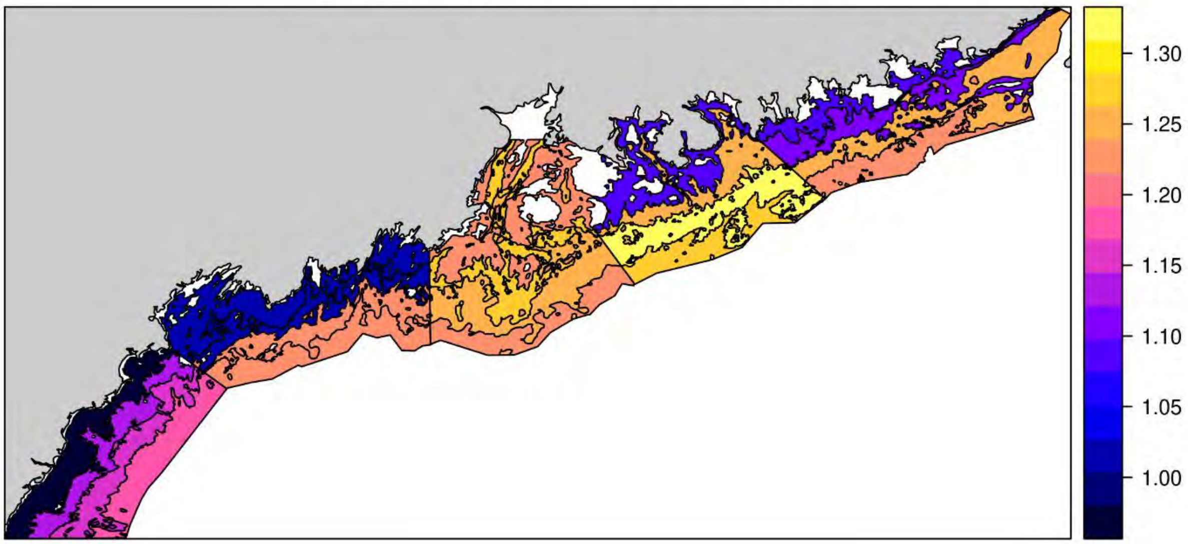


Figure 141. Ratio of catch rates between the early (2003-2010) and current (2011-2018) time periods (top) and mean annual growth rate in catches (bottom) for the spring Maine / New Hampshire trawl survey.

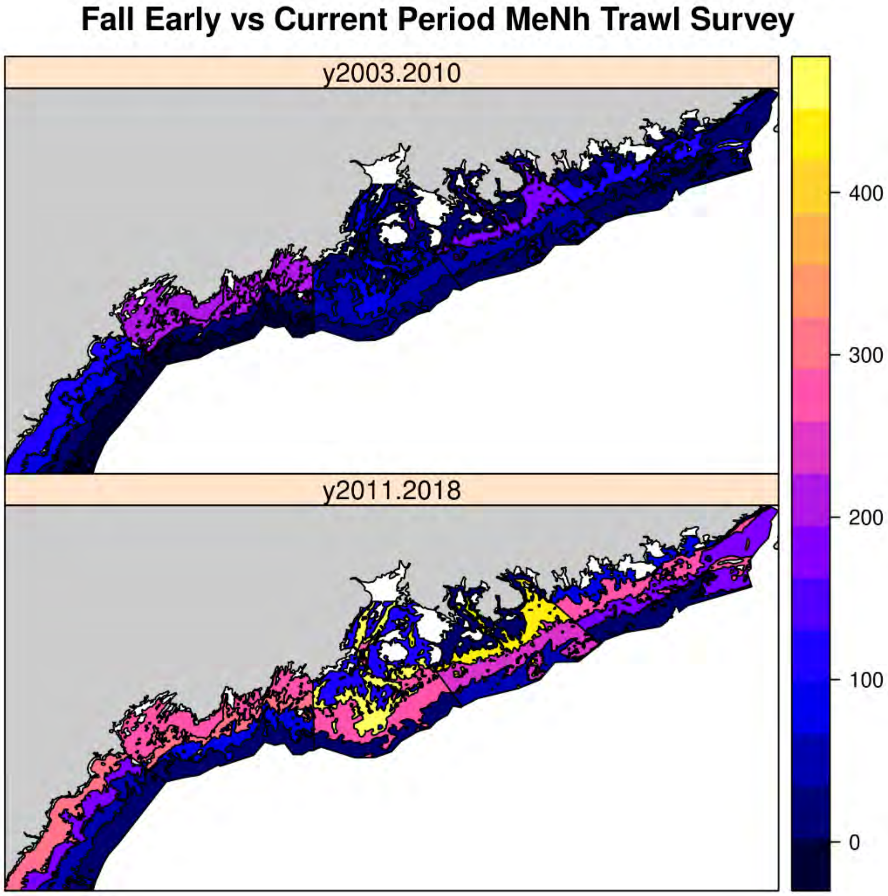


Figure 142. Mean catch per tow for the fall Maine / New Hampshire trawl survey for the early (2003-2010) and current (2011-2018) period of the time series.

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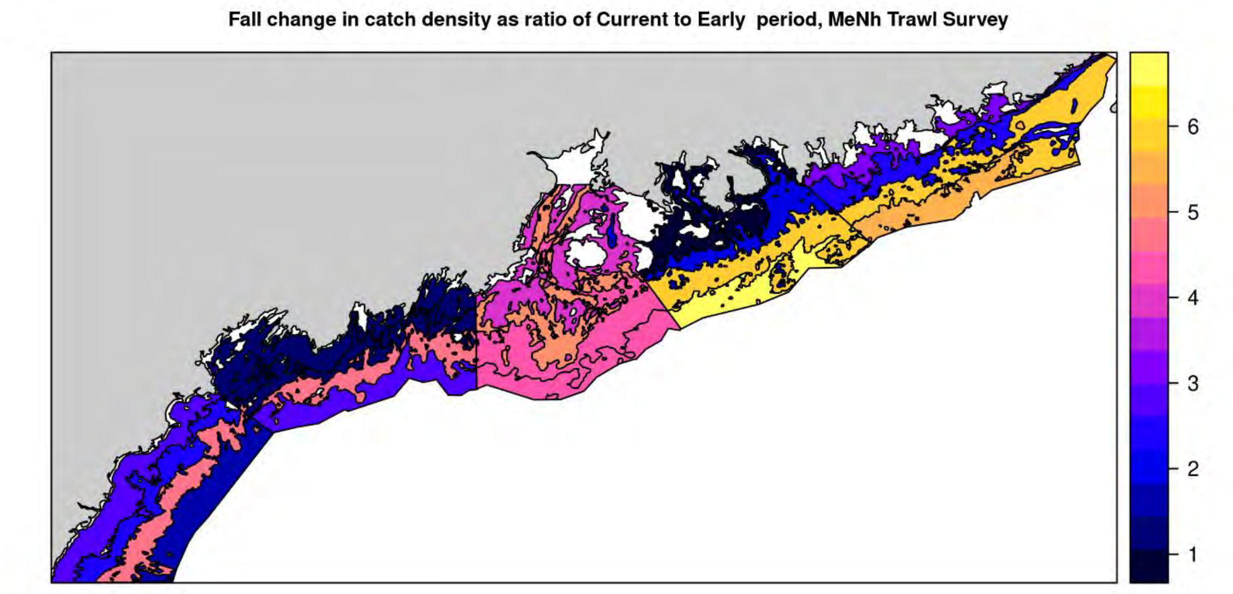
Fall change in catch density as ratio of Current to Early period, MeNh Trawl Survey

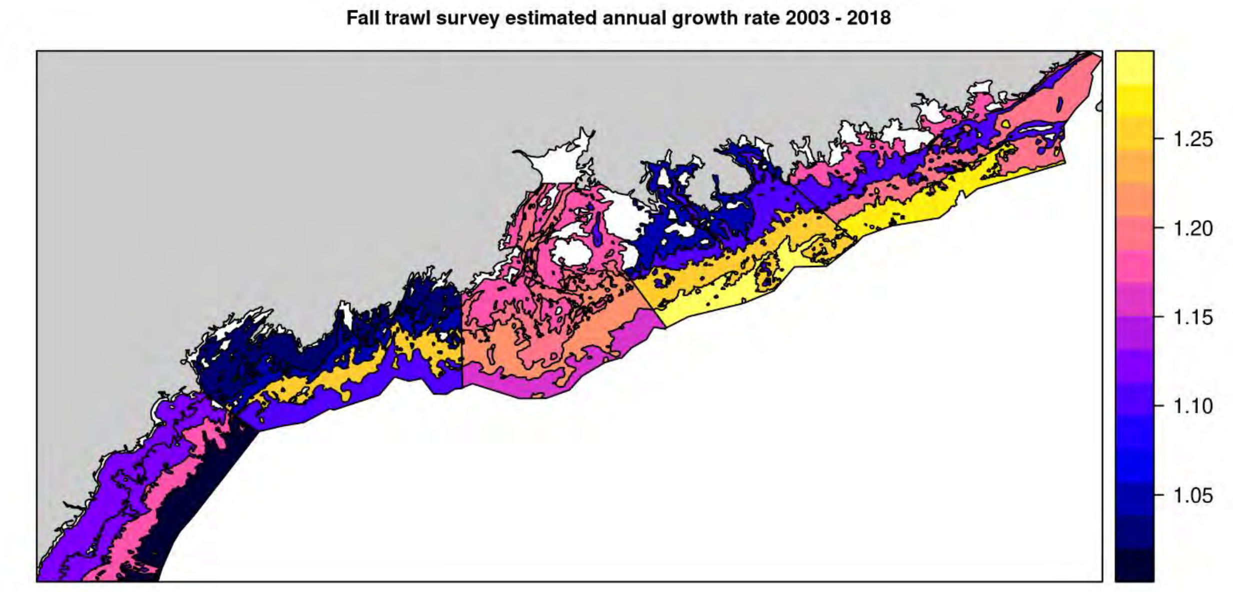
Fall trawl survey estimated annual growth rate 2003 - 2018

Figure 143. Ratio of catch rates between the early (2003-2010) and current (2011-2018) time periods (top) and mean annual growth rate in catches (bottom) for the fall Maine / New Hampshire trawl survey.

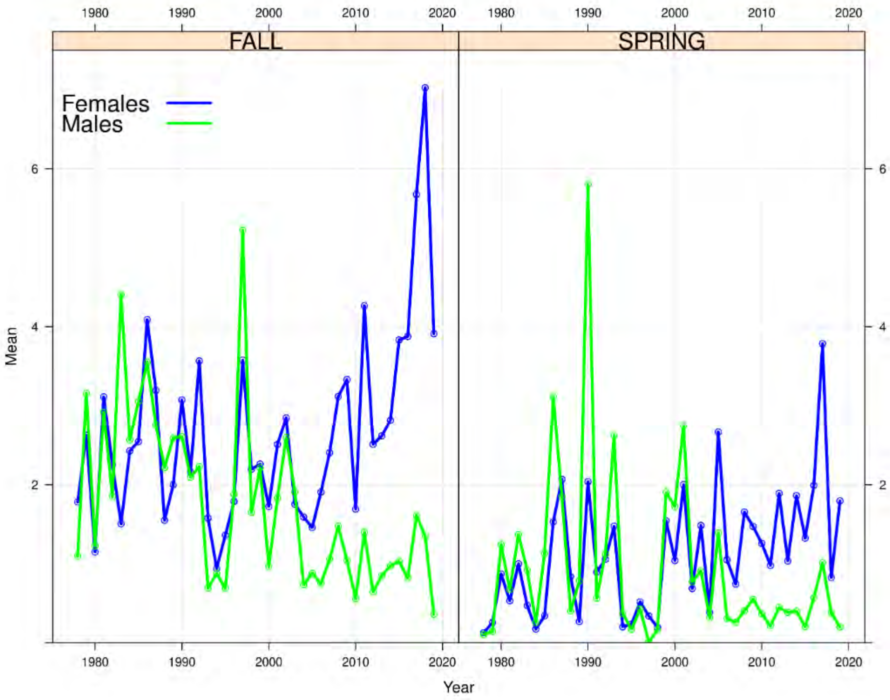

Figure 144. NEFSC trawl abundance indices for the Georges Bank region by sex and season.

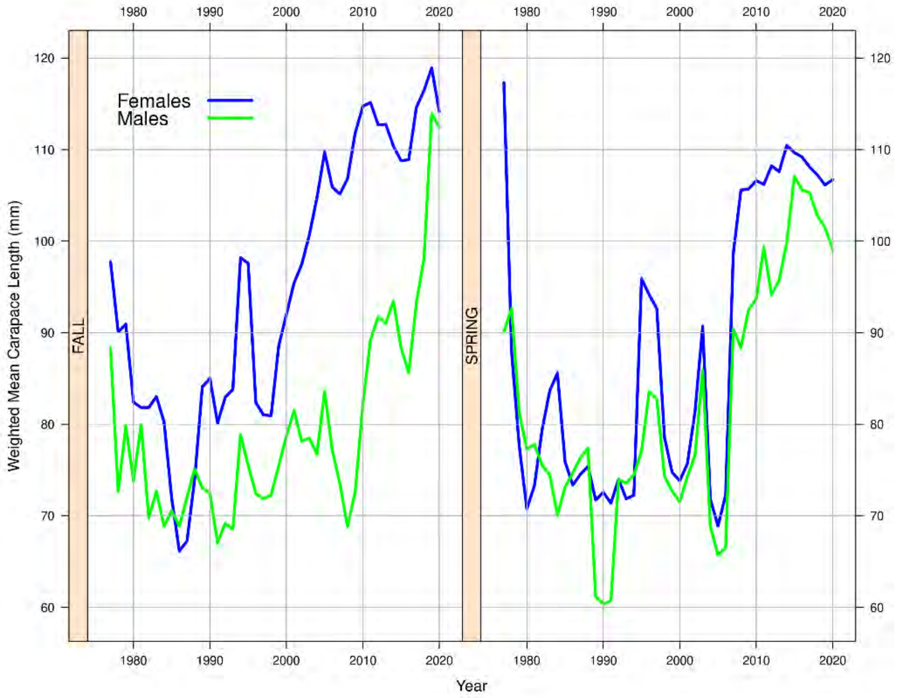

Figure 145. Mean lobster size observed in the NEFSC trawl survey on Georges Bank. Time series are three-year moving averages and weighted by catch abundance to smooth trends.

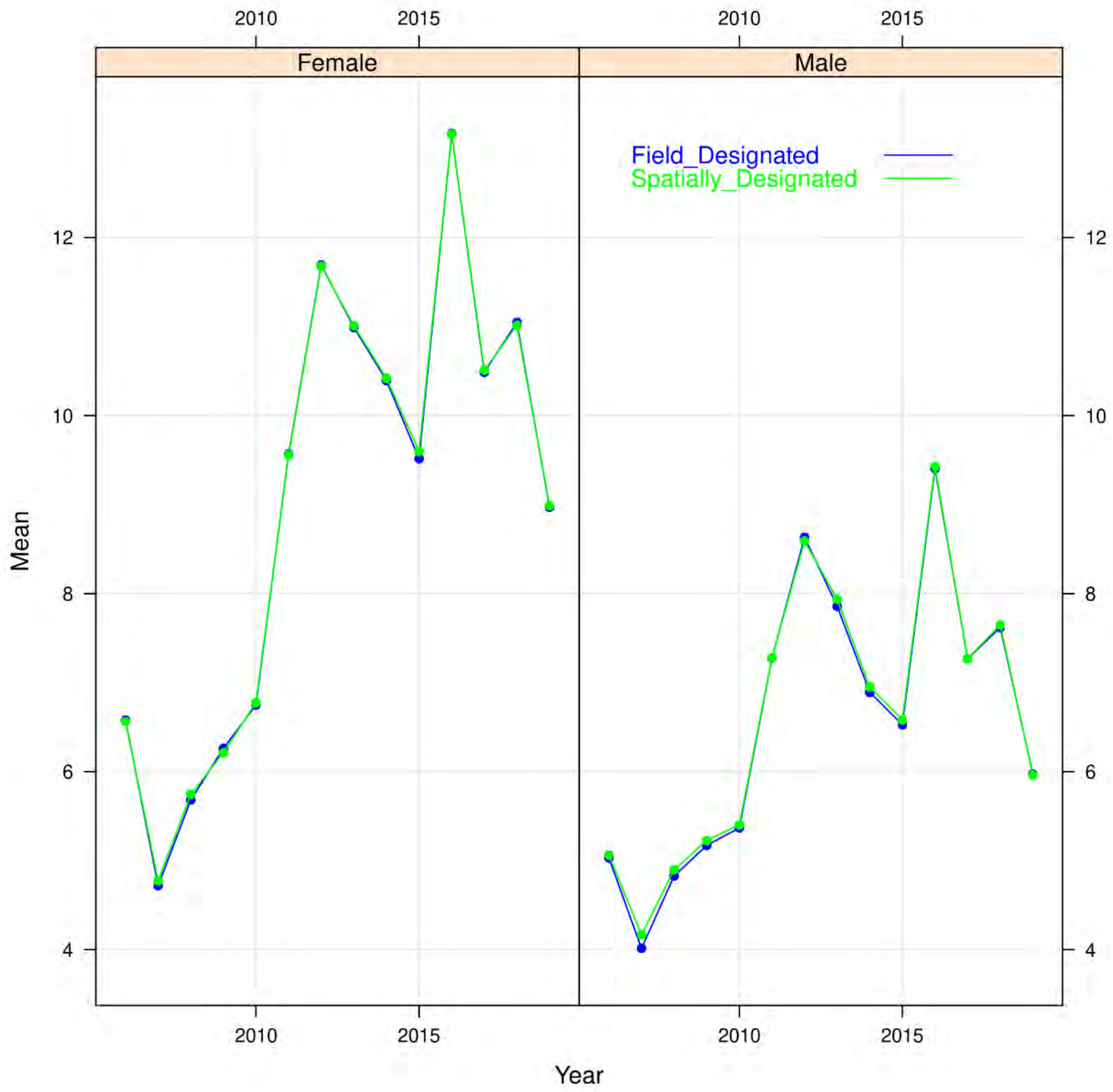

Figure 146. Comparison of the sex specific Maine Ventless Trap Survey indices from Field Designated vs Spatially Designated methods.

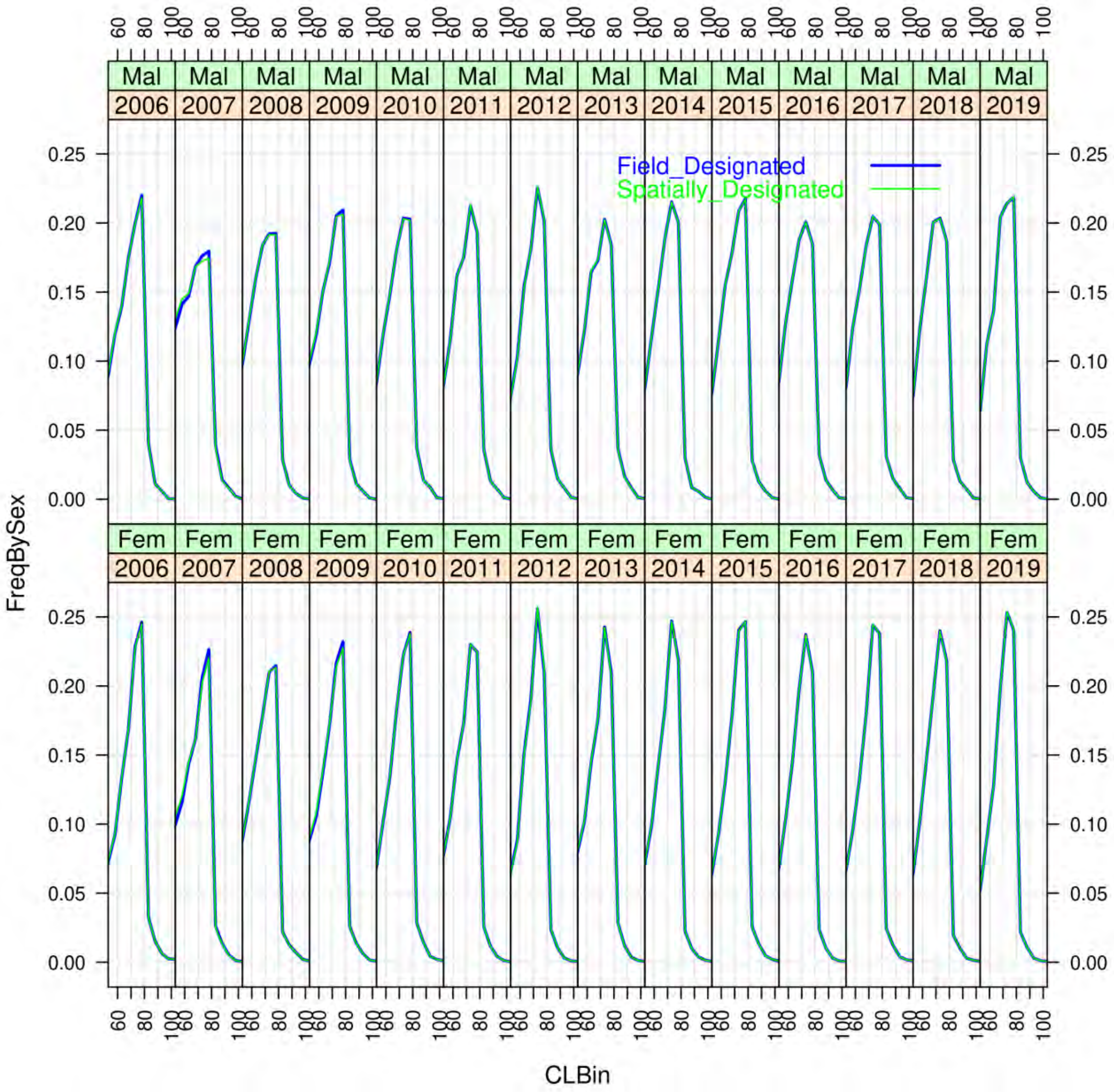

Figure 147. Comparison of the sex specific Maine Ventless Trap Survey length compositions from Field Designated vs Spatially Designated methods.

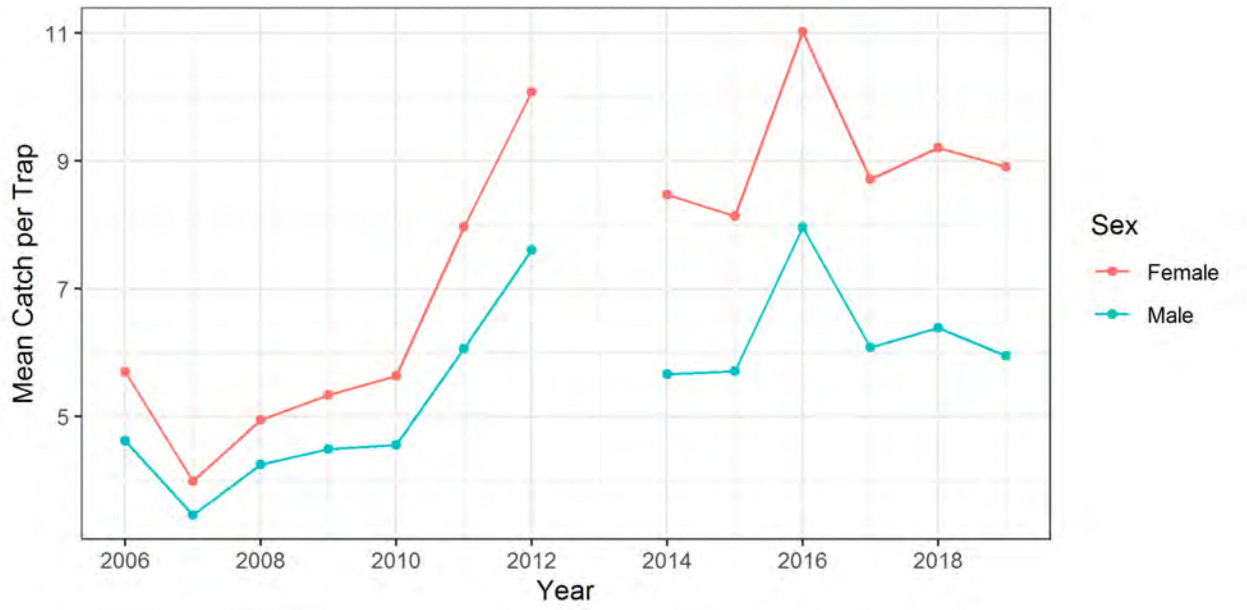

Figure 148. Ventless Trap Survey GOM stratified mean catch per trap of 53+ mm CL lobsters.

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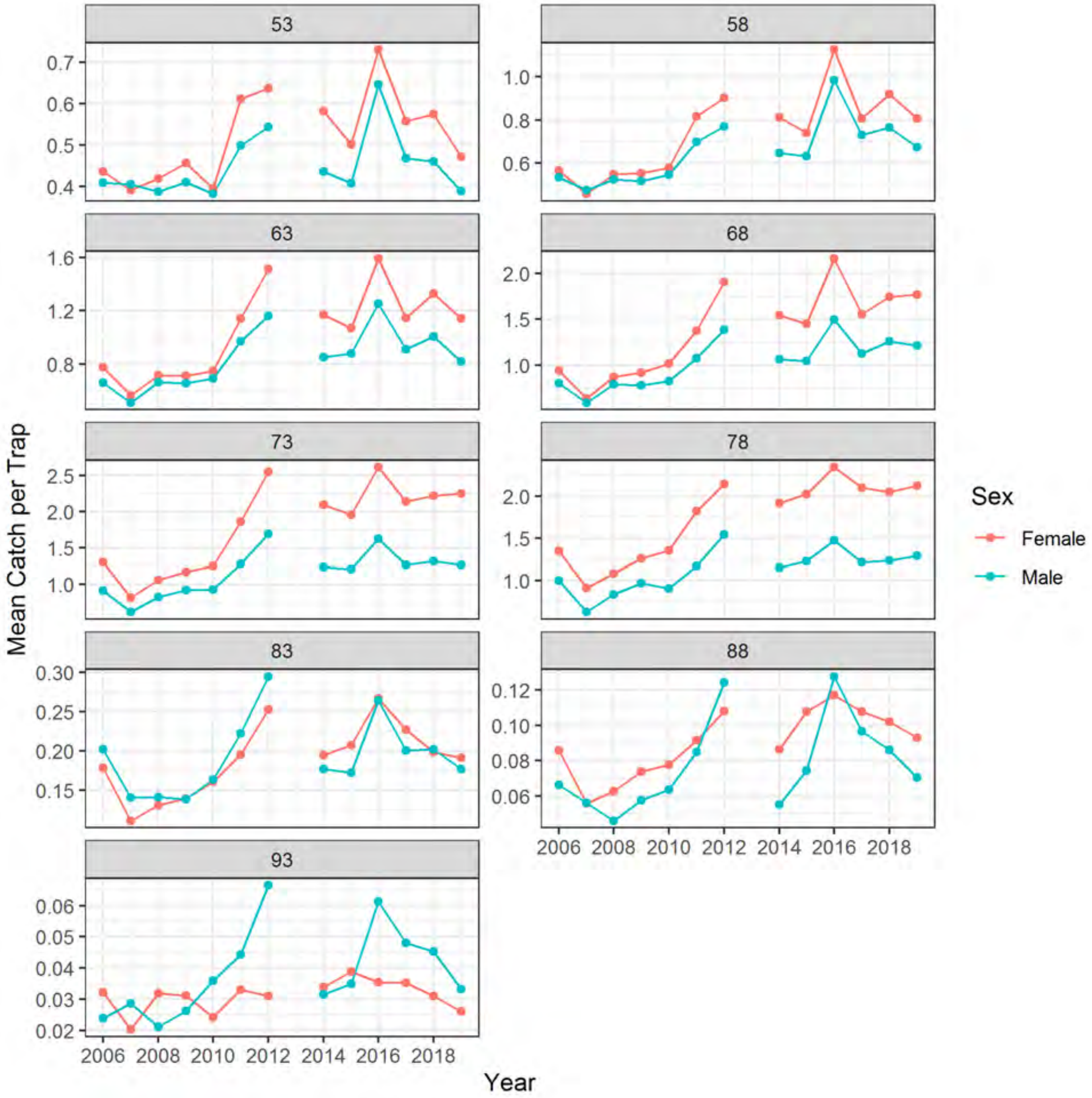

Figure 149. Ventless Trap Survey GOM stratified mean catch per trap of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 93 mm size bin (93-97 mm CL) as catches of larger sizes are relatively infrequent and variable.

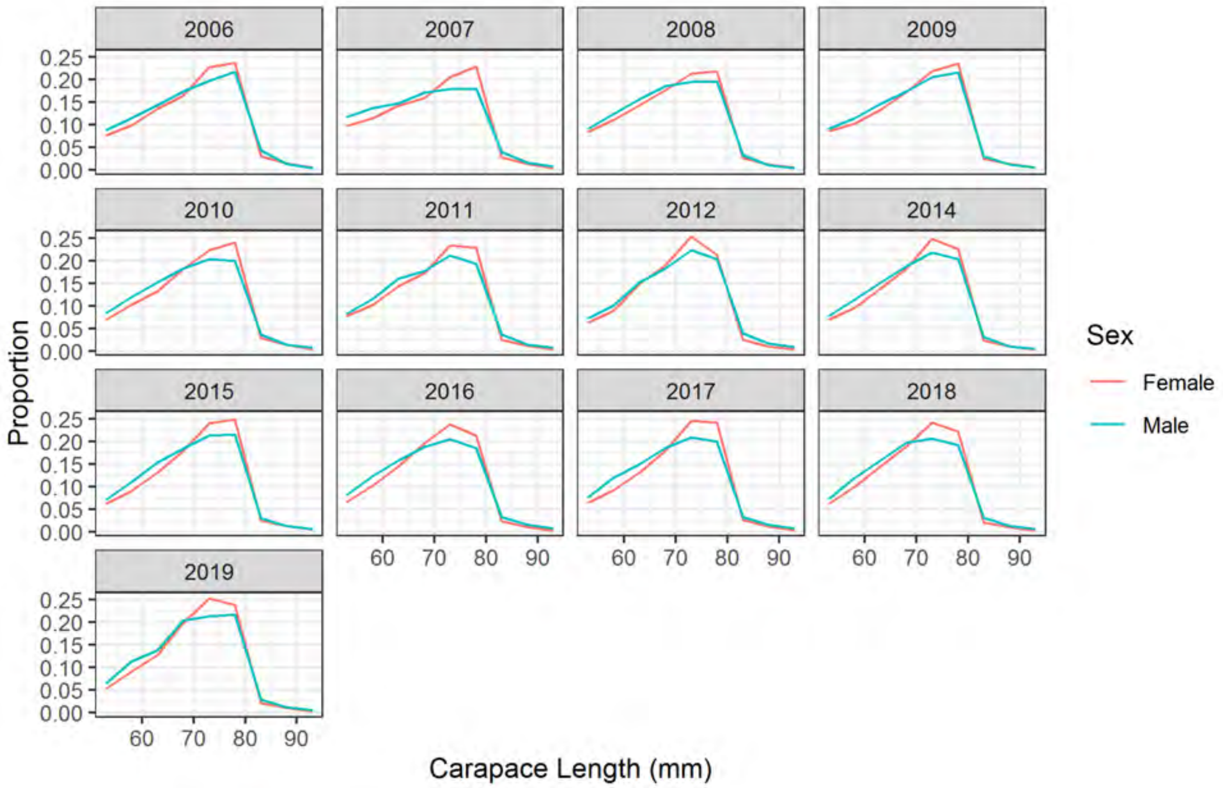

Figure 150. Ventless Trap Survey GOM 53+ mm CL lobster catch size compositions. Size bins are truncated at the 93 mm size bin (93-97 mm CL) as catches of larger sizes are relatively infrequent and variable.

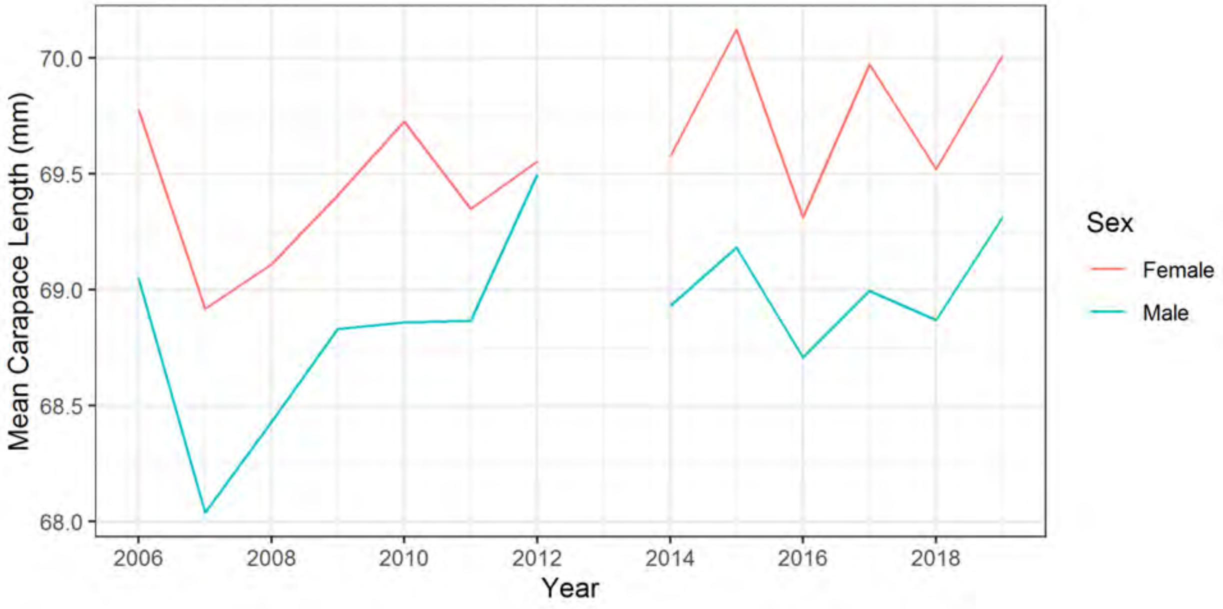

Figure 151. Mean CL of Ventless Trap Survey GOM 53+ mm CL lobster catch.

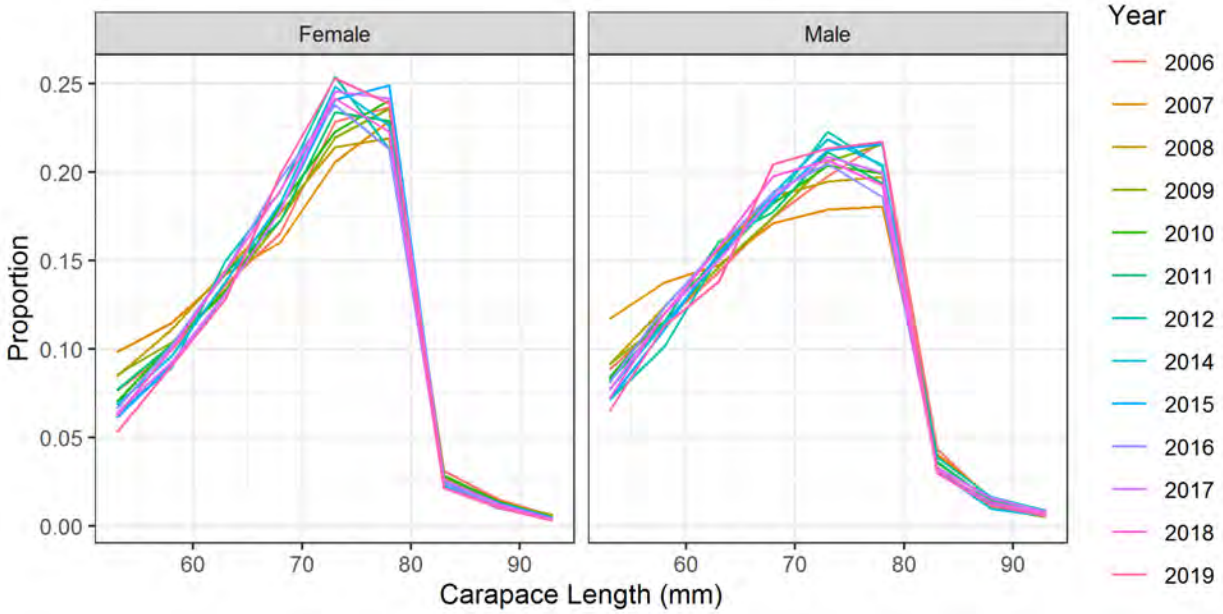

Figure 152. Ventless Trap Survey GOM 53+ mm CL lobster catch size compositions among years. Size bins are truncated at the 93 mm size bin (93-97 mm CL) as catches of larger sizes are relatively infrequent and variable.

Figure 153. Ventless Trap Survey mean catch per trap of 53+ mm CL lobsters by statistical area (left number in panel title) and depth strata (right number in panel title; median depth of 20 meter bin) in ME (no state prefix in panel title) and NH (NH- prefix in panel title) state waters within GOM.

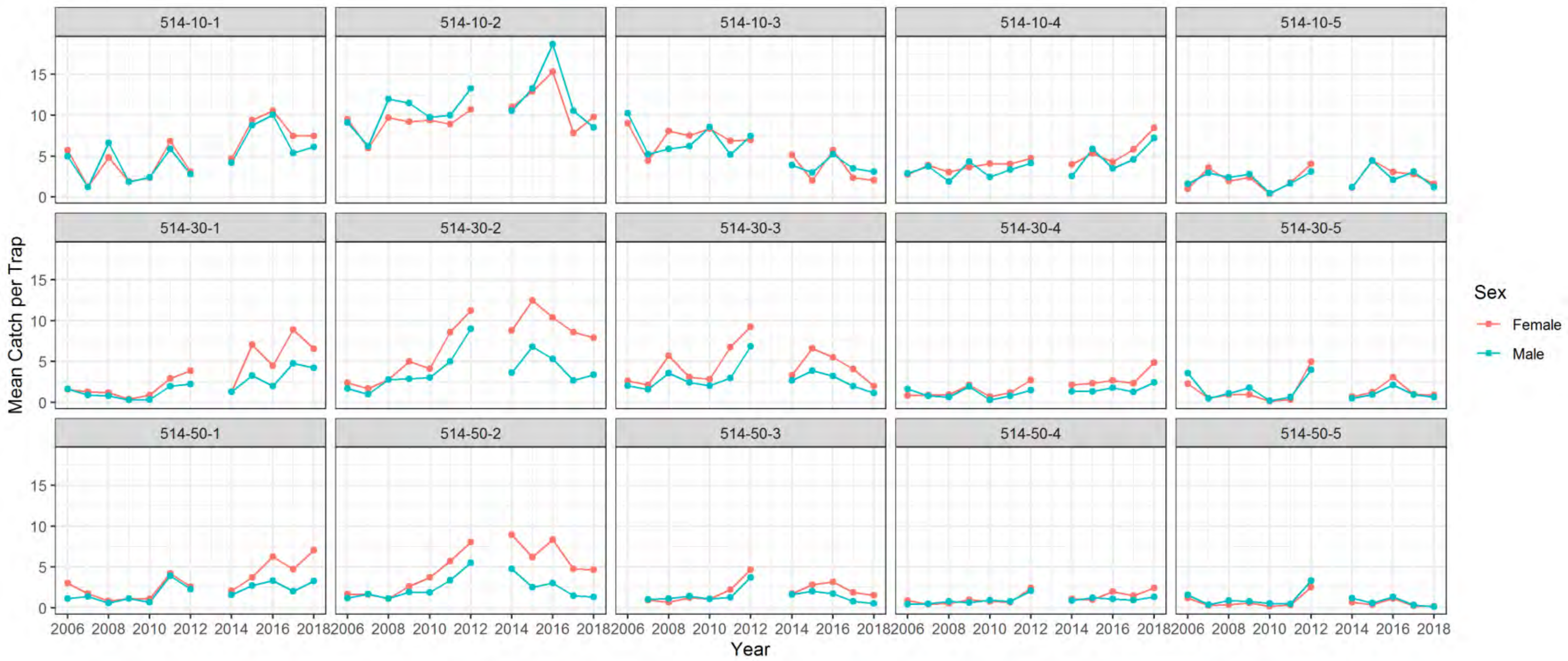

Figure 154. Ventless Trap Survey mean catch per trap of 53+ mm CL lobsters by statistical area (left number in panel title), depth strata (middle number in panel title; median depth of 20 meter bin), and geographic zones (right number in panel title) in MA state waters within GOM.

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Figure 155. Mean CL of Ventless Trap Survey 53+ mm CL lobster catch by statistical area (left number in panel title) and depth strata (right number in panel title; median depth of 20 meter bin) in ME (no state prefix in panel title) and NH (NH- prefix in panel title) state waters within GOM.

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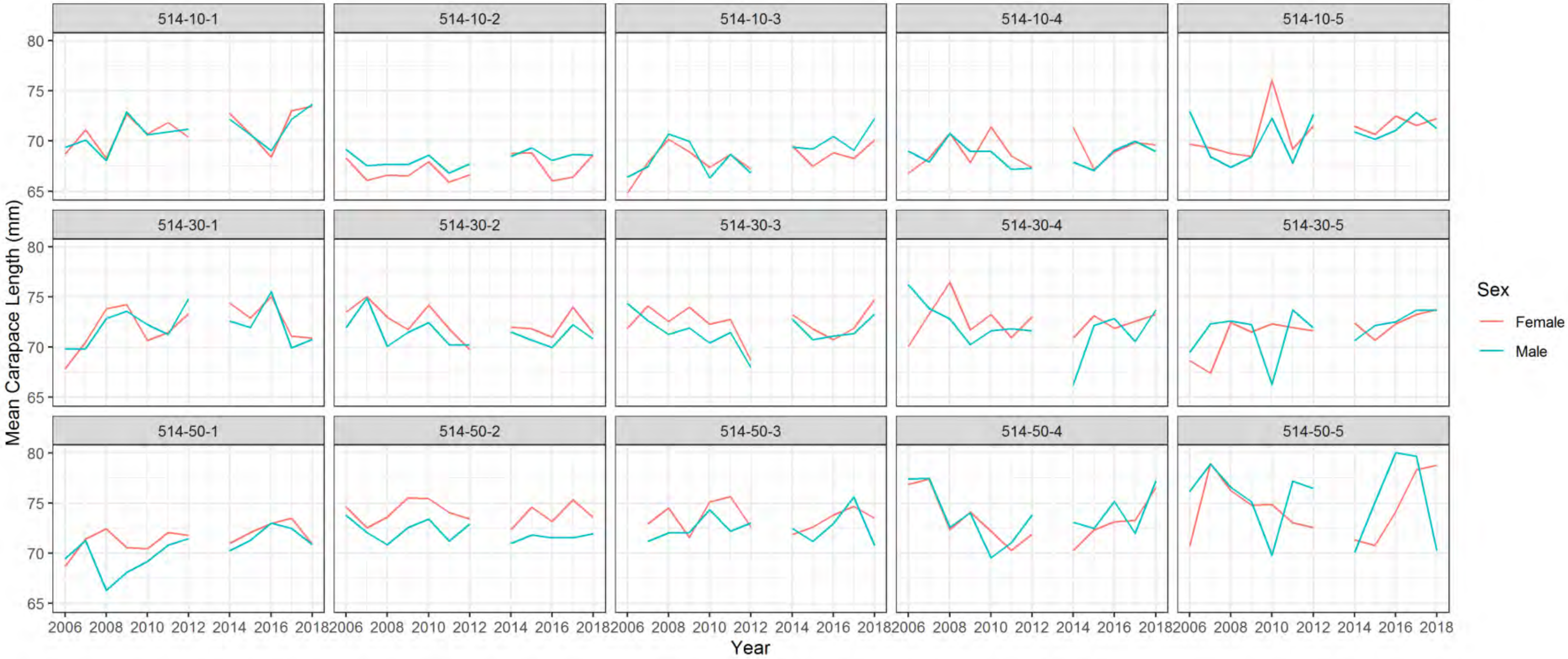

Figure 156. Mean CL of Ventless Trap Survey 53+ mm CL lobster catch by statistical area (left number in panel title), depth strata (middle number in panel title; median depth of 20 meter bin), and geographic zones (right number in panel title) in MA state waters within GOM.

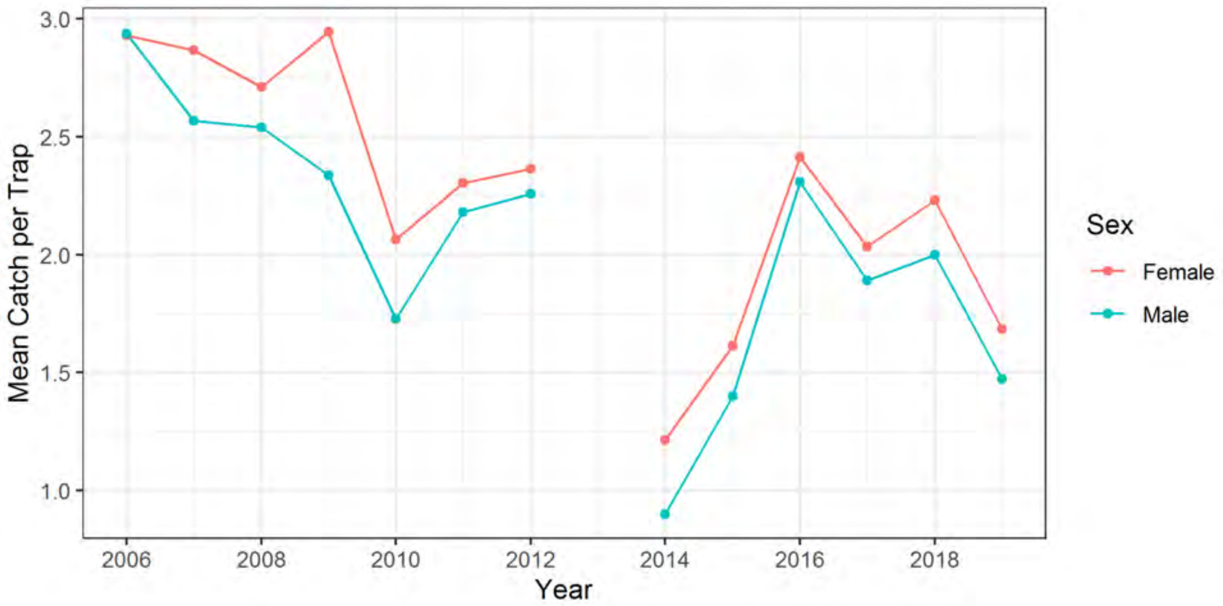

Figure 157. Ventless Trap Survey SNE stratified mean catch per trap of 53+ mm CL lobsters.

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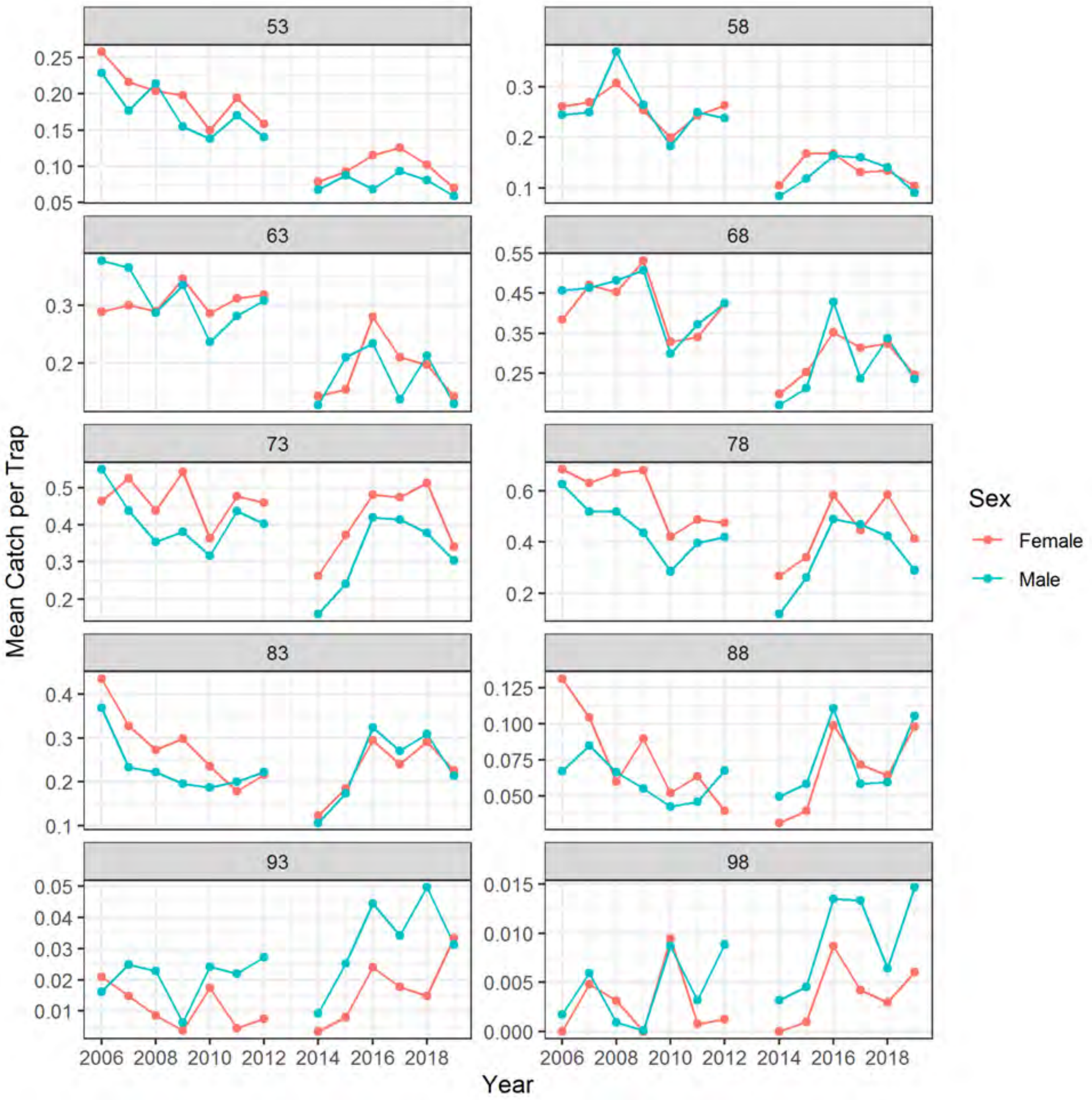

Figure 158. Ventless Trap Survey SNE stratified mean catch per trap of lobsters by 5 mm CL size bins. The y-axis scale is not fixed to better reflect size-specific trends. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

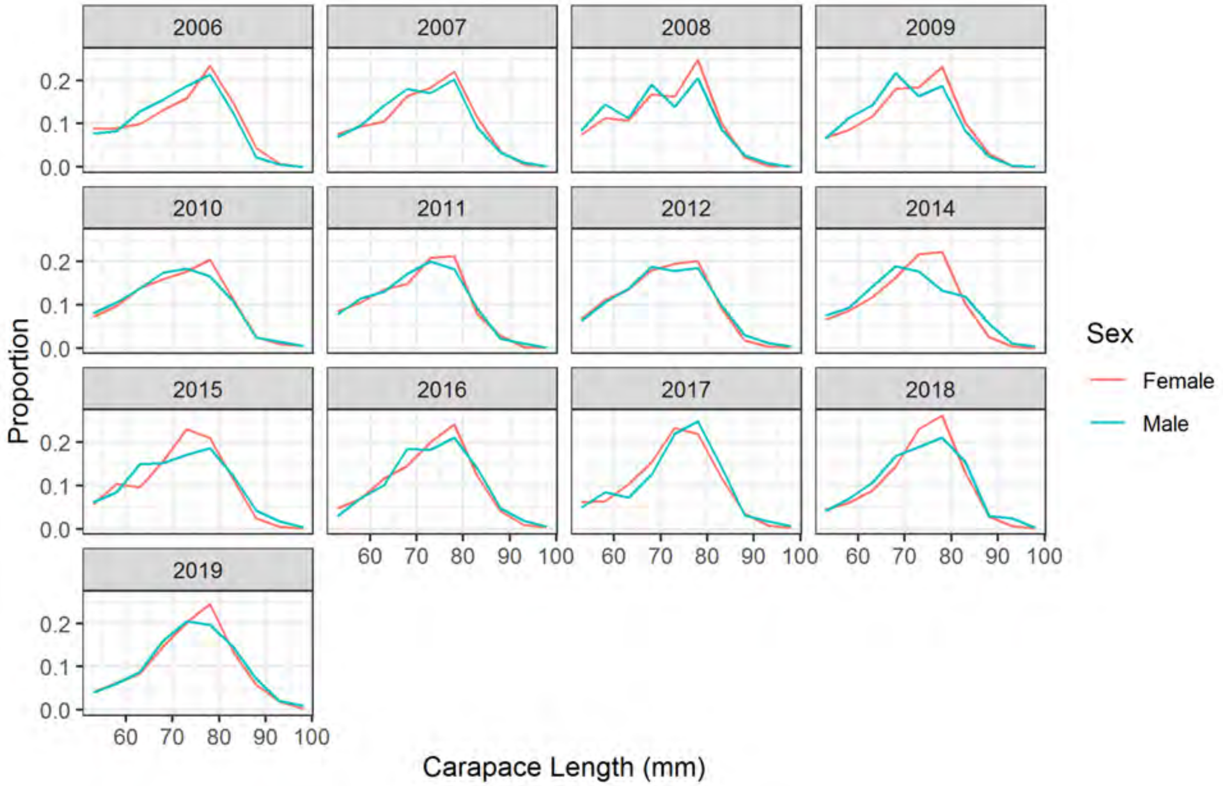

Figure 159. Ventless Trap Survey SNE 53+ mm CL lobster catch size compositions. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

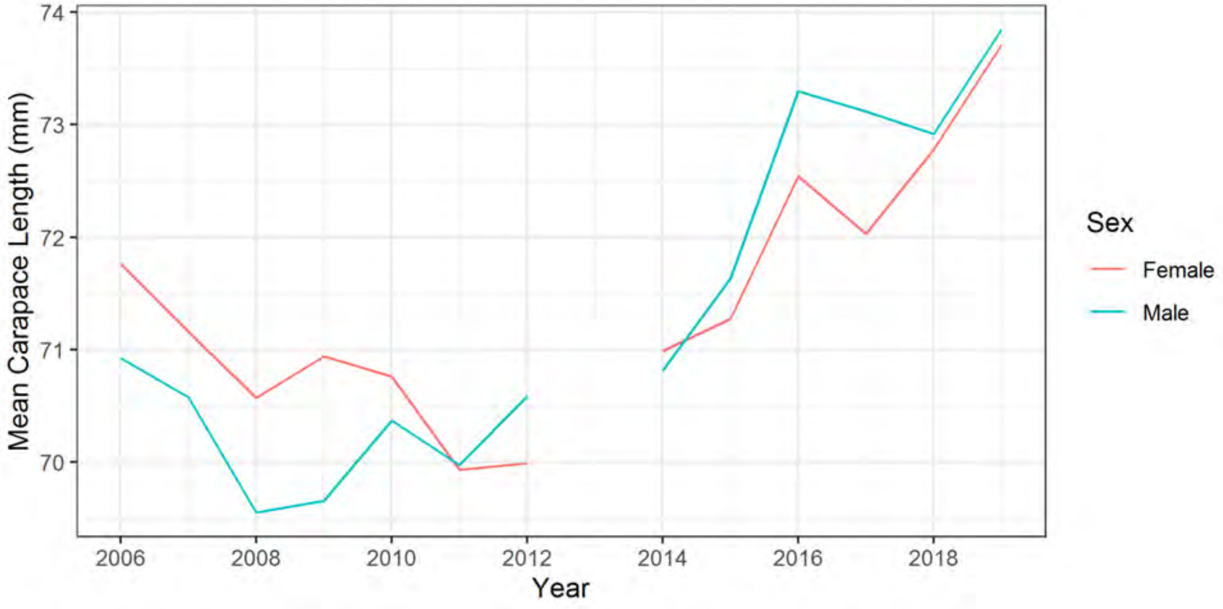

Figure 160. Mean CL of Ventless Trap Survey SNE 53+ mm CL lobster catch.

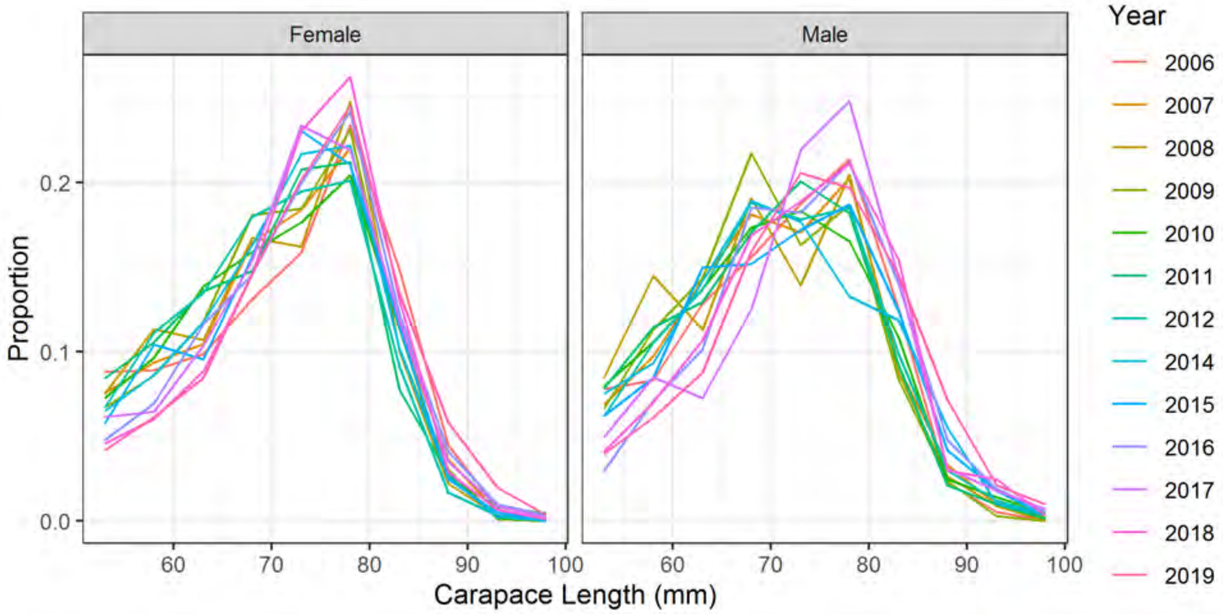

Figure 161. Ventless Trap Survey SNE 53+ mm CL lobster catch size compositions among years. Size bins are truncated at the 98 mm size bin (98-102 mm CL) as catches of larger sizes are relatively infrequent and variable.

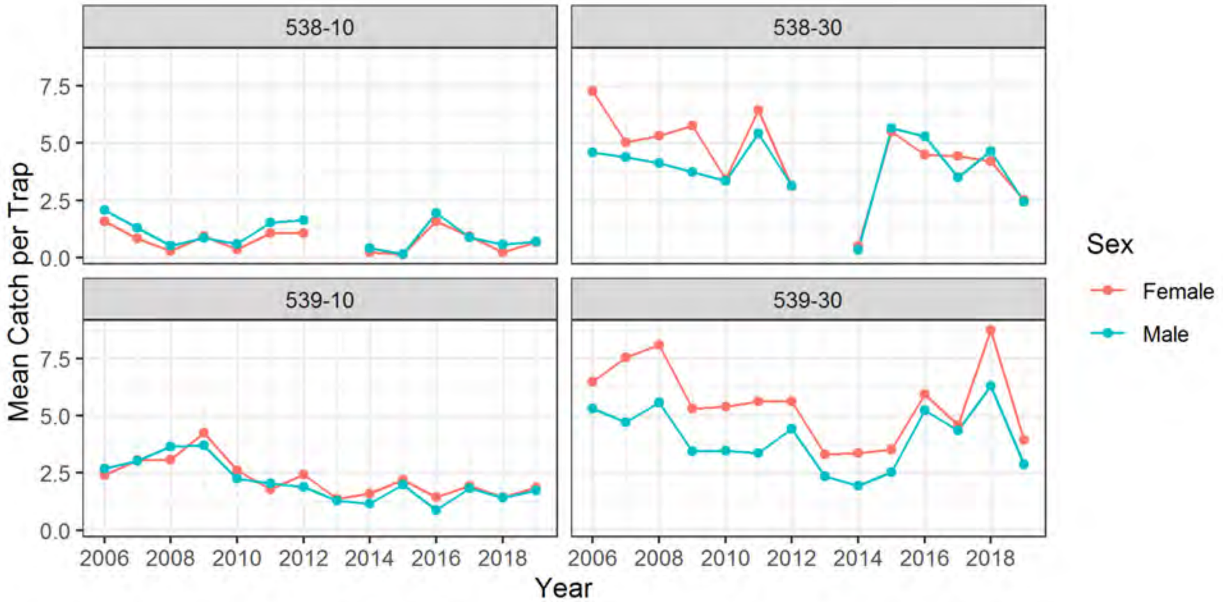

Figure 162. Ventless Trap Survey mean catch per trap of 53+ mm CL lobsters by statistical area (left number in panel title) and depth strata (right number in panel title; median depth of 20 meter bin) in RI (SA 539) and MA (SA 538) state waters within SNE.

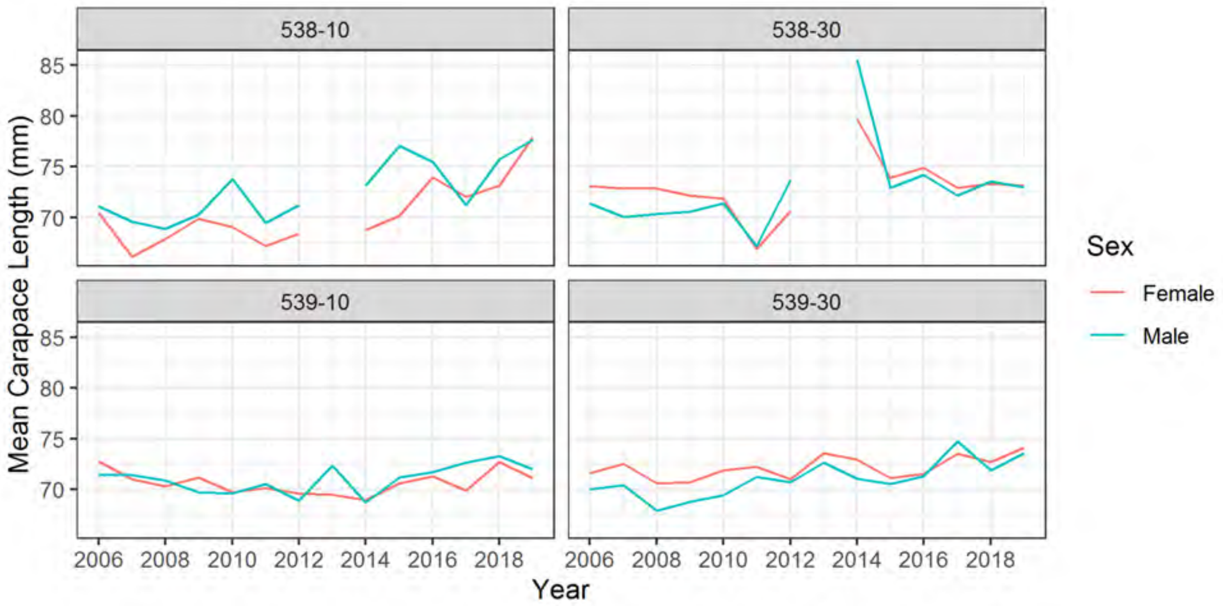

Figure 163. Mean CL of Ventless Trap Survey 53+ mm CL lobster catch by statistical area (left number in panel title) and depth strata (right number in panel title; median depth of 20 meter bin) in RI (SA 539) and MA (SA 538) state waters within SNE.

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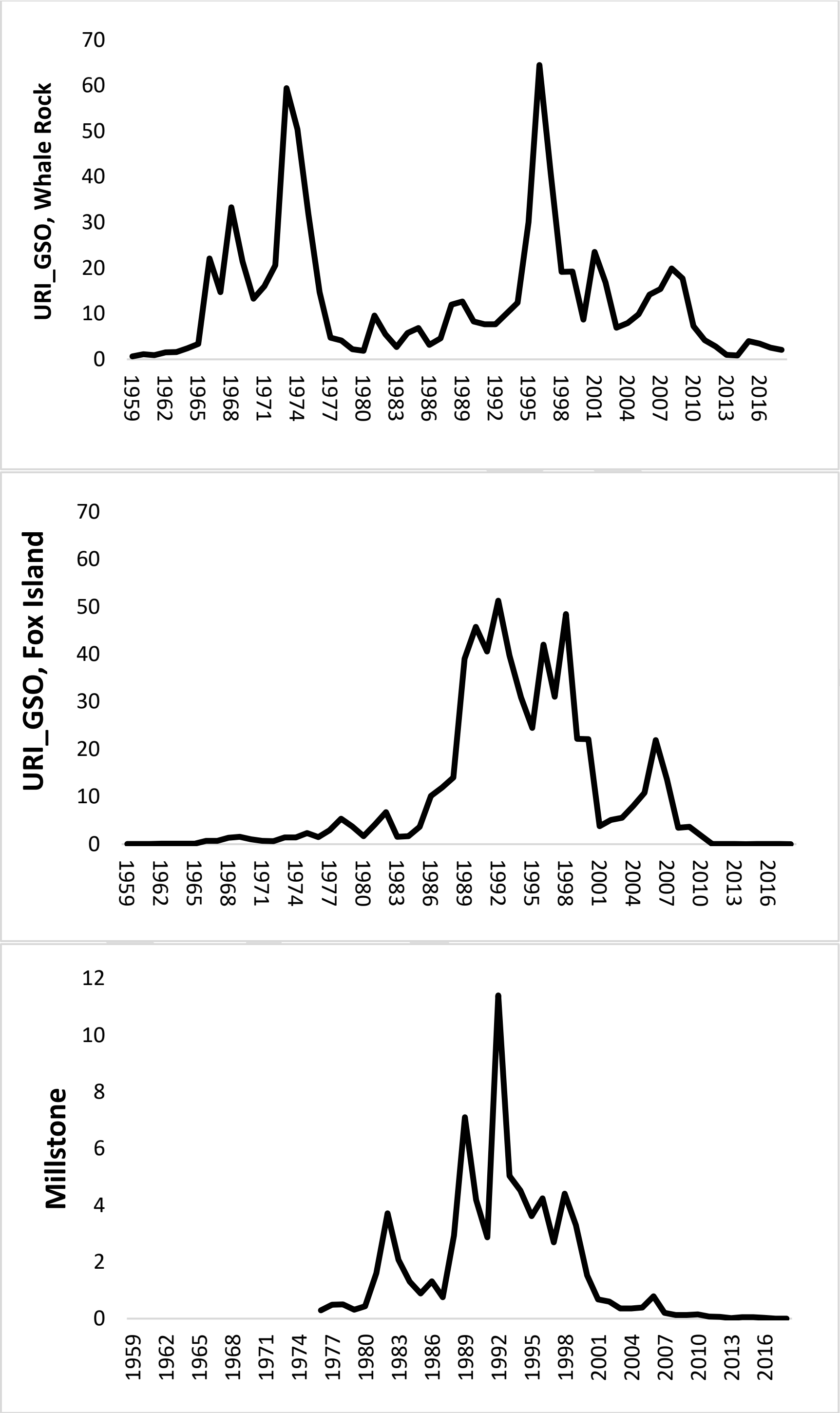

Figure 164. URI_GSO trawl survey index (Narragansett Bay, 1959 - 2018) and Millstone Power Station trawl survey index (Long Island Sound, 1976 - 2018).

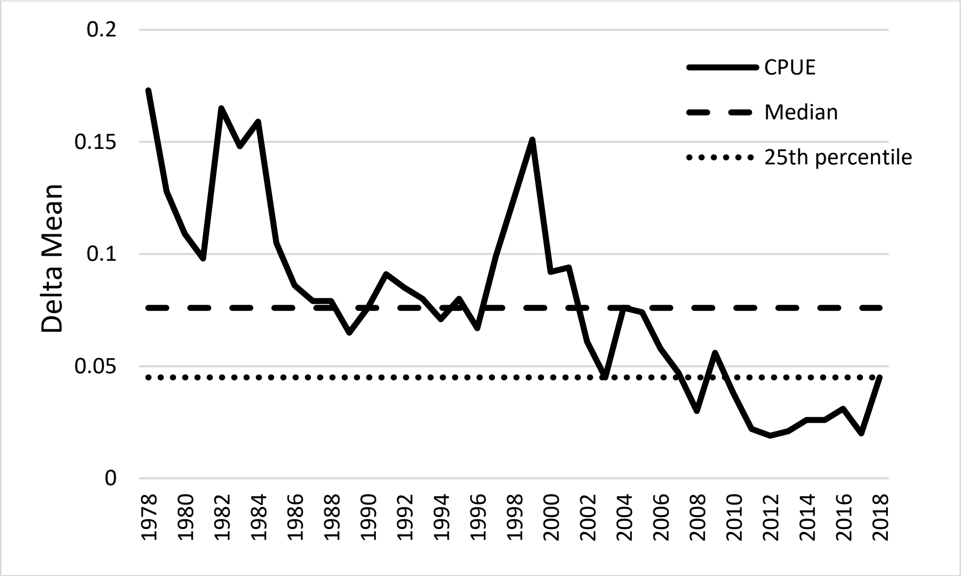

Figure 165. Average CPUE from the Millstone Power Station (Long Island Sound) ventless trap survey, 1978 to 2018. Time series median, and 25th percentile are also shown.

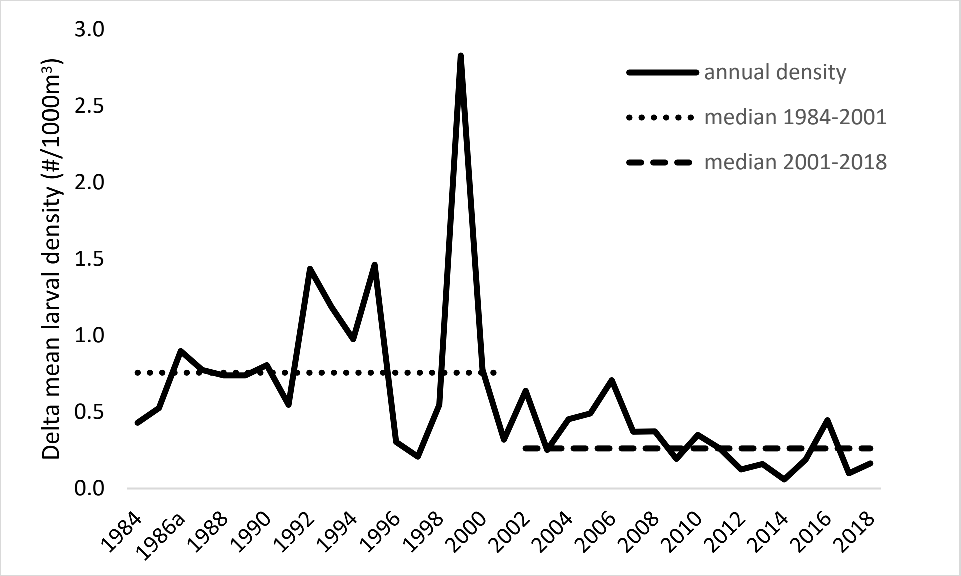

Figure 166. Average larval density (delta mean # larvae / 1000 m^3) from the Millstone Power Station (Long Island Sound) larval lobster entrainment index, 1984 to 2018.

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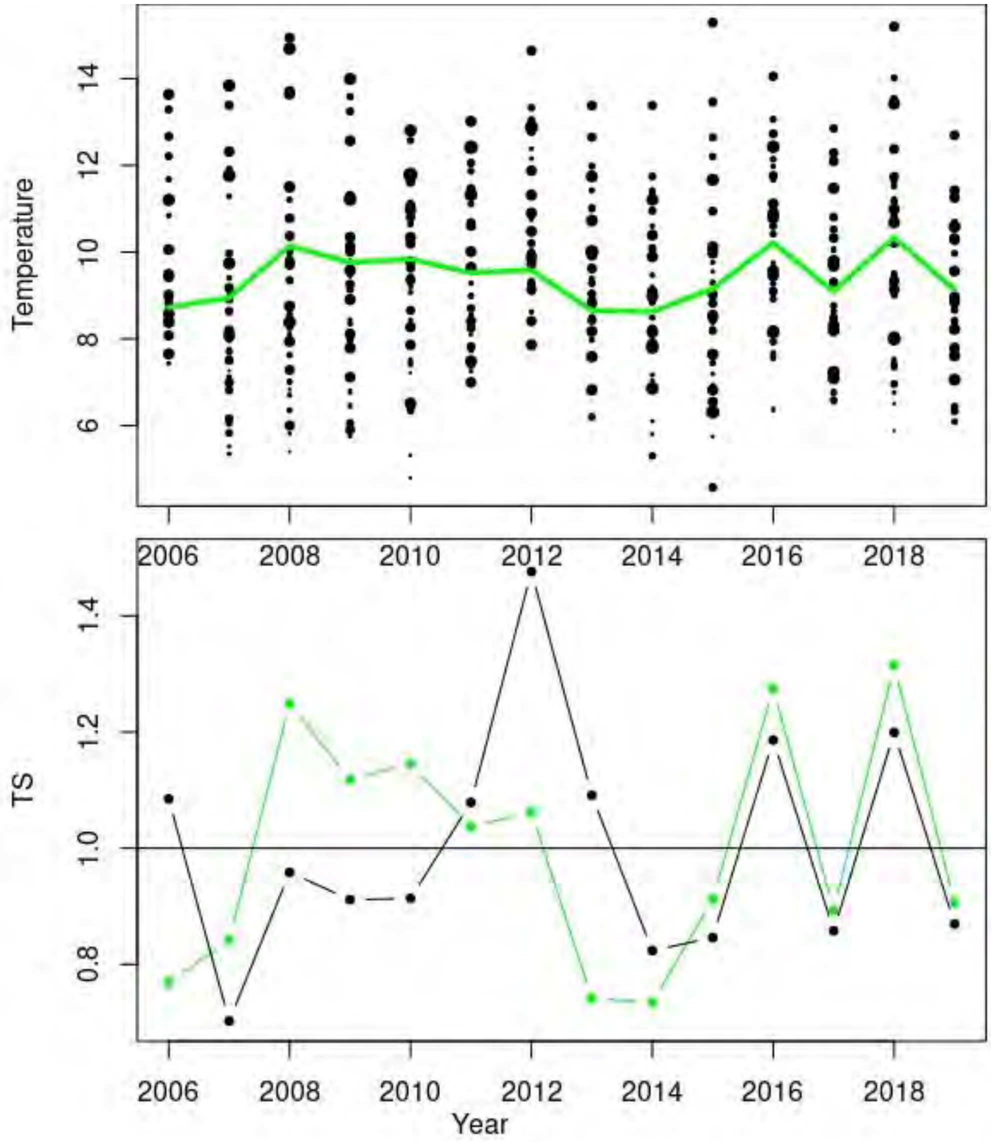

Figure 167. Temperature time series (top panel) and transformed temperature covariates (bottom panel) for the Gulf of Maine ventless trap survey. Black dots represent means for individual strata with dot size indicating weighting. Green time series is year-specific of weighted temperatures while the black time series (bottom panel) is the unweighted time series.

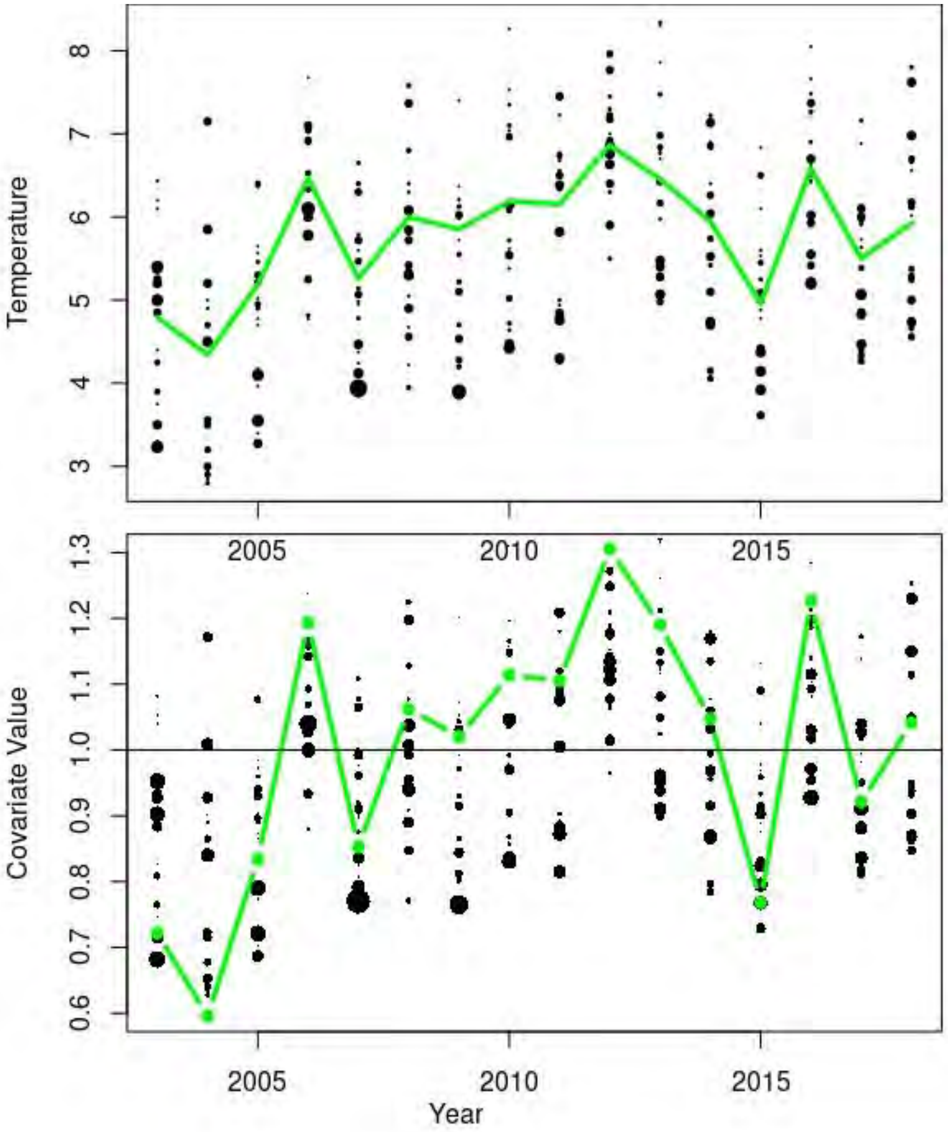

Figure 168. Spring temperature time series (top panel) and transformed temperature covariate (bottom panel) for the Maine / New Hampshire bottom trawl survey. Black dots represent means for individual strata with dot size indicating weighting. Green time series is year-specific means.

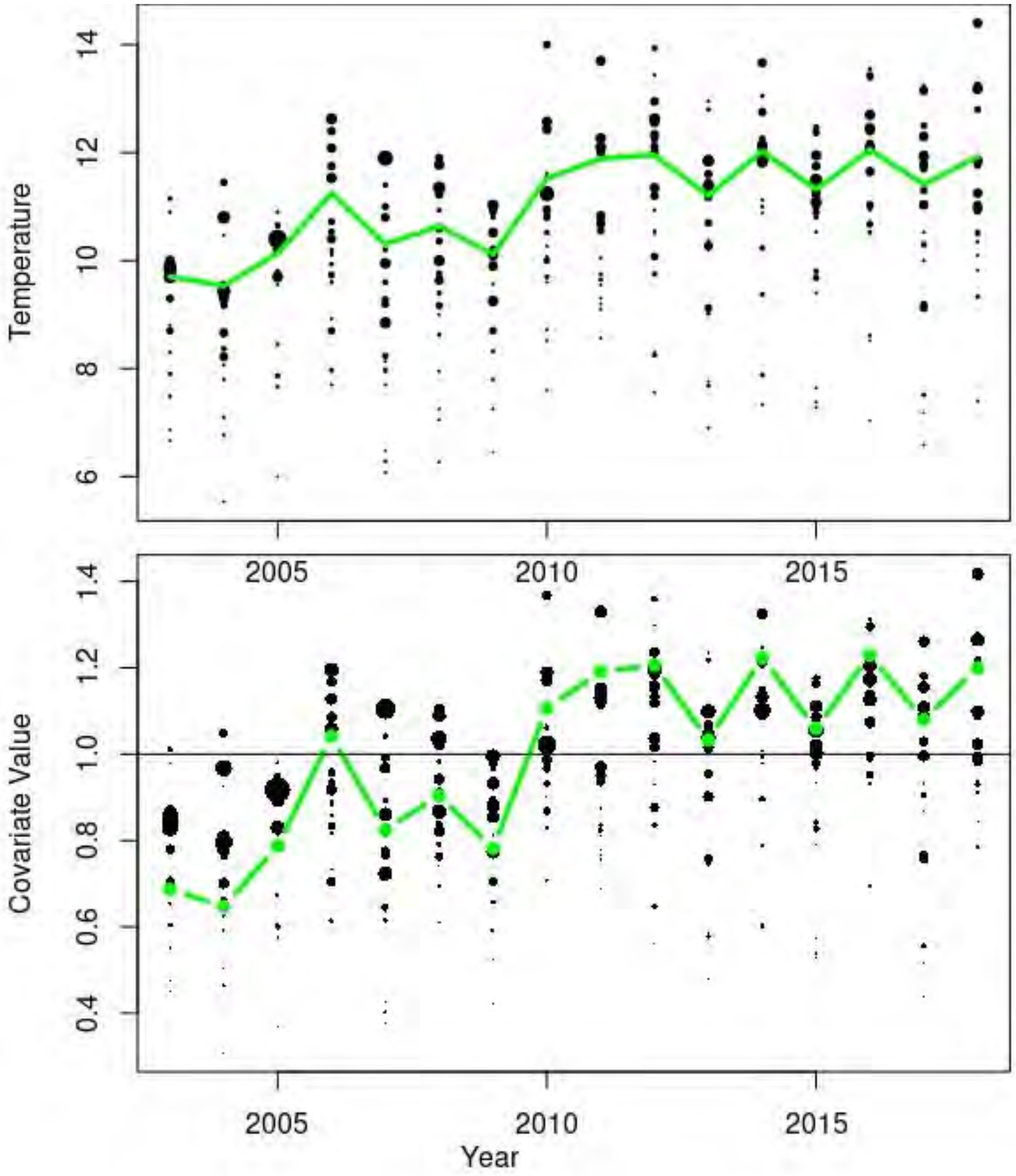

Figure 169. Fall temperature time series (top panel) and transformed temperature covariate (bottom panel) for the Maine / New Hampshire bottom trawl survey. Black dots represent means for individual strata with dot size indicating weighting. Green time series is year-specific means.

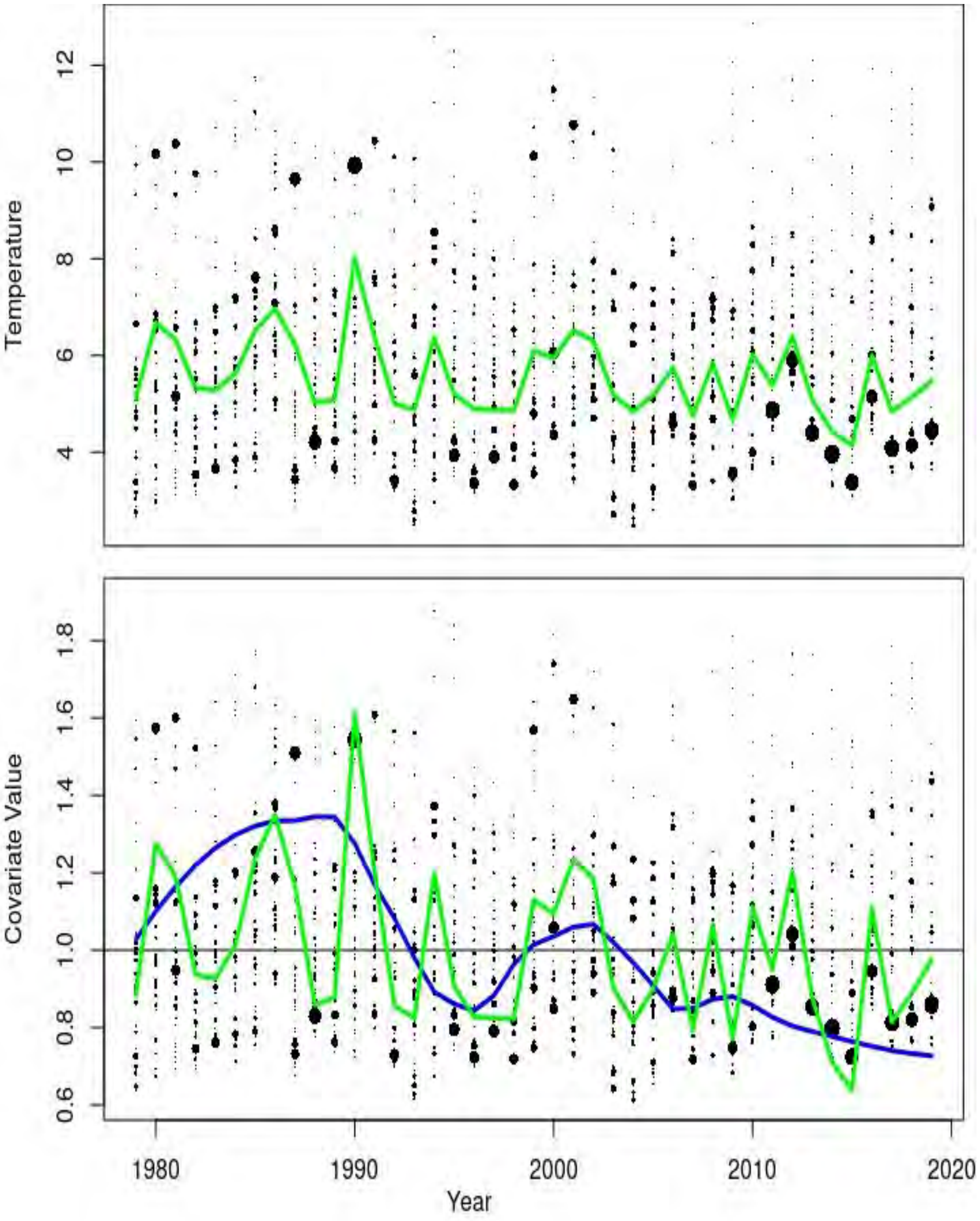

Figure 170. GOMGBK spring temperature time series (top panel) and transformed temperature covariate (bottom panel) for the NEFSC bottom trawl survey. Black dots represent means for individual strata with dot size indicating weighting. Green time series is year-specific calculations while the blue trend line is the result of a lowess smoother.

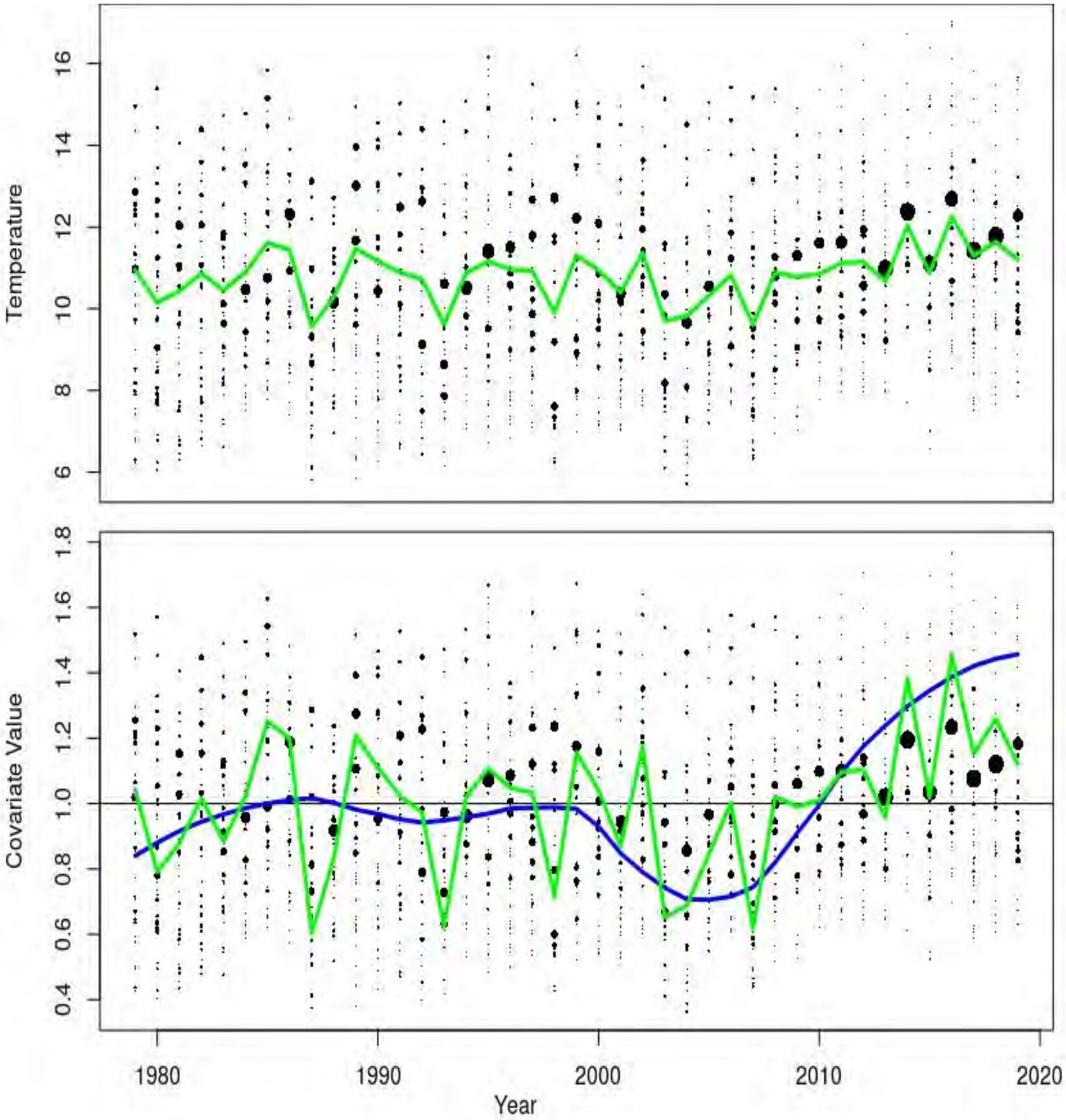

Figure 171. GOMGBK fall temperature time series (top panel) and transformed temperature covariate (bottom panel) for the NEFSC bottom trawl survey. Black dots represent means for individual strata with dot size indicating weighting. Green time series is year-specific calculations while the blue trendline is the result of a lowess smoother.

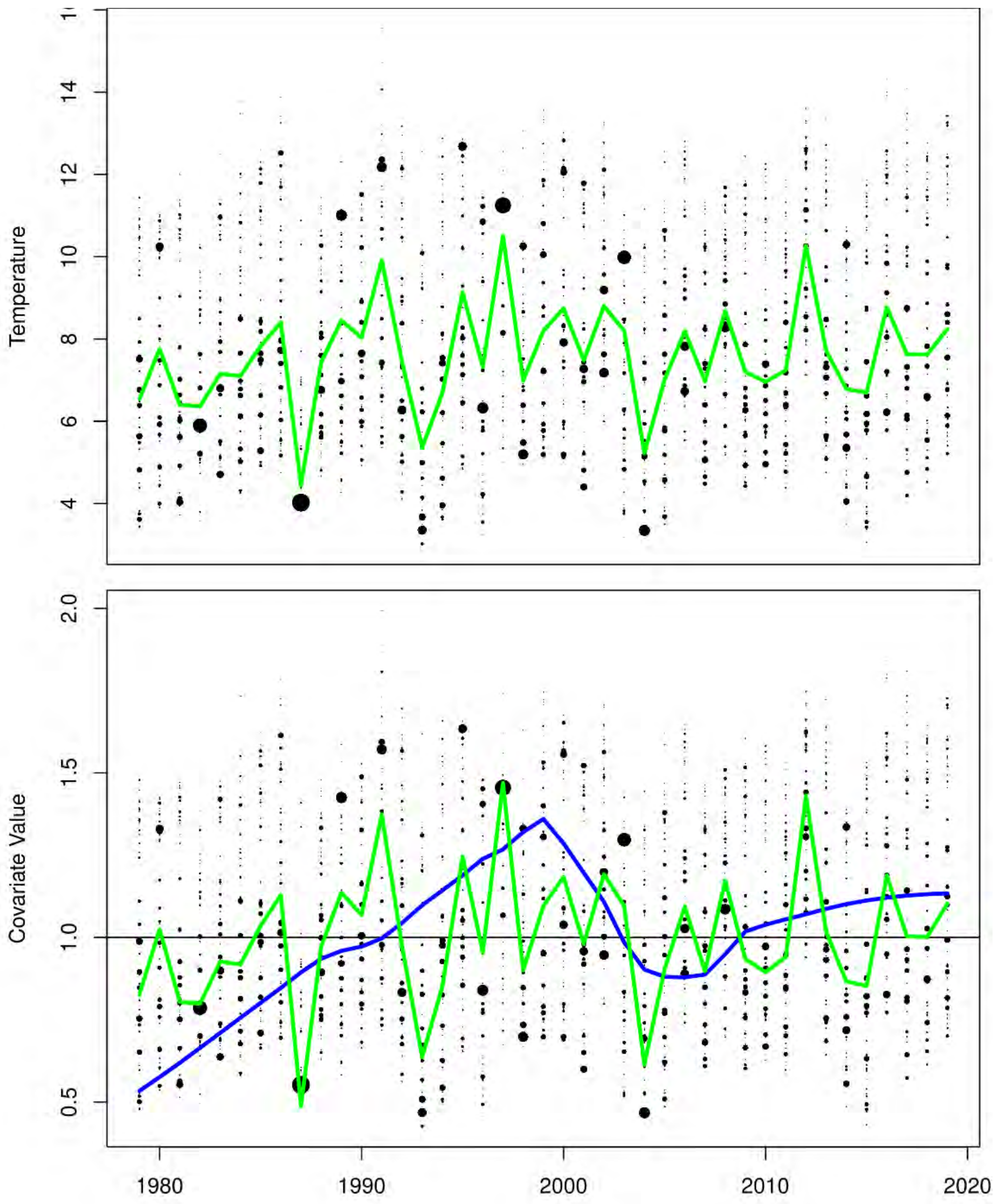

Figure 172. SNE spring temperature time series (top panel) and transformed temperature covariate (bottom panel) for the NEFSC bottom trawl survey. Black dots represent means for individual strata with dot size indicating weighting. Green time series is year-specific calculations while the blue trendline is the result of a lowess smoother.

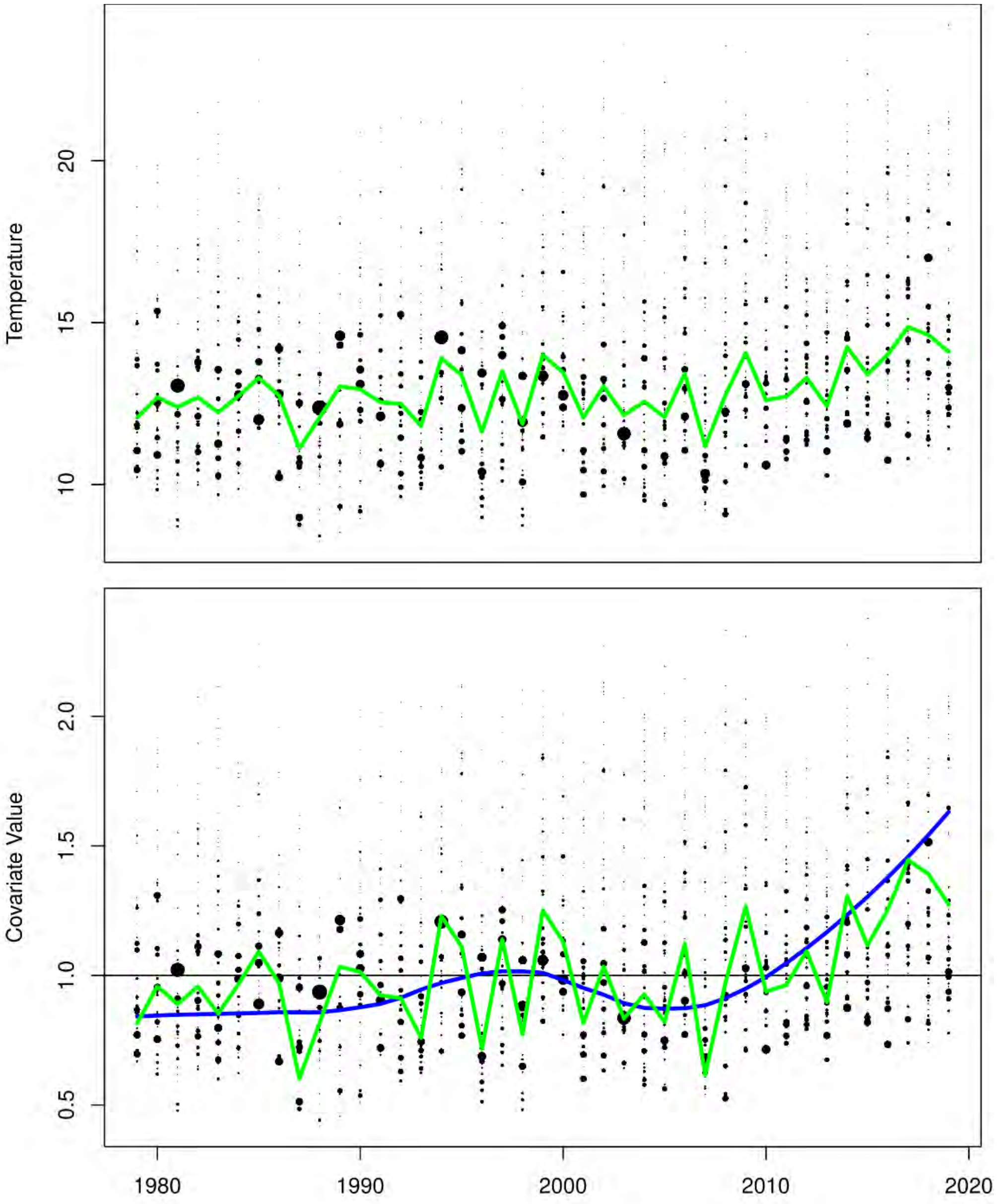

Figure 173. SNE fall temperature time series (top panel) and transformed temperature covariate (bottom panel) for the NEFSC bottom trawl survey. Black dots represent means for individual strata with dot size indicating weighting. Green time series is year-specific calculations while the blue trendline is the result of a lowess smoother.

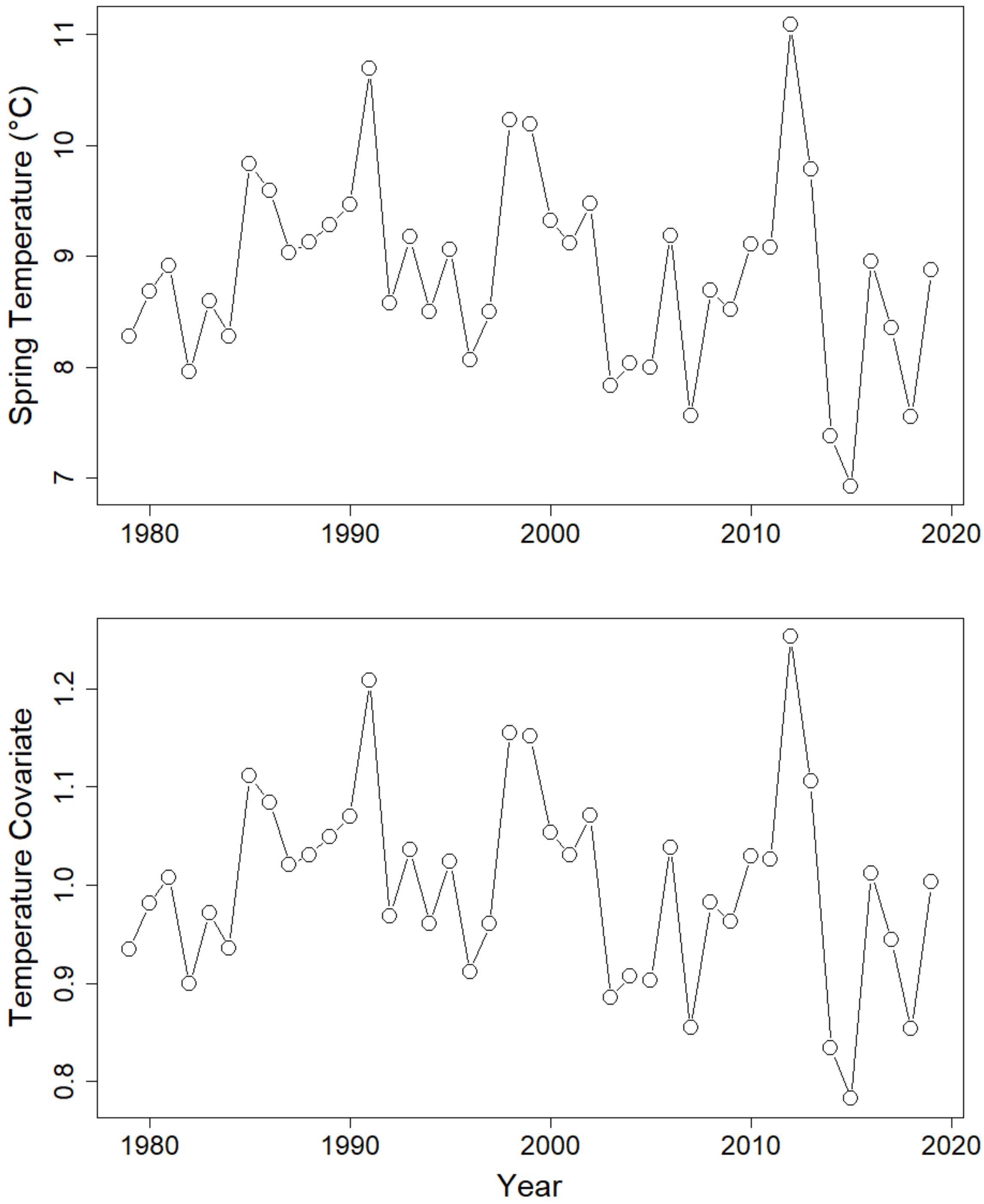

Figure 174. Mean spring (April-May) bottom temperature from the URI GSO survey (top) and the corresponding temperature covariate index (bottom).

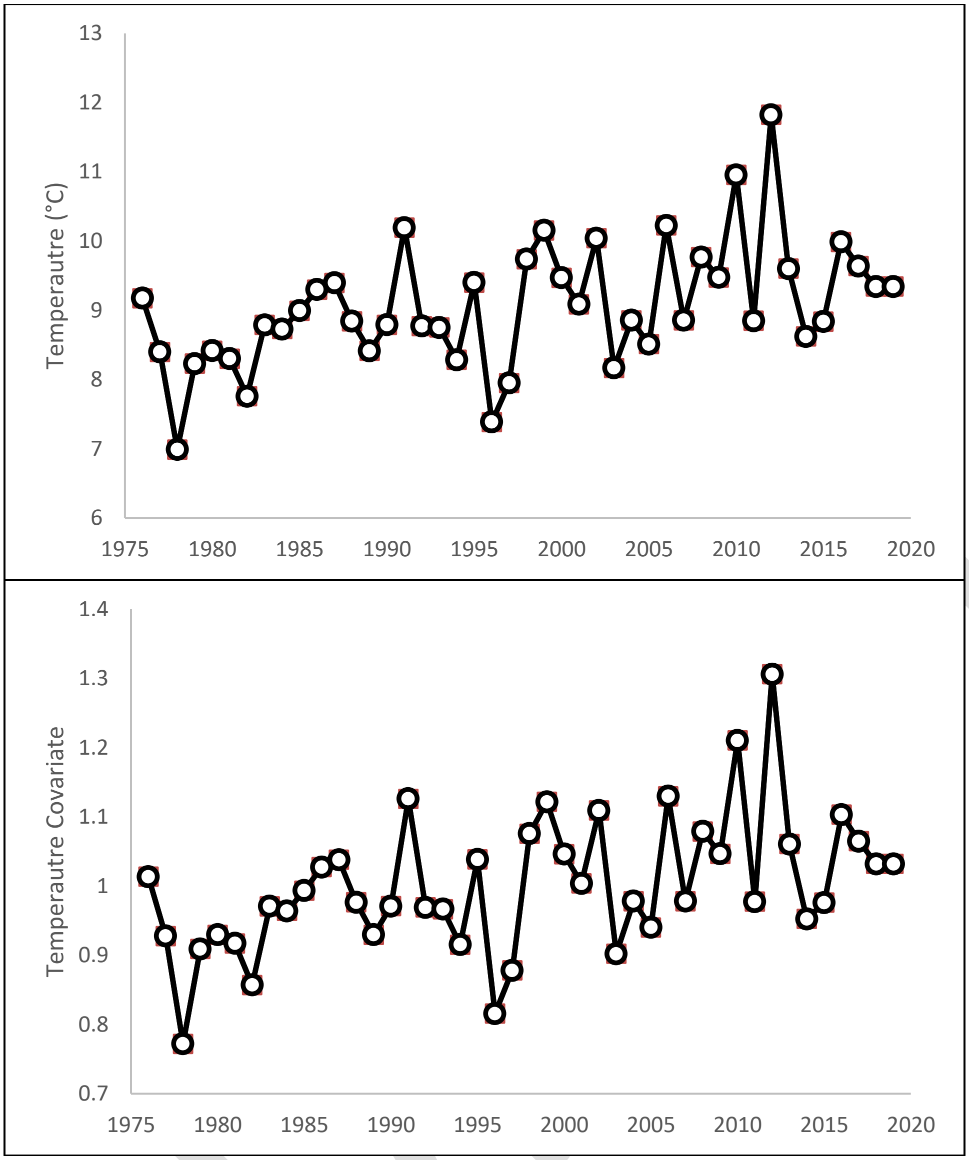

Figure 175. Mean spring (April-May) temperature from the Millstone Power Plant (top) and the corresponding temperature covariate index (bottom).

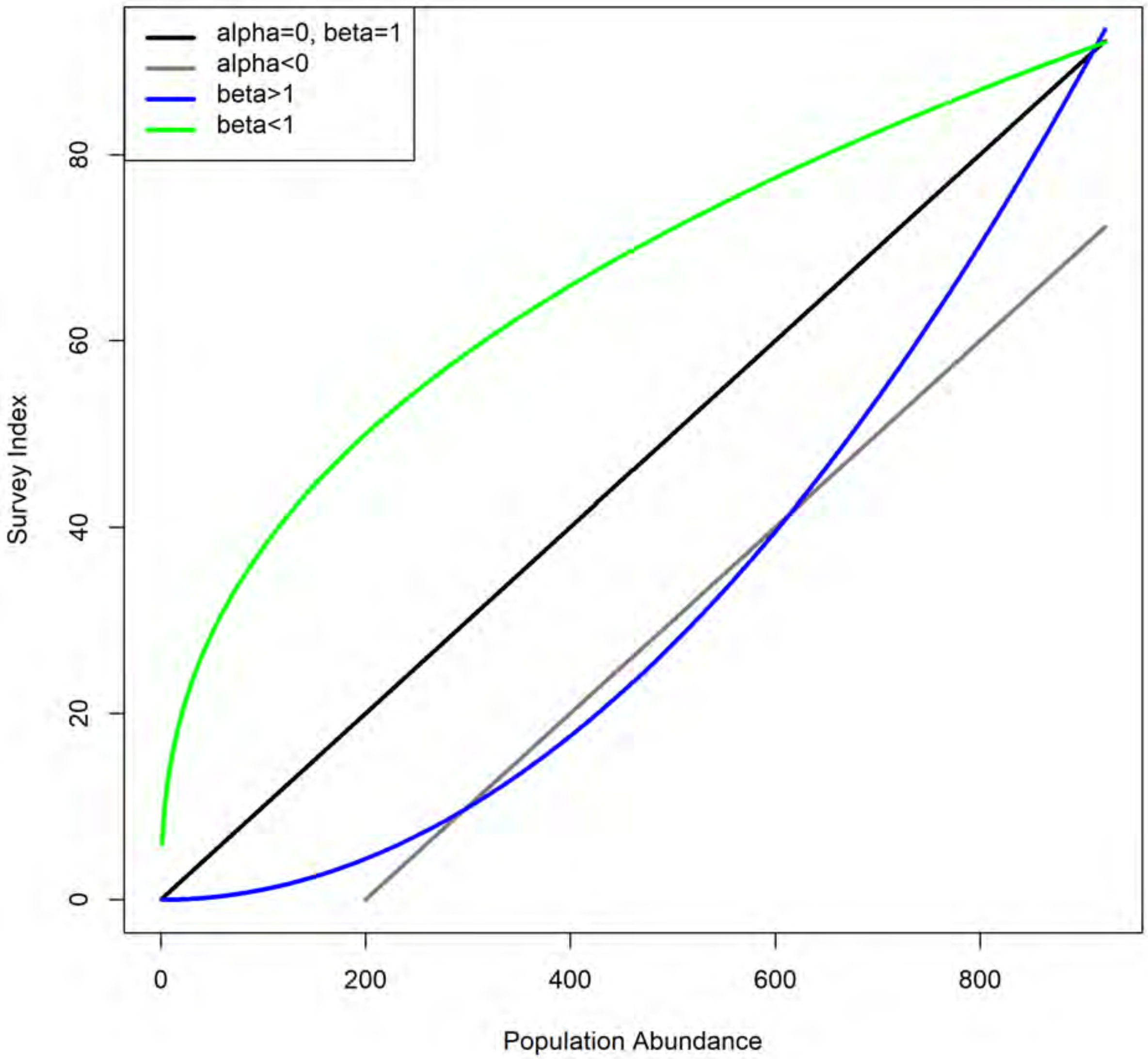

Figure 176. Examples of density-dependent survey catchability. Alpha=0 and beta=1 results in a standard, linear relationship between population abundance and catchability. Beta>1 creates a hyperdepletion response curve while beta<1 produces a hyperstable response. Alpha<0 would be an offset where a survey could reach zero catch despite a non-zero population abundance.

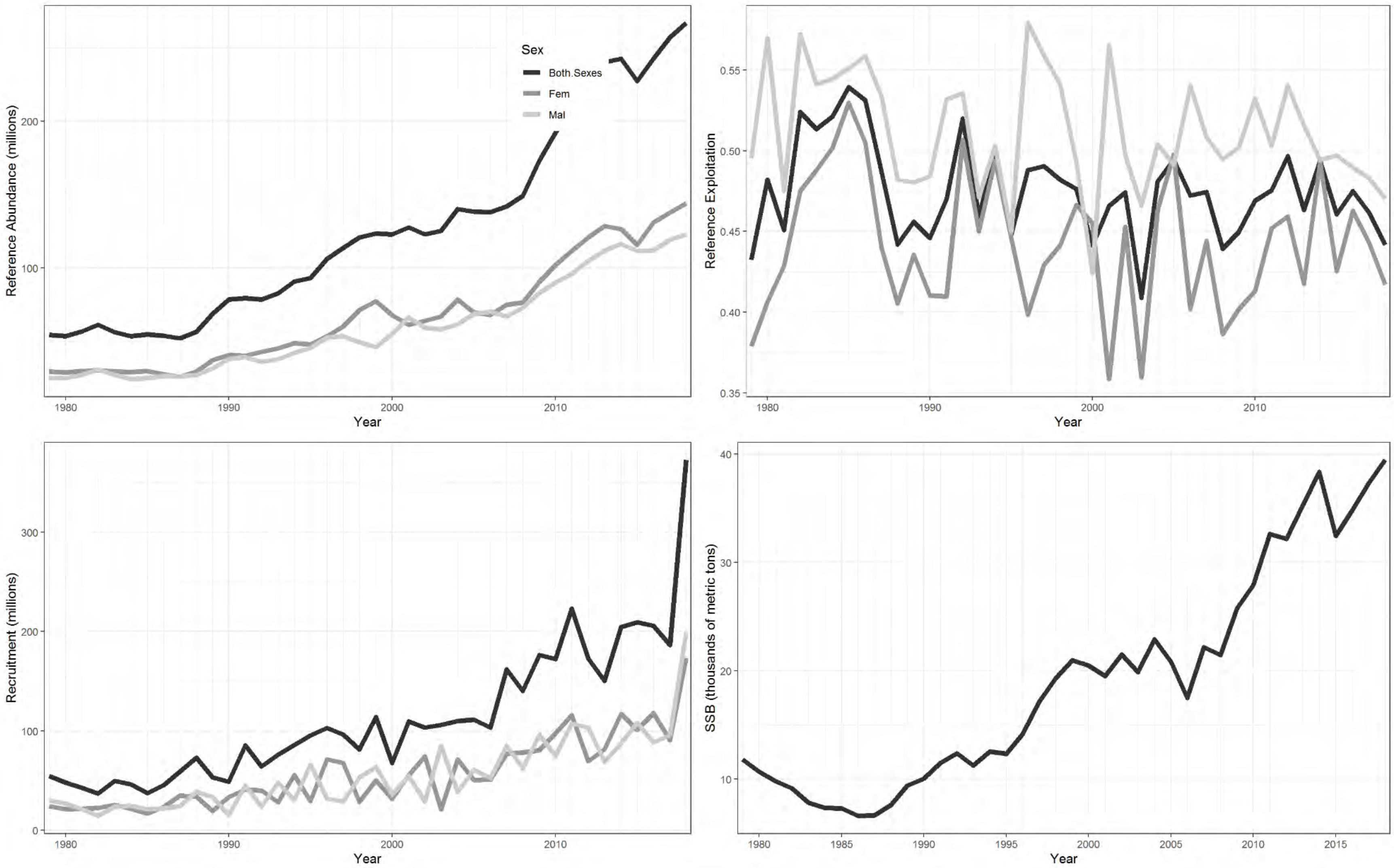

Figure 177. Reference abundance, effective exploitation, recruitment, and spawning stock biomass (SSB) estimates for GOMGBK American lobster during 1979-2018 from the basecase model. SSB represents female values in quarter three, while others indicate annual values by sex as specified.

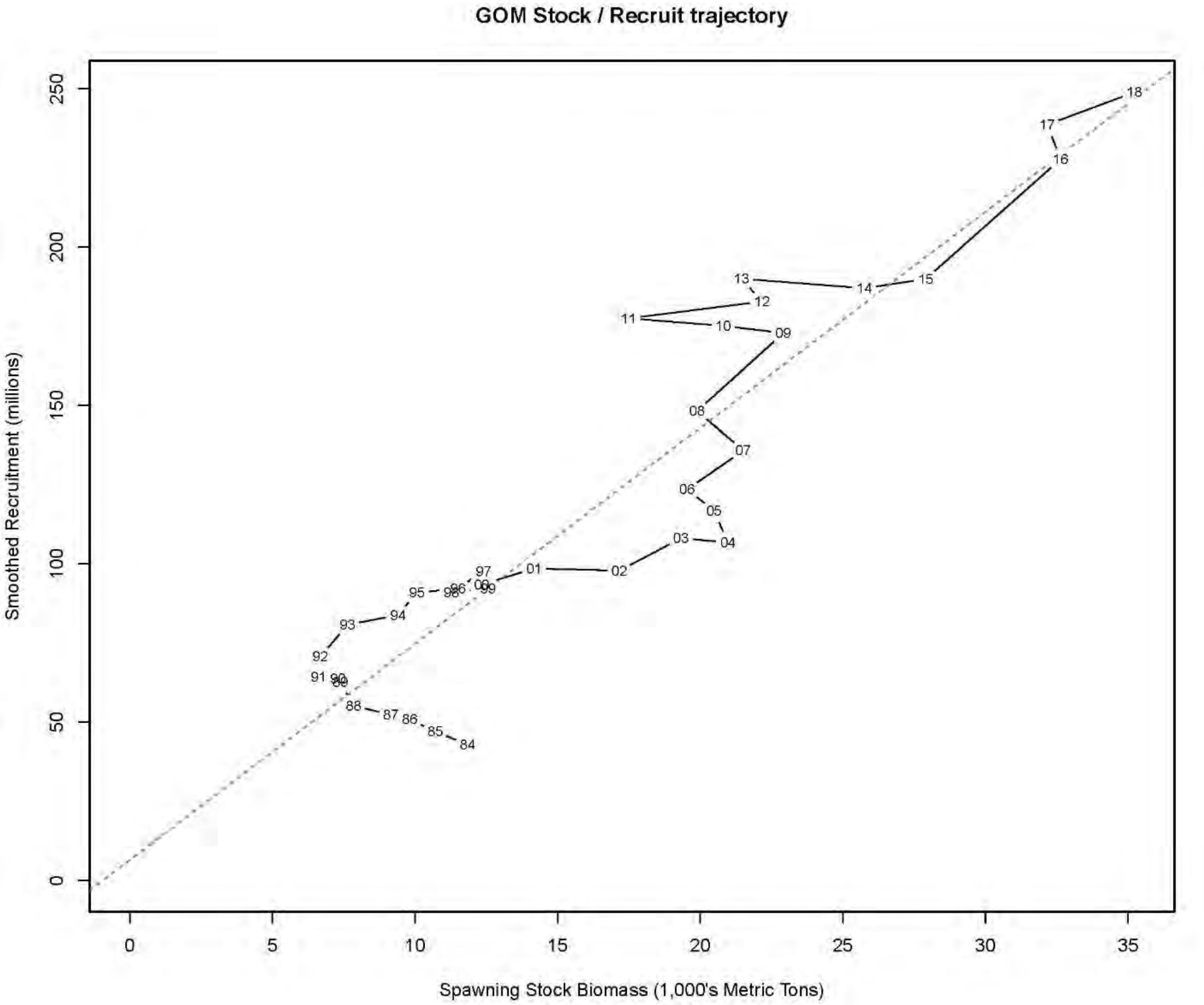

Figure 178. Stock-recruit trajectory for the GOMGBK stock. Marker numbers indicate recruitment year with SSB lagged by five years. Dotted line indicates the mean trend.

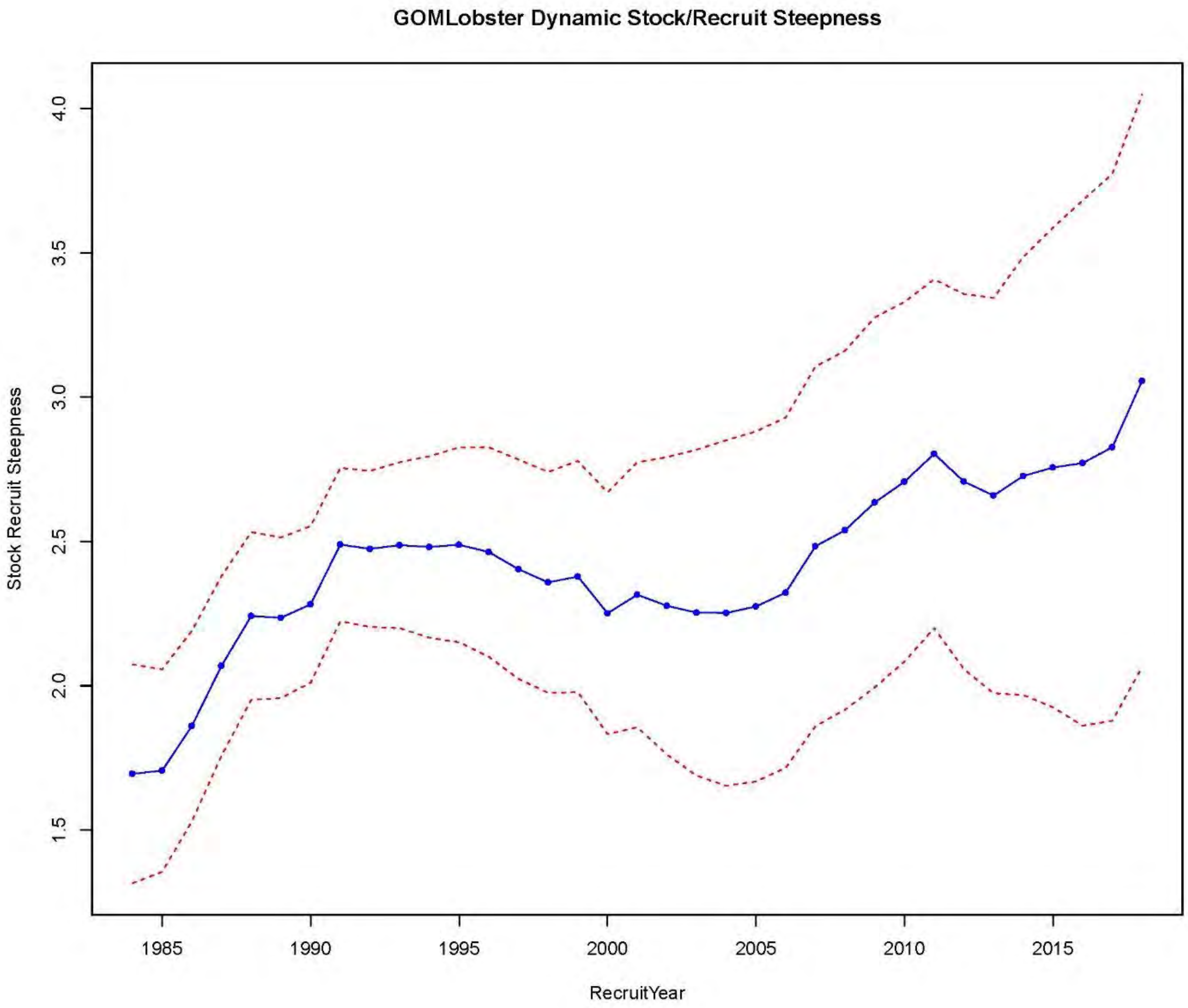

Figure 179. State-space trajectory of stock-recruit steepness (α_y-parameters) with confidence intervals for the GOMGBK stock.

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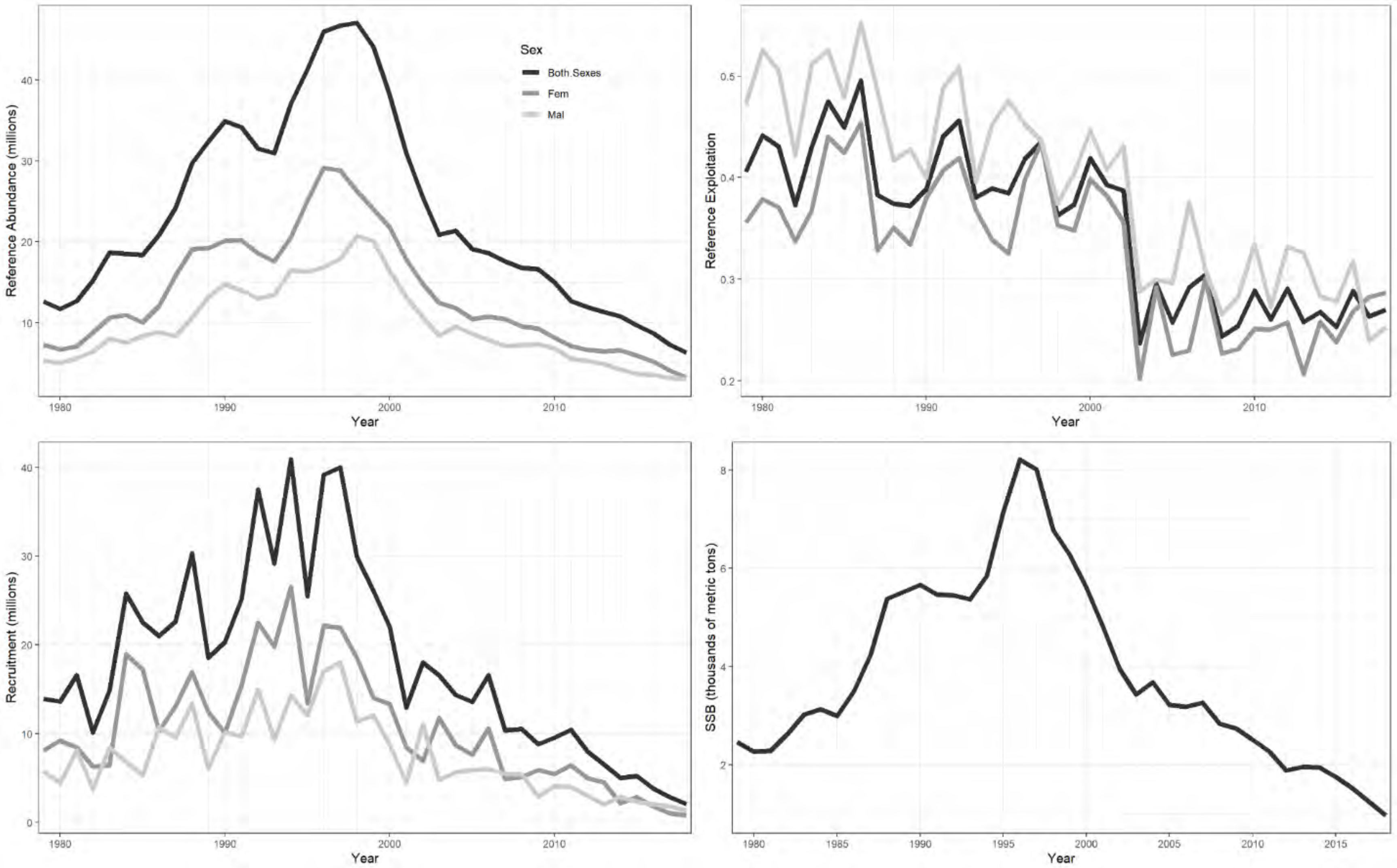

Figure 180. Reference abundance, effective exploitation, recruitment, and spawning stock biomass (SSB) estimates for SNE American lobster during 1979-2018 from the basecase model. SSB represents female values in quarter three, while others indicate annual values by sex as specified.

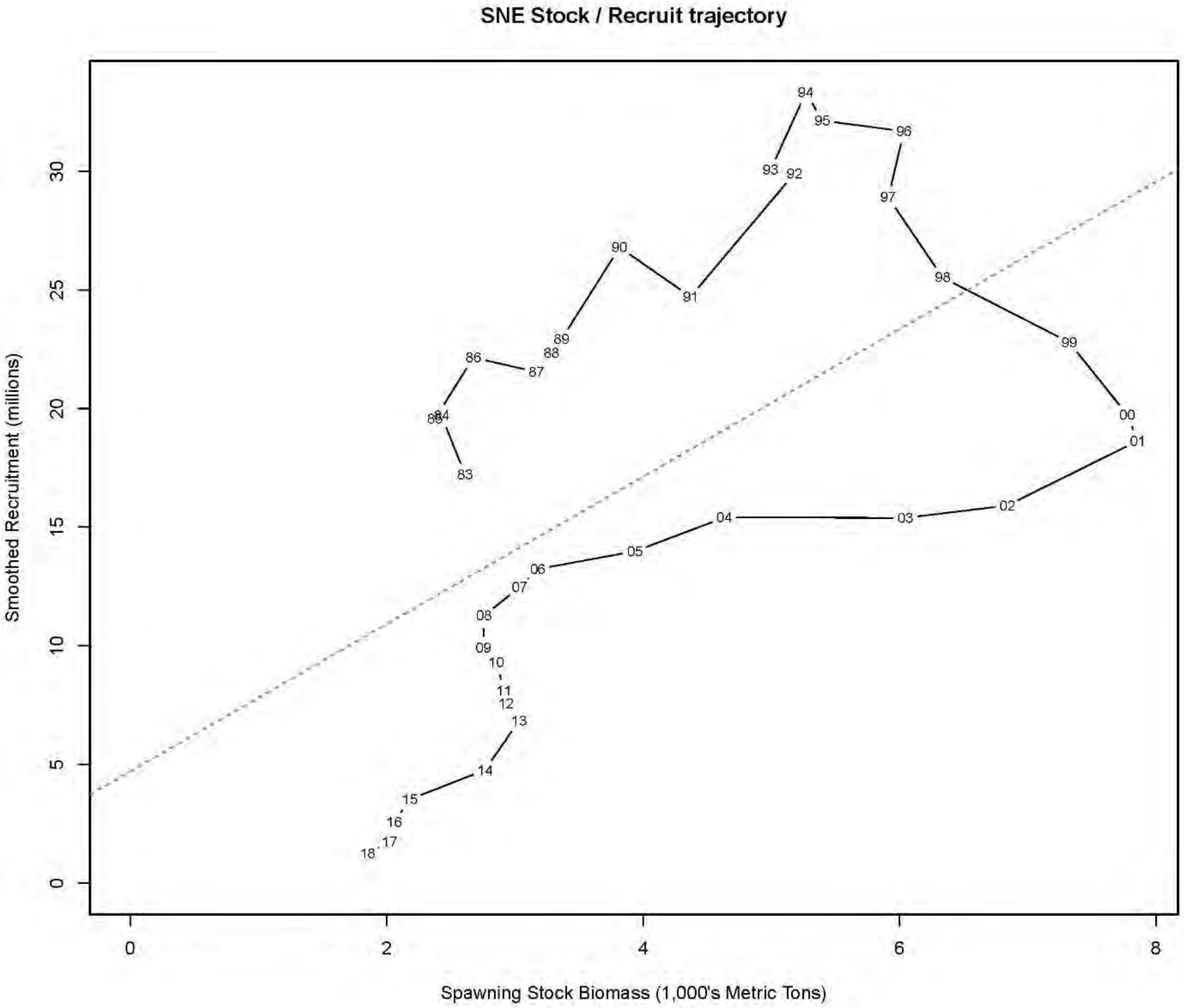

Figure 181. Stock-recruit trajectory for SNE stock. Marker numbers indicate recruitment year with SSB lagged by four years. The dotted line indicates the mean trend.

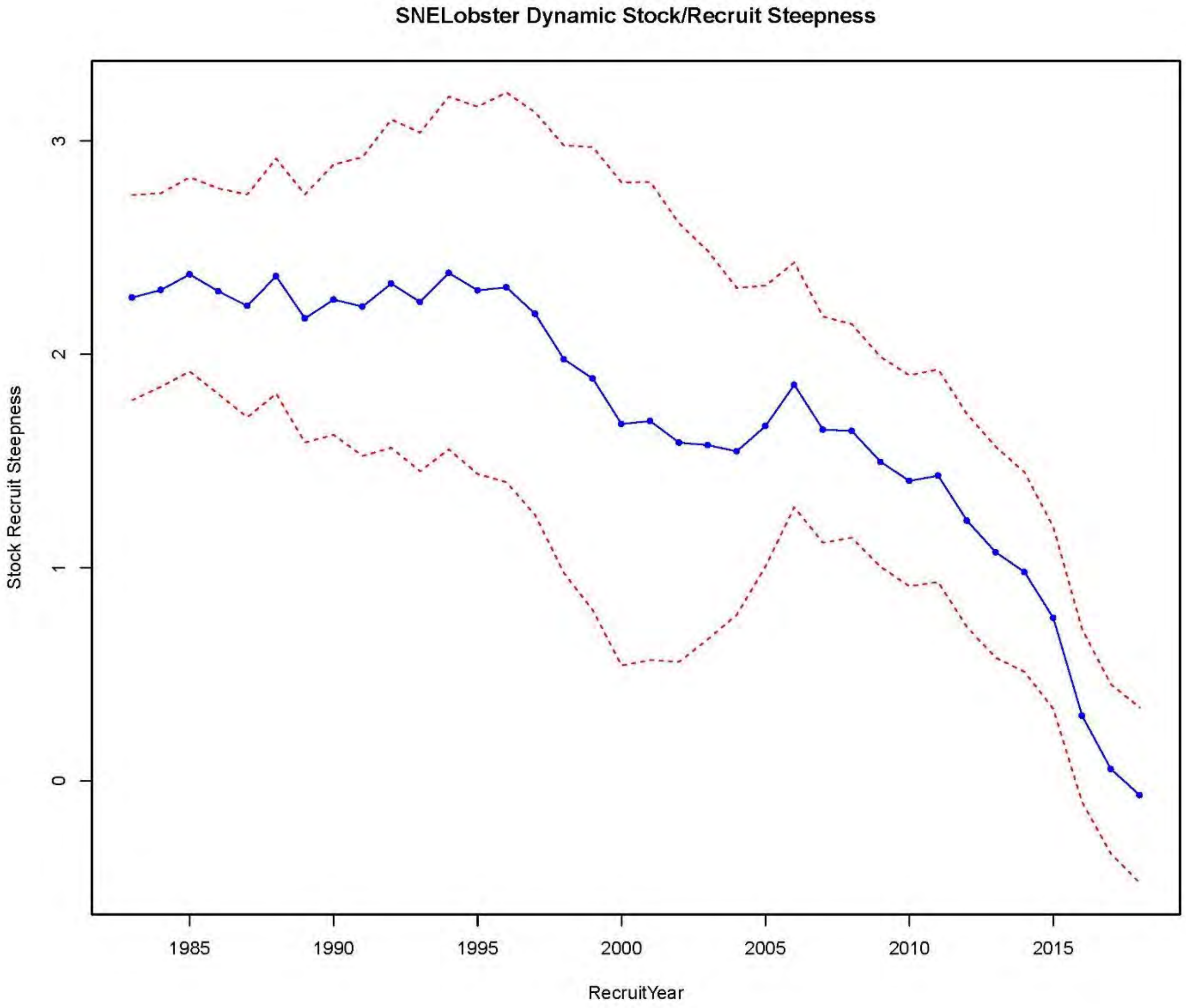

Figure 182. State-space trajectory of stock-recruit steepness (α_y-parameters) with confidence intervals for the SNE stock.

D

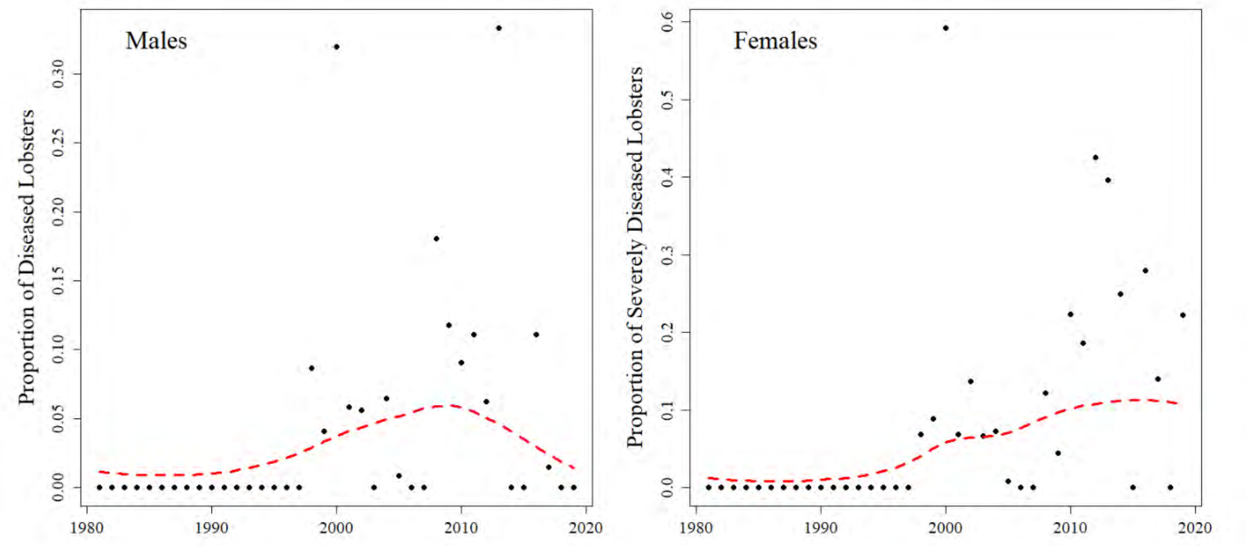

Figure 183. Proportions of lobsters severely diseased in the Rhode Island Department of Environmental Management Spring Trawl Survey. Severely diseased excludes lobsters characterized as mildly diseased (i.e. includes disease codes 2 and 3 only).

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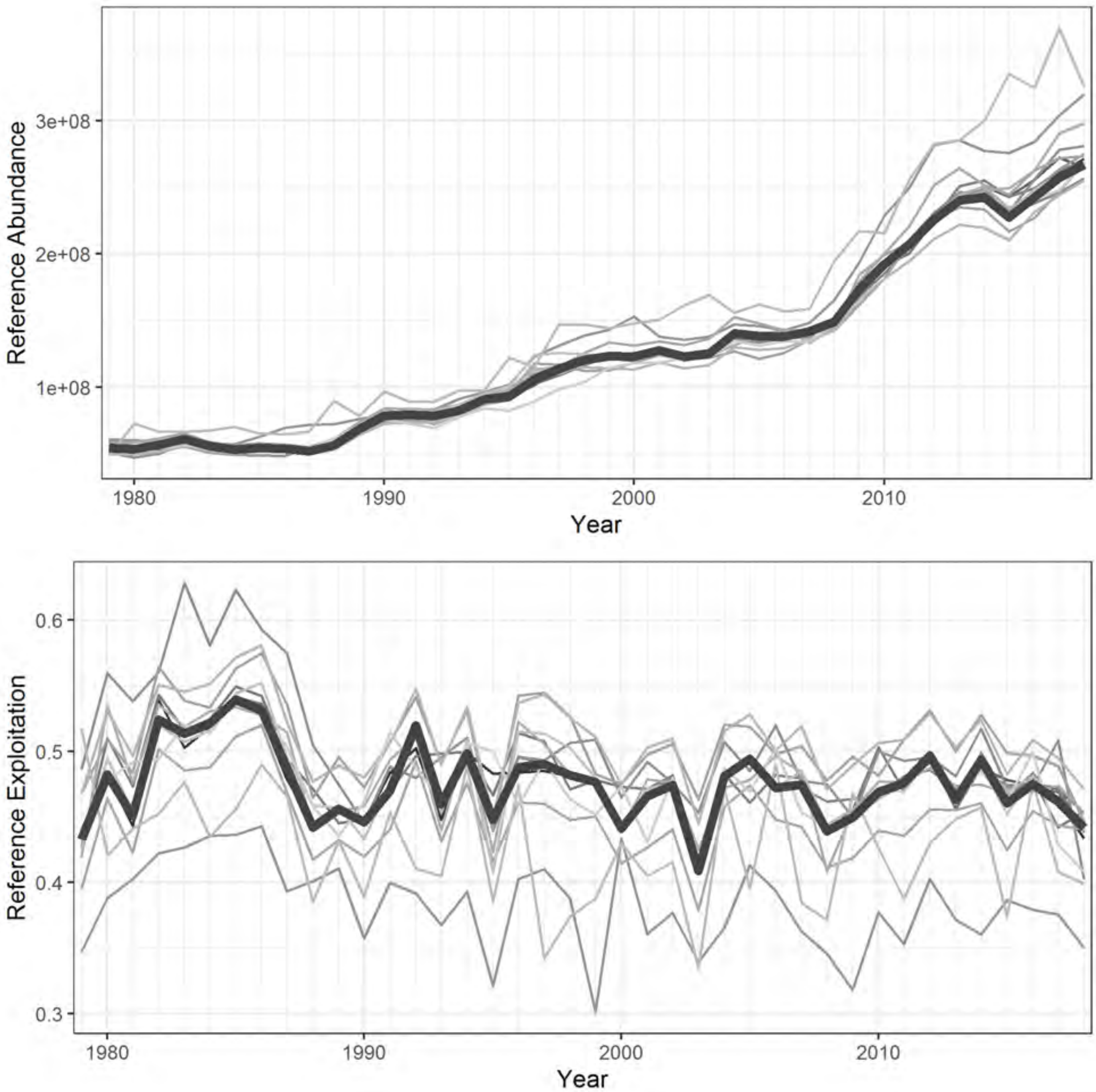


Figure 184. GOMGBK annual reference abundance and effective exploitation for the basecase model and sensitivity analyses. The basecase model is represented in bold lines with sensitivities in thin lines.

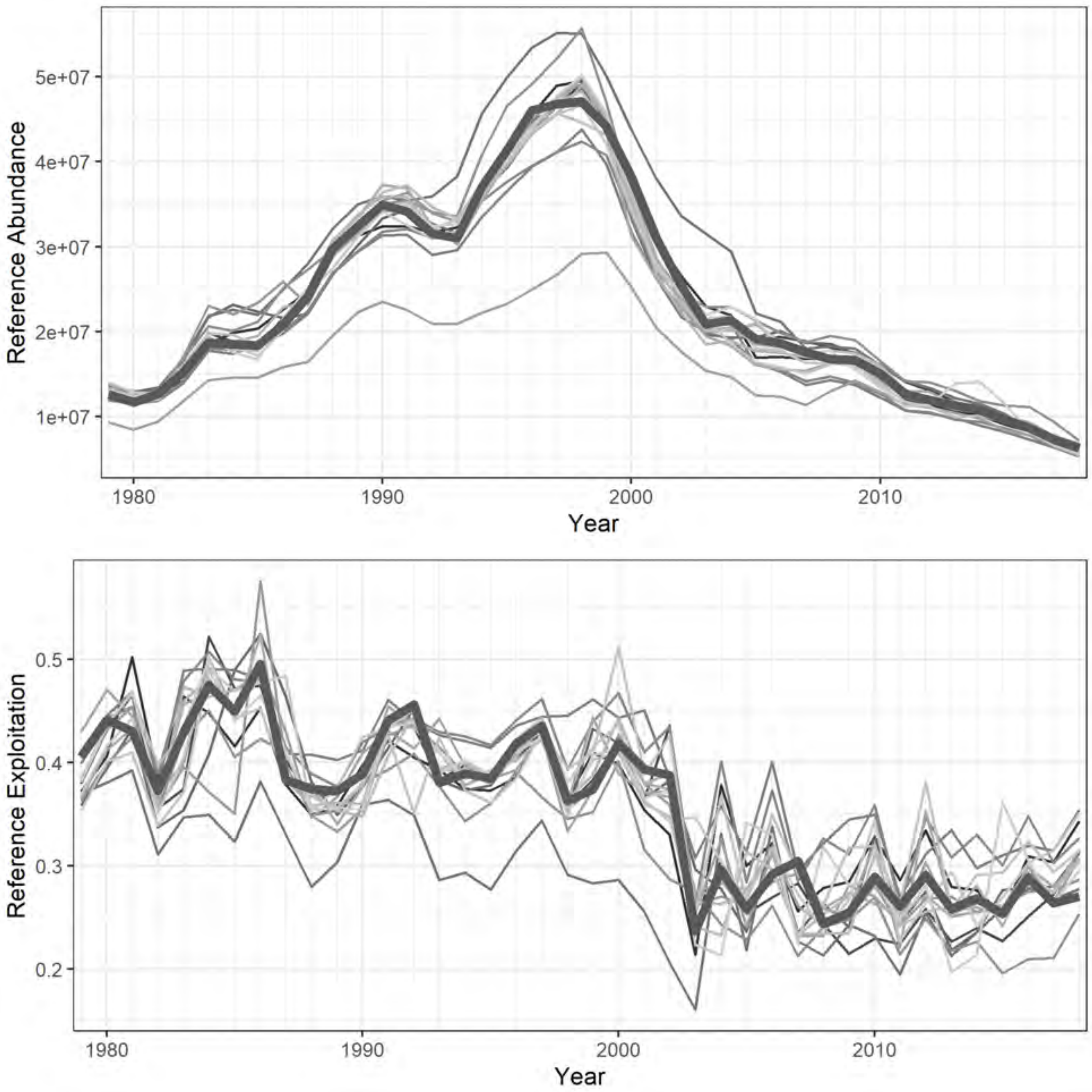


Figure 185. SNE annual reference abundance and effective exploitation for the basecase model and sensitivity analyses. The basecase model is represented in bold lines with sensitivities in thin lines.

Figure 186. Annual reference abundance, effective exploitation, and recruitment estimates for GOMGBK American lobster during 1979-2018 from the basecase model (grey) and 1979-2013 from the previous assessment (ASMFC 2015a, black).

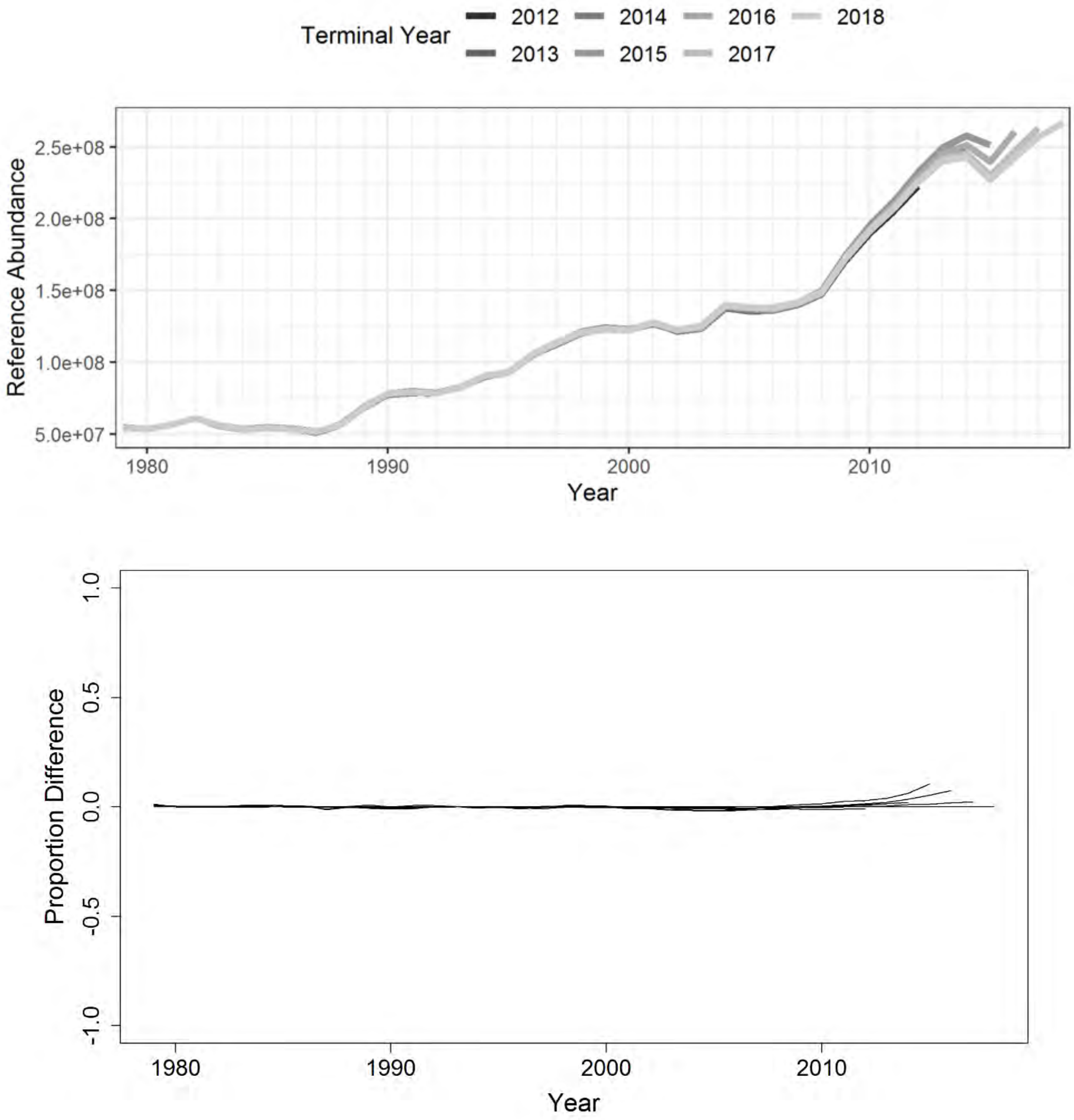


Figure 187. Retrospective analysis for GOMGBK lobster reference abundance estimates from the basecase model. The top figure highlights the absolute reference abundance trajectories for the peels, and the bottom figure indicates the proportional annual differences for peels from the basecase scenario.

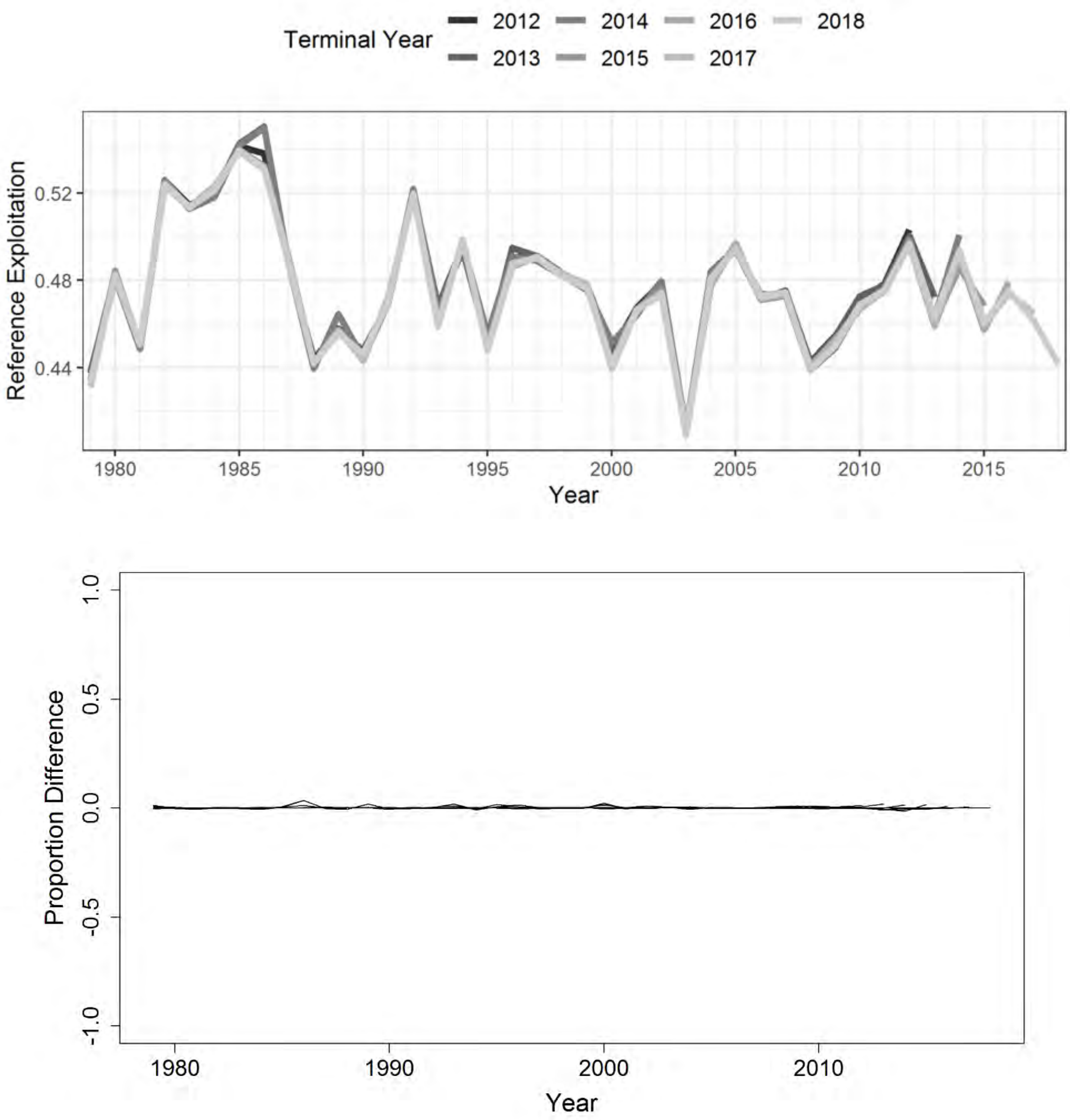


Figure 188. Retrospective analysis for GOMGBK lobster exploitation estimates from the basecase model. The top figure highlights the absolute exploitation trajectories for the peels, and the bottom figure indicates the proportional annual differences for peels from the basecase scenario.

Figure 189. Annual reference abundance, effective exploitation, and recruitment estimates for SNE American lobster during 1979-2018 from the basecase model (grey) and 1979-2013 from the previous assessment (ASMFC 2015a, black).

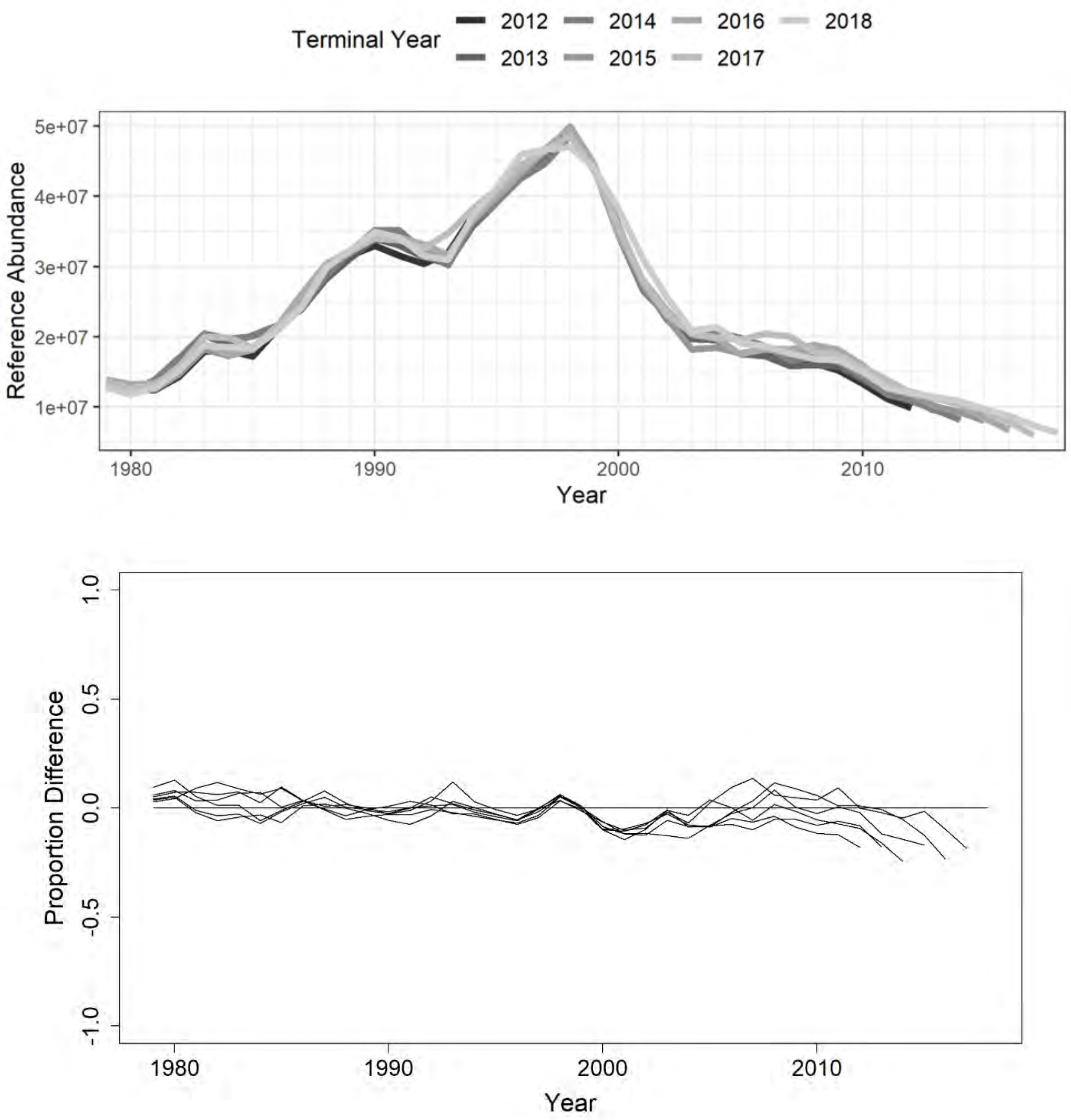
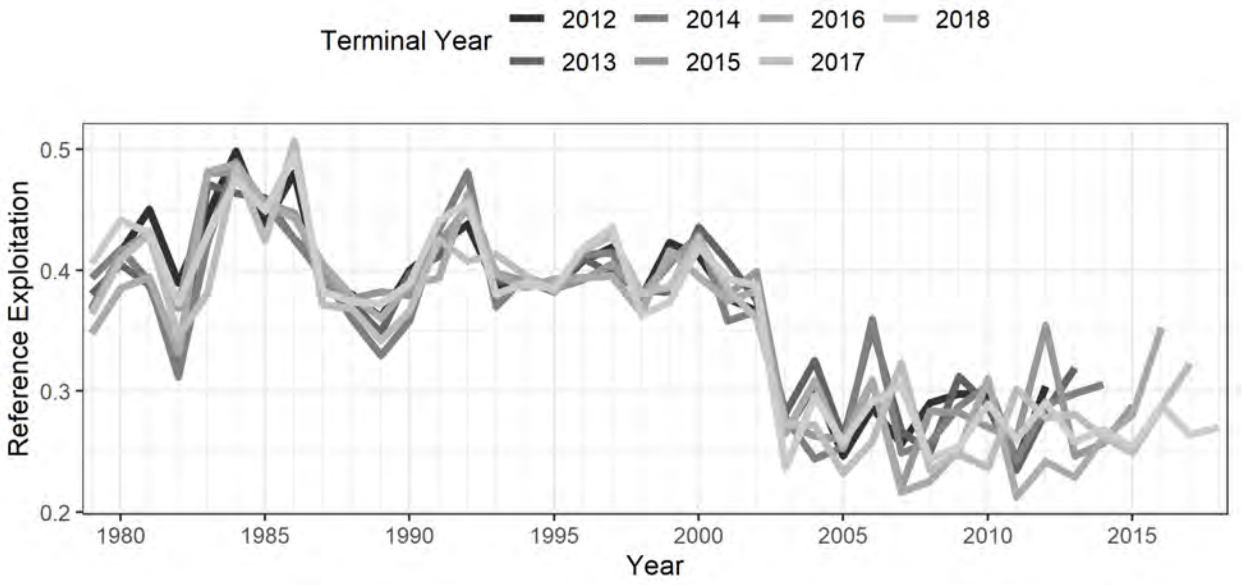


Figure 190. Retrospective analysis for SNE lobster reference abundance estimates from the basecase model. The top figure highlights the absolute reference abundance trajectories for the peels, and the bottom figure indicates the proportional annual differences for peels from the basecase scenario.



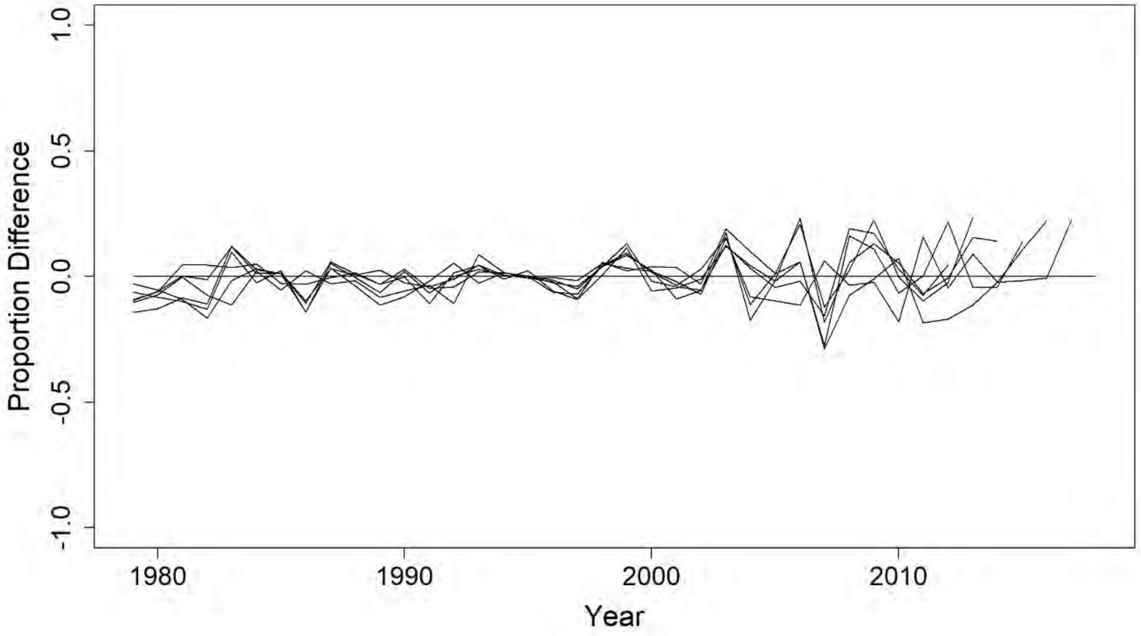


Figure 191. Retrospective analysis for SNE lobster exploitation estimates from the basecase model. The top figure highlights the absolute exploitation trajectories for the peels, and the bottom figure indicates the proportional annual differences for peels from the basecase scenario.

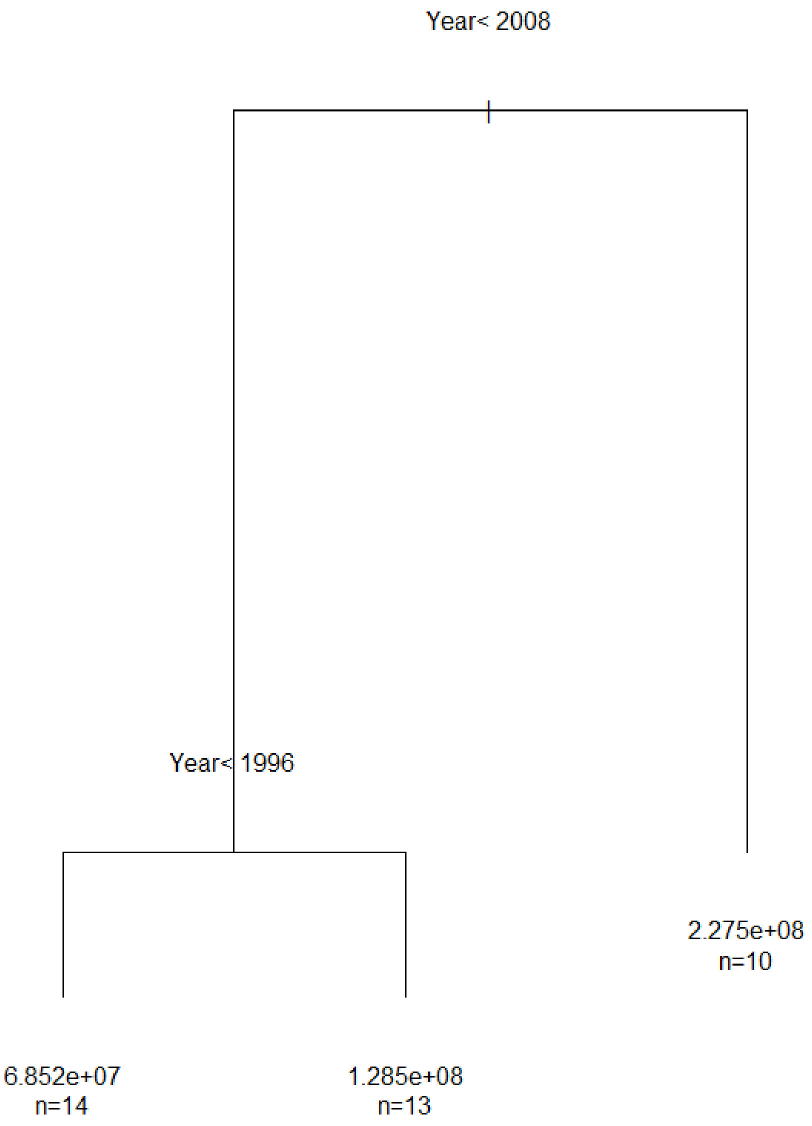


Figure 192. rpart analysis classification tree estimated from 1982-2018 GOMGBK stock reference abundance. The years show splits in regimes detected with the analysis and the values at the base of each branch show the mean reference abundance (top value) and number of years (bottom value) to each side of the split (i.e., regime). The number of years were used to define break points (i.e., the 14 years under the leftmost node correspond to 1982-1995, the 13 years under the middle node correspond to 1996-2008, and the 10 years under the rightmost node correspond to 2009-2018).

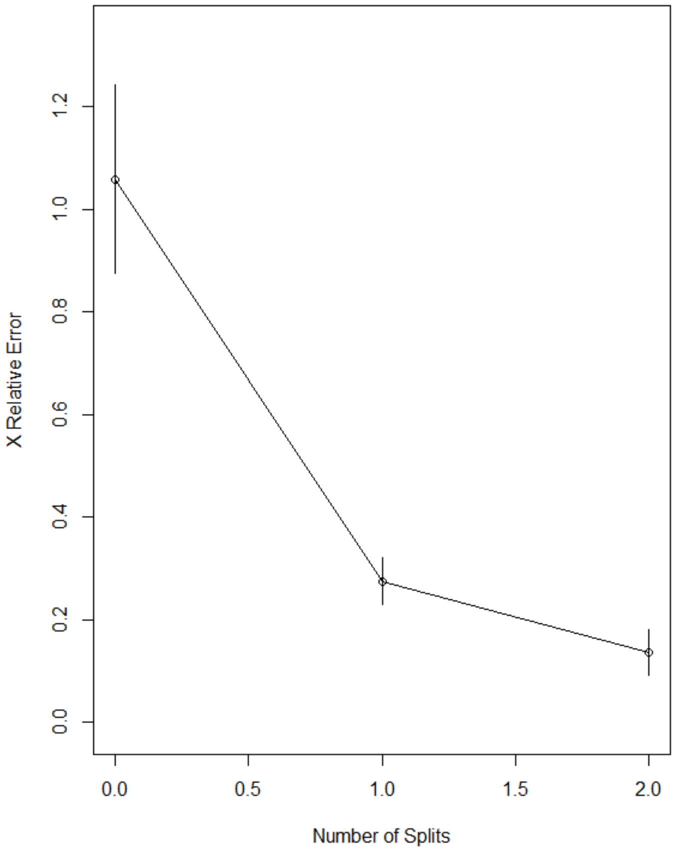


Figure 193. Error from cross-validation in the rpart analysis of 1982-2018 GOMGBK stock reference abundance. Circles are the mean estimate of the cross-validation error and error bars are +/- 1 standard error.

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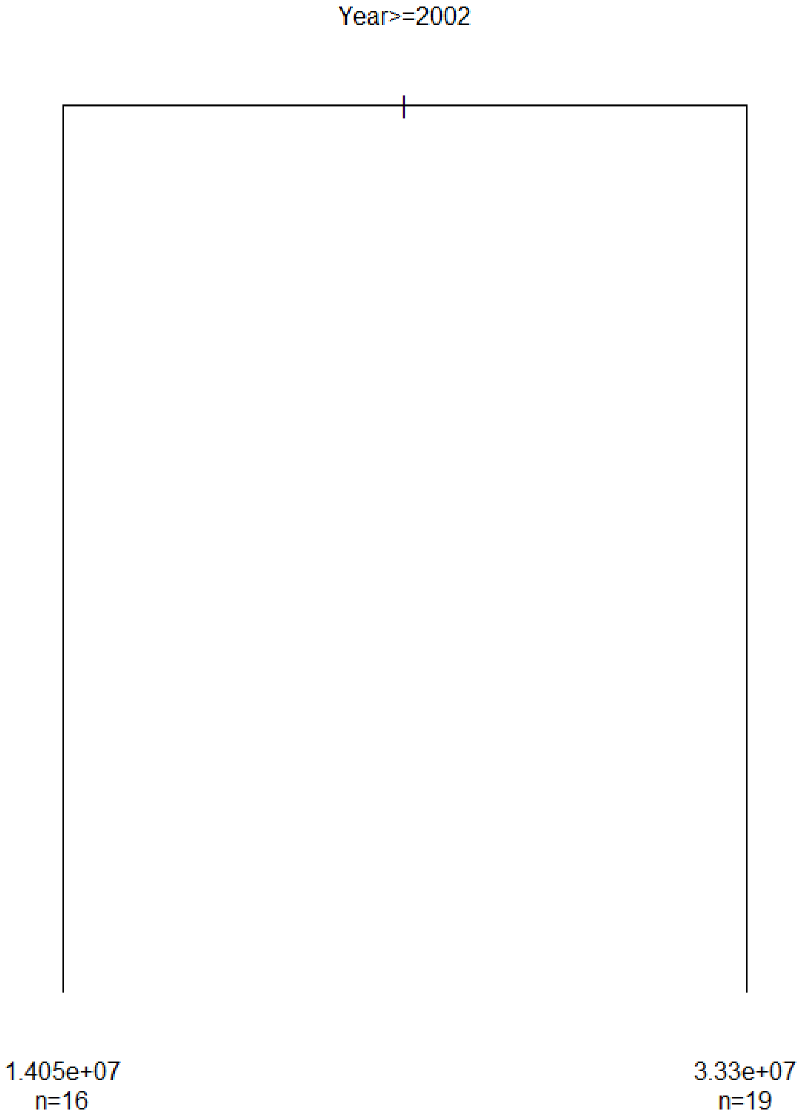

Figure 194. rpart analysis classification tree estimated from 1984-2018 SNE stock reference abundance. The year shows the split in regimes detected with the analysis and the values at the base of each branch show the mean reference abundance (top value) and number of years (bottom value) to each side of the split (i.e., regime). The number of years were used to define break points (i.e., the 16 years under the left node correspond to 2003-2018 and the 19 years under the right node correspond to 1984-2002).

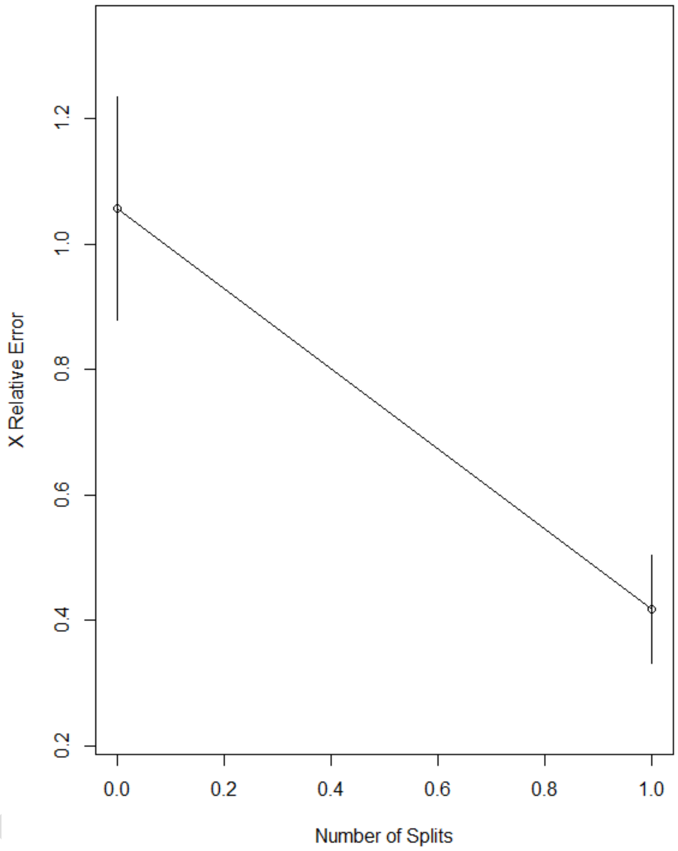

Figure 195. Error from cross-validation in the rpart analysis of 1984-2018 SNE stock reference abundance. Circles are the mean estimate of the cross-validation error and error bars are +/- 1 standard error.

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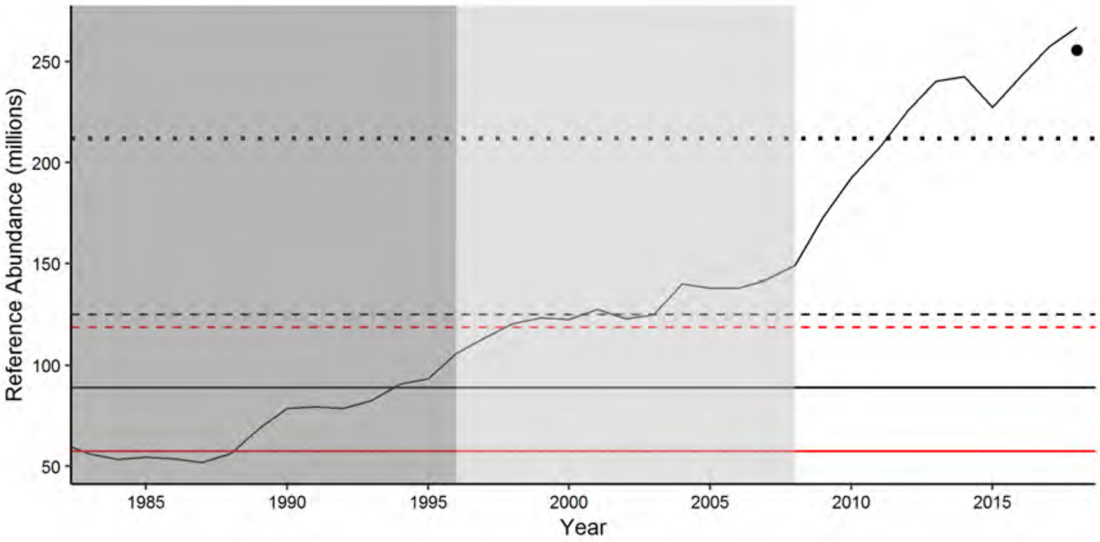

Figure 196. GOMGBK stock reference abundance compared to current (black horizontal lines) and previous (red horizontal lines) reference points. The current reference points include the Fishery/Industry Target (dotted black line), Abundance Limit (dashed black line), and Abundance Threshold (solid black line) based on detected low (dark grey period), moderate (light grey period), and high (white period) abundance regimes. The previous reference points include the target (dashed red line) and threshold (solid red line). The circle is the terminal three-year (2016-2018) average reference abundance.

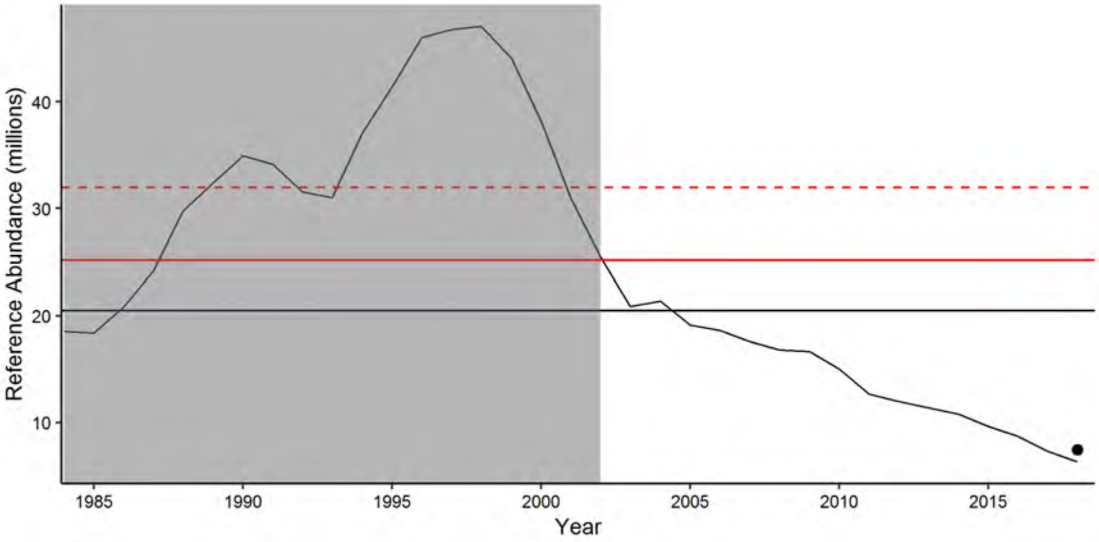

Figure 197. SNE stock reference abundance compared to current (black horizontal lines) and previous (red horizontal lines) reference points. The current reference point includes the Abundance Threshold (solid black line) based on detected high (grey period) and low (white period) abundance regimes. The previous reference points include the target (dashed red line) and threshold (solid red line). The circle is the terminal three-year (2016-2018) average reference abundance.

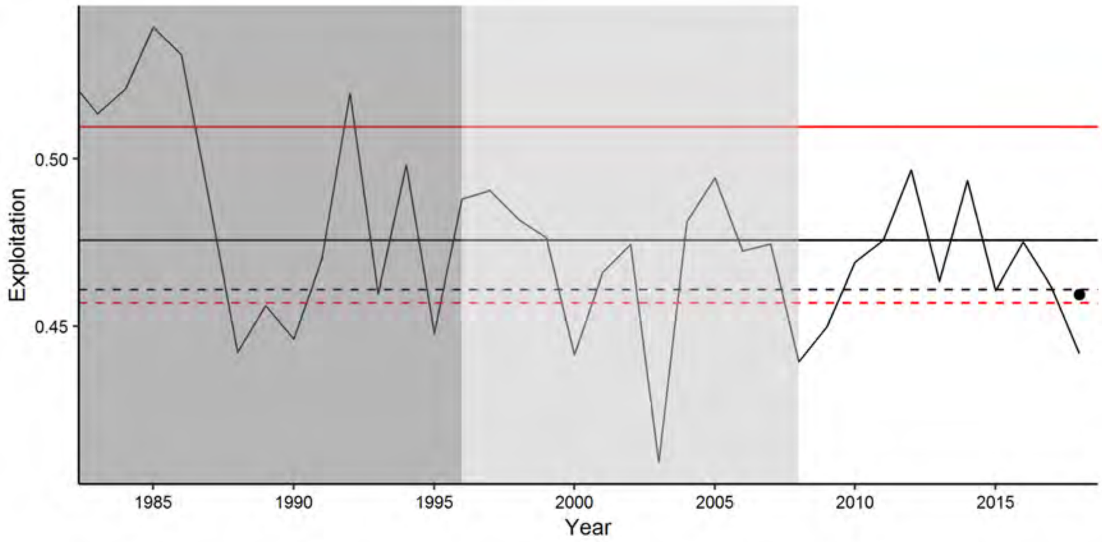

Figure 198. GOMGBK stock exploitation compared to current (black horizontal lines) and previous (red horizontal lines) reference points. The current reference points include the target (dotted black line), and threshold (solid black line). The previous reference points include the threshold (solid red line) and target (dashed red line). The circle is the terminal three-year (2016-2018) average exploitation. Shaded periods are detected low (dark grey period), moderate (light grey period), and high (white period) abundance regimes.

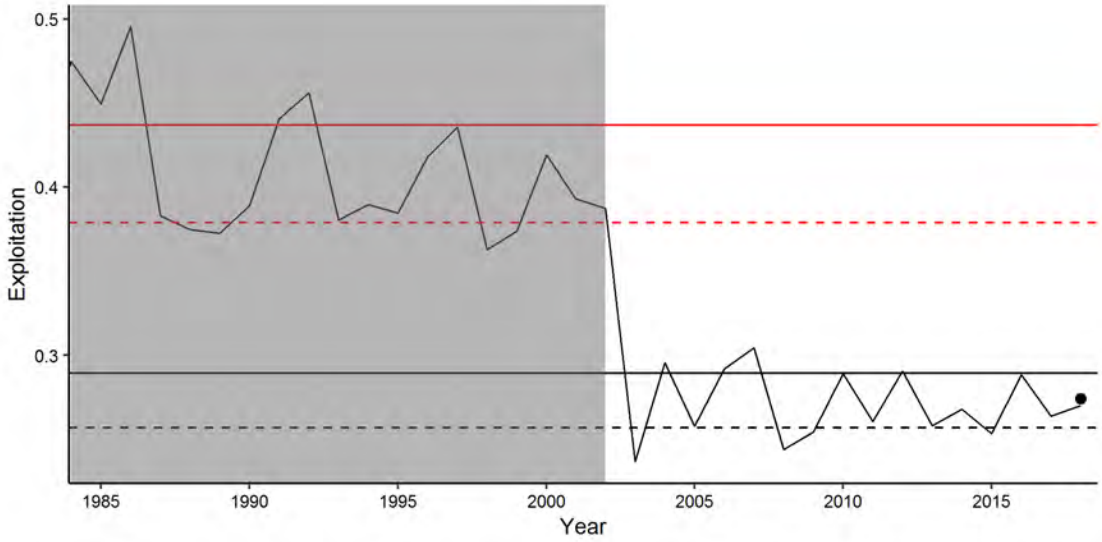

Figure 199. SNE stock exploitation compared to current (black horizontal lines) and previous (red horizontal lines) reference points. The current reference points include the target (dotted black line), and threshold (solid black line). The previous reference points include the threshold (solid red line) and target (dashed red line). The circle is the terminal three-year (2016-2018) average exploitation. Shaded periods are detected high (grey period) and low (white period) abundance regimes.

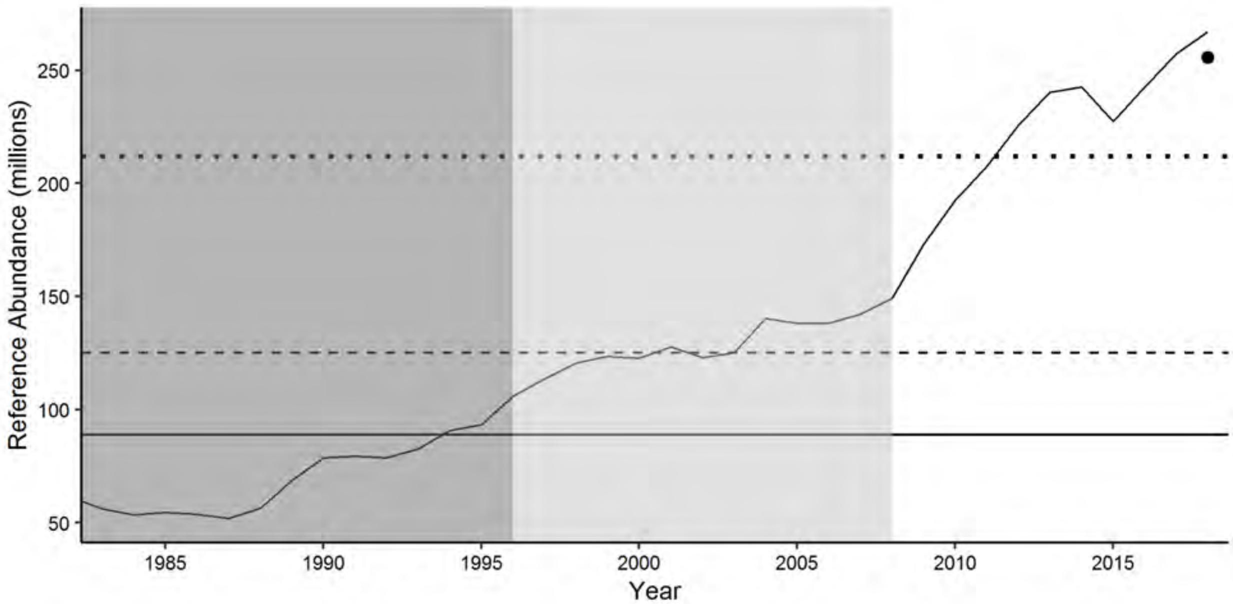

Figure 200. GOMGBK stock reference abundance compared to the Fishery/Industry Target (dotted black line), Abundance Limit (dashed black line), and Abundance Threshold (solid black line) reference points based on detected low (dark grey period), moderate (light grey period), and high (white period) abundance regimes. The circle is the terminal three-year (2016-2018) average reference abundance.

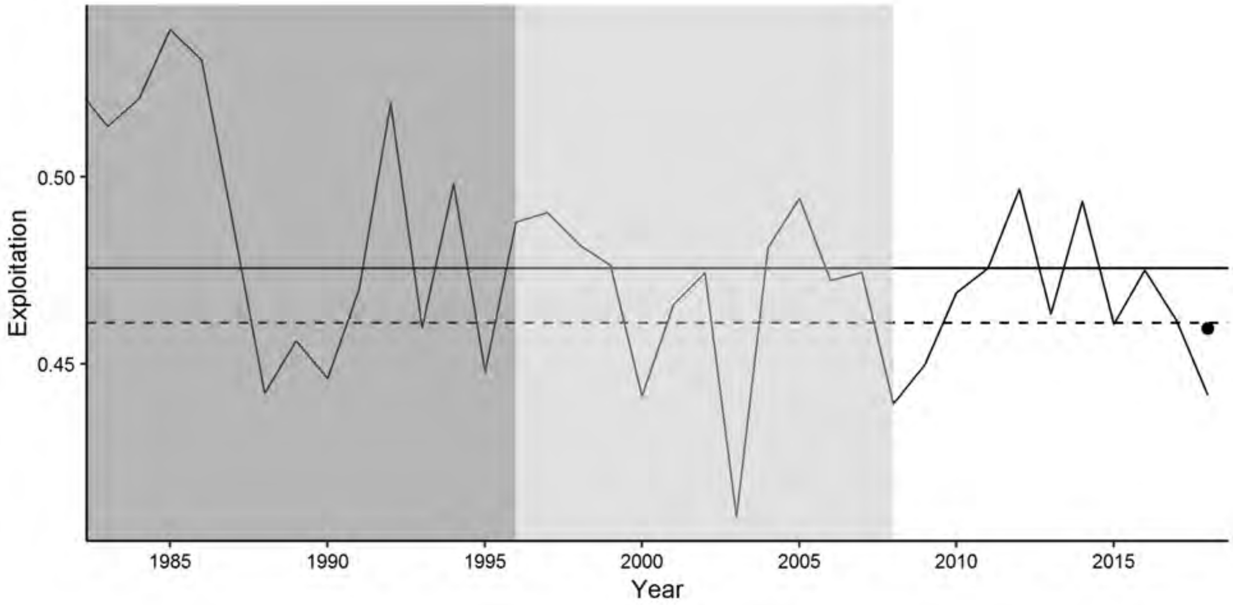

Figure 201. GOMGBK stock exploitation compared to the current target (dotted black line) and threshold (solid black line) reference points. The circle is the terminal three-year (2016-2018) average exploitation. Shaded periods are detected low (dark grey period), moderate (light grey period), and high (white period) abundance regimes.

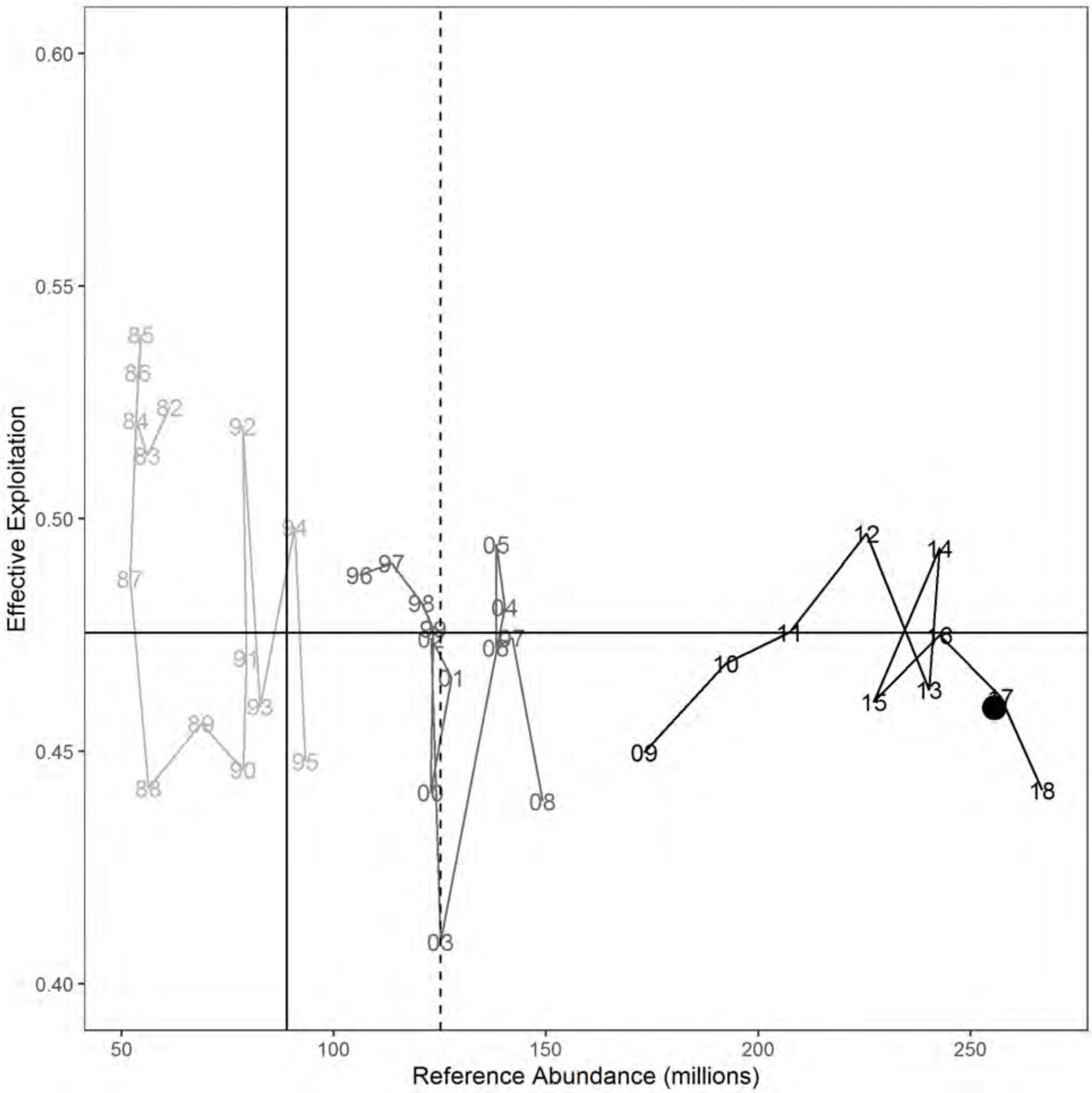

Figure 202. Annual GOMGBK reference abundance and effective exploitation estimates for both sexes combined compared to new recommended limit and threshold reference points. The horizontal solid line is the exploitation threshold. The vertical solid line is the Abundance Threshold and the vertical dashed line is the Abundance Limit. The light grey, dark grey, and black years and lines show estimates during the low, moderate, and high abundance regimes, respectively. The black circle is the 2016-2018 average reference abundance and effective exploitation.

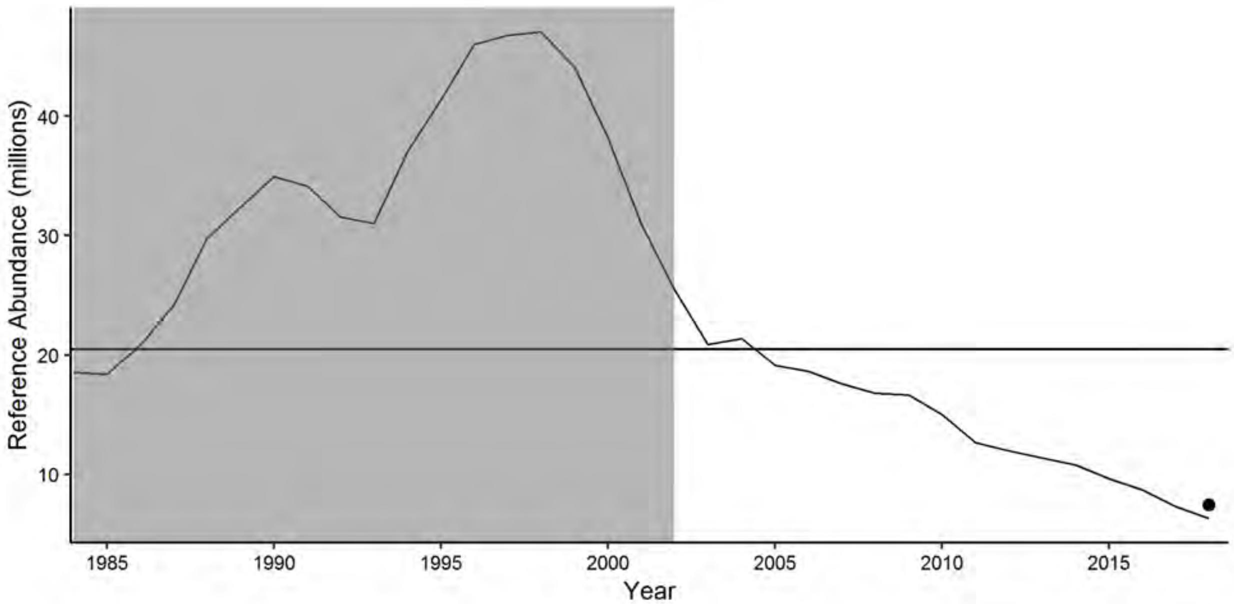

Figure 203. SNE stock reference abundance compared to the Abundance Threshold (solid black line) reference point based on detected high (grey period) and low (white period) abundance regimes. The circle is the terminal three-year (2016-2018) average reference abundance.

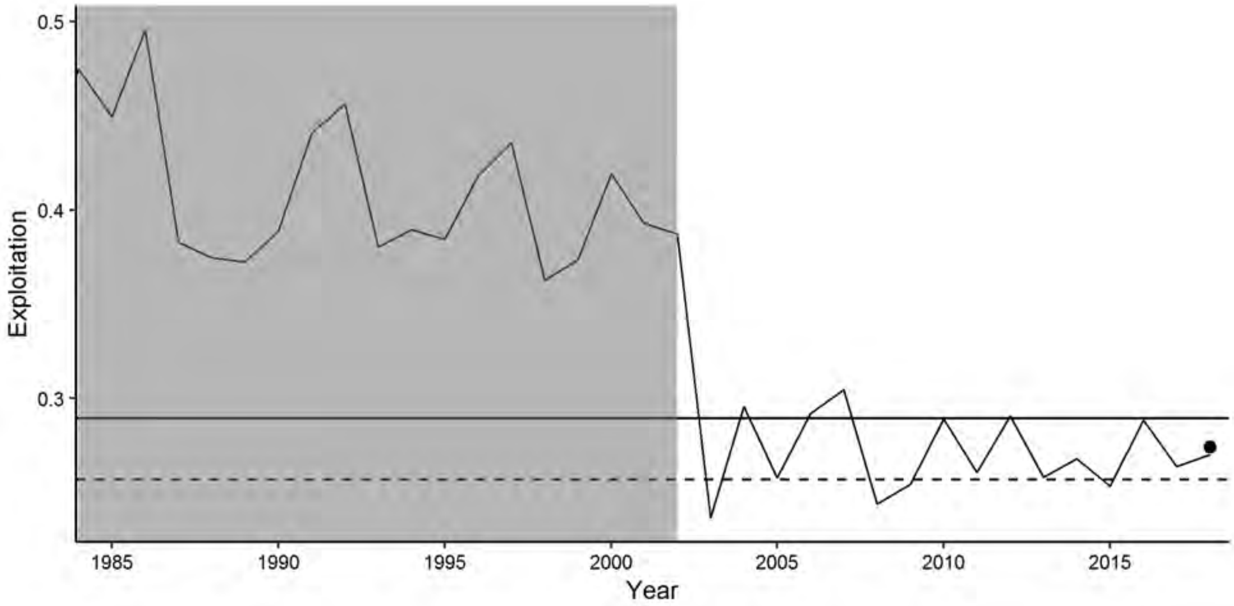

Figure 204. SNE stock exploitation compared to the current target (dotted black line) and threshold (solid black line) reference points. The circle is the terminal three-year (2016-2018) average exploitation. Shaded periods are detected high (grey period) and low (white period) abundance regimes.

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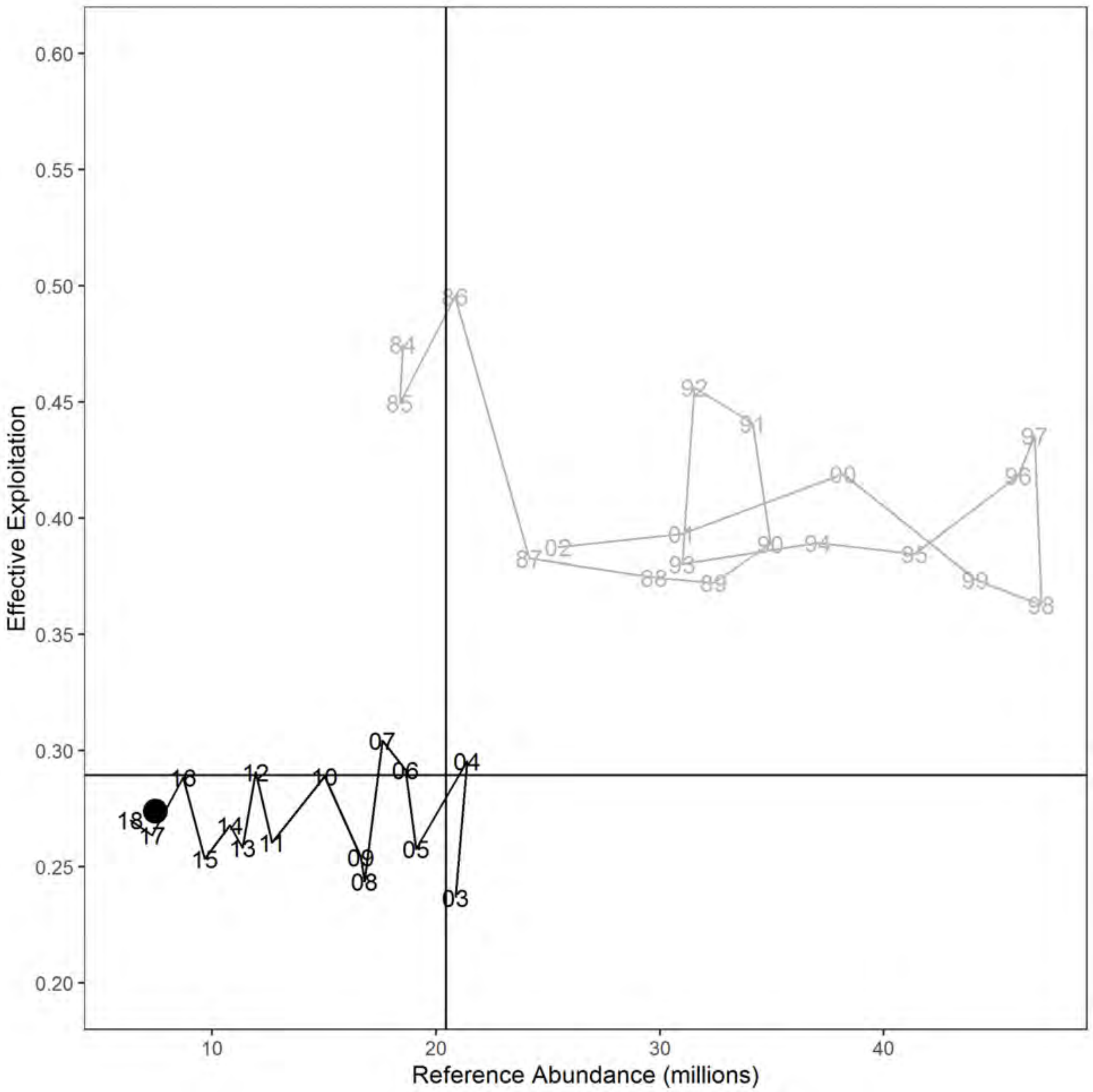


Figure 205. Annual SNE reference abundance and effective exploitation estimates for both sexes combined compared to new recommended threshold reference points. The horizontal solid line is the exploitation threshold. The vertical solid line is the Abundance Threshold. The grey and black years and lines show estimates during the high and low abundance regimes, respectively. The black circle is the 2016-2018 average reference abundance and effective exploitation.

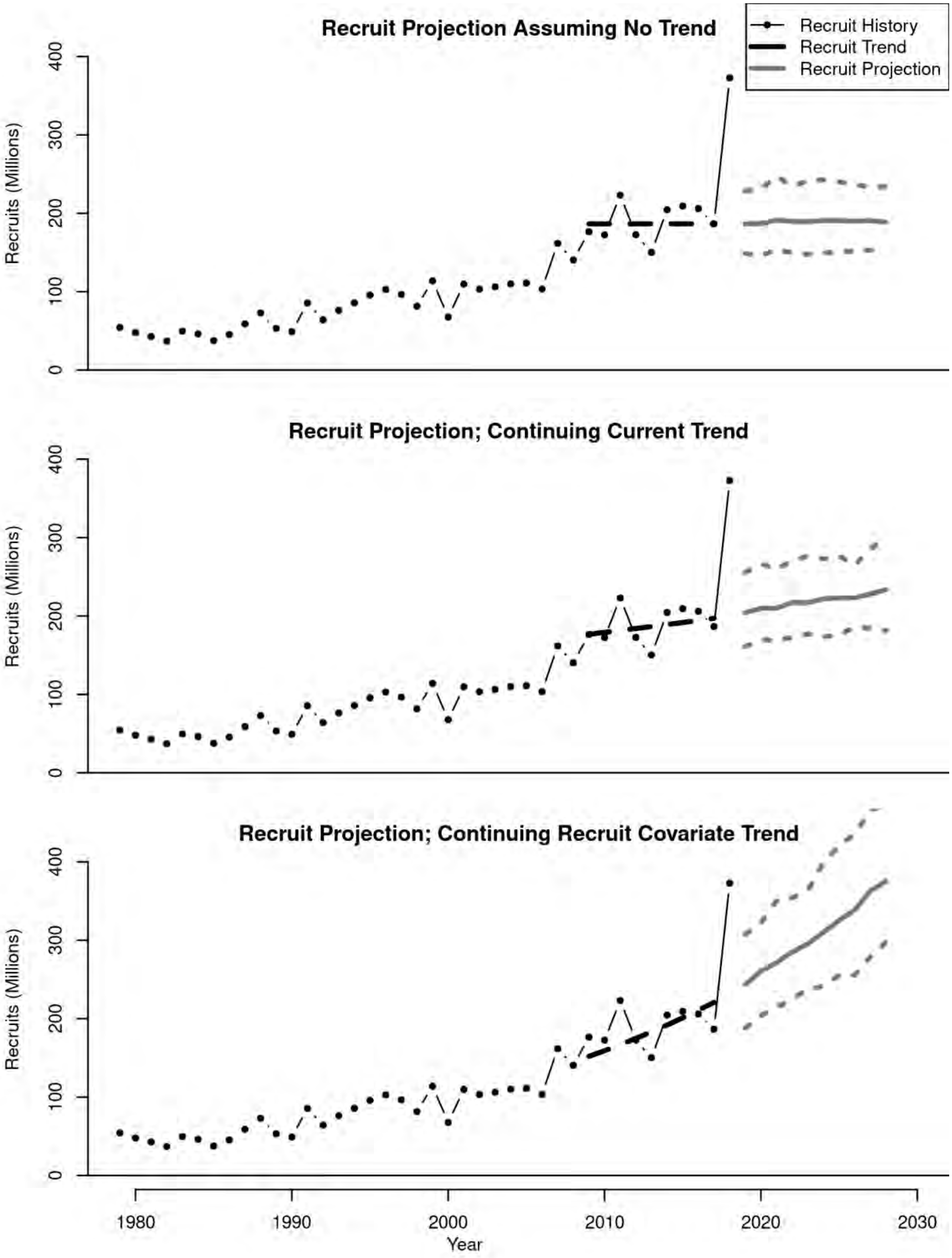


Figure 206. GOMGBK Recruitment estimates and Basecase Projection scenarios (mean +/- 95% CI).

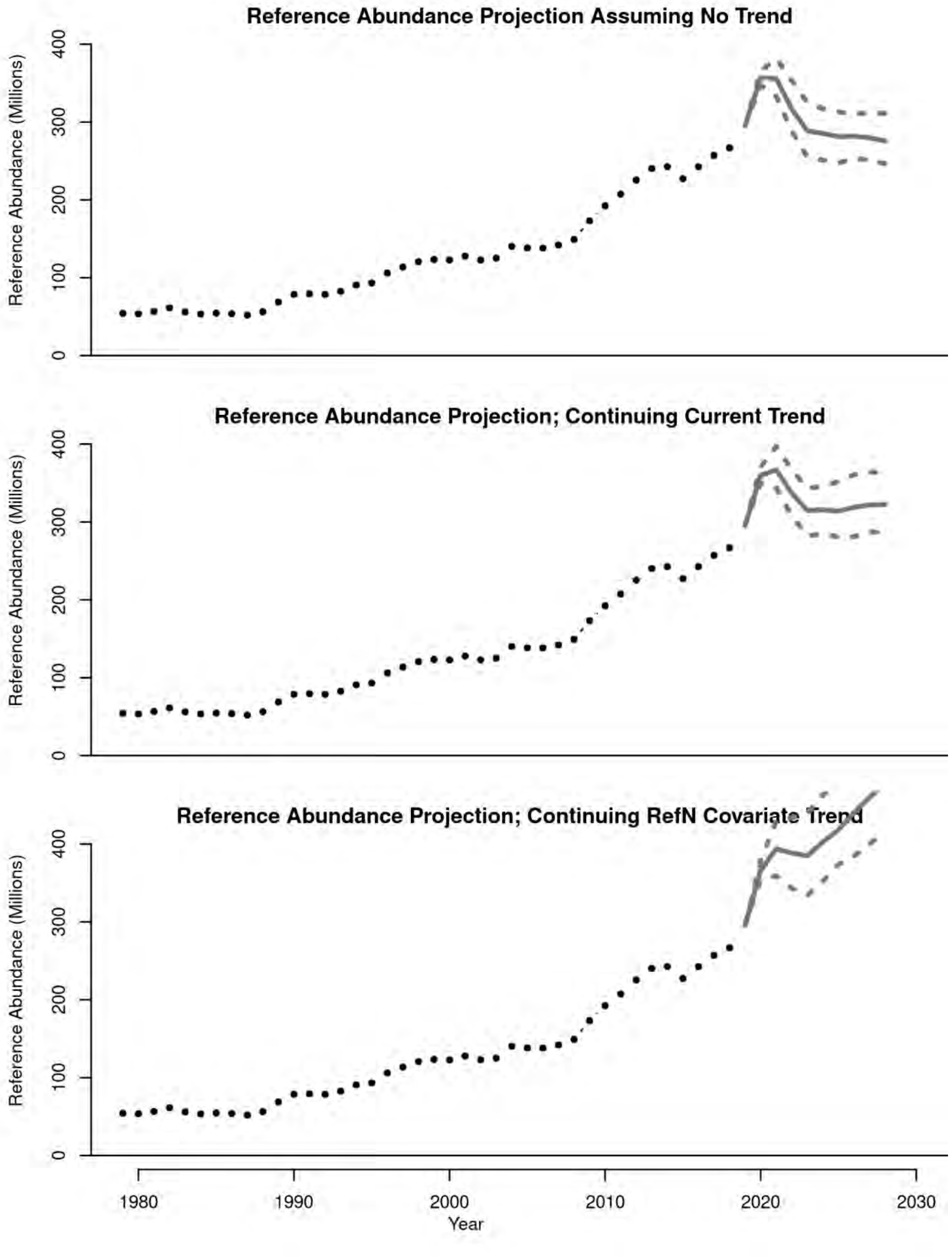


Figure 207. GOMGBK Reference Abundance estimates and Basecase Projection scenarios (mean +/- 95% CI).

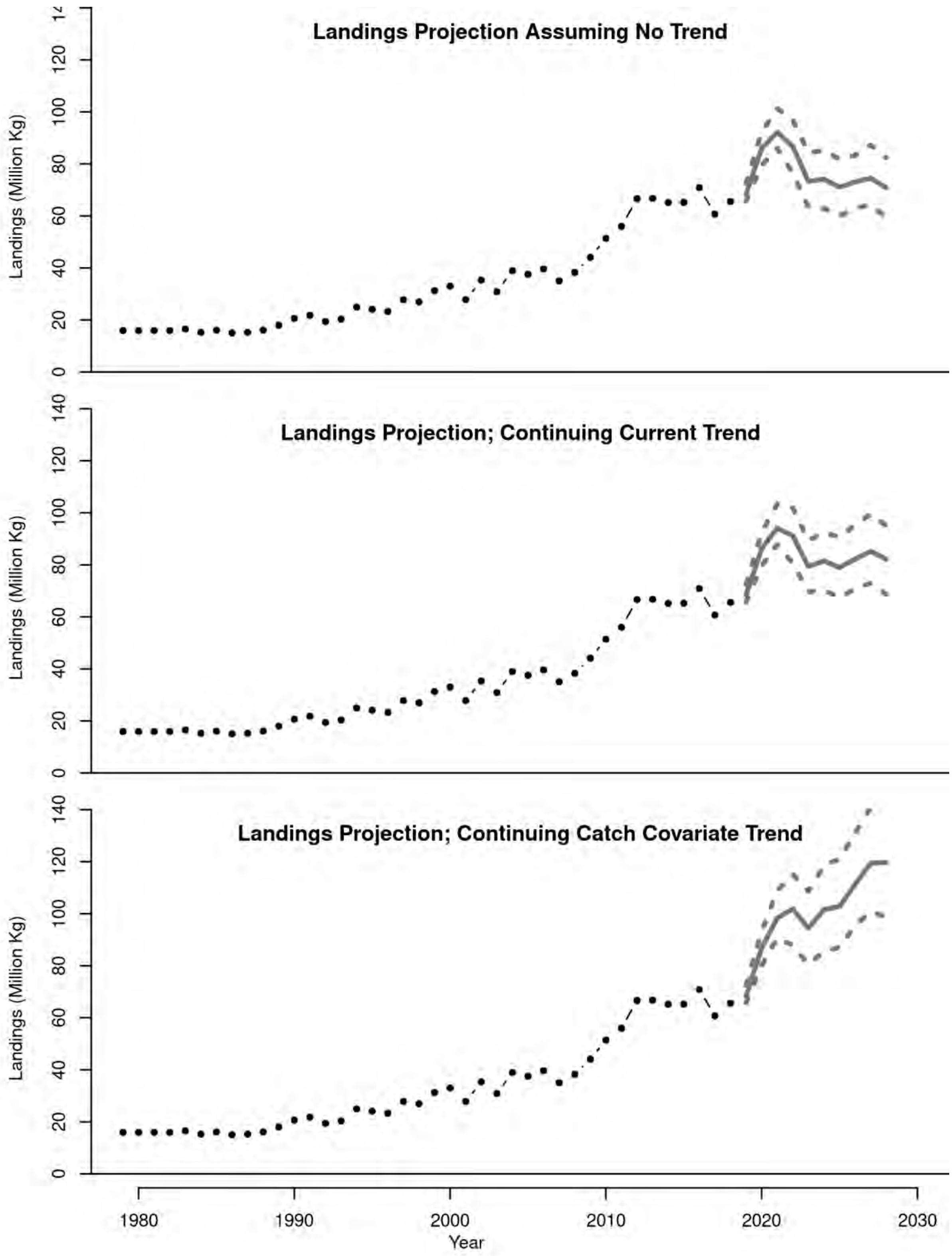


Figure 208. GOMGBK observed landings and Basecase Projection scenarios (mean +/- 95% CI).

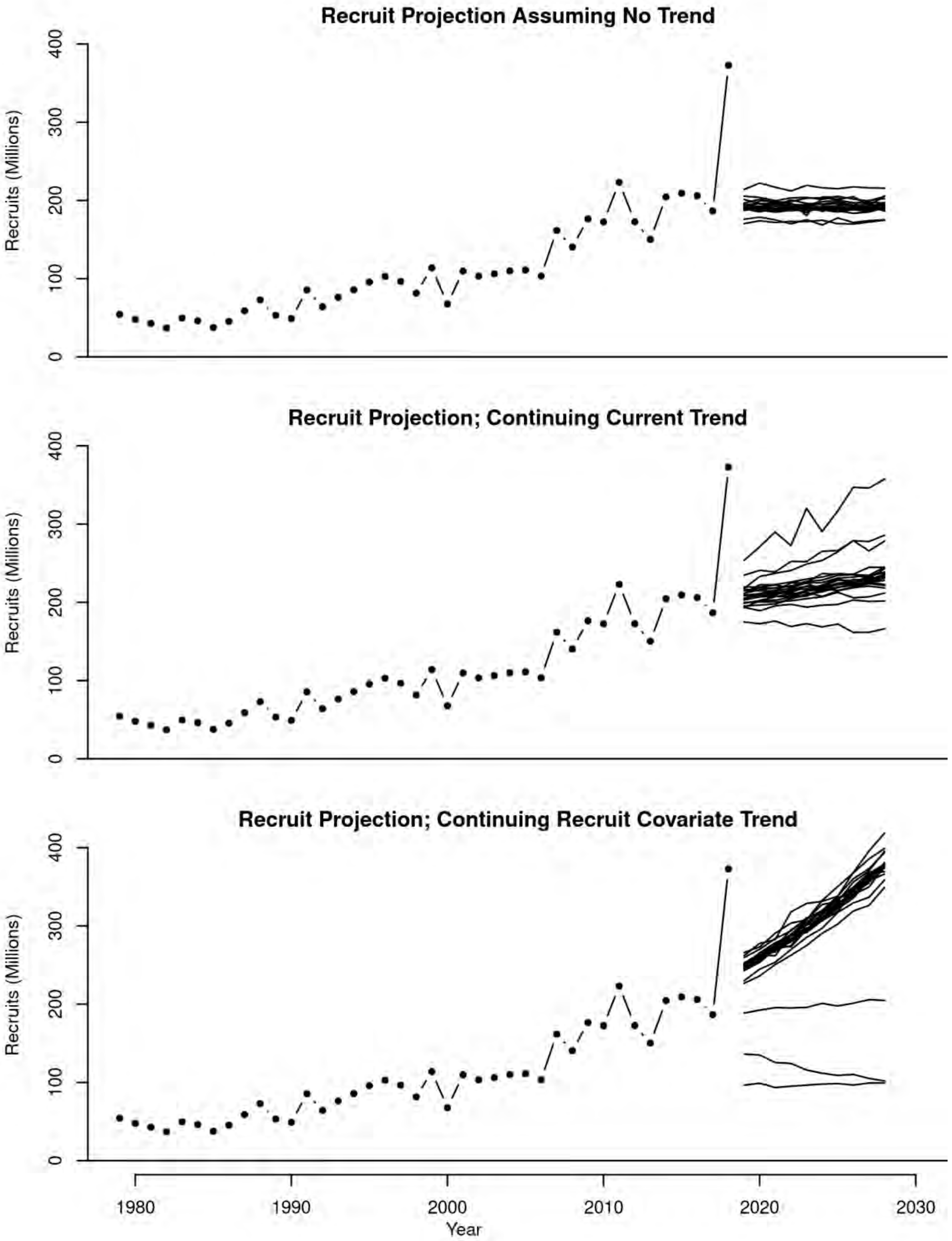


Figure 209. GOMGBK Recruitment estimates and Sensitivity Projection scenarios (mean +/- 95% CI).

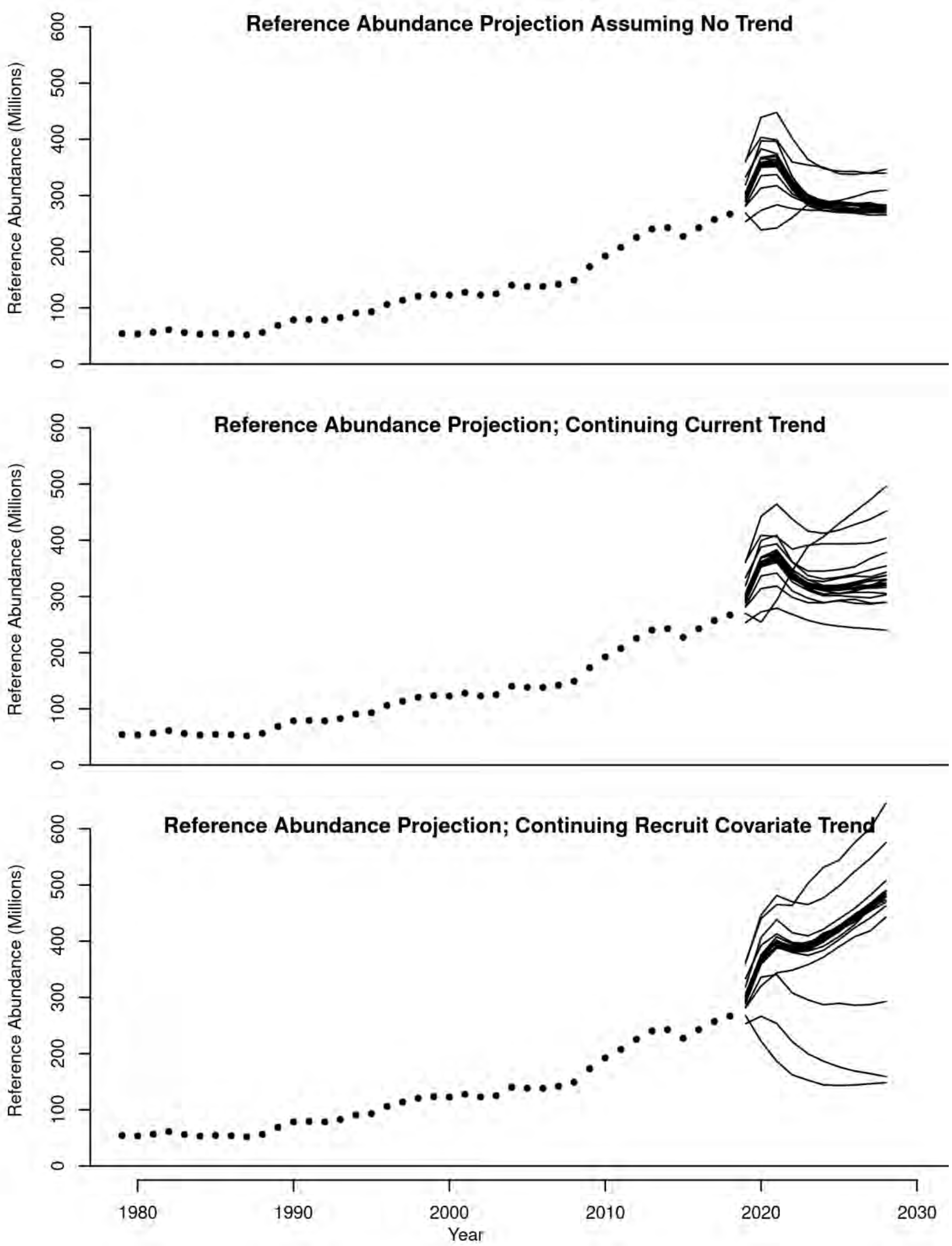


Figure 210. GOMGBK Reference Abundance estimates and Sensitivity Projection scenarios (mean +/- 95% CI).

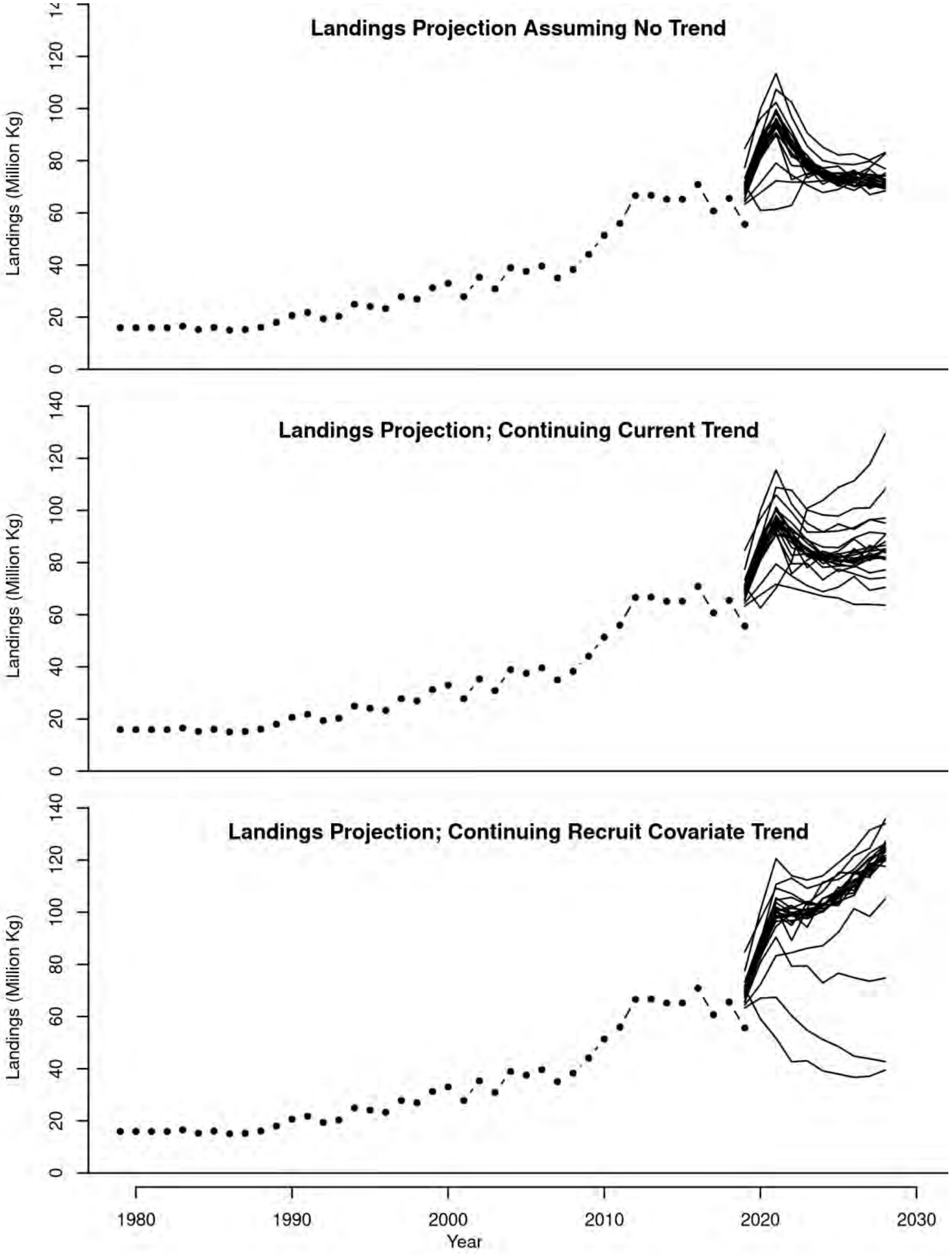
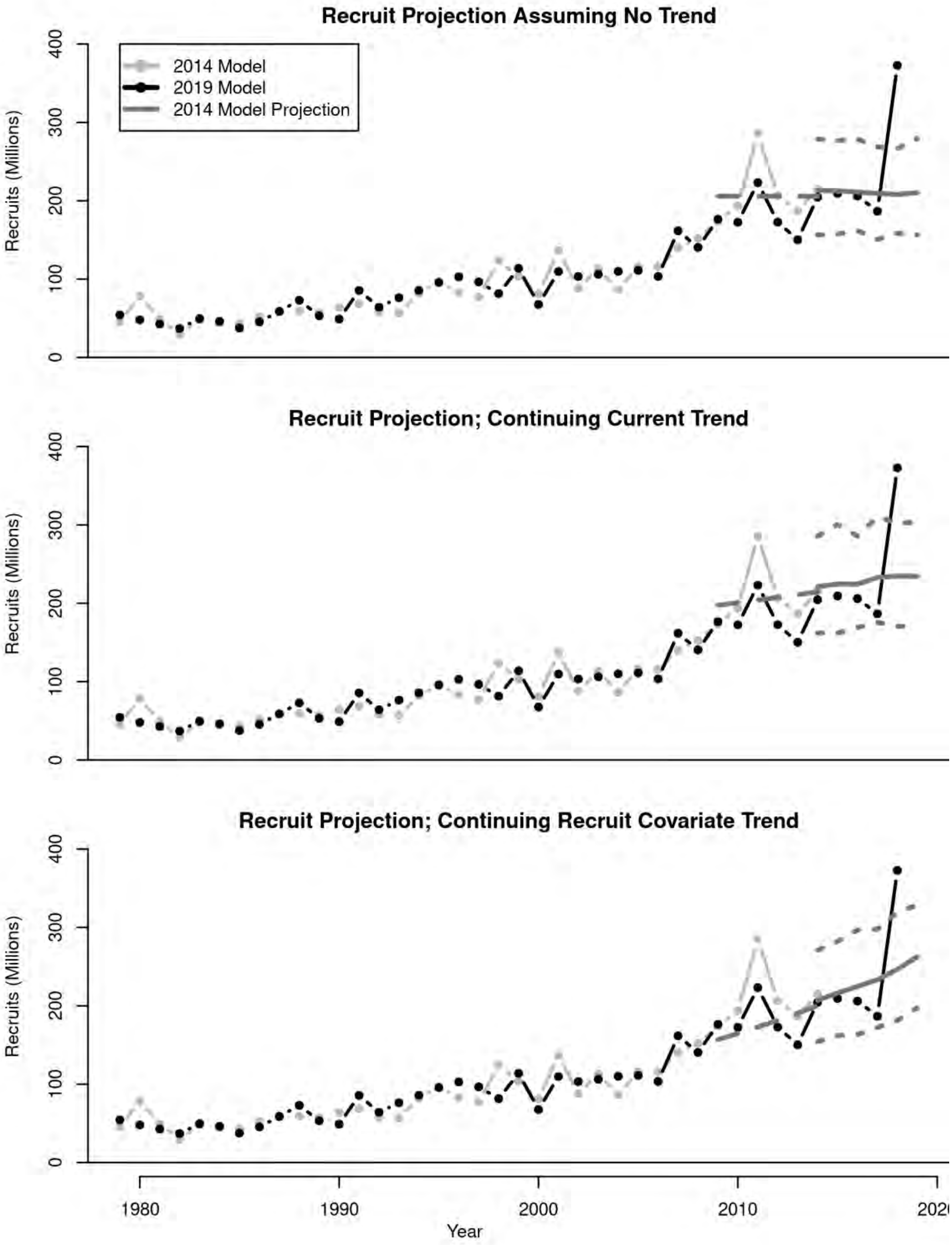


Figure 211. GOMGBK observed landings and Sensitivity Projection scenarios (mean +/- 95% CI).



Recruit Projection Assuming No Trend

Recruit Projection; Continuing Current Trend

Recruit Projection; Continuing Recruit Covariate Trend

Figure 212. GOMGBK previous and current basecase recruit estimates and Prior Projections (mean +/- 95% CI).

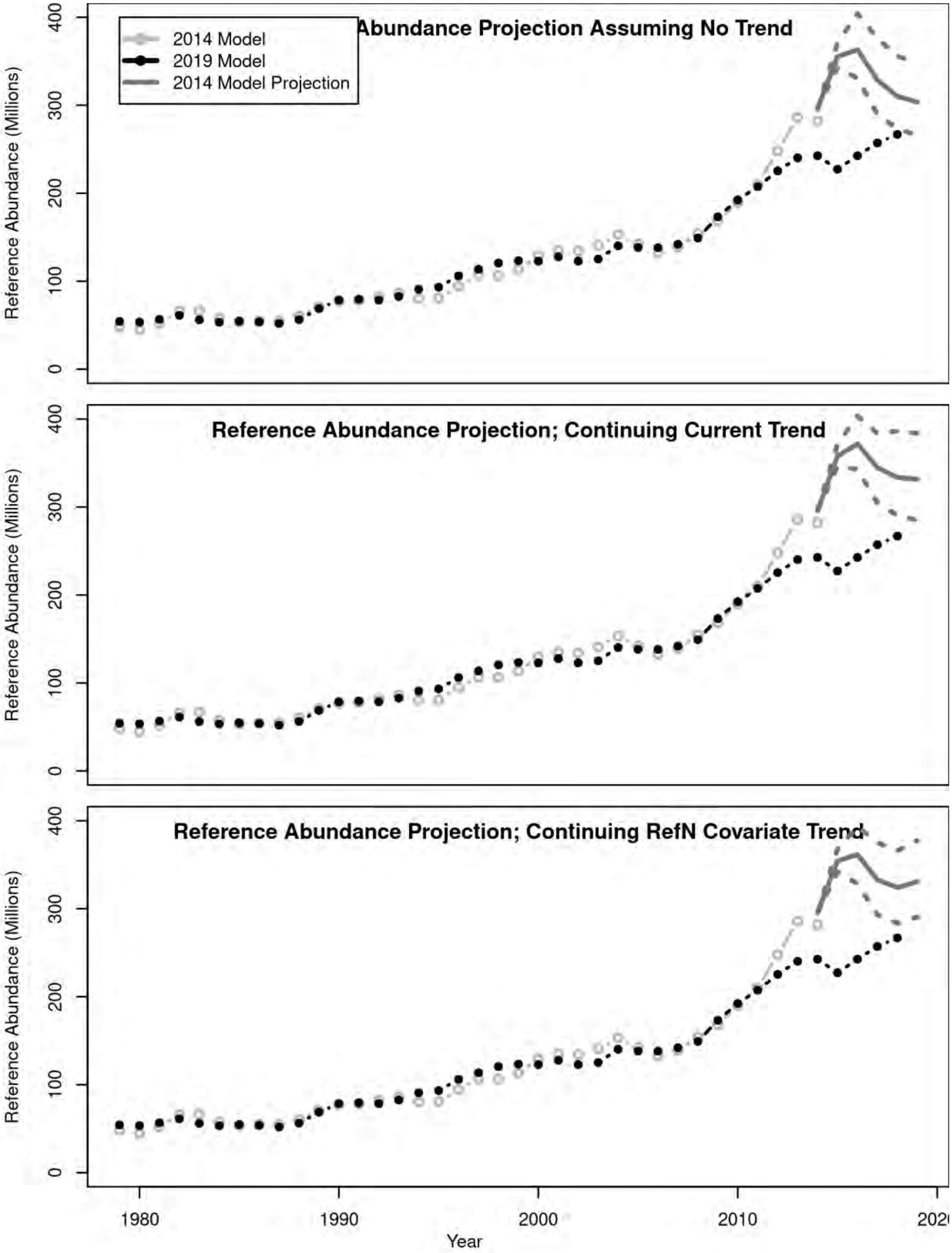


Figure 213. GOMGBK previous and current basecase reference abundance and Prior Projection scenarios (mean +/- 95% CI).

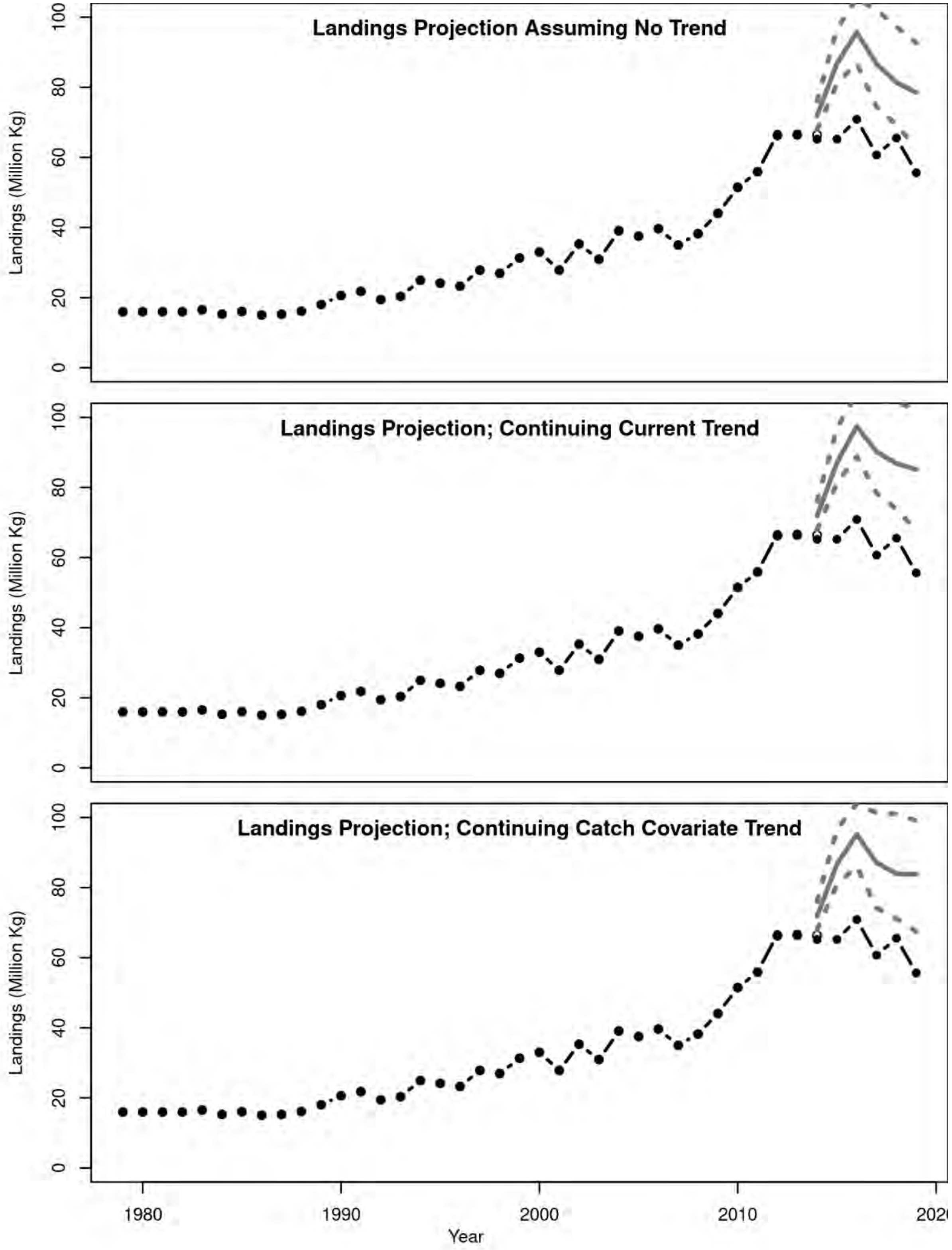


Figure 214. GOMGBK observed landings and Prior Projection scenarios (mean +/- 95% CI).

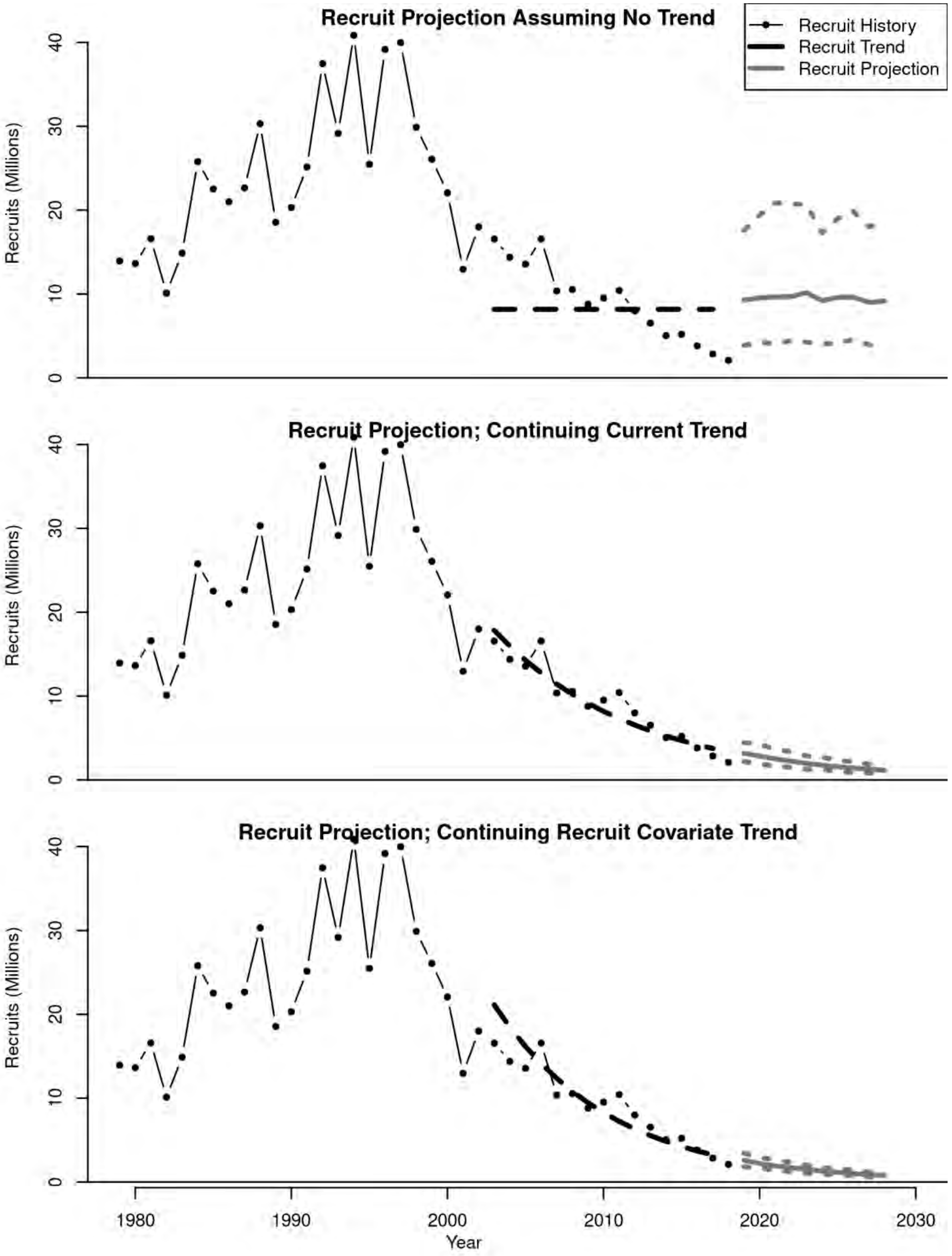


Figure 215. SNE Recruitment estimates and Basecase Projection scenarios (mean +/- 95% CI).

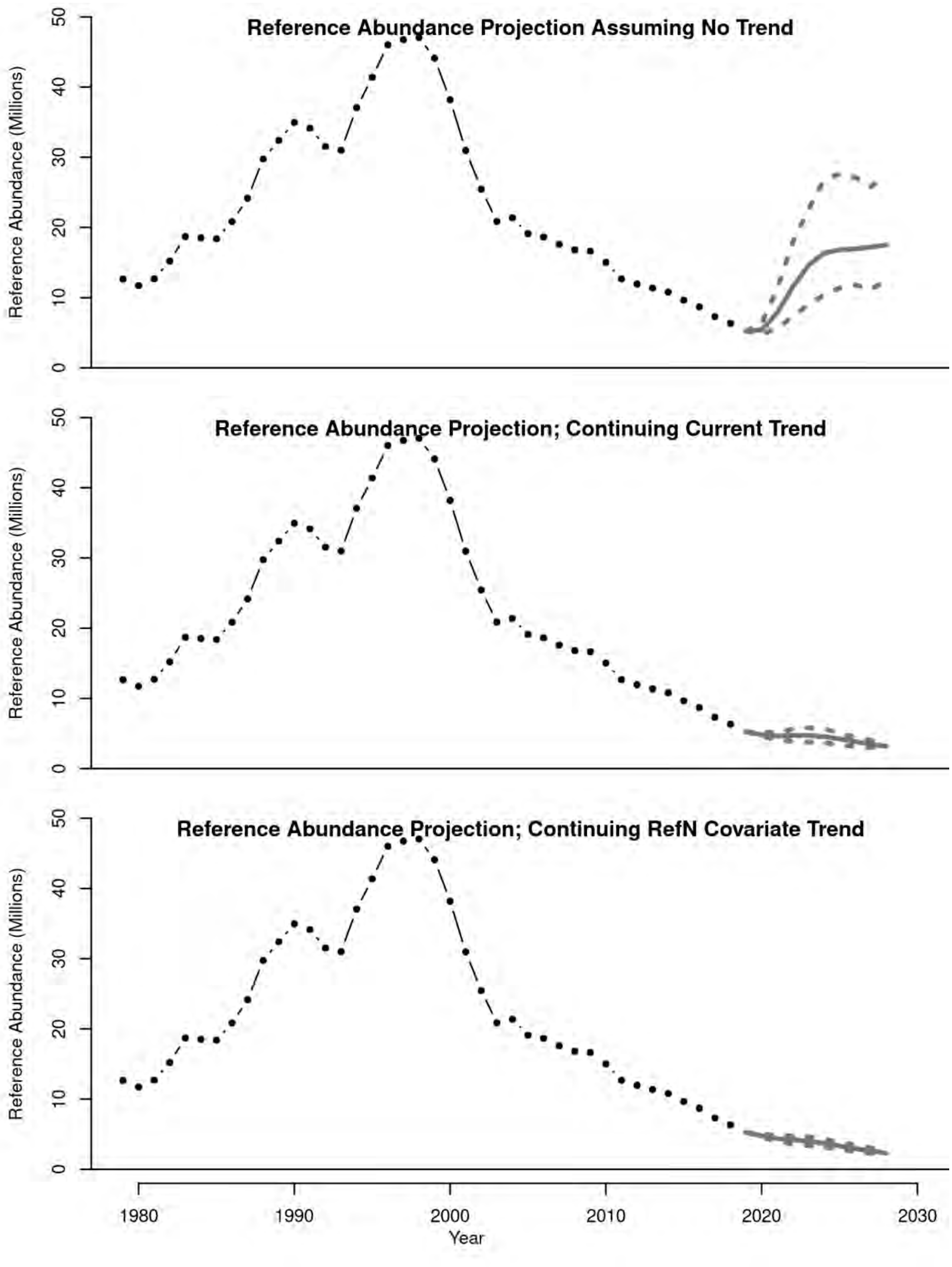


Figure 216. SNE Reference Abundance estimates and Basecase Projection scenarios (mean +/- 95% CI).

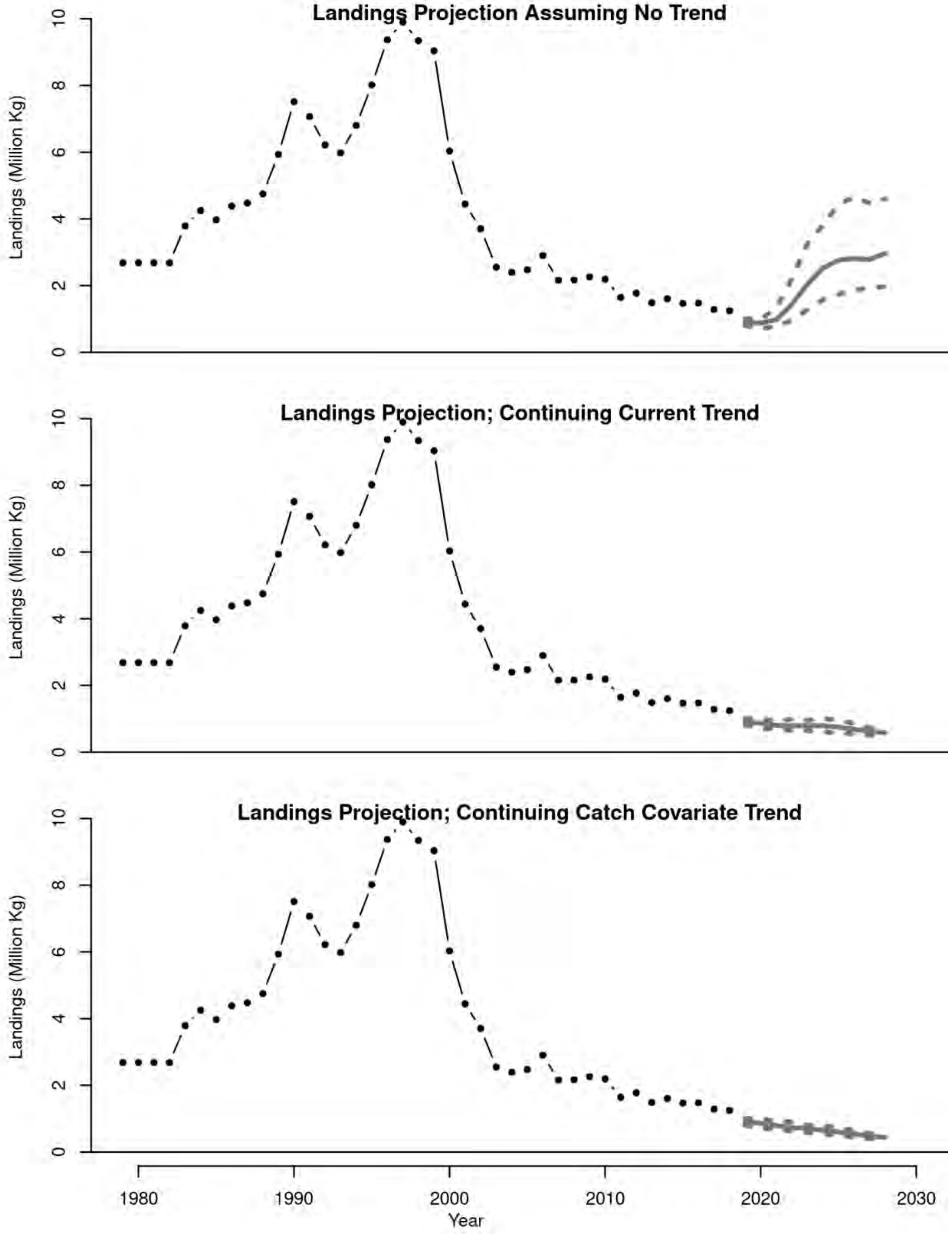


Figure 217. SNE observed landings and Basecase Projection scenarios (mean +/- 95% CI).

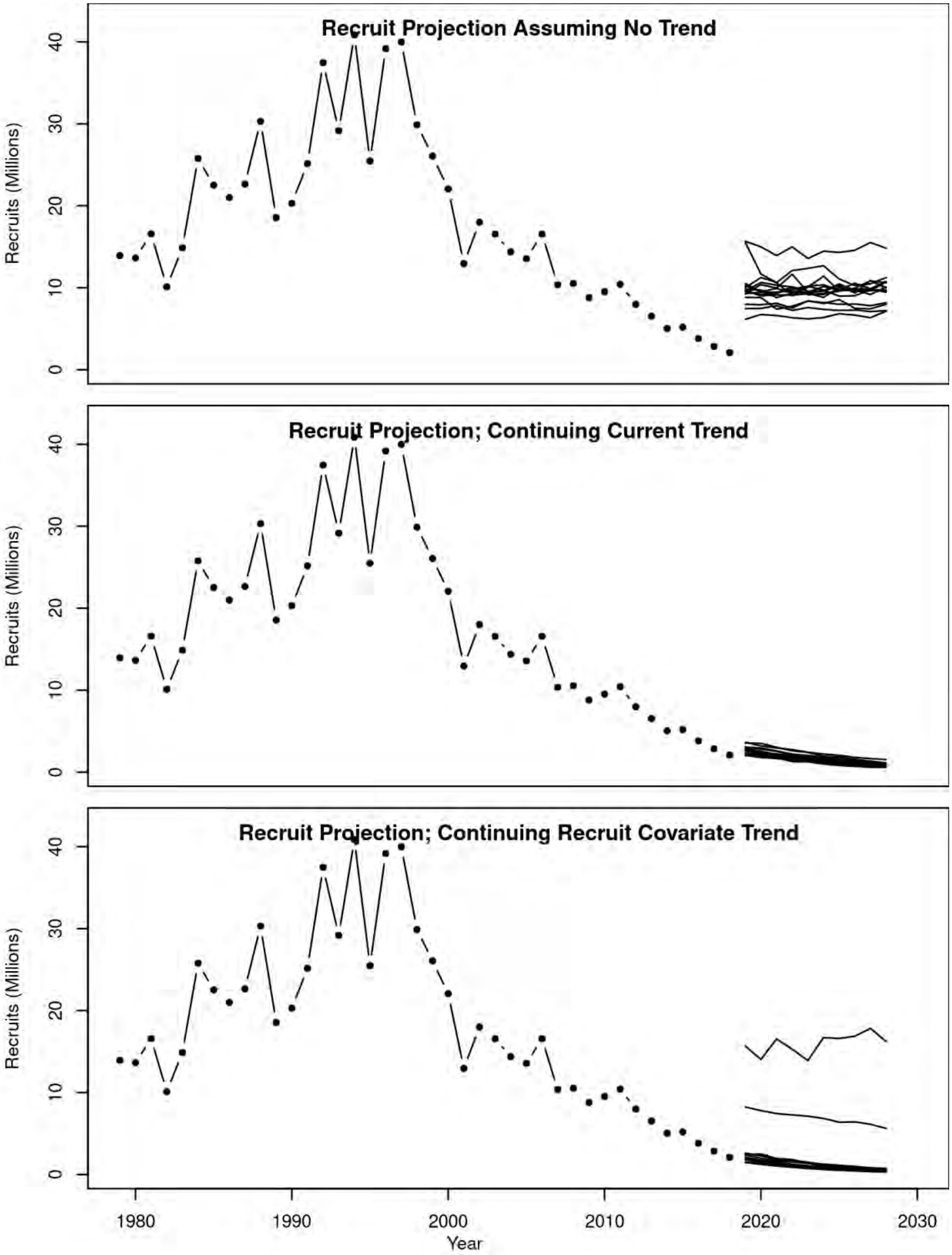


Figure 218. SNE Recruitment estimates and Sensitivity Projection scenarios (mean +/- 95% CI).

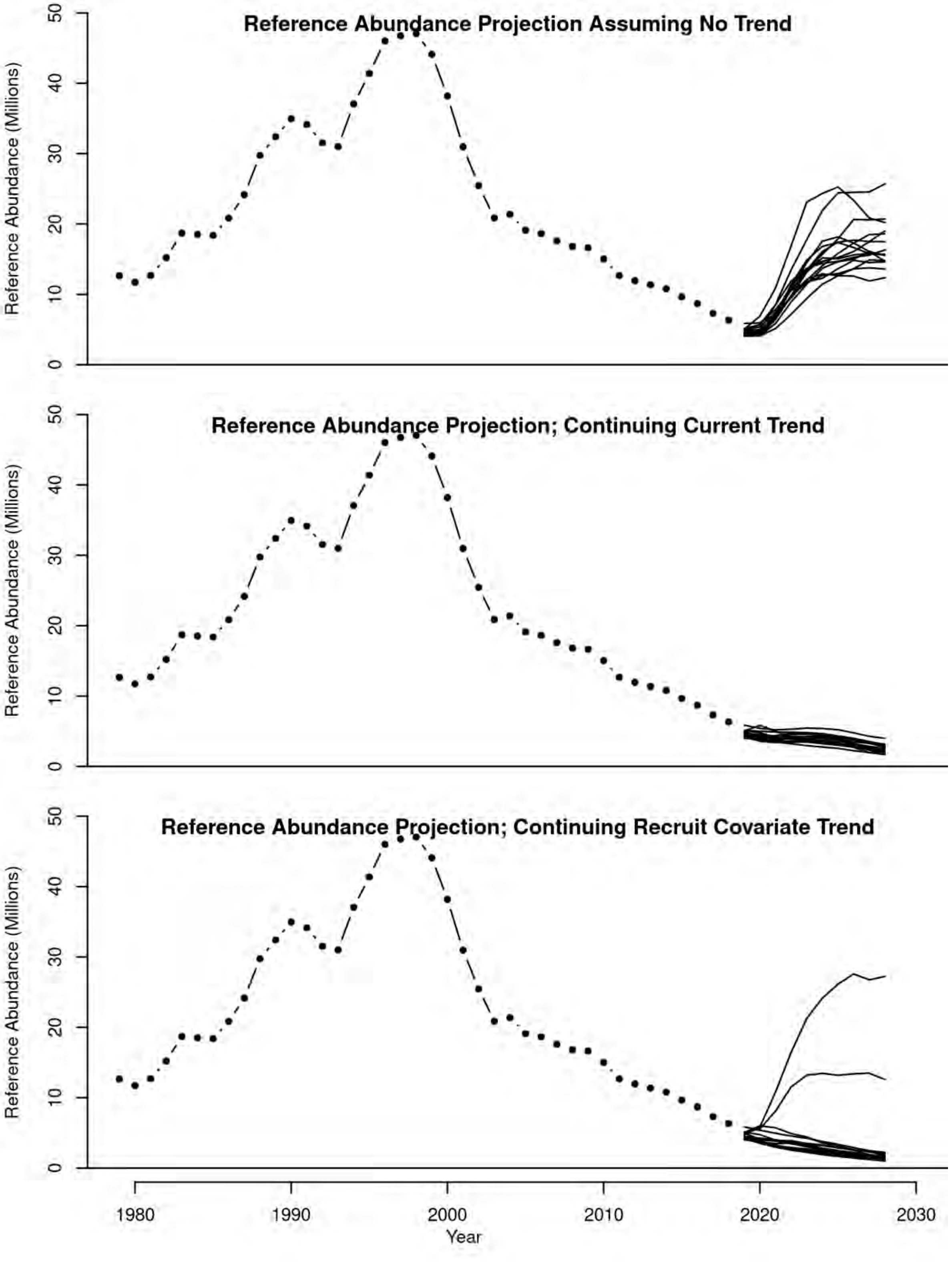


Figure 219. SNE Reference Abundance estimates and Sensitivity Projection scenarios (mean +/- 95% CI).

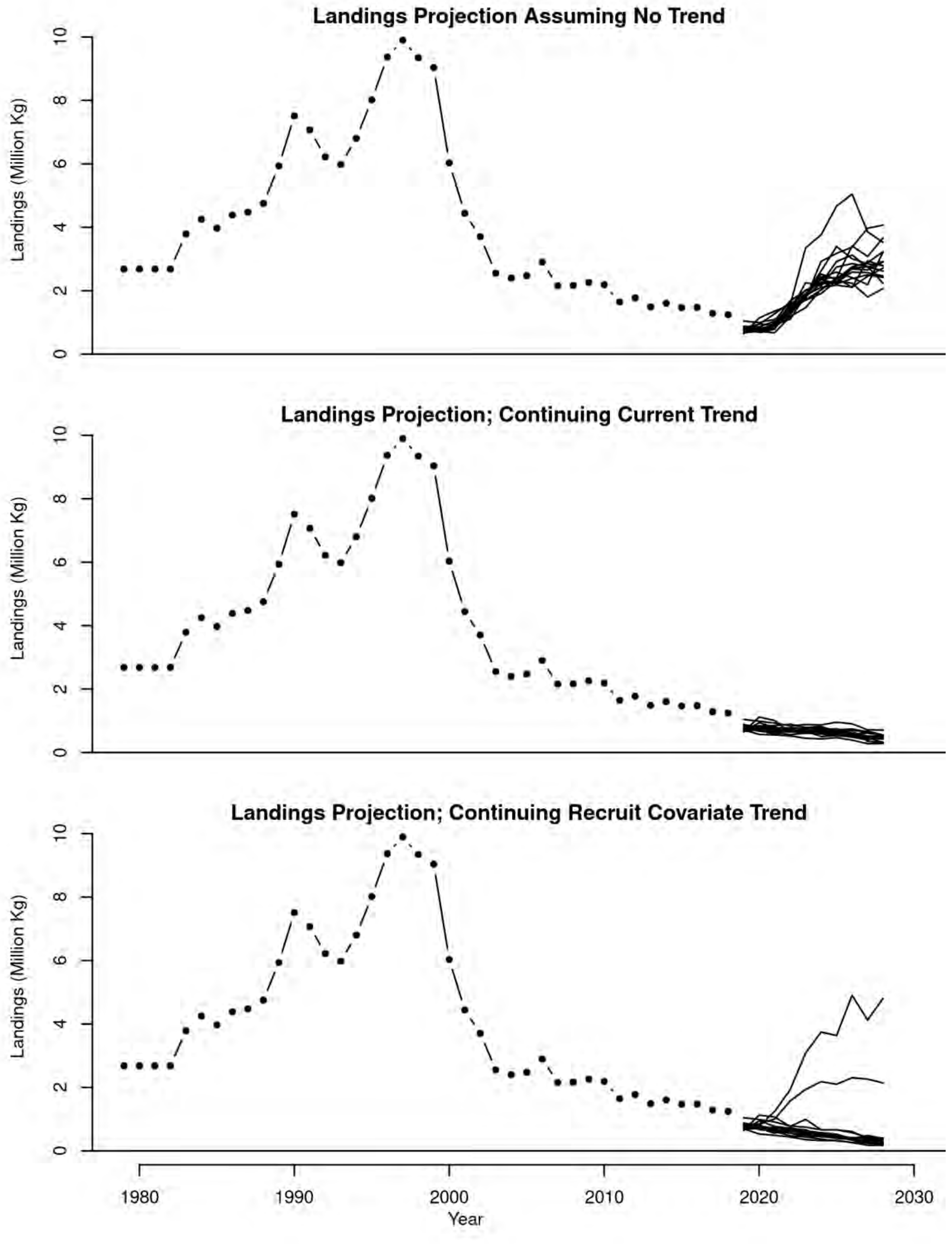


Figure 220. SNE observed landings and Sensitivity Projection scenarios (mean +/- 95% CI).

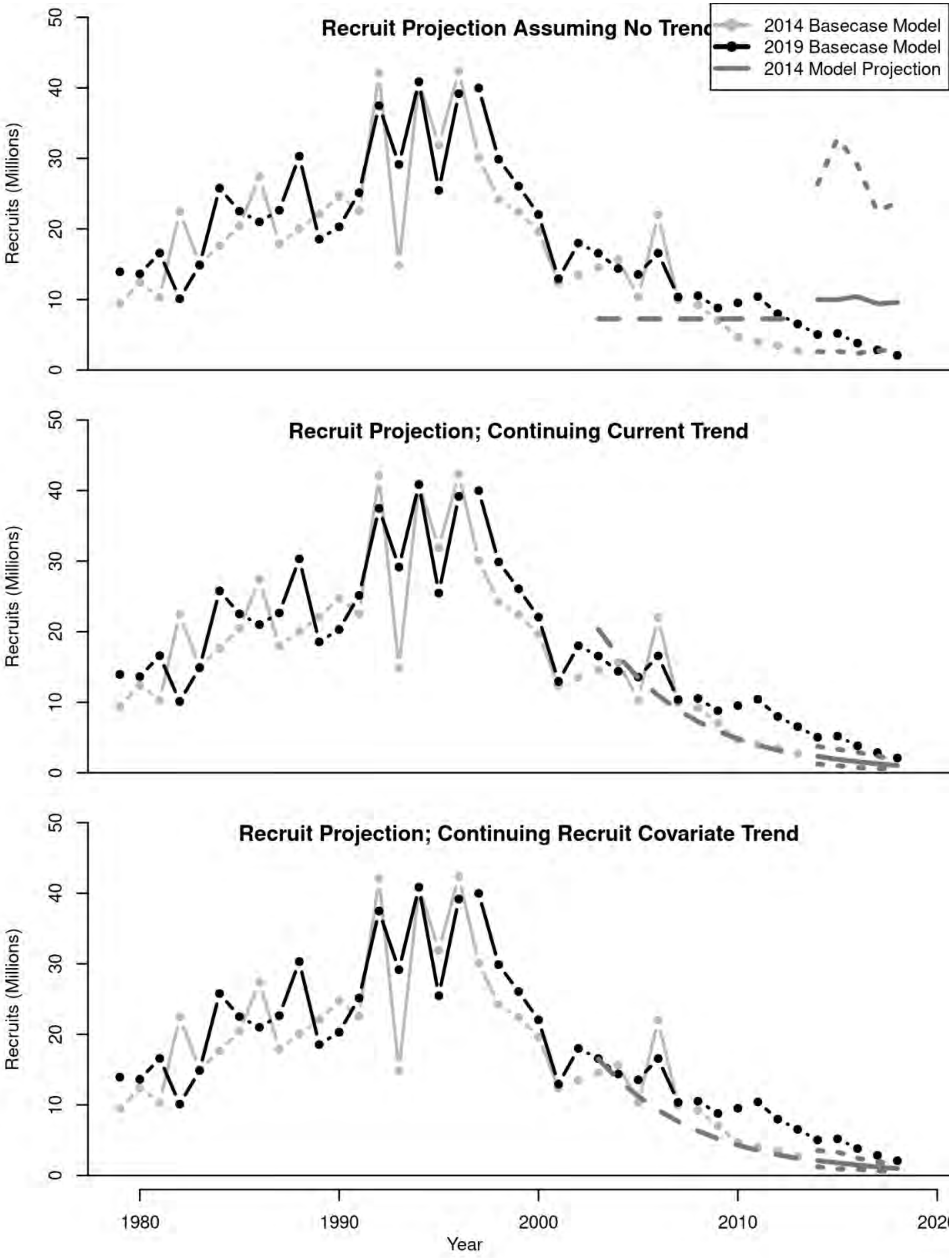


Figure 221. SNE previous and current basecase recruit estimates and Prior Projections (mean +/- 95% CI).

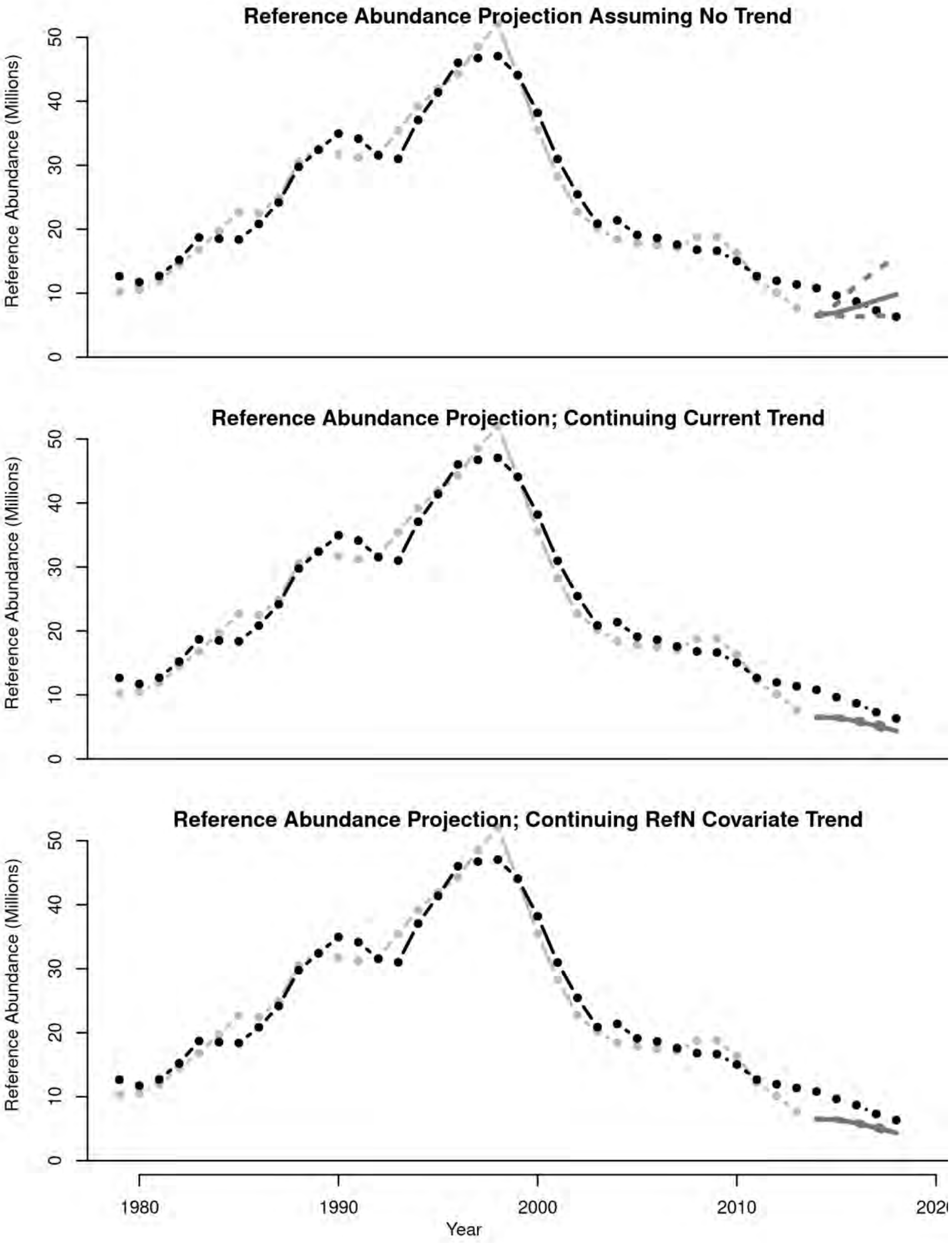


Figure 222. SNE previous and current basecase reference abundance and Prior Projection scenarios (mean +/- 95% CI).

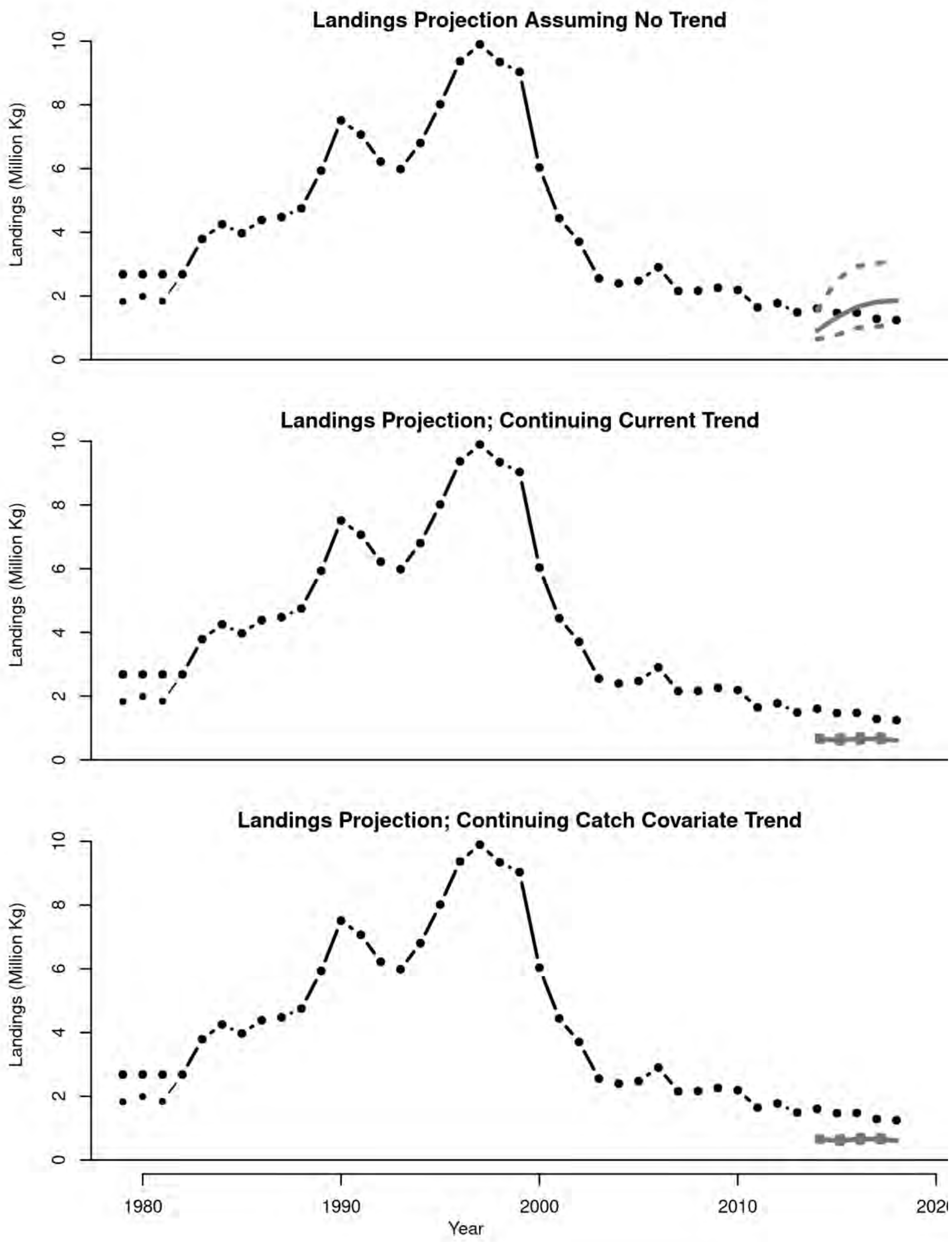


Figure 223. SNE observed landings and Prior Projection scenarios (mean +/- 95% CI).

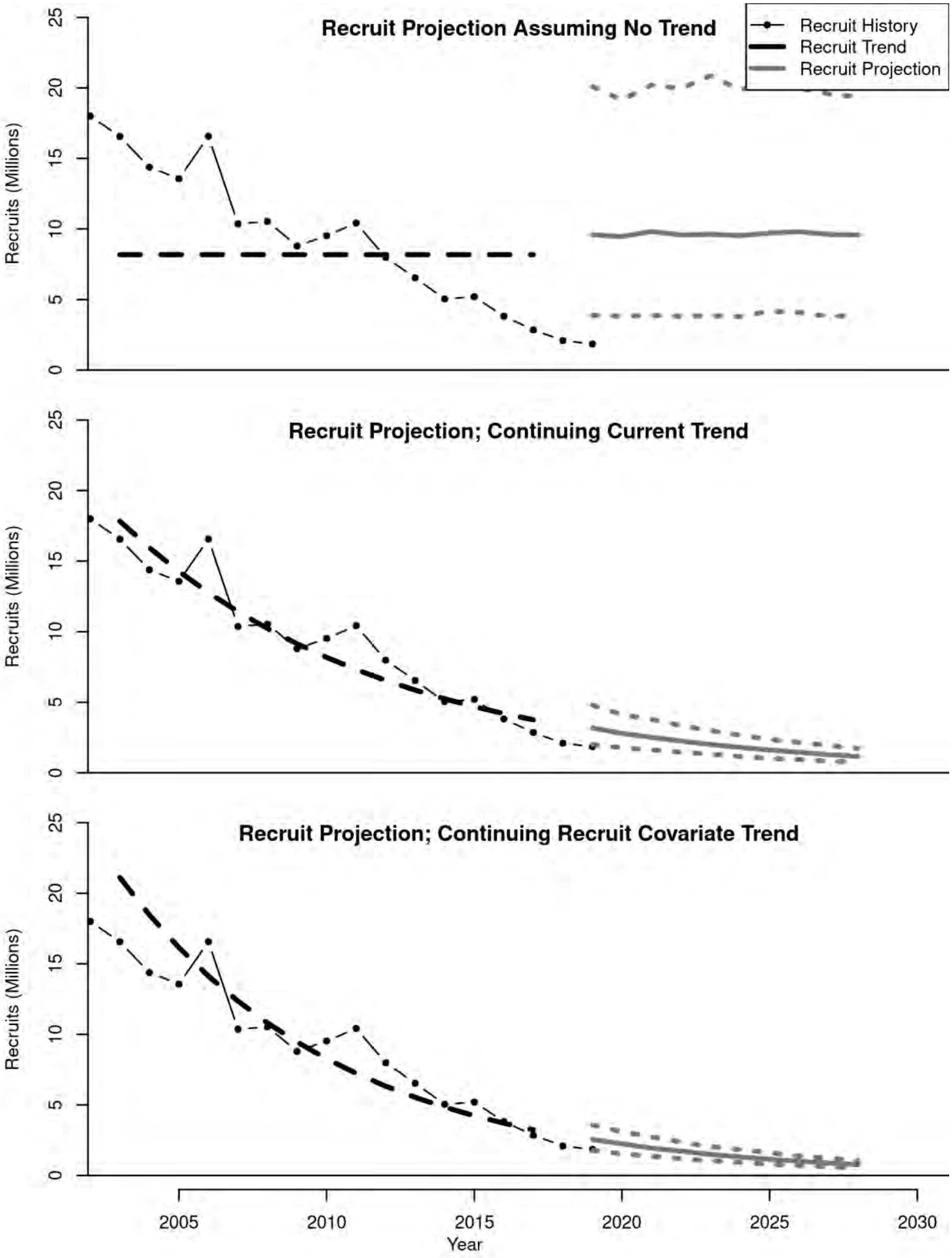


Figure 224. SNE recruitment estimates for the current regime and recruitment projections for a no fishing mortality scenario.

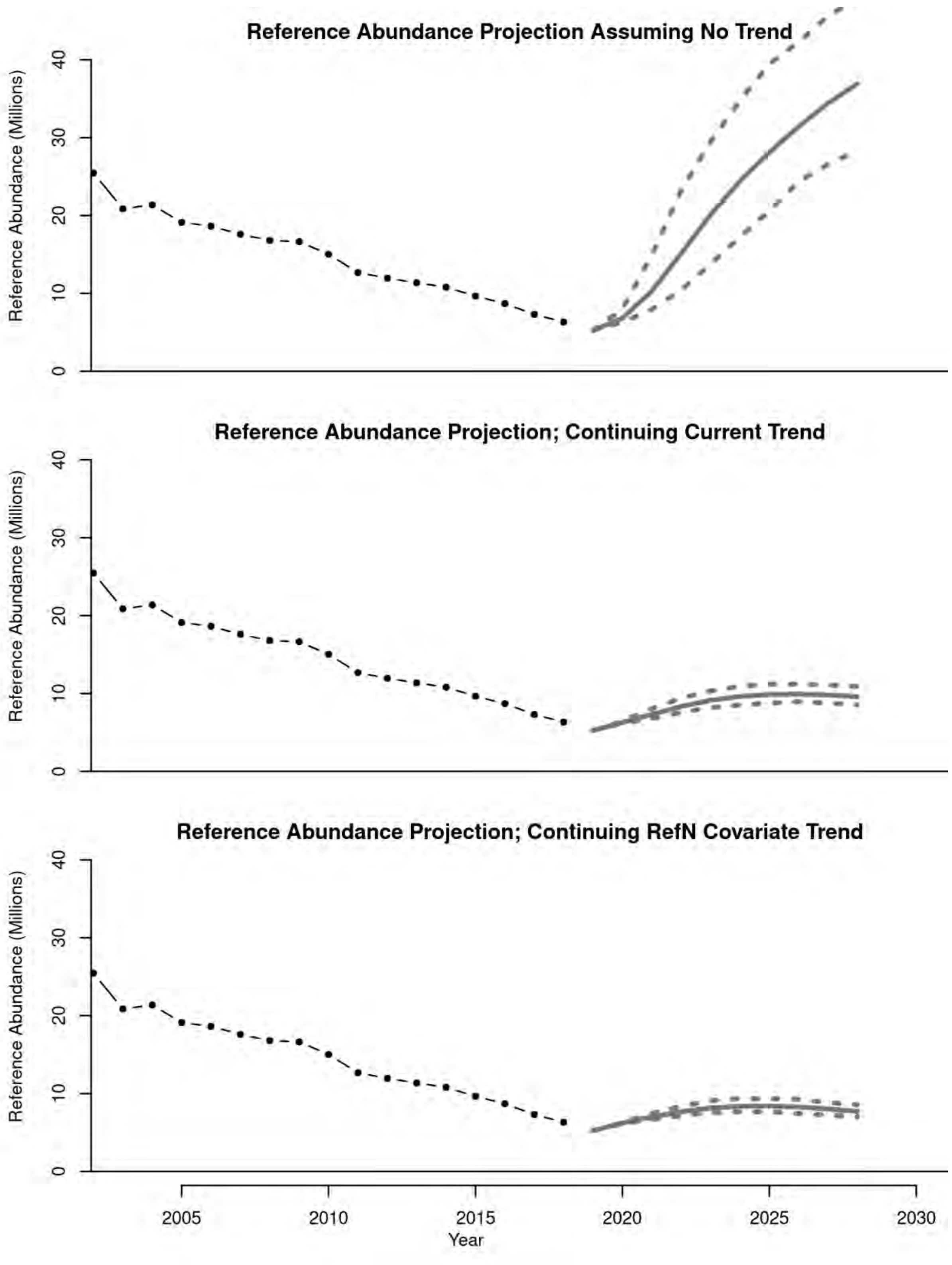


Figure 225. SNE reference abundance estimates for the current regime and projection scenarios for a no fishing mortality scenario.

Appendix 1. Maturity data update

The maturity data used in the previous lobster stock assessment (ASMFC 2015a) was in many cases more than 30 years old, and given the relationship between water temperature and lobster maturity, along with the changing climate conditions, the Lobster SAS felt it was time to re-examine and update the maturity data used for assessment purposes.

Historical data and ogive generation for the 2015 assessment

Maturity ogives for each stock were historically derived primarily from data on ovarian and cement gland staging of lobsters collected from several locations in state waters of Maine (ME), Massachusetts (MA), Rhode Island (RI), and New York (NY). ME and NY studies used ovarian staging while the MA study (Estrella and McKiernan 1989) used cement gland development data which were verified with ovarian staging. The RI work combined ovarian stage 4 females (Aiken and Waddy 1982) determined based on ovary color as seen by external examination, aka ‘candling,’ with ovigerous females as a maturity index.

Gulf of Maine Female Lobster Maturity

In an attempt to account for geographic differences in female lobster sexual maturity within the Gulf of Maine (GOM) stock unit, maturity ogives from different portions within GOM were weighted by landings and combined to produce a stock-wide maturity ogive. Maturity ogives for three regions in the GOM were utilized. Two were based on ova diameter data collected by the state of Maine (Boothbay Harbor and Sorrento, ME). The third was based on several maturity indicators (D. Pezzack, Department of Fisheries and Oceans, Canada, personal communication) and represents the offshore section of the GOM (Brown’s Bank, Canada).

The maturity curve from lobsters sampled around Boothbay Harbor, ME was used to represent the inshore southwest portion of the Gulf of Maine (western GOM) including NMFS SAs 513 and 514. The maturity curve from lobsters sampled from Sorrento, ME was used to represent the inshore northern portion of the Gulf of Maine (eastern GOM) including SAs 511 and 512. The maturity curve from lobsters sampled from Browns Bank, Canada is representative of the offshore Gulf of Maine, SAs 464, 465, and 515. These three maturity curves were weighted by applying the proportion of the total GOM landings (mean landings for 2008-2012) represented by those specific statistical areas to the respective maturity ogives. The three weighted curves were then combined to create a maturity ogive representative of the entire GOM. A logistic function was used to fit the combined curve and to obtain the parameters ($\alpha = 27.243$, $\beta = -0.300$). The resulting combined maturity ogive was considered representative of the whole GOM stock unit, and the estimated size at 50% maturity was 91 mm CL for the 2015 assessment.

Georges Bank Female Lobster Maturity

The maturity ogive for the Georges Bank stock was based on ovigerous condition (adjusted for the interaction between growth and extrusion) of lobsters collected from northern Georges Bank (Cooper and Uzmann 1977, Fogarty and Idoine 1988). No weighting was applied, as this was the only maturity data source available. The estimated size at which 50% of females are mature was 100 mm CL.

Southern New England Female Lobster Maturity
In an attempt to account for geographic differences in female lobster sexual maturity within the Southern New England (SNE) stock unit, maturity ogives from different regions within SNE were weighted by landings and combined. Maturity ogives were available from five regions within the SNE assessment area. They are as follows; Long Island Sound based on a re-analysis ova diameter data from Briggs and Mushacke (1979), Buzzards Bay based on ova diameter adjusted cement gland data collected by the state of MA (Estrella and McKiernan 1989), the south shore of Long Island based on ova diameter data collected by the state of NY (Briggs and Mushacke 1980), Block and Hudson Canyons based on ova color determined by external observation ('candling') from lobsters collected by the state of RI, and Coastal Rhode Island Canyons (SA 539) based on ova color determined by external observation ('candling') from lobsters collected by the state of RI.

Weighting factors were derived as proportions of 2008 to 2012 average SNE landings based on combined landings from statistical areas that are representative of where each maturity curve originated. The maturity curve from lobsters sampled in the southern New England canyons was weighted with the proportion of landings from SAs 616 and 537 combined. The maturity curve from lobsters sampled in Buzzards Bay, MA was weighted with the proportion of landings from SA 538. The maturity curve from lobsters sampled in inshore RI waters was weighted with the proportion of landings from SA 539. The maturity curve from lobsters sampled in Long Island Sound (CT data) was weighted with the proportion of landings from SA 611. The maturity curve from lobsters sampled from the ocean side of Long Island, New York was weighted with the proportion of landings from SAs 612 and 613 combined. The five weighted curves were then combined to create a maturity ogive representative of the entire SNE. A logistic model was fit to the combined curve to obtain the parameters ($\alpha = 14.288$, $\beta = -0.188$). The resulting combined maturity ogive was considered representative of the whole SNE stock unit, and estimated the size at 50% maturity to be 76 mm CL.

Updated maturity data

Maine DMR initiated an update of maturity data from lobsters collected in SA 513 (Boothbay region, published in Waller et al 2019) and from an area near Millbridge, ME in SA 511. This work was completed during 2018 and 2019. Data from these studies were provided to the Lobster SAS for use in the 2020 assessment. Determination of maturity was based on ovarian staging technique; details on maturity determination and data analyses available in Waller et al 2019.

ASMFC provided funding to MEDMR and the Commercial Fisheries Research Foundation (CFRF) to sample and process lobsters from offshore SAs 562 and 537. This work was conducted during the summer of 2019. Determination of maturity was based on ovarian staging technique (see Appendix 2 for the final report of that work, including details on methods and analyses).

Massachusetts DMF collected updated maturity data during a study on reproduction in SNE lobsters for SA 538, and opportunistically from lobsters collected during the NEFSC fall and spring bottom trawl surveys in SA 562 and SA 537. Data for SA 538 were collected during the summer of 2017. Lobsters from the NEFSC survey were collected during three surveys: fall 2015, spring 2016, fall 2016. Due to logistical constraints, lobsters collected from the trawl survey were frozen aboard the survey vessel for preservation and handed over to DMF staff after the conclusion of the survey. Live lobsters from SA 538 were briefly placed in a freezer (~15 minutes) to 'anesthetize' them prior to dissection, and frozen lobsters from the NEFSC survey collections were thawed prior to dissection. Determination of maturity for all lobsters was based on the ovarian staging technique minus the measurements of individual ova. Consistent with historical maturity study methods and with methods used by Waller et al (2019), only non-ovigerous females were included in the final analyses. These data were used as the complete dataset for SA 538, and to supplement the data provided by the CFRF/DMR work for SAs 537 and 562.

The data for SAs 537 and 562 from the two different studies (CFRF/DMR and DMF) were combined to produce ogives for use in this assessment. Inclusion of both datasets increased the overall sample size and improved the number of samples at the extremes of the size ranges sampled. See Table 1 for the size ranges sampled by each effort for each SA. The estimated size at 50% maturity for SA 537 is 79.5 mm CL, and the estimate for SA 562 is 91.5 mm CL (Figure 1 and Table 2). The historical data for Georges Bank (described as "northern Georges Bank") estimated an SOM of 100 mm, so the updated data indicate a decrease in SOM for the area. Historic data for SA 537 does not exist for comparison.

All updated maturity ogives were derived with the logistic equation $p_{mat} = \frac{e^{a+bCL}}{1+e^{a+bCL}}$

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Table 1. Size ranges sampled by DMF and by CFRF/DMR in SAs 537 (left) and 562 (right), and the final combined N for each SA.

SNE - SA 537

size bin	DMF	CFRF/DMR	Combined N
56-60	1	3	4
61-65	7	3	10
66-70	7	2	9
71-75	8	8	16
76-80	11	23	34
81-85	3	53	56
86-90	3	46	49
91-95	3	4	7
96-100	2	4	6
101-105	3	4	7
106-110		2	2
111-115	2		2
116-120		2	2
121-125			0
TOTAL	50	154	204

GBK - SA 562

size bin	DMF	CFRF/DMR	Combined N
56-60	0	2	2
61-65	5	1	6
66-70	3	12	15
71-75	2	11	13
76-80	3	17	20
81-85	7	20	27
86-90	6	12	18
91-95	11	14	25
96-100	9	22	31
101-105	19	12	31
106-110	19	18	37
111-115	34	11	45
116-120	17	0	17
121-125	3	1	4
TOTAL	138	153	291

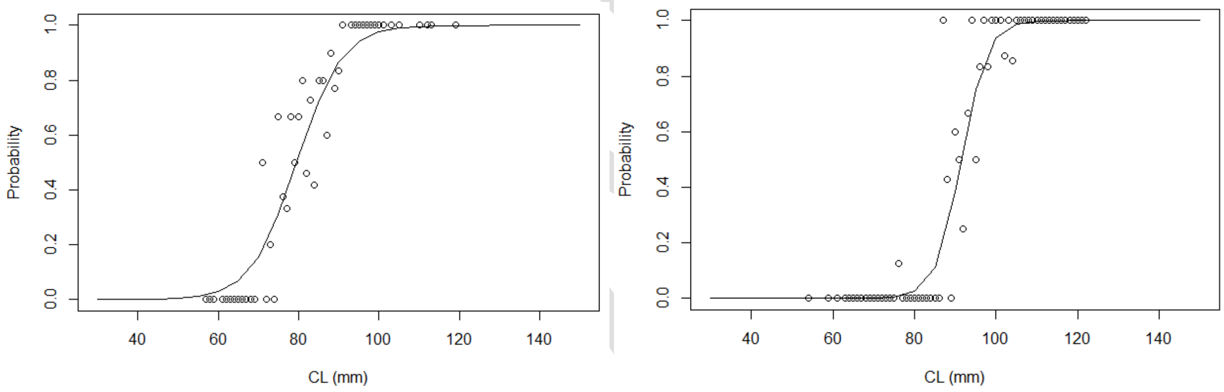

Figure 1. Left: Proportion mature at length and logistic fit to the data for SA 537. Right: Proportion mature at length and logistic fit to the data for SA 562.

Table 2. Parameter estimates, estimated size at which 50% of females are mature (L50) and lower and upper confidence for SAs 537 and 562. The equation used to fit maturity data was:

$$p_{mat} = \frac{e^{a+bCL}}{1+e^{a+bCL}}$$

	a	b	L50	LCI	UCI
SA 537	-14.2111	0.1788	79.48	77.47	81.49
SA 562	-29.0399	0.3174	91.5	89.91	93.09

The new estimated size at 50% maturity for SA 538 is 76.1 mm (see Figure 2), which is very similar to the old estimate provided by Estrella & McKiernan (1989) in Buzzards Bay (SA 538) from the 1980s. It is unclear why this area did not experience a decrease in SOM when other areas studied did, although there are several possible explanations including physiological constraints and changes in the location of nursery and juvenile habitats; this could be an area for future research.

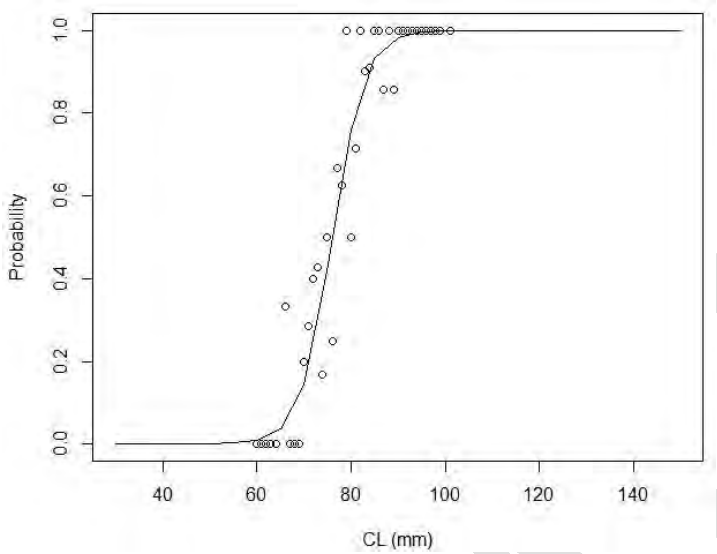

Figure 2. Proportion mature at-length and logistic fit to the data for SA 538. L50=76.1 (LCI=74.7, UCI=77.5) Parameter estimates: a = -22.2754, b = 0.29271

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Determination of new stock-wide maturity ogives

After examining all the available maturity data, new and old (see Table 3), the Lobster SAS decided to use only the recently collected data for this assessment. This was based on the opinion that the new data more closely represents current maturation schedules than the historical data does.

Table 3. Old and new estimates for size at which 50% of females mature for GOMGBK SAs (left) and SNE SAs (right).

	SAs	Pmat50
OLD	513/514	~88
	511/512	~92
	515	~94
	??	~100
NEW	513/514	~83
	511/512	~88
	562	~91

	SA	Pmat50
OLD	538	~76 mm
	539	~74 mm
	611	~72 mm
	612/613	~71 mm
	616	~80 mm
NEW	537	~80 mm
	538	~76 mm

In order to account for differences in maturation schedules in different regions within a stock, the maturity data from each area was weighted based on the landings from each area (as an approximation of population abundance).

In the GOMGBK stock, three regions were identified that represent the majority of GOMGBK landings and align with new maturity data: eastern inshore GOM (SAs 511 & 512), western inshore GOM (513 & 514), and offshore GBK (561 & 562) (see Figure 3 and Table 4).

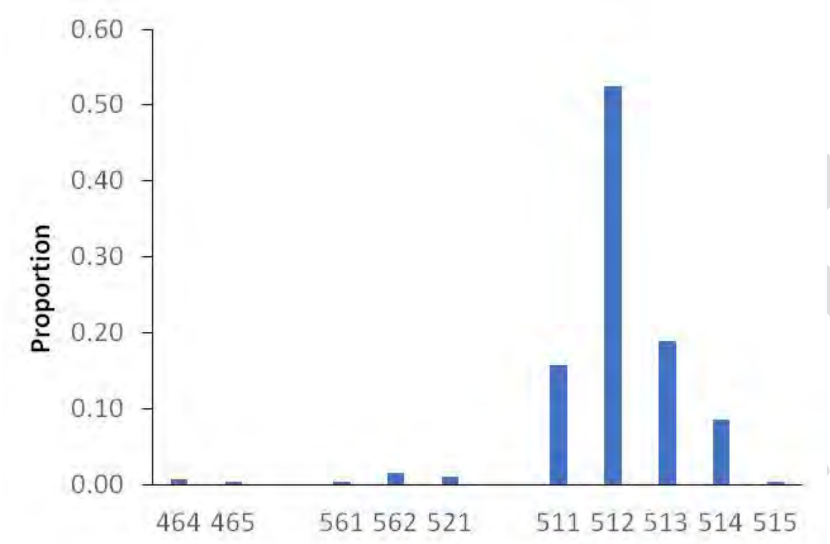
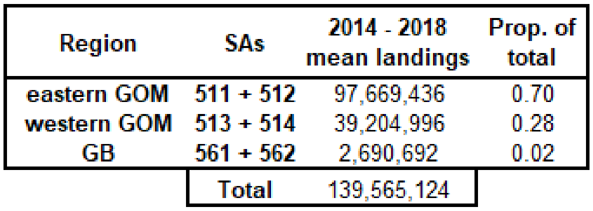


Figure 3. The proportion of GOMGBK landings (five-year average, 2014-2018) from each of the primary GOMGBK SAs. No new maturity data exists for SAs 464&465, 521, or 515, so these areas were not included in the maturity weighting procedure.

Table 4. Proportion of landings (five-year average, 2014-2018) from each of GOMGBK SAs with updated maturity data. The total and proportions here include only landings from these six SAs.



Region	SAs	2014 - 2018 mean landings	Prop. of total
eastern GOM	511 + 512	97,669,436	0.70
western GOM	513 + 514	39,204,996	0.28
GB	561 + 562	2,690,692	0.02
	Total	139,565,124	

For each SA's maturity ogive, the landings weighting was applied by multiplying the proportion of that SA's landings to the proportion mature in each size bin (resulting in a weighted proportion mature for each size bin). Then add together the resulting ogives to get a stock-wide ogive. For GOMGBK this procedure resulted in a stock-wide ogive with parameter estimates a = -17.1406 and b = 0.19664 for the logistic equation $p_{mat} = \frac{e^{a+bCL}}{1+e^{a+bCL}}$ (Figure 4). The estimated size at 50% maturity for the GOMGBK stock is 87 mm CL.

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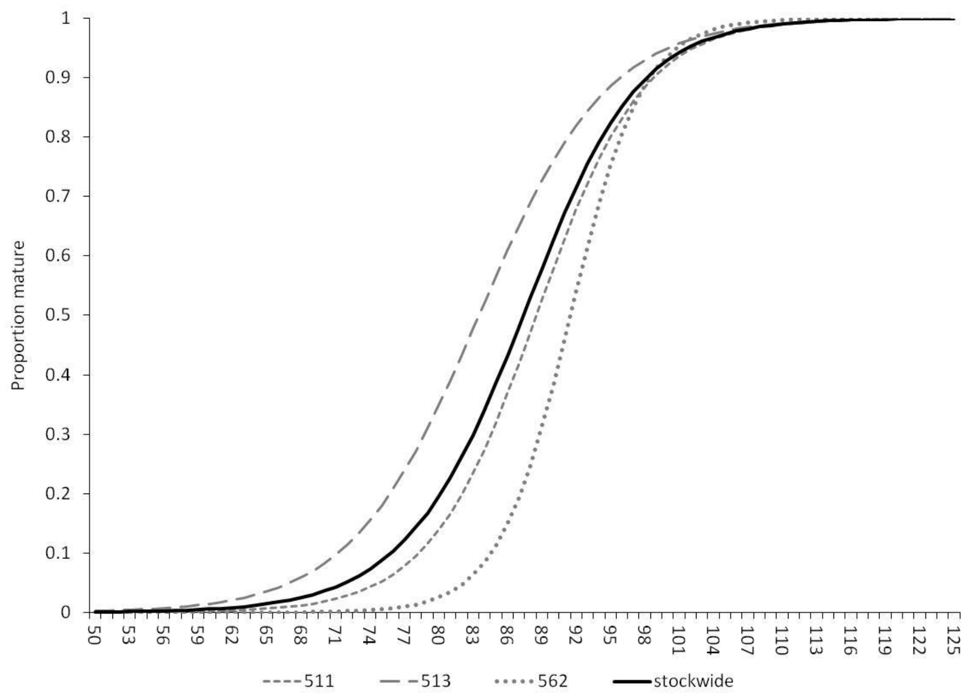

Figure 4. Maturity ogives for SAs 511, 513, and 562, and the landings-weighted stock-wide maturity ogive for GOMGBK.

Since only updated maturity data were available for SAs 537 and 538, landings from only those two SAs were included in the development of the new stock-wide maturity ogive, which accounts for ~53% of all SNE landings. Ideally additional maturity data from other important SAs would have been used to update the stock-wide maturity ogive (see Figure 5), however none were available. Since landings from SAs 612, 613, and 616 are also predominantly offshore while 539 and 611 are inshore landings, the Lobster SAS felt that the relatively heavy influence of 537 (offshore) and the lesser weighting from inshore 538 would reflect maturity schedules for the SNE stock relatively well in the absence of additional new maturity data.

Using the landings-weighting procedure and data for SAs 537 and 538 (Table 5), the resulting new stock-wide ogive with parameter estimates a = -14.6026 and b = 0.18466 for the logistic equation $p_{mat} = \frac{e^{a+bCL}}{1+e^{a+bCL}}$ (Figure 6). The estimated size at 50% maturity for the SNE stock is 79 mm CL. Note that this SOM is slightly larger than that used in the previous assessment, reflective of the increased influence of the offshore SA (537), which reflects the current distribution of this stock.

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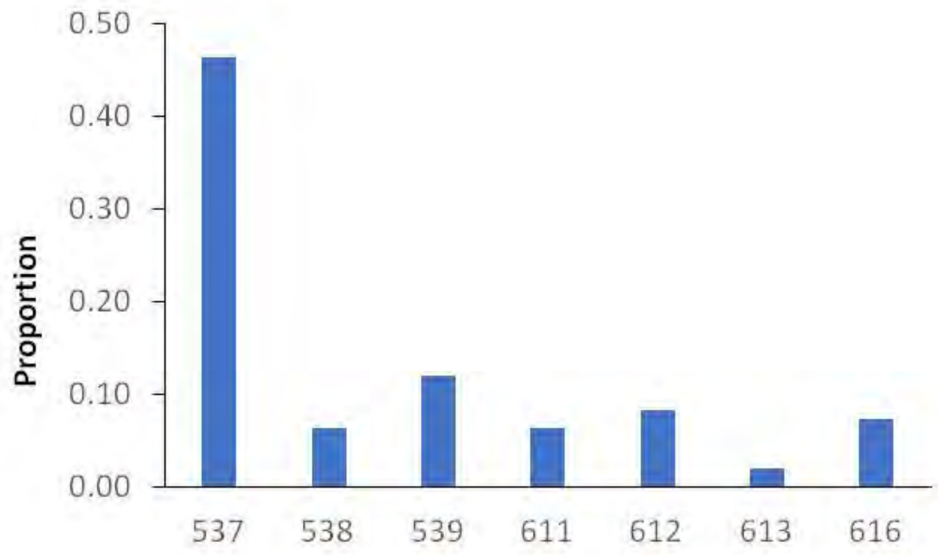
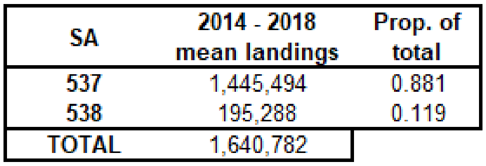


Figure 5. Statistical areas that together comprise ~88% of all SNE landings and that had historical maturity data to examine, and the proportion of landings accounted for by each SA.

Table 5. Proportion of landings (five-year average, 2014-2018) from each of the SNE SAs with updated maturity data. The total and proportions here include only landings from these two SAs.



SA	2014 - 2018 mean landings	Prop. of total
537	1,445,494	0.881
538	195,288	0.119
TOTAL	1,640,782	

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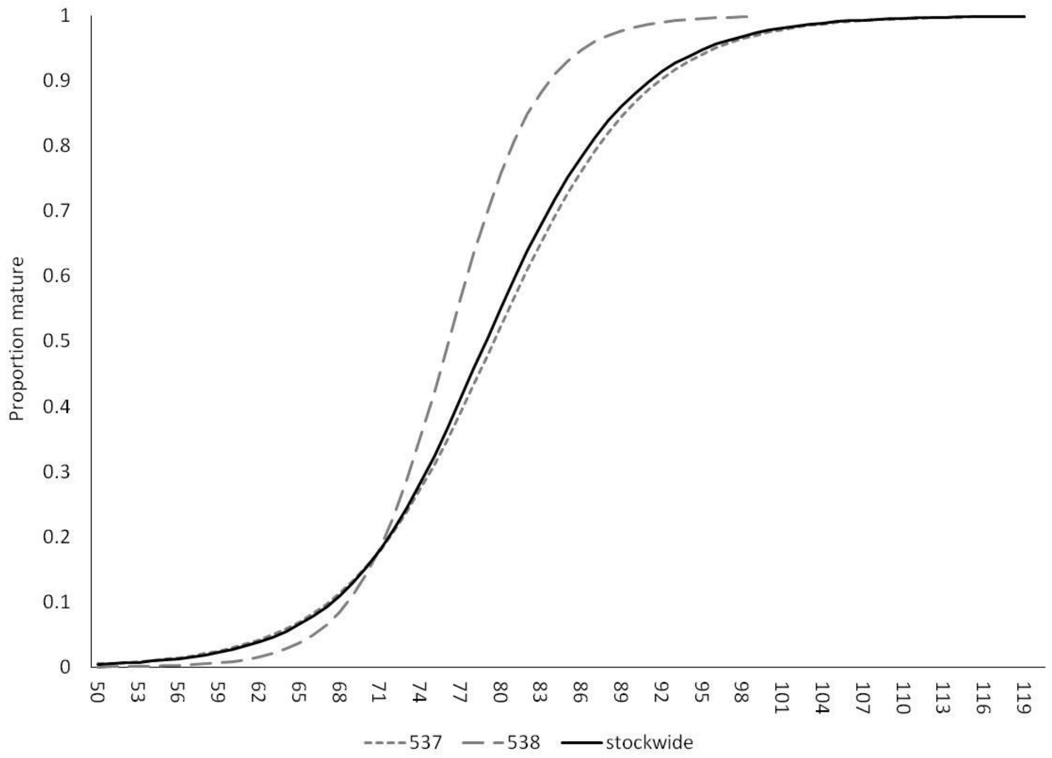

Figure 6. Maturity ogives for SAs 537 and 538, and the landings-weighted stock-wide maturity ogive for SNE.

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Acknowledgements
The Lobster SAS would like to thank Jesica Waller at MEDMR and Aubrey Ellertson at the Commercial Fisheries Research Foundation for their work on collecting and analyzing data from SAs 537 and 562. ASMFC funded the DMR/CFRF work under award numbers 19-0301 and 19-0302. MADMF maturity work in SA 538 was funded by a Saltonstall-Kennedy grant (NOAA award No. NA16NMF4270242). Thanks also to Jakub Kircun (NEFSC) for assistance with lobster collections from the NEFSC bottom trawl survey. Finally thanks to several MADMF staff members (E. Morrissey, K. Whitmore, and A. Boeri) and intern M. Foote who assisted with the DMF maturity work.

Appendix 2. American Lobster Maturity Assessment

See supplemental PDF file “Appendix 2 - American Lobster Maturity Assessment.pdf”.

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Appendix 3. Derivation of Assessment Model Inputs from Fishery-Dependent Biosamples and Raw Landings Data

Fishery-dependent data, typically collected by state or federal port- and sea-sampling programs, are used for multiple inputs to the University of Maine stock assessment model including:

- the catch length composition by sex, quarter, and year;
- landings by sex, quarter, and year;
- percent of the catch that is legal by size, sex and year;
- conservation discards (probability of discarding for egg-bearing and v-notched females) by size, quarter, and year (only applicable to females).

While all of these are important inputs to the assessment model, it is worth noting that the catch length composition and landings by sex are treated as estimates with error that the model attempts to fit given the other inputs. However, the legal percentage and conservation discards are specified constraints that the model has to accept and work around, similar to the gear selectivity. Calculations of these inputs are necessarily complex due to spatial variations in the length composition and sex ratios of lobster and different minimum and maximum size limits associated with each LCMA. Additionally, these size compositions change seasonally due to molting and seasonal migrations. Statistical areas are the finest spatial scale to which the landings data can be attributed, setting the finest scale at which other inputs can be estimated. Thus, it is most appropriate to estimate the above inputs by year, quarter, and SA, and then aggregate them across SAs and quarters as is appropriate. This often results in requiring data at finer resolution than has been historically collected, necessitating the estimation of data for year / quarter / SA combinations where data are otherwise lacking, commonly called gap-filling. Because this process can be subjective but the resulting inputs are important to the outcome of the assessment model, producing a single, reproducible and rule-based, computational routine to calculate these inputs from the raw data is appropriate. This process is performed within an R computer script (“script Lobster_CALF_Landings_ConservDisc_1.8.R”) and detailed below.

Biosampling data require some pre-processing, standardization, and thinning before being used for estimating model inputs. For each agency, ovigerous status and v-notch data are standardized and data from gear other than lobster traps are excluded. Given the variety of conditions that biosampling data are collected under, it is difficult to define replicate samples (i.e. all lobster from one trawl of traps, one vessel’s catch for a day, multiple vessel’s catch for a day port-sampled at a single dock, or a vessel’s catch from a multi-day trip, etc.). Further, not all data can be assigned to a specific vessel and sampling session. For lack of a better identifier of sampling units, data are treated as replicates based on trip identifiers composed of available data on Stock, Sample Type (port vs sea), Agency (state, federal ,etc.), Date, Port, SA, Supplier Trip Id and Observer Trip Id, though not all fields are available for all data from all agencies. These replicate sampling bouts, considered “Trips” generally represent samples from one vessel trip but also include a day’s port-sampling across multiple vessels at a port or one day’s sea-

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sampling from a multi-day cruise and further study and refinement of the definition of replicates is probably justified. Trips are further assessed for having sampled a minimum of 2 lobsters and having sexed a minimum of 90% of the individuals, and data from trips not meeting these requirements are discarded.

Investigation on the spatial and temporal variability of catch lengths and sex ratios indicate that catch composition is generally more stable across years within a season and SA, than across seasons within a SA and year or across SAs within a year and season. Thus, gap-filling of model inputs were generally performed by finding comparable data across years within a season and SA. The exceptions to this are offshore SAs that are infrequently sampled but have comparable SAs where data may be shared and SAs that have very little sampling, are outdated, or have very little reported landings, which were lumped with an appropriate neighboring SA (Appendix 3 Table 1).

To apply appropriate length regulations to data from SAs, individual SAs were assigned the regulations from their most appropriate LCMA based on spatial overlap and knowledge of the spatial distribution of landings within the LCMA. Such assignments were reasonably intuitive with the exceptions of SAs 521 and 537. SA 521 was finally assigned to the Outer Cape Cod LCMA based on primarily inshore landings. SA 537 has significant landings from both inshore and offshore LCMA's with some overlap of the LCMAs and historically more landings from the inshore area. SNE model results were found to be robust in a sensitivity run with Area 537 assigned to either the inshore or offshore LCMA, so 537 was left assigned to the inshore LCMA2.

In the previous assessment (ASMFC 2015a), a threshold of ten sampling trips was defined to trigger gap-filling (note: the intention was to use a three trip threshold). If ten sampling trips were not conducted in a given year, SA, and quarter, data were gap-filled by borrowing from comparable SAs until the data set contained at least ten sampling tips. As noted earlier, the trip definition may not provide the best definition of a replicate sample and information content may vary among trips. Further, spatio-temporal aggregations of like-sized individuals sampled from trips likely results in a cluster sampling design. In a cluster sampling design, the true information content on a population parameter of interest (e.g., mean size) from individuals sampled tends to be less than the information content from the same number of individuals sampled under a true random sampling design. As similarity among individuals within a trip, or cluster, increases relative to similarity between individuals from other clusters, the information content decreases. To quantify the true information content in the biosampling data available for a year, quarter, and SA, the effective sample size in terms of mean length was calculated according to Nelson 2014 assuming one-stage sampling. First, the mean size ($\hat{l}$) was calculated as:

$$\hat{l} = \frac{\sum_{i=1}^{n} M_i \hat{\mu}_i}{\sum_{i=1}^{n} M_i} \qquad \text{(Eq. 1)}$$

Where n = total number of clusters sampled, $\hat{\mu}_i$ = mean length of individuals measured in cluster i, and Mi = number of individuals measured in cluster i.

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The variance of $\hat{\mathrm{l}}$ calculated as:

$$\mathrm{var}(\hat{\mathrm{l}}) = \frac{\sum_{i=1}^{n}\left(\frac{M_i}{\bar{M}}\right)^2 (\hat{\mu}_i - \hat{\mathrm{l}})^2}{n(n-1)} \qquad \text{(Eq. 2)}$$

Where $\bar{M}$ is the average number of individuals measured per cluster. If there was only one trip within a year, quarter, and SA, those data were dropped from the data set because variance is undefined.

An estimate of the population variance was calculated as:

$$\hat{\sigma}_{\mathrm{l}}^2 = \frac{\sum_{i=1}^{n}\sum_{j=1}^{Mi}(l_{ij} - \hat{\mathrm{l}})^2}{(\sum_{i=1}^{n} M_i) - 1} \qquad \text{(Eq. 3)}$$

Where l_{ij} is the length of individual j from cluster i.

Finally, the effective sample size was calculated as:

$$\hat{m}_{\mathrm{eff}} = \frac{\hat{\sigma}_{\mathrm{l}}^2}{\mathrm{var}(\hat{\mathrm{l}})} \qquad \text{(Eq. 4)}$$

Nelson (2014) found that the effective sample size relative to the actual number of individuals measured ranged from 0.1-12%. To generate a data set for a year, quarter and SA, a threshold effective sample size had to be met. Statistical area-specific thresholds were defined as the product of the median of the effective sample size relative to the actual number of individuals measured and the median of the average number of individuals measured during three trips among all year and quarter combinations with at least two trips (i.e., the effective sample size associated with the 3 trips threshold for the respective "population"; Eq. 5). This removes the equal weighting of trips to trigger gap-filling under the previous trip-based threshold and, rather, considers the information content of all biological sampling collectively.

$$\mathrm{threshold}_{\mathrm{eff}} = \mathrm{median}\left(\frac{\hat{m}_{\mathrm{eff}}}{\sum_{i=1}^{n} M_i}\right) * \mathrm{median}(\bar{M}) * 3 \qquad \text{(Eq. 5)}$$

Two sets of threshold had to be developed: one set from combined sea- and port-sampling data used to characterize commercial landings length compositions and sex ratios and one set from sea-sampling data only used to characterize legal proportions and conservation discards. GOMGBK statistical area thresholds for only sea-sampling data range from 9-296 (Appendix 3 Figure 1) and thresholds for combined sea and port-sampling data range from 2-45 (Appendix 3 Figure 2). Thresholds for both data sets are generally lower in nearshore statistical areas and greater in offshore statistical areas. SNE statistical area thresholds for only sea-sampling data range from 8-83 (Appendix 3 Figure 3) and thresholds for combined sea and port-sampling data range from 5-284 (Appendix 3 Figure 4). Similar to GOMGBK thresholds, SNE thresholds for both data sets are generally lower in nearshore statistical areas and greater in offshore statistical areas.

Further, offshore SAs were required to have data from at least two different years to avoid having length compositions characterized by a small number of multi-day sea-sampling trips. Length composition data were first extracted for a SA and any comparable SAs and assessed if the effective sample size threshold and minimum number of years were represented. If not, the data set was iteratively expanded across years, including comparable SAs, and the effective sample size was recalculated until the threshold and the minimum number of years were achieved. Two different sets of length compositions were extracted; one for characterizing commercial landing compositions and one characterizing commercial catch compositions, the latter used to provide relative weighting factors for legal proportions and conservation discards calculations. The iterative process of searching across years for minimum adequate data sets is different for the two data sets. It is important to note that the current effective sample size thresholds are based on size composition sampling, but these data are used to characterize sex ratios as well. Further work is needed to determine if the effective sample size thresholds should be modified to account for sex ratio information content as well.

Commercial landings length compositions and sex-specific landings

Commercial landings length compositions were characterized using both port- and sea-sampling data (without v-notched or ovigerous lobsters) for legal-sized individuals only. Minimum and maximum length regulations often changed across years which affected the catch proportions. To account for this, years were assigned to management regimes where the length regulations were consistent across years and management regimes were ordered according to how restrictive their regulations were. Where data from two or more years were necessary to characterize a length composition, the process first searched across adjacent years symmetrically (future and past years) within its appropriate management regime. If the entire management regime was included without reaching the minimum sampling requirement, the process next searched temporally through less-restrictive management regimes (usually backwards in time). Only if all less-restrictive management regimes had been searched without reaching the minimum sampling requirement did the process search forward into more-restrictive management regimes for data. If all management regimes from the time series were included without reaching the sampling requirement the process was stopped and the length composition estimated based on the available data. Once the effective sample size threshold was met, the raw data from the appropriate trips were further constrained to the legal length requirements for the target year before calculating compositions.

Because the final landings length composition was weighted across SAs by landings, the landings length composition for each year, quarter and SA is calculated by tracking the proportion of the catch represented by each size bin and later transformed back into a relative abundance estimate. Mass for each lobster is calculated for each of the appropriate trips using the length/mass relationships derived for this assessment for males and non-ovigerous females. The proportion of the mass represented by each bin within a trip is then calculated as:

$$\mathrm{pLbM}_{b,t,s} = \frac{\sum_{b,s} M_{b,t,s}}{\sum M_t} \qquad \text{(Eq. 6)}$$

Where $\mathrm{pLbM}_{\mathrm{b,t,s}}$ is the proportion of the landings by mass for bin b, trip t and sex s, $\mathrm{M}_{\mathrm{b,t,s}}$ is the mass of all lobster for a bin from a trip and M_{t} is the mass of all lobster from a trip. From the appropriate trips, the proportion of mass by bin for a given year (y), quarter (q), sex (s) and SA (a) is then calculated by averaging pLbM across trips within bins, sexes and years, then averaging across years within bins and sexes

$$\mathrm{pLbM}_{\mathrm{b,y,q,s,sa}} = \frac{\sum_{\mathrm{y}} \frac{\sum_{\mathrm{t}} \mathrm{pLbM}_{\mathrm{b,t,s}}}{\mathrm{N}_{\mathrm{t_y}}}}{\mathrm{N}_{\mathrm{y}}} \qquad \text{(Eq. 7)}$$

where $\mathrm{N}_{\mathrm{t_y}}$ is the number of trips in a year and N_{y} is the number of years in the set of trips. The proportion of mass by sex is calculated as the sum across bins within a sex divided by the total sum across bins:

$$\mathrm{pLbM}_{\mathrm{y,q,s,sa}} = \frac{\sum_{\mathrm{b}} \mathrm{pLbM}_{\mathrm{b,y,q,s,sa}}}{\sum_{\mathrm{b,s}} \mathrm{pLbM}_{\mathrm{y,q,sa}}} \qquad \text{(Eq. 8)}$$

The landings by year, quarter and sex are then calculated from the raw landings and the proportion by sex as:

$$\mathrm{Landings}_{\mathrm{y,q,s}} = \sum_{\mathrm{sa}} \mathrm{Landings}_{\mathrm{y,q,sa}} \times \mathrm{pLbM}_{\mathrm{y,q,s,sa}} \qquad \text{(Eq. 9)}$$

The proportional mass for each bin, year, quarter and sex are then calculated across statistical areas as:

$$\mathrm{pLbM}_{\mathrm{b,y,q,s}} = \sum \frac{\sum_{\mathrm{sa}} \mathrm{pLbM}_{\mathrm{b,y,q,s,sa}} \times \mathrm{Landings}_{\mathrm{y,q,sa}}}{\mathrm{Landings}_{\mathrm{y,q,s}}} \qquad \text{(Eq. 10)}$$

These mass proportions are then converted to proportions of landings by number as:

$$\mathrm{pLbN}_{\mathrm{b,y,q,s}} = \frac{\frac{\mathrm{pLbM}_{\mathrm{b,y,q,s}}}{\widehat{\mathrm{M}_{\mathrm{b}}}}}{\sum_{\mathrm{b}} \frac{\mathrm{pLbM}_{\mathrm{b,y,q,s}}}{\widehat{\mathrm{M}_{\mathrm{b}}}}} \qquad \text{(Eq. 11)}$$

Where $\widehat{\mathrm{M}_{\mathrm{b}}}$ is the estimated mean mass for a lobster of length b.

Finally, the effective sample size for each year, quarter, and sex is calculated from the trips that actually occurred in a year and quarter across SAs. If fewer than two trips occurred within the year and quarter, the effective sample size was set at 1. While this is an imperfect proxy for sample size, as not all SAs have equal biosampling coverage, it provides an initial representation of how sampling effort occurred in a given year.

Legal proportions and conservation discards

Both the calculation of legal proportions and conservation discards require an estimate of the proportion of the raw catch.

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Commercial catch compositions represent the raw length composition of the catch and were calculated using only sea-sampling data since port sampling data represent the catch after minimum and maximum size requirements and other regulations have been applied to them. The search process for a minimally acceptable data set involves iteratively including adjacent years (future and past) until the minimum sample requirements or the limits of the time series are reached. Once the data set has been discovered, the calculation of proportions proceeds similar to Eq.6 except that proportions within a sex sum to one rather than across sexes as in the landings proportions.

$$\mathrm{pCbM}_{b,t,s} = \frac{\sum_{b,s} \mathrm{CbM}_{b,t,s}}{\sum \mathrm{M}_{t,s}} \qquad \text{(Eq. 12)}$$

Where CbM is Catch by Mass and $\mathrm{M}_{t,s}$ is the mass of all lobster from a trip for a sex. Proportions are then similarly aggregated up to trip and year resolution and averaged across years as:

$$\mathrm{pCbM}_{b,y,q,s,sa} = \frac{\sum_y \frac{\sum_t \mathrm{pCbM}_{b,t,s}}{\mathrm{N}_{t_y}}}{\mathrm{N}_y} \qquad \text{(Eq. 13)}$$

For both legal proportions and conservation discards it is important to get estimates of catch rates of larger lobsters where observations are relatively sparse, resulting in volatile estimates. To address this, a single smoothed catch proportion is estimated across years for each sex, quarter, and SA using a General Additive Model (GAM) with the form:

$$\mathrm{pCbM}_{b,y,q,s,sa} \sim \mathrm{s}\big(\mathrm{Bin}, \mathrm{by} = \mathrm{c}(\mathrm{Sex}, \mathrm{Quarter}, \mathrm{SA})\big), \mathrm{family} = \mathrm{Binomial}) \qquad \text{(Eq. 14)}$$

For legal proportions, the mass of lobster caught for each year, quarter, sex, SA is estimated. The smoothed proportion caught by mass ($\widehat{\mathrm{pCbM}}_{b,q,s,sa}$ from Eq.14) is predicted at 1 mm increments over the range of the size bins, and the minimum and maximum legal sizes are applied for each sex, quarter, SA and year before being aggregated back to 5mm to determine the percentage of the catch that is legal for each bin ($\mathrm{pL}\widehat{\mathrm{egalC}}\mathrm{bM}_{b,q,s,sa}$). The reciprocal of the proportion of all catch that was of legal size for each SA, sex, quarter and year is used as an expansion factor that is applied to the landings to get the estimated total catch:

$$\mathrm{Catch}_{y,q,s,sa} = \frac{\mathrm{Landings}_{y,q,s,sa}}{\sum_b \mathrm{pL}\widehat{\mathrm{egalC}}\mathrm{bM}_{b,q,s,sa}} \qquad \text{(Eq. 15)}$$

The legal proportions by bin are then calculated across SAs from the proportions of the catch by bin, proportion legal for the bin, and the expanded catch for the SA.

$$\mathrm{pLegal}_{b,y,s} = \frac{\sum_{b,q,sa} (\widehat{\mathrm{pCbM}}_{b,q,s,sa} \times \mathrm{pLegalCbM}_{b,y,q,s,sa} \times \mathrm{Catch}_{y,q,s,sa})}{\sum_{q,sa} \mathrm{Catch}_{y,q,s,sa}} \qquad \text{(Eq. 16)}$$

Appendix 3 Figure 5 shows an example output for the percent legal for the GOMGBK stock area. The lines from the 1980s stand out on the right from the period before minimum sizes were increased. The drop at 128 mm is due to the maximum size restriction inshore and the differences among years in the larger size classes reflect the proportions of the landings from the inshore and offshore where larger lobsters are legal. Legal proportions for very large lobsters drop to zero for the recent years when the maximum size went into effect for the offshore LCMA.

The conservation discards are the probability that a captured female lobster is ovigerous and / or v-notched and therefore released. The data are constrained to females from sea sampling so data for many size classes, particularly larger individuals, are again very sparse. As a result, the probability of discarding was modeled with a GAM, using only data for 43 mm – 153 mm CL individuals, with the 153+ mm treated as a plus-group. The model was built in a forward stepwise manner, based on AIC's and model diagnostics. The best model for both stocks had the final form:

$$\mathrm{pDisc}_{\mathrm{b,y,q,sa}} \sim \mathrm{s(Bin, by = factor(Quarter), k = K) + s(Year, by = factor(Quarter), k = 2) + factor(SA) + factor(Quarter), family = Binomial)} \qquad \text{(Eq. 17)}$$

Where $\mathrm{pDisc}_{\mathrm{b,y,q,sa}}$ is the probability of discard by bin, year, quarter, and SA and K is the number of knots allowed in the Bin spline (K=2 for SNE, K=4 for GOMGBK). The number of knots on the smoothers was constrained as splines with sparse data can yield unrealistic results. Interestingly, there is strong evidence for the temporal shift in discard rates and inclusion of the year term, based on model AIC scores. The terminal value at 153 mm was used to fill in all larger size classes. Appendix 3 Figure 6 shows the model-based discard probabilities for GOMGBK. The model finds insufficient data to produce a smoother for the first quarter so returns a fixed line. For the second through fourth quarters, the model finds a maximum around 120 mm and an increase in the probability of discard across years.

The final stock-level retention rates by bin, year and quarter are calculated from the product of the retention rate (1- discard rate), and the catch proportion, weighted by the catch.

$$\mathrm{pRetention}_{\mathrm{b,y,q}} = \frac{\sum_{\mathrm{b,q,sa}} \left((1 - \mathrm{pDisc}_{\mathrm{b,y,q,sa}}) \times \mathrm{p}\widehat{\mathrm{CbM}}_{\mathrm{b,q,sa}} \times \mathrm{Catch}_{\mathrm{y,q,sa}} \right)}{\sum_{\mathrm{sa}} \mathrm{Catch}_{\mathrm{y,q,sa}}} \qquad \text{(Eq. 18)}$$

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Appendix 3 Table 1. Data-poor and comparable statistical areas. Length data and landings from statistical areas with Method=1 were reassigned to their comparable area while statistical areas with Method=2 borrowed length data from comparable areas for characterizing length compositions.

Statistical Area	Method	Comparable Area
464	2	465, 515
465	2	464, 515
467	1	511
515	2	464, 465
521	2	526
522	2	525
523	1	561
524	1	562
533	1	537
534	1	537
538	2	539
541	1	526
542	1	525
543	1	525
551	1	561
561	2	562
613	2	616
614	2	612
615	2	616
621	2	612
622	2	616
623	2	616
624	1	623
625	1	621
626	2	616
627	1	626
628	1	626
631	1	621
632	2	616
635	2	612
636	2	616

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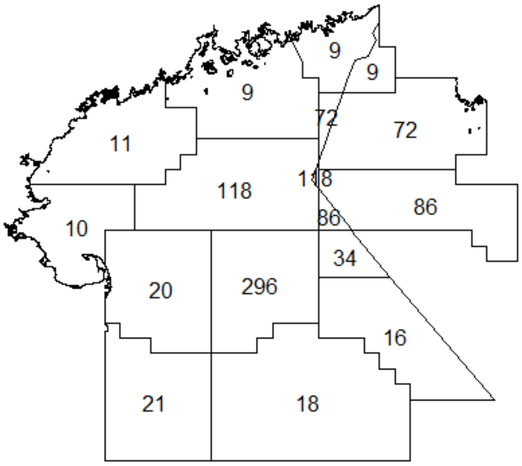
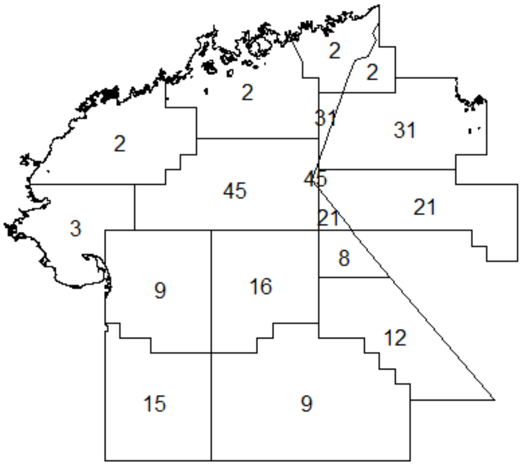
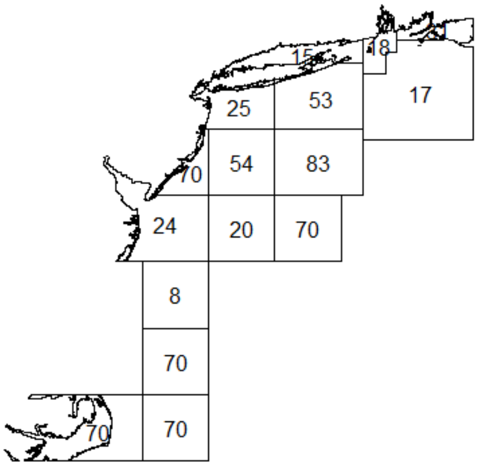


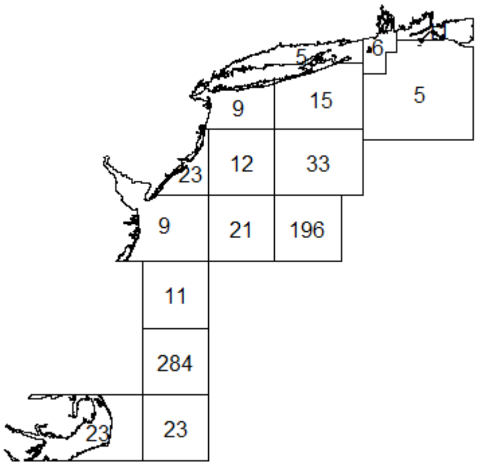
Appendix 3 Figure 1. Effective sample size thresholds by GOMGBK statistical area for characterizing legal proportions and conservation discard rates from sea-sampling data.



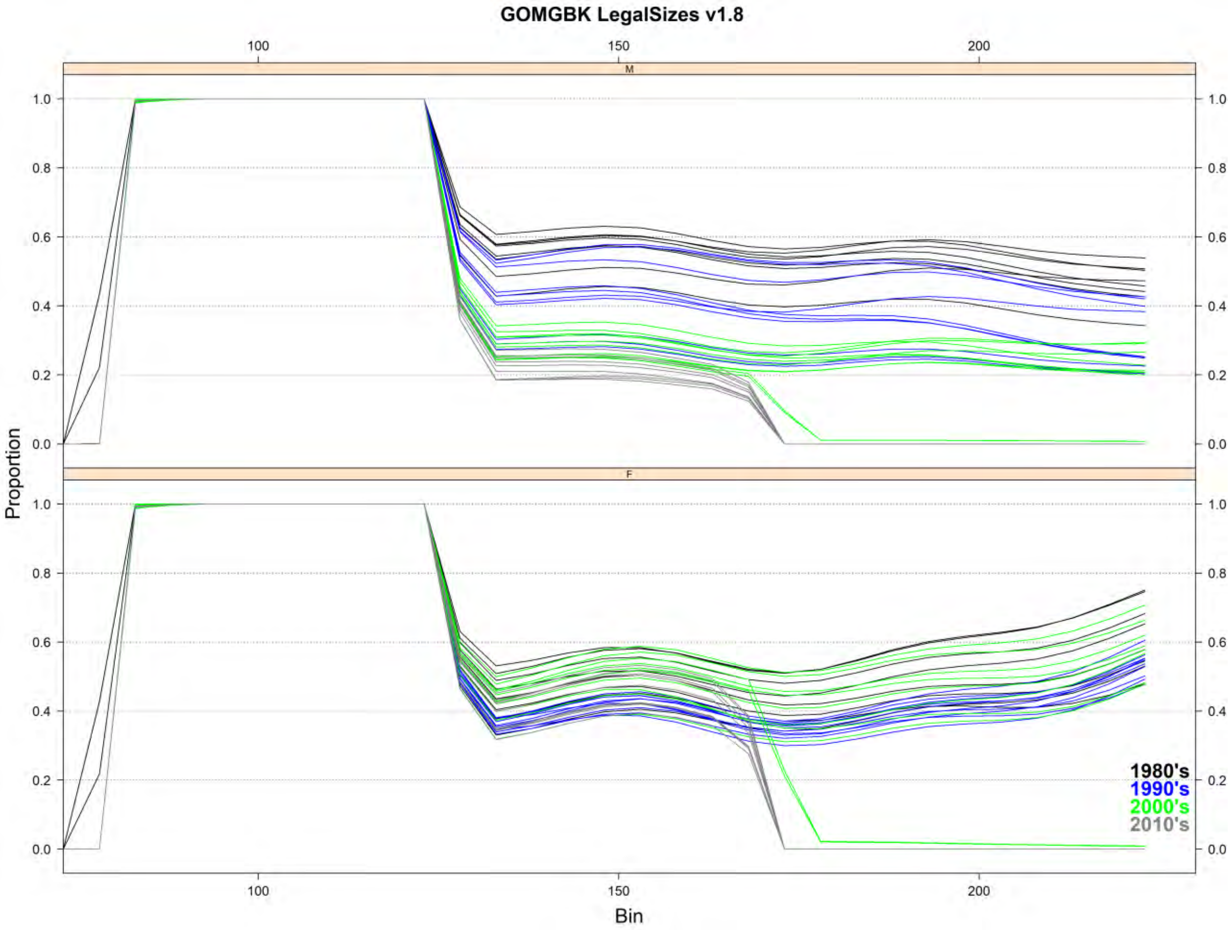
Appendix 3 Figure 2. Effective sample size thresholds by GOMGBK statistical area for characterizing commercial landings length compositions and sex ratios from sea- and port-sampling data.



Appendix 3 Figure 3. Effective sample size thresholds by SNE statistical area for characterizing legal proportions and conservation discard rates from sea-sampling data.



Appendix 3 Figure 4. Effective sample size thresholds by SNE statistical area for characterizing commercial landings length compositions and sex ratios from sea- and port-sampling data.



Appendix 3 Figure 5. Estimated percent of catch that is legal by size bin, sex, and year for the GOMGBK stock.

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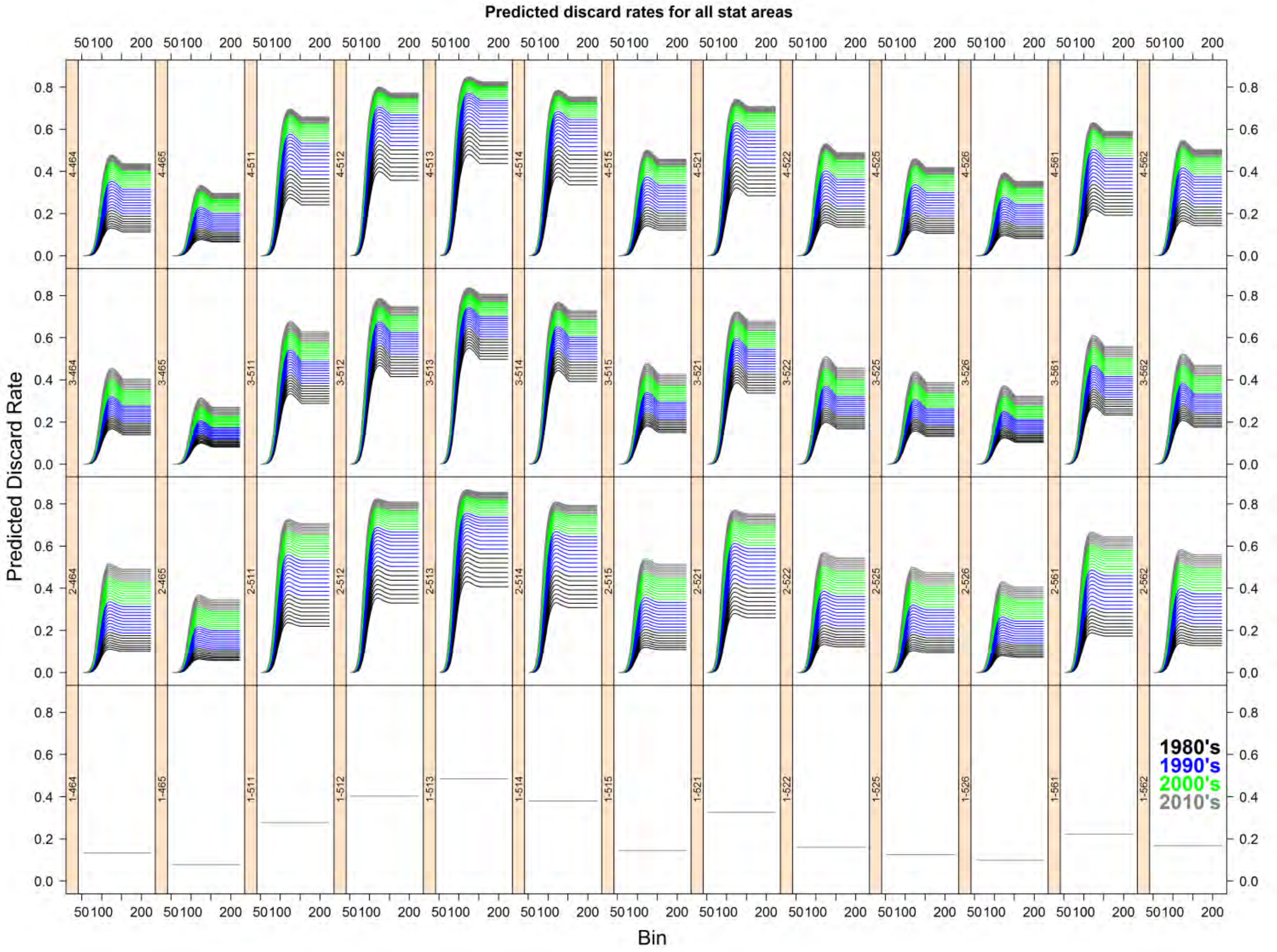

Appendix 3 Figure 6. Model-based discard rate of ovigerous or v-notched females for GOMGBK by size, quarter, SA, and year.

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Appendix 4. Port and Sea Sampling Intensity in 2018 Relative to the Spatial and Temporal Distribution of Landings.

Fishery dependent port and sea sampling supports the stock assessment through collecting data on commercial length composition, sex ratios and discard rates (Section 4.1.3). With a benchmark assessment, it is appropriate to examine, however briefly, the adequacy of the current sampling programs to support the stock assessment and identify spatial or temporal gaps that might be addressed ahead of future assessments. Similarly, sea sampling data come from state and federal sampling programs but is augmented by industry-based collaborations and it is important to understand if this collaborative data is critical to maintaining adequate sampling.

While current gap-filling for stock assessment inputs are conducted to reach a threshold minimum sample size (Appendix 3), here the number of samples collected are examined by statistical area and quarter for simplicity. Similarly, statistical areas with annual landings less than 100,000 pounds in 2018 are dropped, as sampling in these areas is less important to the stock assessment.

Based on a plot of cumulative landings vs sampling intensity, most landings are probably adequately characterized (Appendix 4. Figure 1). Statistical areas and quarter that cumulatively represent 50% of 2018 are sampled more than 20 times per time period and about 75% of landings are sampled 10 times or more per period, the previous sampling threshold for gap filling in the 2015 assessment. About 3% of landings are sampled less than three times per period.

Using a minimum sampling threshold of three times per statistical area and quarter, 4.35 million pounds of landings were inadequately sampled by sea sampling and 7.16 million pounds would have been inadequately sampled in the absence of industry collaborative data. Similarly, 3.26 million pounds were inadequately sampled by both port and sea sampling and 4.0 million pounds would have been inadequately sampled in the absence of industry collaborative data. Under-sampling is most prevalent in the offshore statistical areas including the Gulf of Maine (SAs 464, 465, and 515) and on Georges Bank (SAs 522, 525, 561, 562) but some under-sampling is occurring in some inshore SAs (514, 521, 538) in the winters when catches are lower (Appendix 4 Table 1, Appendix 4 Figures 2-5). The largest current sampling gap identified here is SA 562 in quarter 4 with landings of 887,000 lbs with two sea samples. SAs 514 (quarter 1), 521 (quarter 4), 525 (quarter 4) and 562 (quarter 1) also were sampled less than three times and reported landings over 200,000 lbs.

Industry contributed sea sampling data are helping reach sampling thresholds, particularly in the offshore fisheries (SAs 464, 465, 525, 537, 561, 562, and 616) including areas where the only fishery dependent data is coming from industry collaborators. Most of this industry collaborative data is coming from the CFRF research fleet and additional vessels have been added since 2018 which may partially address these identified gaps.

This analysis should be referenced when allocating effort for NMFS port sampling and the CFRF research fleet to more effectively use these sampling sources, as spatial and temporal allocation of effort by these sampling programs is most flexible.

		Sea Sampling Only				Port and Sea Sampling			
Stock	StatArea	Qtr1	Qtr2	Qtr3	Qtr4	Qtr1	Qtr2	Qtr3	Qtr4
GOMGBK	464	2 / 1	2 / 1	7 / 2	9 / 6	8 / 7	8 / 7	10 / 5	12 / 9
GOMGBK	465	2 / 1	0 / 0	2 / 0	4 / 3	2 / 1	0 / 0	2 / 0	4 / 3
GOMGBK	511	4 / 4	6 / 6	8 / 8	6 / 6	4 / 4	6 / 6	8 / 8	6 / 6
GOMGBK	512	9 / 6	30 / 24	25 / 25	17 / 17	11 / 8	32 / 26	26 / 26	17 / 17
GOMGBK	513	7 / 7	30 / 30	41 / 41	29 / 29	7 / 7	30 / 30	41 / 41	29 / 29
GOMGBK	514	0 / 0	14 / 14	21 / 21	15 / 15	0 / 0	14 / 14	21 / 21	15 / 15
GOMGBK	515	4 / 2	0 / 0	0 / 0	0 / 0	5 / 3	3 / 3	2 / 2	0 / 0
GOMGBK	521	0 / 0	3 / 3	5 / 5	2 / 2	0 / 0	3 / 3	5 / 5	2 / 2
GOMGBK	522	0 / 0	0 / 0	0 / 0	0 / 0	3 / 3	2 / 2	0 / 0	1 / 1
GOMGBK	525	3 / 0	3 / 0	1 / 0	1 / 0	4 / 1	3 / 0	1 / 0	1 / 0
GOMGBK	526		17 / 5	16 / 7	10 / 6		19 / 7	17 / 8	10 / 6
GOMGBK	561	2 / 1	6 / 3	5 / 1	3 / 3	4 / 3	9 / 6	7 / 3	3 / 3
GOMGBK	562	2 / 0	9 / 0	7 / 0	2 / 0	3 / 1	11 / 2	11 / 4	2 / 0
SNE	537	3 / 0	21 / 6	23 / 7	15 / 11	3 / 0	22 / 7	25 / 9	16 / 12
SNE	538	0 / 0	5 / 5	2 / 2	0 / 0	0 / 0	5 / 5	2 / 2	0 / 0
SNE	539		59 / 14	76 / 25	32 / 22		59 / 14	76 / 25	32 / 22
SNE	611		3 / 3	2 / 2			4 / 4	4 / 4	
SNE	612		0 / 0	5 / 5	2 / 2		0 / 0	6 / 6	2 / 2
SNE	616		2 / 0	18 / 6	8 / 7		2 / 0	18 / 6	8 / 7

Appendix 4 Table 1. Number of quarterly biosamples collected in 2018. For each cell, first value is all sampling programs including industry collaboration while second value is sampling programs excluding industry collaboration. Uncolored cells have three or more samples. Cells colored in yellow have less than three total samples including industry contributions while cells in gray have less than three samples excluding industry collaboration. Empty cells with slash-marks landed less than 10,000 lbs in 2018 so are not assessed.

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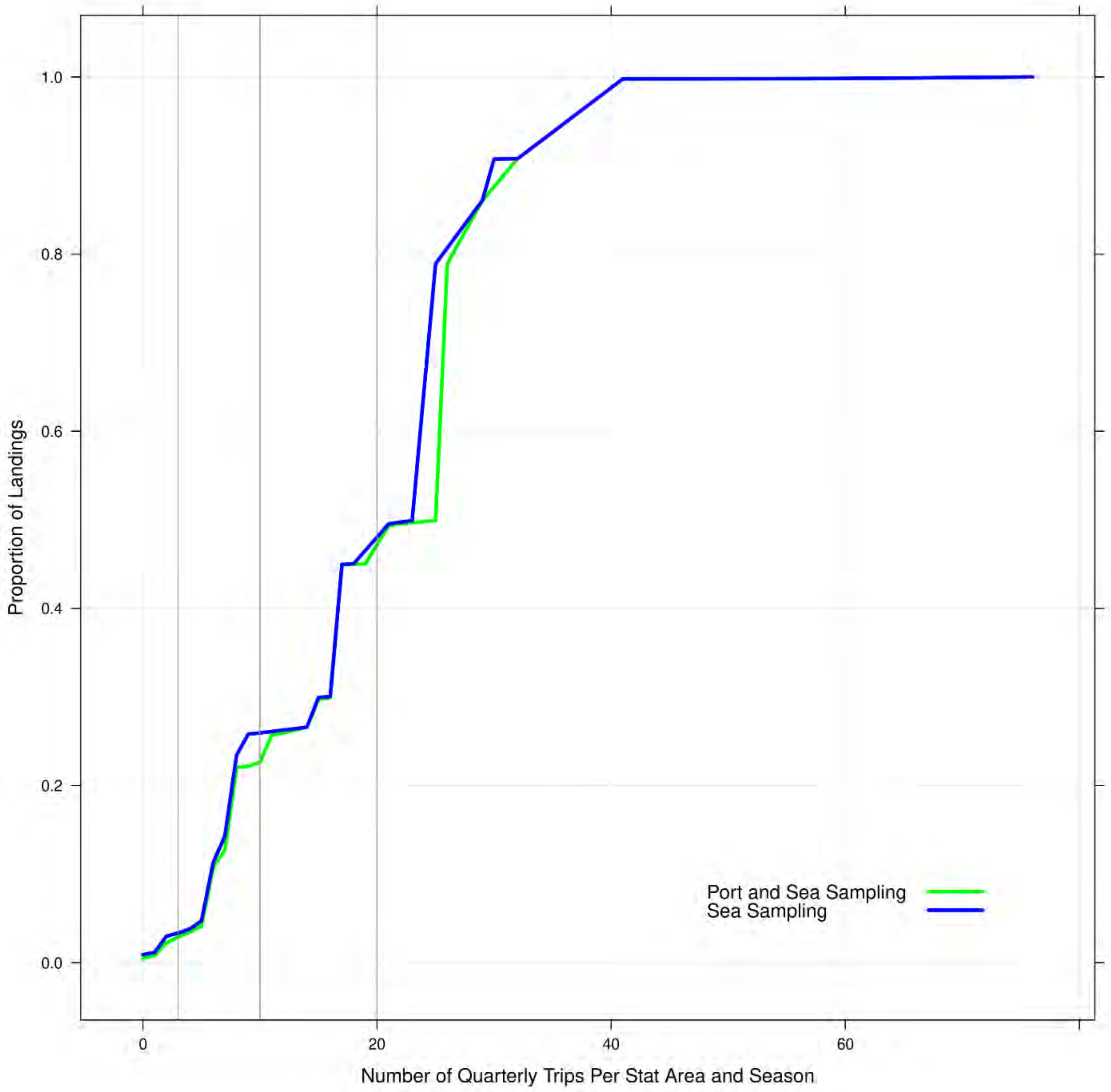
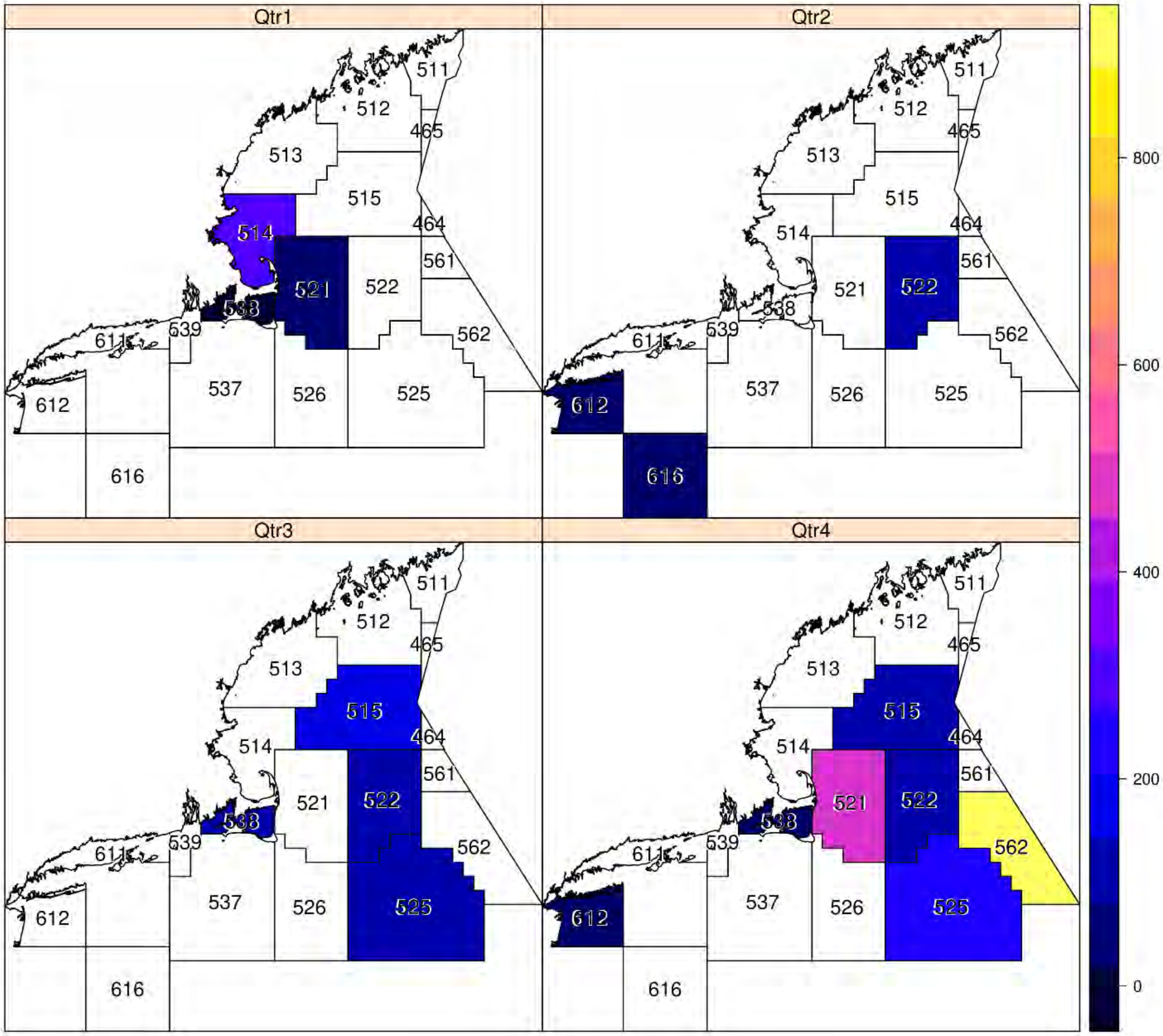
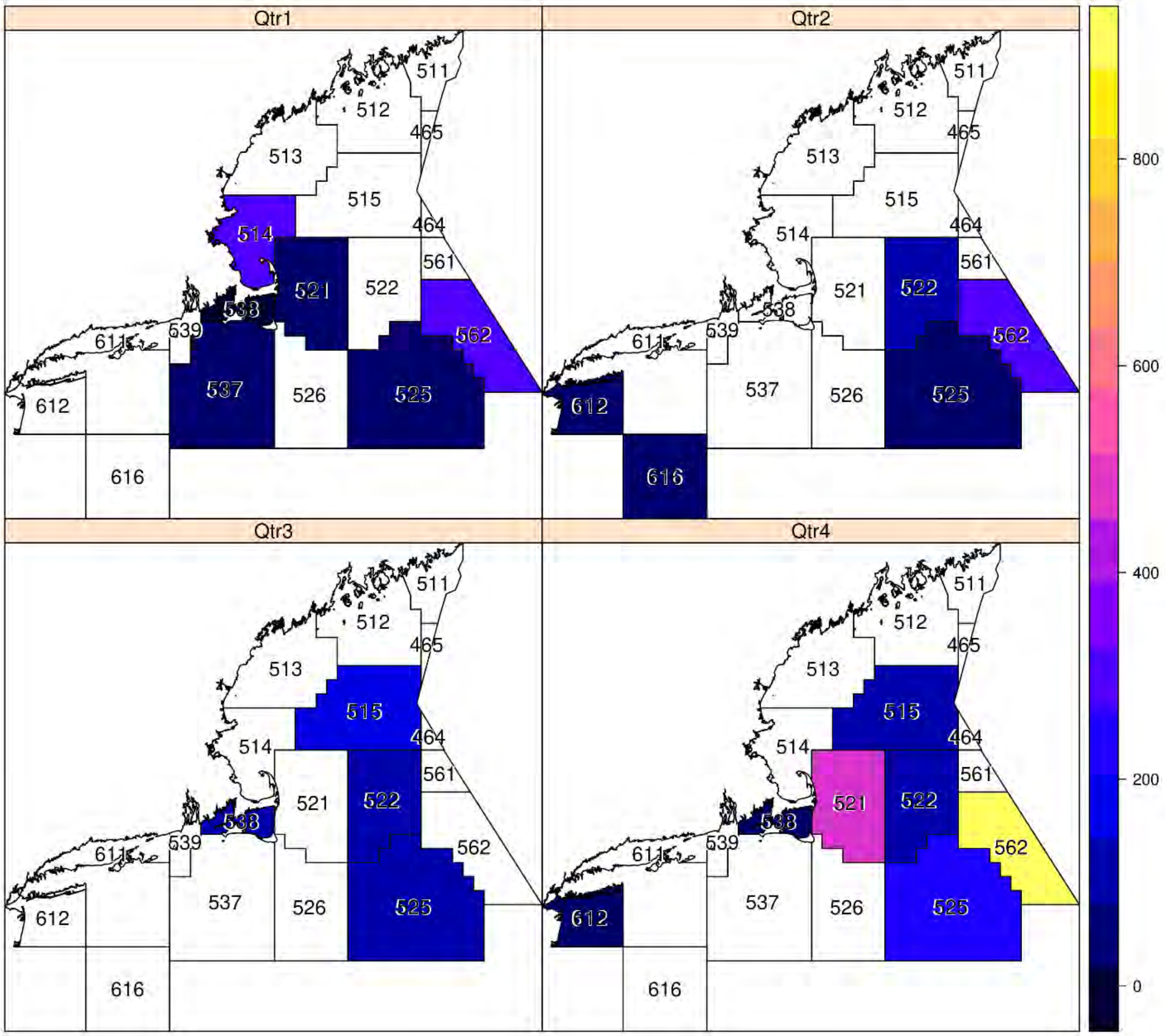


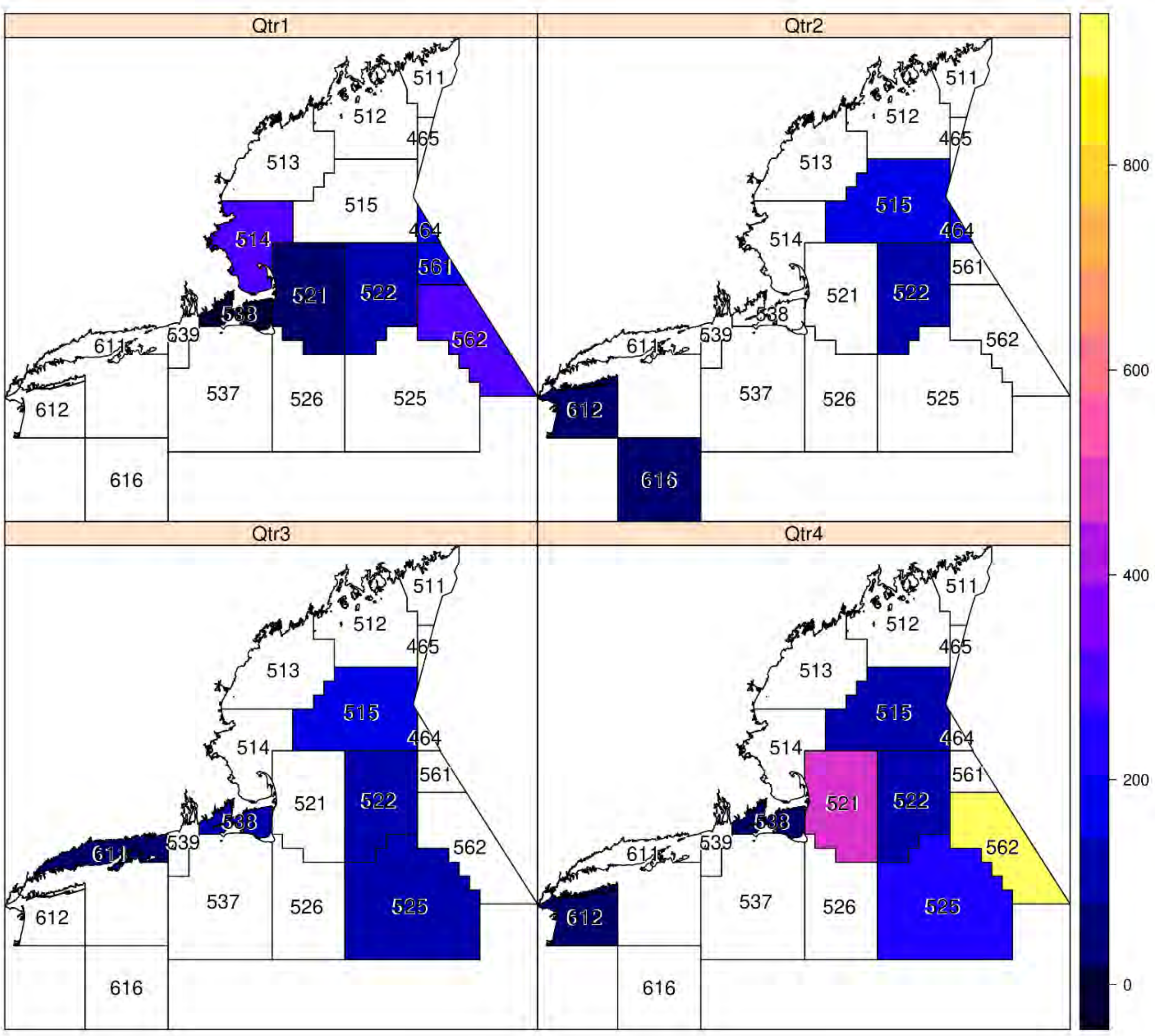
Appendix 4 Figure 1. Cumulative proportion of 2018 landings with less than a given number of sampling events. About 25% of landings were sampled less than 10 times per statistical area and quarter while about 3% of landings were sampled less than 3 times.



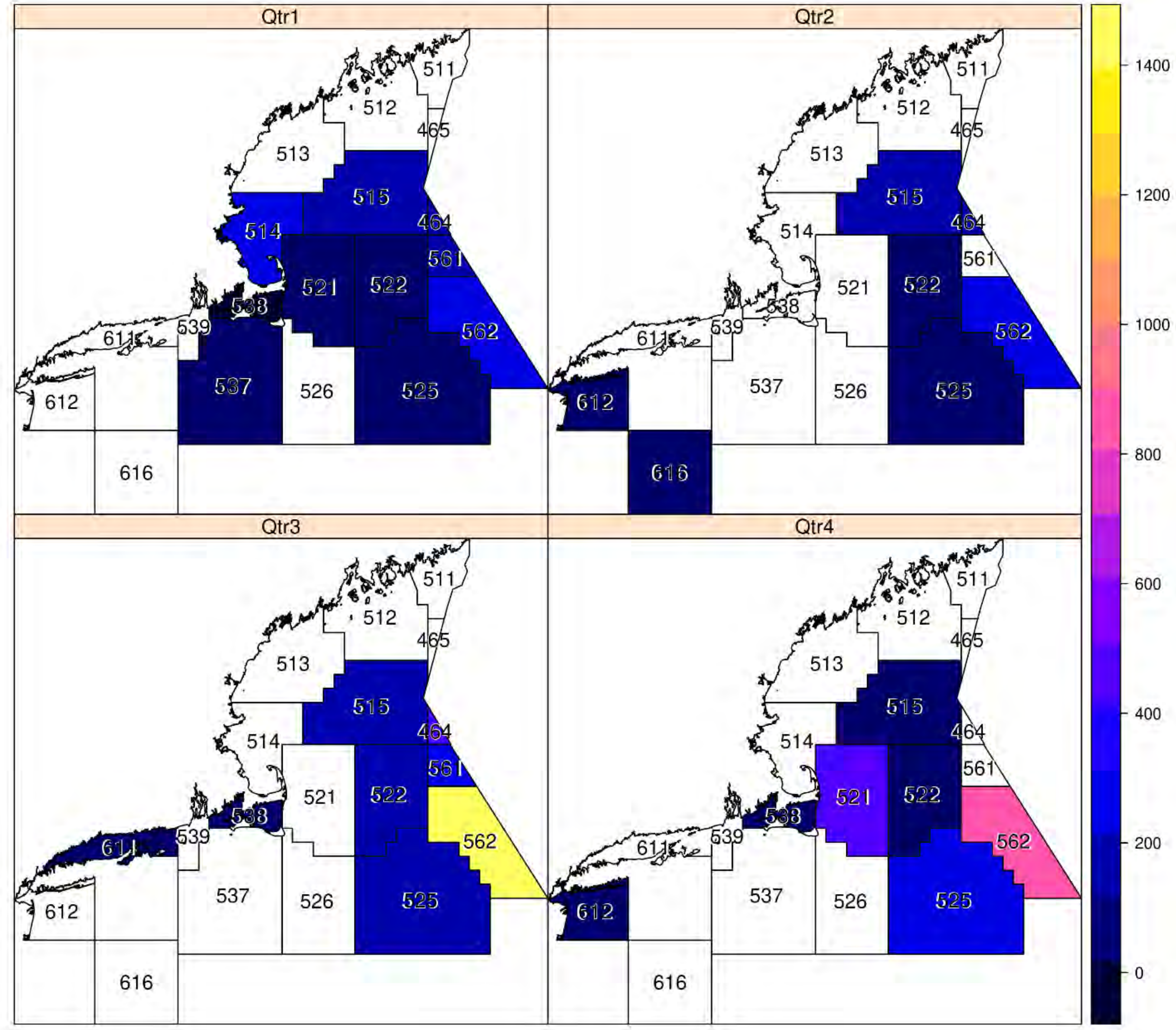
Appendix 4 Figure 2. 2018 quarterly landings (thousands of pounds) from statistical areas that were under-sampled for commercial length compositions (port and sea samples combined), including industry collaboration. Statistical areas with three or more samples are unshaded. A small number of statistical areas were not shaded for purpose of confidentiality but see Appendix 4 Table 1.



Appendix 4 Figure 3. 2018 quarterly landings (thousands of pounds) from statistical areas that were under-sampled for commercial length compositions (port and sea samples combined), excluding industry collaboration. Statistical areas with three or more samples are unshaded. A small number of statistical areas were not shaded for purpose of confidentiality but see Appendix 4 Table 1.



Appendix 4 Figure 4. 2018 quarterly landings (thousands of pounds) from statistical areas that were under-sampled for commercial discard characterization (sea samples only), including industry collaboration. Statistical areas with three or more samples are unshaded. A small number of statistical areas were not shaded for purpose of confidentiality but see Appendix 4 Table 1.



Appendix 4 Figure 5. 2018 quarterly landings (thousands of pounds) from statistical areas that were under-sampled for commercial discard characterization (sea samples only), excluding industry collaboration. Statistical areas with three or more samples are unshaded. A small number of statistical areas were not shaded for purpose of confidentiality but see Appendix 4 Table 1.

Appendix 5. Ventless Trap Survey Design

Maine Department of Marine Resources

The territorial waters of each participating state were stratified by NMFS Statistical Area and by three depth ranges; 0 – 20 meters, 21 – 40 meters, and 41 – 60 meters. There are three survey areas in Maine territorial waters: NMFS SAs 511, 512 and 513. Depth strata and potential sampling cells were generated by overlaying the bathymetry of the study area with a one minute latitude/longitude grid in ArcGIS (Figure MEDMR 1). The estuaries associated with the Kennebec and Penobscot Rivers were excluded from the survey area to ease sampling logistics. The two layers were then intersected, and the percent cover that each depth range occupied within a cell was calculated, relative to the total area of the cell. Each grid cell was then assigned a final depth stratum based on which depth category comprised at least 75% of the cell's surface area. Since much of the bathymetry of Maine's coastal waters is highly variable, defined by rocky ridges and troughs, there was a high occurrence of 'mixed' cells with all depth categories comprised < 75% of the cell (Figure MEDMR 1). Unlike neighboring states participating in the survey that eliminated mixed cells, in Maine waters mixed cells were categorized based on the depth at the center of the grid cell.

Each survey area was divided into routes for logistical purposes and to spread the geographic distribution of the sampling locations over a broad area along the coast. New sampling sites were randomly selected each survey year, stratified by statistical area and depth. In 2006, the first year of the survey, 76 sites were selected, two of which (9991, 9992) were fishermen's choice sites (Table MEDMR 1). In 2007, 124 sites were selected, one of which (9999) was a fishermen's choice site (Table MEDMR 1). From 2008-2014 there were 138 sites selected per year (Table MEDMR 1). Beginning in 2015, the vented control traps were eliminated so as to maximize spatial coverage of a very diverse coastline and maximize efficiency, since there were nine years of data to compare selectivity of the vented and ventless traps. This enabled the number of sites to increase to 276 in 2015 (Table MEDMR 1), thereby doubling the spatial coverage with the same total number of traps.

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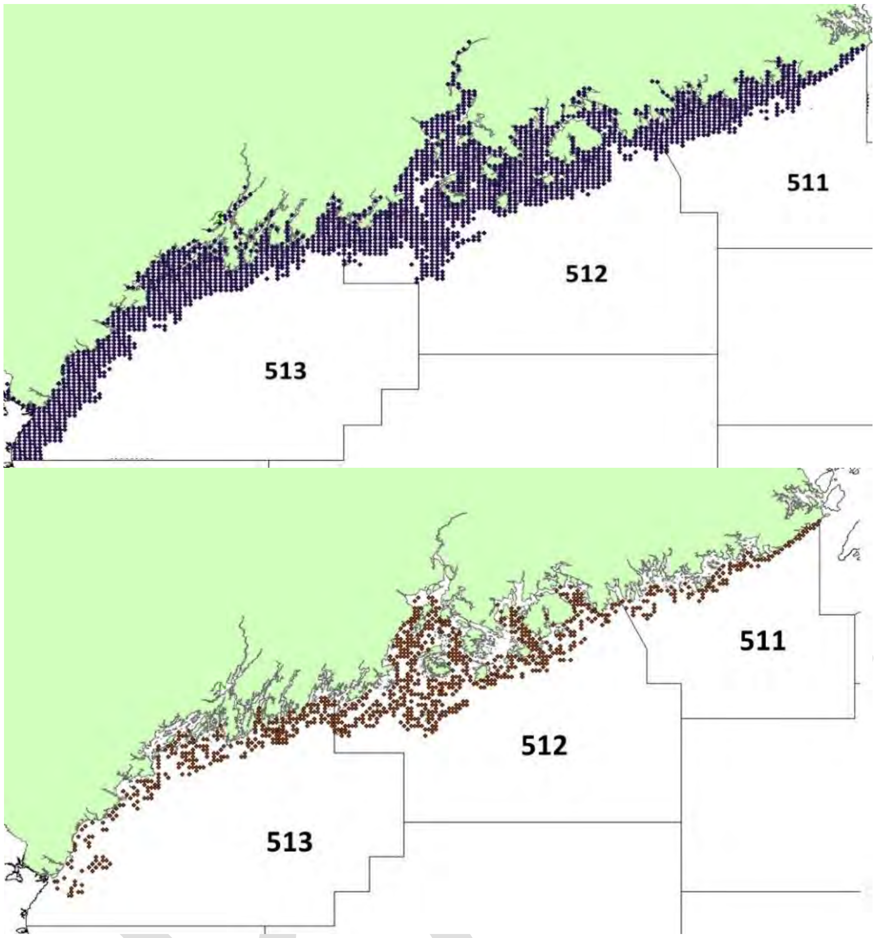

Figure MEDMR 1. All grid centerpoints (A) and ‘mixed’ depth grid cells (B).

Table MEDMR 1. Number of randomly selected sites per statistical area and depth stratum (1 = 0 – 20 m, 2 = 21 – 40 m, 3 = 41 – 60 m) by year.

Statistical Area	**511**			**512**			**513**			**Total Sites**
Depth Stratum	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	
2006	8	8	8	8	8	8	8	8	8	**72**
2007	8	8	8	20	20	20	13	13	13	**123**
2008-2014	8	8	8	23	23	23	15	15	15	**138**
2015-2018	16	16	16	46	46	46	30	30	30	**276**

From 2006-2014, each station was sampled with six traps configured as two triples or a single six trap trawl in which vented and ventless traps were alternated (three of each trap type per trawl; Figure MEDMR 2). Starting in 2015 just three ventless traps were deployed per site. Traps were spaced 18.3 m (60 ft) apart, with each trap tied into the main groundline with a 1.8 m (6 ft) gangion. Survey traps were constructed of polyvinyl-coated 12-gauge wire mesh (2.5 cm (1”) mesh) with a single parlor and cement runners. Entrance heads were made of standard shrimp mesh netting with 12.7 cm (5 in) entrance hoops. Overall trap dimensions were 101.6 cm x 53.3 cm x 40.6 cm (40” x 21” x 16”) with a 10.2 cm x 15.2 cm (4 in x 6 in) disabling door and a single rectangular escape vent (14.6 cm x 4.9 cm (5 ¾ in x 1 $^{15}/_{16}$ in)) in the parlor of the vented traps. Traps were constructed by Brooks Trap Mill in Thomaston, Maine. All survey gear conformed to Federal “whale-safe” regulations (see http://www.maine.gov/dmr/science-research/species/lobster/trapgear.html).

The central position (latitude/longitude) of each grid served as an initial starting location from which industry participants selected the final location (no further than 0.5 nm from central position) within the appropriate depth strata. Industry participants selected alternates if needed to replace the first selection based on location in relation to other sites, unsuitable bottom, high traffic areas, and gear conflicts. Once the initial location was chosen for each grid, it remained in the same location for the duration of the survey season.

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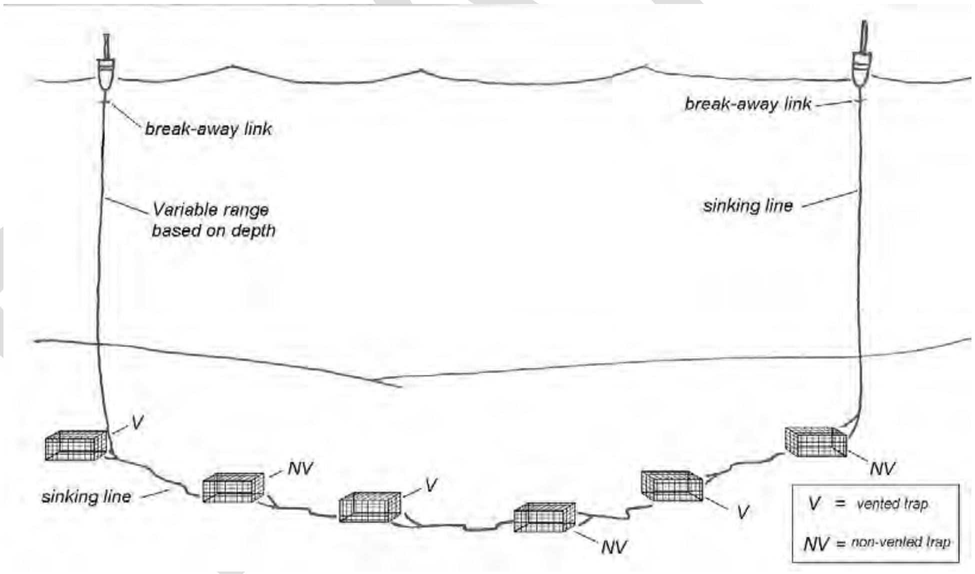

Figure MEDMR 2. Diagram of the arrangement of a ventless trap survey trawl.

Data Collection

Trap deployment, maintenance, and hauling were contracted to commercial lobstermen. All traps were hauled and sampled twice per month during June, July and August with a three-day soak time between hauls. In the early years of the survey, trips were generally scheduled by working from East to West along the coast as the month progressed, with trips in 511 being conducted at the first of the month and trips in 513 competed during the latter half of the month. In more recent years, fishermen schedule their survey schedule with the goal of scheduling initial baiting days roughly a month apart. It was observed that bait positioning (whether bait is hung high or low in the trap's kitchen), influenced lobster catch. Bait position was standardized to hanging low in 2011.

MEDMR staff accompanied the fishermen on each sampling trip to record catch information and biological data. On each survey trip, the captain and crew counted and recorded the number of each species caught in each trap. Samplers recorded trip information such as set-over-days (standardized to 3, weather-permitting), bait type (standardized to salted herring when available) and amount, and trap type (vented or ventless). Site information collected includes location and depth. Trawl location was confirmed with the station's original coordinates after the first haul of the season. Coordinates were recorded for each site with a Garmin eTrex10 on subsequent hauls. Depth was recorded in fathoms (1 fm = 6 f t= 1.8 m) from each boat's depth sounder.

Biological data were collected for every lobster in the trap including carapace length (to the nearest mm), sex, shell hardness, culls and other shell damage, shell disease symptoms, mortality, developmental stage of extruded ova on ovigerous females, and presence/absence/type of v-notch (new or old, natural or manmade, newly notched, etc.). In 2018, MEDMR began collecting more detailed information on ova developmental stage, specifying three categories for “eyed eggs” in order to track lobster phenology at a finer temporal scale.

In 2016, the DMR began collecting biological data for Jonah crab in an effort to collect population data after the first Jonah crab FMP was instated in August 2015. The same data were collected for Jonahs as for lobsters. In collaboration with MADMF and AOLA, MEDMR tagged Jonah crabs in 2017-2018 to gather more movement and growth information (Figure MEDMR 3).

Figure MEDMR 3. A knuckle tag (right) and a spaghetti tag (left) deployed on Jonah crabs on the 2017 Maine Ventless Trap Survey.

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Bycatch species were identified and enumerated for each trap. Fish were measured and evaluated for damage. Beginning in 2016, bycatch dispensation code was added to record whether fish are used as bait or discarded and whether they float or swim as a proxy for discard mortality.

Water temperature information has been collected since 2007. From 2007-2015 nine Vemco Minilogs supplied by NMFS were deployed on survey trawls, divided equally among depth strata. Since 2016, eighteen Onset Tidbits have been deployed, two per each of the nine survey routes so as to spatially disperse the temperature loggers, one in shallow and the other in the deep depth strata.

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New Hampshire Fish and Game Department

A standardized one-nautical mile (nm) grid with unique identifiers was generated for the entire New England coast, where each grid was assigned a depth stratum. Each grid was assigned a depth stratum under the 75% rule, where 75% of the area in that one mile grid was of a prescribed depth stratum. The one-mile grids that did not conform to this description were labeled as mixed and assigned a depth stratum based on central location. The depth range for stratum one was 0-20 meters, stratum two was 21-40 meters and stratum three was 41-60 meters.

In New Hampshire, one station was randomly chosen in each of the three depth strata from 2009 through 2014. In 2015, sampling intensity was increased and two stations were randomly chosen in each of the three strata. Sites were randomly selected with the RAND function in Microsoft Excel. From 2009 through 2014 stations were sampled with a six trap trawl, in which vented and ventless traps were alternated. Beginning in 2015, vented traps were dropped from the survey, and trawl configuration consisted of three ventless traps spaced at 18 m tied to a common trawl line. Trap dimensions were 40” x 21” x 16” with a single parlor and 5” entrance heads.

The central location of each grid (latitude/longitude) served as an initial starting location and the captain of the boat selected a final location no farther than 0.5 nm from the central position. Once the initial location was chosen for each grid, it remained in the same location for the duration of the annual sampling period. All traps were hauled and sampled twice per month from June through September with a three day soak time. Occasionally, soak times were longer due to weather or boat problems. Once the traps were hauled on board the boat, each lobster was measured for carapace length to the nearest millimeter (mm), and noted for molt stage and shell disease. Egg condition and V-notch condition were also assessed for female lobsters. The number of set days, type of bait, bycatch (numerated by species), surface water salinity and surface water temperature were also collected at each site. Bait was packed into ten inch black mesh bags to with between 750 and 850 grams of Atlantic herring.

Massachusetts Division of Marine Fisheries

The territorial waters of each participating state were stratified by NMFS Statistical Area and by three depth ranges; 0 – 20 meters, 21 – 40 meters, and 41 – 60 meters. There are two survey areas in Massachusetts territorial waters, MAGOM (NMFS SA 514) and MASNE (SA 538). Depth strata and potential sampling cells were generated by overlaying the bathymetry of the study area with a one minute latitude/longitude grid in ArcGIS (Figure MADMF 1). The two layers were then intersected, and the percent cover that each depth range occupied within a cell was calculated, relative to the total area of the cell. The grid cell was then assigned a final depth stratum based on which depth category comprised at least 75% of the cell's surface area. Any 'mixed' cells (all depth categories < 75% of the cell) were excluded from the selection process. The southeastern portion of Cape Cod Bay was excluded from the MAGOM survey area (shallow sand flats considered to be unsuitable lobster habitat, and Vineyard Sound and Nantucket Sound were excluded from the MASNE survey area (unsuitable lobster habitat and extensive gear conflicts with the mobile gear fleet).

Each survey area was divided into zones for logistical purposes related to captain/port selection, and in MAGOM to spread the geographic distribution of the sampling locations over a broad area along the coast. New sampling stations were randomly selected each survey year. In each of the five geographic zones of MAGOM, four stations were randomly selected in each depth stratum, for a total of sixty stations. The study area in MASNE included only the first two depth strata (0 – 20 m and 21 – 40 m), in each of which twelve stations were selected, for a total of twenty-four stations. The total number of sampling stations was increased to these numbers starting in 2007. During the first year of the survey (2006), only sixteen stations in MASNE and twenty-four stations in MAGOM were sampled.

Starting in 2011 the MASNE portion of the survey was expanded spatially into the federal portion of NMFS SA 538, and into the northern-most portion of NMFS SA 537. This expansion was intended to improve the overlap between the survey and the commercial fishing grounds. The majority of commercial effort had shifted progressively further from shore throughout the 2000s, presumably following a shift in lobster distribution, which due to the existing survey boundary (MA territorial waters) could not be monitored. This survey expansion added the third depth stratum (41 – 60 m) to the study area, and the number of stations per strata was increased to 14 (for a total of 42 stations in the newly expanded SNE survey area). Hereafter the MASNE survey area is broken into the "original survey area" and the "expanded survey area" based on the location of the survey stations. Those stations that have always been available to the random selection process are included in the original survey area, while all survey stations from 2011 onwards are included in the expanded survey area. Thus from 2011 – 2016, the original survey area is a subset of the expanded survey area. In 2018, due to logistical issues in MASNE, the survey area was reduced to the original spatial extent (state waters only NMFS Area 538, 24 stations and two depth strata) and will likely remain at this spatial extent in the future.

Each survey station was sampled with one six-trap trawl, in which vented and ventless lobster traps were alternated (three of each per trawl, see Figure MADMF 2). Traps were spaced 18.3 m (60 ft) apart, with each trap tied into the main groundline with a 1.8 m (6 ft) gangion. Survey traps were constructed of polyvinyl coated wire mesh (2.5 cm (1”) mesh) with a single parlor, overall trap dimensions were 101.6 cm x 53.3 cm x 35.6 cm (40” x 21” x 14”) and a single rectangular escape vent (14.6 cm x 4.9 cm (5 ¾” x 1 $^{15}/_{16}$”)) in the parlor of the vented traps. All survey gear conformed to Federal “whale-safe” regulations (see http://www.mass.gov/eea/agencies/dfg/dmf/laws-and-regulations/322-cmr-12-00-protected-species.html#12.01).

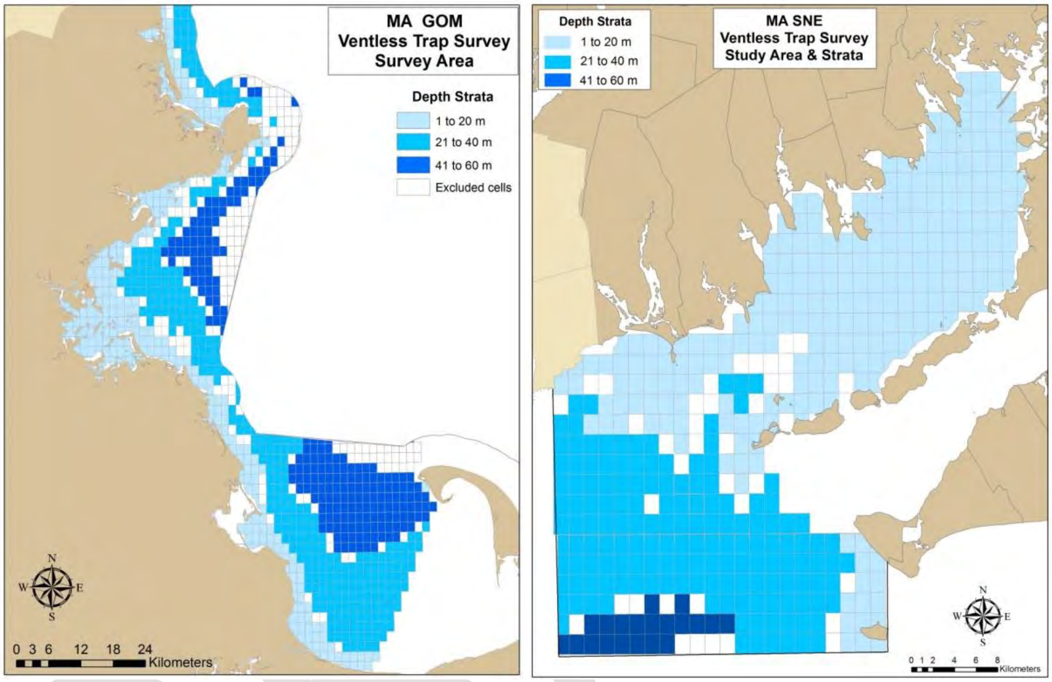

Figure MADMF 1. MAGOM (A) and MASNE (B) survey areas (expanded area shown) with depth strata grid cells available for random selection of stations.

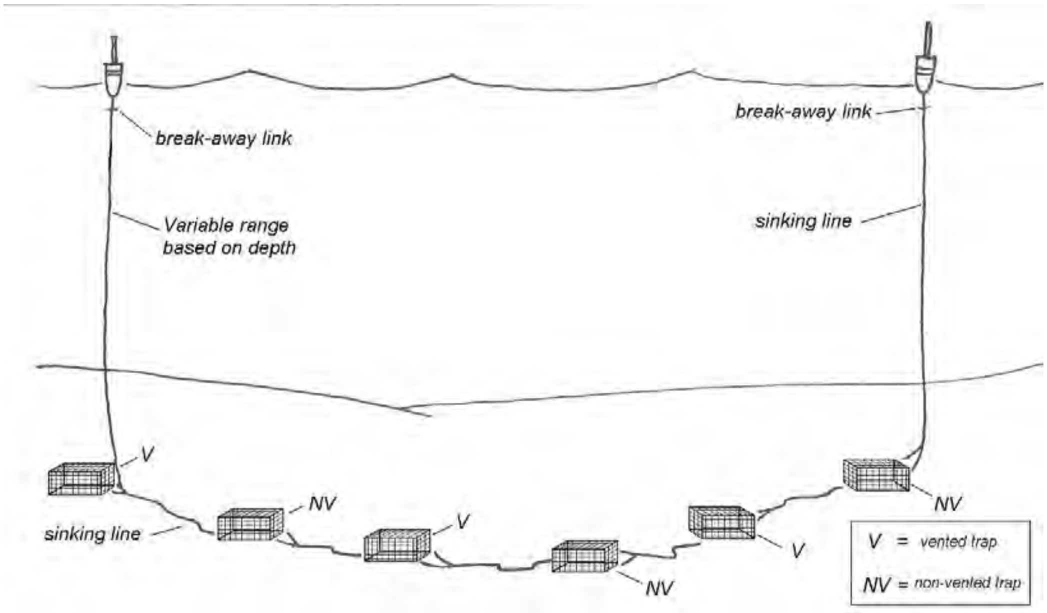

Figure MADMF 2. Diagram of the arrangement of a ventless survey trawl.

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Data Collection

Stations were sampled twice per month from June through September in 2007 – 2012 and in 2014 - 2018. In 2006, sampling took place in MAGOM from July – August, and in MASNE from June – August. There was no survey conducted in 2013 due to lack of funding.

Trap deployment, maintenance, and hauling were contracted to commercial lobstermen. To the degree possible, survey gear was hauled on a three to five day soak time, in the attempt to standardize catchability among trips. At request of the ASMFC Lobster Technical Committee, in recent years soak times have been standardized to three days with the sole exceptions of weather-related delays to the haul cycle.

During the initial set-out, captains were instructed to set one end of the trawl exactly on the assigned coordinates (representing the center-point of the station). If an obstruction identified on NOAA charts (shallow reef, e.g.) prior to setting the gear would prevent safely setting the gear on the center point, the captain was instructed by the survey coordinator (T. Pugh) as to which section of the survey cell to use to avoid the obstruction on the chart yet remain within the selected survey cell. If an obstruction or gear conflict was identified on the water, the captain used his/her discretion to offset the gear, with general instructions to remain within ½ mile of the center point so as to remain within the selected survey cell. Captains were specifically prohibited from ‘looking for good bottom’ during this process. All trawls were reset in the same assigned location after each haul. All trawl locations were confirmed with the station’s original coordinates (and cell boundaries) after each haul via GPS. Depth at mean low water for each trawl location was recorded from NOAA navigational charts as a coastwide standard to avoid variability from tidal fluctuations.

MADMF staff accompanied the fishermen on each sampling trip to record CPUE and biological data. Samplers used the standard MADMF lobster trap sampling protocol, which records: catch in number of lobster, number of trap hauls, set-over-days, bait type, trap type (vented or ventless), and biological data for every lobster in the trap including carapace length (to the nearest mm), sex, shell hardness, culls and other shell damage, external gross pathology (including shell disease symptoms), mortality, and presence and gross stage of extruded ova on females (ovigerous).

On the first haul of each month, each lobster was 'tagged' by placing a band on one chelae around the 'knuckle,' such that the claw was not disabled (Figure MADMF 3). Recaptures of tagged individuals were recorded on all subsequent trap hauls.

Figure MADMF 3. Applying a "knuckle band" to a lobster. Note the claw is not disabled.

Information on bycatch species has been collected since 2007. From 2007 – 2014, bycatch species were identified and enumerated for each trap. Starting in 2015, along with identification and counts per trap, data collection was increased for certain commercially important bycatch species: Jonah crabs (Cancer borealis), rock crabs (Cancer irroratus), whelk (Channeled and knobbed), cod, haddock, pollock, flounder (multiple species), ocean pout, cusk, black sea bass, tautog, wolfish, scup, and blue crabs. Additional information collected varied by species, but at minimum included size (and sex for crabs). For potentially high-volume species (crabs and scup in particular) sub-sampling protocols were developed for use as needed. Currently the bycatch data are housed in a database separate from the lobster biological data, making linkage of biological attributes (length frequencies, e.g.) between lobster and any given bycatch species a challenge but not impossible.

Rhode Island Department of Environmental Management

The Rhode Island Department of Environmental Management Division of Marine Fisheries (RIDEM DMF) began its lobster ventless trap survey (hereafter RI VTS) in 2006. The survey follows the same or similar sampling design Massachusetts south of Cape Cod (Glenn and Pugh, 2009), creating consistency within the SNE stock. At each sampling station, lobster traps are set to estimate lobster catch per unit effort (CPUE). The gear at each station is comprised of lobster traps attached to a ground line, with each ground line end linked to up-and-down lines (or end line) that are attached to floats. These floats and end lines are used to haul the ground line and traps, referred to in its entirety as a 'trawl'. There are six traps on each ground line, spanning over 300 ft. of ground line, with traps separated from each other by approximately 60 feet. In each trawl, there are three ventless traps, and three vented traps. Vented and ventless traps alternate within the trawl (Figure RIDEM 1). The ventless traps are used to assess subleagal (or recruit) lobster abundances, while the vented traps are used to compare abundances between ventless traps and a commercial-style trap (i.e. vented trap). Vents are 5 3/4“ wide and 1 15/16” tall, corresponding to vent regulations of LCMA 1 and as used in MA survey. For further trap configurations, please refer to Figure RIDEM 2.

The program operates during the summer months in RI state waters. Sampling as been intended for the months of June, July, and August; however, in years where funding constraints delayed the project, sampling occurred in July, August, and September (Table RIDEM 1). Lobster traps are baited with bait at the discretion of the commercial fishing participant. The selection is typically the result of bait costs and/or trying to use bait that will breakdown well and “fish” effectively. While bait types have varied through time, the most common bait type that has been used is skates (Table RIDEM 2). Traps are baited and left for three nights (i.e. 3-night soak). On occasion, traps have been fished on a different night soak (e.g. 2, 4, 5, or 6 nights) if weather conditions forced sampling to a different day. Each station is sampled twice per month, following a typical schedule of baiting traps (sample day one), sampling traps and rebaiting them three days later (sample day two), and another sampling of traps three days after that and leaving the traps on site but not fishing (sample day three).

The RI VTS survey is divided into three components by geographic region: Narragansett Bay (NB), Block Island Sound (BIS), and Rhode Island Sound (RIS). Stations are classified by their depth as it relates to three coastwide strata bins: 0-20m, 21-40m, and 41-60m. It should be noted that unlike other states, there are no 41-60m depth stratum stations in RI state waters. Each area has a different commercial fishing participant and number of stations allocated for sampling: seven stations are sampled in NB, eight in BIS, and nine in RIS. Stations to be sampled are selected randomly, based on the possible station options for each region. Through time, random stations have been selected either by providing a participant with several different combinations of stations to be sampled, or selecting one set of stations and each station having alternates if needed. A primary station selected is not sampled only if there is a conflict with another fishery (such as draggers) or there is high risk of the gear being lost due to boat traffic. Stations with such issues have not been removed through time because the conflicts can be time-varying based on activity on the water, and this are not removed from the random draw. While the station is often sampled in the center of its box, to avoid such conflicts, the station can be moved within the box. Total stations to select from are demarcated by two periods: 2006 to 2009 and 2010 to present. The former period had more possible stations than the current selection grid, and included stations that had multiple depth stratums within. The latter

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period only has stations comprised of a single depth stratum (as done in MA), and removed stations that were definitively prone to drag grounds and better align with the areas used to calculated formal VTS survey indices in the stock assessment (Figure RIDEM 3).

Station information is collected each sampling day, including: MM/DD/YYYY, depth, station name, lat/long (or loran coordinates to be later converted to lat/lon), sediment type, soak time, and bait type used. Bottom temperature has been collected sporadically from various stations through time using HOBO temperature loggers attached to the traps. Such data are sparse enough to not have great value for time series analyses; however, temperatures are being collected more consistently now to try and provide a better time series of bottom temperatures for RI state waters. Currently, FVCOM bottom temperatures and salinities are pulled for RI VTS data for such analyses. At the trap level, the vent type and all organisms in the trap are counted. Crustacean species Jonah crab and Rock crab are counted, measured, and sexed. Most fish species are counted and measured for length. Any trap malfunctions or odd characteristics are noted during the hauls.

Lobsters have the greatest number of measurements taken of any other species in the survey. Lobster count, sizes (mm), and sex are recorded. Lobster conditions are also recorded regarding shell hardness, shell disease state, egg stage for females bearing eggs, cull status (or claw damage), and V-notch presence.

Literature Cited

Glenn, R.P., and Pugh, T.L. 2009. Coastwide random stratified ventless trap survey for American lobster – Massachusetts portion. Final report for the Atlantic States Marine Fisheries Commission. 49pp.

Table RIDEM 1. Number of traps hauled in each year of the RI VTS by month.

Year	June	July	August	September
2006		276	288	288
2007	278	288	282	
2008	288	288	288	
2009		264	276	264
2010		288	282	288
2011		288	288	282
2012	275	275	283	
2013	280	281	275	
2014	282	261	285	
2015	283	286	278	
2016	286	270	269	
2017	262	273	288	

Table RIDEM 2. Bait type frequency over the history of the RI VTS.

Bait Type	Frequency
Herring	0.41%

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Menhaden	3.89%
Skates	72.20%
Menhaden and Skates	14.74%
Flounder and Skates	0.61%
Sea Robin	1.23%
Skates and Sea Robin	4.56%
Menhaden and Sea Robin	1.27%
Skate, Menhaden, and Sea Robin	0.61%
Skate and Haddock	0.48%

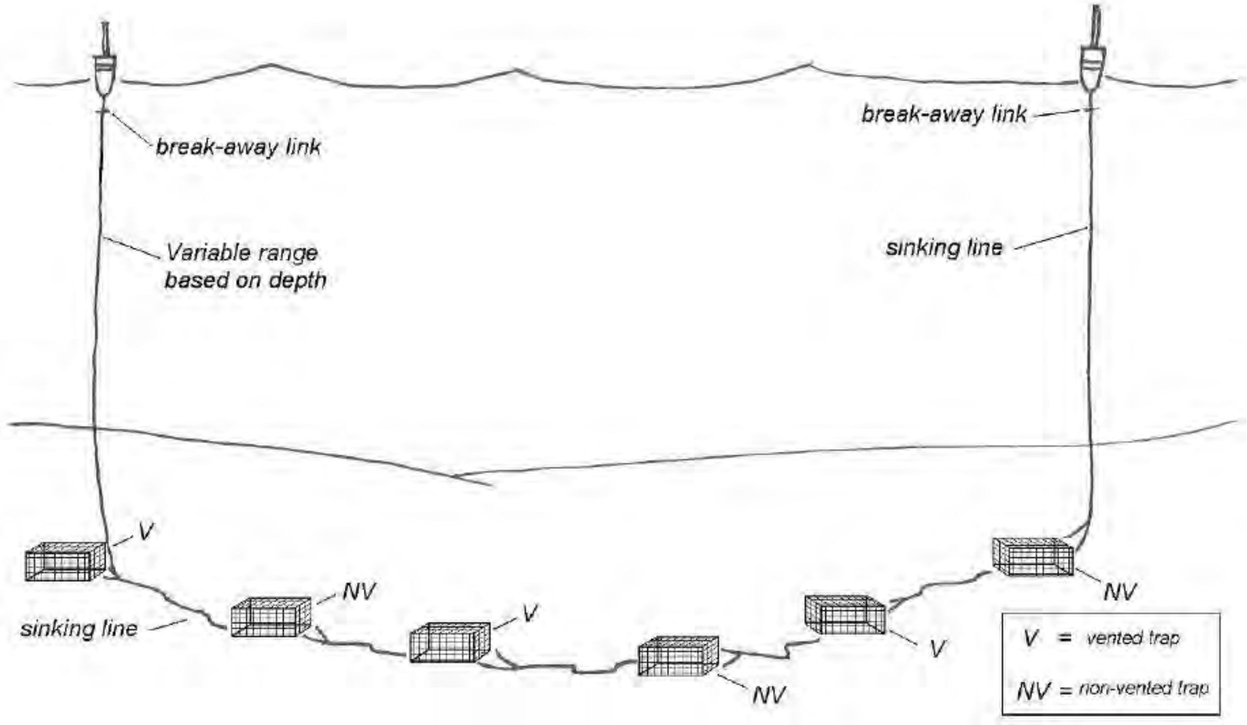

Figure RIDEM 1. Typical haul configuration for the RI VTS. Illustration from Glenn and Pugh (2009).

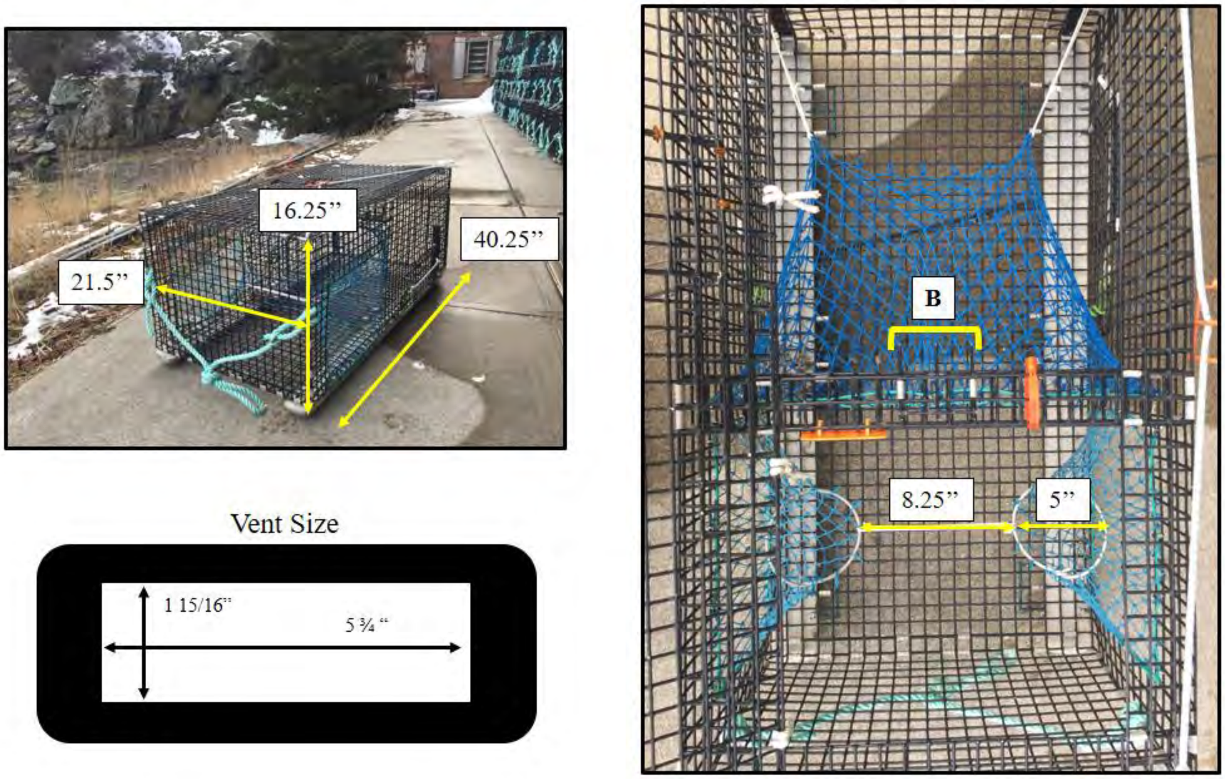

Figure RIDEM 2. General trap configurations for a RI VTS trap. ‘B’ signifies where the bait is strung and hung into the kitchen. Dimensions lengths are in inches.

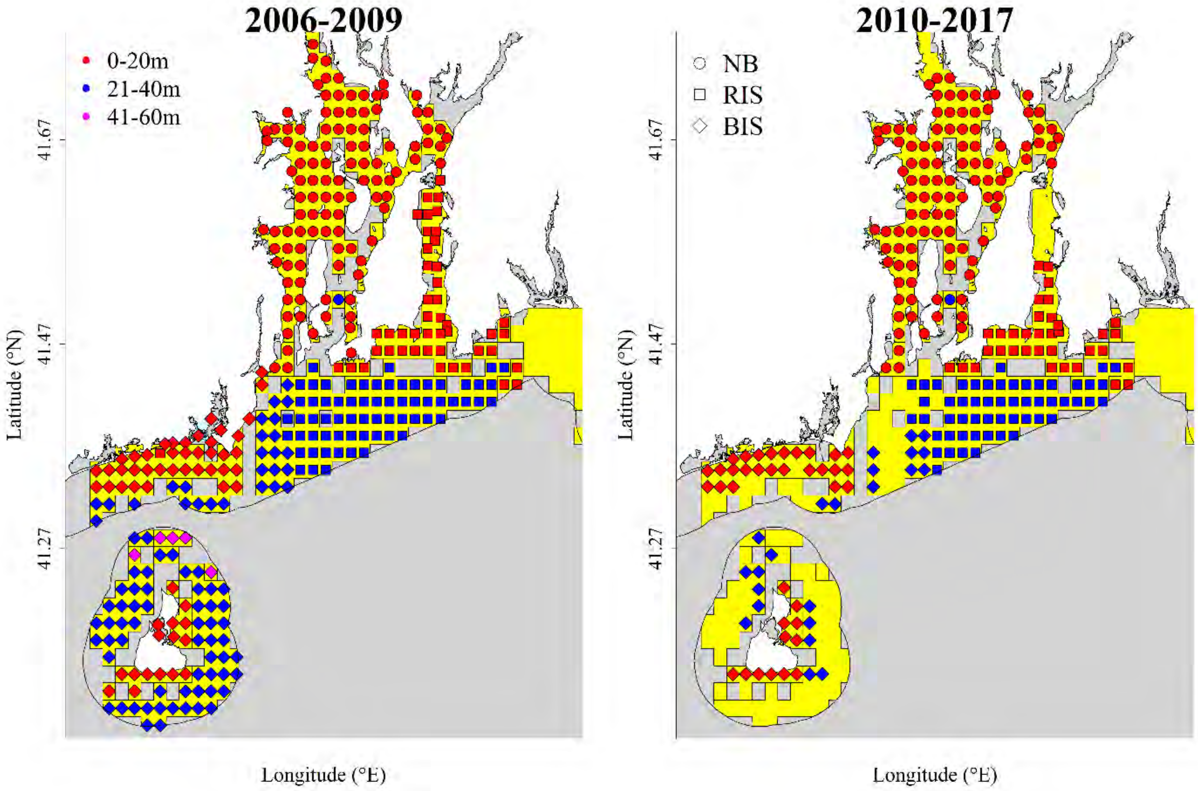

Figure RIDEM 3. RI VTS possible station selections for the two major stanzas through time: 2006-2009 and 2010-present. Station symbols are colored and shaped by their region (Narragansett Bay, Block Island Sound, Rhode Island Sound) and depth strata (0-20m, 21-40m, 41-60m). Yellow polygons represent the depth strata used in calculating the formal VTS indices.

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New York State Department of Environmental Conservation

The coastwide VTS employed a random stratified survey design, using NMFS Statistical Area and depth as the primary strata classifications. The NY-CT sampled Long Island Sound (LIS) which is the major portion of SA 611. LIS was further stratified into 3 areas based on NMFS Statistical Subareas, detailed below:

Western Long Island Sound (WLIS) – Subareas 141, 142

Central Long Island Sound (CLIS) – Subareas 143, 144

Eastern Long Island (ELIS) – Subareas 145, 146

Depth strata classification is detailed below:

Shallow = 0 to 20m

Moderate = 21 to 40m

Deep = 41-60m

The NY-CT survey sampled 24 stations throughout LIS. The deep strata was only found in ELIS, so all eight deep stations were randomly selected in ELIS. The deep strata in ELIS was not sampled in 2006 due to difficulties in finding a fisherman to sample that area. The shallow and moderate strata were sampled within WLIS and CLIS. Each station within each stratum was sampled by one six-trap trawl, with alternating vented and vent-less traps. Sites were randomly selected at the beginning of the year and traps were re-set at the same location throughout the year. Traps were sampled two times per month. Sampling was scheduled for June through September. Sampling was delayed during several years due to contract delays. Below is a table indicating yearly sampling months:

Year	Months Sampled	# Stations Sampled
2006	Sept - Nov	16
2007	June - Sept	24
2008	July - Oct	24
2009	July - Oct	24

Trap deployment, maintenance, and hauling was contracted to commercial fishermen. The goal was to haul survey gear on a 3-day soak time to standardize trap catchability among sampling trips. All trawls were reset at same assigned location each time. Research staff accompanied the fisherman on each sampling trip to record CPUE and biological data. Funding was unavailable after 2009 to continue the survey.

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Appendix 6. Model-Based Ventless Trap Survey Indices of Abundance

See supplemental PDF file “Appendix 6 – Model-Based Ventless Trap Survey Indices of Abundance.pdf”.

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Appendix 7. GOMGBK Model Figures

See supplemental PDF file “Appendix 7 – GOMGBK Model Figures.pdf”.

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Appendix 8. SNE Model Figues

See supplemental PDF file “Appendix 8 – SNE Model Figures.pdf”.

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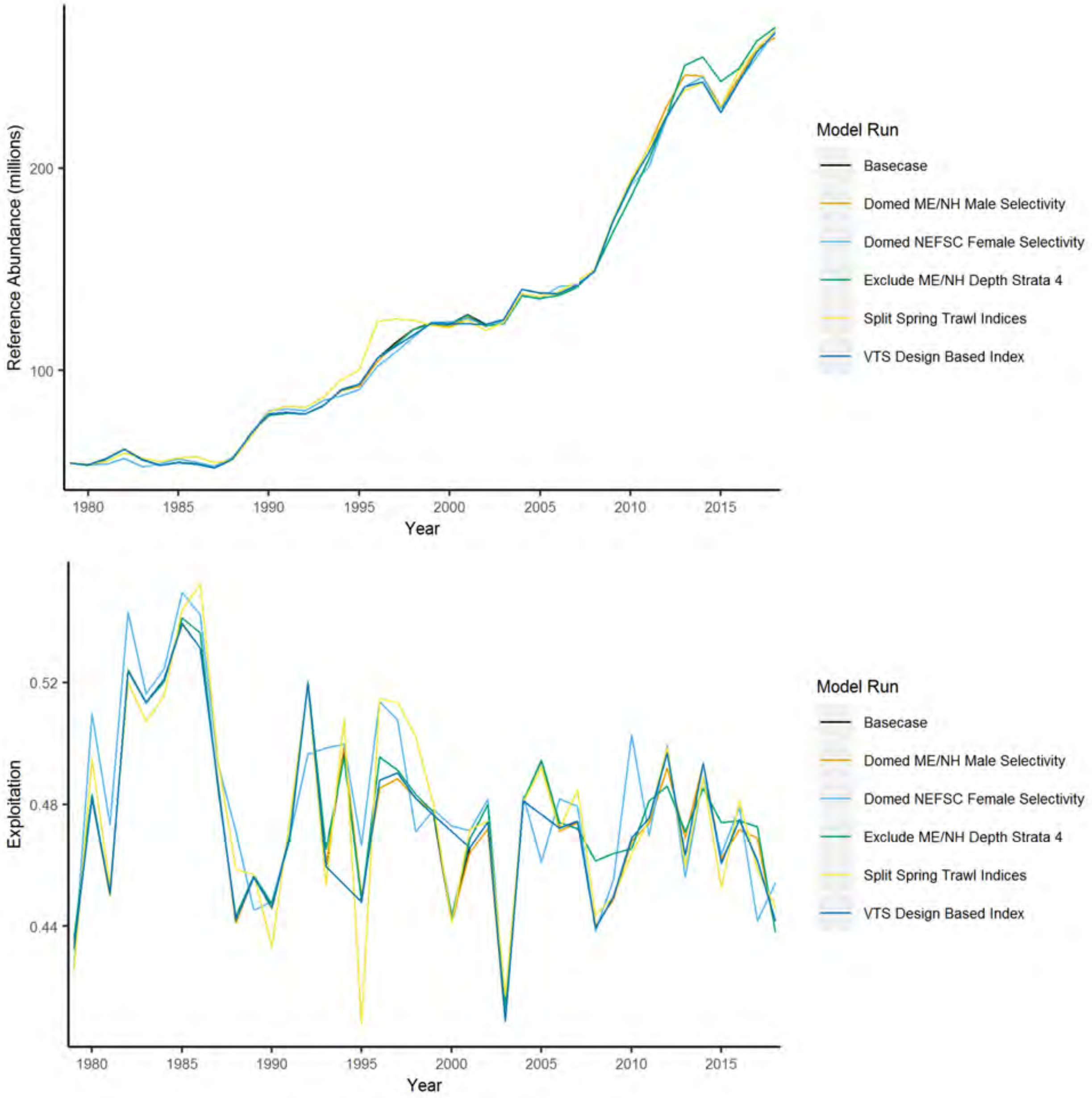
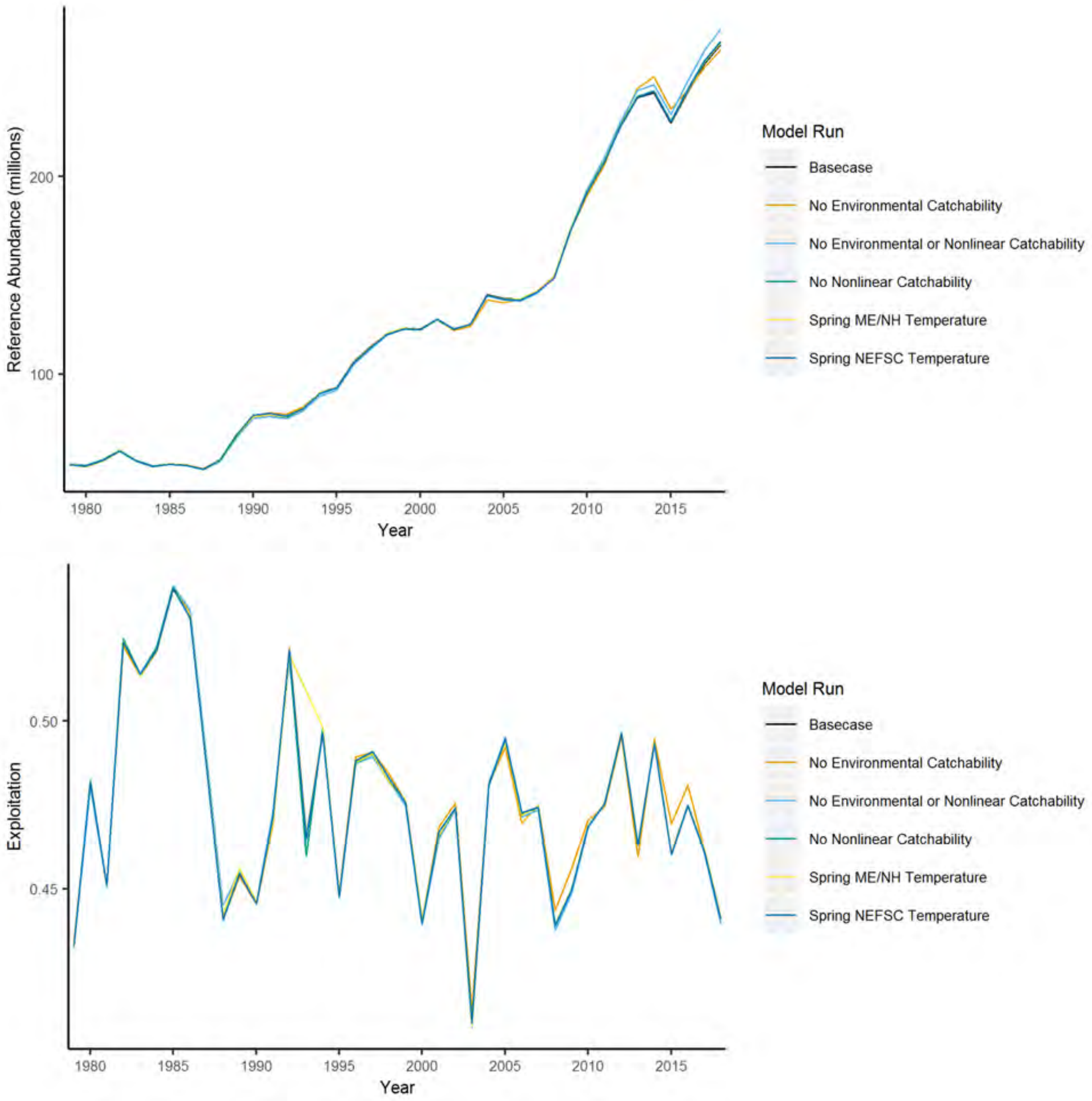
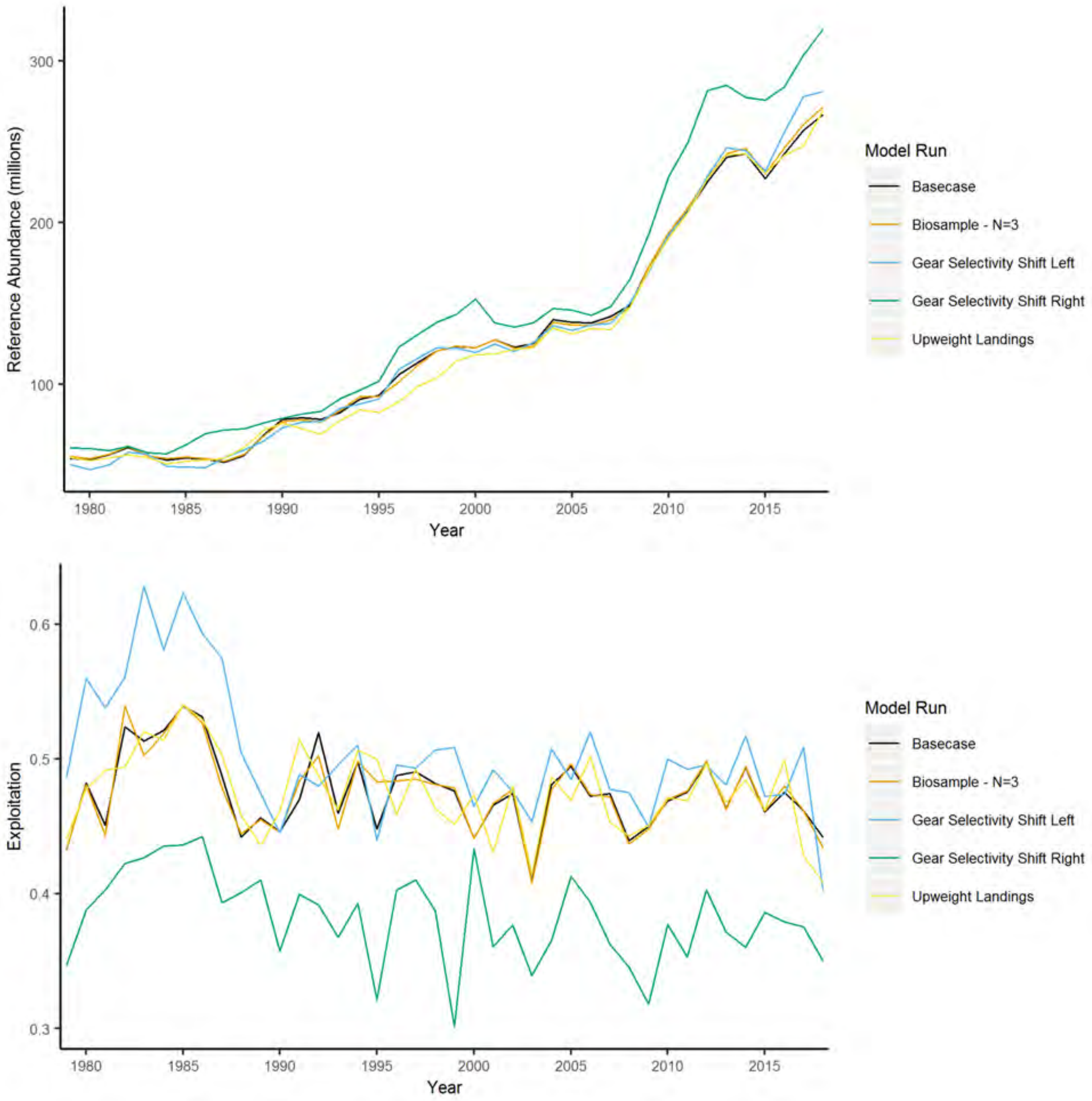
Appendix 9. GOMGBK Stock Sensitivty Analyses by Category



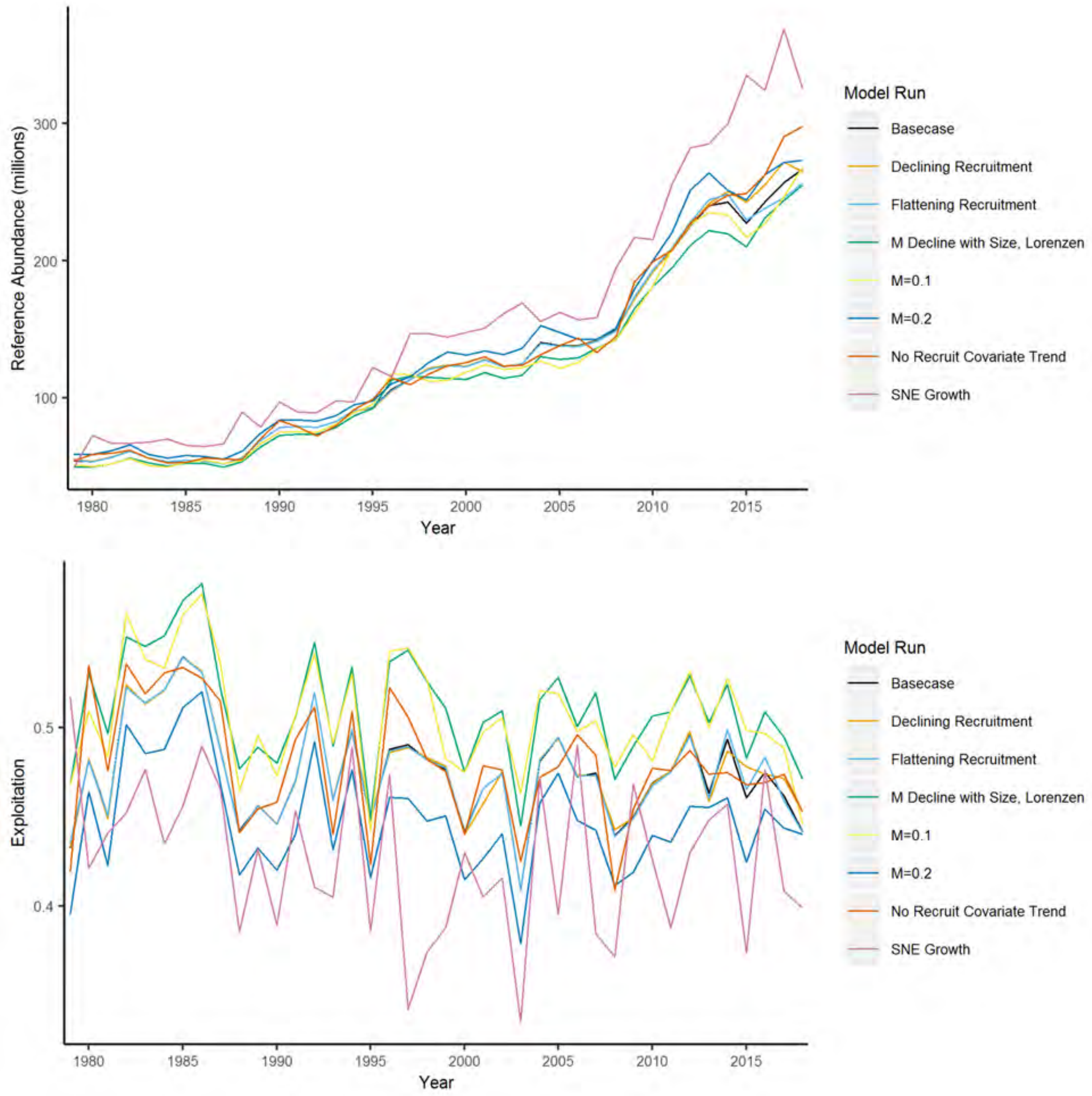
Appendix 9 Figure 1. Reference abundance and exploitation trends for the basecase model (base) and sensitivity runs evaluating non-catchability survey inputs and assumptions.



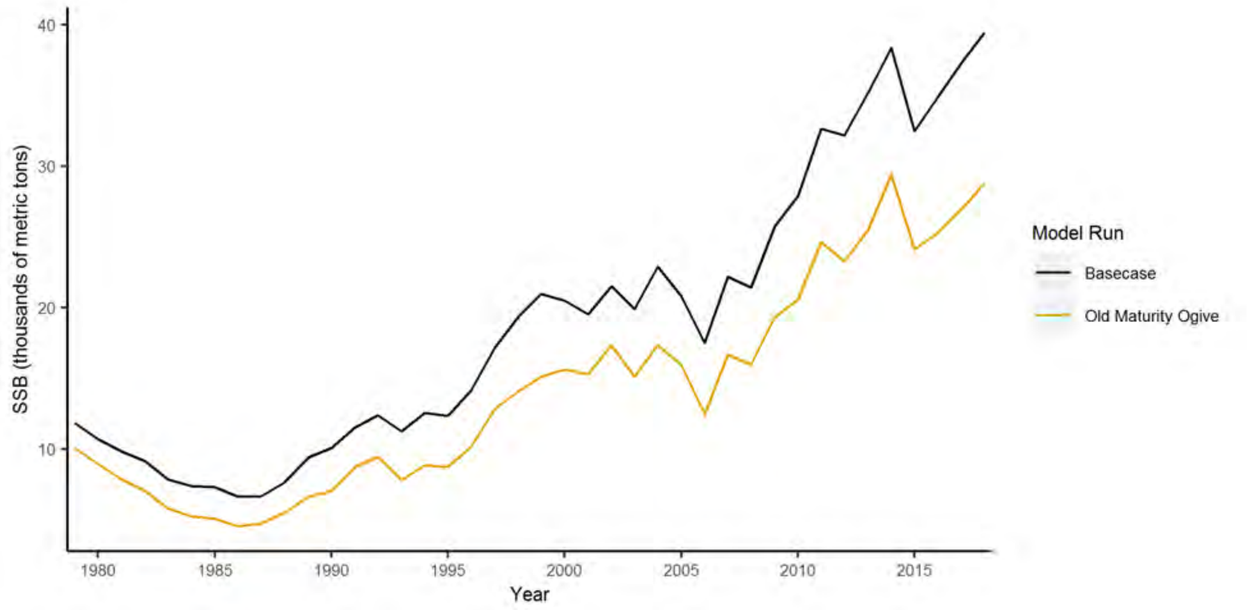
Appendix 9 Figure 2. Reference abundance and exploitation trends for the basecase model (base) and sensitivity runs evaluating survey catchability inputs and assumptions.



Appendix 9 Figure 3. Reference abundance and exploitation trends for the basecase model (base) and sensitivity runs evaluating commercial fishery inputs and assumptions.



Appendix 9 Figure 4. Reference abundance and exploitation trends for the basecase model (base) and sensitivity runs evaluating growth, natural mortality, and recruitment.



Appendix 9 Figure 5. Summer (quarter three) spawning stock biomass trends from the basecase model with the updated maturity information compared to when using the maturity ogive (Old Maturity Ogive) used in ASMFC (2015a).

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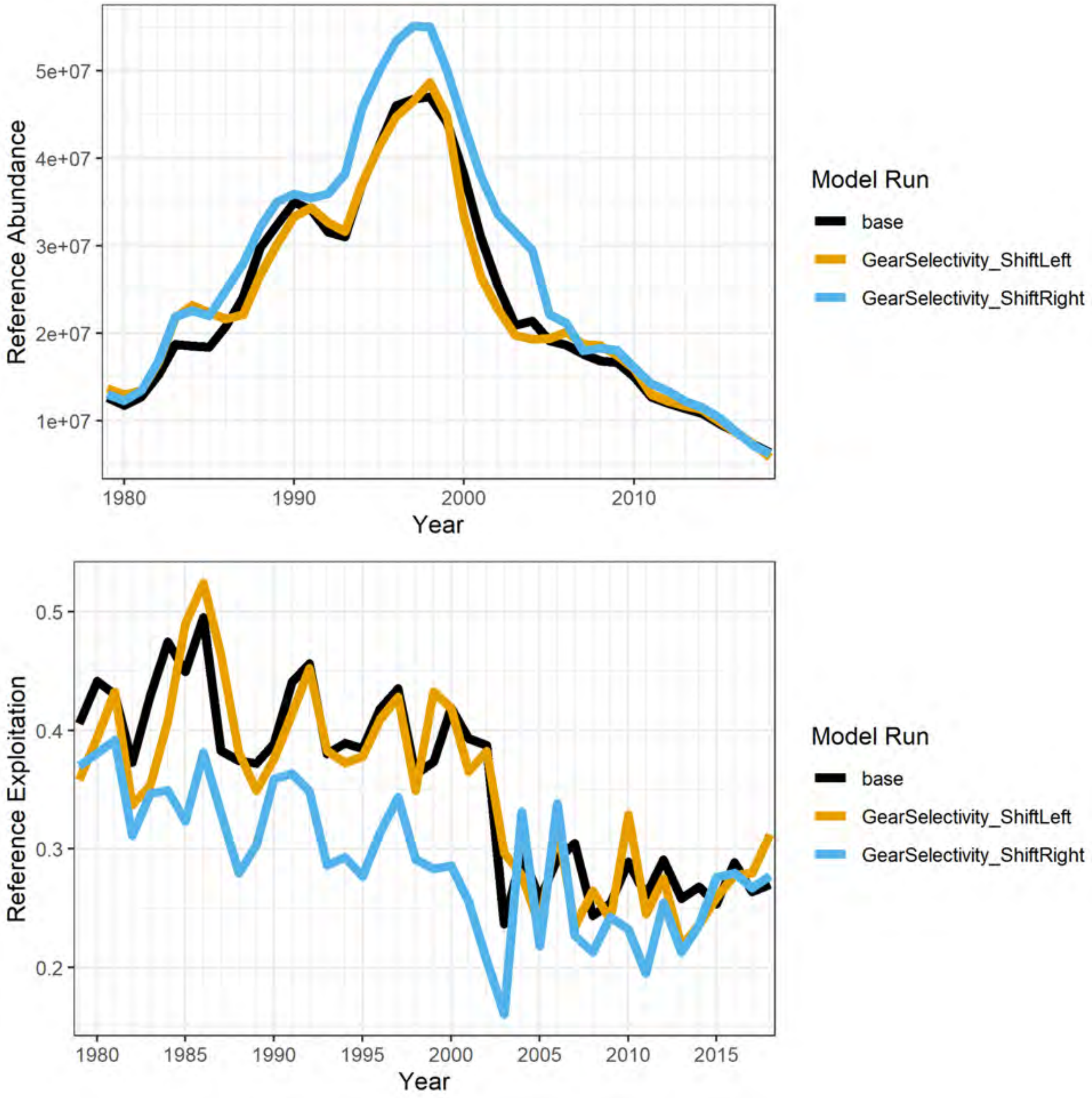
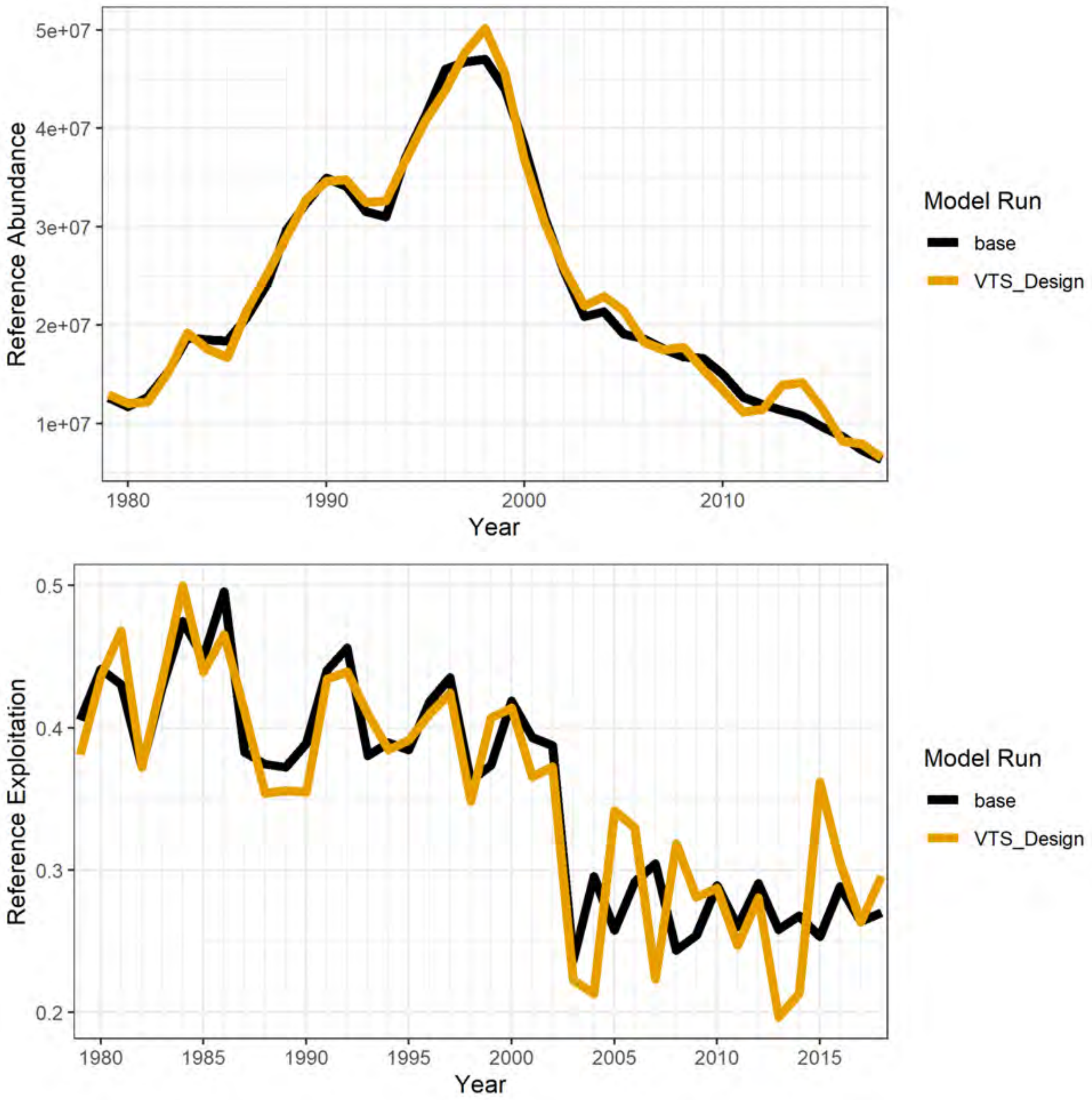
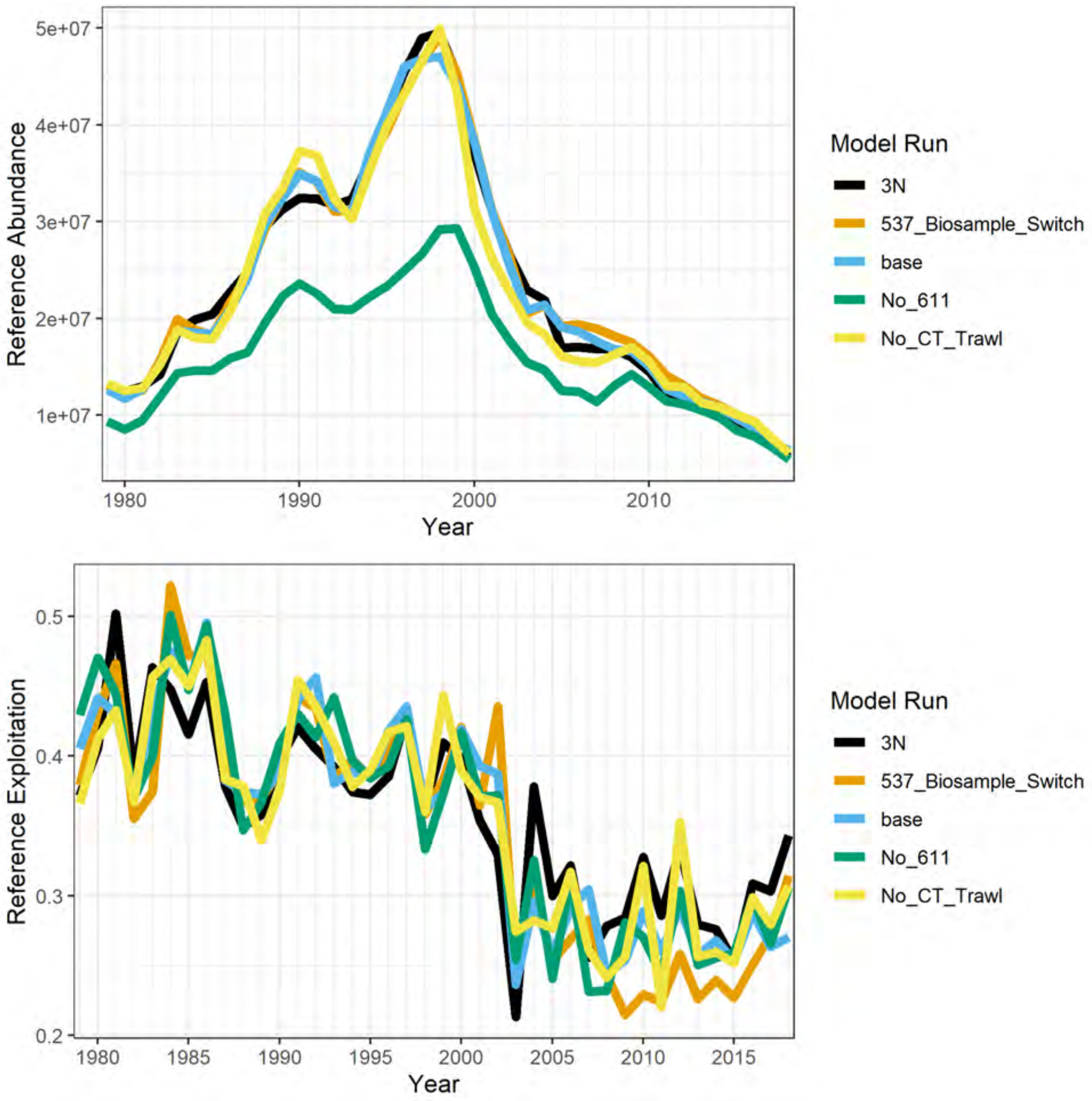
Appendix 10. SNE Stock Sensitivty Analyses by Category



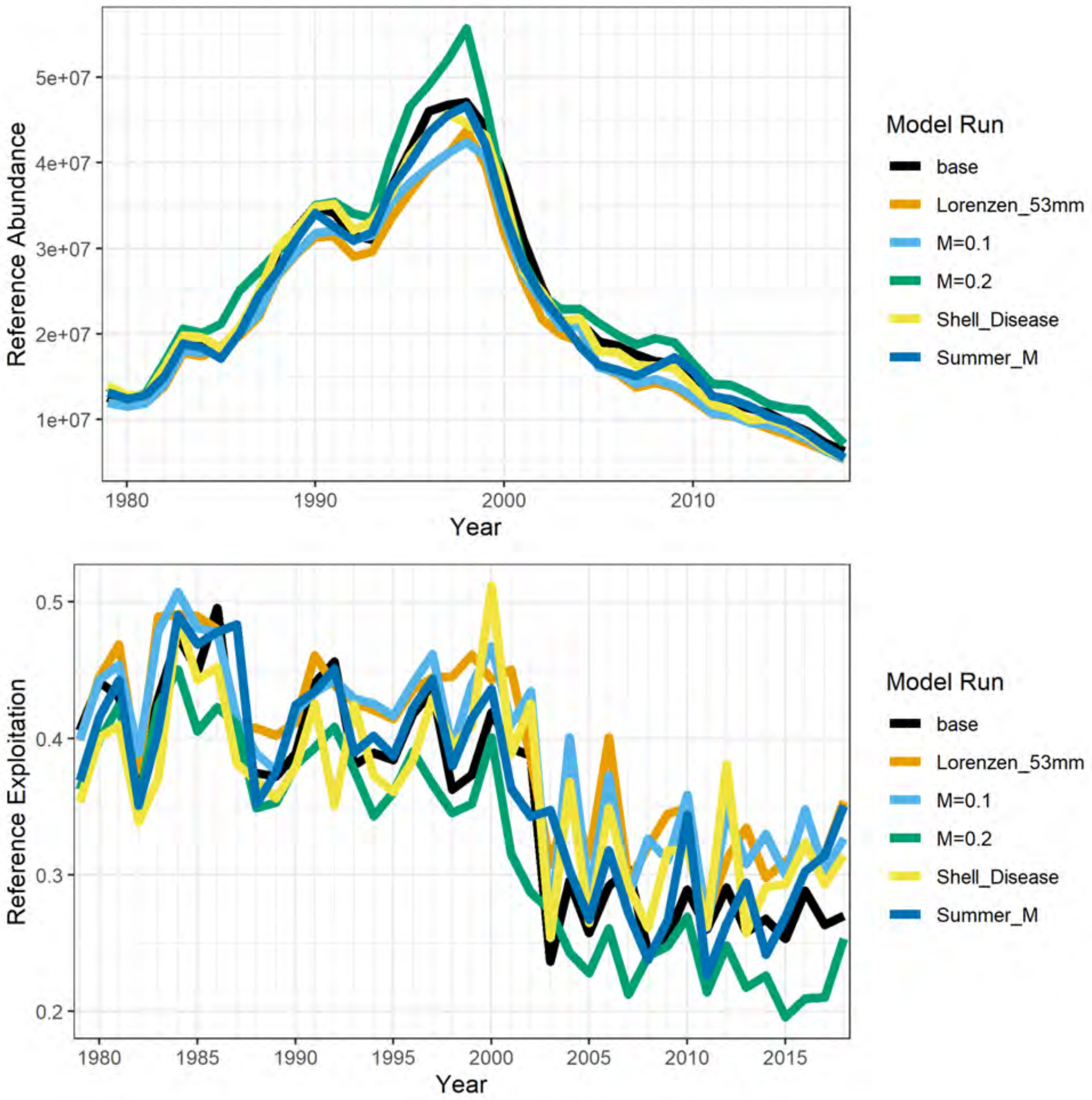
Appendix 10 Figure 1. Reference abundance and exploitation trends for the basecase model (base), when shifting gear selectivity one size bin smaller (GearSelectivity_ShiftLeft), and when shifting it one size bin larger (GearSelectivity_ShiftRight).



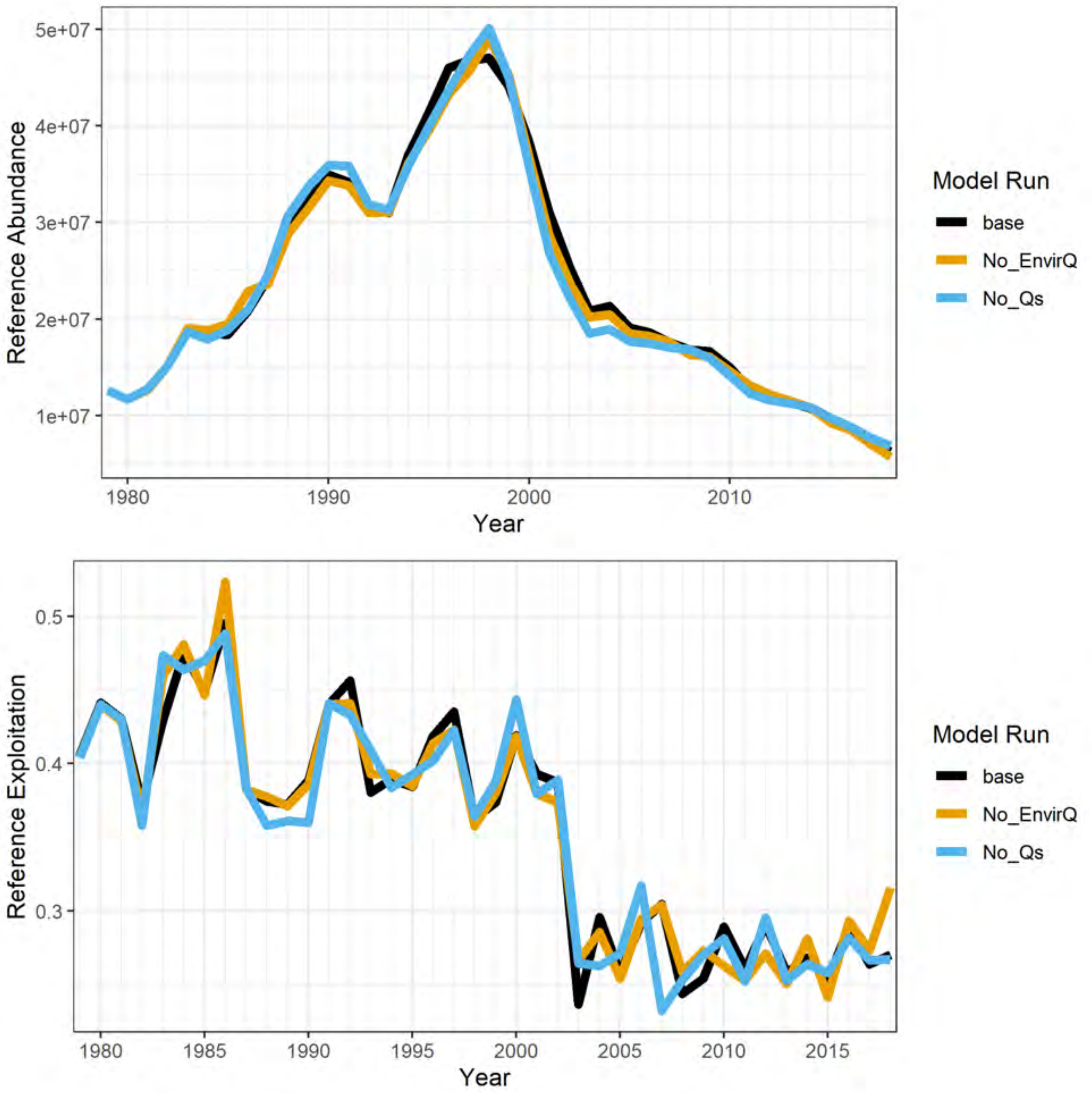
Appendix 10 Figure 2. Reference abundance and exploitation trends for the basecase model (base) employing the model-based Ventless Trap Survey index, and when using the design-based index (VTS_Design).



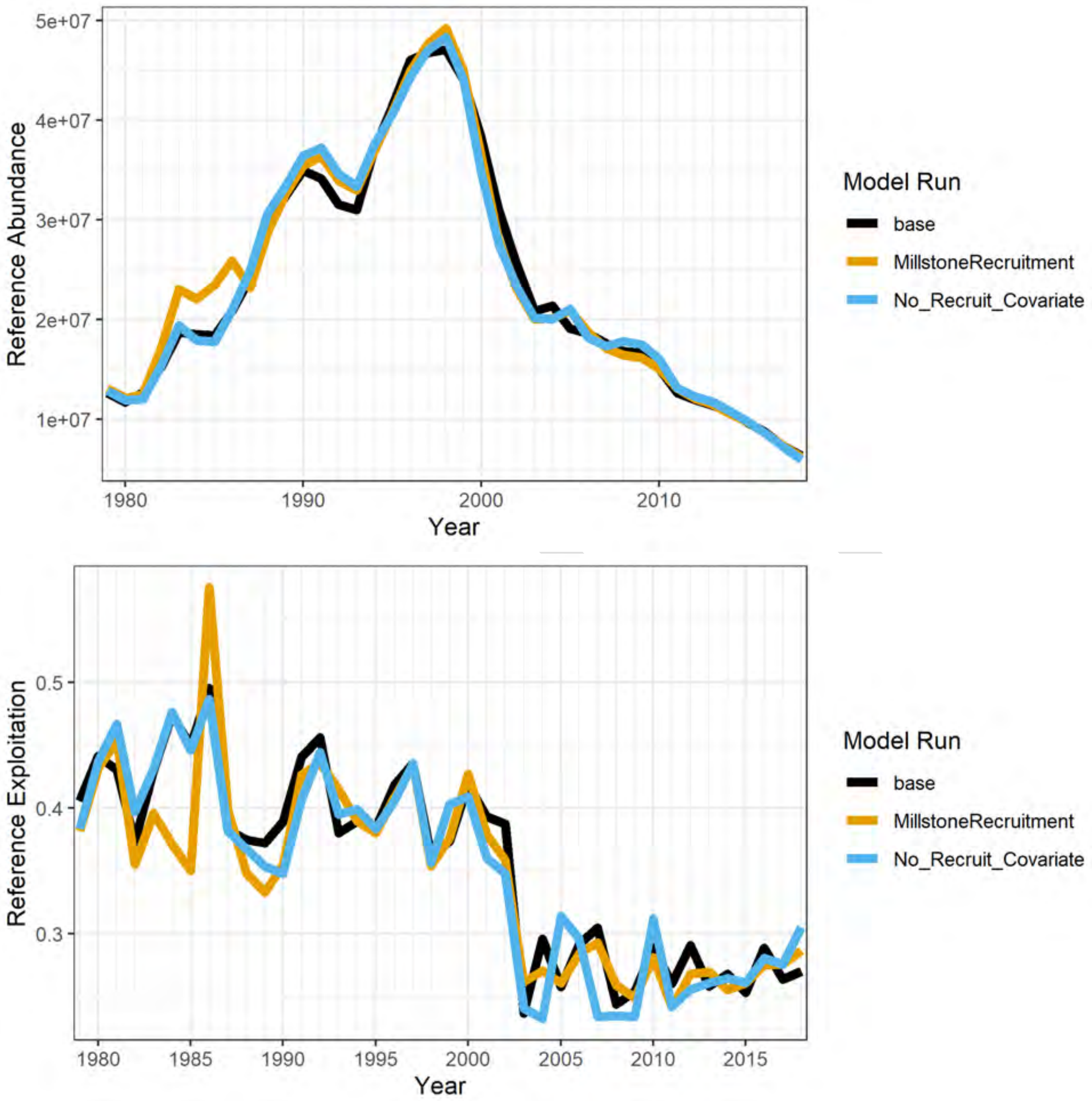
Appendix 10 Figure 3. Reference abundance and exploitation trends for the basecase model (base), compared to when excluding the CT Trawl survey information (No_CT_Trawl), excluding both SA 611 landings and CT Trawl survey information (No_611), using the biosample borrowing scheme of three samples or fewer (3N), and recharacterizing 537 landings based on Area 3 management instead of Area 2 (537_Biosample_Switch).



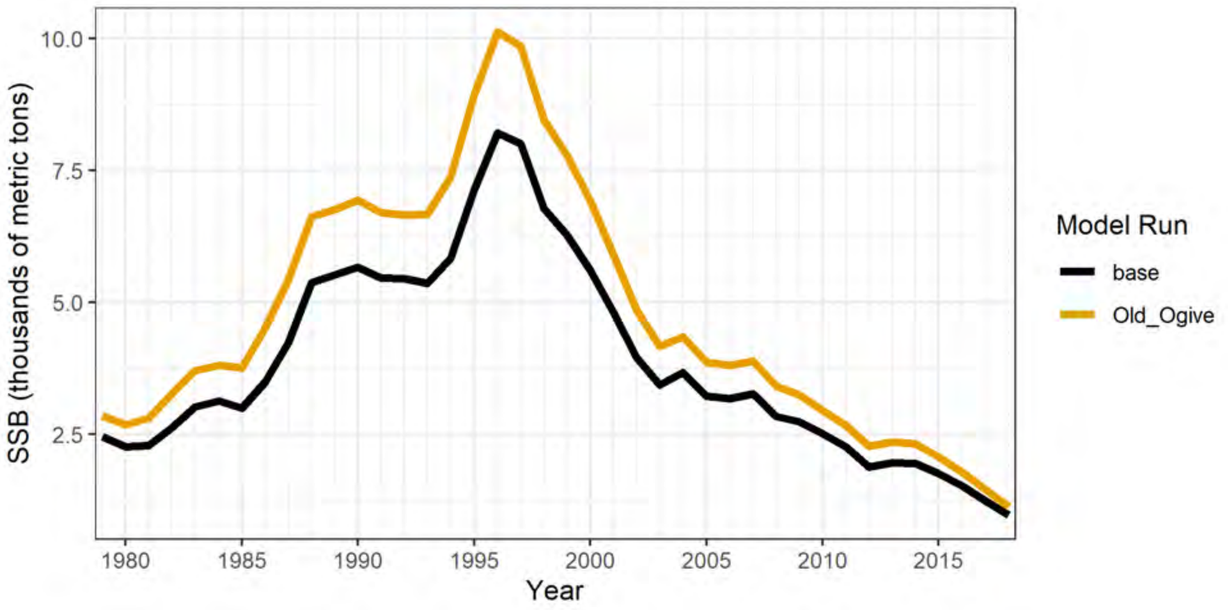
Appendix 10 Figure 4. Reference abundance and exploitation trends for the basecase model (base), when having decreasing natural mortality at larger sizes based on Lorenzen (1996) (Lorenzen_53mm), shifting annual mortality down (M=0.1) and up (M=0.2) by 0.05, using shell disease information from the RI Spring Trawl survey to inform interannual mortality trends (Shell_Disease), when allocating 80% of the annual morality to quarter three (Summer_M).



Appendix 10 Figure 5. Reference abundance and exploitation trends for the basecase model (base), when having nonlinear catchability applied with no environmental catchability (No_EnvirQ), and when neither environmental nor nonlinear catchability are applied (No_Qs).



Appendix 10 Figure 6. Reference abundance and exploitation trends for the basecase model (base), when having the recruitment trend informed by the days > 20°C at the Millstone Power Station (Millstone Recruitment), and have a stable, time invariant recruitment pattern (No_Recruit_Covariate).



Appendix 10 Figure 7. Summer (quarter three) spawning stock biomass trends from the basecase model with the updated maturity information (base) compared to when using the maturity ogive used in ASMFC (2015a).

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American Lobster Maturity Assessment

Funded through ASMFC Award Number: 19-0301(CFRF) and 19-0302 (ME DMR)

Final Project Report

May 2019 - September 2019

Authors:

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Commercial Fisheries Research Foundation

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Maine Department of Marine Resources

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BACKGROUND

The American lobster (*Homarus americanus*) supports the largest commercial fishery in North America (ASMFC; Le Bris *et al.,* 2017). In 2017, 136.7 million pounds of lobster were landed coastwide, representing $566.4 million in ex-vessel value (ASMFC). The vast majority of these landings came from the Gulf of Maine/Georges Bank, where the stock is at record abundance. In contrast, lobster abundance in the Southern New England stock area has drastically declined since 1999 (Angell 2013; ASMFC 2015). Despite the economic and cultural importance of the lobster fishery, managers, research scientists and industry members agree that the datasets being used to assess these stocks lack sufficient spatial and temporal coverage, particularly in Southern New England (ASMFC 2010). Specifically, there is a mismatch between the location of primary lobster fishing grounds in this region (10-200 miles offshore) and the location where data are being collected (0-3 miles from shore).

Complicating the issue is the potential impact on the resource attributable to changing environmental factors, such as rising water temperatures. In the Southern New England stock, lobster abundance has drastically declined since the 1990's (Angell 2013; ASMFC 2015; Kavanaugh *et al.,* 2017). At the same time, southern New England waters have experienced dramatic and widespread warming, suggesting an environmental mechanism for the lobster population downturn (Manning & Pelletier 2009; ASMFC 2010; Wahle *et al.,* 2015). Projections of future bottom temperatures in the region suggest that there will be a significant number of days per year in which temperatures exceed 20°C, a temperature unsuitable for lobster habitat (Rheuban *et al.,* 2017). Many inshore regions that were historically important for lobster habitat have been undergoing prolonged periods of time over 20°C for more than a decade now (ASMFC 2015), and the stock is currently depleted and experiencing recruitment failure due in part to changing ocean conditions (ASMFC 2015). It has been well-documented that female lobsters often migrate to avoid temperatures that could harm or delay egg development (Crossin *et al.,* 1998, Cowan *et al.,* 2007), influencing the distribution and concentration of ovigerous females (Jury *et al.,* 2019; Carloni & Watson, 2018). Scientists have begun to theorize that female lobsters are moving out of their traditional sheltered bays to more open ocean environments in response to rising water temperatures, affecting juvenile lobster settlement (Glenn *et al.,* 2011).

Temperature is perhaps the most significant environmental force in the American lobster life history and determinations of habitat suitability. Sea temperatures have been known to influence molting, growth (Waddy *et al.,* 1995), and reproductive development (Templeman 1936; Estrella & McKiernan 1989; Little & Watson 2005; LeBris *et al.,* 2017; Waller *et al.,* 2019). Female lobsters mature at a smaller size in warmer waters than those in colder waters (Aiken & Waddy, 1976). Research in inshore areas has shown a strong linkage between the timing of spring warming in Southern New England and the timing of the lobster molt (Groner *et al.,* 2018) with subsequent consequences to the prevalence of shell disease. Increases in water temperature in this region have likely resulted in changes in female lobster size at maturity and growth patterns, given that temperature has a strong influence on these vital processes.

The maturity datasets used in the 2015 American Lobster Benchmark Stock Assessment are more than 20 years old, making it probable that changes have occurred since these data were collected. As a result, the Commercial Fisheries Research Foundation (CFRF) in partnership with the Massachusetts Division of Marine Fisheries(MA DMF), the Atlantic States Marine Fisheries Commission (ASMFC), and the Maine Department of Marine Resources (ME DMR), conducted an American lobster maturity study in the summer of 2019 to provide updated maturity information for the Southern New England and Georges Bank stocks. The objective of this work was to provide high quality biological datasets that could be used in the upcoming lobster stock assessment.

During the January 2019 American Lobster Stock Assessment Workshop, the Stock Assessment Subcommittee discussed how to conduct an effective, updated American Lobster maturity study in NMFS statistical areas (stat areas) of commercial and ecological significance. Details of the sampling protocols were discussed, and this group agreed that future works should follow the methodologies described in Waller et al., (2019). This approach relies upon the collection of non-ovigerous females and maturity determinations using ovarian staging (Aiken & Waddy, 1982). The size range of females to be collected and analyzed (53-118 mm carapace length, grouped by 5 mm bins) was set to align with the current stock assessment size bins. This included a break at the minimum size limit to ensure adequate sampling at and above the minimum legal harvest size in these areas. Following Waller et al., (2019), the target sample size was set to 20 females per 5 mm carapace length (CL) size bin. During these discussions of sampling protocols, it was recommended that this work exclude egg-bearing female lobsters since they are known to be mature without having to retain and analyze ovaries. Due to the variability in v-notch definitions and interpretation, the group concluded that v-notched females should be included in this work.

Stock-wide maturity schedules (ogives) for the assessment are typically generated by weighting stat area-specific biological data by stat area-specific landings. Therefore, average annual female landings from 2015-2017 by stat area were compared to stat areas sampled by CFRF's Lobster and Jonah Crab Research Fleet to prioritize stat areas for sampling. The six Southern New England stat areas with the highest average landings from greatest to least were 537, 539, 611, 538, 612 and 616. Stat area 537 was broken into inshore and offshore sub-areas for sampling considerations. Additionally, offshore stat areas 561 and 562 in the Gulf of Maine/Georges Bank stock were noted as needing sampling. Stat area 562 averaged more annual female landings than stat area 561 from 2015-2017. As a result, stat areas 537 (offshore southwest corner), and 562 were identified as the highest priorities.

To make accurate determinations via ovarian staging, non-ovigerous female lobsters must be collected and analyzed before the onset of the egg-hatching and molting seasons (Waddy & Aiken, 2005). We were able to evaluate the proportion of ovigerous females in these stat areas during each month using recent datasets from CFRF. Proportions from stat areas 537 and 539 tended to decline from peaks in May to low values in July, suggesting hatching throughout June. Proportions from stat areas 561 and 562 were more variable but declined from peaks in June to low values in July during several years, suggesting slightly later hatching in these stat areas. Based on these data, sampling was conducted from mid-May to mid-June for stat area 537, and throughout June for stat area 562. During this time, Jesica Waller (ME DMR) would evaluate the newly collected data weekly to ensure all protocols were being applied correctly. After all data collection was completed (July 2019), all data analysis would be conducted by J. Waller.

METHODS

Lobster collection, lab and image analysis

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Each fishing vessel participating in this project followed CFRF's Lobster and Jonah Crab Research Fleet sampling protocols. They would collect fishing effort and biological lobster data from a subset of randomly-selected commercial gear hauls. A gear haul consists of one string of lobster traps. To minimize sampling bias, fishermen either sampled the catch from all of the traps within a gear haul or the first 20 traps. Fishermen aimed to sample a minimum of 100 lobsters or 20 traps during each sampling session. For each sampling session, participant fishermen would use CFRF's On Deck Data application to record a suite of fishing effort data, including the depth and soak time of sampled traps, and the total number of traps sampled. The date, time, latitude, and longitude of each sampling session were automatically recorded via the tablet's internal clock and GPS. For biological data collection the On Deck Data application prompted Research Fleet participants to record the carapace length (CL), sex, shell disease severity, presence or absence of eggs and/or v-notch, and disposition for each individual lobster. Digital electronic calipers were used to measure CL to the nearest millimeter and fleet participants manually entered length data into the On Deck Data app.

Non-ovigerous female lobsters were collected by CFRF's Lobster and Jonah Crab Research Fleet participants from May 24th to June 23rd, 2019. Sample collection occurred in offshore NMFS statistical area 537 and NMFS statistical area 562 (Figure 1). The timing of lobster collections was determined with ASMFC's American Lobster Technical Committee members by evaluating CFRF's Lobster and Jonah Crab Research Fleet sea sampling data. These data were used to select a sampling timeframe within a few weeks of the onset of the expected egg-hatching and molting seasons (Waddy & Aiken, 2005). The timeframe was selected so that all female lobsters would be at distinct points of ovarian development during this time (Aiken & Waddy, 1982). The CFRF worked with three fishing vessels in CFRF's Lobster and Jonah Crab Research Fleet (F/V Lady Clare, F/V Excalibur, F/V Direction) to target 20 female lobsters from each 5 mm size bin for stat areas 537 and 562 (Table 1). A target of 240 female lobsters (20 from each size bin) were anticipated for stat area 537 and 240 female lobsters for stat area 562. F/V Lady Clare and F/V Excalibur collected female lobsters from offshore stat area 537, and F/V Direction collected female lobsters from stat area 562.

Before collecting lobsters CFRF staff participated in a two-day training in New Bedford, MA on May 1st and 2nd with Tracy Pugh (MA DMF) and Jesica Waller (ME DMR). The goal of this training was for CFRF staff to learn proper lobster dissection protocols and how to photograph oocytes and pleopods for maturity staging. After this training there were some unexpected delays in lobster collection efforts. During May several fishing vessels participating in this summer study underwent spring vessel maintenance and were not actively fishing until late May/early June. As a result, the first lobsters collected for this study began on May 24th, 2019 for stat area 537, and June 12th, 2019 for stat area 562. Fishermen involved in this maturity study collected 10 females on May 24th, 30 females on June 7th, 55 females on June 8th, 92 females on June 12th, 15 females on June 18th, 45 females on June 19th, and 61 females on June 23rd, 2019.

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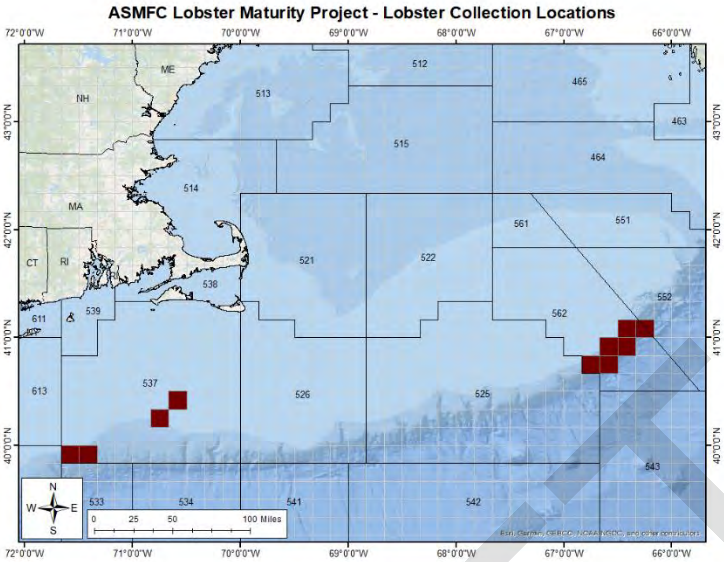

Figure 1. National Marine Fisheries Service statistical areas and locations of female lobster collection trips by CFRF's Lobster and Jonah Crab Research Fleet participants.

Table 1. American Lobster (*Homarus americanus)* target carapace length size bins for each NMFS stat area studied.

Carapace Length Size Bins (mm)
53- 58 mm
58-63 mm
63-68 mm
68-73 mm
73-78 mm
78-83 mm
83-88 mm
88-93 mm
93-98 mm
98-103 mm
103-108 mm
108-113 mm
113-118 mm
>118 mm

Lobsters were banded and kept communally in flow-through tanks at the University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) in New Bedford, MA. Lobsters were put in four different tanks depending on collection date and stat area to prioritize dissections and processing efficiency. For each lobster a suite of collection and biological data was collected and recorded before lab processing. These data included vessel ID, lobster lab ID number, stat area, date of capture, processing date, sex, carapace length (mm), width of the second abdominal segment (mm), presence or absence of eggs, cull status, shell disease severity, presence or absence of v-notch, weight of whole body (g), and weight of body with no claws (g). Each female was also examined for the presence of a sperm plug in the seminal receptacle. This was done by inserting a blunt tip needle into the seminal receptacle. If there was resistance before reaching the bottom of the receptacle, it was assumed that a sperm plug was present (Goldstein *et al.,* 2014).

Females were kept in a freezer for 15-20 minutes prior to dissection. The carapace of the lobster was then removed to determine the color of the ovary (Appendix 1). The ovary was then weighed (g) and at least 10 oocytes were removed and photographed under a dissecting microscope. The diameter (mm) of each oocyte was measured in NIH ImageJ. Next, a pleopod from the second pair on the right side when holding the lobster (ventral side up) was removed from each female and examined under a dissecting microscope to determine the setogenic stage (Aiken, 1973; Appendix 2). If the pleopod was missing or damaged, we took the third pleopod on the top right-hand side. A female with a pleopod at setogenic stage 3.0 or higher was assumed to be in active pre-molt condition (Waddy & Aiken, 1992). If in active pre-molt, it was assumed that the lobster would have molted in the coming weeks/months and the ovaries would have suspended development until that molt occurs. A female with a pleopod at setogenic stage of 2.5 or less was assumed to be in intermolt/premolt stage. This means lobsters in these stages are unlikely to molt soon and ovary development can occur during these stages. Finally, the pleopod was then examined under a dissecting microscope and photographed to record cement gland stage (Appendix 3). Females at cement gland stage 2 or higher can be classified as mature using this approach (Aiken & Waddy, 1982).

Final maturity determinations and data analysis

All measurements and data were shared with the Maine Department of Marine Resources (ME DMR), so that the maturity status of each female lobster could be determined using ovarian staging. This method assigns ovary development stages to a non-ovigerous female based on the color of the ovary, the range of oocyte diameters, and the relative ovary weight (ovary factor). A female that met the criteria for stage 4b or higher was classified as mature (Aiken & Waddy, 1982). Females at this stage or higher have medium to dark green ovaries, an ovary factor of at least 200 and oocytes that ranged from 0.8-1.6mm in diameter (Aiken & Waddy, 1982). All biological data and collection meta-data was collected, entered and organized by A. Ellertson and shared with Jesica Waller (ME DMR) on a weekly basis. Final maturity determinations were conducted by J. Waller at ME DMR.

Ovarian staging was used as the primary maturity determination method, but cement gland staging and the abdomen width to carapace length ratio were considered when the results of ovarian staging were inconclusive or if key data parameters were missing. These secondary maturity metrics were used to evaluate the maturity status of 26 females collected from stat area 537. Ovarian staging could not be applied to these females for a suite of reasons ranging from timing of collections to missing data. After careful consideration and consultation with MA DMF, final maturity determinations were made for all females. J. Waller also relied on all images and lab notes provided by CFRF to perform quality control checks and validate initial maturity determinations.

Each female was assigned an ovarian stage (Aiken & Waddy, 1982) and then a value of 0 (immature) or 1 (mature) to represent the final maturity determination. For each stat area, females were grouped into the appropriate 5 mm carapace length (CL) size bins and a logistic regression (binomial

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distribution, logit link) was fit to these data using the GLM function in RStudio **(**RStudio Team, 2015). Model fit was assessed for each logistic regression using a goodness-of-fit test, a pseudo-R2 from the "descr" package and inspection of the residuals (Faraway, 2006). The CL at which 50% of females in a population are mature (L50) was calculated using the "p.dose" feature in the MASS package in RStudio. This produces an estimated value and a standard error at a set proportion. The model parameters and 95% confidence intervals were derived from each logistic regression and used to generate maturity ogives for each stat area sampled. All figures were generated in RStudio.

RESULTS

Lobster collections and sample sizes by NMFS statistical area

From May 24th, 2019 to June 23rd, 2019, a total of 315 lobsters were collected (308 females, and 7 males) from all stat areas sampled. The males, however, were not used as part of this project, and were collected by accident from participating fishermen who mistook v-notched males for female lobsters. 155 female lobsters were collected from offshore stat area 537 (Table 2), and 153 were collected from stat area 562 (Table 3). On June 28th, A. Ellertson reached out to Tracy Pugh (MA DMF) and Jesica Waller (ME DMR) to share recent photos of ovigerous females observed by lobstermen involved in the project . It was determined that the eggs were close to hatching and sample collection would need to cease in the next week or so. A Ellertson was away on vacation July 1-8th, 2019 and as a result collection of lobsters had to stop at the end of June.

For stat area 537, two fishing vessels collected female lobsters for this maturity study (F/V Lady Clare and F/V Excalibur). During the time of lobster collection, both fishing vessels were primarily targeting Jonah crab. Any of the legal-sized lobsters they caught they wanted to give to their dealer despite CFRF offering to compensate them. As a result, A. Ellertson was often given undersized female lobsters and or v-notched legal females, which created a skew in the number of individual lobsters in each size bin (Table 2). Of the 155 female lobsters sampled in stat area 537, 23 of them were v-notched, and 13 of the v-notched females were over 90 mm. Size bin 83-88 mm had the most individual females per size bin, with 78-83 mm, and 88-93 mm in second and third place.

Table 2. Number of female lobsters collected per size bin from NMFS statistical area 537.

Carapace Length Size Bins (mm)	Number of Individuals per Size Bin
53- 58 mm	0
58-63 mm	5
63-68 mm	1
68-73 mm	5
73-78 mm	13
78-83 mm	35
83-88 mm	50
88-93 mm	32
93-98 mm	4
98-103 mm	5
103-108 mm	2
108-113 mm	1
113-118 mm	0
>118 mm	2

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For stat area 562, F/V Direction collected individual female lobsters for dissection. When comparing stat area 537 and 562, stat area 562 had a more even distribution of individuals per 5 mm CL size bin (Table 3). Nine of the bins had 10 or more individual lobsters collected. The most female lobsters collected were in the 98-103 mm size bin.

Table 3. Number of female lobsters per size bin from NMFS statistical area 562.

Carapace Length Size Bins (mm)	Number of Individuals per Size Bin
53- 58 mm	1
58-63 mm	1
63-68 mm	5
68-73 mm	11
73-78 mm	19
78-83 mm	12
83-88 mm	18
88-93 mm	14
93-98 mm	13
98-103 mm	23
103-108 mm	12
108-113 mm	16
113-118 mm	7
>118 mm	1

Maturity ogive for NMFS statistical area 537

Of the 154 females collected and analyzed from stat area 537, 103 were classified as sexually mature using the maturity criteria discussed above. The smallest mature female occurred at 71 mm CL and all females were mature after 90 mm CL. A logistic regression was fit to these data to evaluate the relationship between CL and maturity and provide a maturity ogive (Figure 2). All model diagnostics indicated a suitable fit to these data (GOF tests: X-squared = 0.544, df = 8, p-value = 0.999; pseudo-R2: McFadden's R2=0.899). Large 95% confidence intervals were observed at points in the curve. This can likely be attributed to small samples sizes at the extremes of the CLs collected and analyzed. The L50 in this area in 2019 was estimated to occur at 78.5 mm CL(LCI:75.58, UCI: 81.42).

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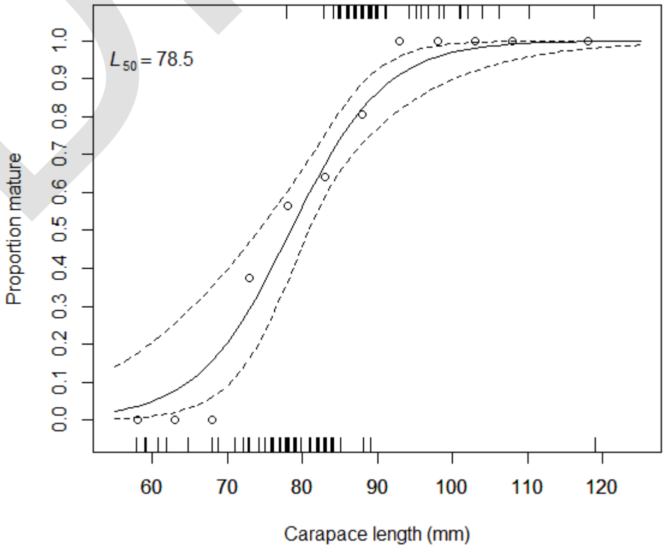

Figure 2. Logistic regression (solid line, α= 12.589, β= - 0.160) showing the predicted proportion of mature female *Homarus americanus* from offshore NMFS statistical area 537 as a function of carapace length and associated 95% confidence intervals (dashed lines). Open circles represent the calculated proportion mature by 5 mm carapace length size bin. Tick marks represent the binary (0=immature, 1=mature) maturity determination for each female analyzed. The estimated L50 is also represented on this plot.

Maturity ogive for NMFS statistical area 562

A logistic regression was also used to generate a maturity ogive for female lobsters collected from stat area 562 in 2019 (Figure 3). All model tests and evaluations indicated a good fit to these data (GOF tests: X-squared = 0.684, df = 8, p-value = 0.996; pseudo-R2: McFadden's R2=0.934). A total of 153 females were collected from this stat area, and 47 % were classified as mature. Compared to the females collected from stat area 537, maturity seemed to occur over a narrow range of CLs and at a larger size in general. One female at 76 mm CL was classified as mature but the onset of maturity appeared more widely at 85 mm and above. All females were classified as mature by 105 mm. The L50 in this area in 2019 was estimated to occur at 92.2 mm CL (LCI:90.15, UCI: 94.25).

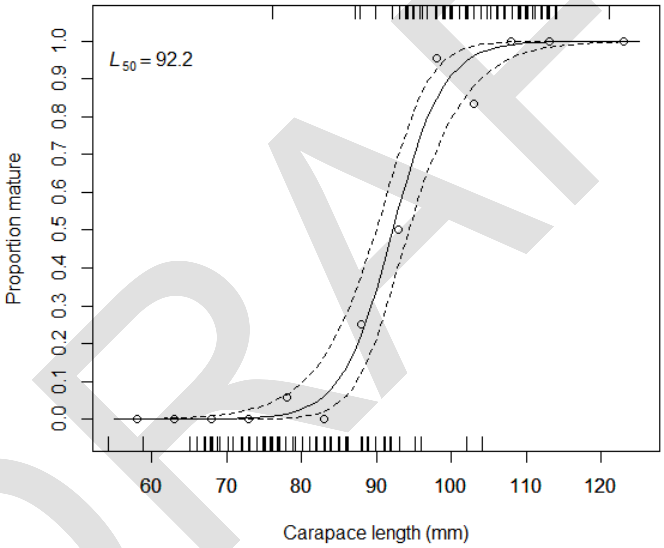

Figure 3. Logistic regression (solid line, α= 27.273, β= - 0.296) showing the predicted proportion of mature female *Homarus americanus* from NMFS statistical area 562 as a function of carapace length and associated 95% confidence intervals (dashed lines). Open circles represent the calculated proportion mature by 5 mm carapace length size bin. Tick marks represent the binary (0=immature, 1=mature) maturity determination for each female analyzed. The estimated L50 for this area is also represented on this plot.

Changes in female carapace length at maturity over time

The length at which 50% of females reach maturity in a population (L50) is a ready point of comparison between studies. Comparisons of this value also make it possible to examine changes in the size at maturity in female lobsters in a specific region over time (Table 4). Two studies conducted in the 1970's and 1980's estimated L50 to occur at 100 mm CL in females from stat area 562 and Georges Bank (Cooper & Uzmann, 1977; Fogarty & Idoine, 1988). We see by examining the results of the work presented in this report that L50 has shifted to 92.2 mm CL in this region. This value is also similar to preliminary work conducted by MA DMF in this region in 2016 and

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2017. A downward shift in L50 over time was also observed in female lobsters collected from stat area 537. This value was estimated to occur at 82 mm CL in the early 2000s while more recent work in the area, including this study, estimated L50 between 76-78 mm CL.

Table 4. The estimated carapace length at which 50% of female *Homarus americanus* are mature (L50) in NMFS statistical areas 562 and 537. The historical studies listed below included females from other surrounding NMFS statistical areas, but these studies represent the most appropriate point of historical comparison. When possible, upper and lower 95% confidence limits are listed in parentheses below each L50 estimate. Values attributed to MA DMF are preliminary and were acquired through personal communication with Tracy Pugh (MA DMF). The values calculated during this work are attributed to ASMFC (2019).

Data source (NMFS statistical area 562)	L50	Data source (NMFS statistical area 537)	L50
Cooper & Uzmann, 1977 *Fogarty & Idoine, 1988*	100 mm	*Little & Watson (2005)*	82 mm (81.3, 83.4)
MA DMF (2016-2017)	87 mm	*MA DMF (2017-2018)*	76.1 mm (74.7, 77.5)
ASMFC (2019)	92.2 mm (90.2, 94.3)	*ASMFC (2019)*	78.5 mm (75.6, 81.4)

CONCLUSIONS

Aubrey Ellertson (CFRF) and Jesica Waller (ME DMR) presented the full results of this work to the ASMFC American Lobster Stock Assessment Technical Committee via webinar on October 10th, 2019. A. Ellertson presented the results of CFRF's collection efforts and the methodology used for laboratory and image analysis. J. Waller shared the data analysis, full results and comparisons to historical work described above. This committee agreed that these data were of value to future American lobster stock assessment efforts and should be incorporated into aspects of the current stock assessment model. J. Waller submitted all maturity determinations and data analysis to Jeff Kipp (ASMFC) on October 11th, 2019 in order to conclude this project and ensure that the ASMFC American Lobster Stock Assessment Technical Committee has access to this work.

This study provided detailed female *Homarus americanus* size at maturity datasets for two NMFS statistical areas (562, 537). A comparison of this work to historical studies conducted in these areas supports the notion that the size at maturity has decreased over time. This downward trend aligns with recent size at maturity work that recorded similar decreases over the span of the last several decades (Le Bris *et al.,* 2017; Waller *et al.,* 2019). Key results of this study also aligned closely with recent preliminary work conducted from 2016-2018 in these areas (T. Pugh, MA DMF, per. comm). Taken together these comparisons bolster confidence in the work described here and the maturity ogives generated for each stat area sampled. The results described in this report will be used by the ASMFC American Lobster Stock Assessment Technical Committee to update key parameters in the

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stock assessment model related to female growth, egg production and stock determination (ASMFC 2015).

ACKNOWLEDGEMENTS

We would like to thank Fiona Hart for her dissection and sampling efforts. This work would not have been possible without John Peabody (F/V Lady Clare), Jim Violet (F/V Excalibur), and Grant Moore (F/V Direction) who allowed CFRF staff to collect lobsters from their fishing vessels. We would also like to thank Dr. Tracy Pugh (Massachusetts Division of Marine Fisheries) for offering valuable insight and for sharing her expertise on this topic. This work was supported by funds from the Atlantic States Marine Fisheries Commission.

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Appendix 1: Ovary Color Guide

Ovary Stage 1: white

Ovary Stage 2: yellow, orange, beige

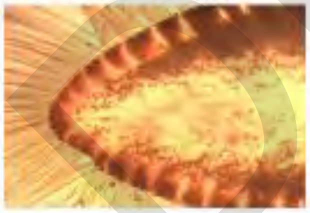
Ovary Stage 5: dark green

Ovary Stage 3: light to medium green

Ovary Stage 4: medium to dark green

Appendix 2: Pleopod Staging

Pleopod Stage: 0



Pleopod Stage: 1:

Pleopod Stage: 1.5:

Pleopod Stage: 2

Pleopod Stage: 2.5

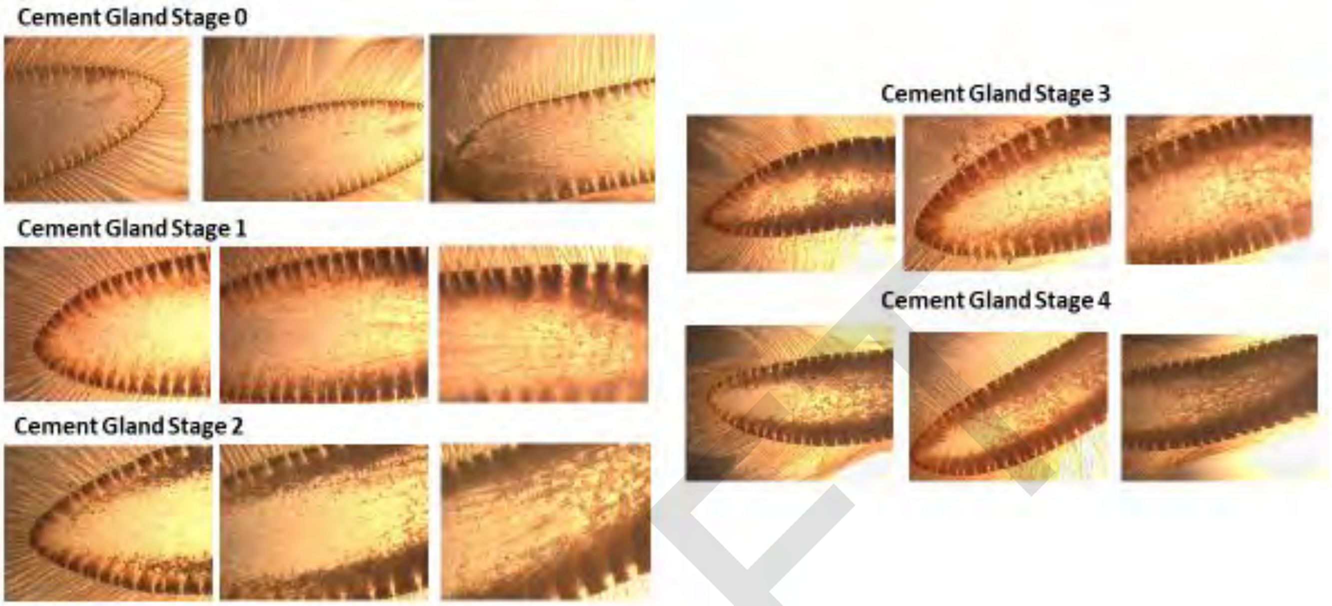
Pleopod Stage: 3

Pleopod Stage: 3.5

Pleopod Stage: 4

Criteria used was from Factor Jr, ed. Biology of the lobster Homarus americanus. San Diego: Academic Press, 1995: p. 225. Pictures taken by A. Ellertson and F. Hart during dissection.

Appendix 3: Cement Gland Staging



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Appendix 6. Model-Based Ventless Trap Survey Indices of Abundance

McManus, M.C., Kipp, J., Shank, B., Carloni, J., Pugh, T., Reardon, K., and McKown, K. A model-based approach to standardizing American lobster (*Homarus americanus*) ventless trap survey abundance indices in coastal New England waters. This work is in preparation for publication, please do not cite this appendix without authors' permission.

Objective

This work aimed to understand the impact of several survey attributes on lobster catch per ventless trap (CPVT) from the Coastwide Ventless Trap Survey. Additionally, these sources of variability were accounted for when deriving relative abundance indices. Model-based approaches were utilized to derive sex and stock-specific annual abundance estimates from the lobster ventless trap surveys. Model-derived male and female Gulf of Maine/Georges Bank (GOMGBK) and Southern New England (SNE) CPVT indices were compared to those built based on the survey design (i.e. design-based indices) to ascertain their differences and advantages, and ultimately the significance of including factors documented to influence trap catchability in deriving abundance estimates for the Coastwide Ventless Trap Survey.

Methods

Survey design

Beginning in 2006, the Coastwide Ventless Trap Survey (VTS) has employed a random stratified survey design, using NMFS Statistical Area and depth as the primary strata classifications. The SAs included in the survey are 511, 512, 513, and 514 in the Gulf of Maine-Georges Bank region, and 538, 539, and 611 in Southern New England (SNE). Hereafter, Gulf of Maine-Georges Bank stock strata will be referred to as Gulf of Maine (GOM), as sampling has only been conducted in the Gulf of Maine. The survey is a cooperative effort between state fisheries agencies and commercial lobstermen, in which lobstermen contracted to help deploy and retrieve survey gear from their vessels. States that have or currently participate in the survey include Maine, New Hampshire, Massachusetts, Rhode Island, and New York. The survey design uses three depth strata that span the range of depths that lobsters are typically fished in inshore waters: 1 - 20 m, 21 - 40 m, and 41 - 60 m.

Full description on the VTS can be found in the main body of the assessment document and **Error! Reference source not found.**. Briefly, all states have sampled since 2006 but for three exceptions: New York sampled only from 2006-2009, New Hampshire began sampling in 2009, and Massachusetts did not sample in 2013. All states except Maine began sampling stations with one six-pot trawl, in which vented and ventless lobster traps were alternated for three of each per trawl (0 Table 1). Maine deployed gear either as two three-pot trawls or as one six-pot trawl. Further, in 2015, Maine and New Hampshire have exclusively fished ventless pots and abandoned sampling with vented pots in SAs 511, 512 and 513. Across states, stations are sampled twice per month with a targeted three-night soak time (soak times have exceeded three nights with inclement weather delaying sampling). All traps are baited when actively fishing, with bait type at the discretion of the contracted lobstermen. The primary data stream from the survey is the number of lobsters caught in each trap, which is used for estimating catch per unit effort (CPUE). However, for each lobster, several descriptors are also recorded (carapace length to the nearest mm, sex, shell hardness, culls and other shell damage, external gross pathology, mortality, the presence of extruded ova on females, and shell disease symptoms) and bycatch similarly described where applicable.

Data processing

Samples considered for the model-based standardization included those whose stations' annual average position (latitude and longitude) fell within the survey strata (0 Figure 1). All those that fell out due to inaccurate positions recorded or were sampled at stations that have since been dropped from the survey were not included. This approach resulted in a small portion of samples being dropped from MA, RI, NH and ME, but also resulted in all samples from NY to be excluded.

Several data filters were also used to exclude samples from the modeling effort. All ventless traps that were not fishing efficiently (e.g. hole in netting, vent left open) were excluded from the analysis. Further, only trawls with 6 or fewer traps and soak times between 1 and 6 days were included. The survey has traditionally targeted summer months (June, July, and August) for sampling; however, due to expanded pilot or permanent sampling through time or fishermen contracting logistics, the surveys were not always conducted over those sampling months or included others (e.g. September, October). Samples collected outside June-August were excluded from the analysis for consistency across the survey domain. Lastly, all vented traps were excluded from the analysis, given the focus is on deriving CPUE for ventless traps. Their presence in the modeling was only through their inclusion in the number of traps in a trawl.

Modeling approach

Generalized linear models (GLMs) are a common method for standardizing CPUE data, which utilizes a user-defined statistical distribution on the response variable and linear responses between explanatory variables and CPUE (Maunder and Punt 2004). For continuous data, the effect of the covariate in GLMs is estimated as a linear model with slopes and intercepts estimated. For factorial data, GLMs estimate fixed parameters, which can be compared across the various factors within the variable and be used to scale the response variable at a specific factor. The generalized linear-mixed model (GLMM) framework expands upon the GLM by allowing covariates to be modeled as fixed or random effects (Vidal et al. 2018). Random effects allow for accounting variability among factors of repeated measures, or when randomly selected variables sampled are part of a larger population of which the extents are not completely sampled (Bolker et al. 2009, Deroba 2018).

GLMMs were used to model sex-specific lobster CPVT for both stocks (SNE and GOM). As such, four individual models were built to predict the desired CPVT response variable: male CPVT in

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SNE, female CPVT in SNE, male CPVT in GOM, and female CPVT in GOM. Catch data reflected lobster 53mm and larger to match the data needs of the lobster stock assessment model (ASMFC 2015a). A negative binomial distribution was used to model the response variables (CPVT) in each of the four models given the overdispersion in the catch data (0 Figure 2). Further, the models included zero-inflation to account for the high frequency of zero catches that are often difficult to capture with a traditional negative binomial distribution. The GLMMs were constructed using R package 'glmmTMB' (Brooks et al. 2017).

While the coastwide VTS survey collects many of the same data fields across states to derive lobster abundance estimates, not all relevant data are collected by each state. Continuous, fine scale sediment or bottom type data does not exist across the survey bounds to be included in the standardization. Bathymetric slope was estimated for samples using NOAA's National Geophysical Data Center (NGDC) depth data for the Northeast U.S. Shelf using R package 'raster' (Burrough and McDonnell 1998), but corroboration between the associated depths and those observed from the VTS observed data was poor, thus slope data was excluded in the modeling. While bait type has long been believed to influence lobster catch rates, not all states have consistently collected such data through time. Further, most bait types for samples through time in the SNE and GOM have been skate and herring, respectively, and may not provide enough variation in bait types for the models to confidently assess catch variance associated with bait. Lastly, position of the trap in a trawl was also not included based on the consistency of the information being collected through time by certain states.

Lobster CPVT was modeled based on five covariates: year, unique station, day of year, soak time, and the number of traps in the trawl. Year was modeled as a fixed effect, while the other covariates were modeled as random effects. Designating the four variables as random effects was intended to isolate their population-level effect estimates and remove the effects that a given factor's variation in the data may have on the CPVT. To incorporate the survey's depth stratification into the model-based approach, samples were weighted based on the areal proportion that their strata comprised of the NOAA Statistical Area-Depth-State stratification. The weight served as multipliers on the log-likelihood contributions of the observations.

Despite the immense body of literature highlighting the environmental drivers on lobster abundance and distribution (Chang et al. 2010, Tanaka and Chen 2015, Tanaka and Chen 2016), climate variables were not incorporated into the model-approach. Many of these environmental drivers that vary seasonally or interannually are inherent in the day of year and year covariates, respectively. Including other environmental correlates would risk model overfitting and double counting the effects of a given ecological factor. As such, this index work focused on survey, temporal, and gear configuration concerns as opposed to interannual changes in the environment.

Design-based approach and comparisons

The design-based abundances were constructed as used in the 2015 American Lobster Stock Assessment (ASMFC 2015a), with brief description provided herein. Similar to the model-based approach, only the ventless traps were used to construct design-based abundance indices. Data from ME, NH, and MA were used for the GOM indices, and MA and RI data for the SNE indices. Because MA did not run a VTS survey in the GOM or SNE in 2013 and the MA data can significantly influence the combined indices, design-based indices were not constructed for 2013 (ASMFC 2015a). Additionally, the survey index was constrained to the months of June, July and August when all agencies were conducting their surveys.

Because survey sites were not moved within a survey season, each survey site was treated as an effective replicate and samples within the season as repeated measures. To get the season average for a survey site, catch in the ventless traps were first averaged across ventless traps in a trawl, then across trawls within a month, then across months in a season. Calculating the survey indices from the survey site averages then used standard stratified-random equations with the depth and region strata used in the survey design from each state agency:

$$Catch_y = \frac{\sum_{str} \frac{\sum_s Catch_{s,str,y}}{N_{str,y}} \times A_{str}}{\sum_{str} A_{str}}$$

where $\text{Catch}_{y,s,str}$ the mean catch at site s in stratum str and year y, $N_{y,str}$ is the number of sites in stratum str and year y and A_{str} the area of a given stratum. Both model-based and design-based approaches were compared in terms of their magnitudes and relative trends. The resulting sex ratios for each stock and index type were also compared by dividing the male indices by the female index of the respective stock and index type.

Results

Diagnostics and random effects

All four models - male and female SNE, male and female GOM - converged successfully (0 Table 2). When testing model variants, the greatest improvement in the models was associated with including the site effect (0 Table 3, Supplement Figure 1). This improved performance was larger for SNE models than for GOM models, and SNE females more than SNE males. Stepwise procedure to include covariates suggested that models including site, day of year, year, and soak time were the best fitting across sex and stock-specific models. While including number of traps did not improve model performance, this factor was included in the models for constructing abundance indices to account for this associated variance.

Random effect estimates indicated that in SNE, male and female CPVT was greater in July than June and August (0 Figure 2). In the GOM, male lobster CPVT was greater in August than June and July, whereas female CPVT was similar in June and August, and slightly lower July (0 Figure 2). Soak time random effect intercepts for SNE lobster CPVT did not suggest discernible patterns with changes in soak time. Male CPVT indicated a slight positive effect with increased soak time but was variable, and even more so for females (0 Figure 3). Soak time effects in the GOM CPVT suggested that catch increased incrementally from 3 to 6 nights for males and 4 to 6 nights for females (0 Figure 3). Effects from the number of traps in a trawl on SNE lobster CPVT was variable and of little magnitude difference across the range (0 Figure 4). For GOM, CPVT patterns were similar for males and females; effects increased from 1 trap to a peak of 3 traps and declined from 3 toward 6 traps (0 Figure 4). Random effects indicated spatial variability in positive influences on CPVT for males and female lobsters. In SNE, both sexes' CPVT appear to be lower inside of the shallower estuaries of Buzzards Bay and Narragansett Bay than in the deeper oceanic environment of Block Island Sound and Rhode Island Sound (0 Figure 5). The East Passage of Narragansett Bay seems to be the most preferable estuarine area of lobsters in the SNE survey bounds, perhaps linked to the deep channel. In contrast to SNE, there appeared to be less heterogeneity for the site effects in the GOM (0 Figure 5).

Abundance indices

SNE model-based and design-based indices indicated similar trends. Both SNE female and male abundance indices have declined since 2006, with the model-based approach declines smoother and less variable over time than those from the design-based approach (0 Figure 6). Trends differences between sexes from the model approach appeared less than those of the design-based approach; however, the model-based indices were less in magnitude than the design-based indices (0 Figure 6). The greatest difference between the two approaches for SNE were in recent years; abundances in 2016 were greatest since 2010 for females and 2012 for males, but unlike the design-based indices, abundances in 2017 and 2018 were lower, and more like 2014 and 2015 abundances than 2016 (0 Figure 6). Terminal SNE index values were also trending in opposite directions between methods, with the model-based indices suggesting that 2019 was slightly greater than 2018 and the design-based indices suggesting a decline from 2018. Corroboration in magnitude between model-based and design-based abundance indices for the GOM were stronger than those of SNE. Both male and female abundance indices indicated an increase from 2007 through 2012, with abundance variable but still high through 2018 (0 Figure 6). Design-based indices were modestly lower than the model-based indices throughout the time series except for 2012. The greatest discrepancies between model and design-based indices were in 2019, with model-based indices less than those estimated via the design-based calculations. Standard errors were greater for all model-based indices than their corresponding design-based, likely attributed to the processing of data at the individual trap level and weights applied in the likelihood calculations, (i.e. model-based approach), as opposed to the average station catch level being weighted post-hoc (i.e. design-based approach).

Trends between model and design-based approaches were similar across sexes and stocks except in the early and terminal years of the SNE indices (0 Figure 7). Corroboration in the sex ratios between the approaches also varied by stock. For GOM sex ratios, both model and design-based approaches were similar, highlighting an increasing trend towards female skewed catch (0 Figure 8). In SNE, the design-based approach also indicated a female skewed population in state waters; however, the model-based approach indicated a male-skewed community through time, with males up to 1.5 times more abundant than females (0 Figure 8).

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0 Table 1. Description of VTS by participating states.

State (Statistical Areas)	Operating Years	Trawl Configuration
Maine (511, 512, 513)	2006-2014	Single 6-pot trawls alternating vented and ventless pots or two 3-pot trawls with 3 vented pots on one trawl and 3 ventless pots on the other trawl
	2015-2019	One 3-pot trawl, all ventless pots
New Hampshire (513)	2009-2014	Alternating vented and ventless traps in single 6-pot trawls
	2015-2019	One 3-pot trawl, all ventless pots
Massachusetts* (513, 538)	2006-2012, 2014-2019	Alternating vented and ventless traps in single 6-pot trawls
Rhode Island (539)	2006-2019	Alternating vented and ventless traps in single 6-pot trawls
New York (611)	2006-2009	Alternating vented and ventless traps in single 6-pot trawls

*Massachusetts data in 2019 was only available for SNE stations; GOM stations in 2019 only represent New Hampshire and Maine data

0 Table 2. Brief model diagnostics (log-likelihood and negative binomial overdispersion parameters) for the four models.

Model	Log-Likelihood	Overdispersion Parameter
Female GOM	-14751	2.95
Male GOM	-13590	2.48
Female SNE	-4118	1.92
Male SNE	-4342	1.72

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0 Table 3. Backward, stepwise comparison of model fits using varying model covariates. Akaike information criterion (AIC) and Bayesian information criterion (BIC) values are provided for each model variant. Smaller values within a model type indicate better fit. Bold values indicate the model variant with the lowest AIC score.

Model	Variables	AIC	BIC
SNE Females	Year, Day of Year	9637	9891
	Year, Day of Year, Soak Time	9620	9826
	Year, Day of Year, Soak Time, Site	**8246**	**8830**
	Year, Day of Year, Soak Time, Site, Traps No.	8276	8867
SNE Males	Year, Day of Year	9697	9200
	Year, Day of Year, Soak Time	9697	9207
	Year, Day of Year, Soak Time, Site	**8694**	**8310**
	Year, Day of Year, Soak Time, Site, Traps No.	8724	8344
GOM Females	Year, Day of Year	29518	29670
	Year, Day of Year, Soak Time	29520	29681
	Year, Day of Year, Soak Time, Site	**29501**	**29671**
	Year, Day of Year, Soak Time, Site, Traps No.	29542	29721
GOM Males	Year, Day of Year	27261	27413
	Year, Day of Year, Soak Time	27263	27424
	Year, Day of Year, Soak Time, Site	**27192**	**27362**
	Year, Day of Year, Soak Time, Site, Traps No.	27220	27399

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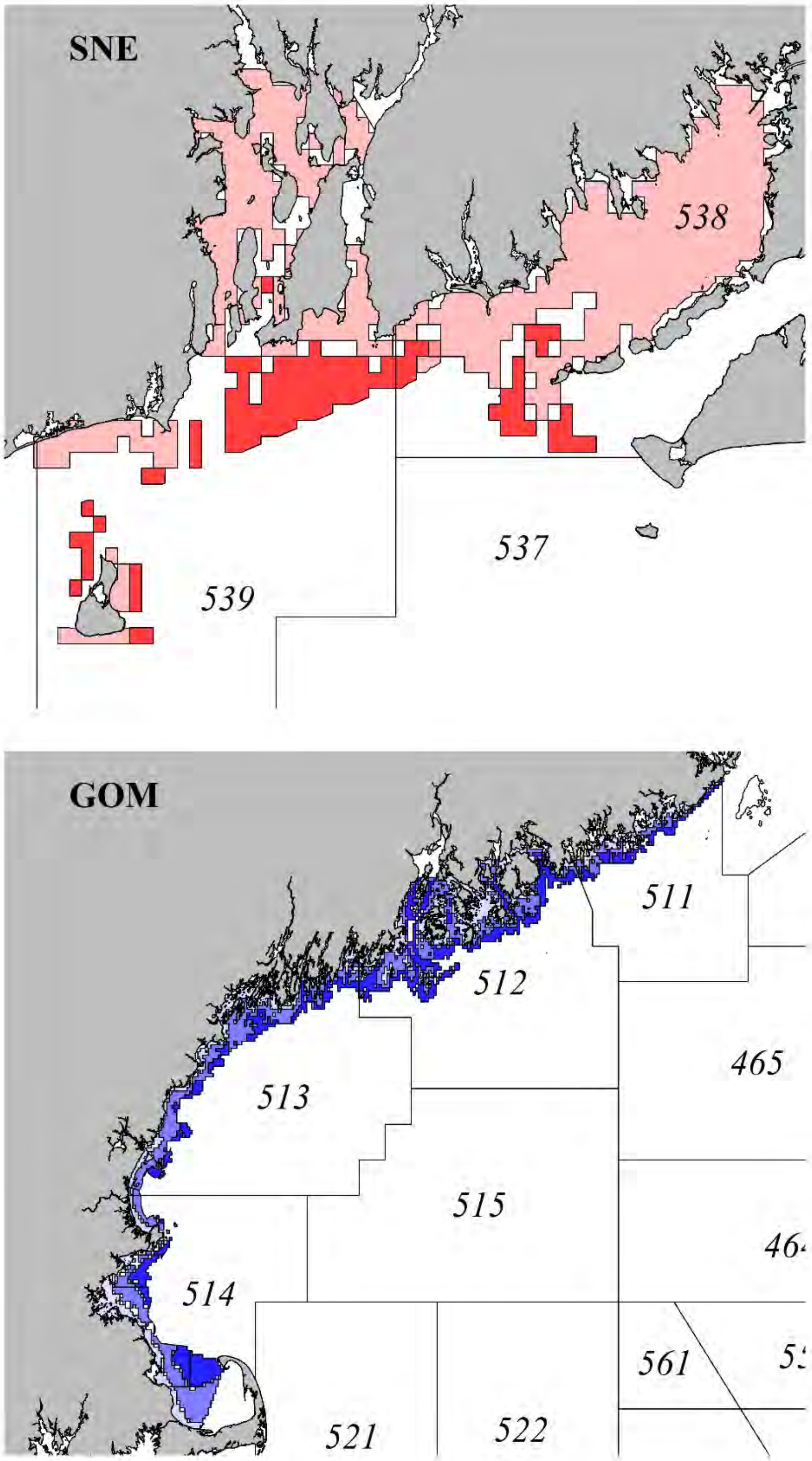
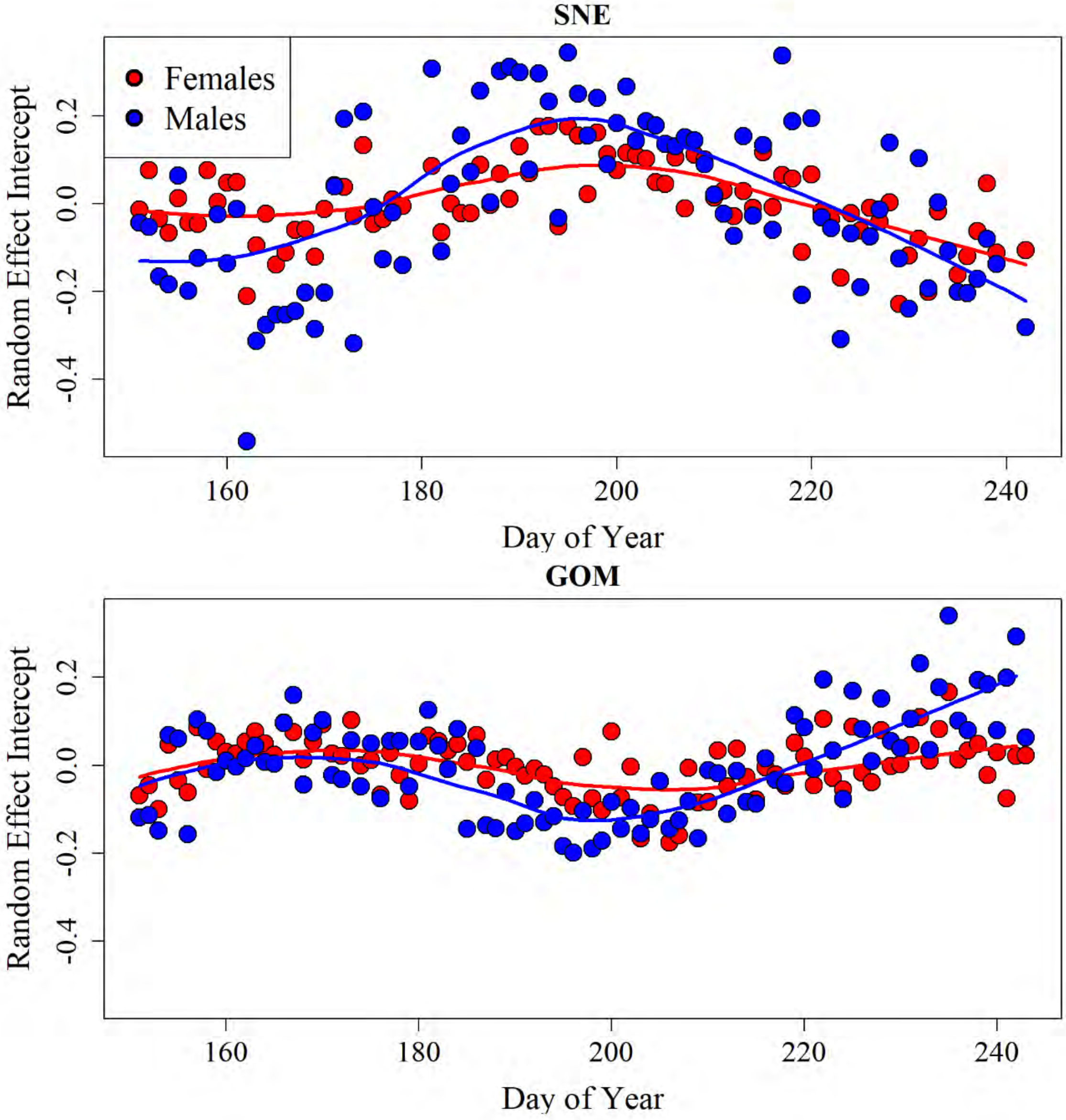
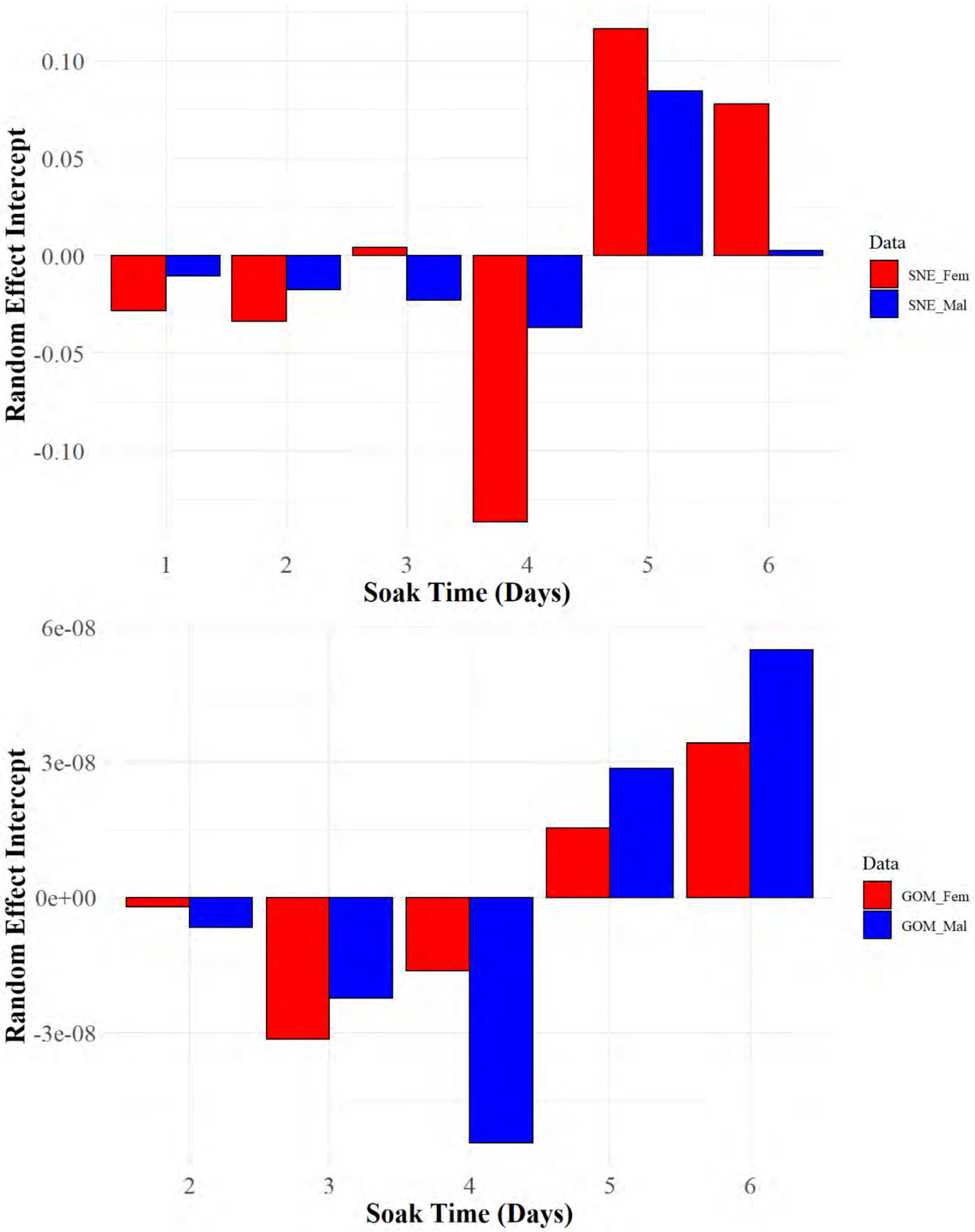


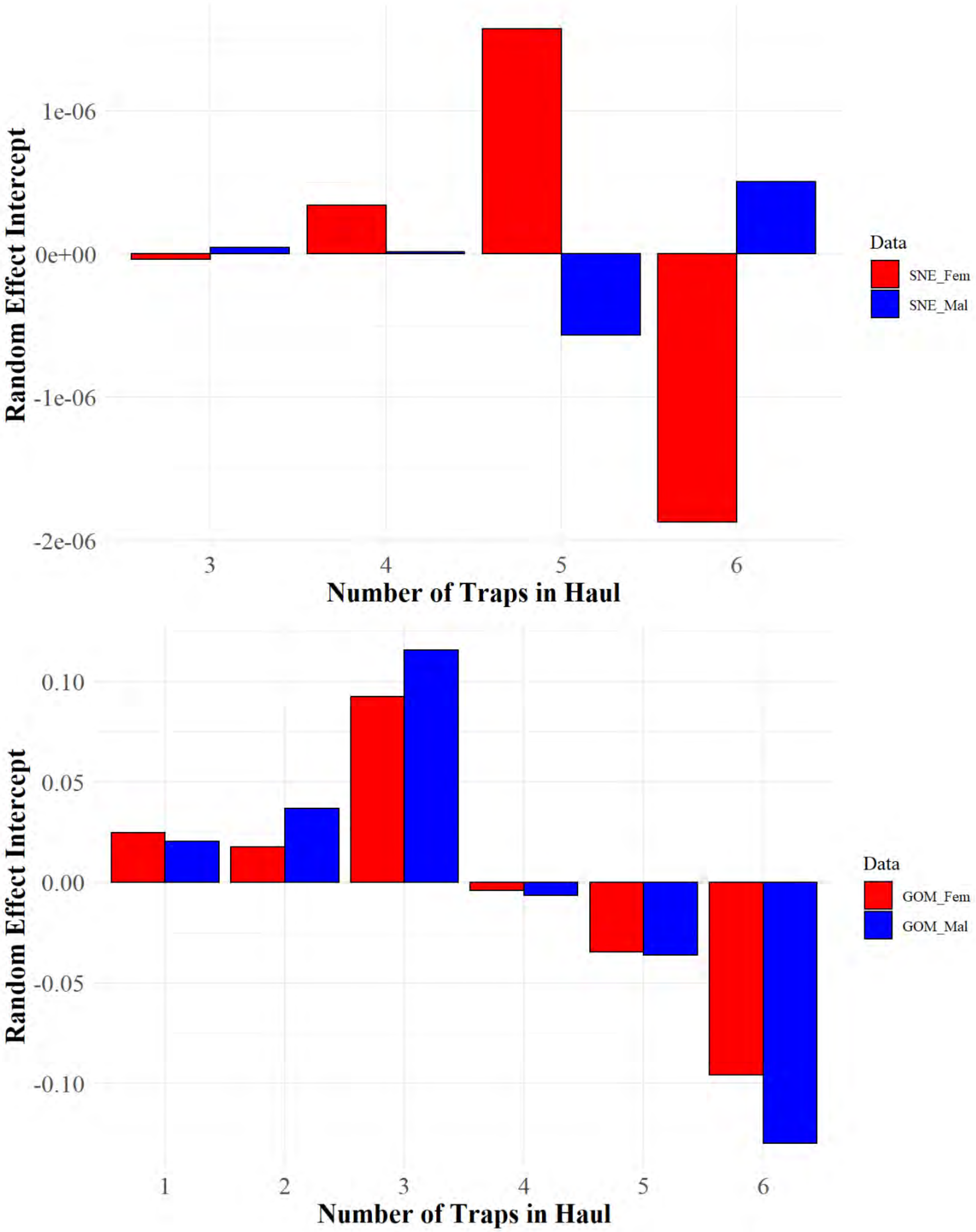
0 Figure 1. Survey domain and stratification for the lobster VTS within the Southern New England (top) and Gulf of Maine (bottom) stock areas. Southern New England strata are 0-20m (light red) and 21-40m (dark red), whereas Gulf of Maine has 0-20m (light blue), 21-40 (blue) and 41-60m (dark blue) strata.



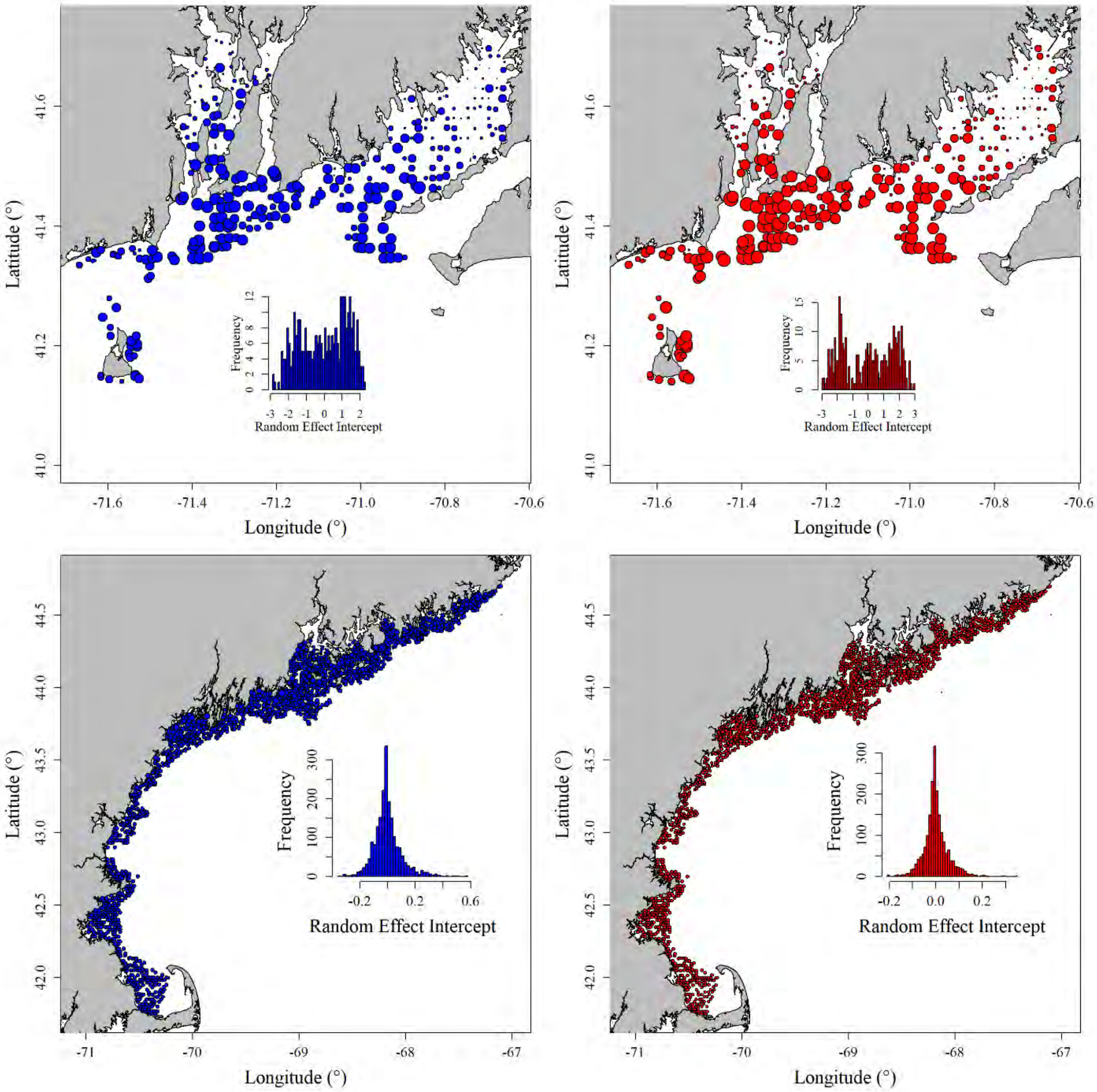
0 Figure 2. Random effects intercepts for the Day of Year variable estimated for the male and female SNE and GOM catch per ventless trap (CPVT) models. Lines represent loess fits through the day of year intercept values.



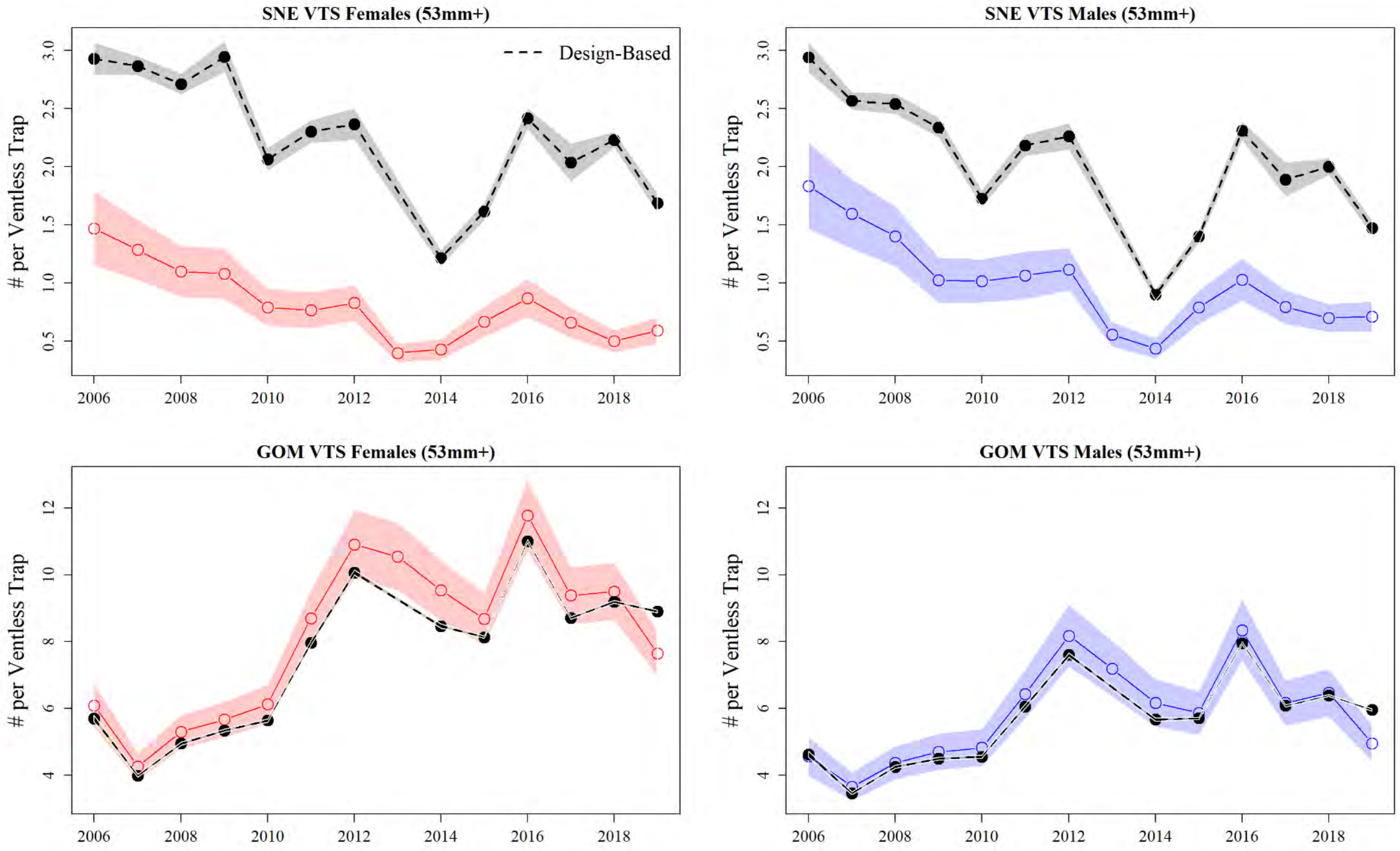
0 Figure 3. Random effects intercepts for the soak time variable estimated for the male and female SNE and GOM catch per ventless trap (CPVT) models.



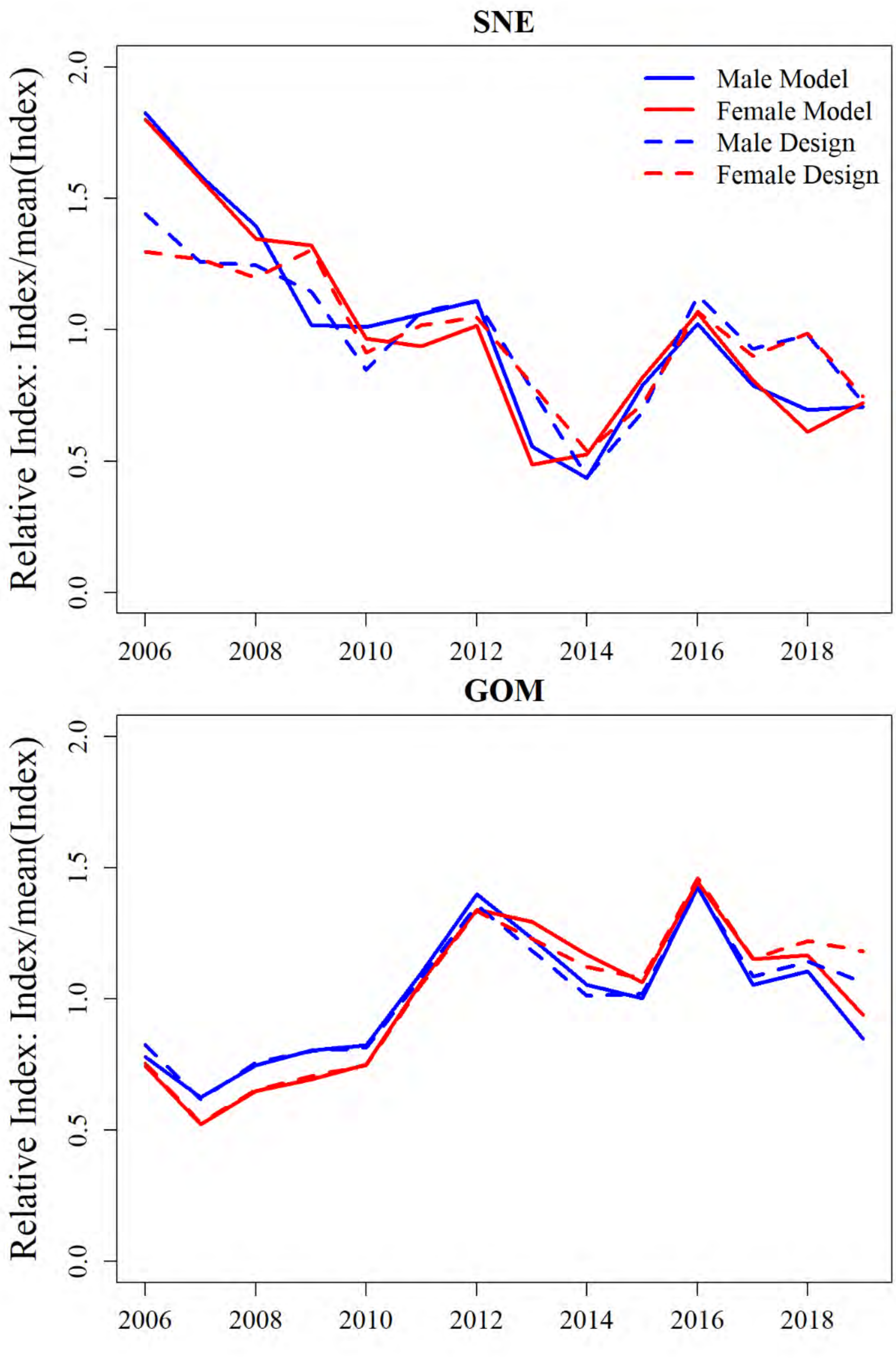
0 Figure 4. Random effects intercepts for the Number of Traps per Trawl variable estimated for the male and female SNE and GOM catch per ventless trap (CPVT) models.



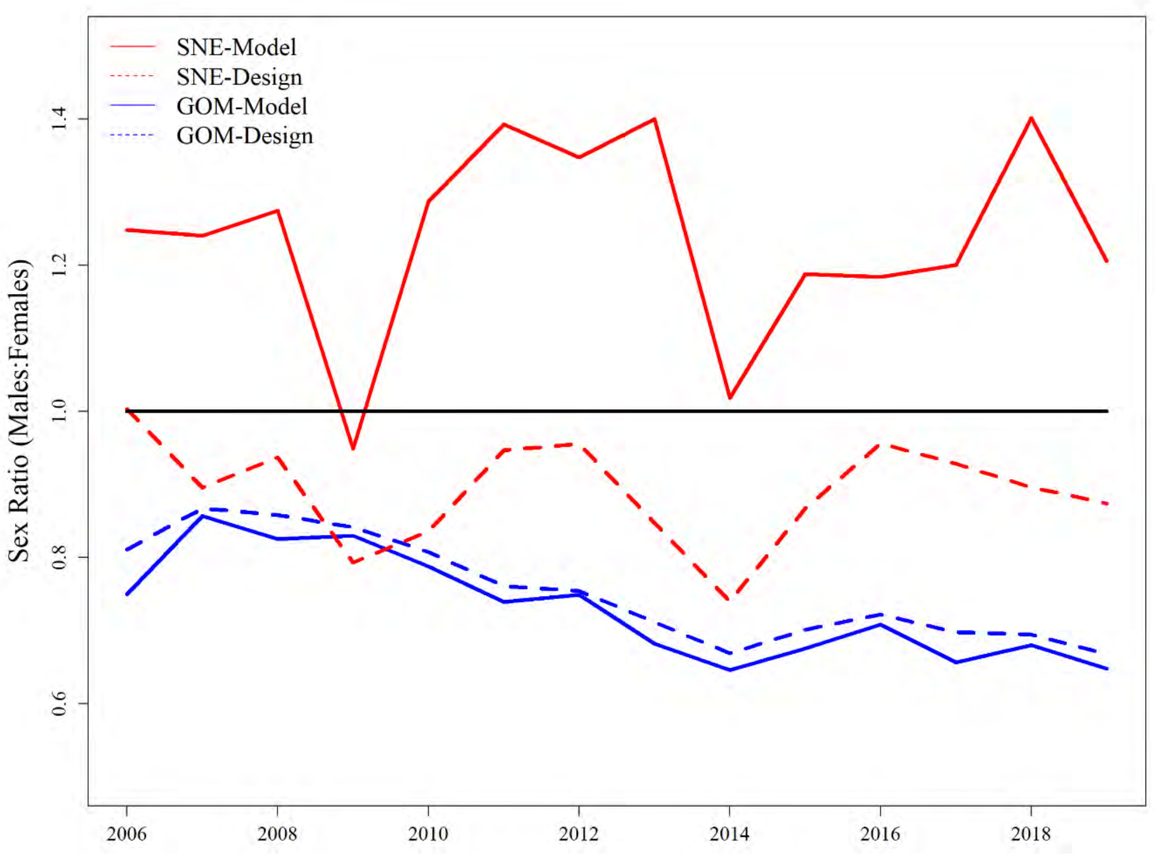
0 Figure 5. Random effect intercepts for the Station variable estimated for the male (left column) and female (right column) SNE (tow row) and GOM (bottom row) catch per ventless trap (CPVT) models. Effects are plotted spatially representing their location, with the size of points relative to their value (more positive random effect intercepts correspond to larger points). Points within a sex-specific figure are relative to that sex only. Inset histograms present the random effect intercepts associated with the Station variable for the respective catch per ventless trap (CPVT) model.



0 Figure 6. Annual catch per ventless trap (CPVT) indices for each specific model. Model-based approach mean indices for males (blue) and females (red) and their associated standard error are presented with mean design-based index (black dashed line).



0 Figure 7. Normalized male and female SNE and GOM CPVT indices using the model-based and design-based approach.



0 Figure 8. Annual sex ratios for stocks' indices using model and design-based approaches. The solid line reflects where the sex ratio represent 1:1.

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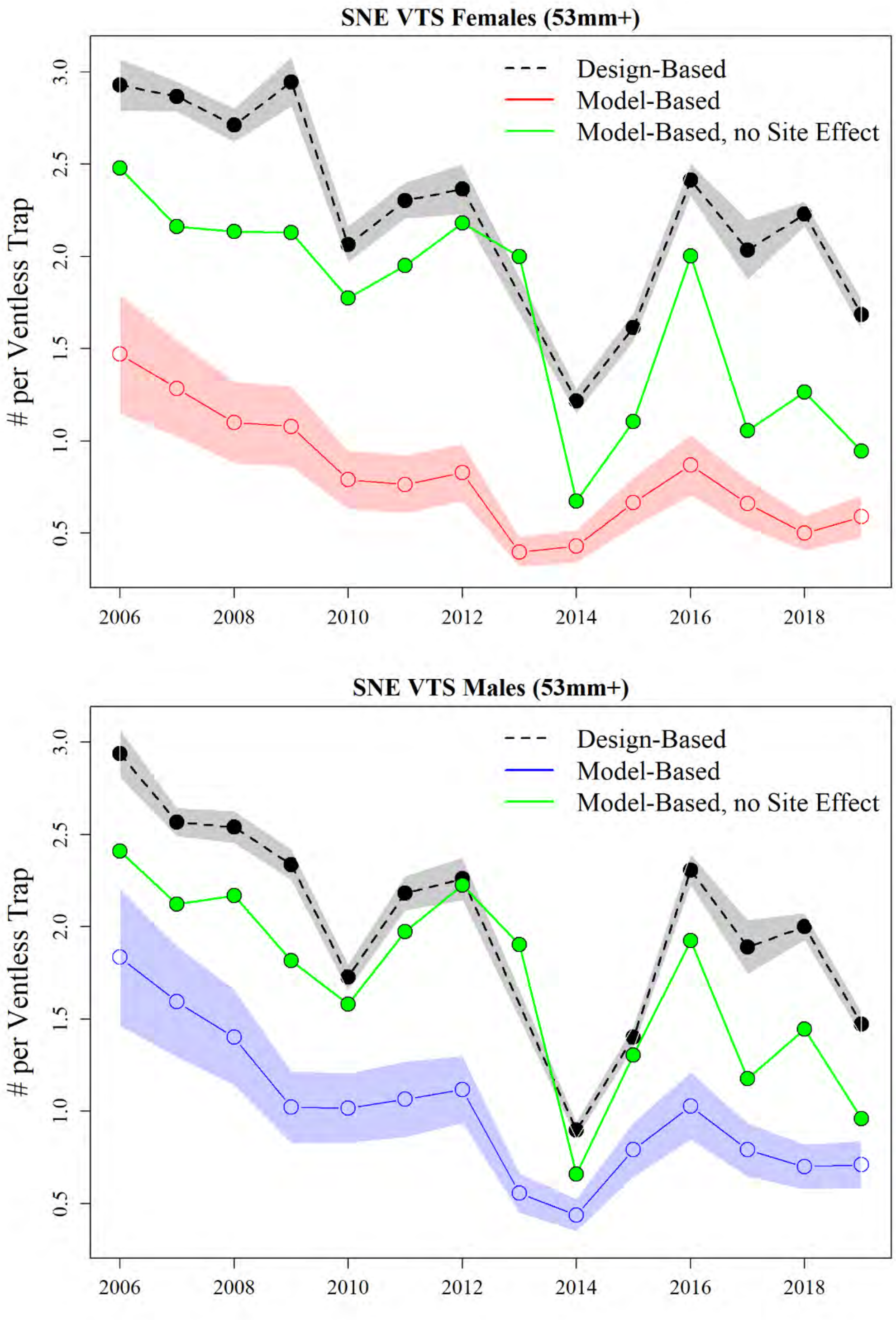
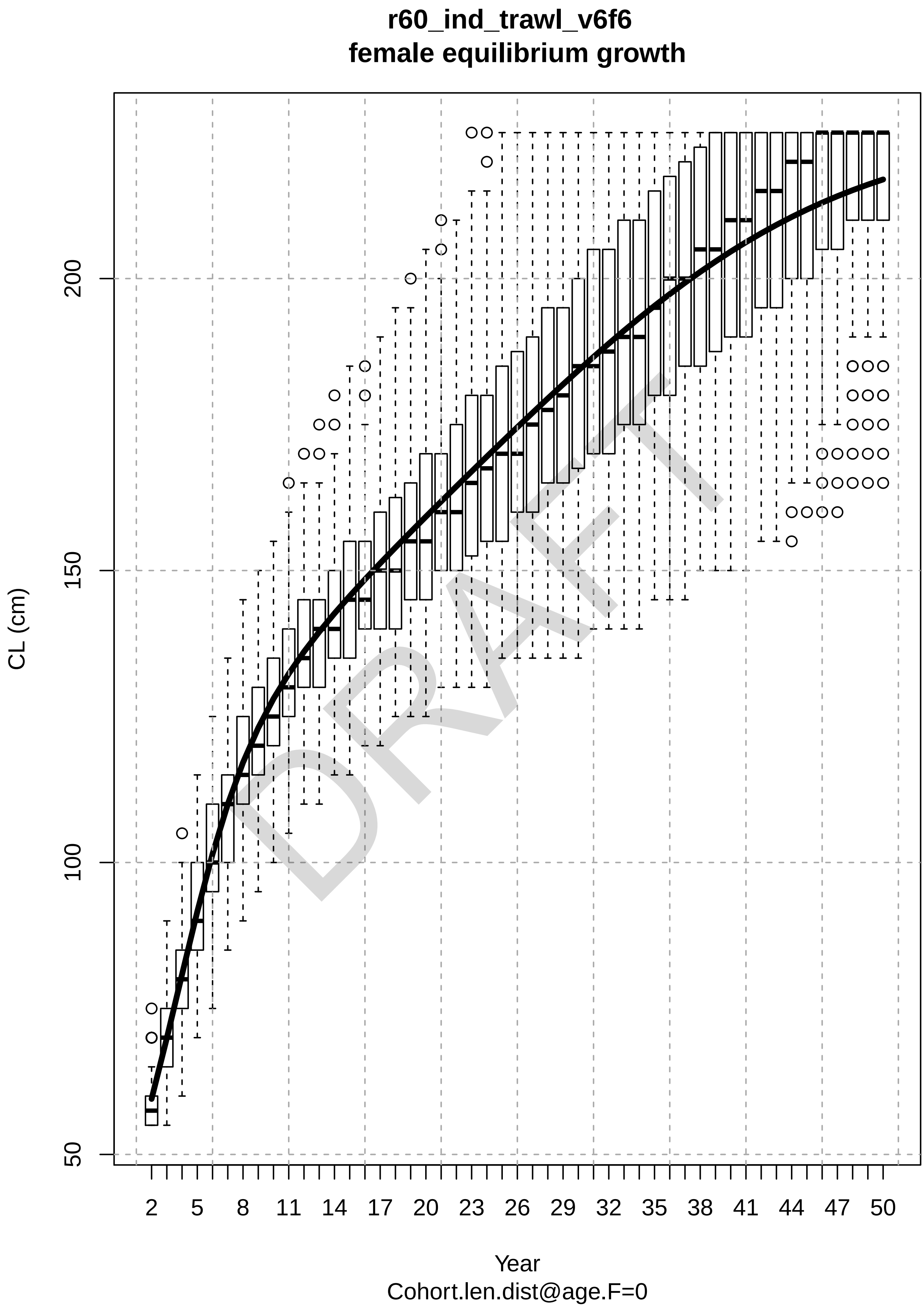


Supplement Figure 1. SNE model-based indices for females (top, red) and males (bottom, blue) compared to the design-based indices (black) and the model-based indices when site is not included in the mode (green).


r60_ind_trawl_v6f6
female equilibrium growth
CL (cm)
50
100
150
200
2
5
8
11
14
17
20
23
26
29
32
35
38
41
44
47
50
Year
Cohort.len.dist@age.F=0

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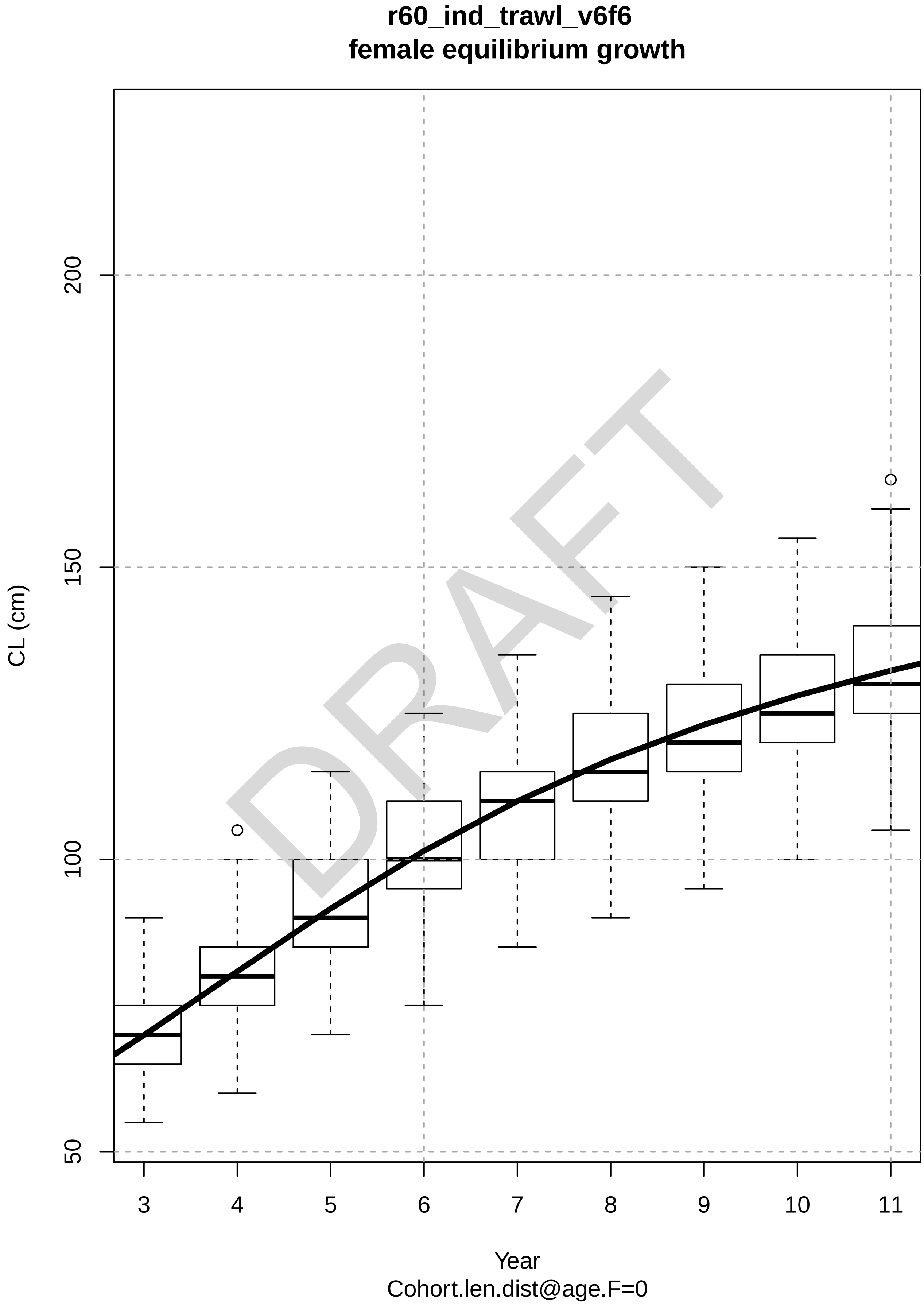
r60_ind_trawl_v6f6
female equilibrium growth
CL (cm)
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100
150
200
3
4
5
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7
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10
11
Year
Cohort.len.dist@age.F=0

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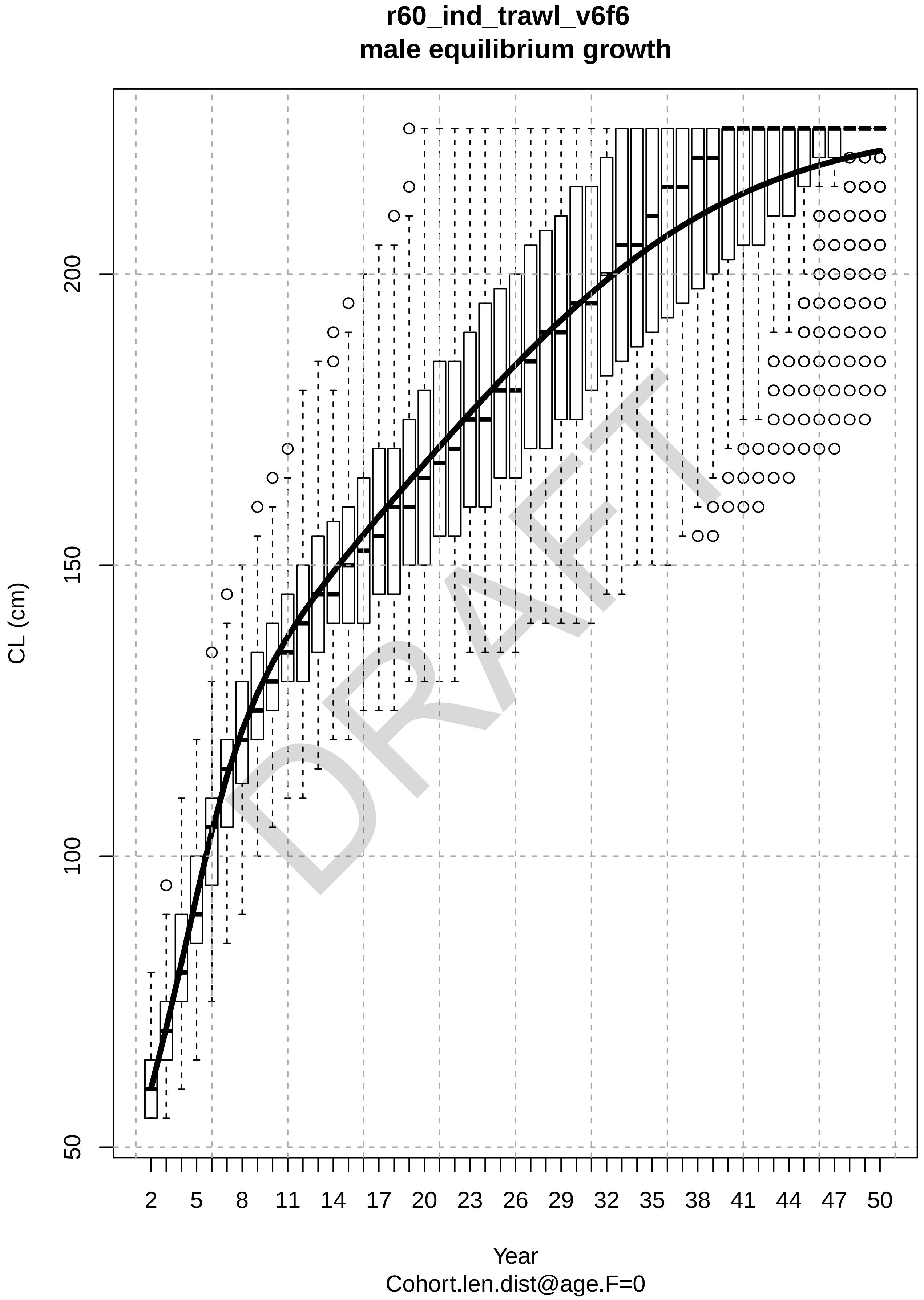
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male equilibrium growth
CL (cm)
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Year
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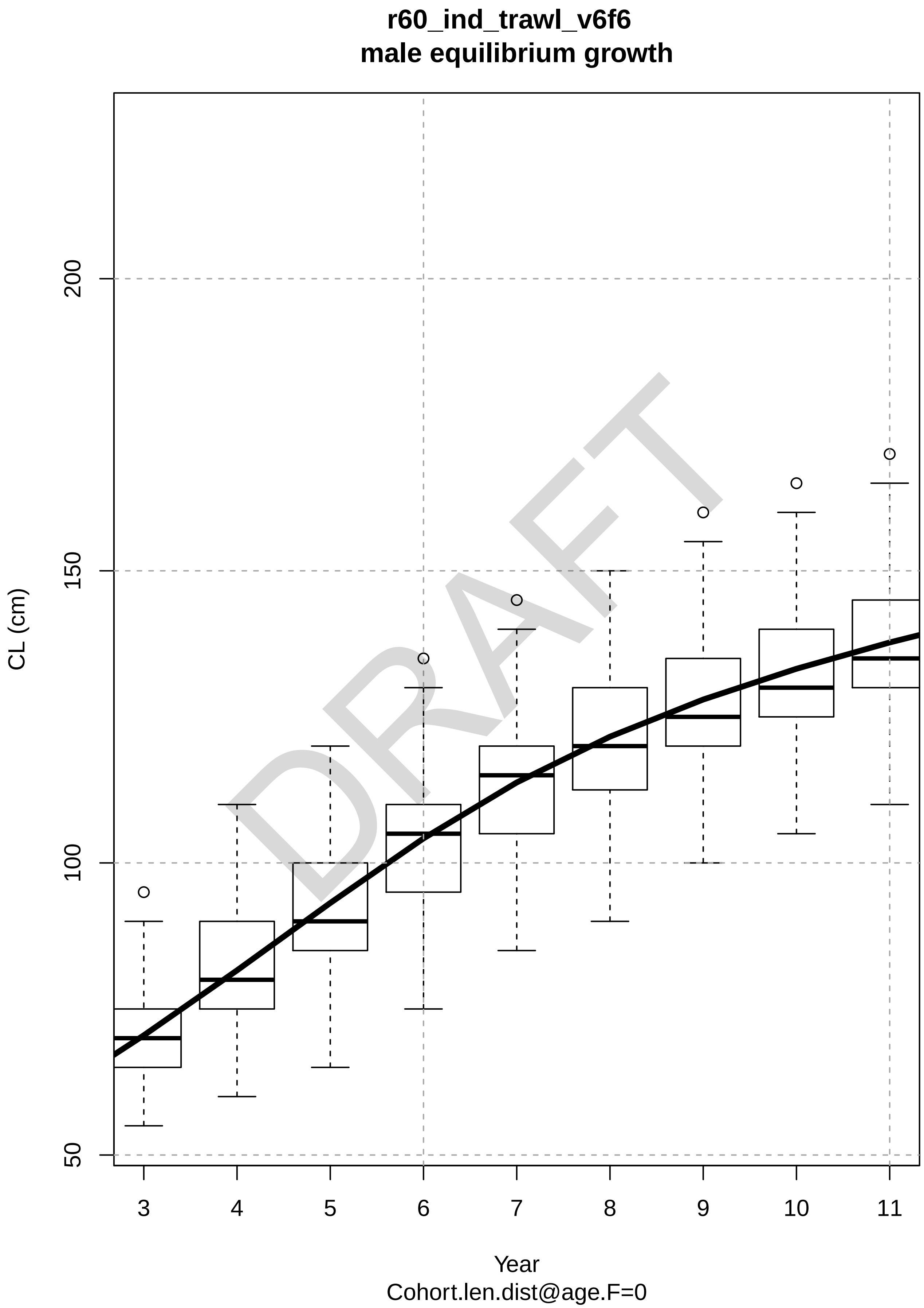
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male equilibrium growth
CL (cm)
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3
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Year
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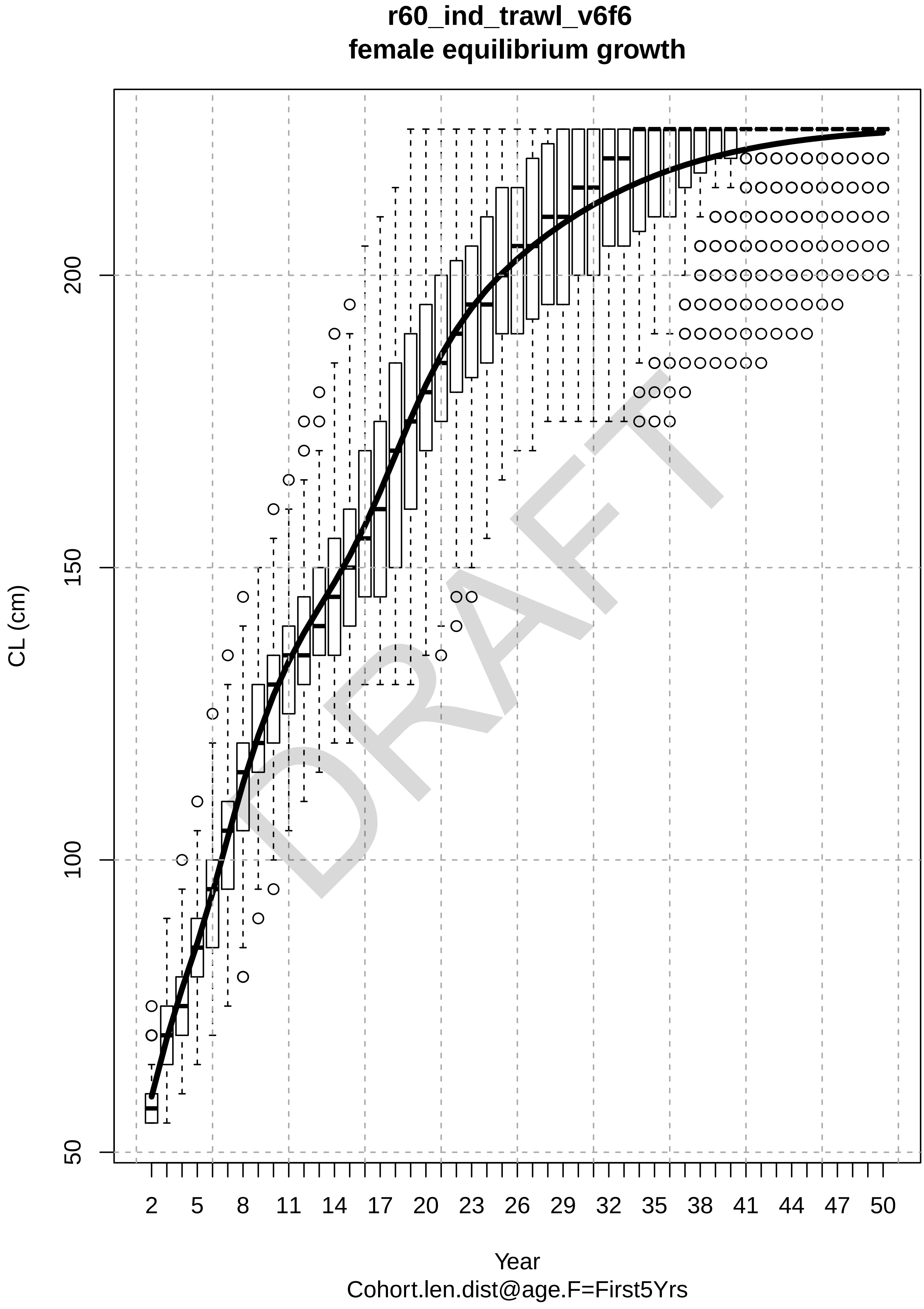

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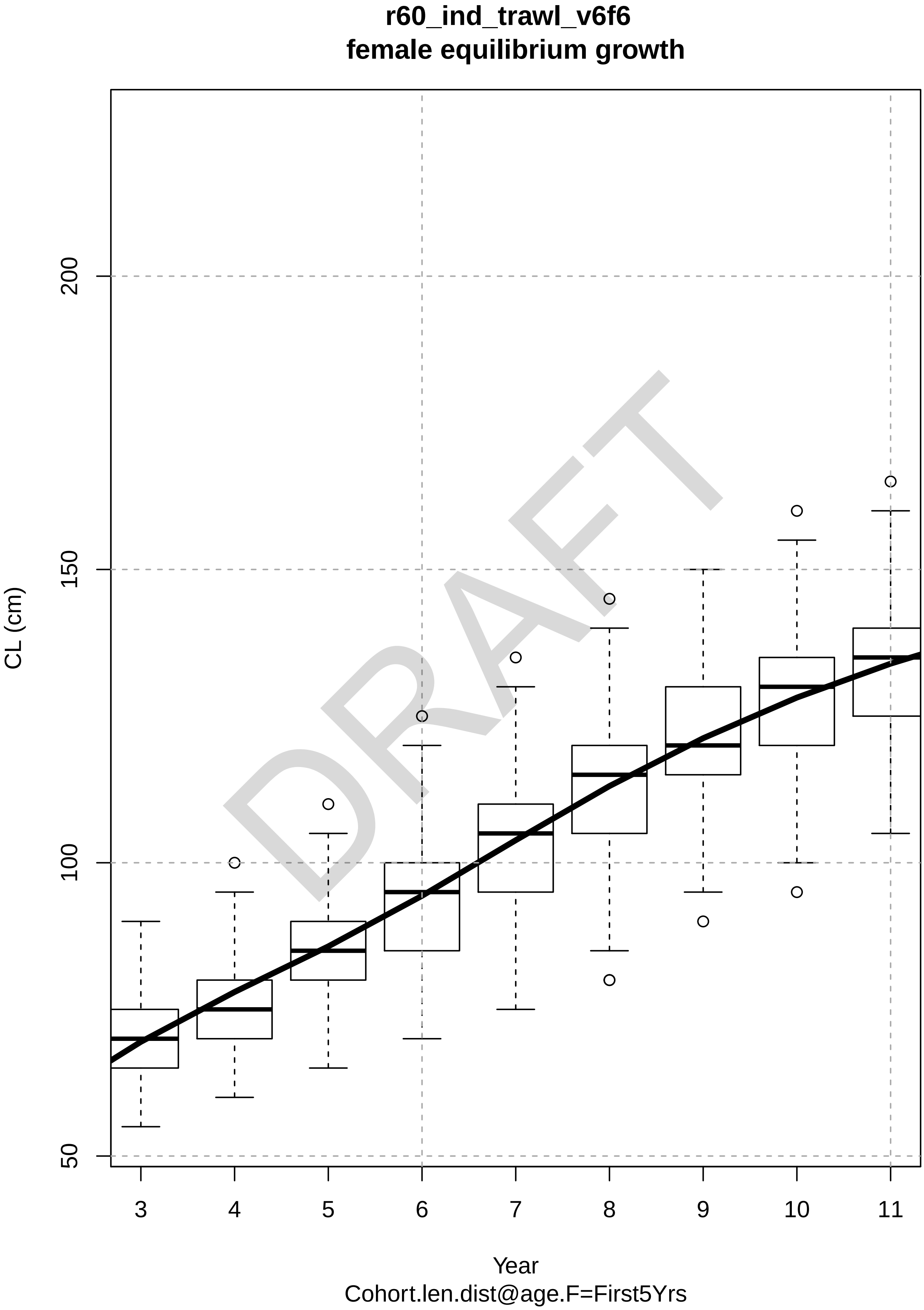
r60_ind_trawl_v6f6
female equilibrium growth
CL (cm)
50
100
150
200
3
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5
6
7
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9
10
11
Year
Cohort.len.dist@age.F=First5Yrs

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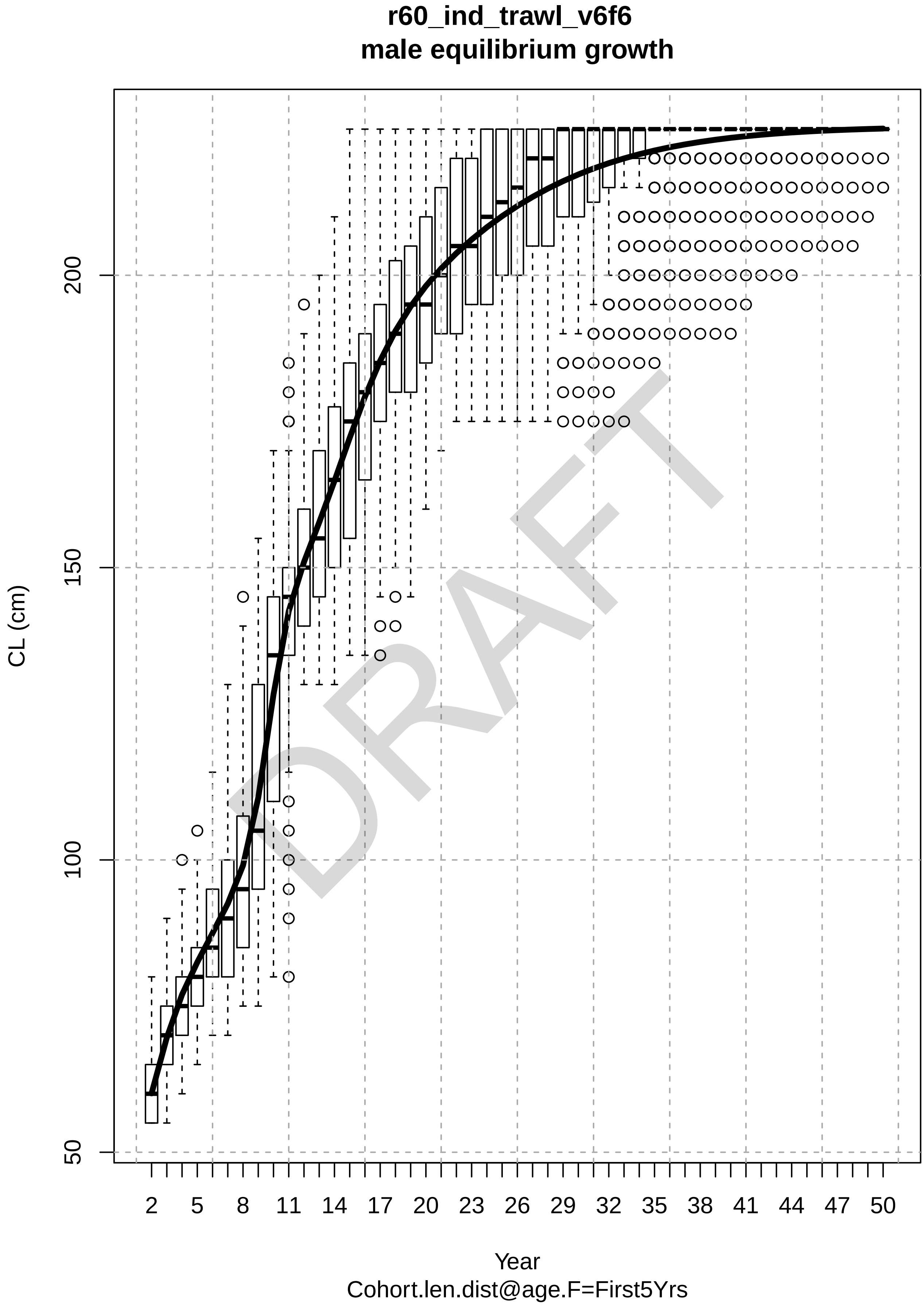

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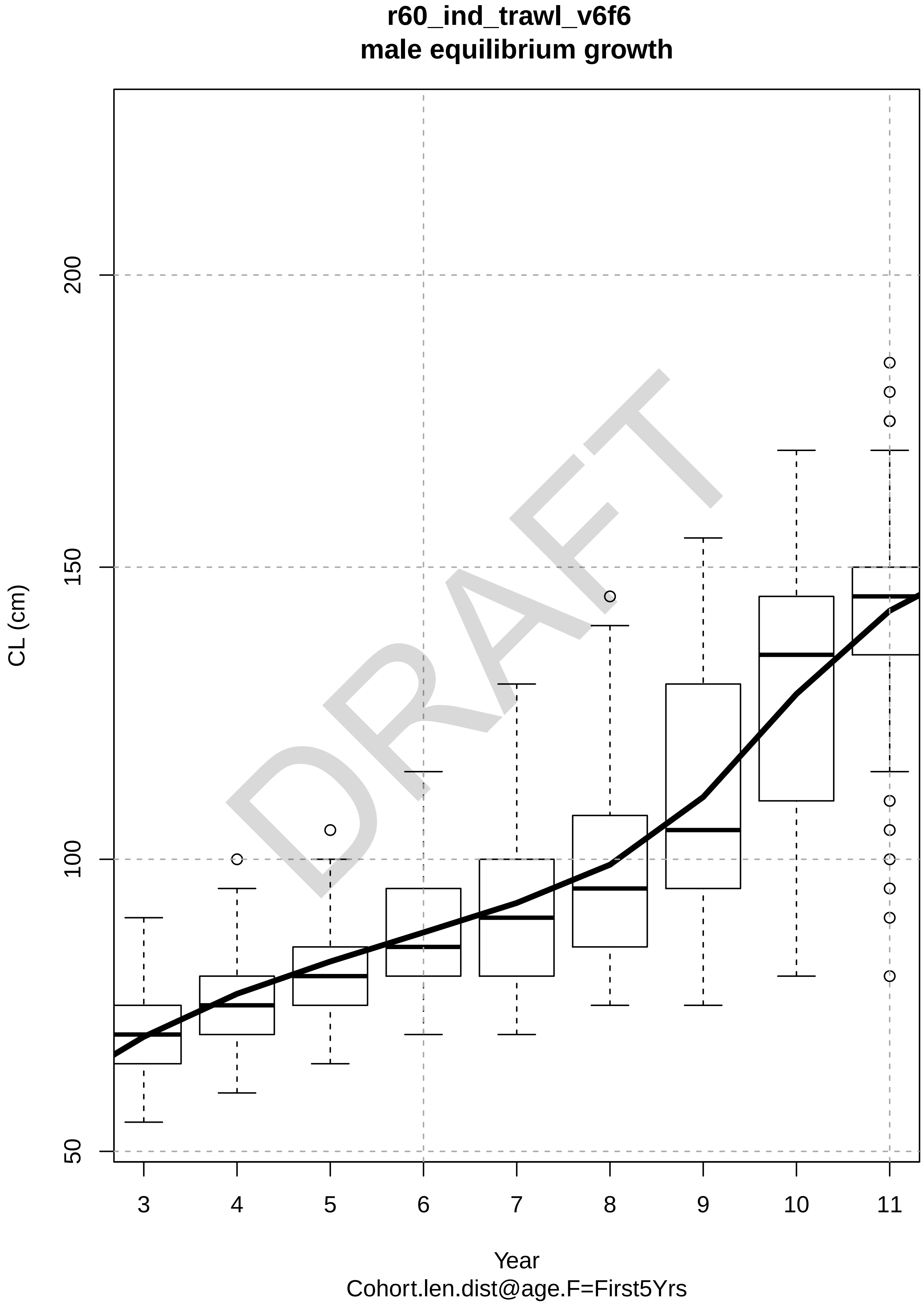
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male equilibrium growth
CL (cm)
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150
200
3
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9
10
11
Year
Cohort.len.dist@age.F=First5Yrs

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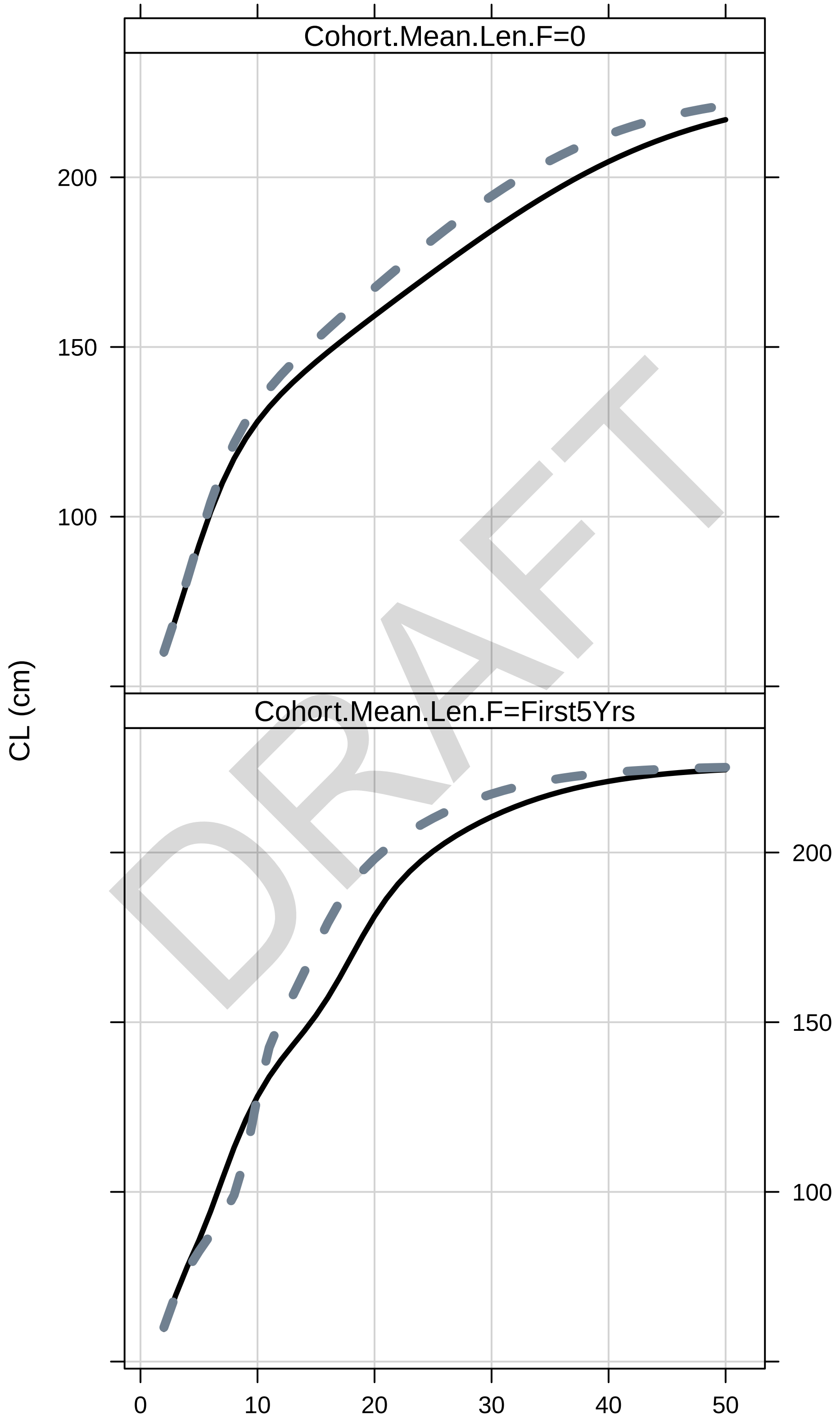
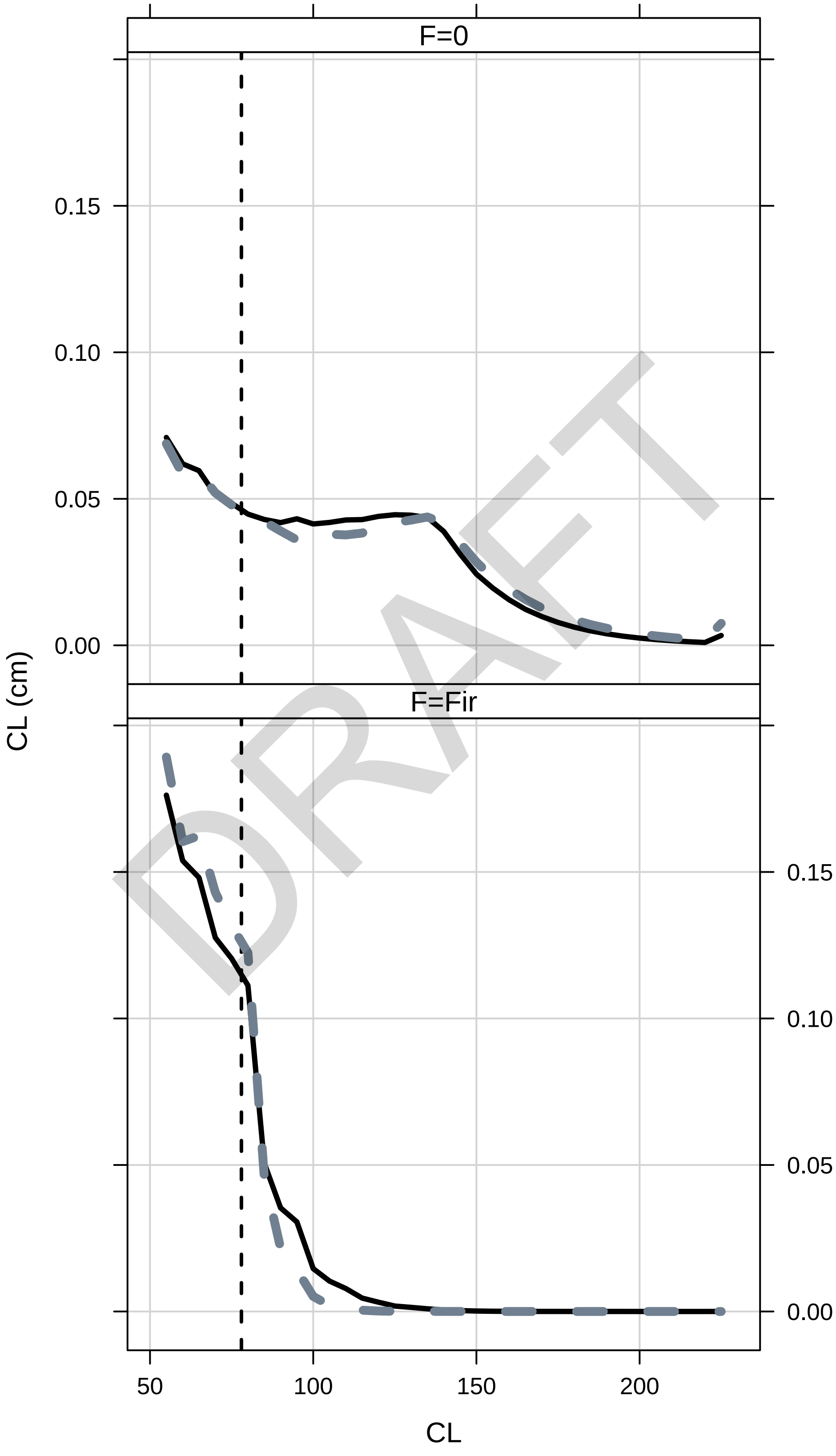
r60_ind_trawl_v6f6
mean size at cohort age



Females black / Males grey

r60_ind_trawl_v6f6
equilbrium size composition (beginning of winter)



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Females black / Males grey − vertical line at 78 mm CL

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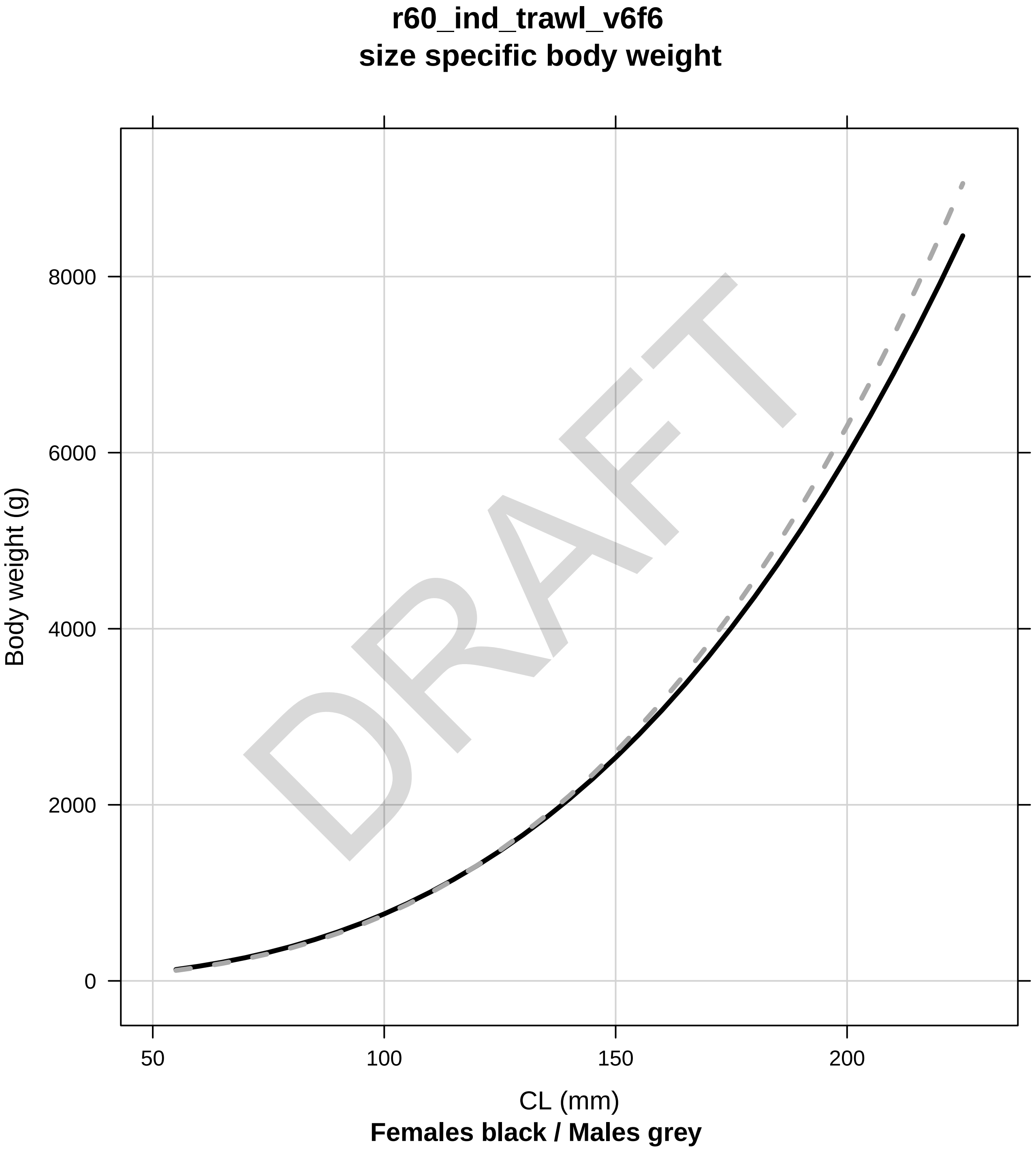

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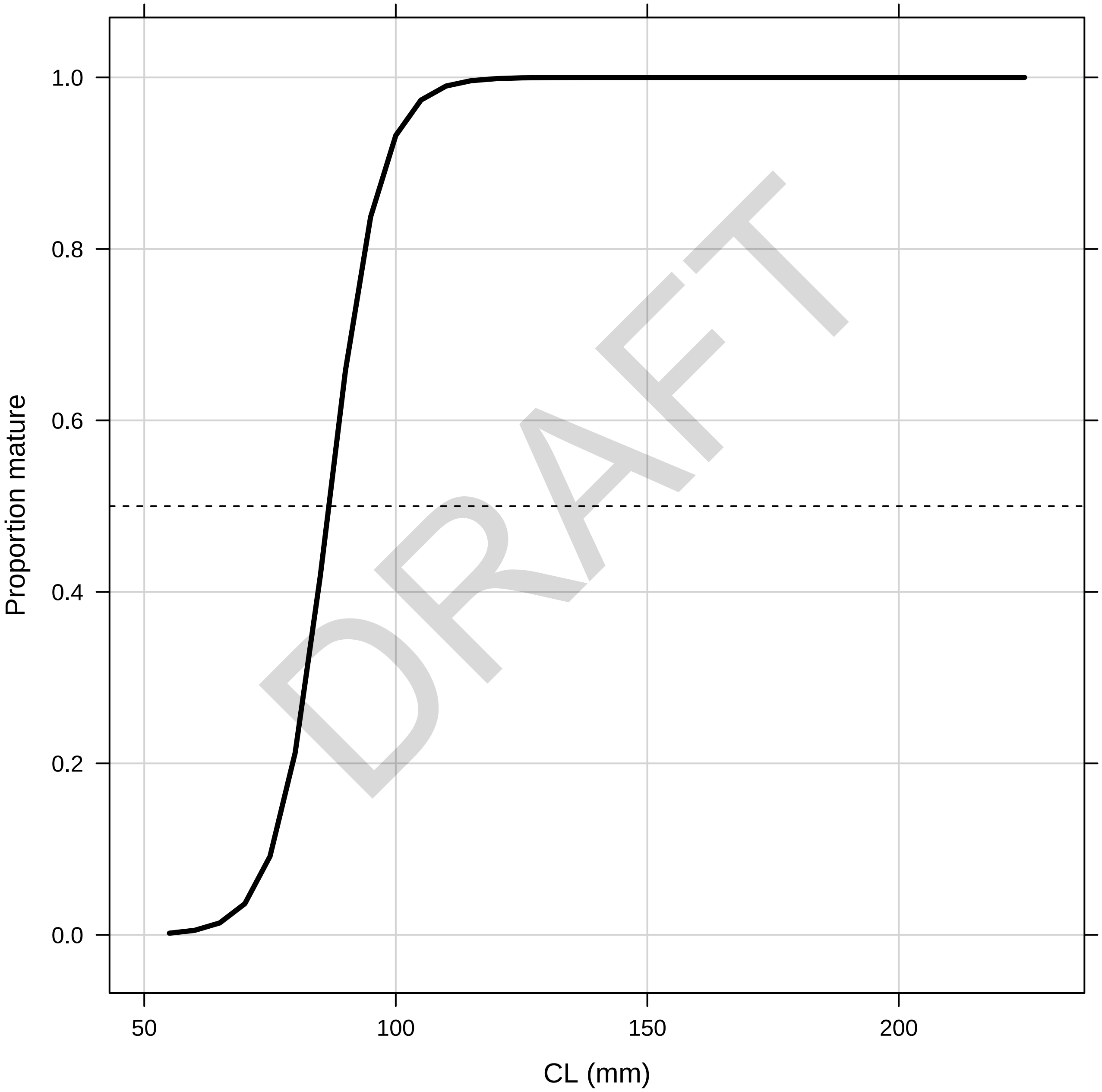
r60_ind_trawl_v6f6
size specific female maturity



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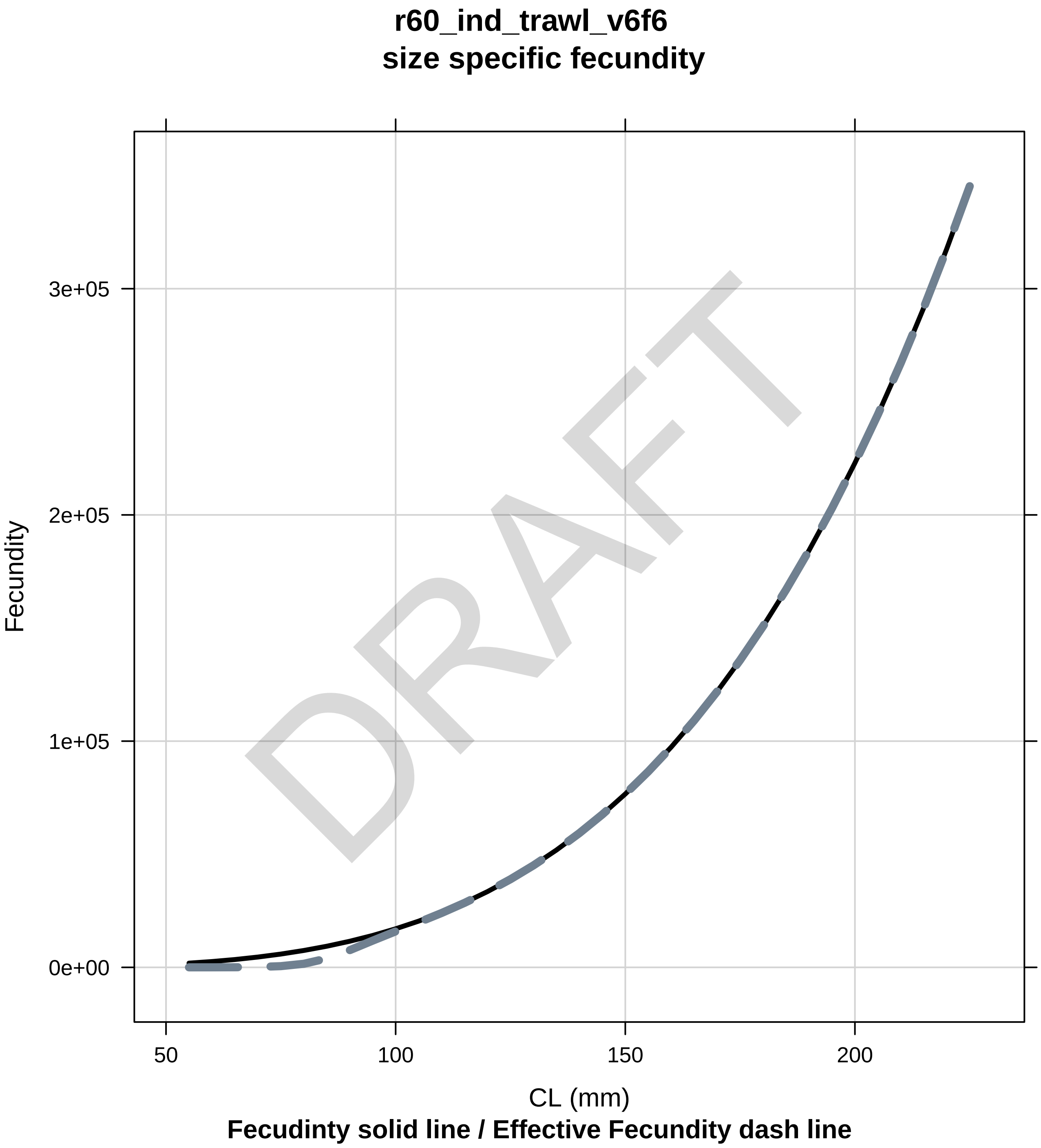
r60_ind_trawl_v6f6
size specific fecundity
Fecundity
3e+05
2e+05
1e+05
0e+00
50
100
150
200
CL (mm)
Fecudinty solid line / Effective Fecundity dash line

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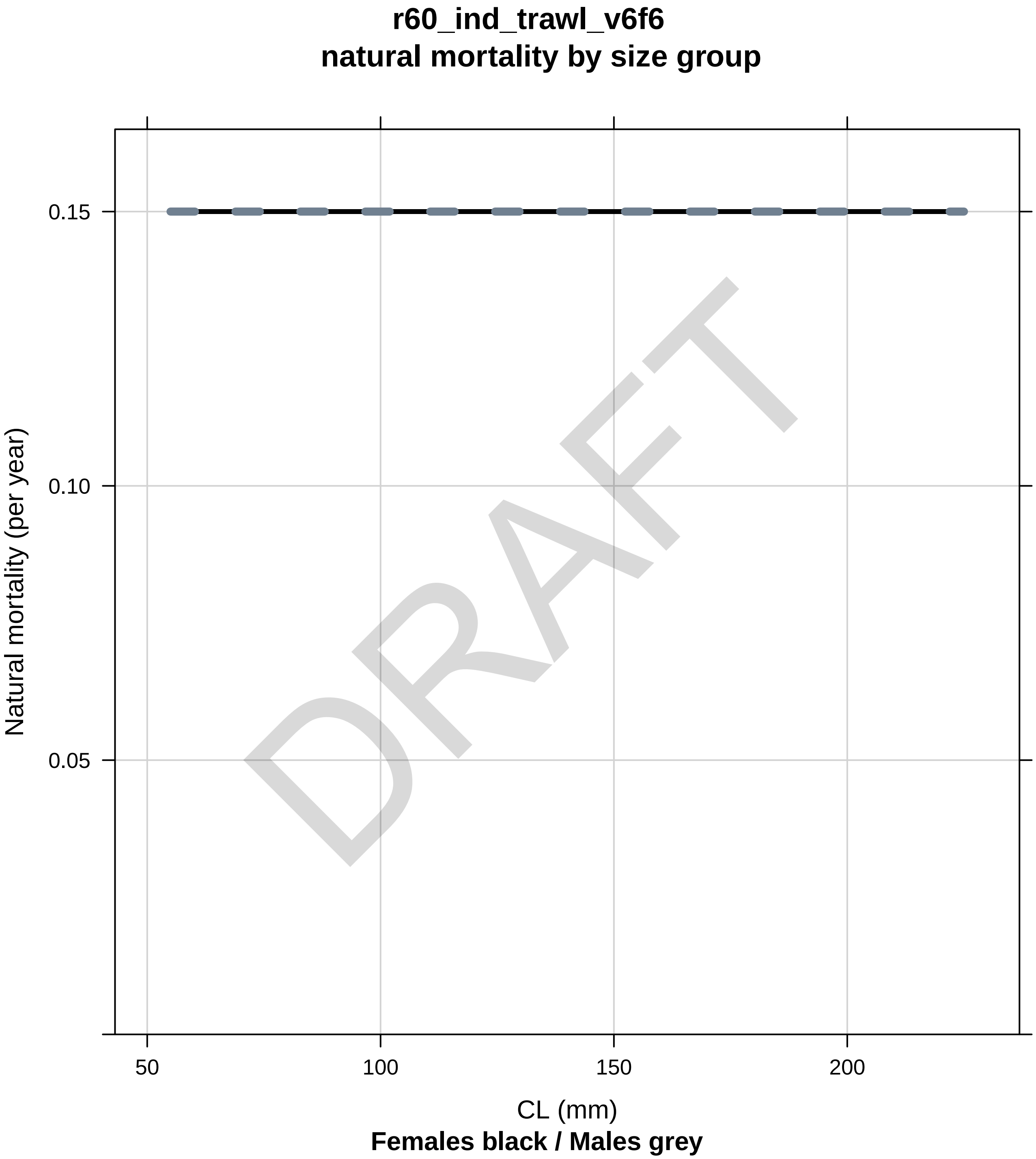
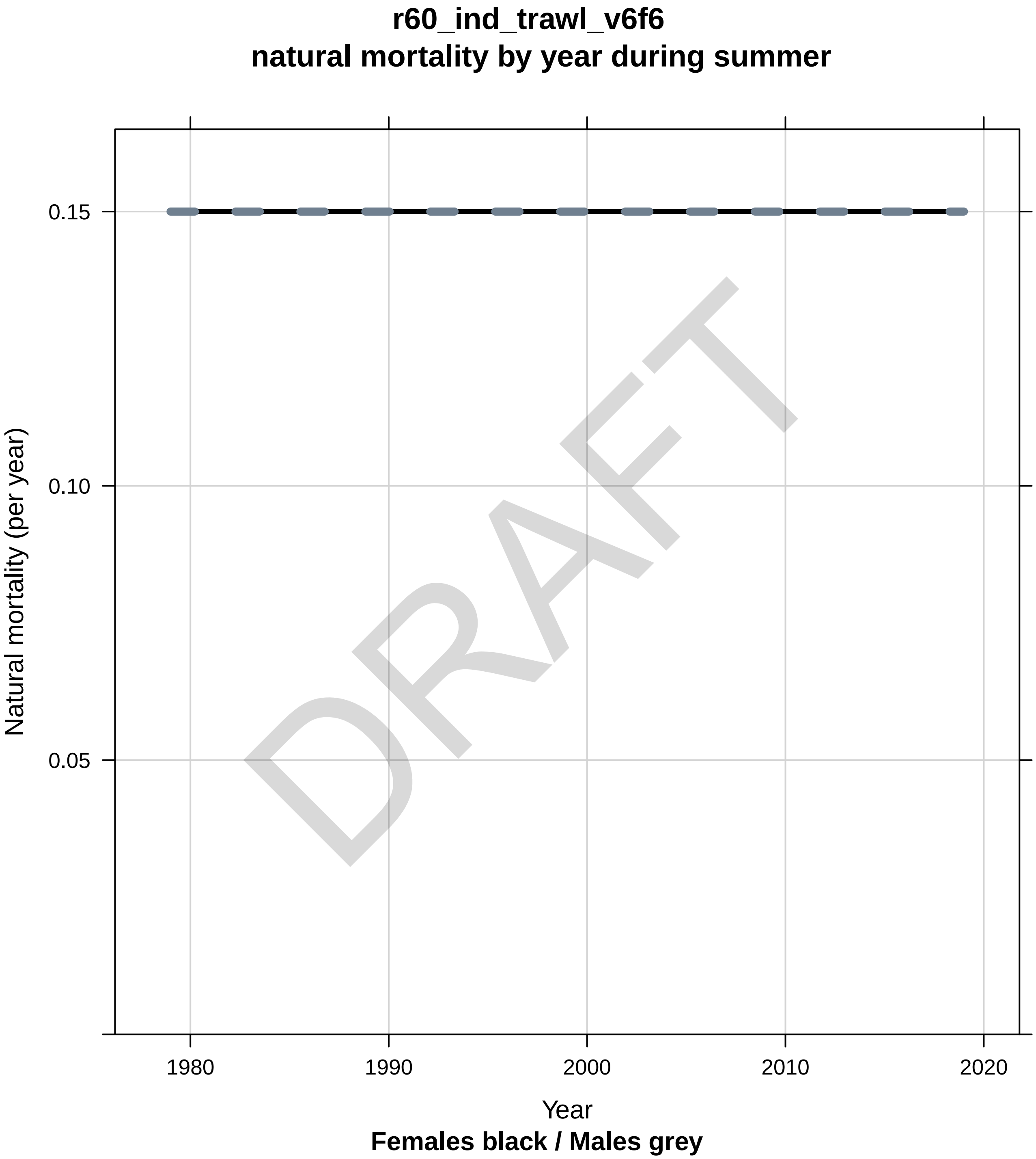
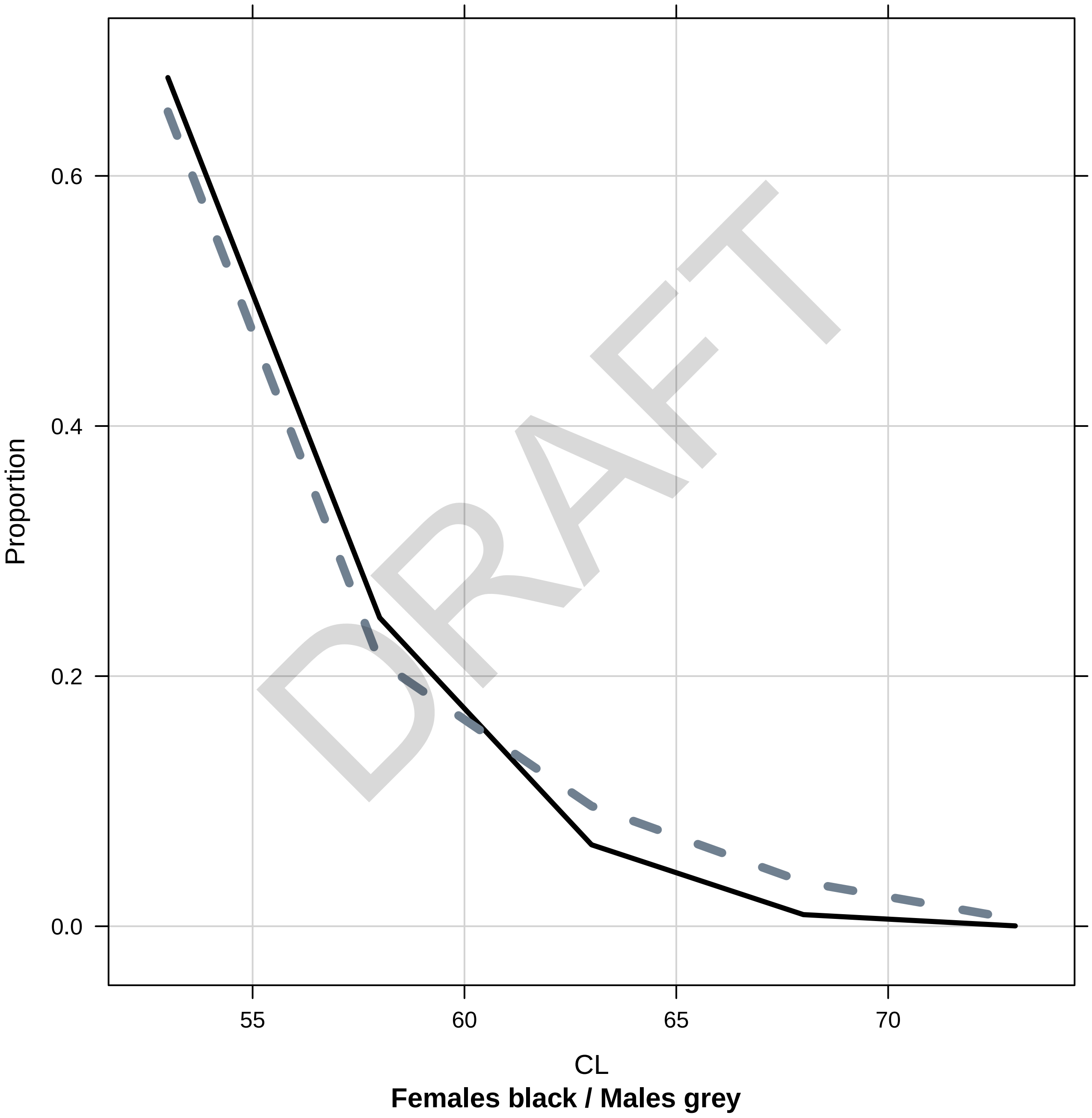

r60_ind_trawl_v6f6
natural mortality by size group
Natural mortality (per year)
0.15
0.10
0.05
50
100
150
200
CL (mm)
Females black / Males grey

DRAFT


r60_ind_trawl_v6f6
natural mortality by year during summer
Natural mortality (per year)
0.15
0.10
0.05
1980
1990
2000
2010
2020
Year
Females black / Males grey

DRAFT

r60_ind_trawl_v6f6
recruit size composition



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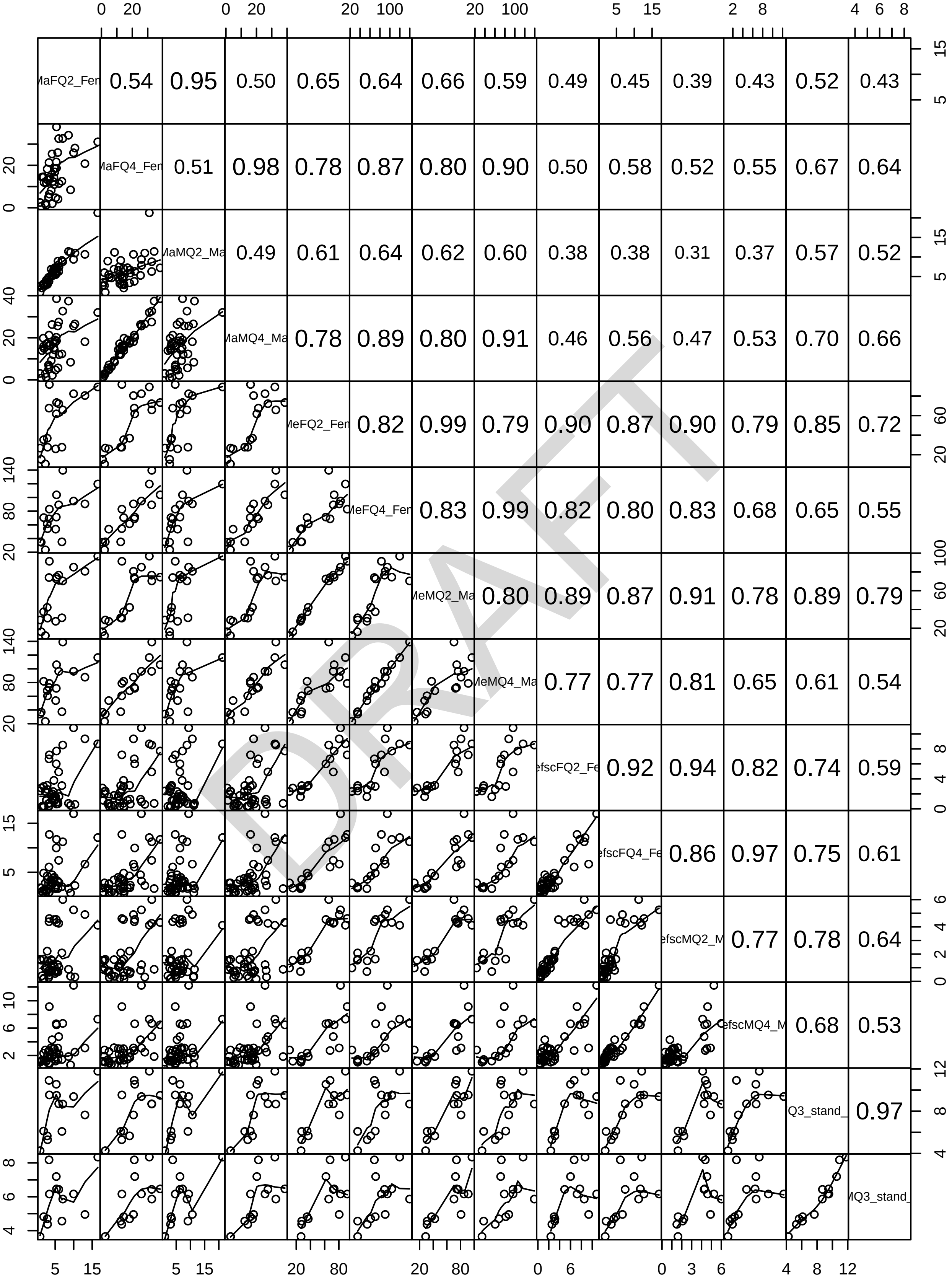
r60_ind_trawl_v6f6
Pairwise scatterplots for survey trend data



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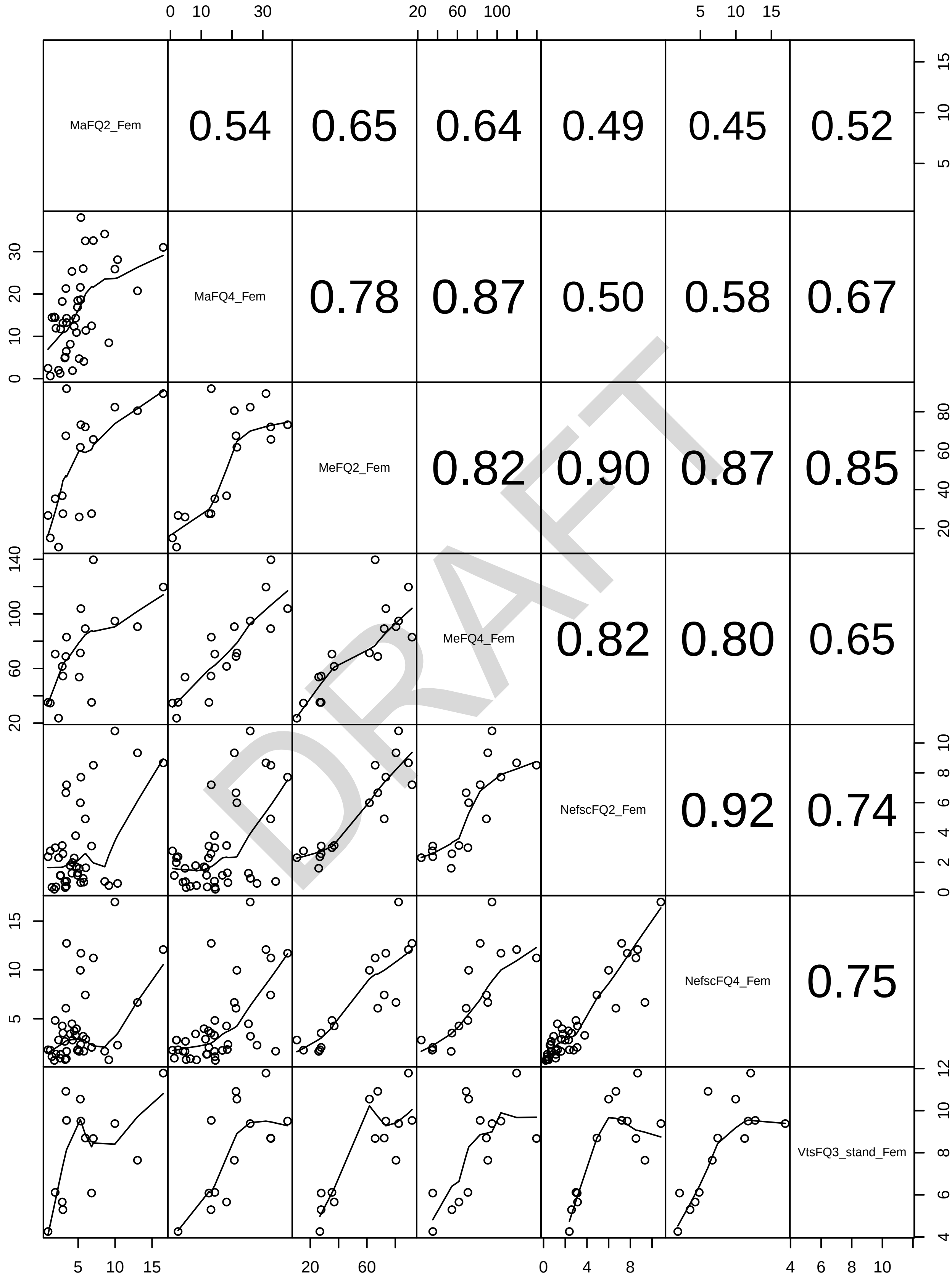
r60_ind_trawl_v6f6
Pairwise scatterplots for survey trend data (Female)



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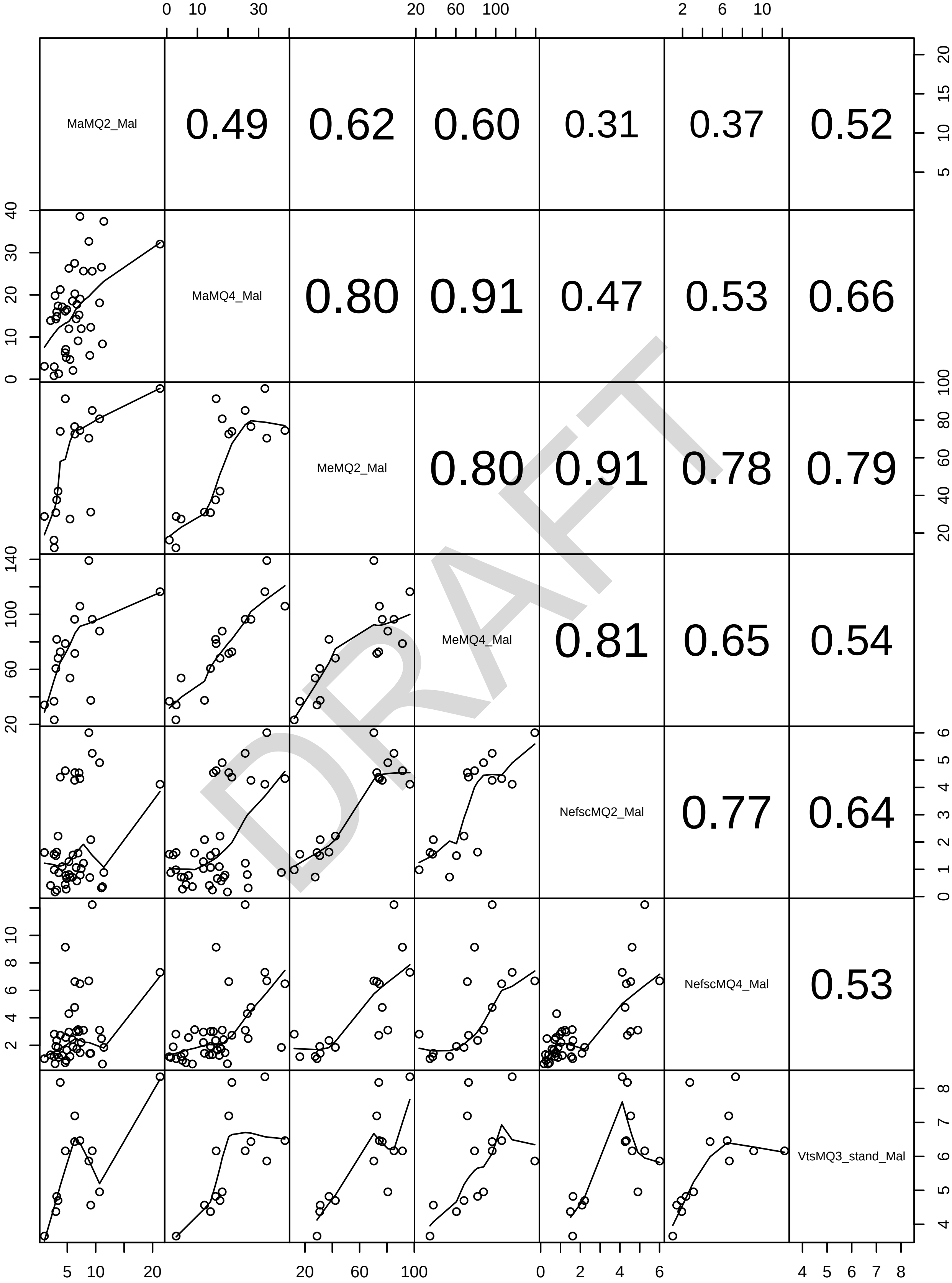
r60_ind_trawl_v6f6
Pairwise scatterplots for survey trend data (Male)



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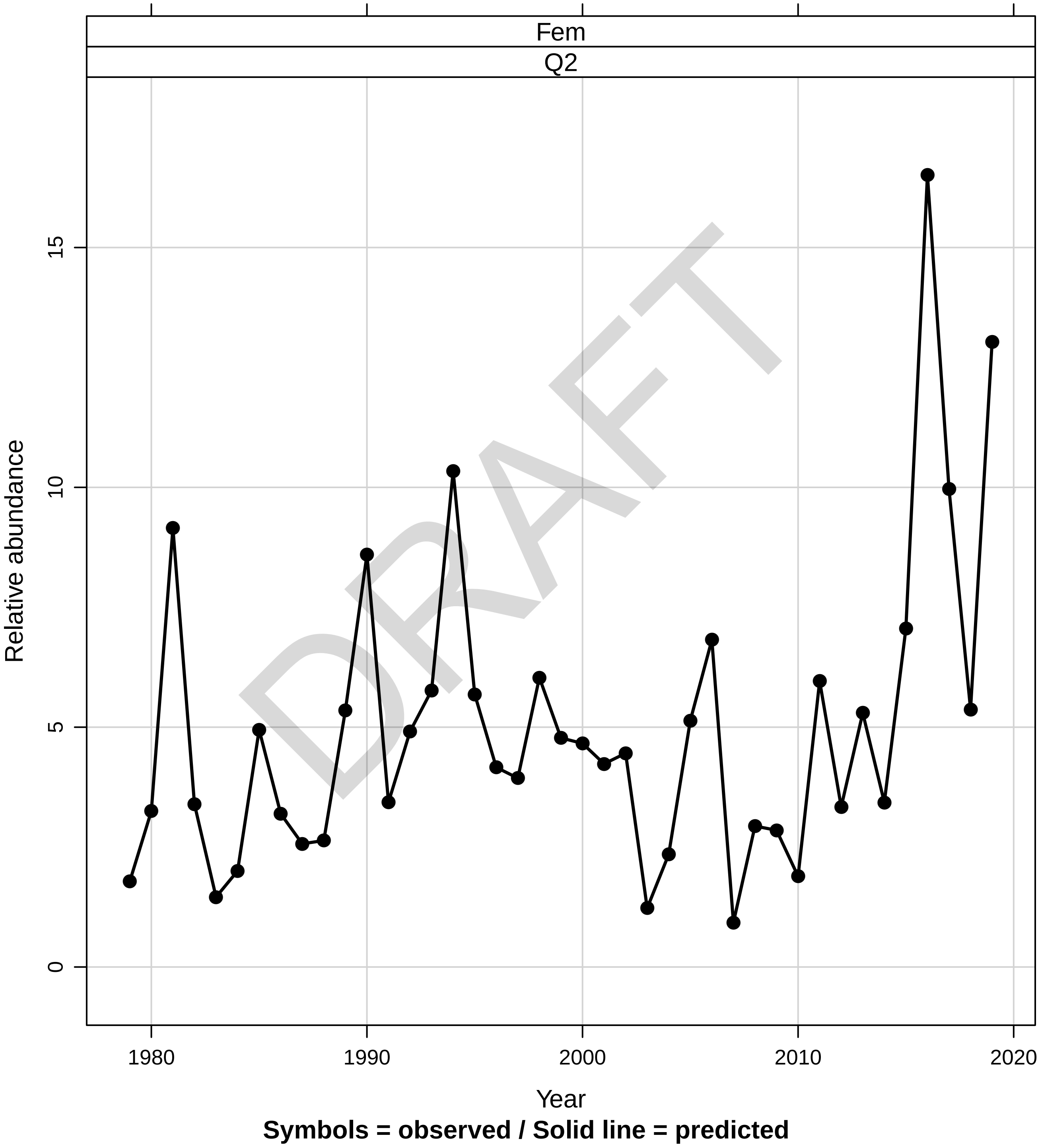
r60_ind_trawl_v6f6
MaFQ2 Survey trend data



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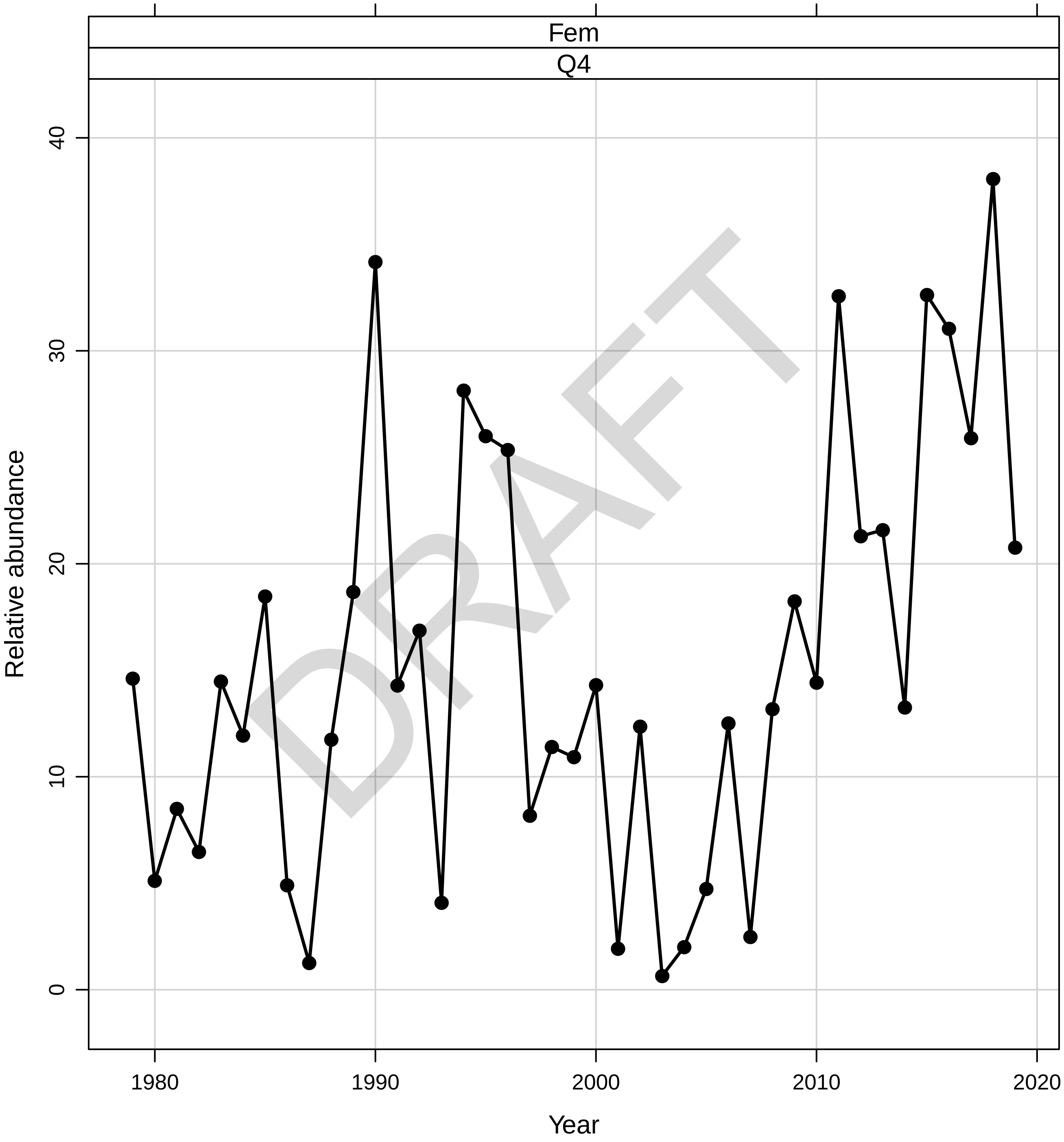
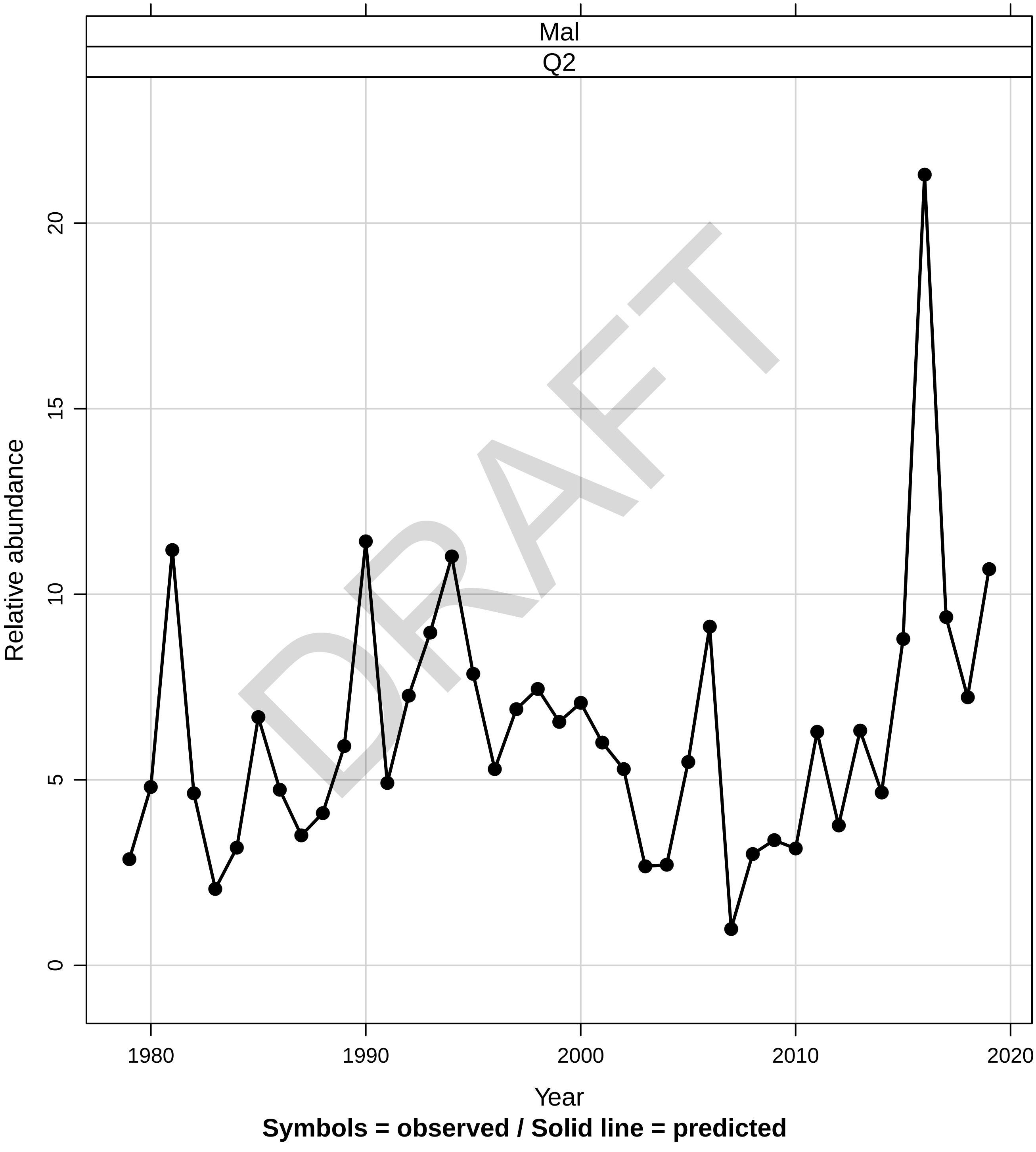
r60_ind_trawl_v6f6
MaFQ4 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

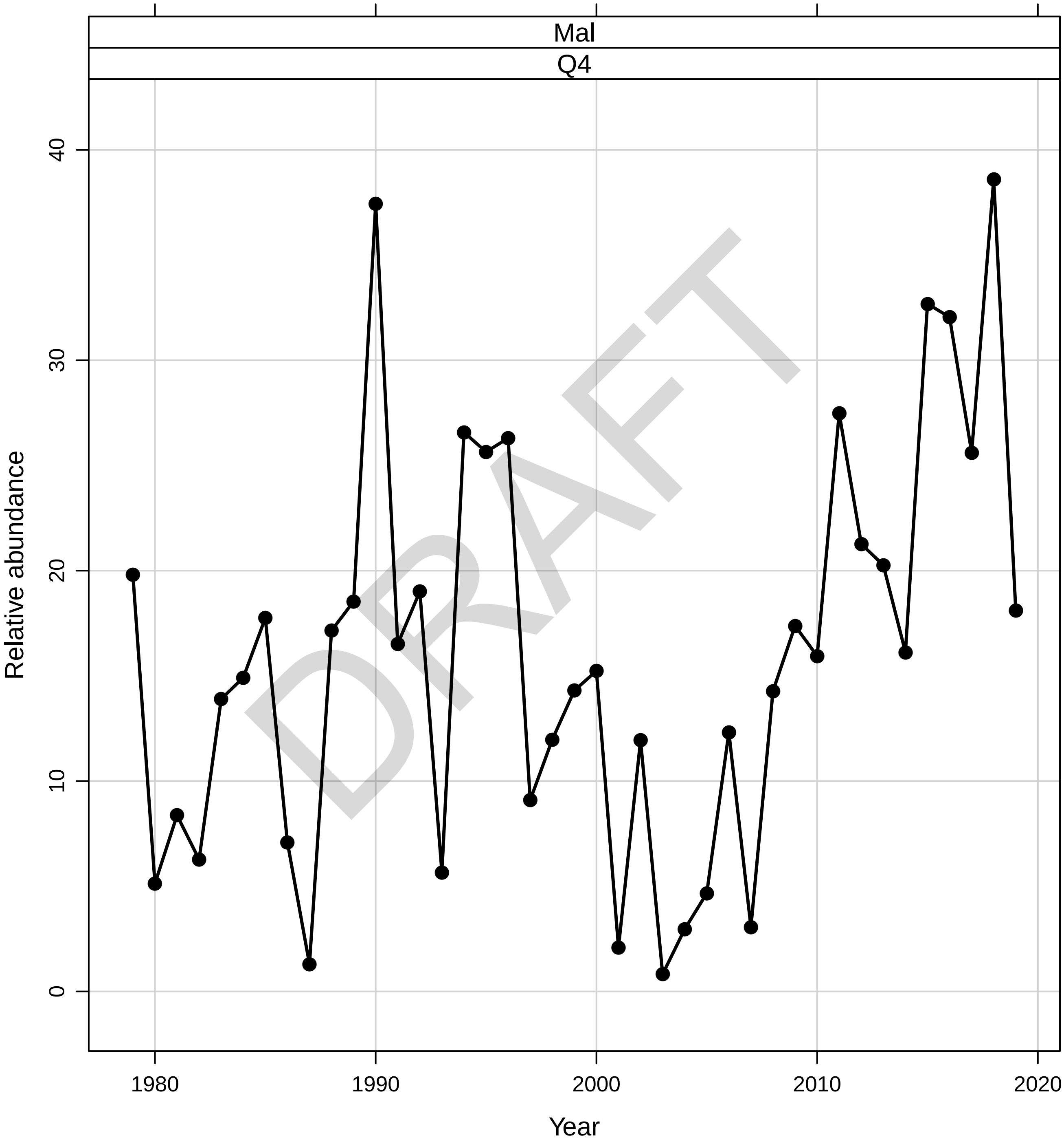
r60_ind_trawl_v6f6
MaMQ2 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

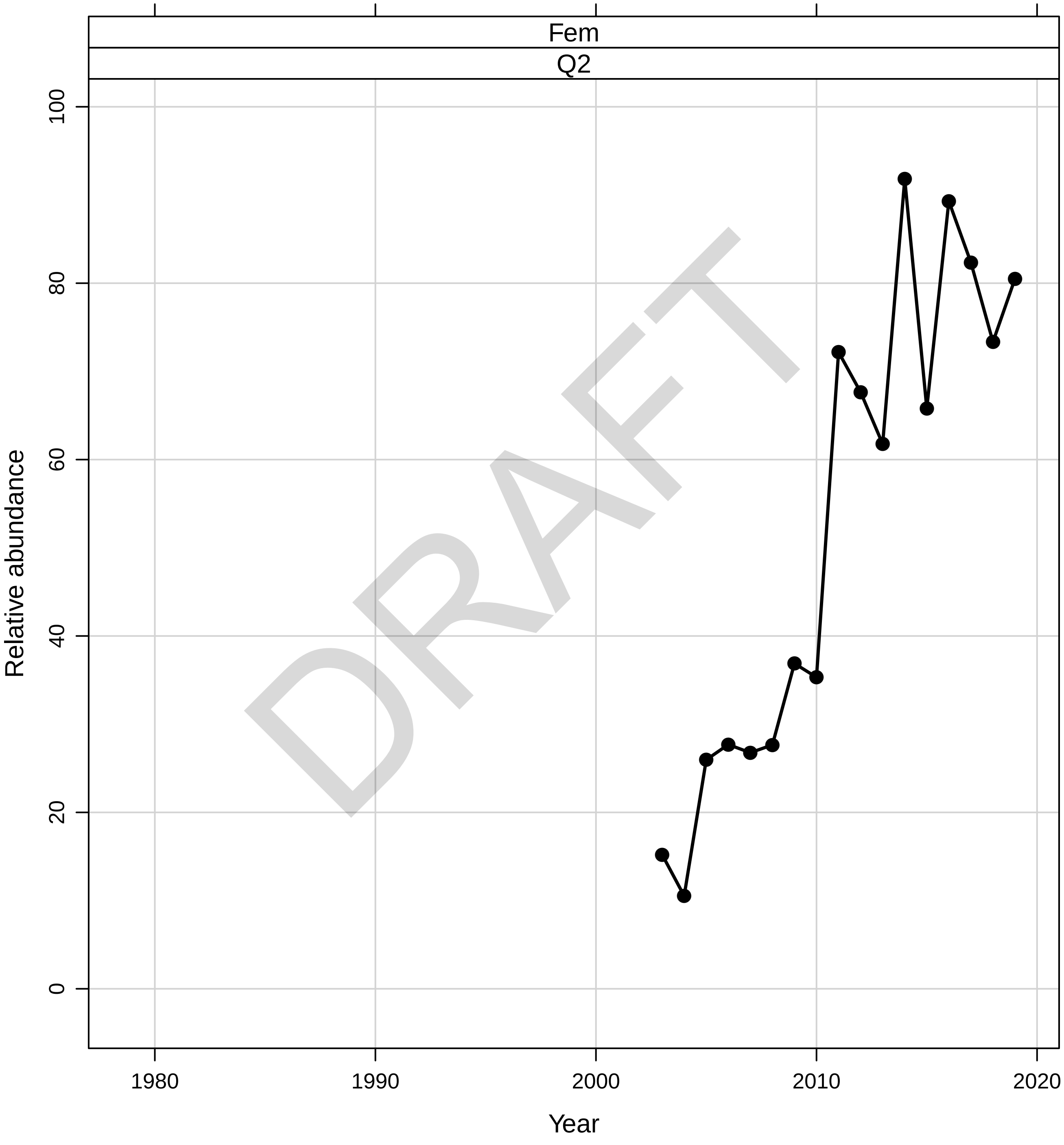
r60_ind_trawl_v6f6
MaMQ4 Survey trend data



Symbols = observed / Solid line = predicted

DRAFT

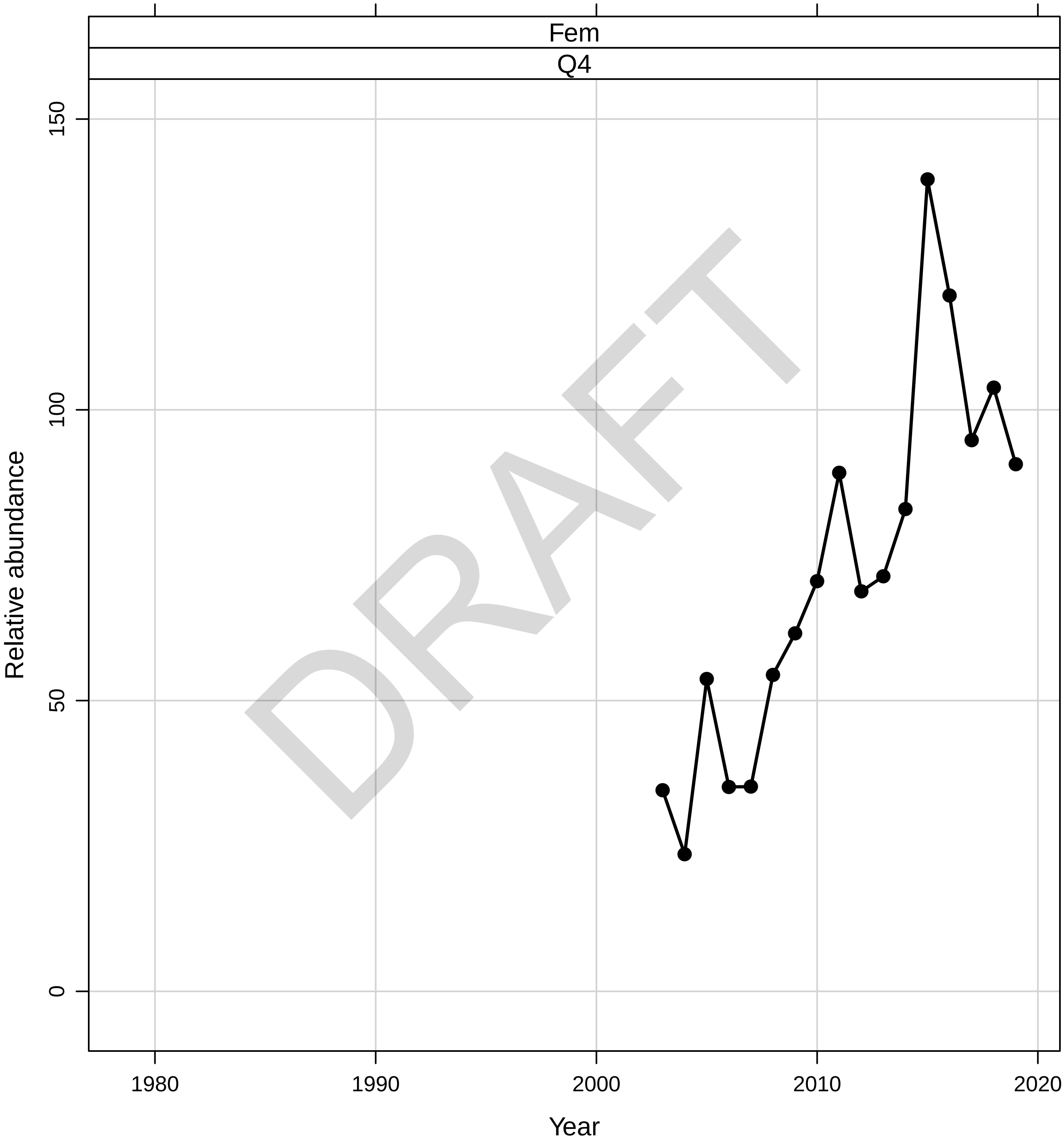
r60_ind_trawl_v6f6
MeFQ2 Survey trend data



DRAFT

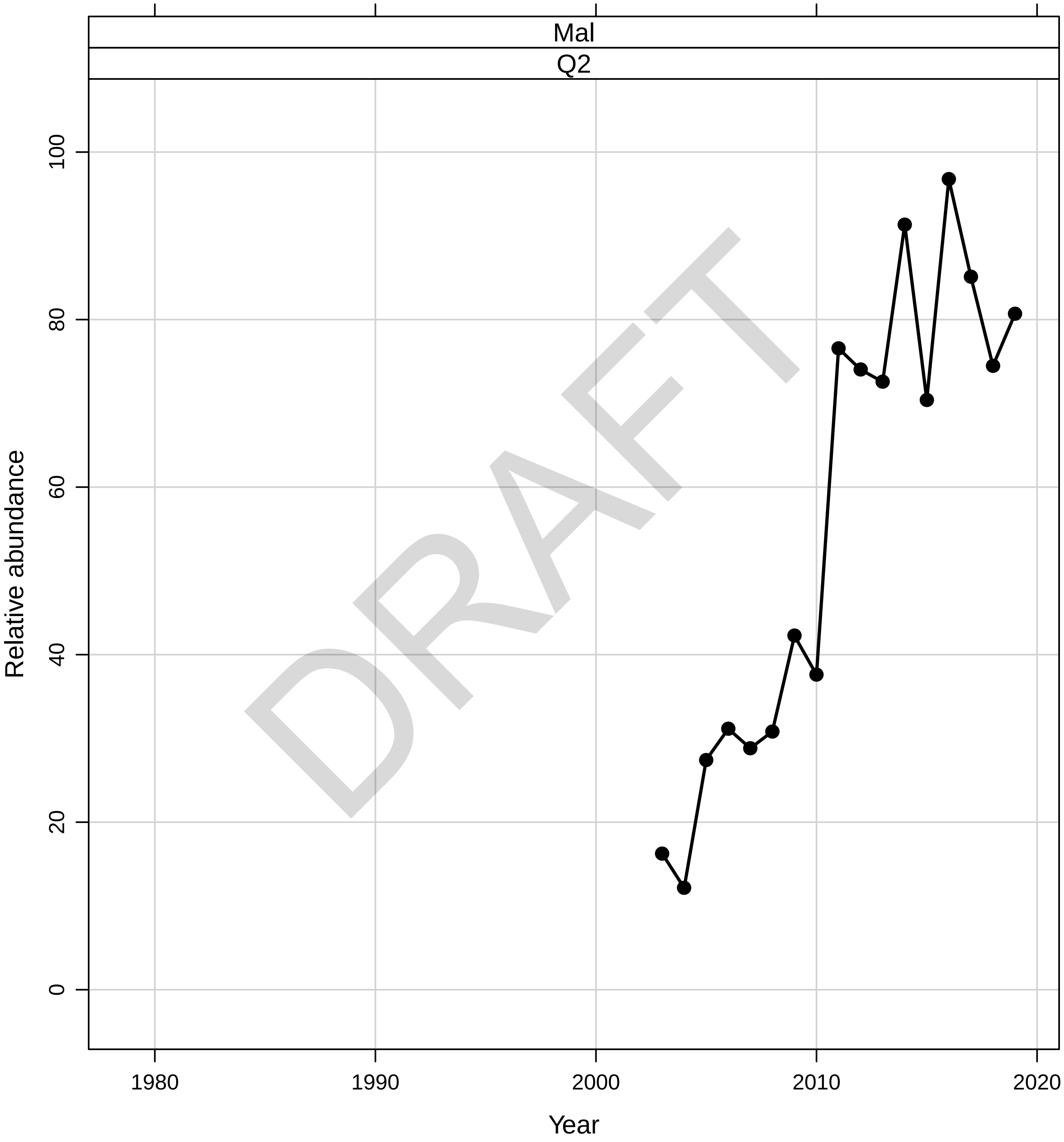
Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
MeFQ4 Survey trend data



DRAFT

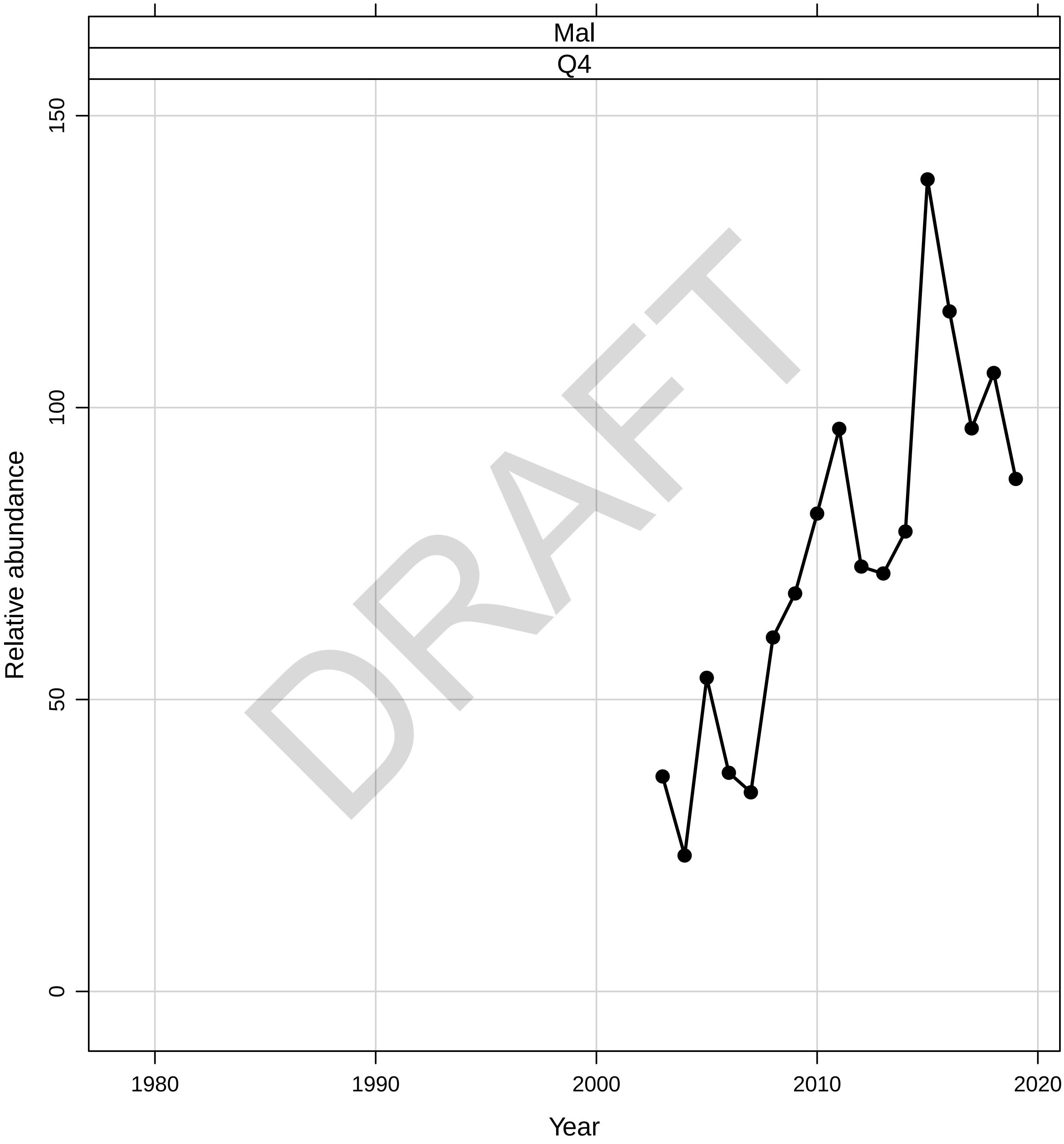
r60_ind_trawl_v6f6
MeMQ2 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

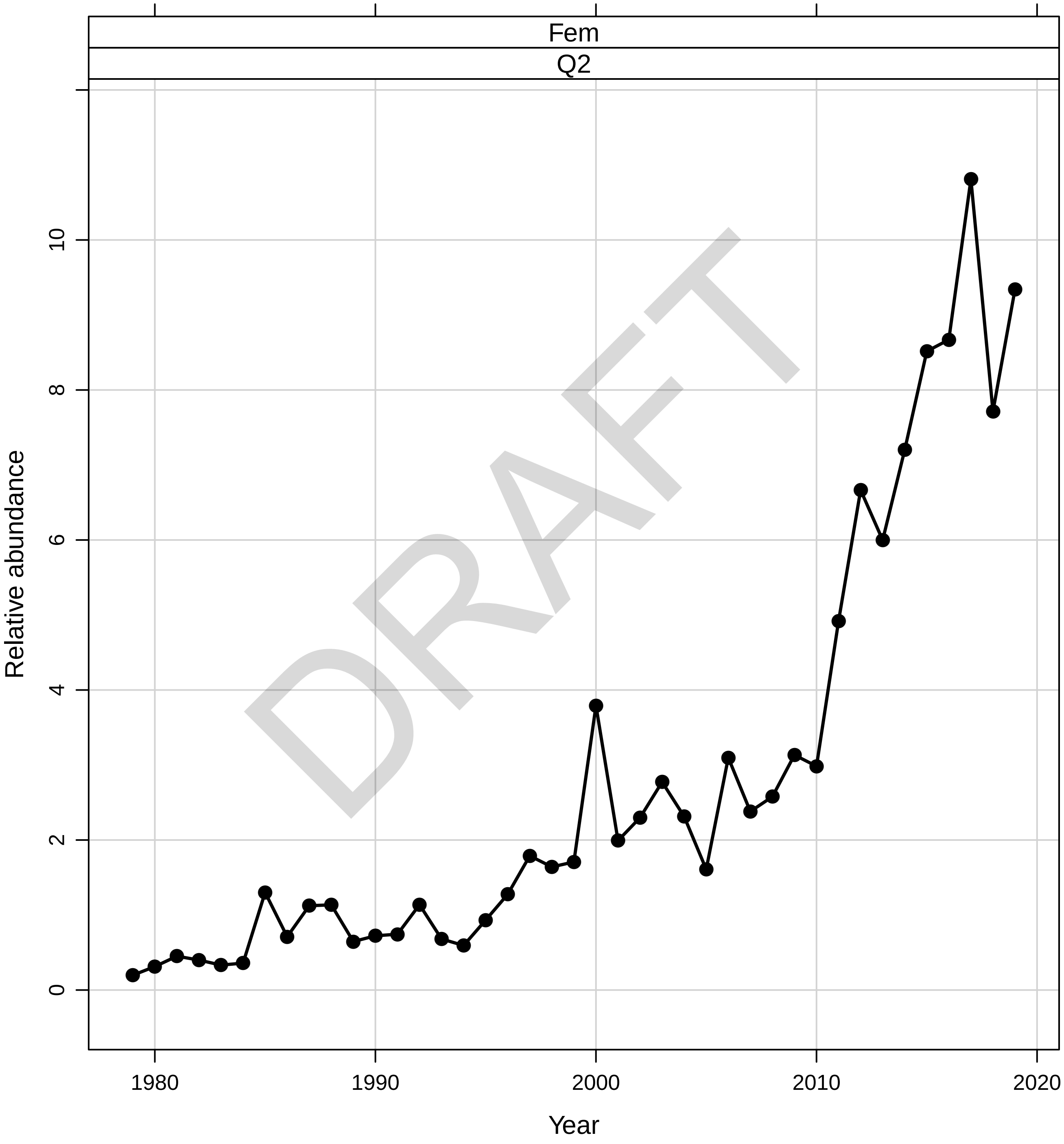
r60_ind_trawl_v6f6
MeMQ4 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
NefscFQ2 Survey trend data



Symbols = observed / Solid line = predicted

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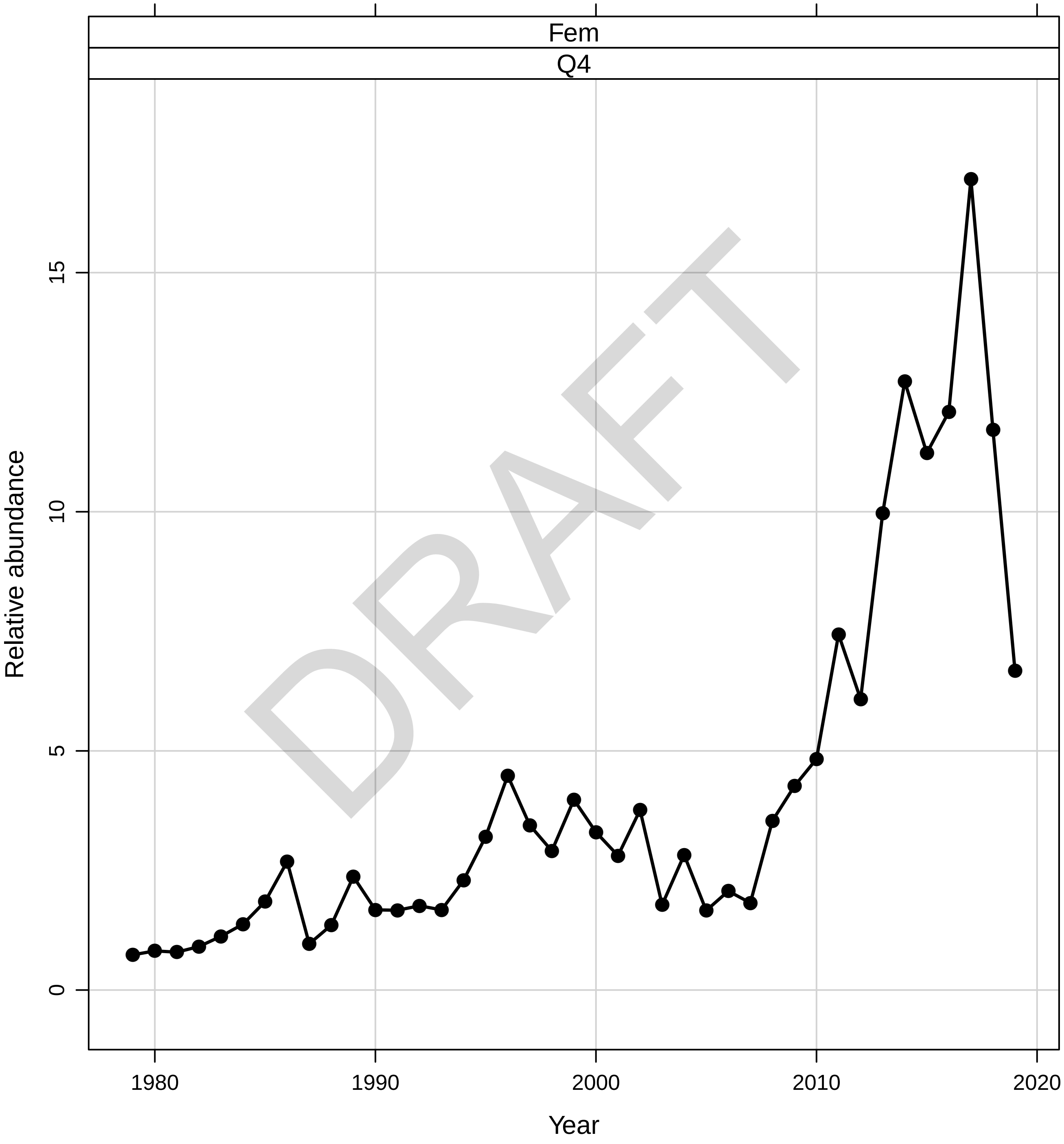
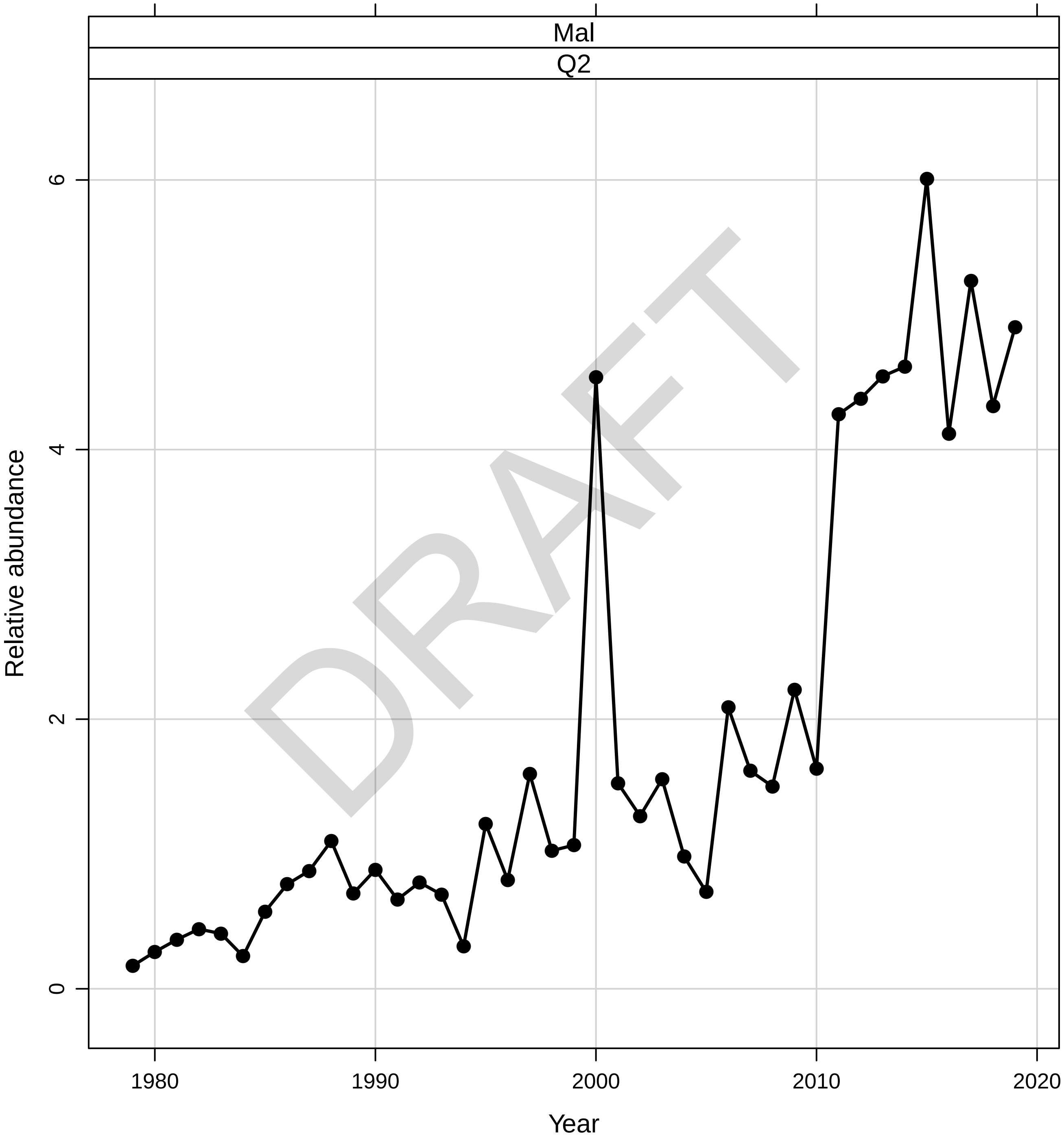
r60_ind_trawl_v6f6
NefscFQ4 Survey trend data



Symbols = observed / Solid line = predicted

DRAFT

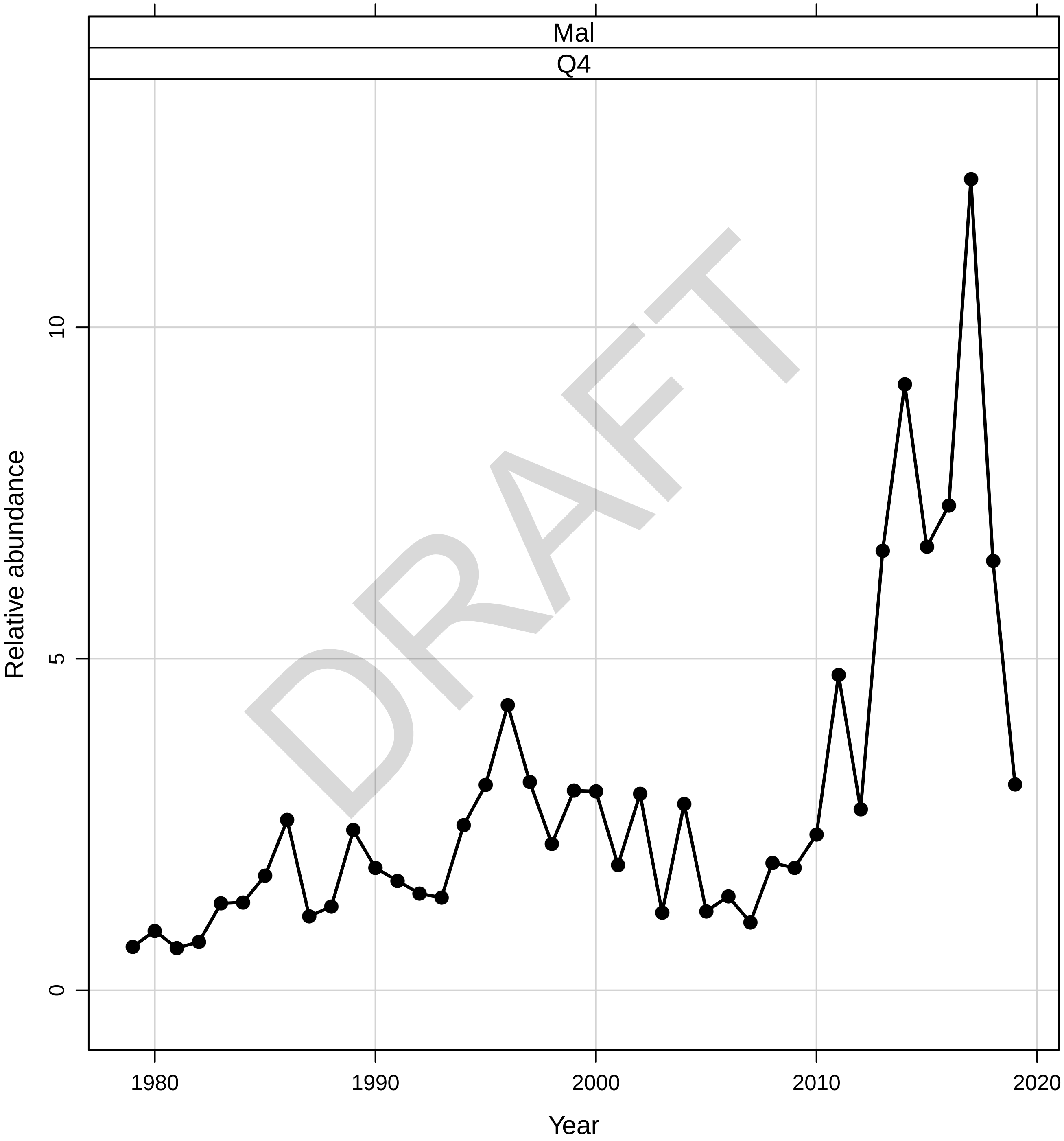
r60_ind_trawl_v6f6
NefscMQ2 Survey trend data



Symbols = observed / Solid line = predicted

DRAFT

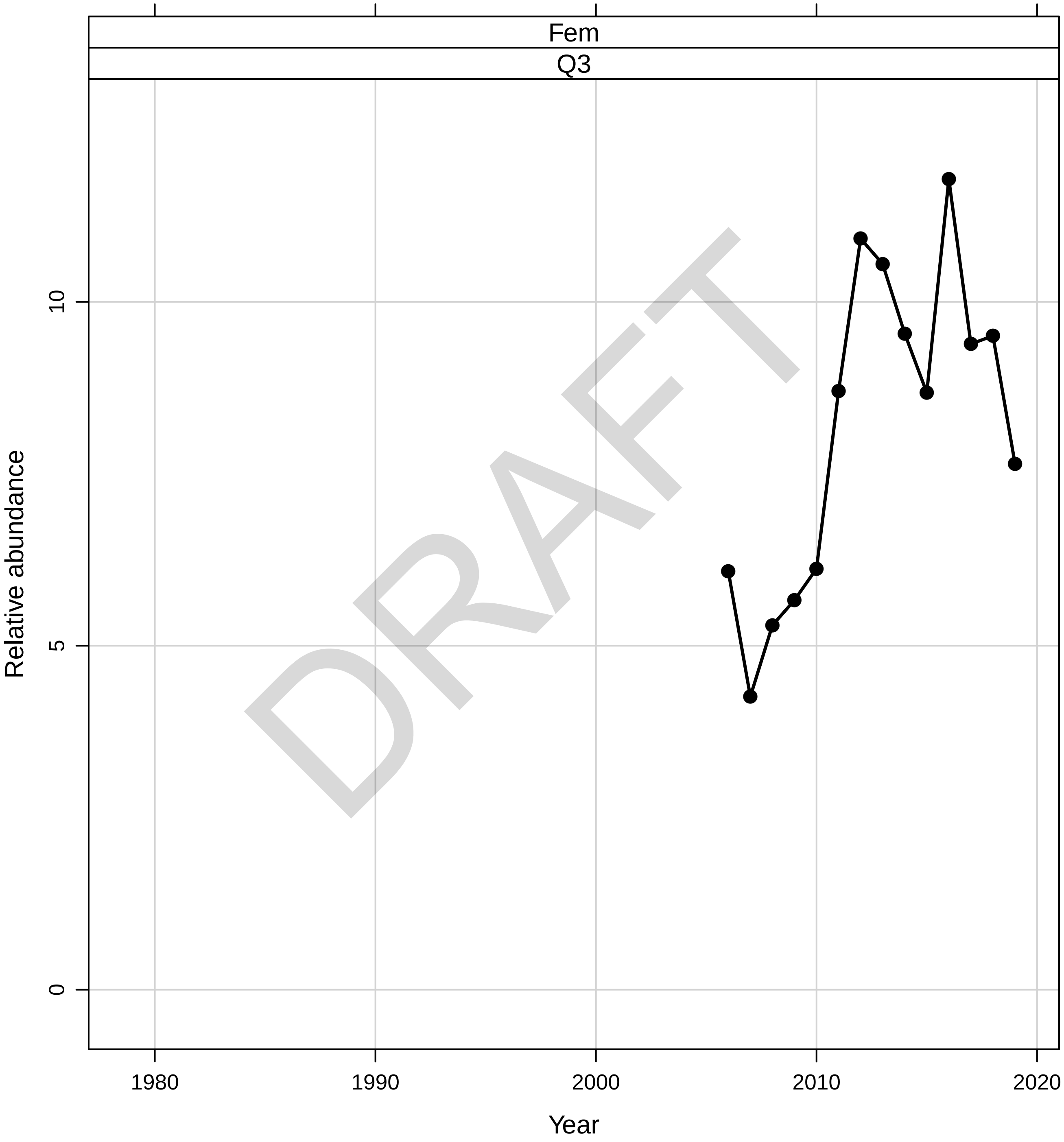
r60_ind_trawl_v6f6
NefscMQ4 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
VtsFQ3_stand Survey trend data



DRAFT

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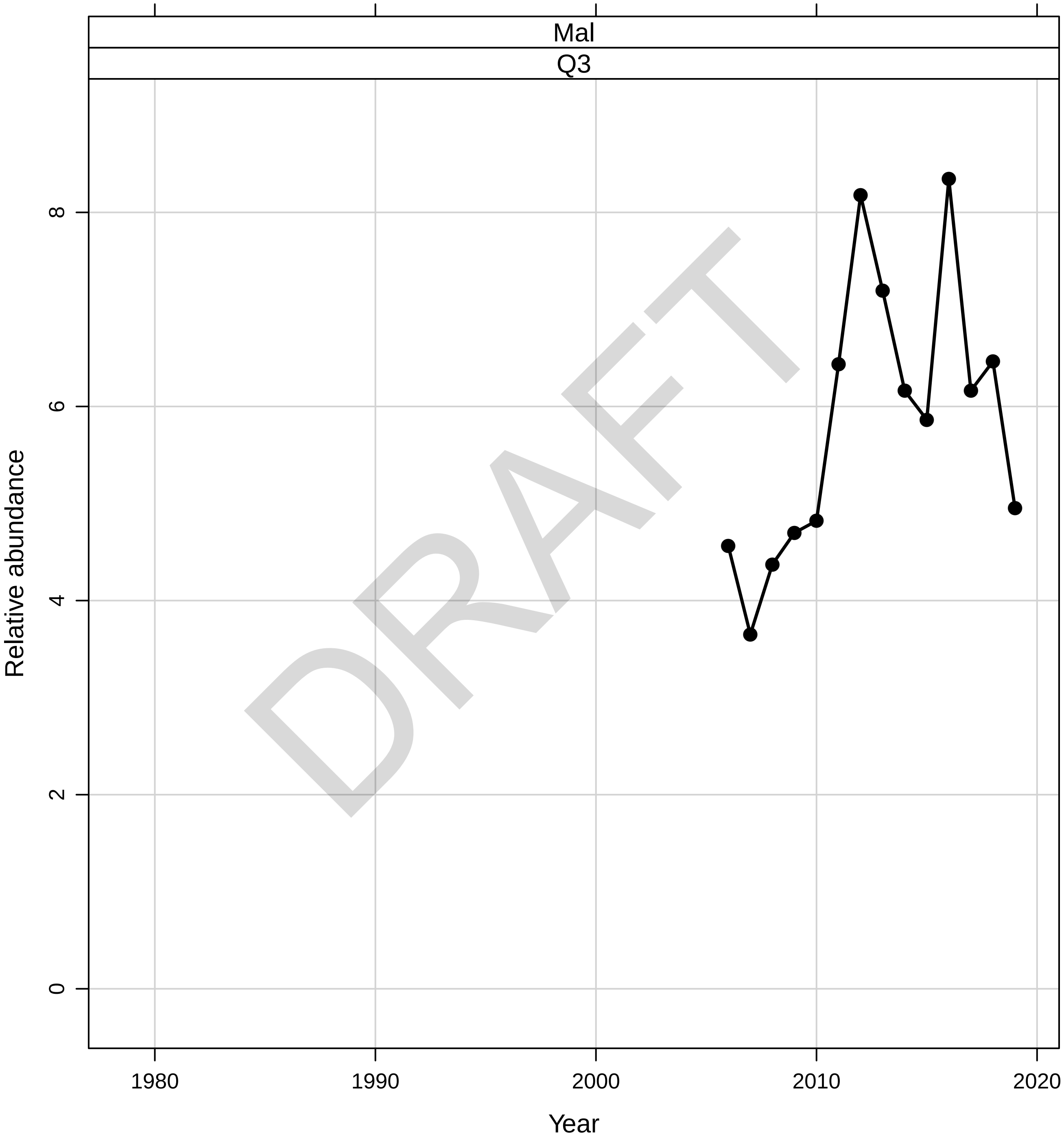
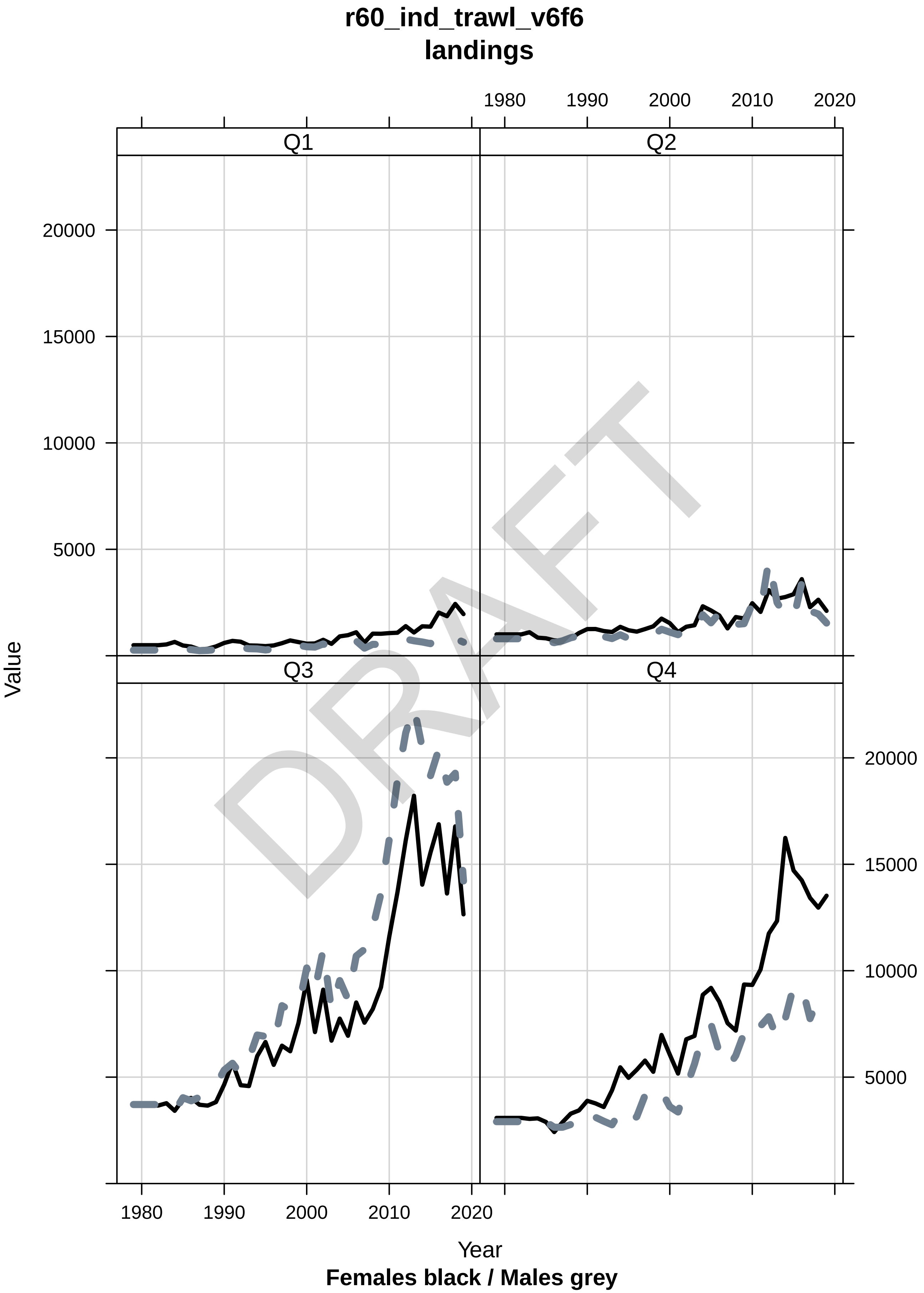
r60_ind_trawl_v6f6
VtsMQ3_stand Survey trend data



DRAFT

Symbols = observed / Solid line = predicted


r60_ind_trawl_v6f6
landings
Q1
Q2
Q3
Q4
1980
1990
2000
2010
2020
5000
10000
15000
20000
Value
Year
Females black / Males grey

DRAFT

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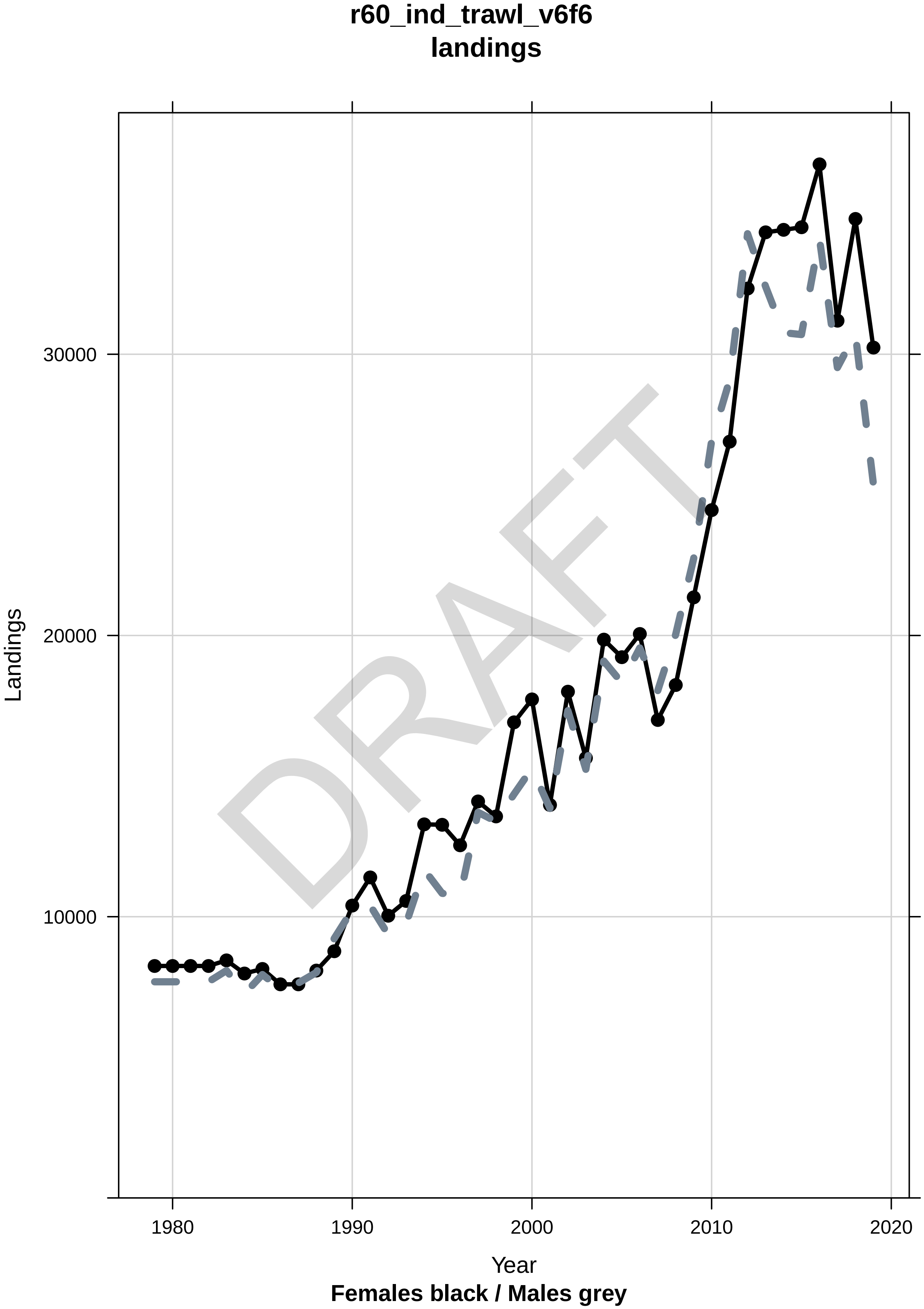
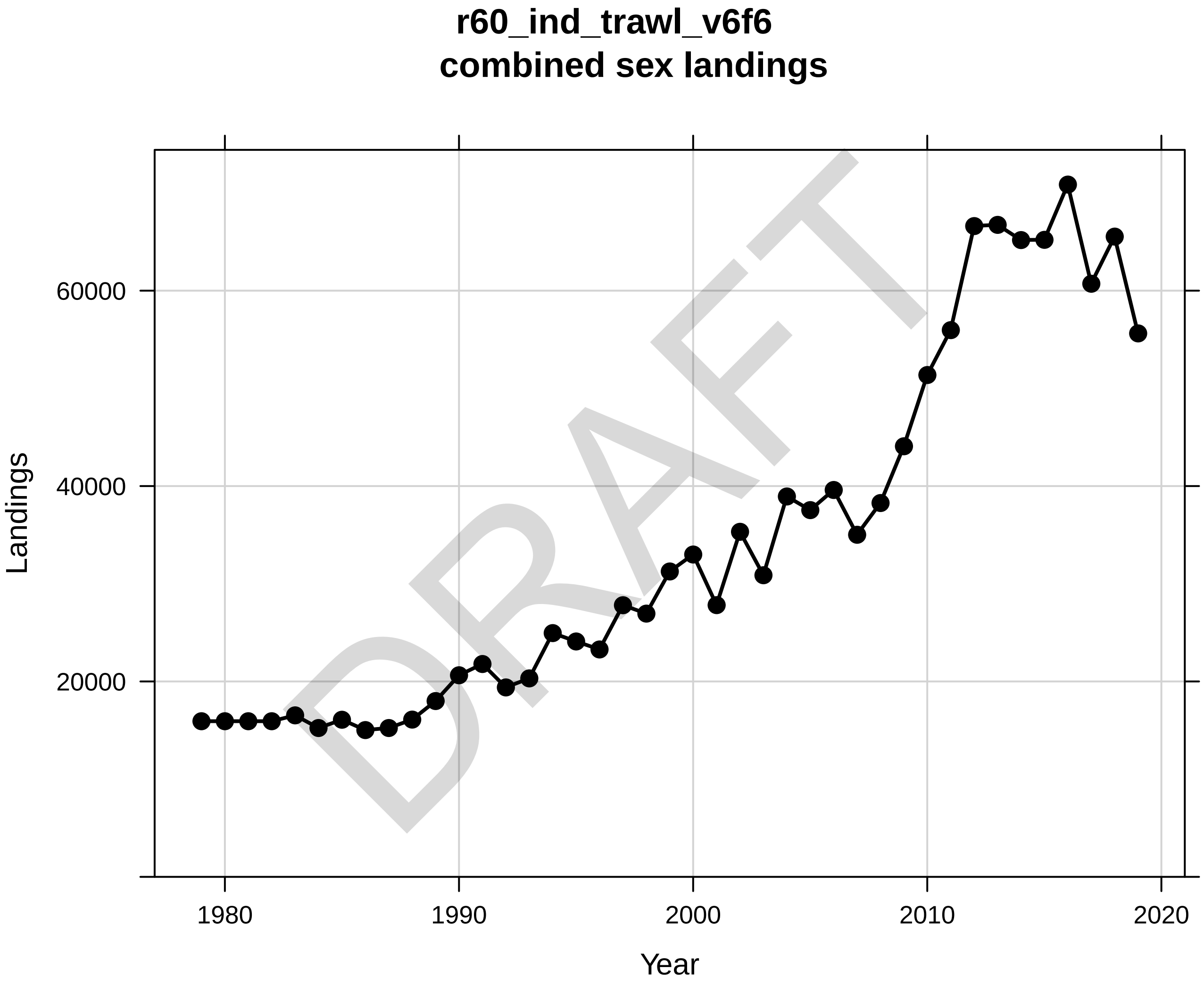
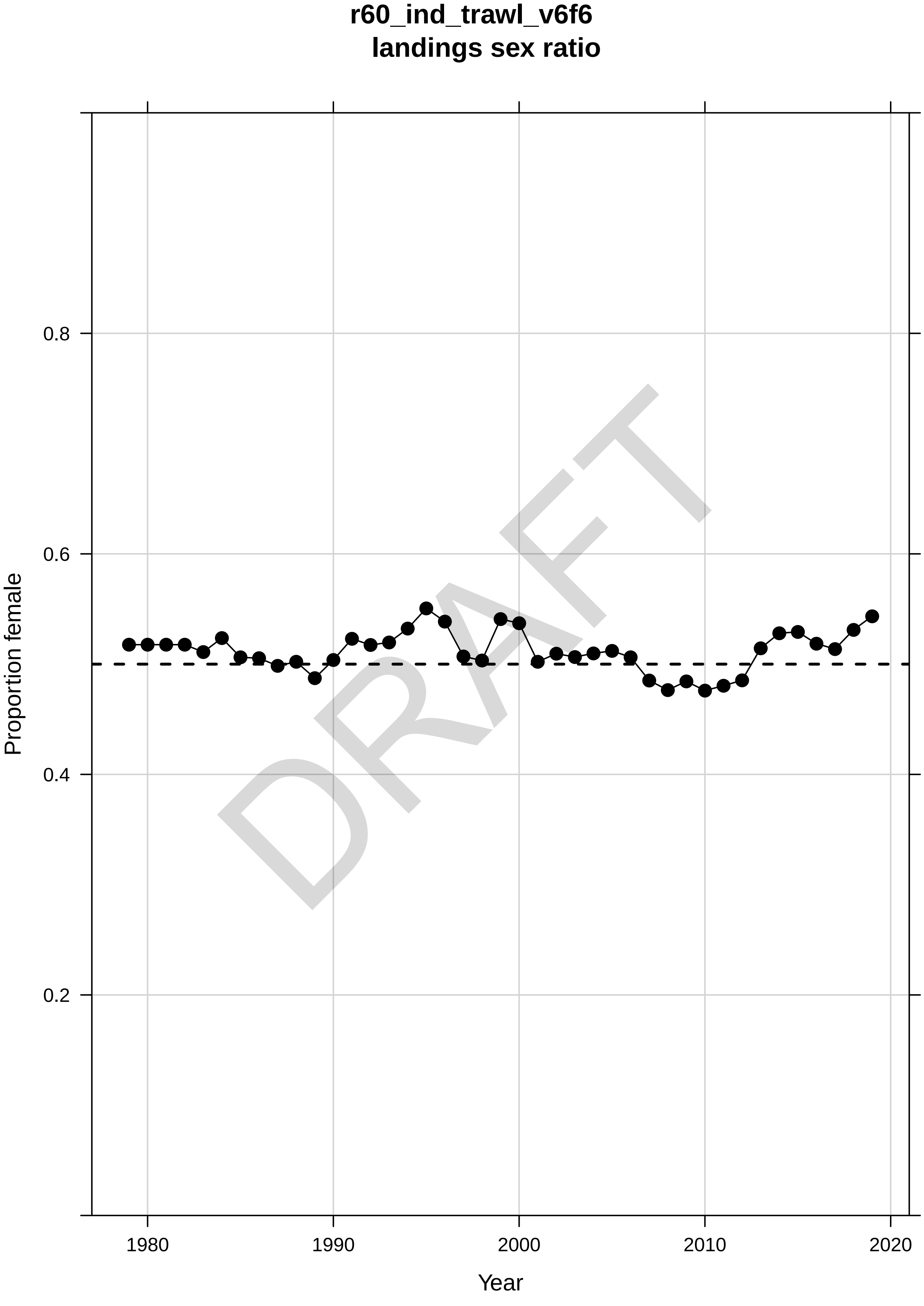


DRAFT

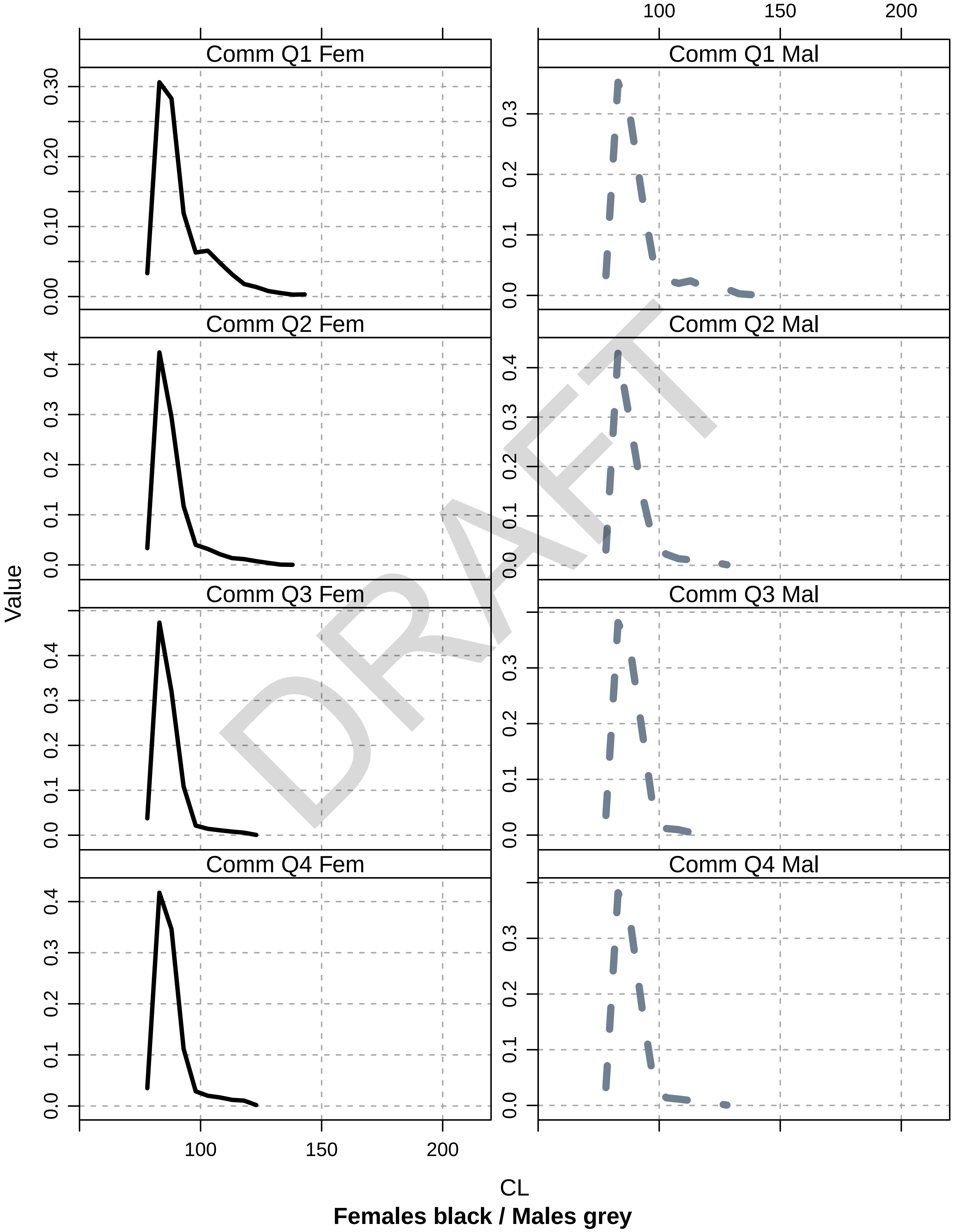

r60_ind_trawl_v6f6
combined sex landings
Landings
60000
40000
20000
1980
1990
2000
2010
2020
Year

DRAFT


r60_ind_trawl_v6f6
landings sex ratio
Proportion female
0.8
0.6
0.4
0.2
1980
1990
2000
2010
2020
Year

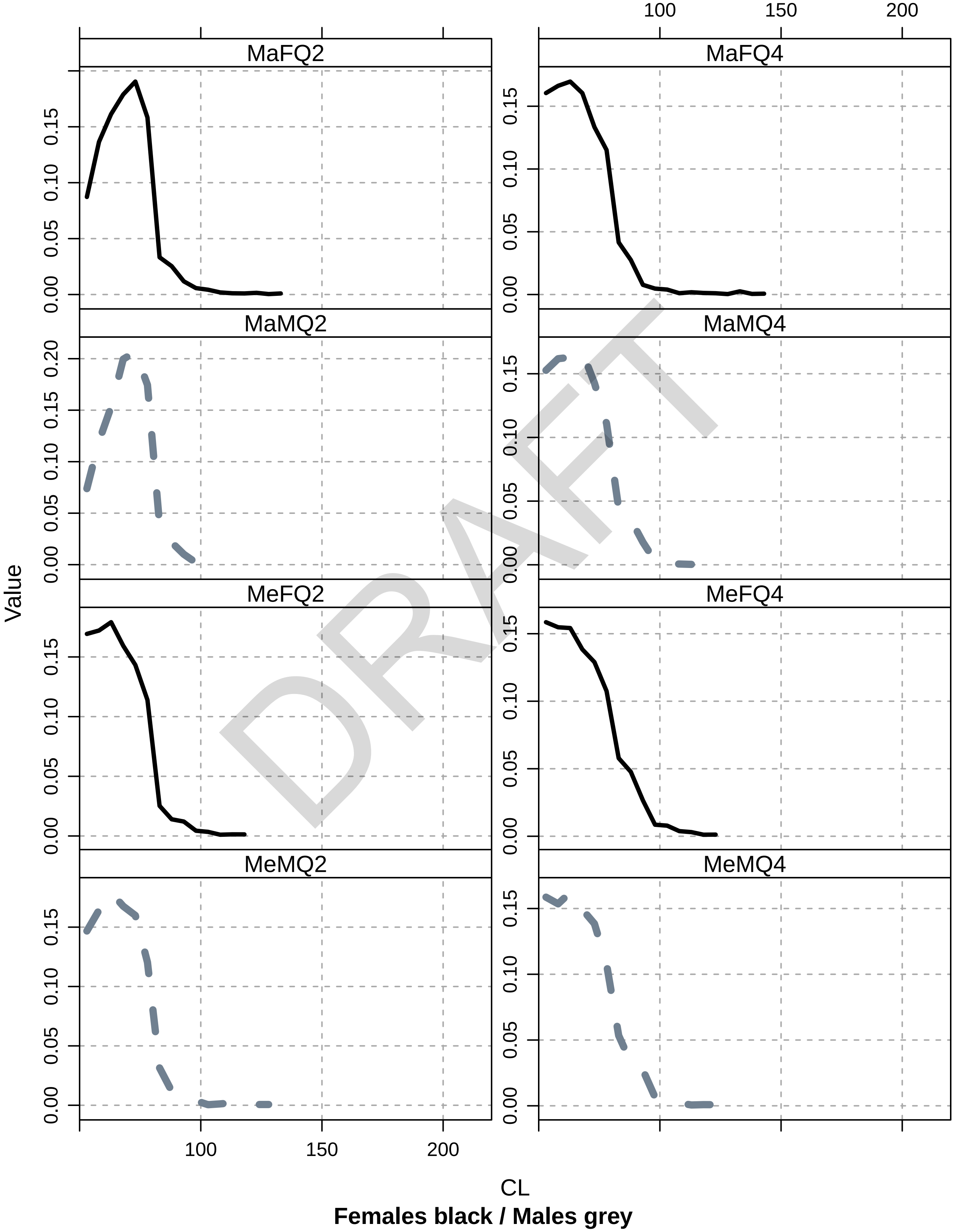
DRAFT

r60_ind_trawl_v6f6
Average length data by season and sex



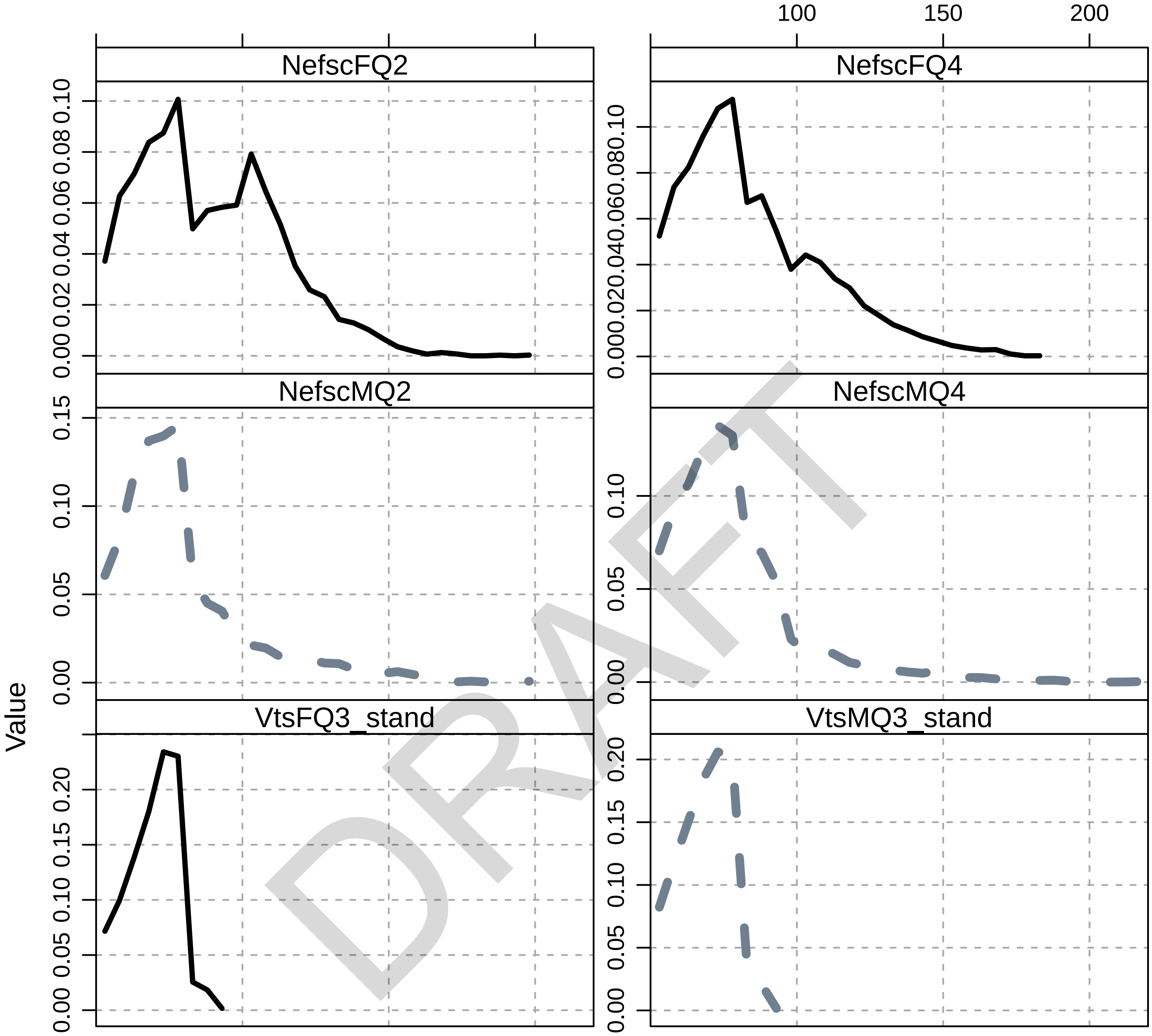
DRAFT

r60_ind_trawl_v6f6
Average length data by season and sex



DRAFT

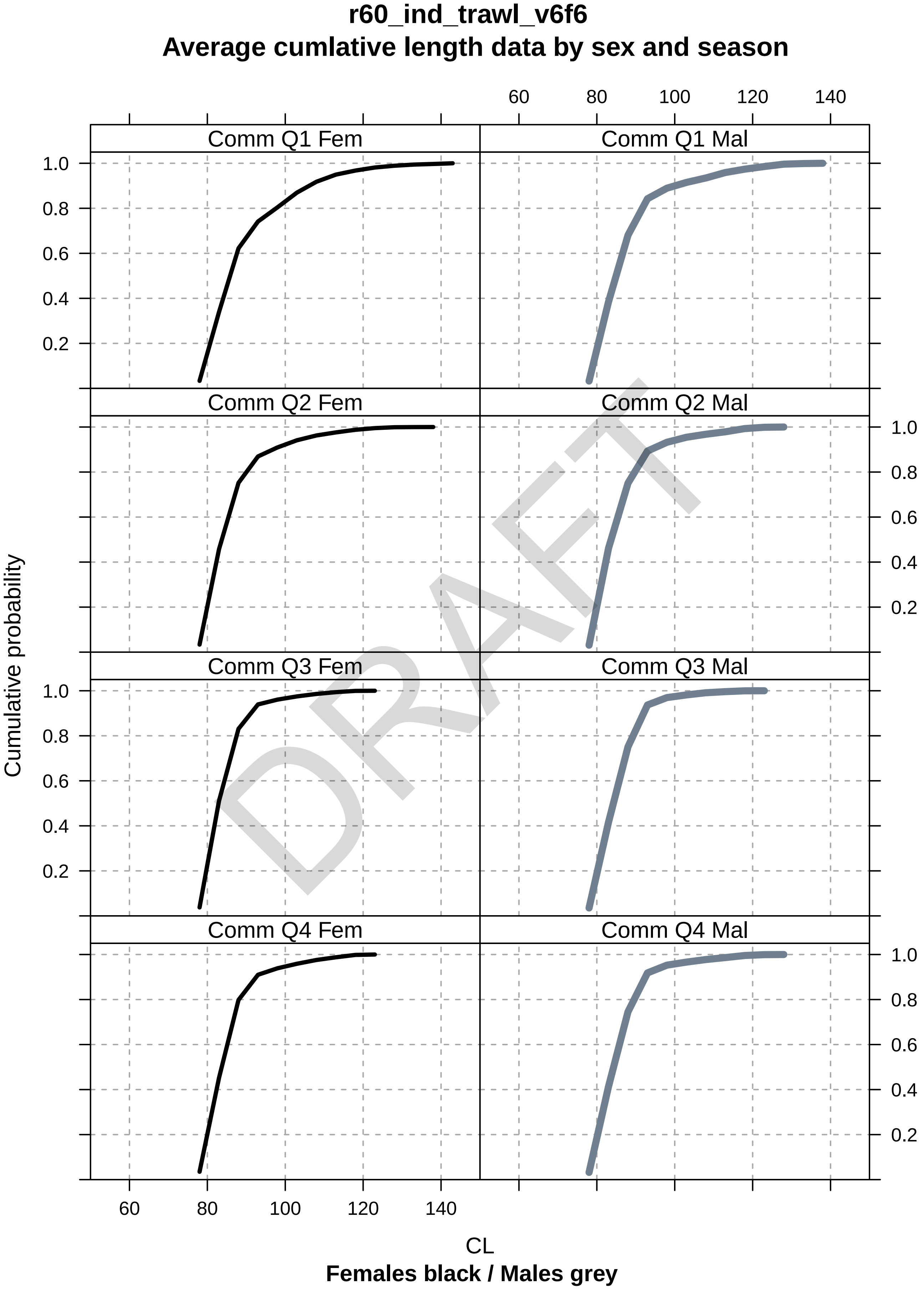
r60_ind_trawl_v6f6
Average length data by season and sex



DRAFT

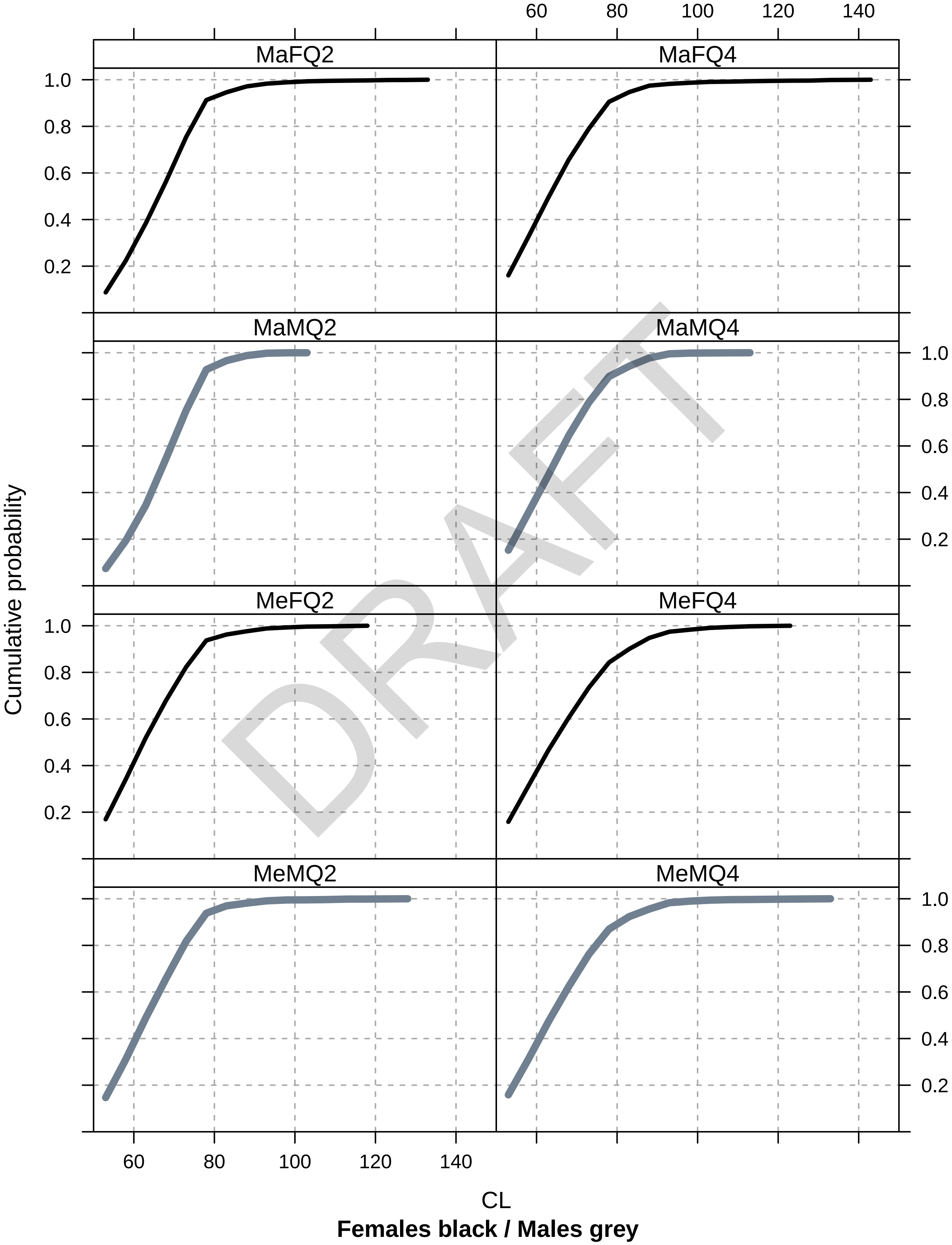
CL

Females black / Males grey


r60_ind_trawl_v6f6
Average cumlative length data by sex and season
Comm Q1 Fem
Comm Q1 Mal
Comm Q2 Fem
Comm Q2 Mal
Comm Q3 Fem
Comm Q3 Mal
Comm Q4 Fem
Comm Q4 Mal
Cumulative probability
0.2
0.4
0.6
0.8
1.0
60
80
100
120
140
CL
Females black / Males grey

DRAFT

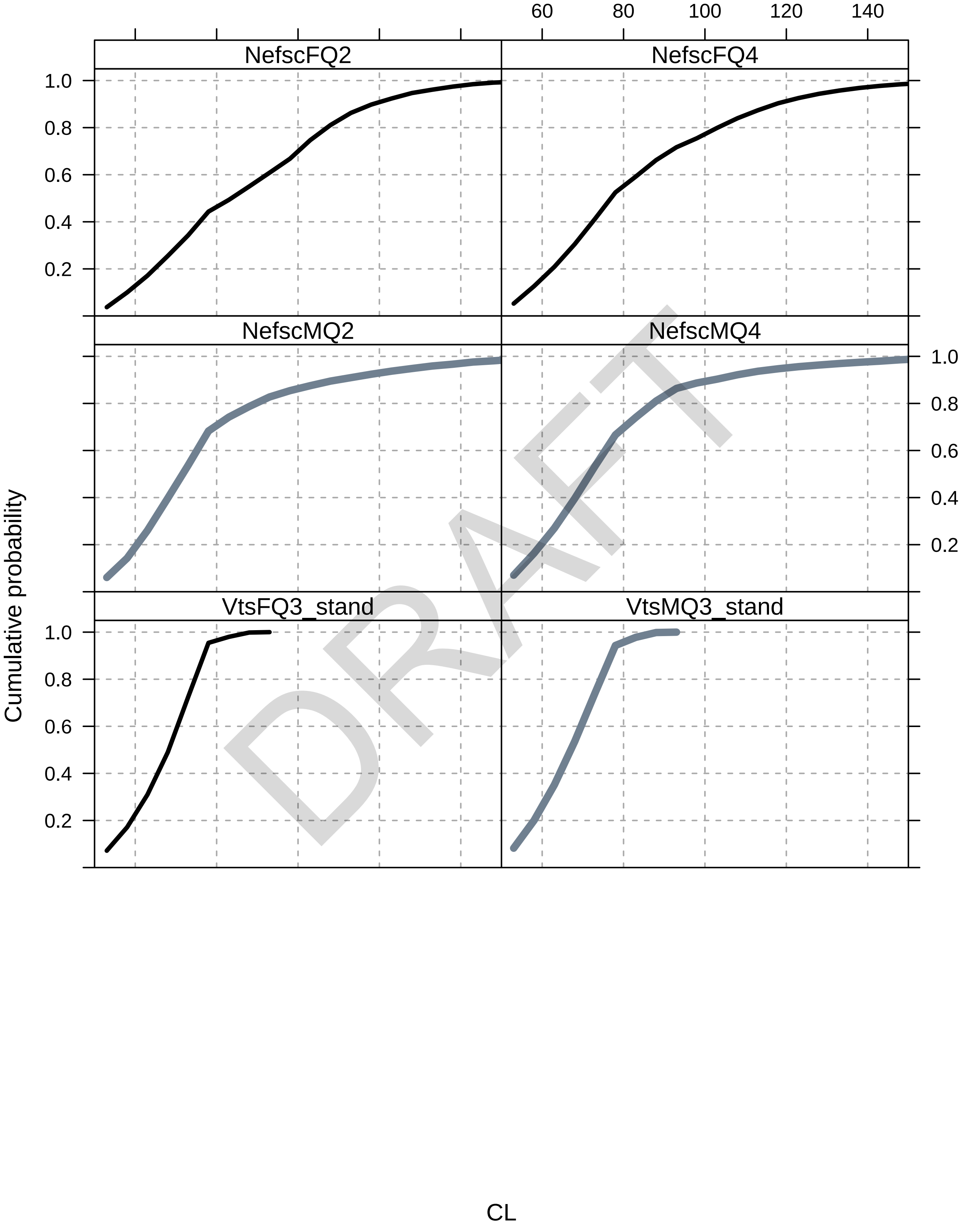
r60_ind_trawl_v6f6
Average cumlative length data by sex and season



DRAFT

DRAFT

r60_ind_trawl_v6f6
Average cumlative length data by sex and season



Females black / Males grey

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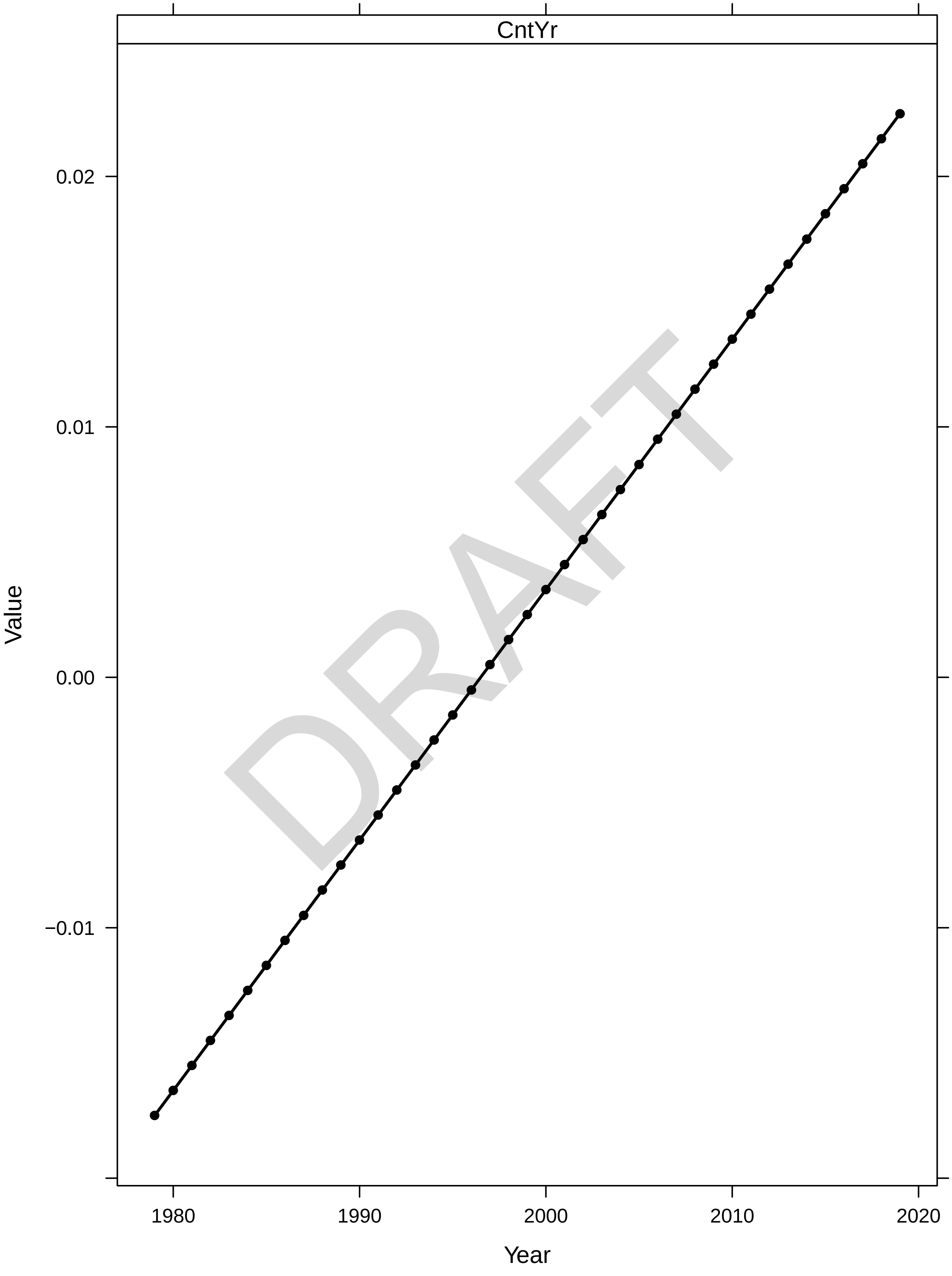
Recruitment covariates used in model Year Covariate



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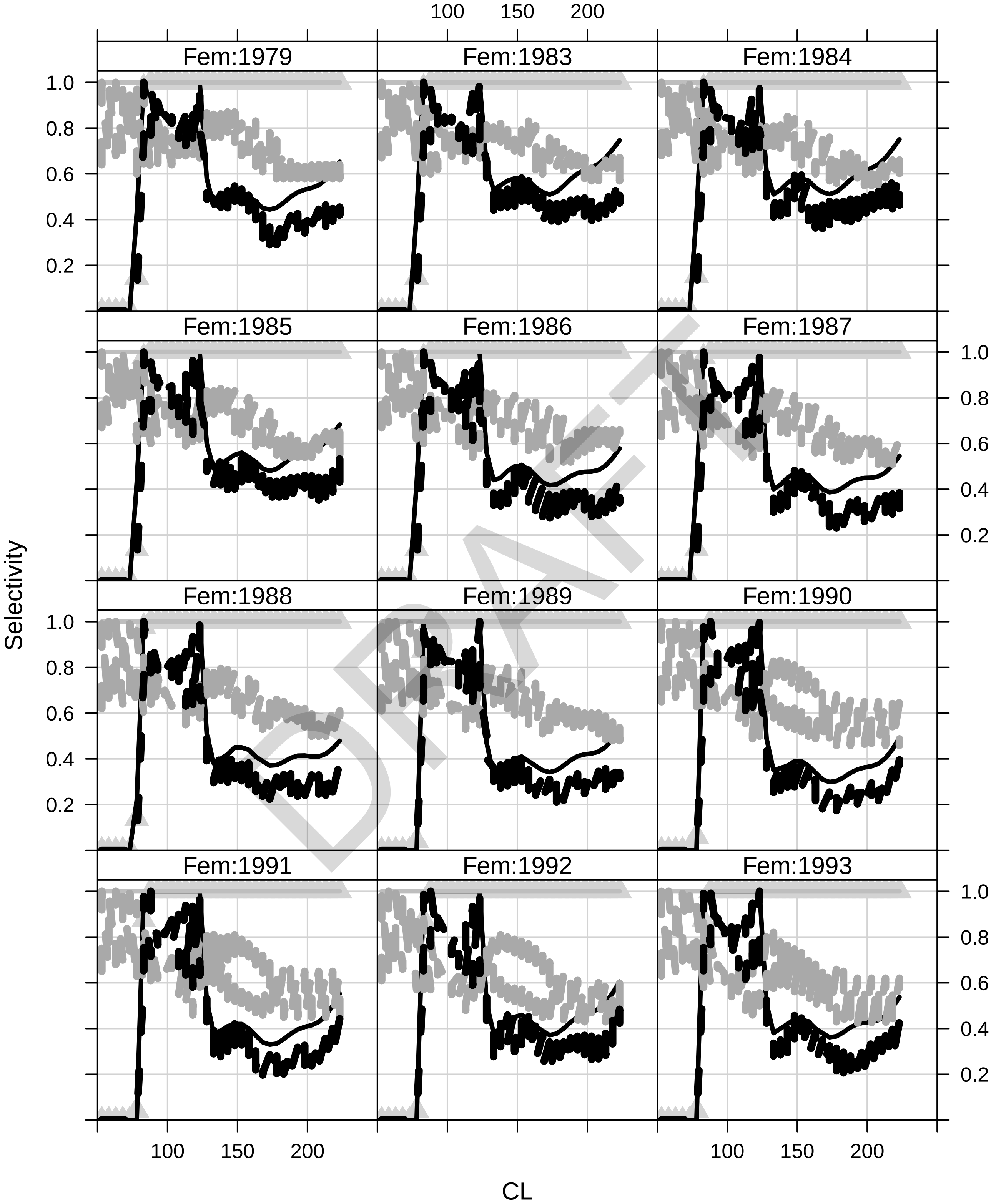
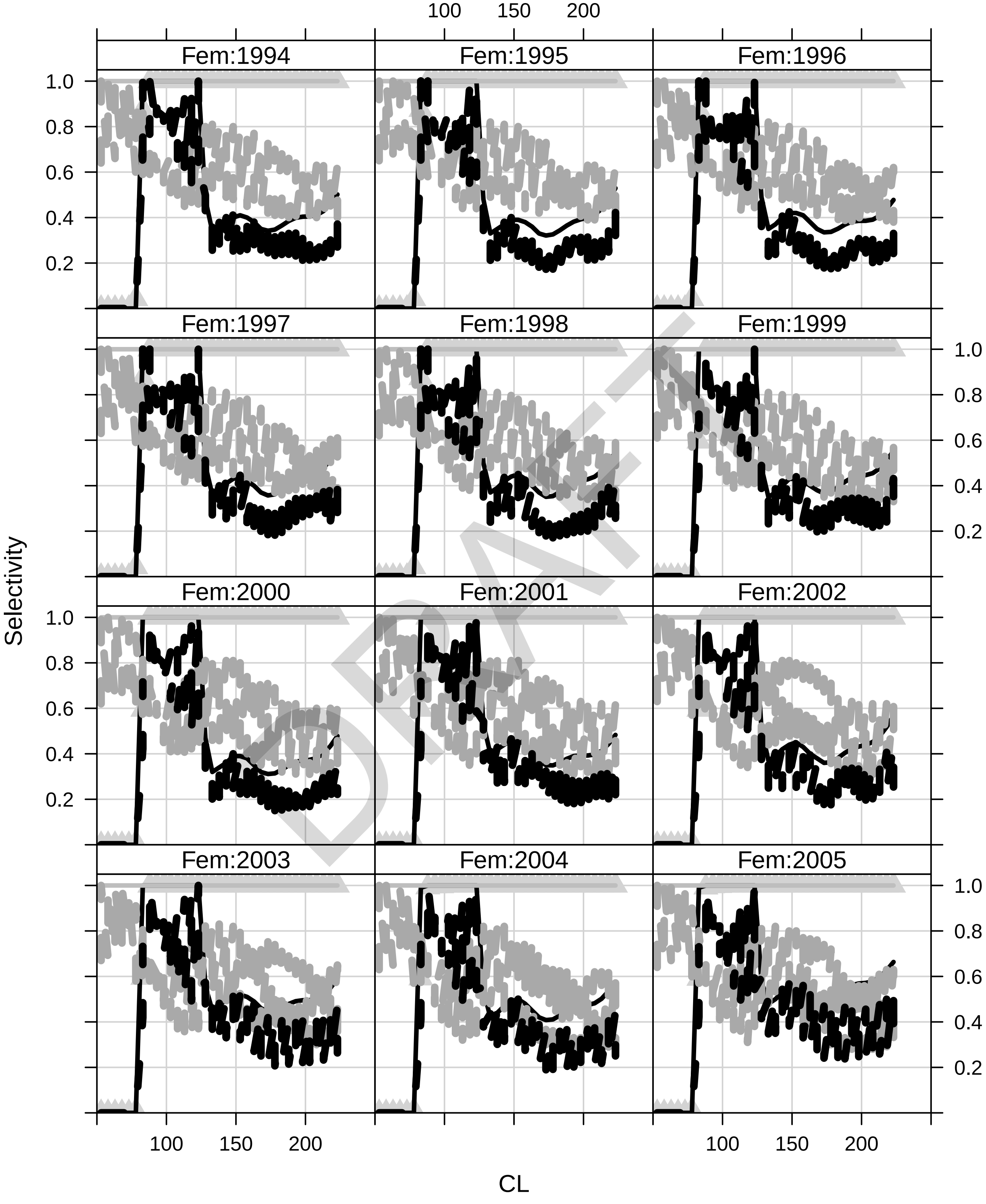
r60_ind_trawl_v6f6
commercial Selectivity (3rd quarter)



DRAFT

Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

r60_ind_trawl_v6f6
commercial Selectivity (3rd quarter)



DRAFT

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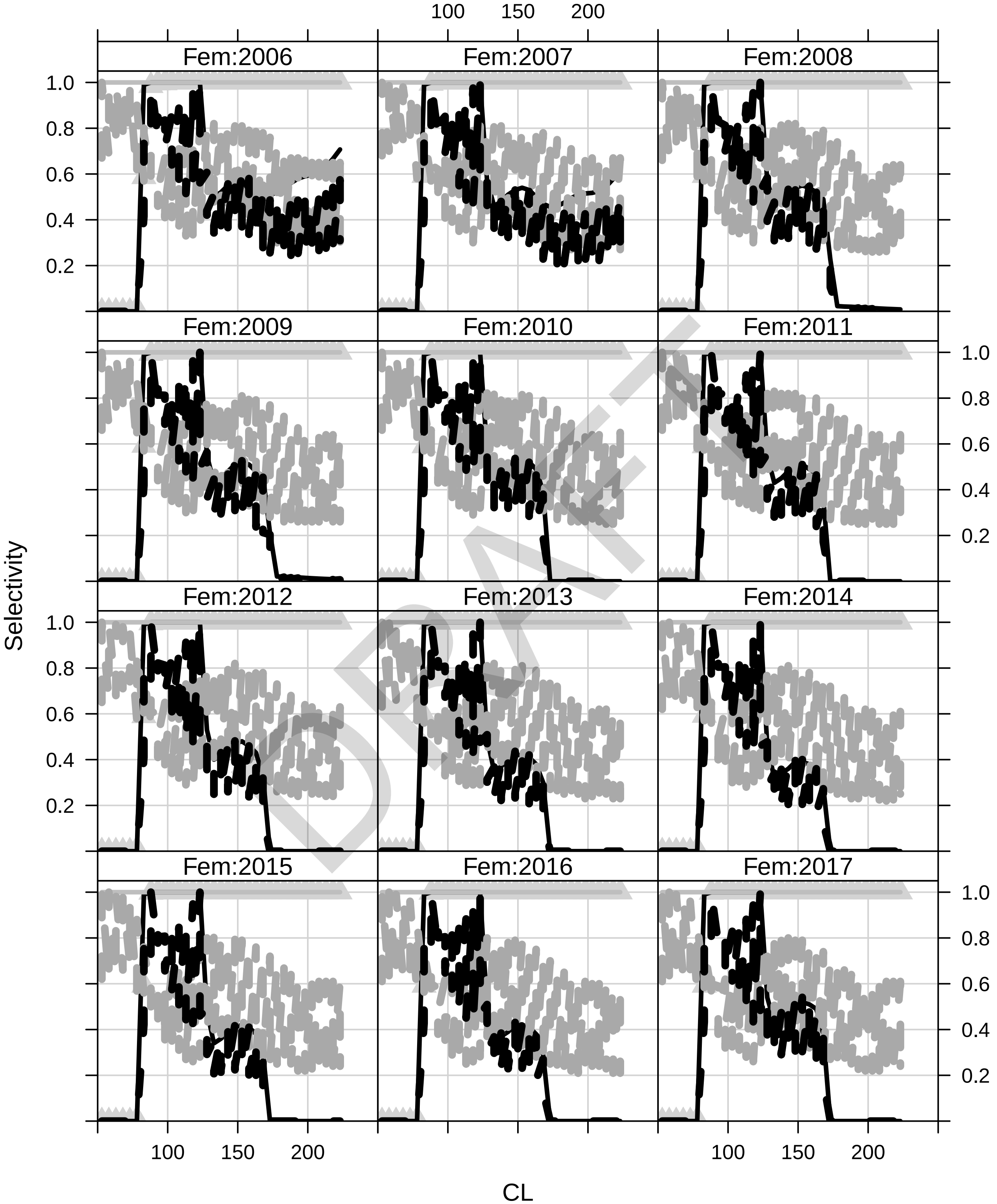
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

r60_ind_trawl_v6f6
commercial Selectivity (3rd quarter)



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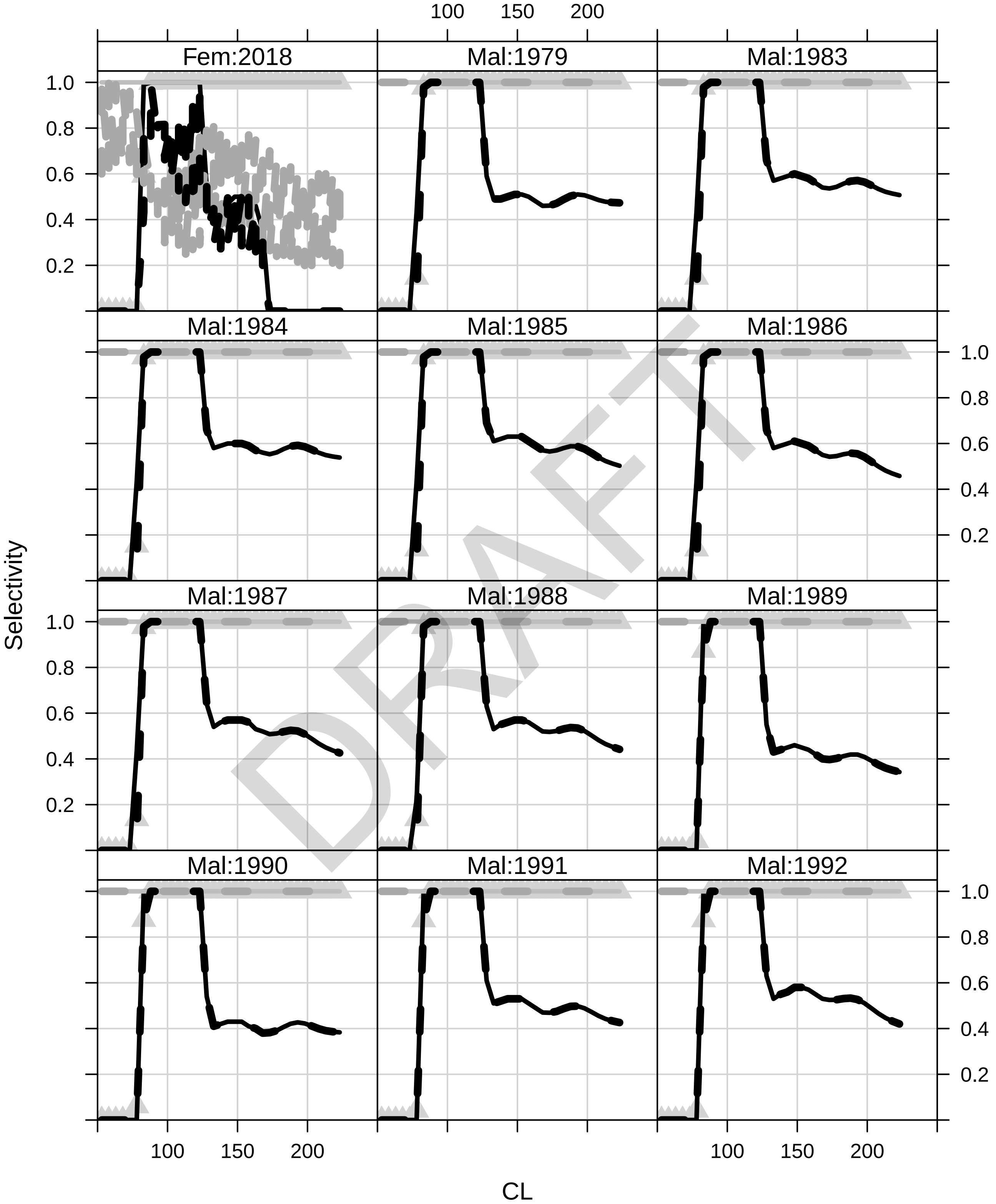
Legal=thin black, Gear=grey filled triangle (no line)

DRAFT

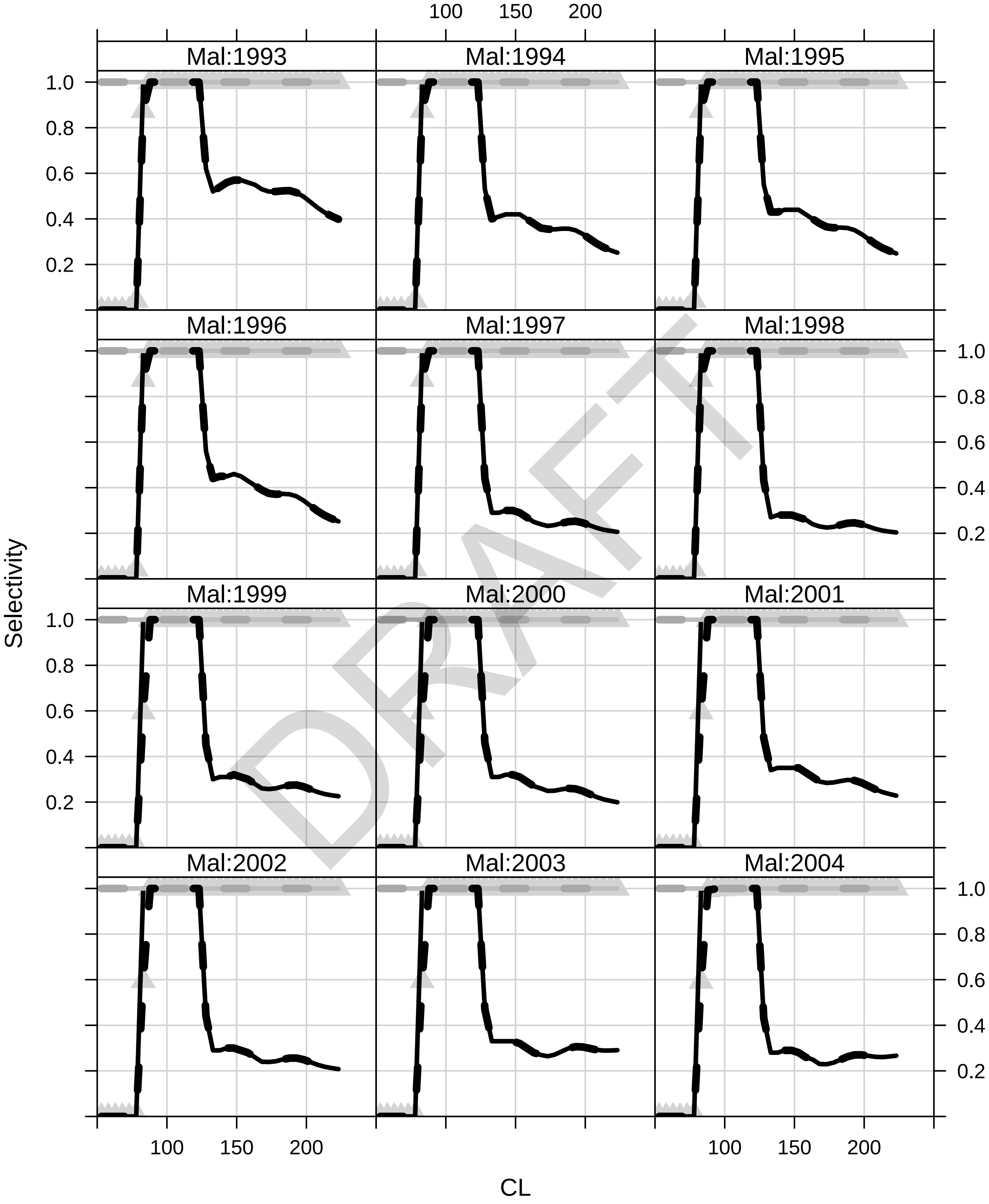
r60_ind_trawl_v6f6
commercial Selectivity (3rd quarter)



DRAFT

Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

r60_ind_trawl_v6f6
commercial Selectivity (3rd quarter)



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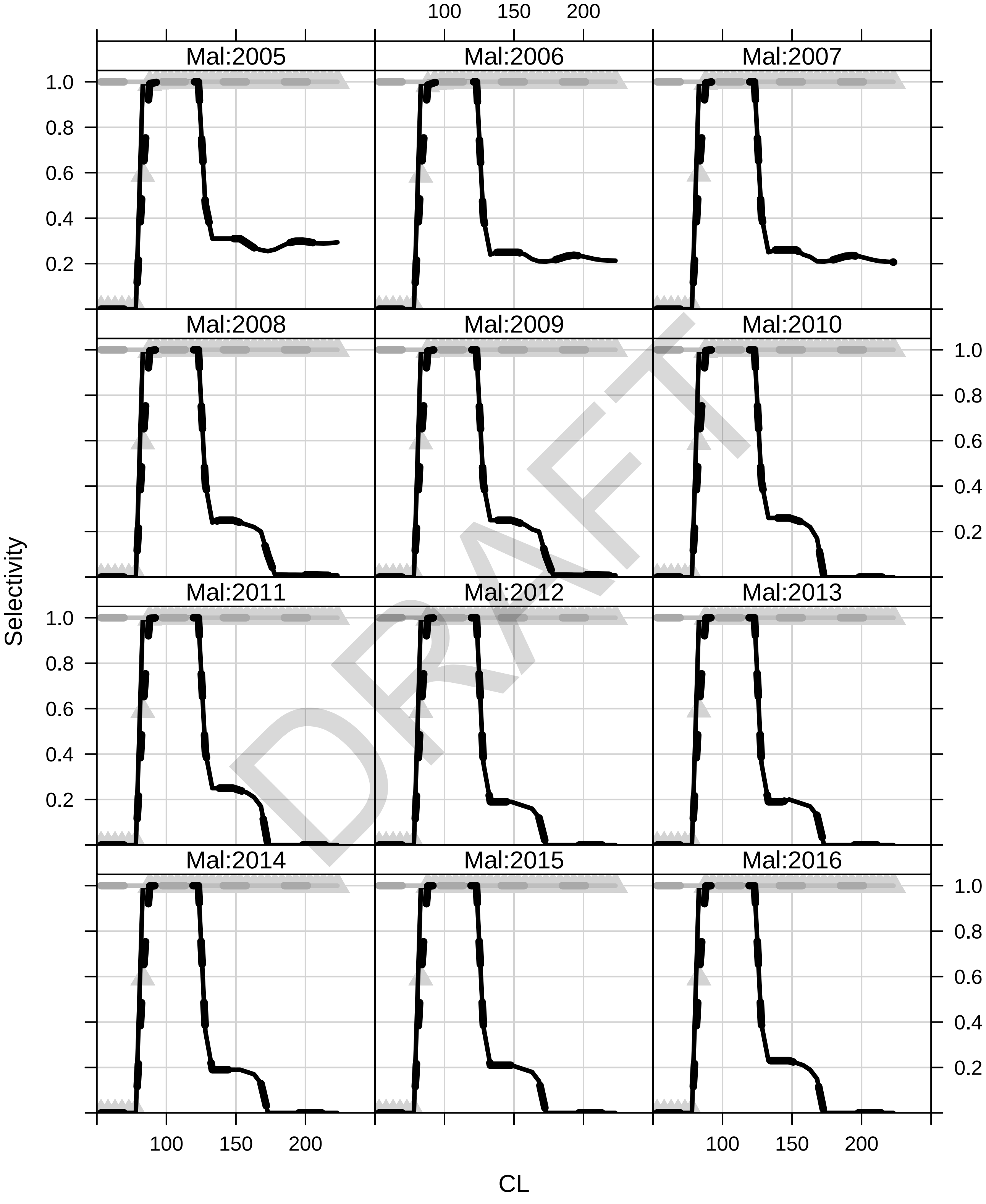
DRAFT

r60_ind_trawl_v6f6
commercial Selectivity (3rd quarter)



DRAFT

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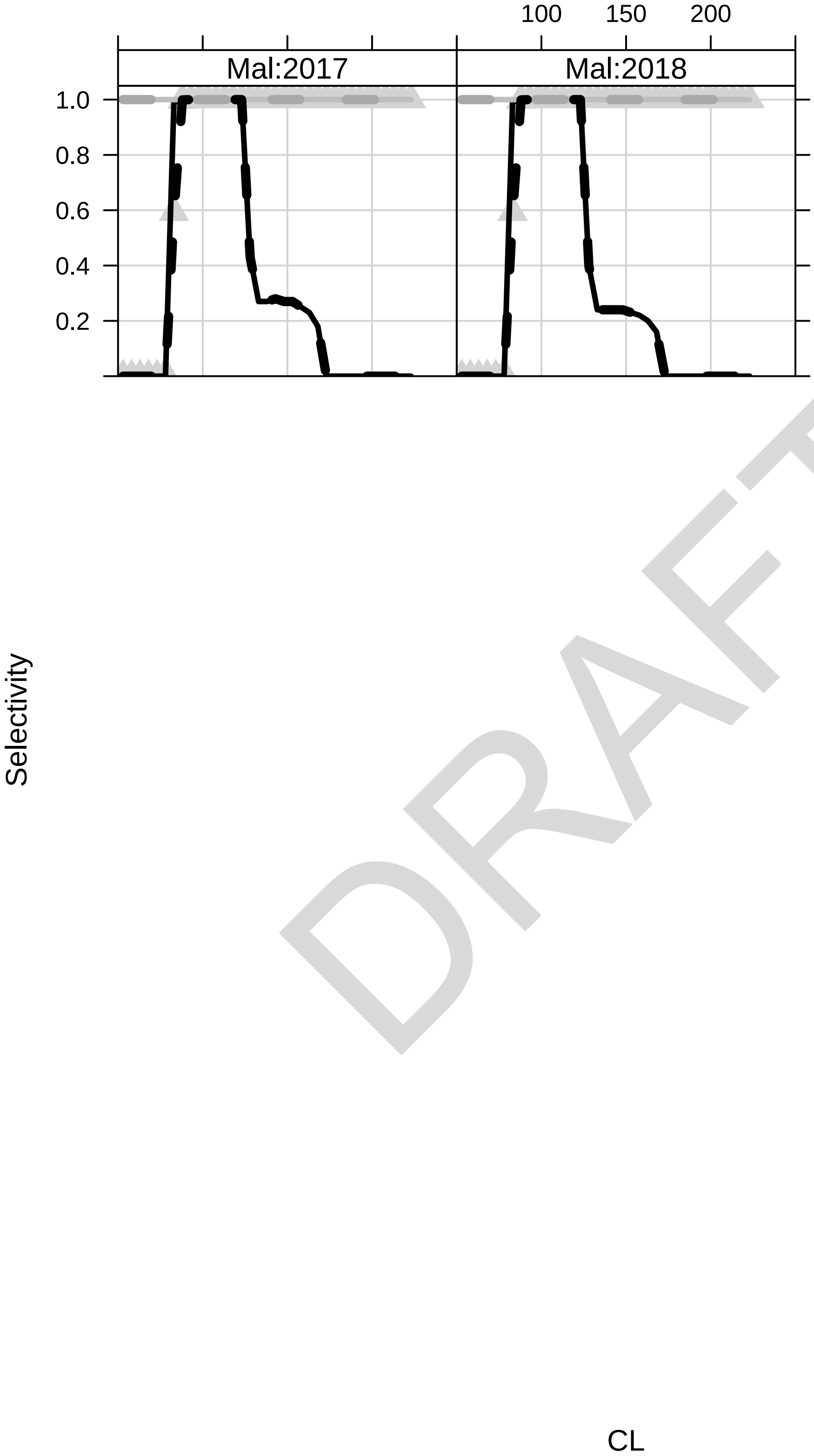
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

r60_ind_trawl_v6f6
commercial Selectivity (3rd quarter)



DRAFT

Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
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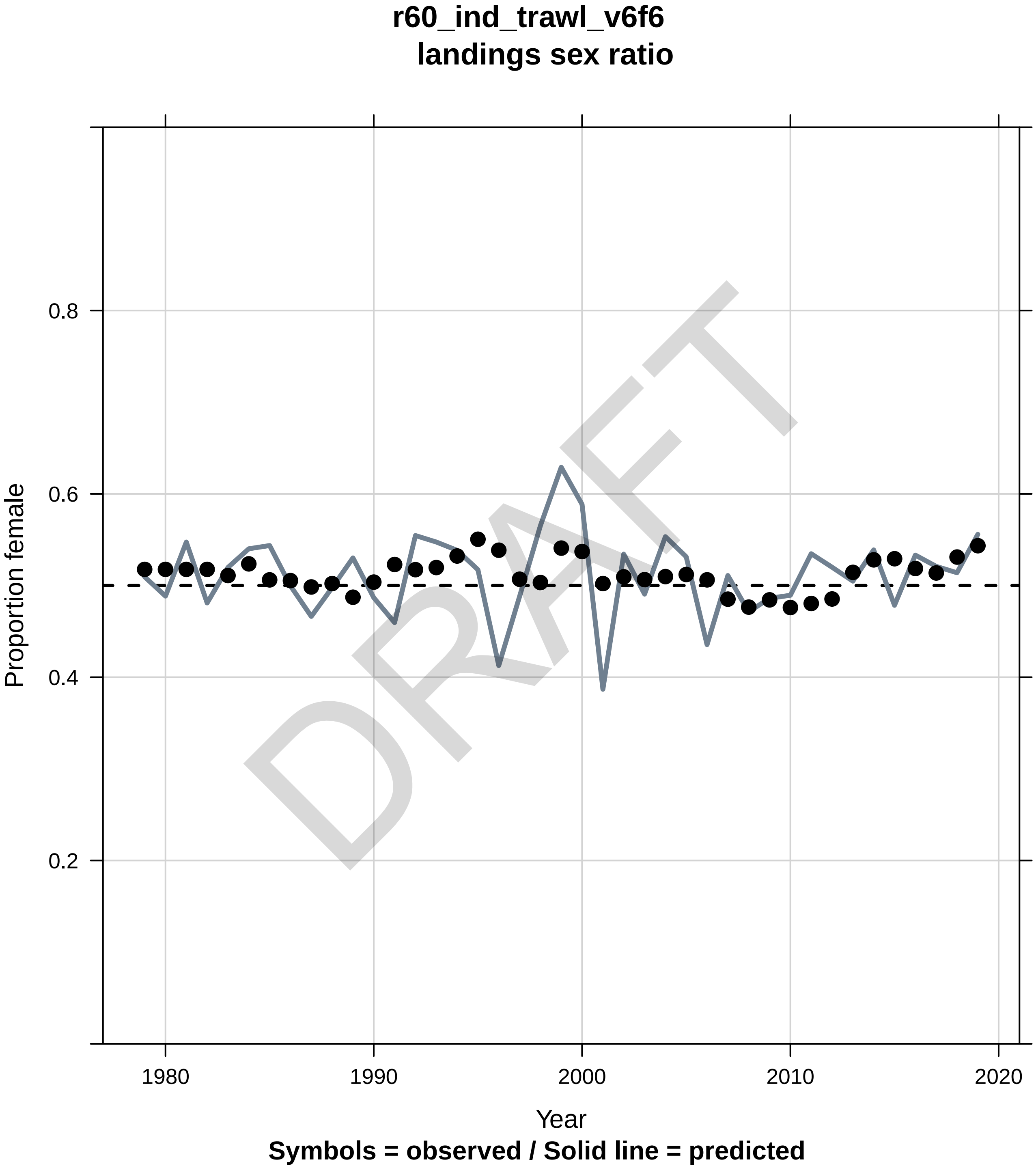
r60_ind_trawl_v6f6
landings sex ratio
Proportion female
0.2
0.4
0.6
0.8
1980
1990
2000
2010
2020
Year
Symbols = observed / Solid line = predicted

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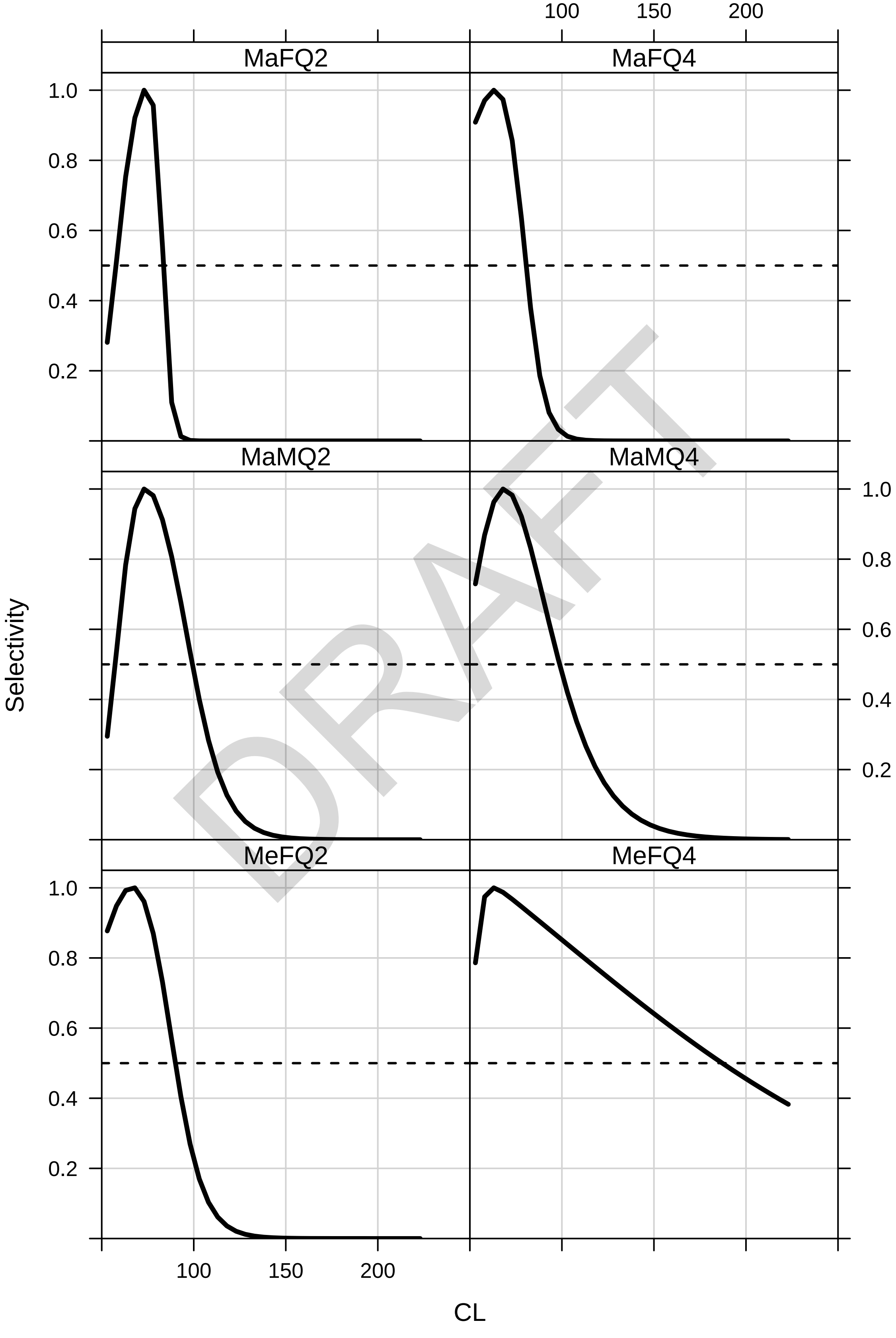
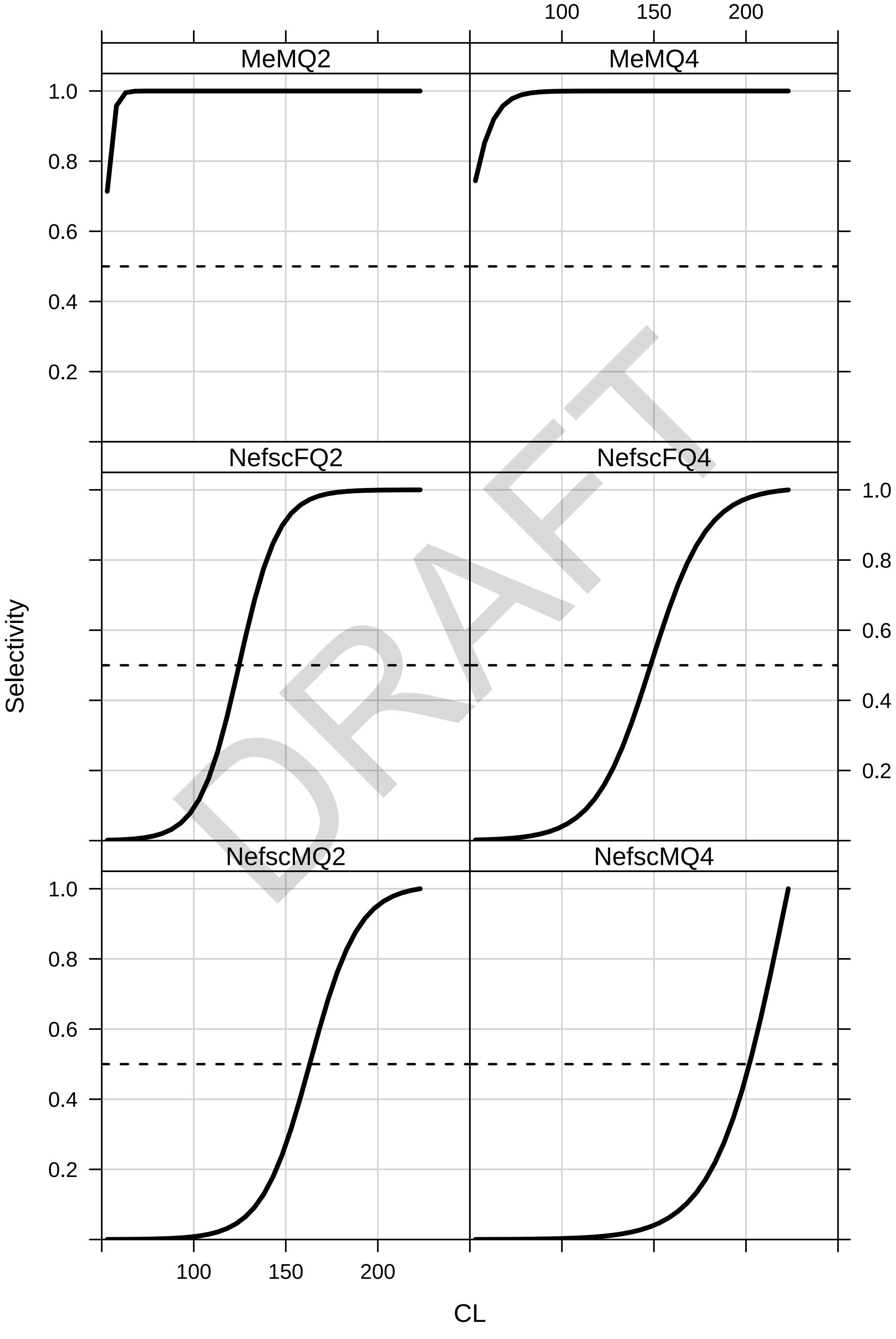
r60_ind_trawl_v6f6
survey selectivity

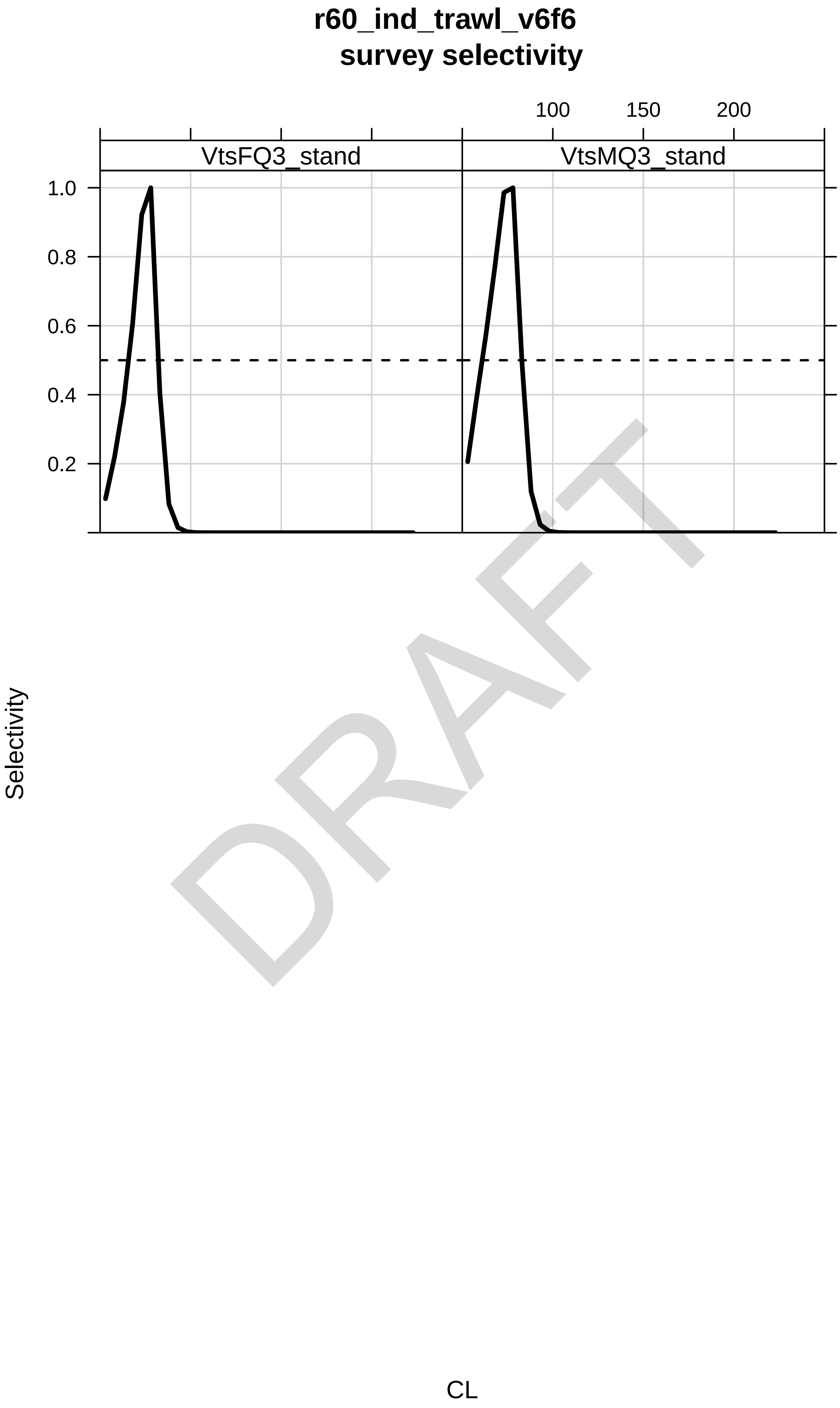


DRAFT

r60_ind_trawl_v6f6
survey selectivity

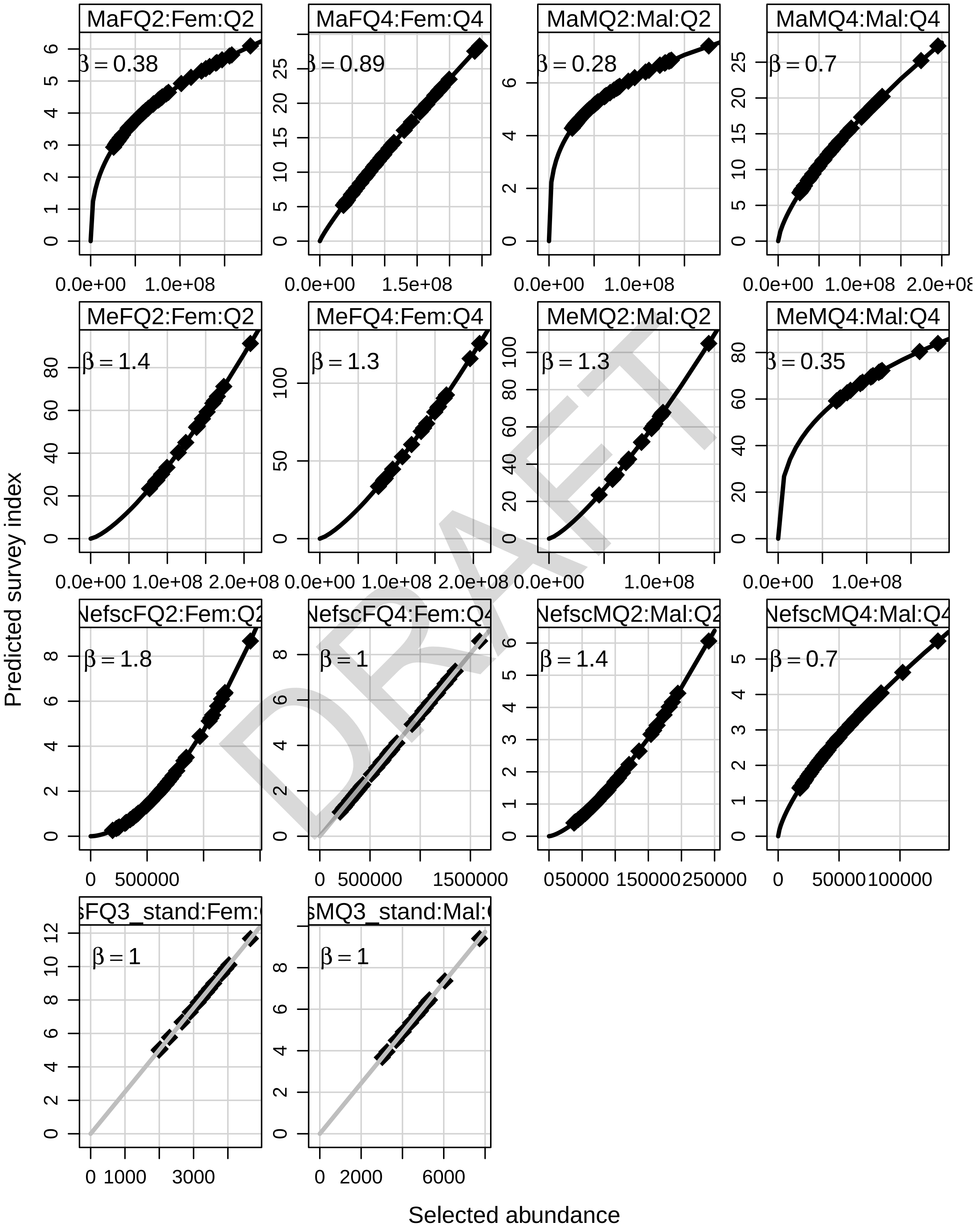


DRAFT


r60_ind_trawl_v6f6
survey selectivity
100
150
200
VtsFQ3_stand
VtsMQ3_stand
1.0
0.8
0.6
0.4
0.2
Selectivity
CL

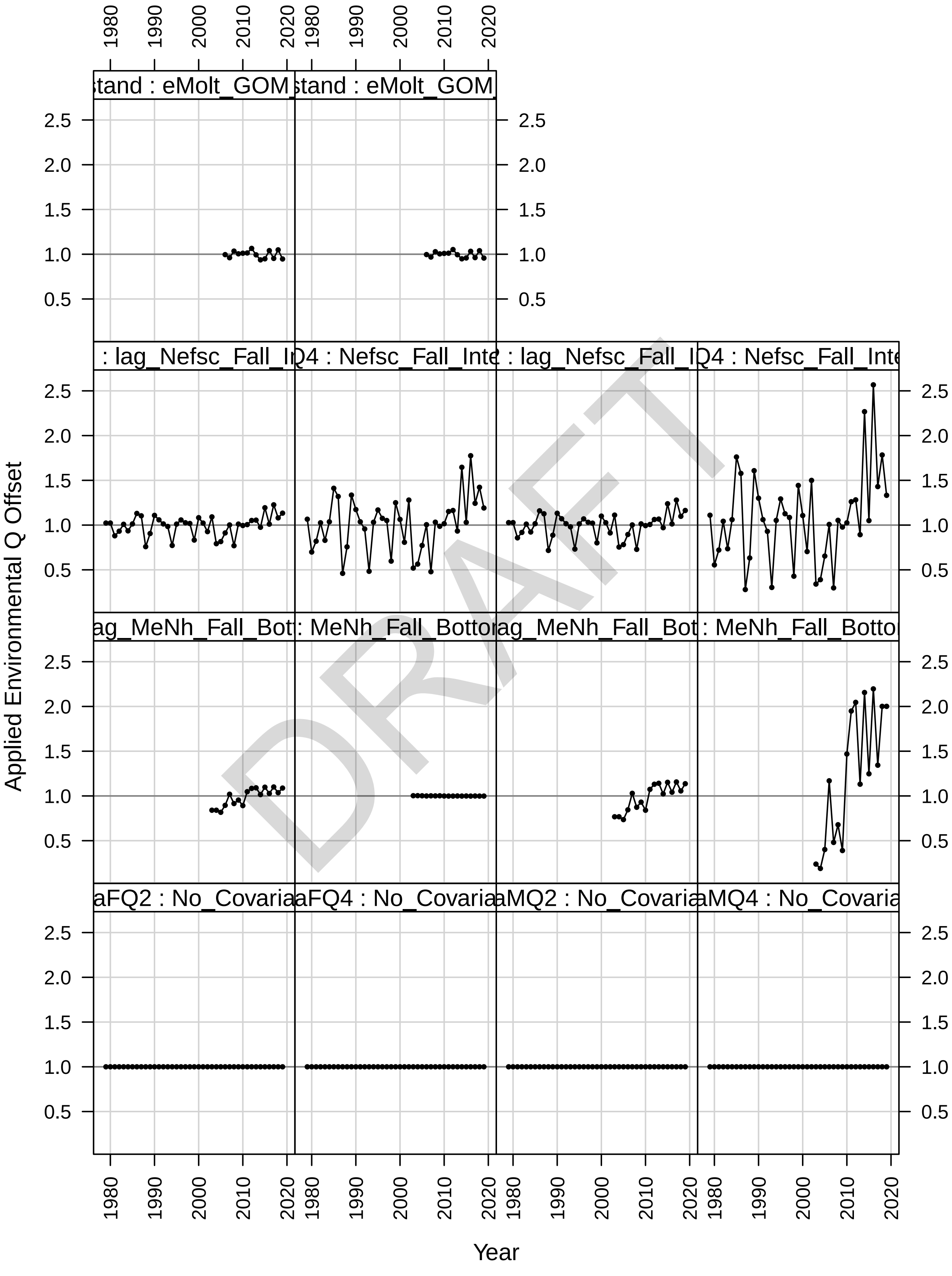
DRAFT

r60_ind_trawl_v6f6
Predicted survey and selected abundance



DRAFT

Survey Q As Modified by Environmental Covariates



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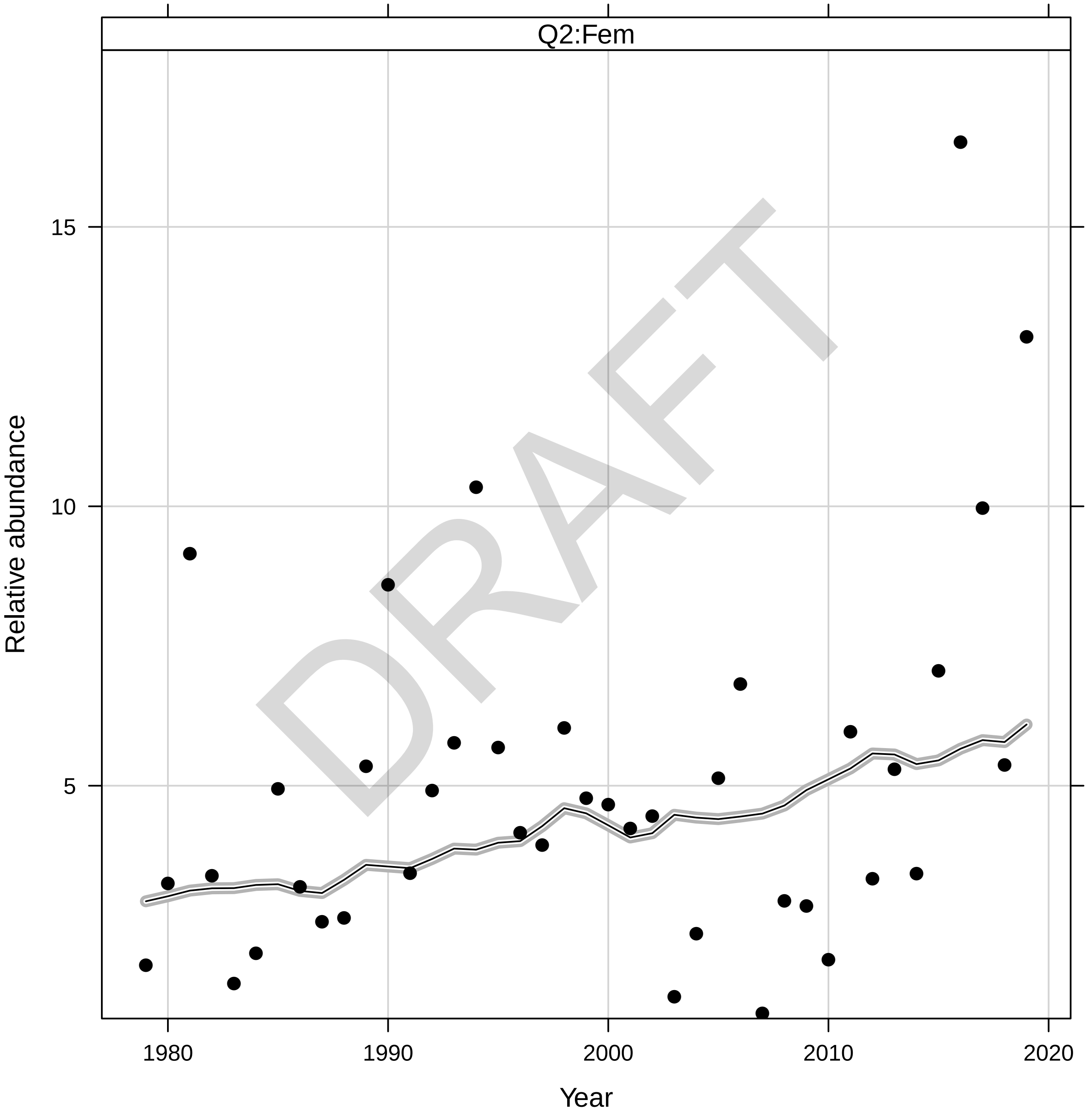
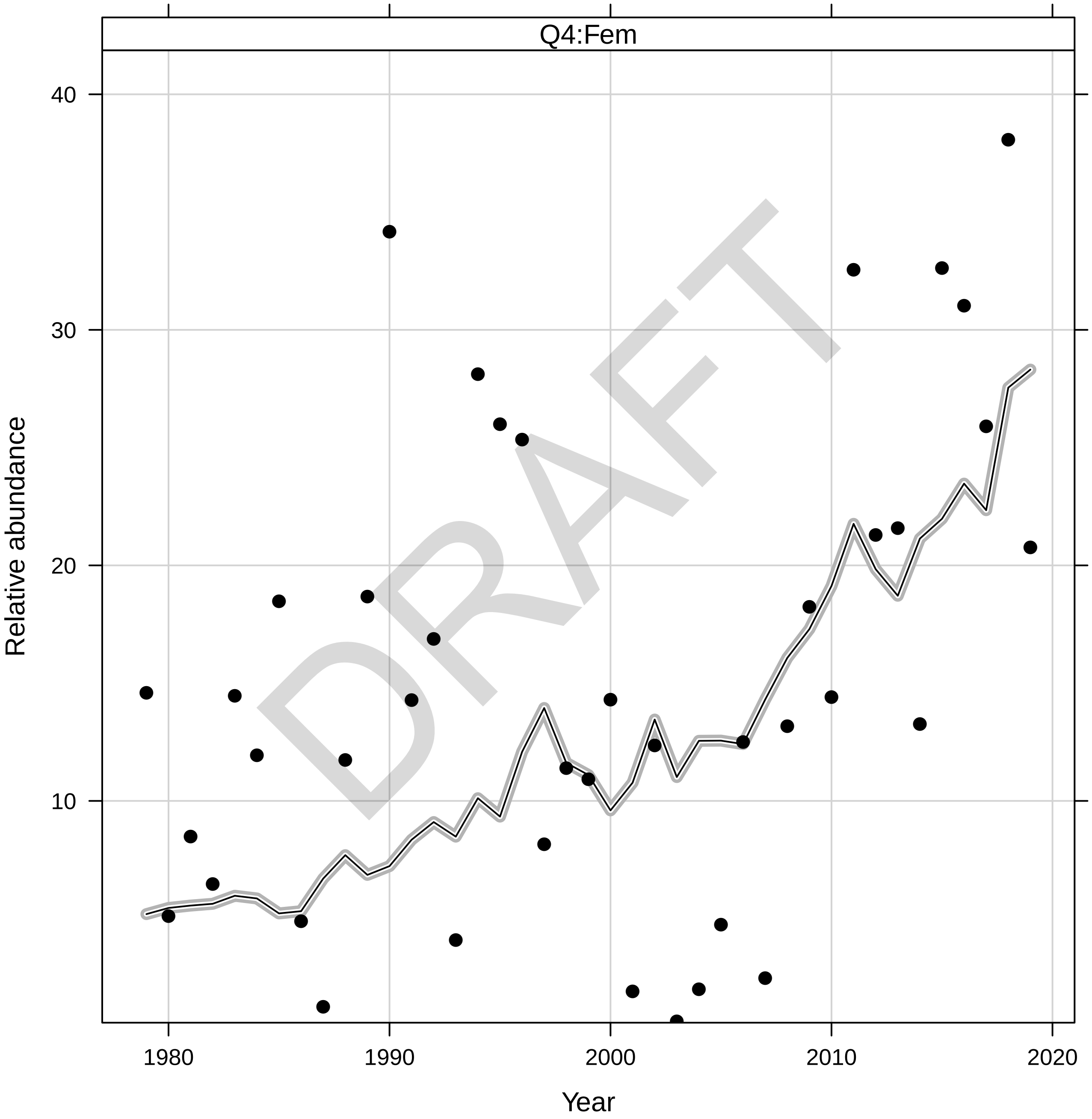
r60_ind_trawl_v6f6
MaFQ2 observed and predicted survey trends



Symbols = observed; Dark line = predicted; Light line = predicted adjust

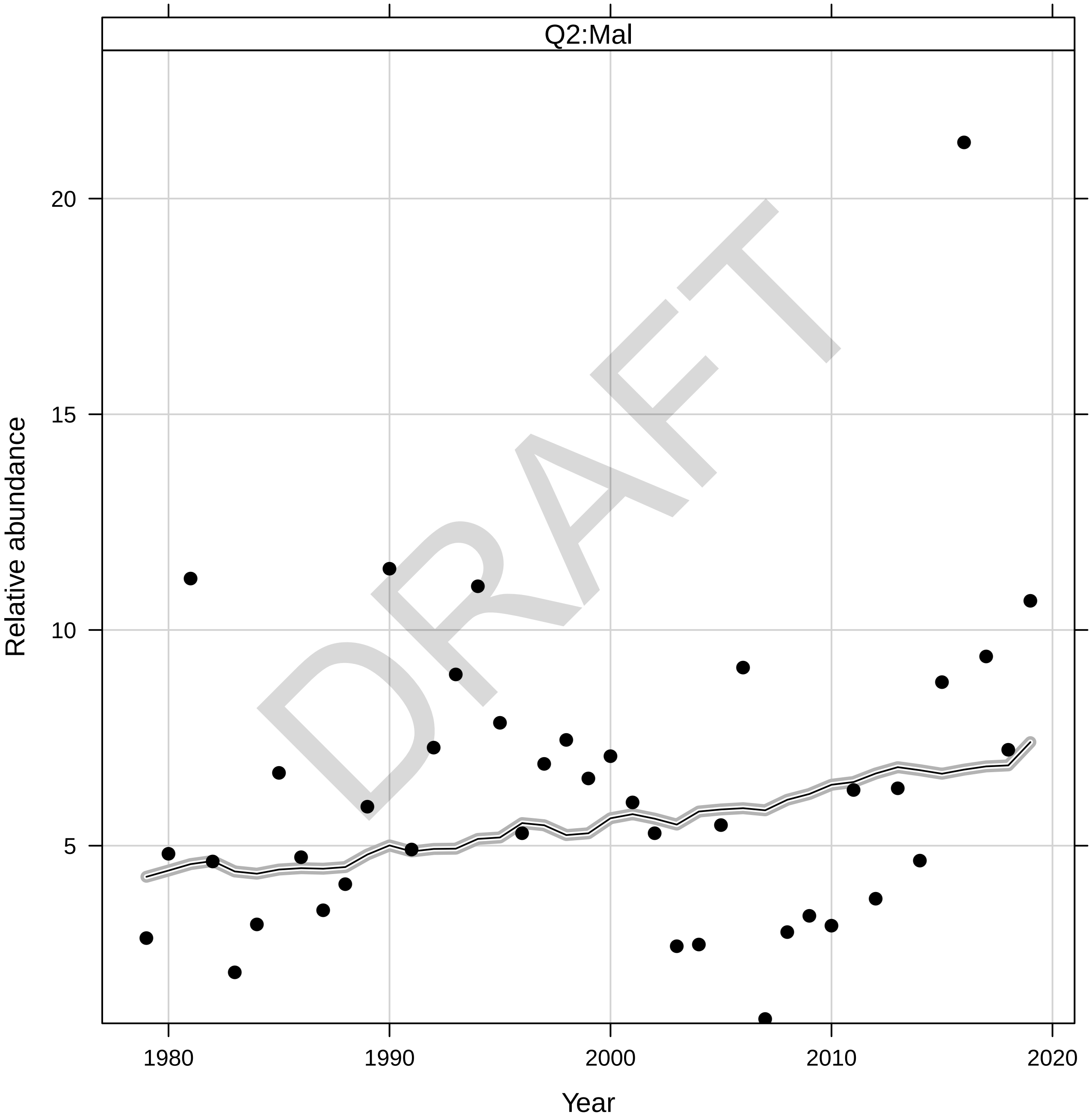
r60_ind_trawl_v6f6
MaFQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

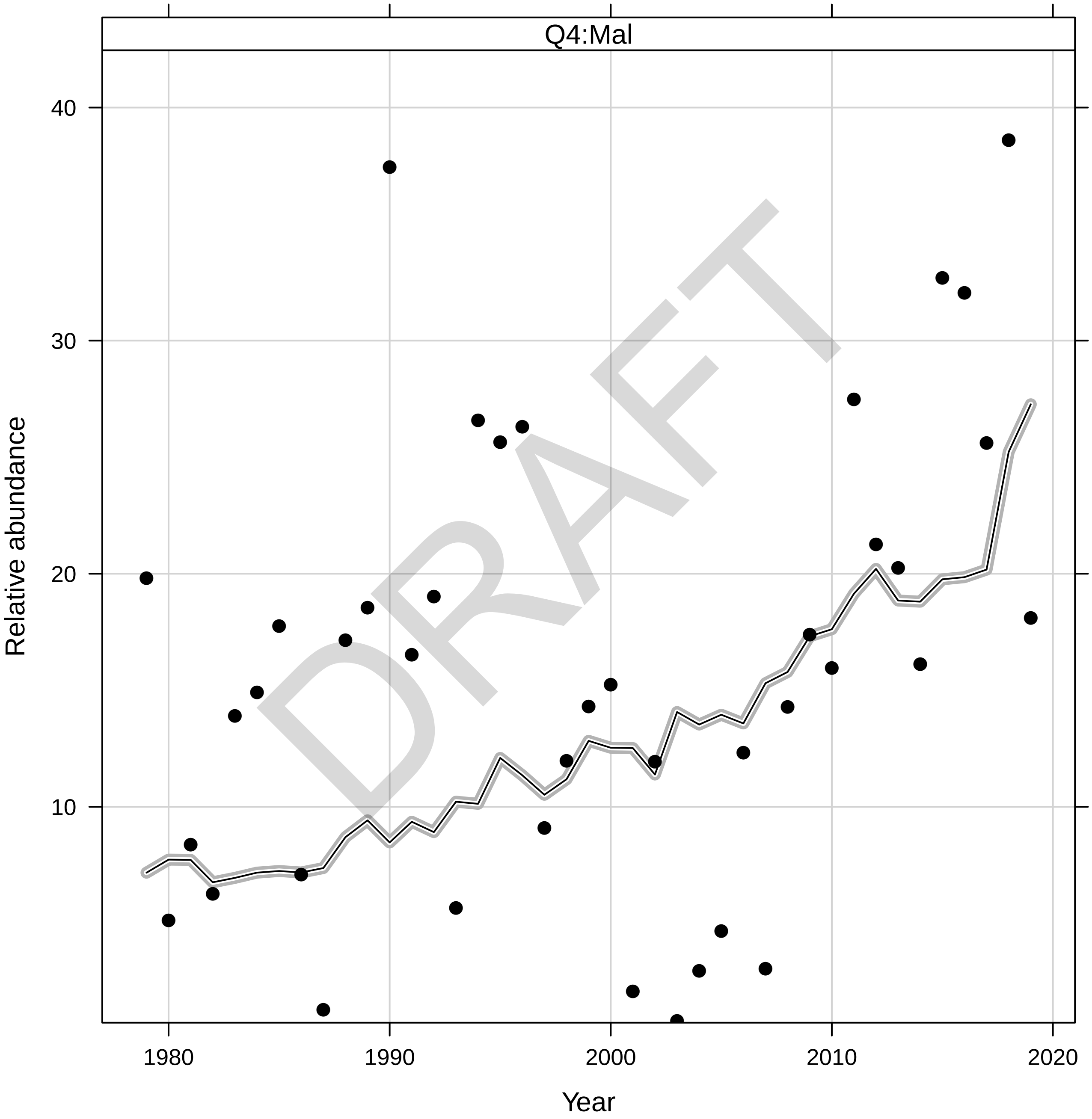
r60_ind_trawl_v6f6
MaMQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

r60_ind_trawl_v6f6
MaMQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

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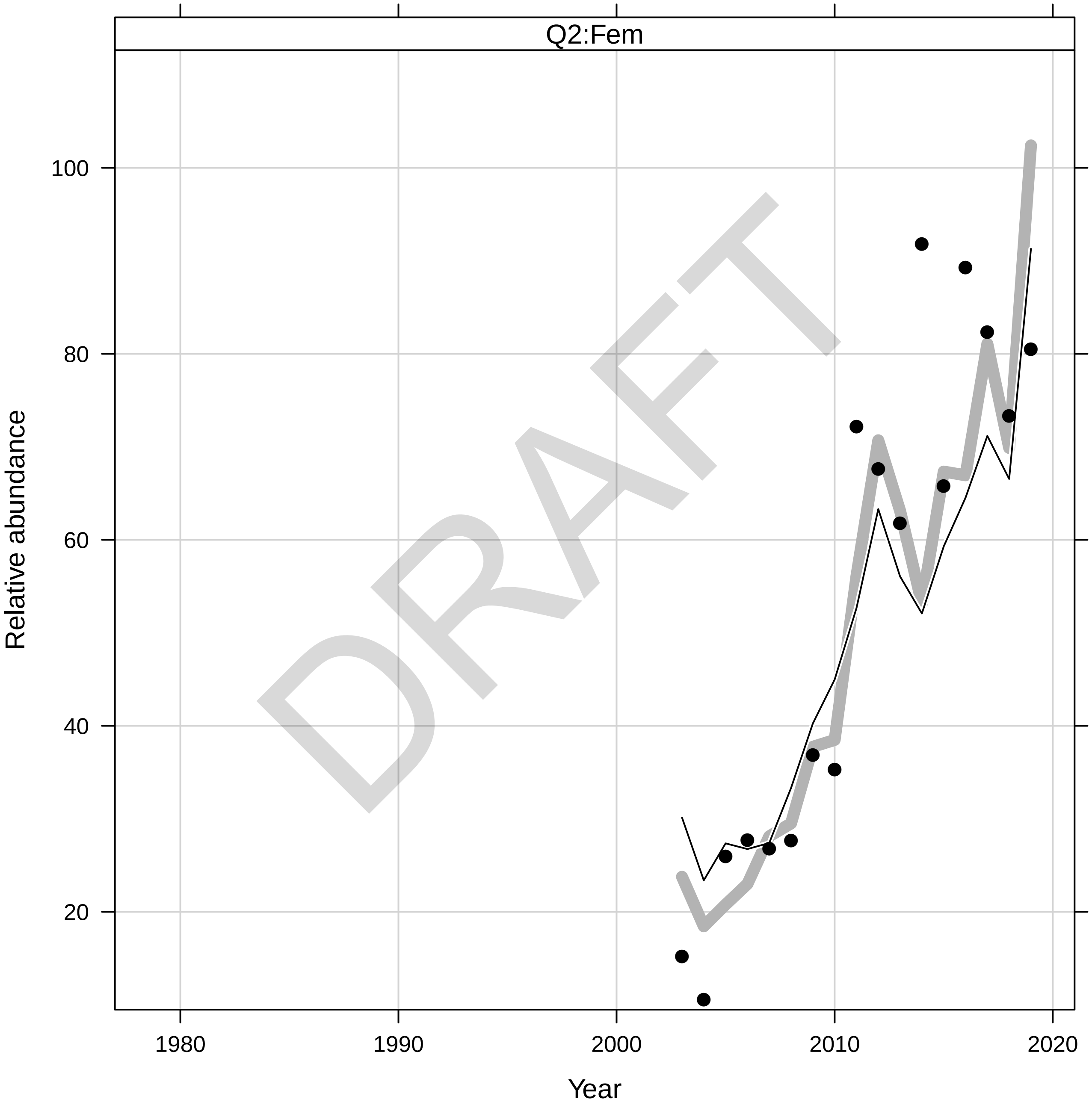
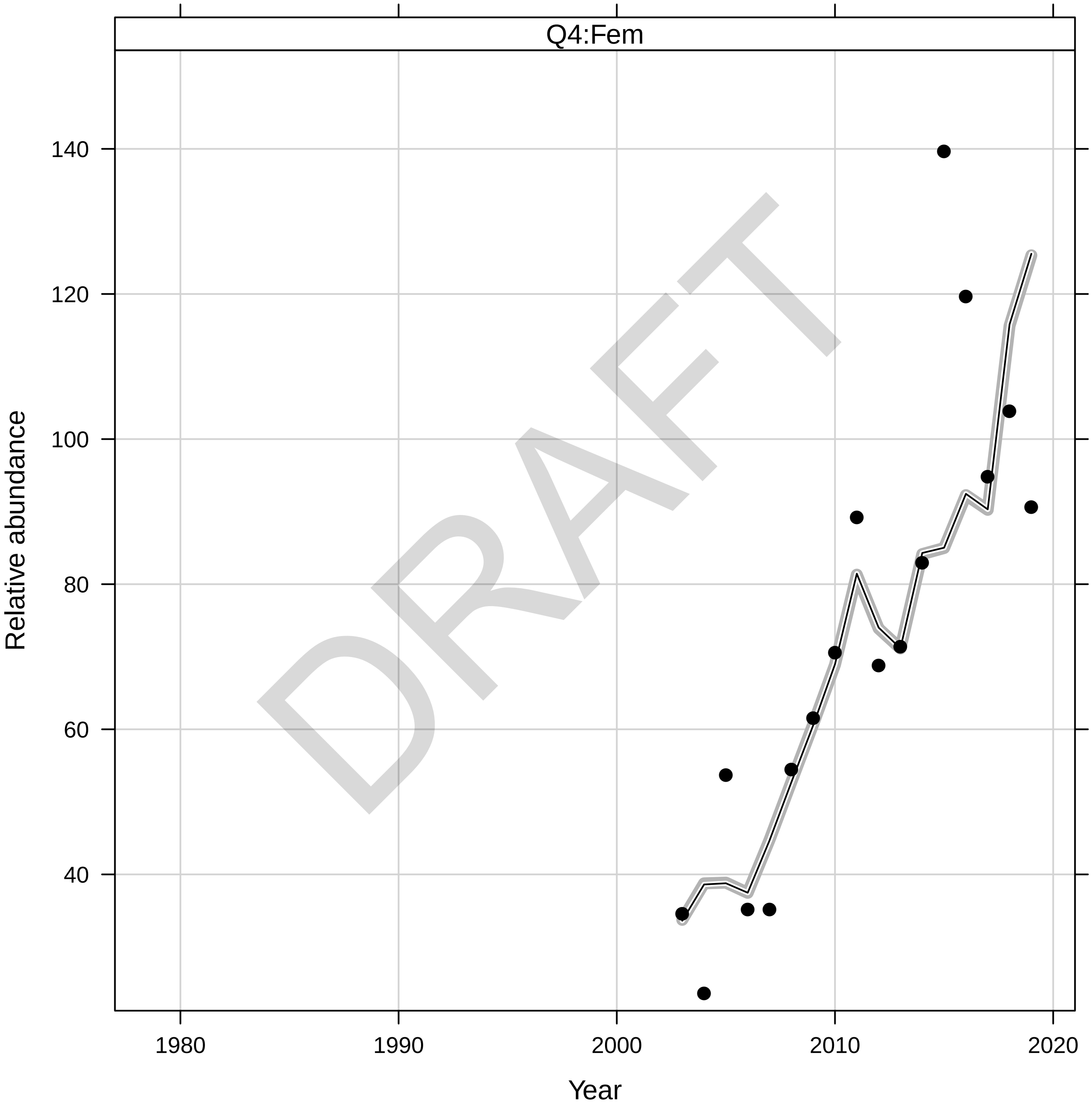
r60_ind_trawl_v6f6
MeFQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

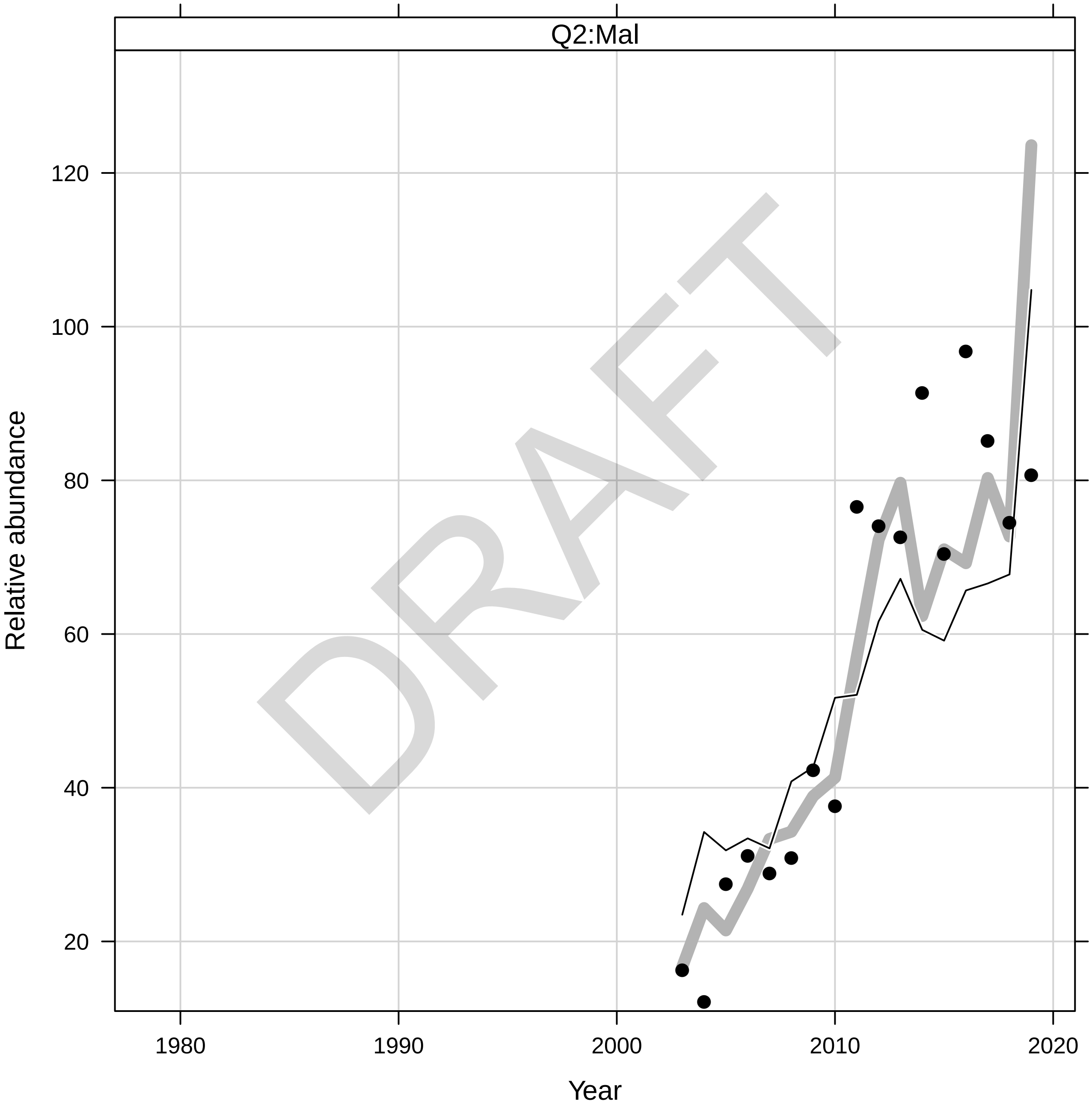
r60_ind_trawl_v6f6
MeFQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

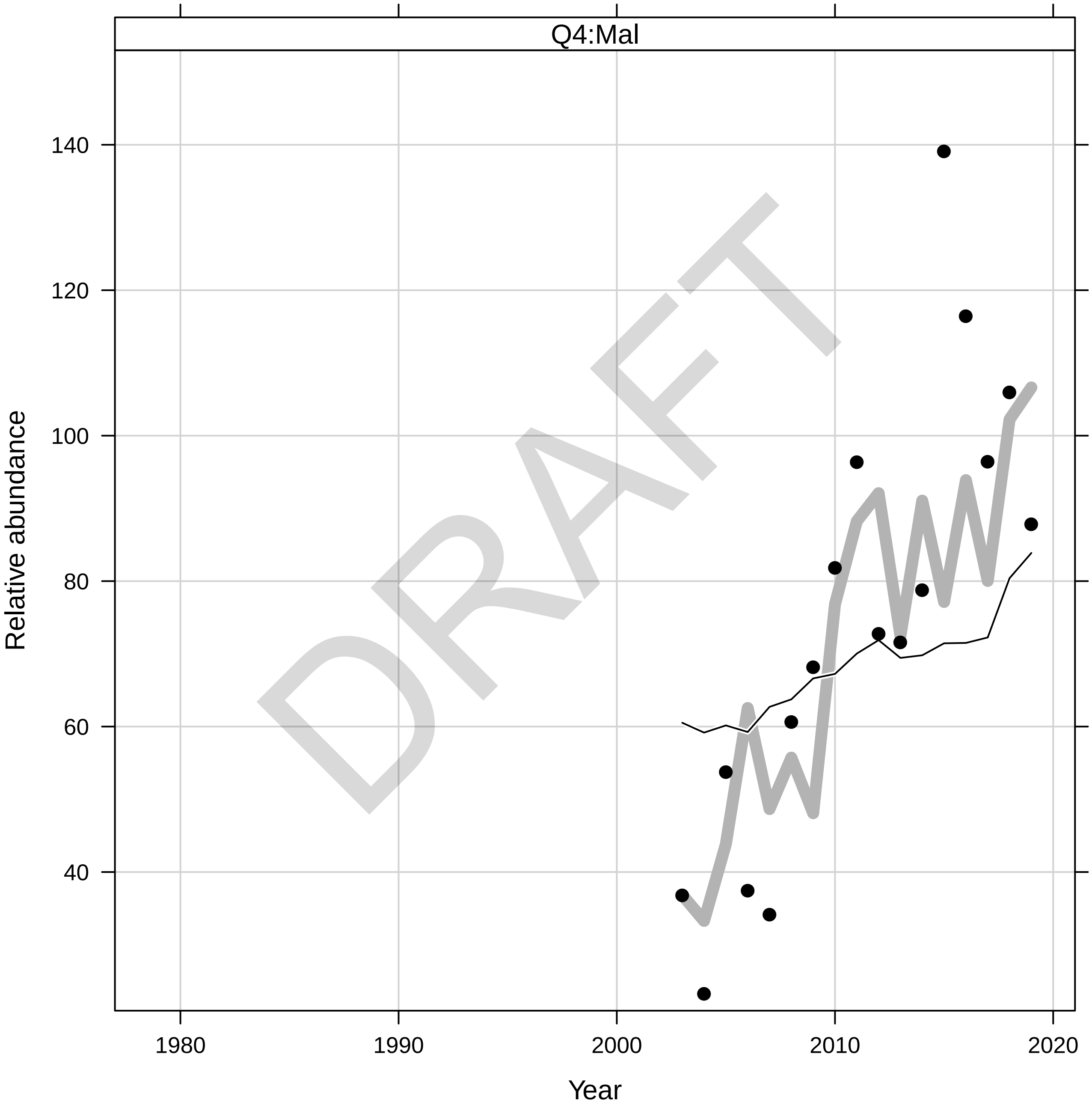
r60_ind_trawl_v6f6
MeMQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

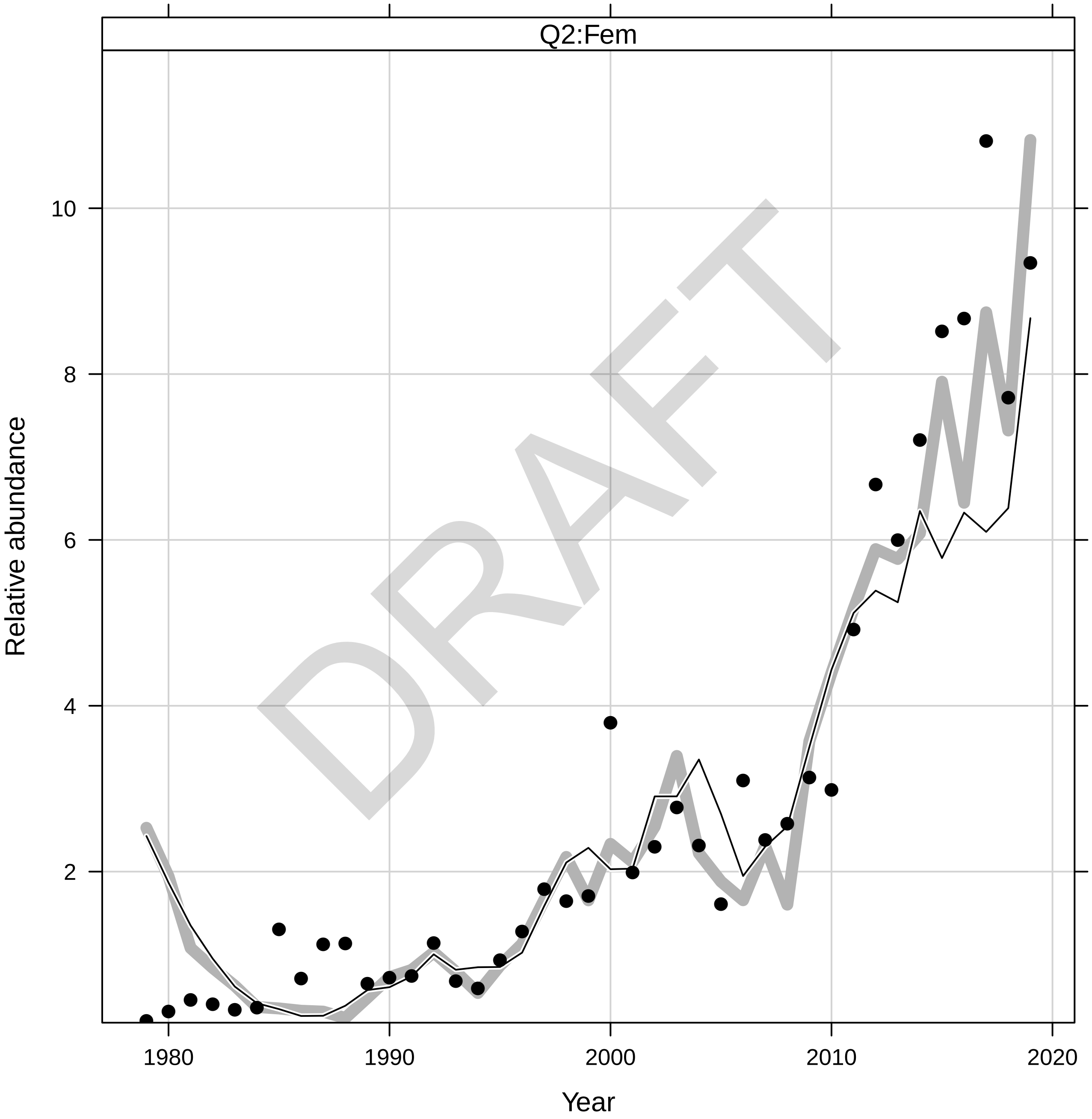
r60_ind_trawl_v6f6
MeMQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

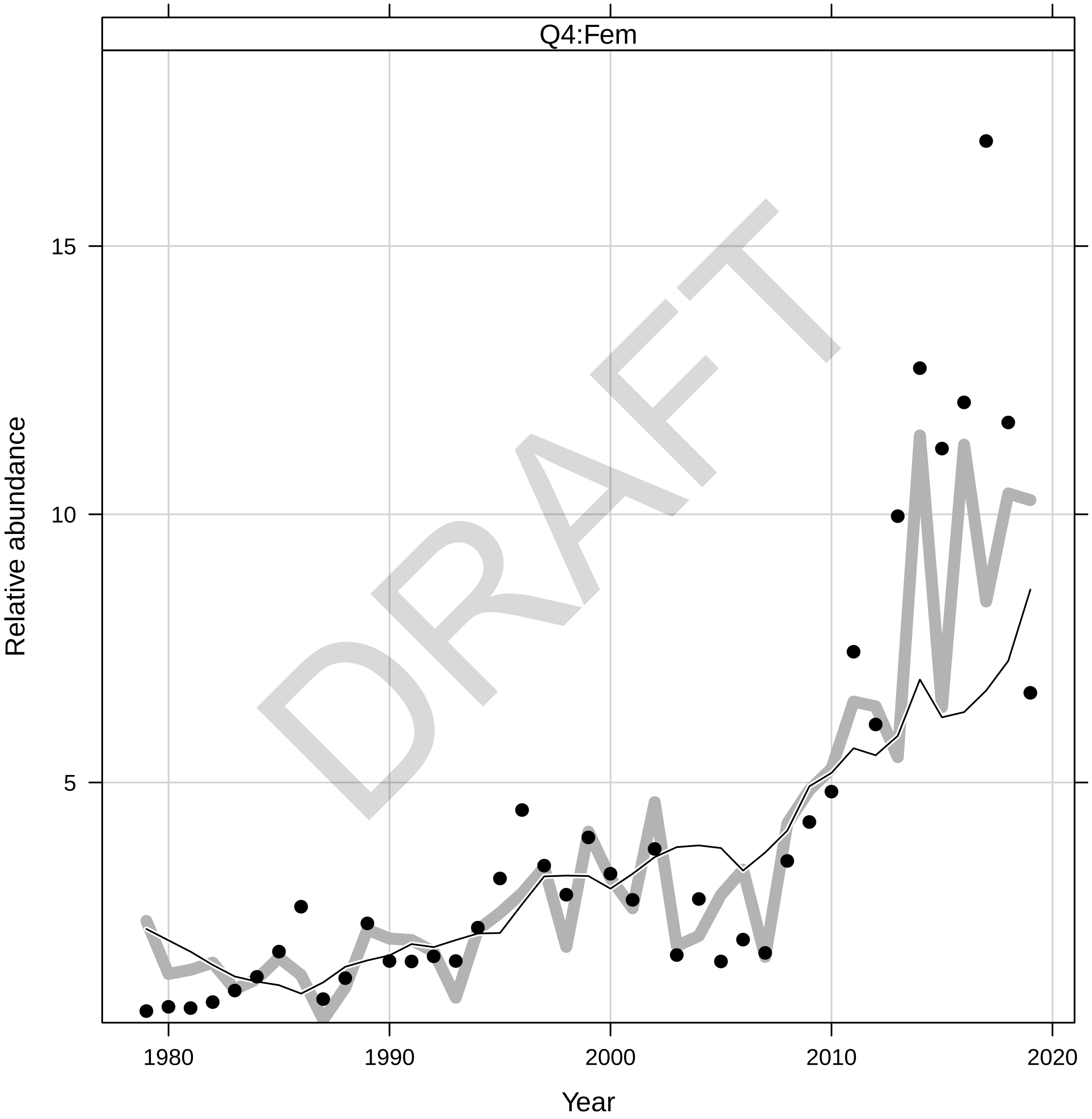
r60_ind_trawl_v6f6
NefscFQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

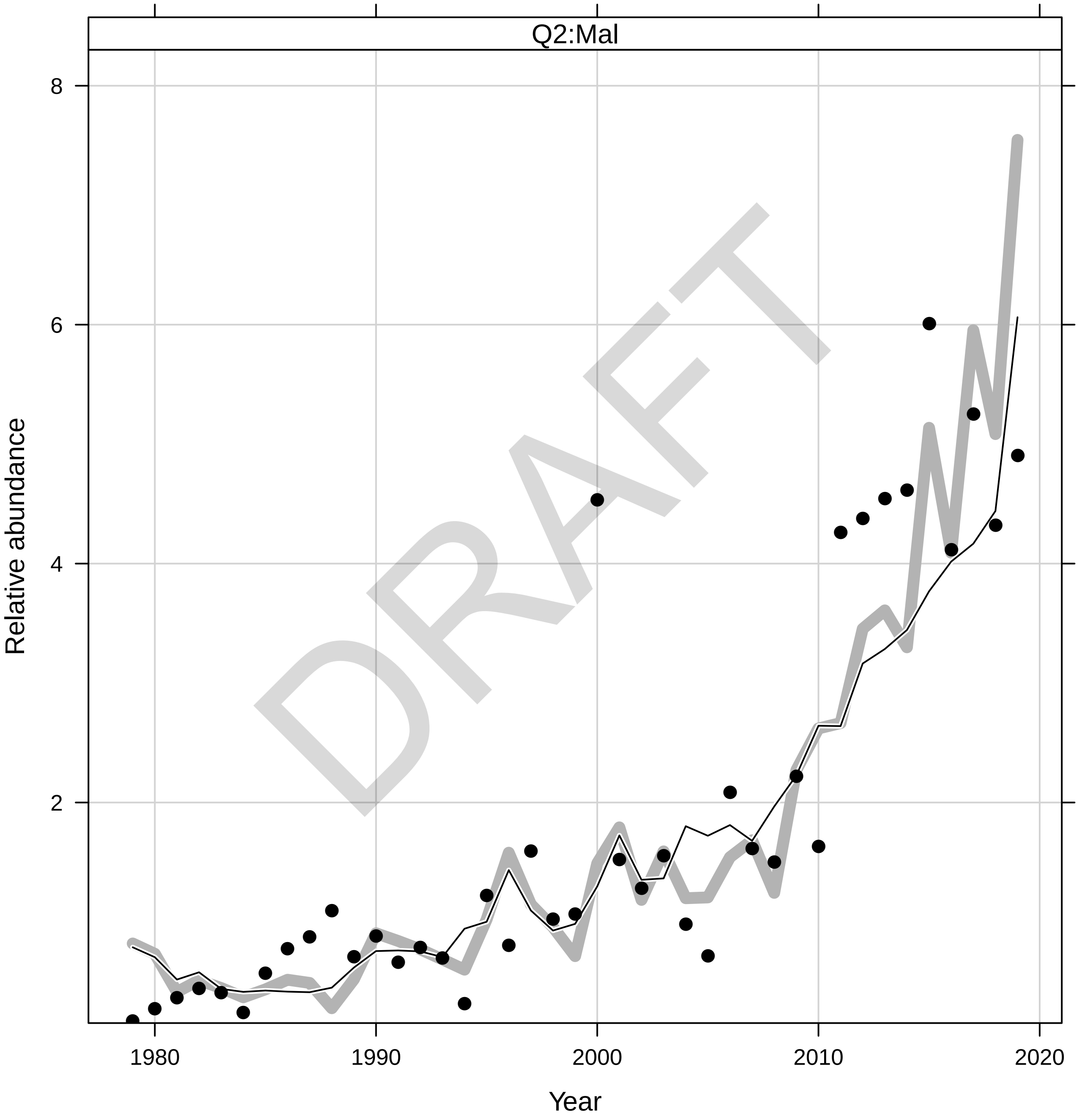
r60_ind_trawl_v6f6
NefscFQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

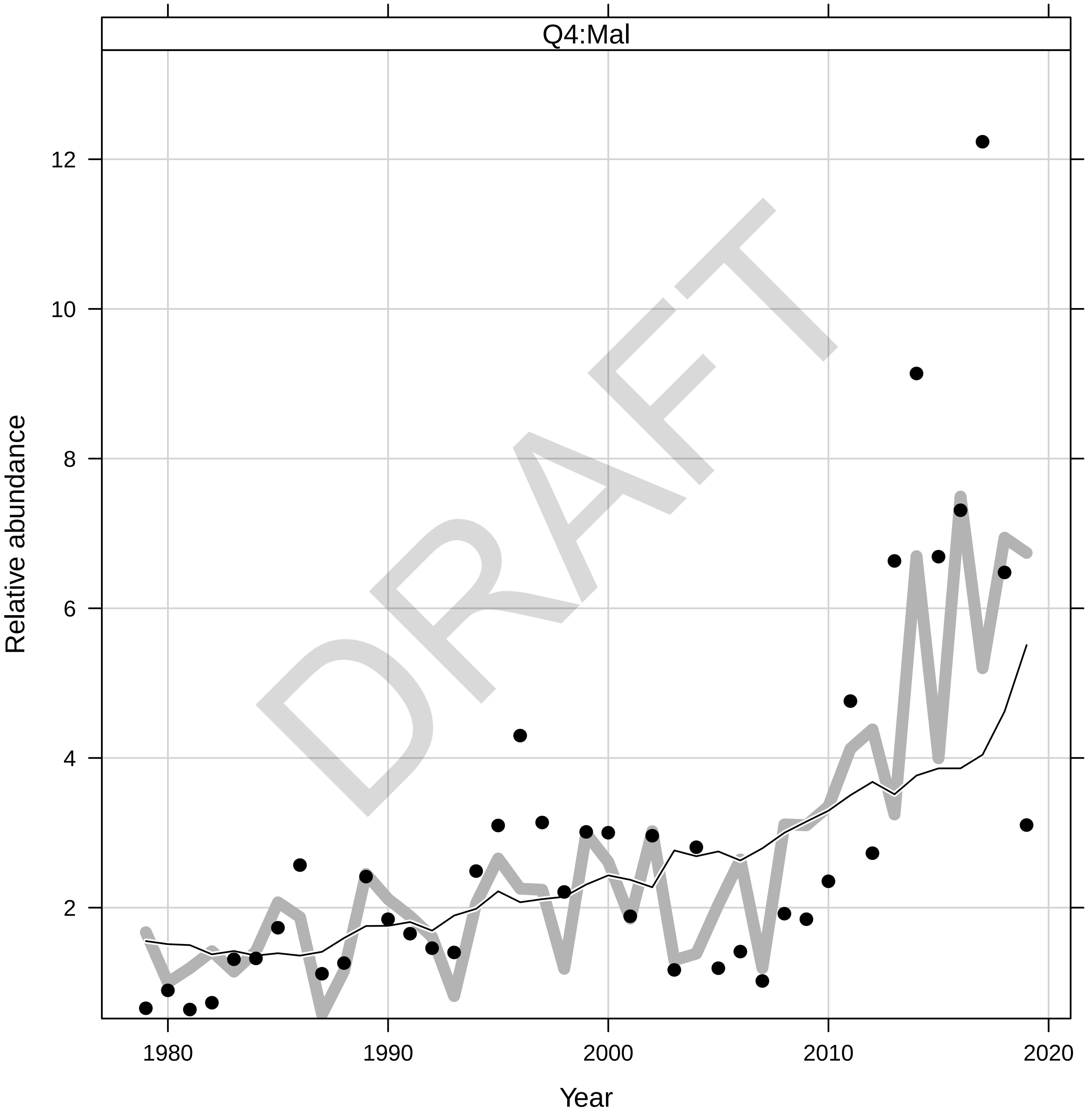
r60_ind_trawl_v6f6
NefscMQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

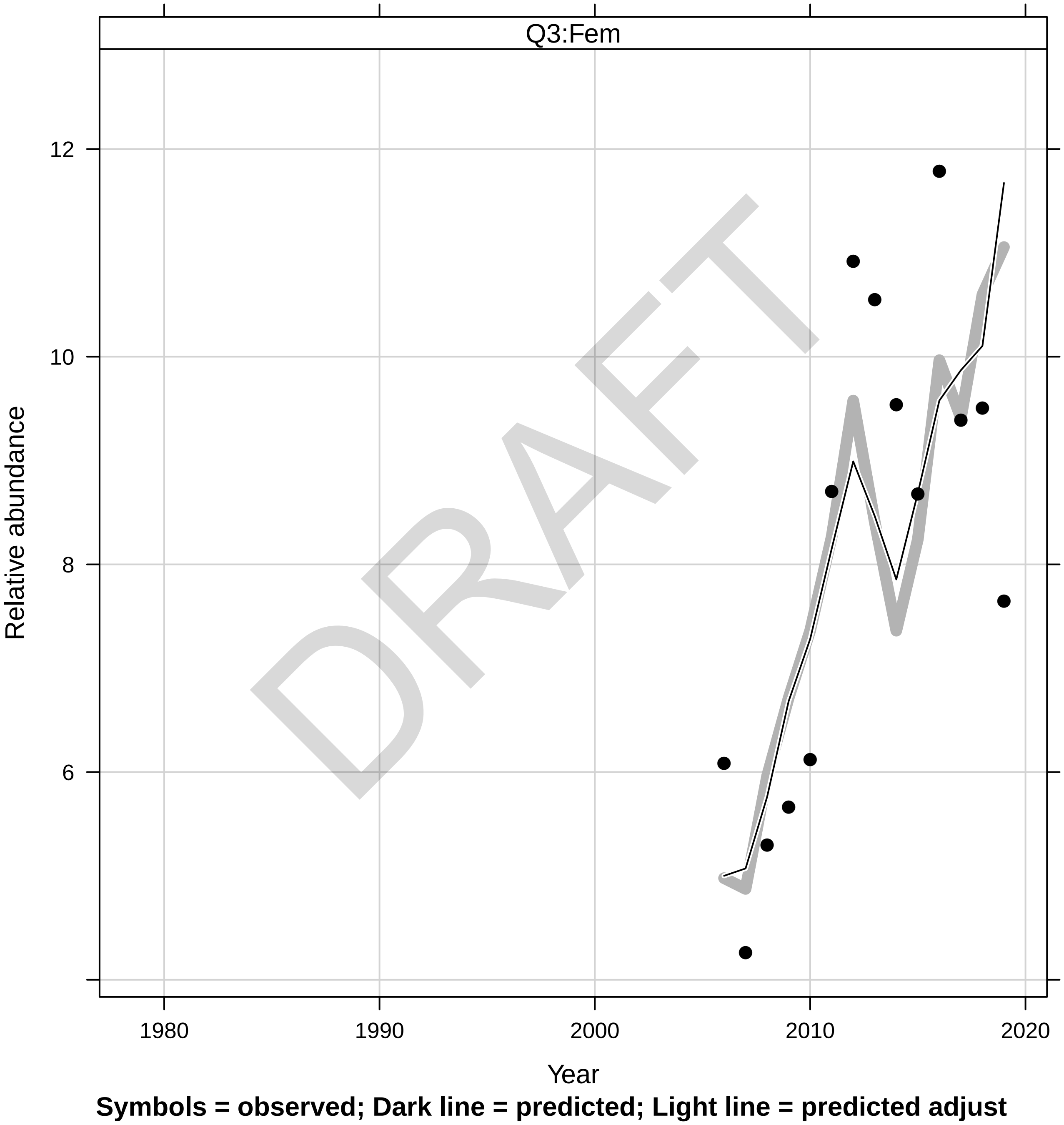
r60_ind_trawl_v6f6
NefscMQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

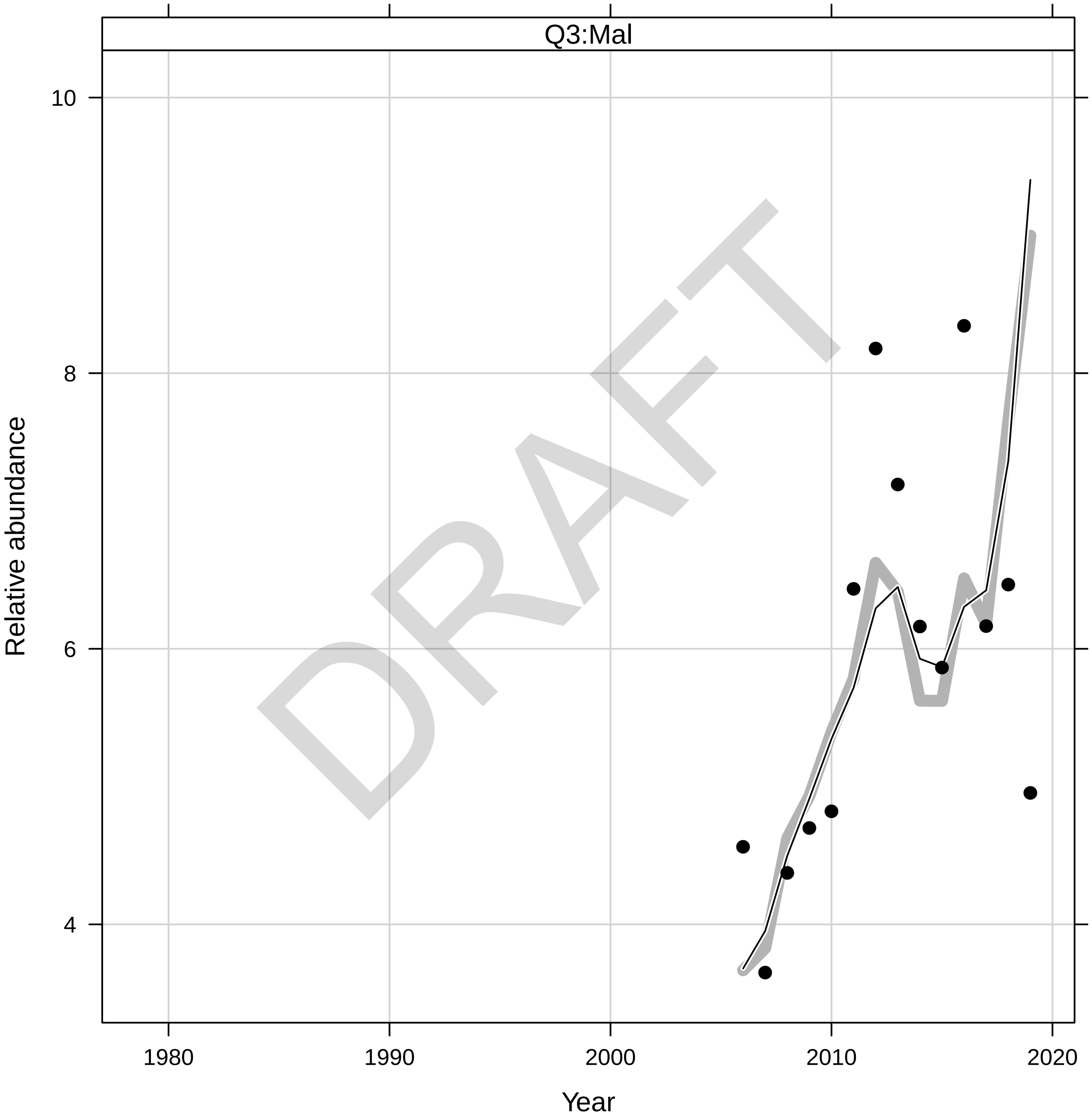
r60_ind_trawl_v6f6
VtsFQ3_stand observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

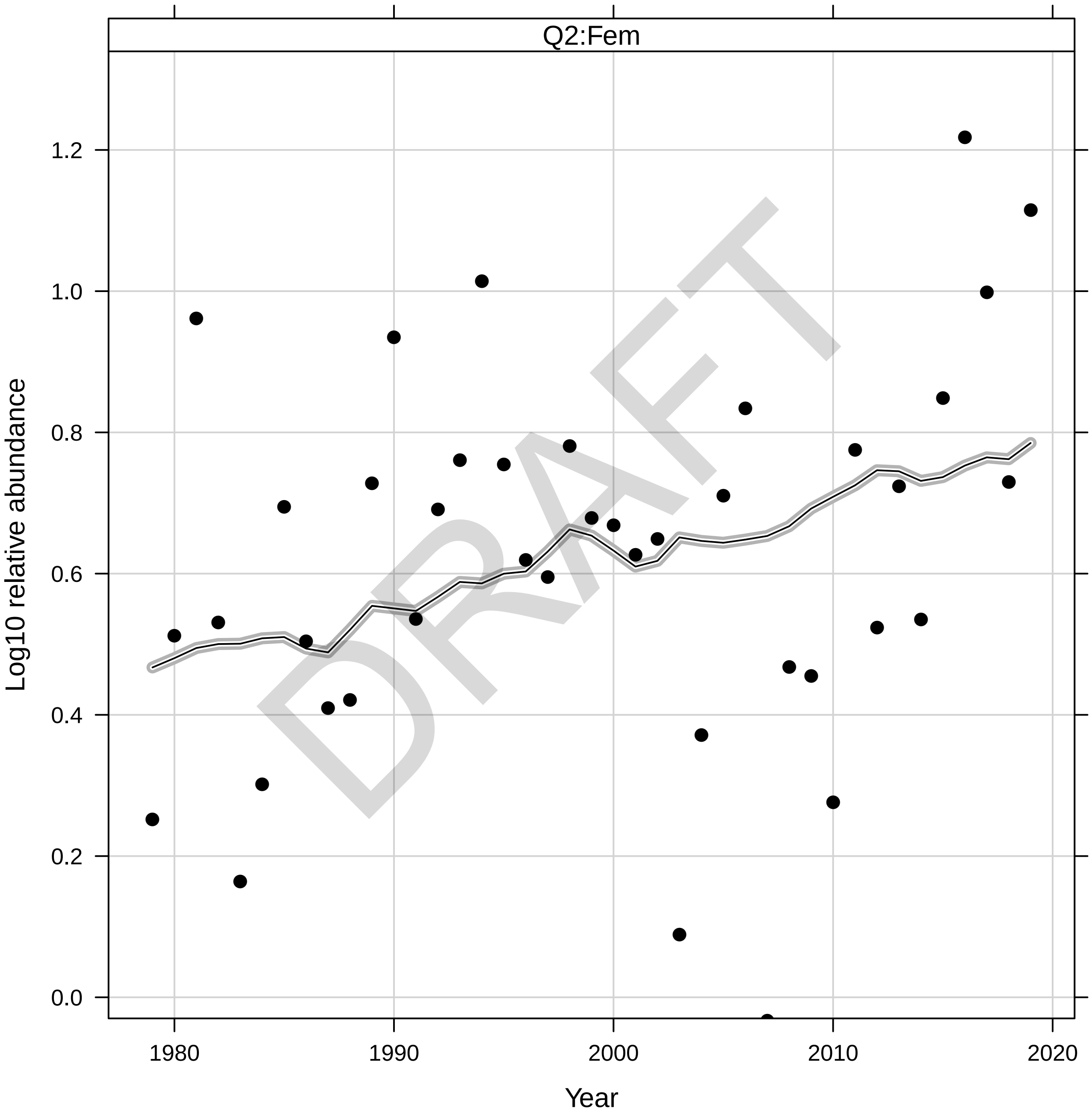
r60_ind_trawl_v6f6
VtsMQ3_stand observed and predicted survey trends



Symbols = observed; Dark line = predicted; Light line = predicted adjust

DRAFT

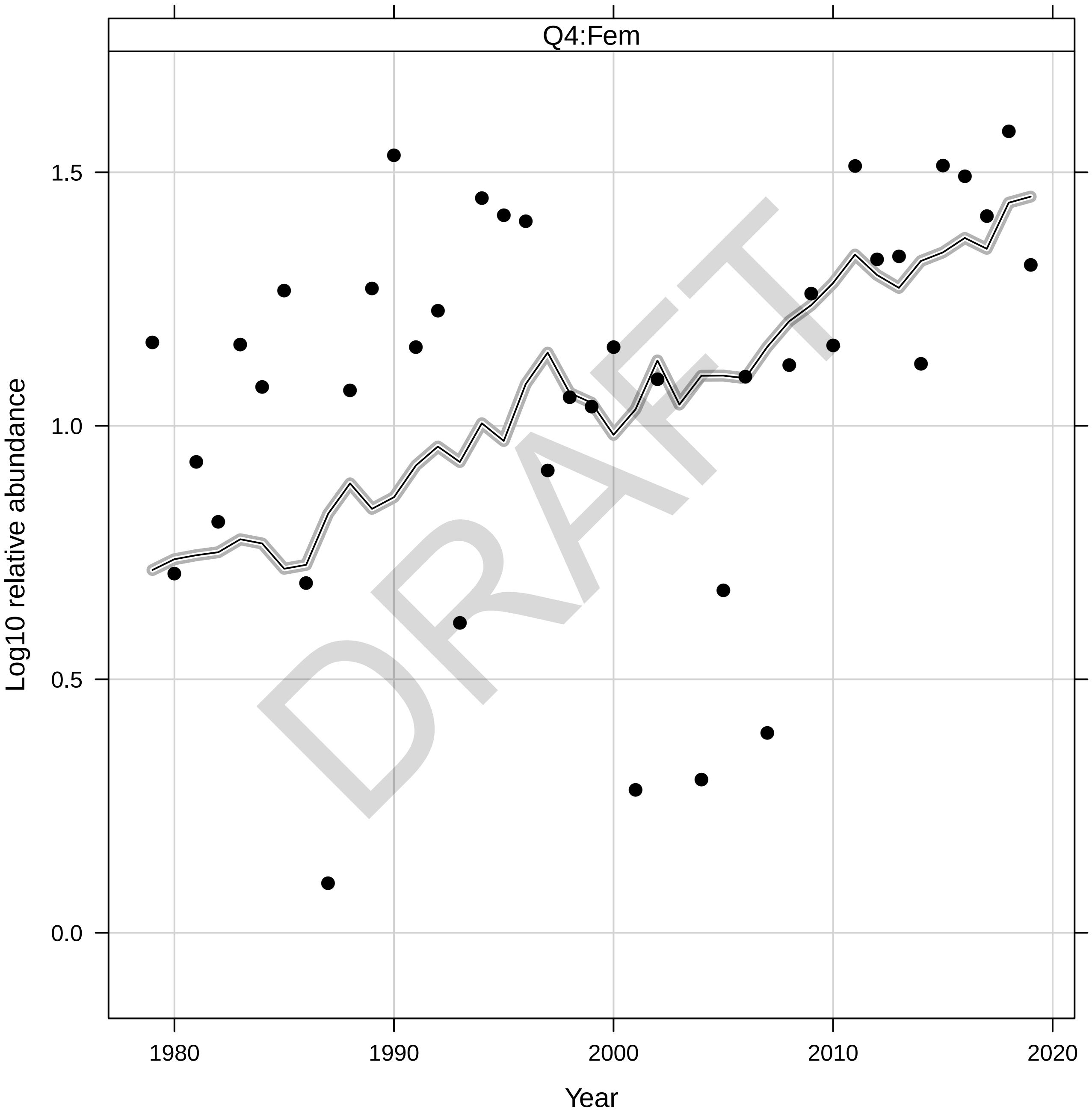
r60_ind_trawl_v6f6
MaFQ2 observed and predicted log survey trends



DRAFT

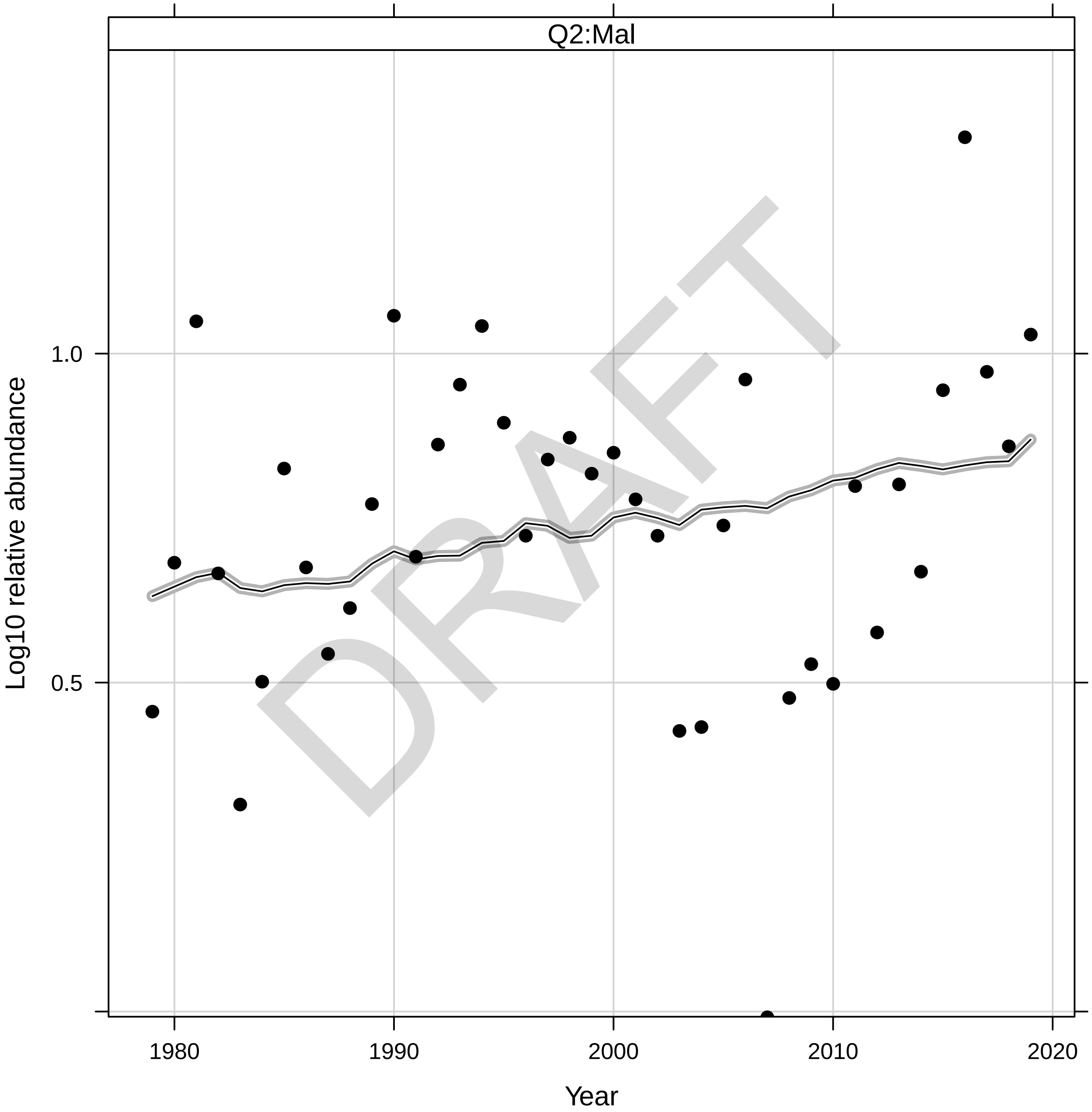
Symbols = observed; Dark line = predicted; Light line = predicted adjust

r60_ind_trawl_v6f6
MaFQ4 observed and predicted log survey trends



Symbols = observed; Dark line = predicted; Light line = predicted adjust

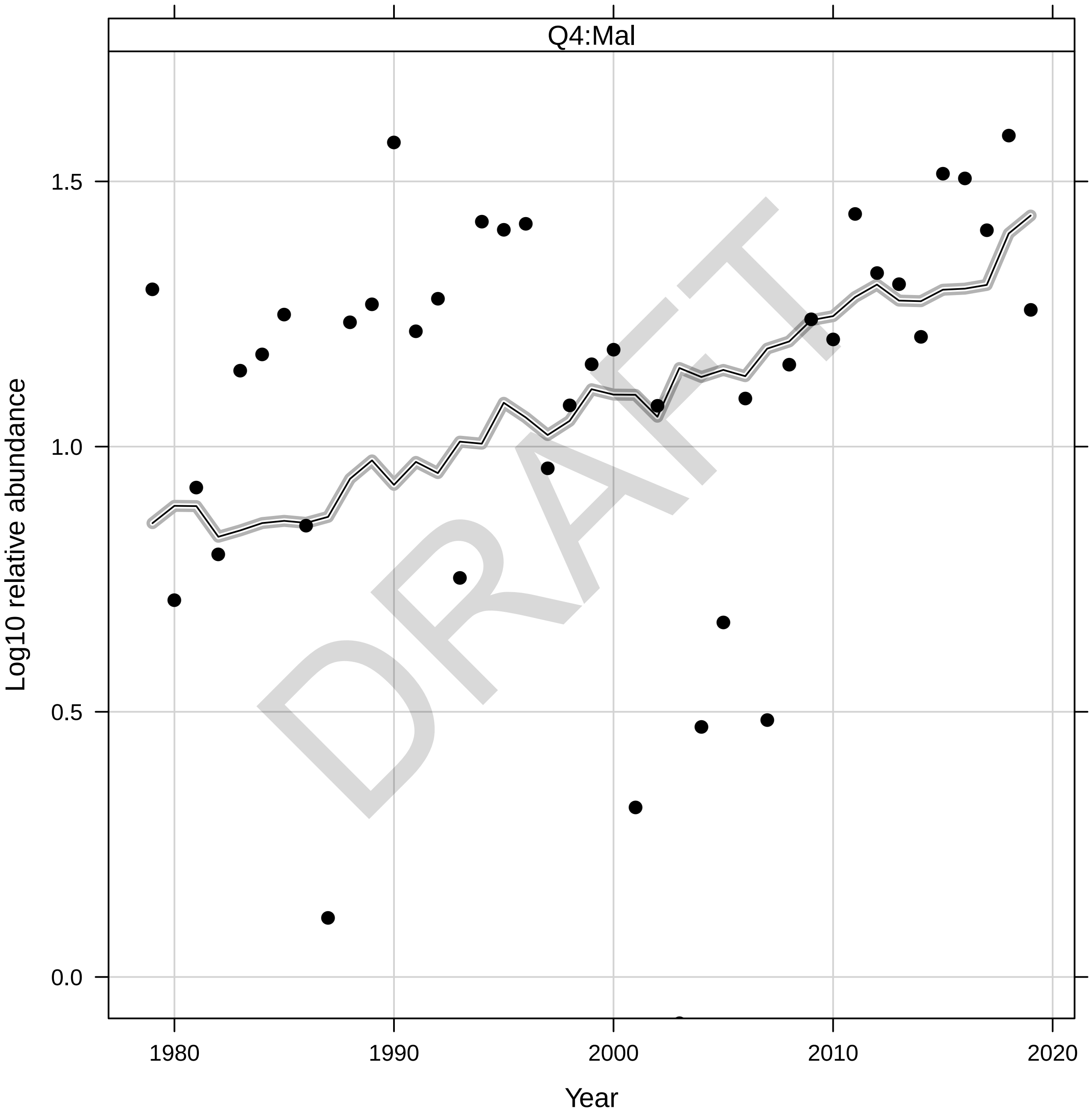
r60_ind_trawl_v6f6
MaMQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

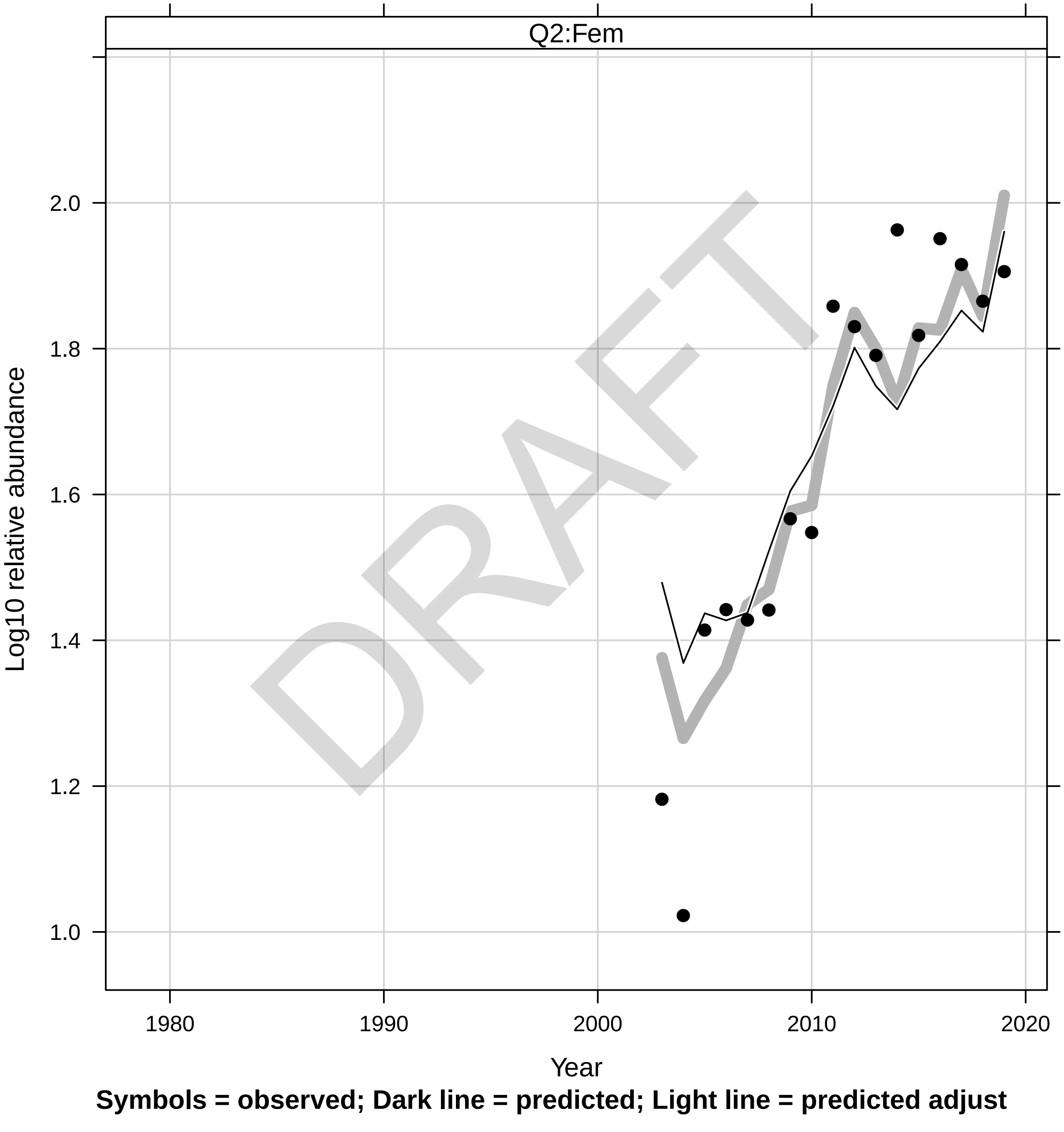
r60_ind_trawl_v6f6
MaMQ4 observed and predicted log survey trends



DRAFT

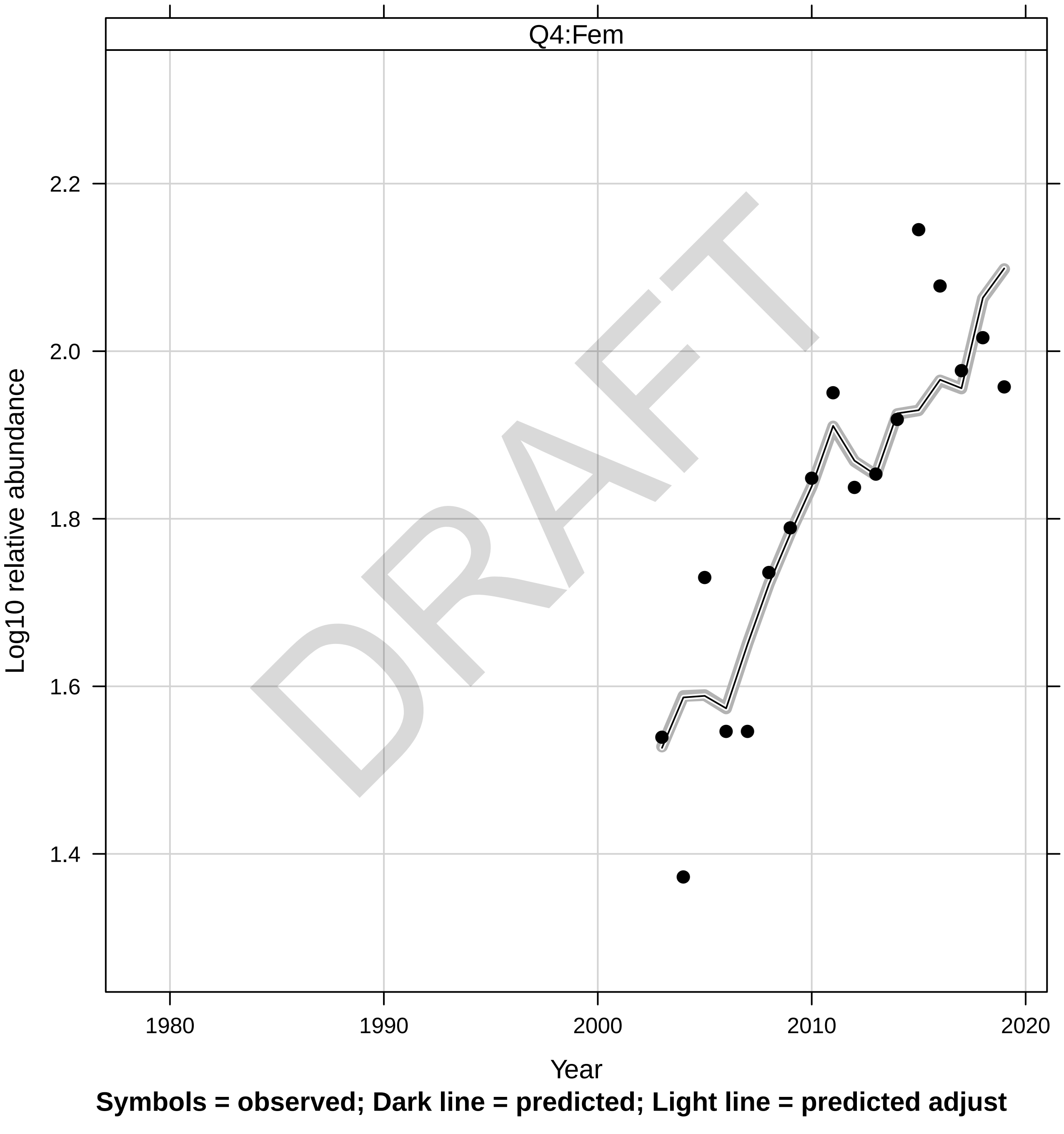
Symbols = observed; Dark line = predicted; Light line = predicted adjust

r60_ind_trawl_v6f6
MeFQ2 observed and predicted log survey trends



Symbols = observed; Dark line = predicted; Light line = predicted adjust

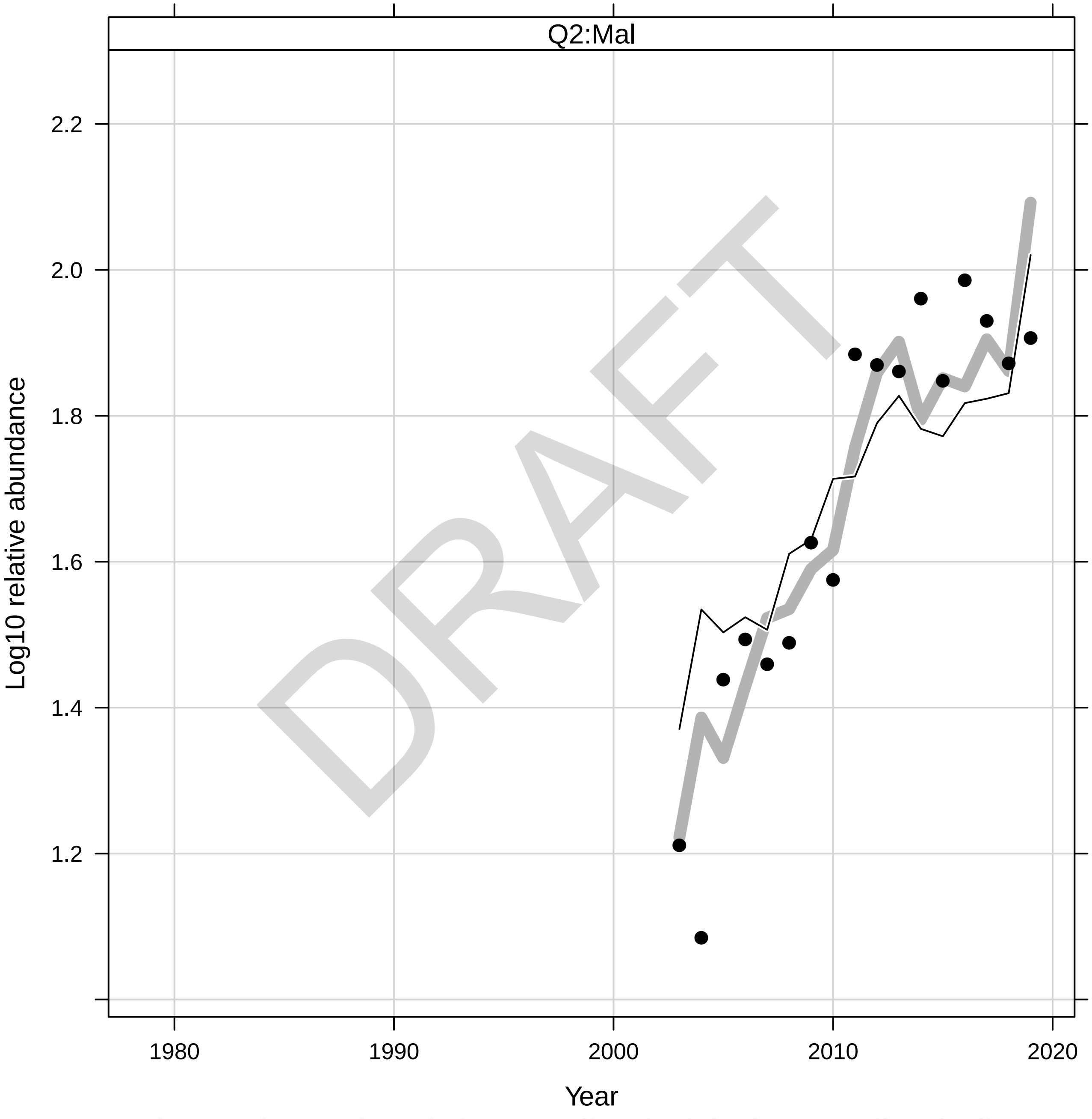
r60_ind_trawl_v6f6
MeFQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

r60_ind_trawl_v6f6
MeMQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

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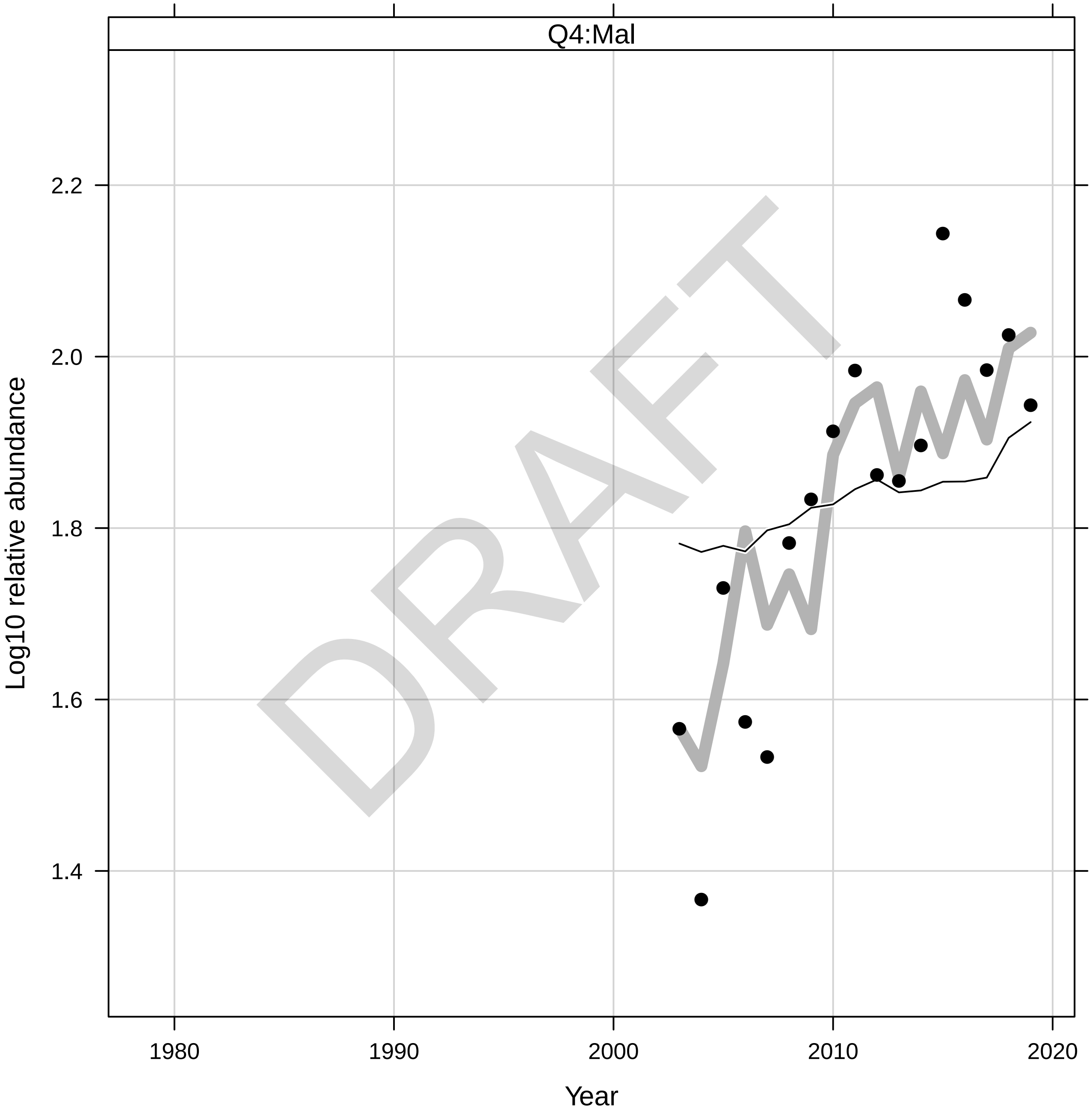
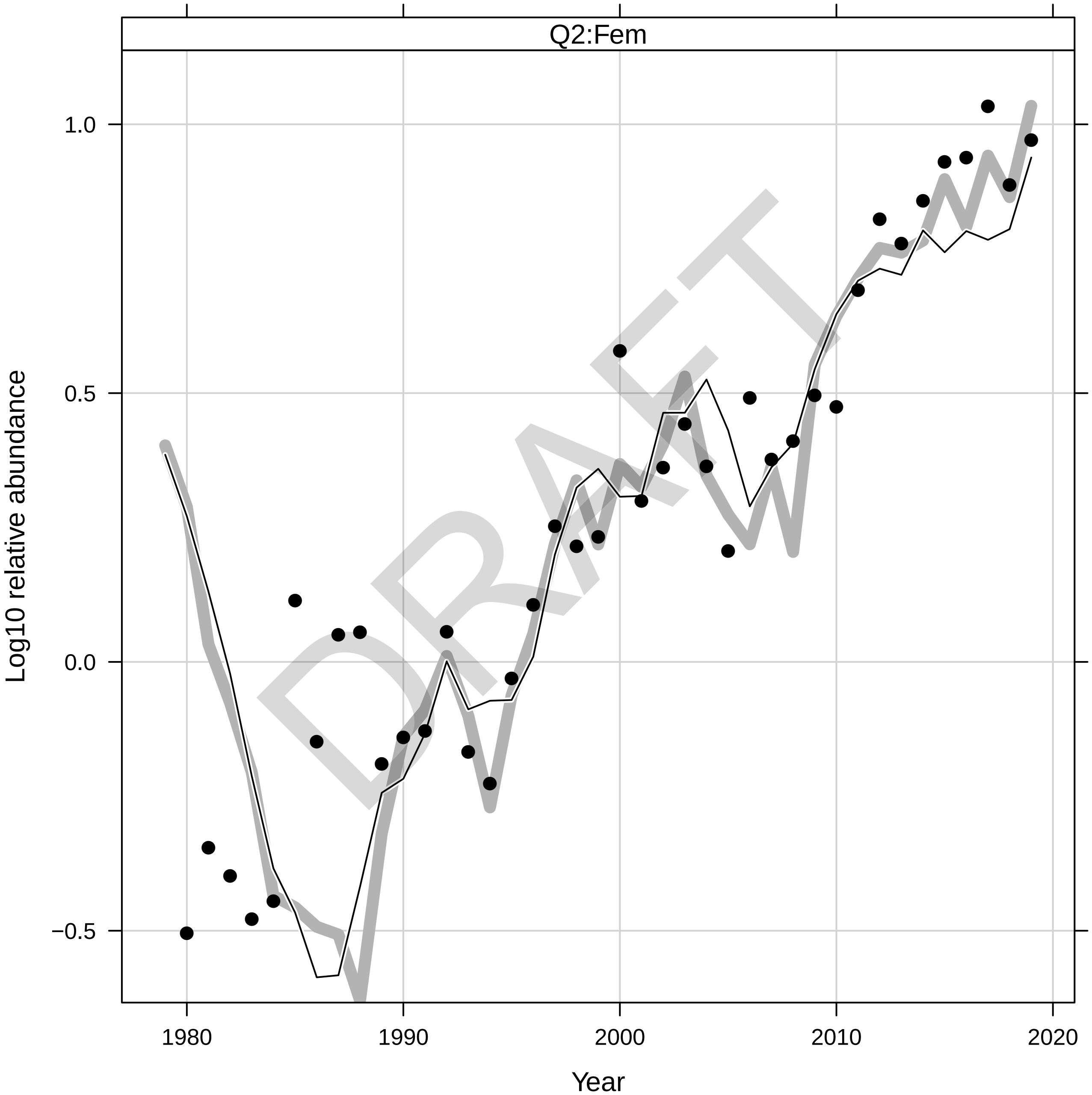
r60_ind_trawl_v6f6
MeMQ4 observed and predicted log survey trends



DRAFT

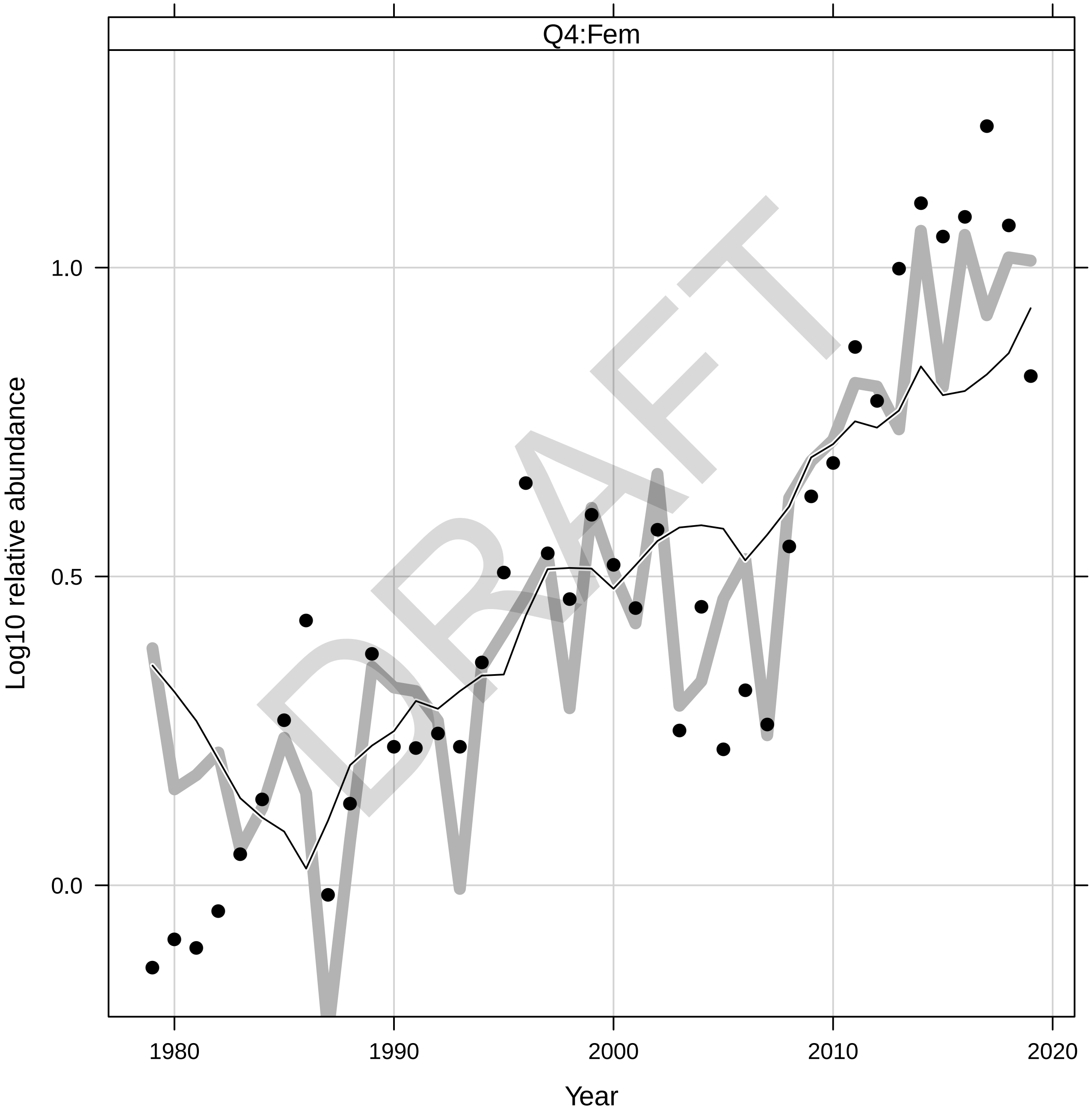
Symbols = observed; Dark line = predicted; Light line = predicted adjust

r60_ind_trawl_v6f6
NefscFQ2 observed and predicted log survey trends



Symbols = observed; Dark line = predicted; Light line = predicted adjust

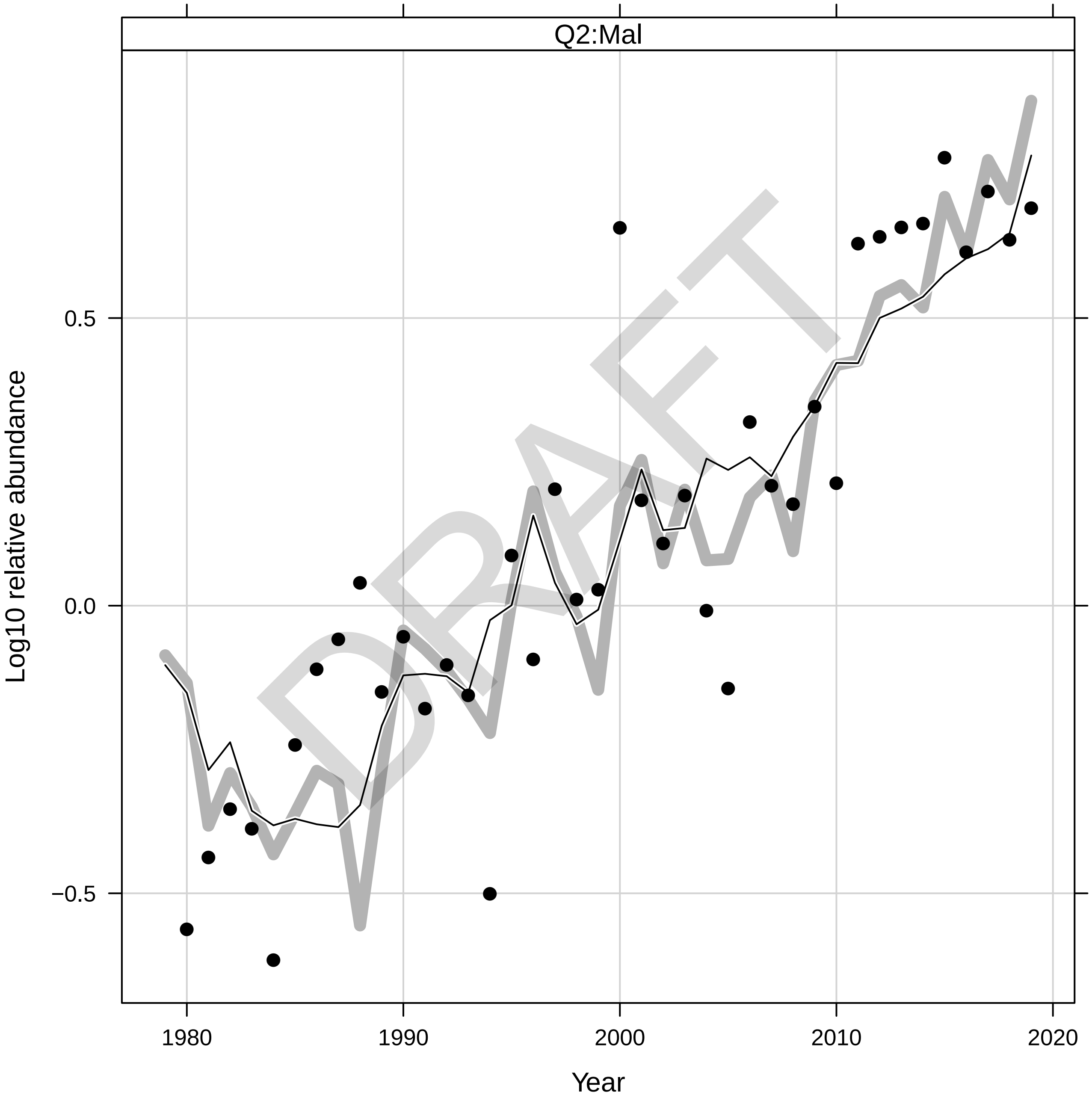
r60_ind_trawl_v6f6
NefscFQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

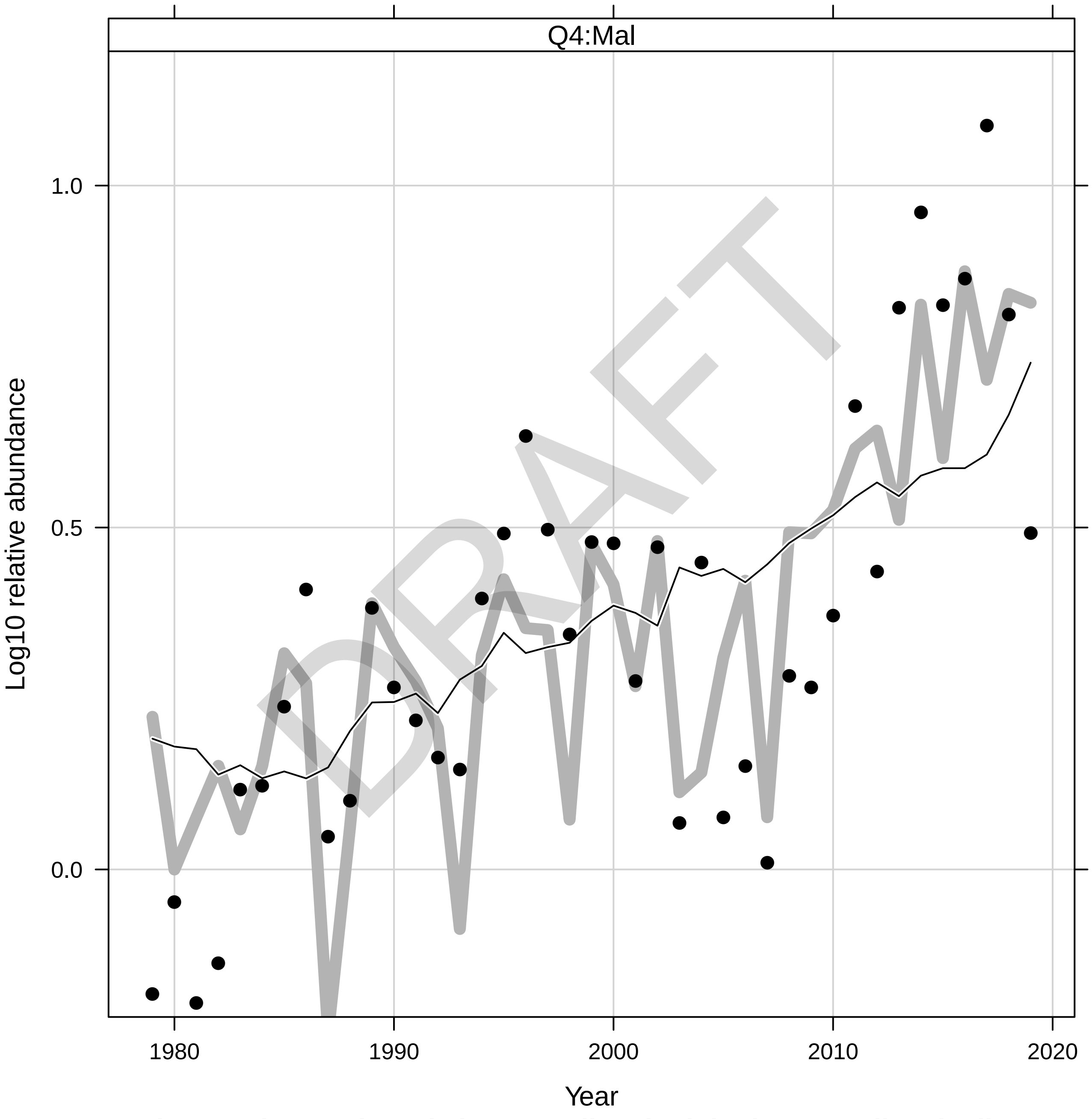
r60_ind_trawl_v6f6
NefscMQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

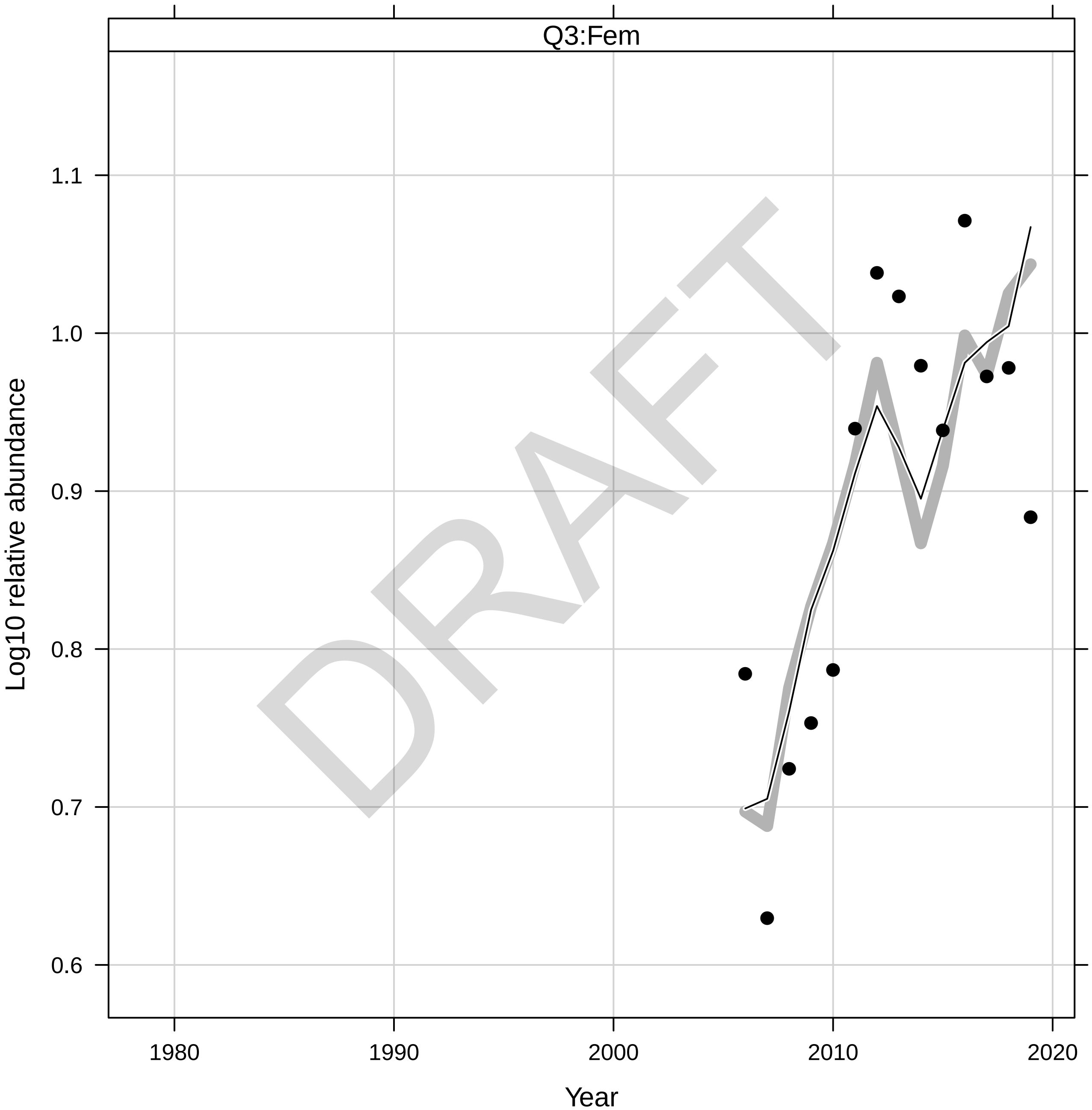
r60_ind_trawl_v6f6
NefscMQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

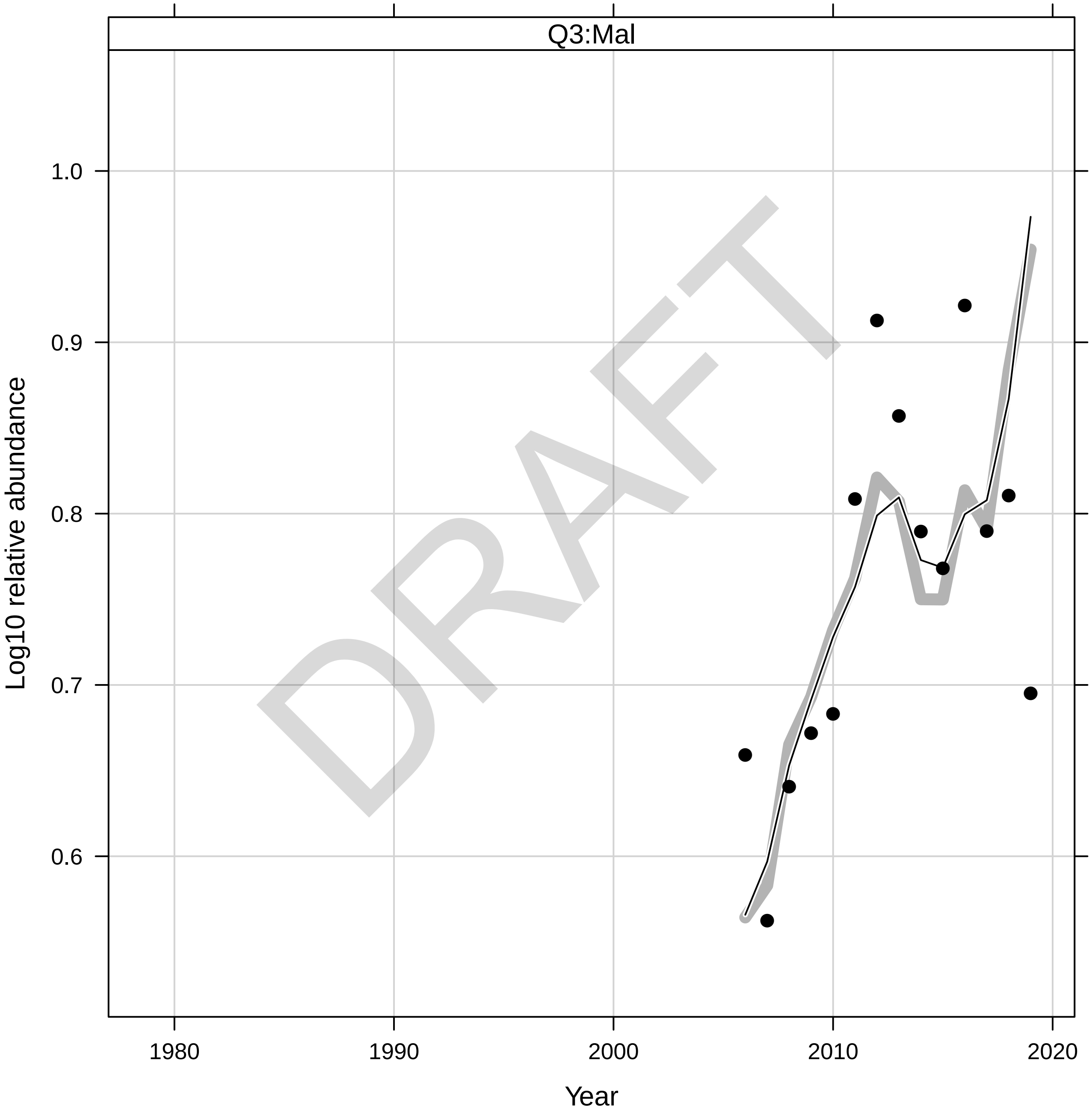
r60_ind_trawl_v6f6
VtsFQ3_stand observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

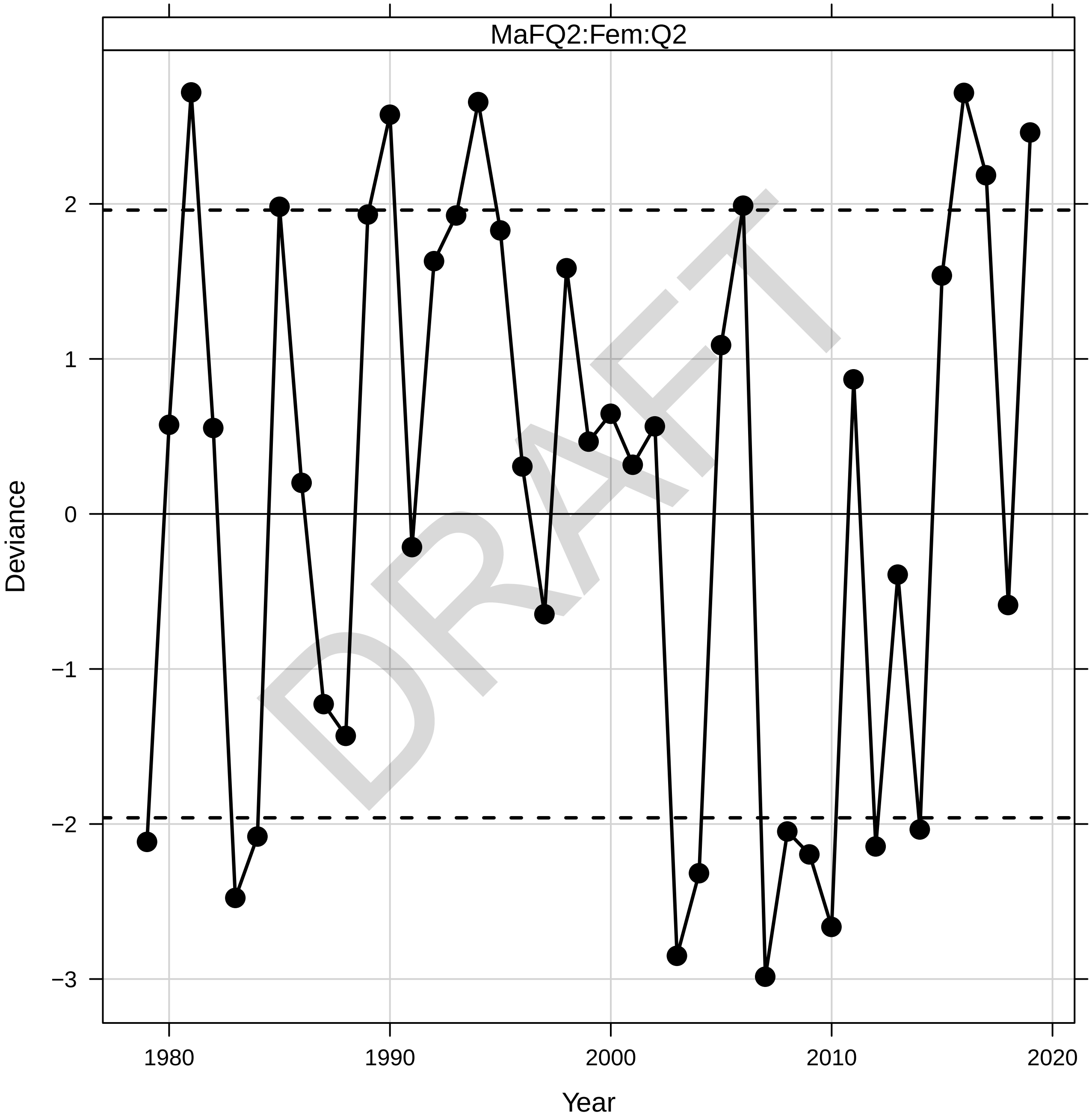
r60_ind_trawl_v6f6
VtsMQ3_stand observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

r60_ind_trawl_v6f6
deviance residuals for trend data MaFQ2



DRAFT

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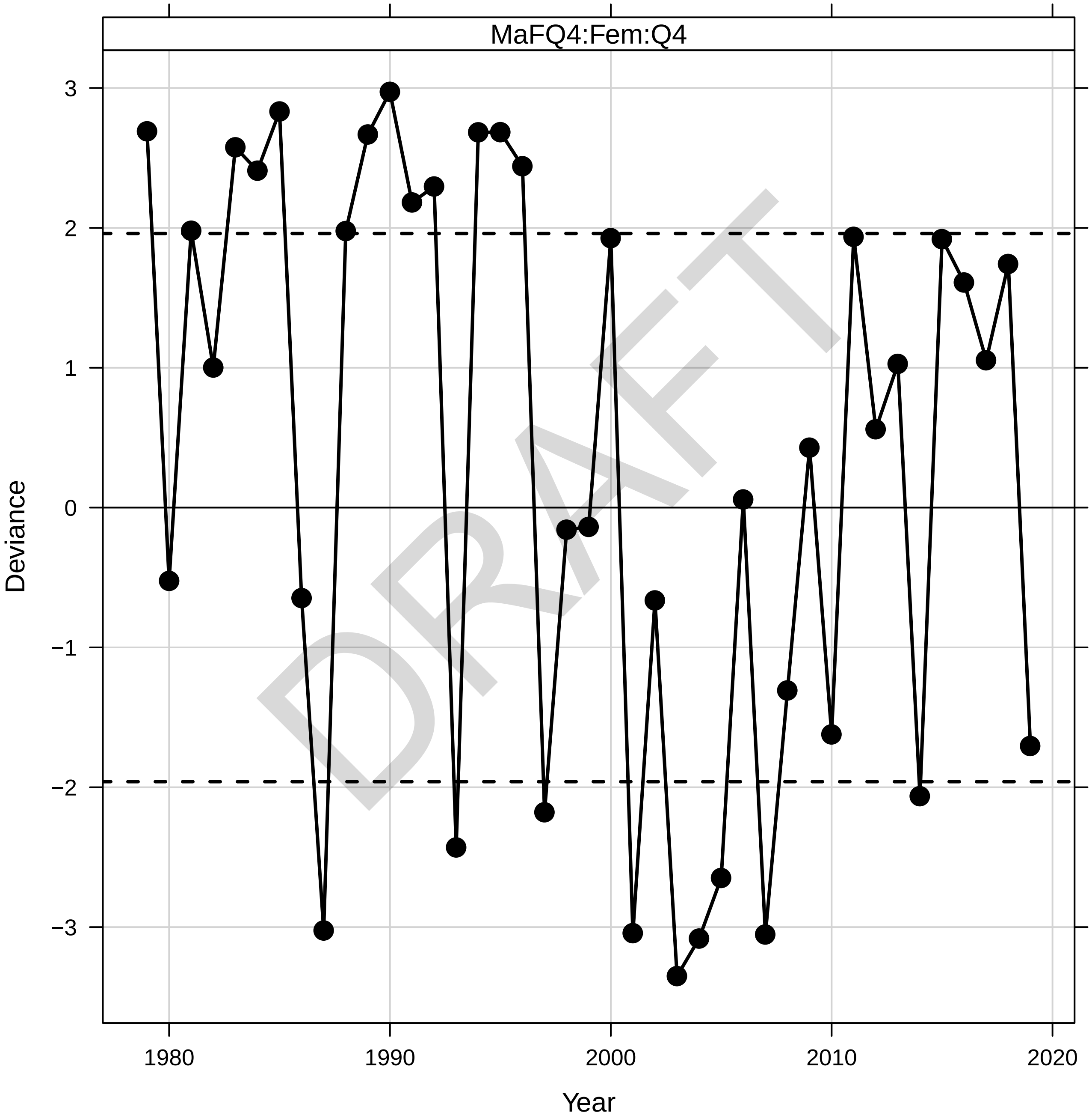
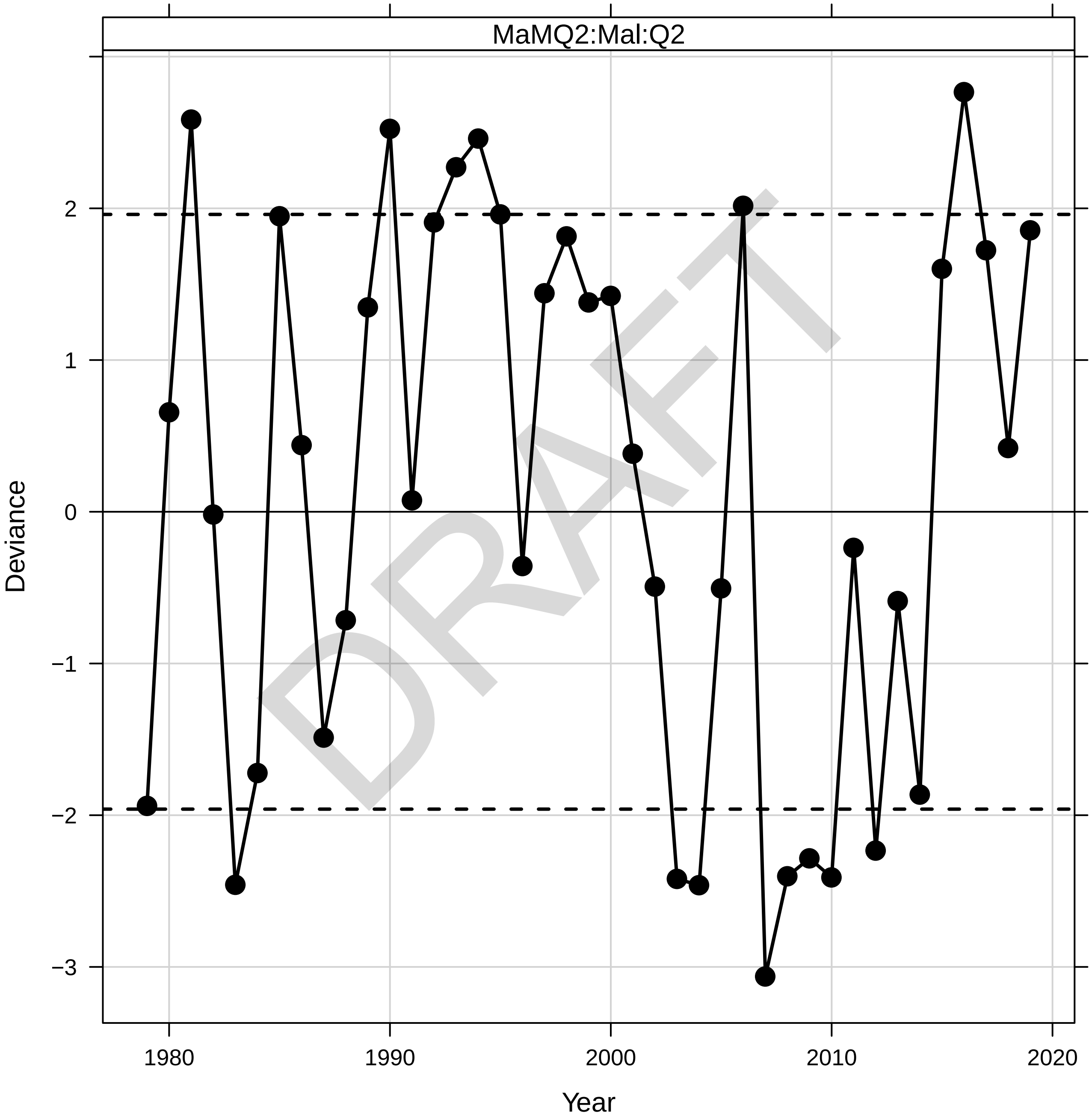
r60_ind_trawl_v6f6
deviance residuals for trend data MaFQ4



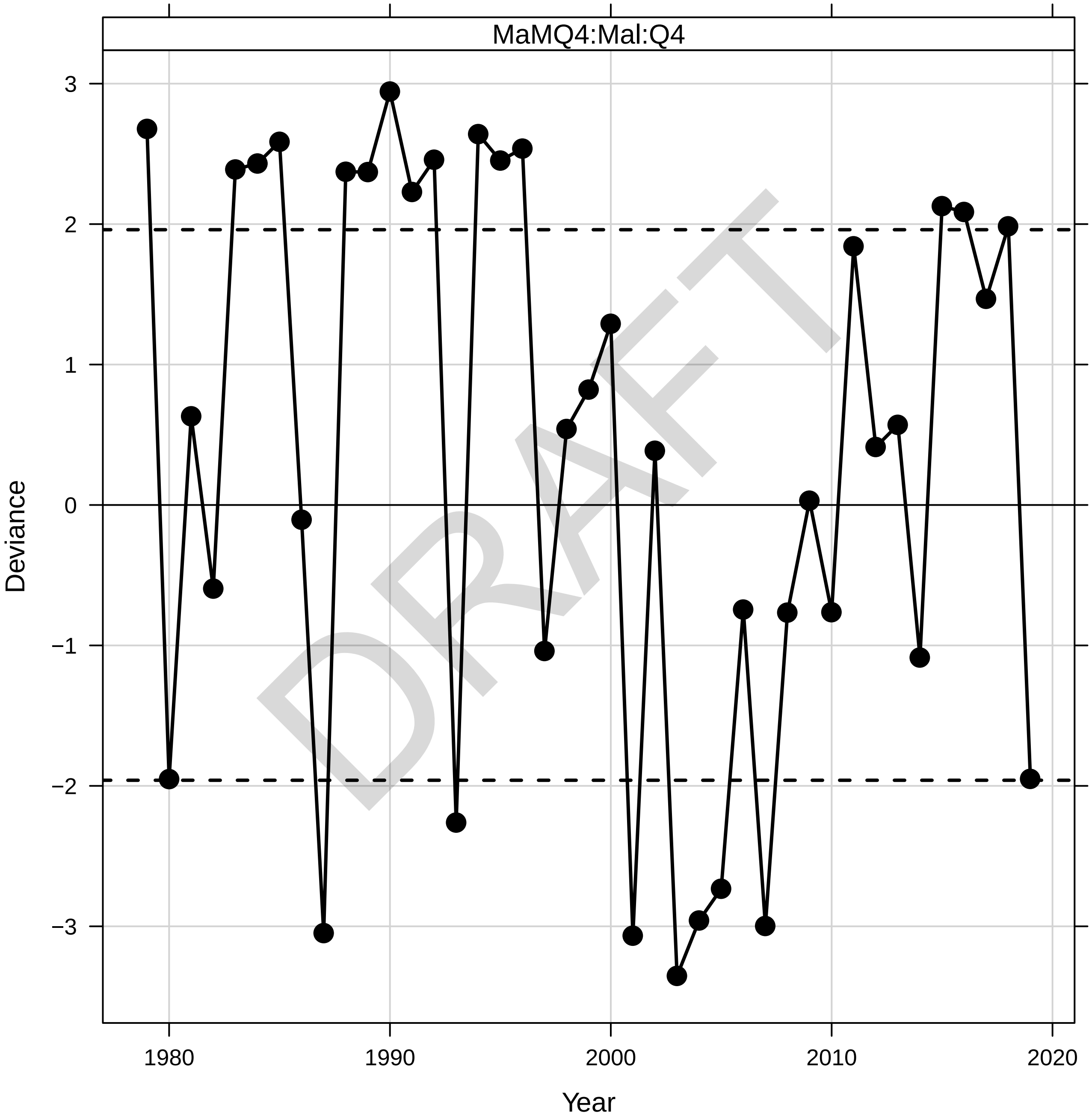
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data MaMQ2



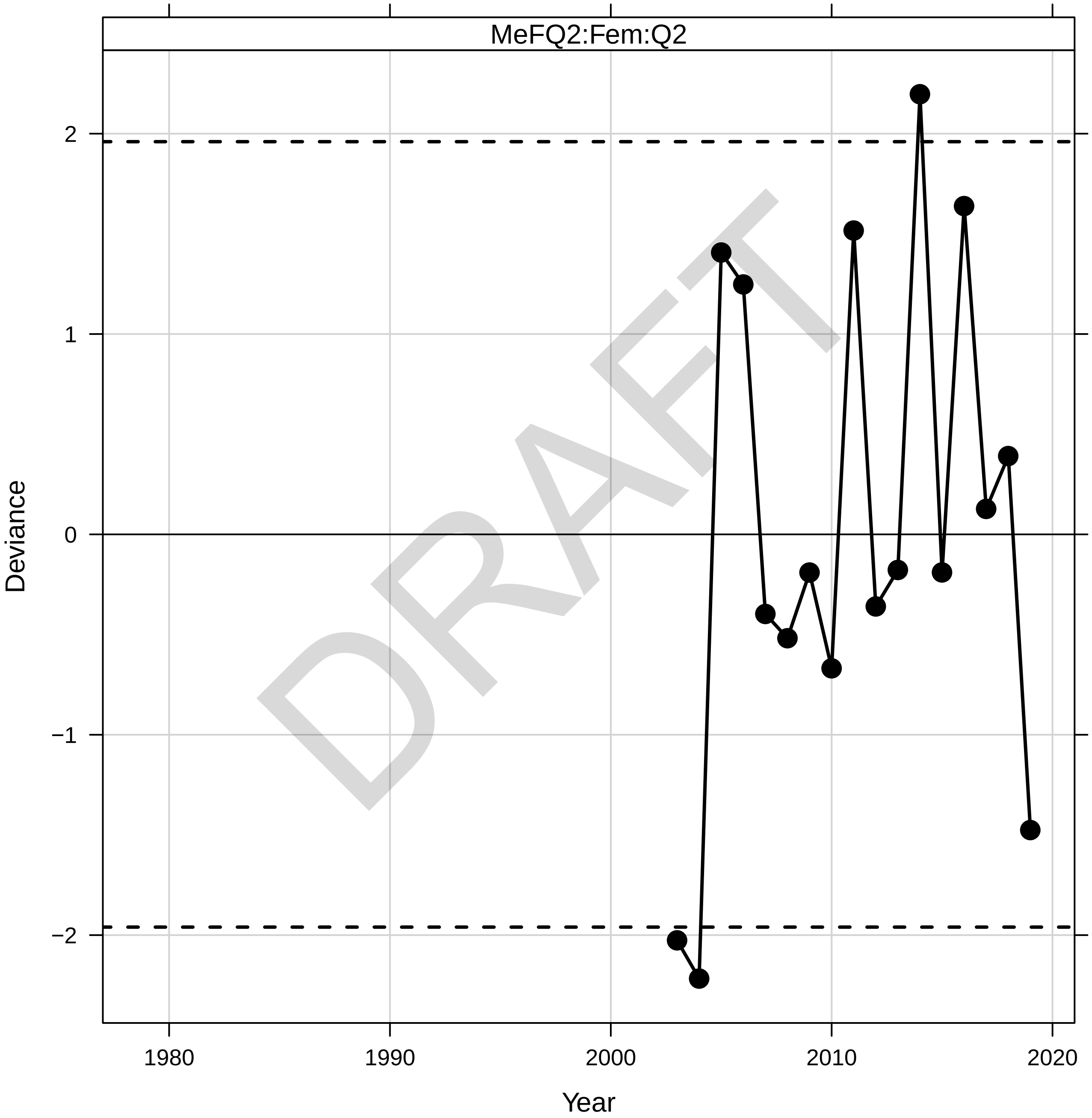
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data MaMQ4



DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data MeFQ2



DRAFT

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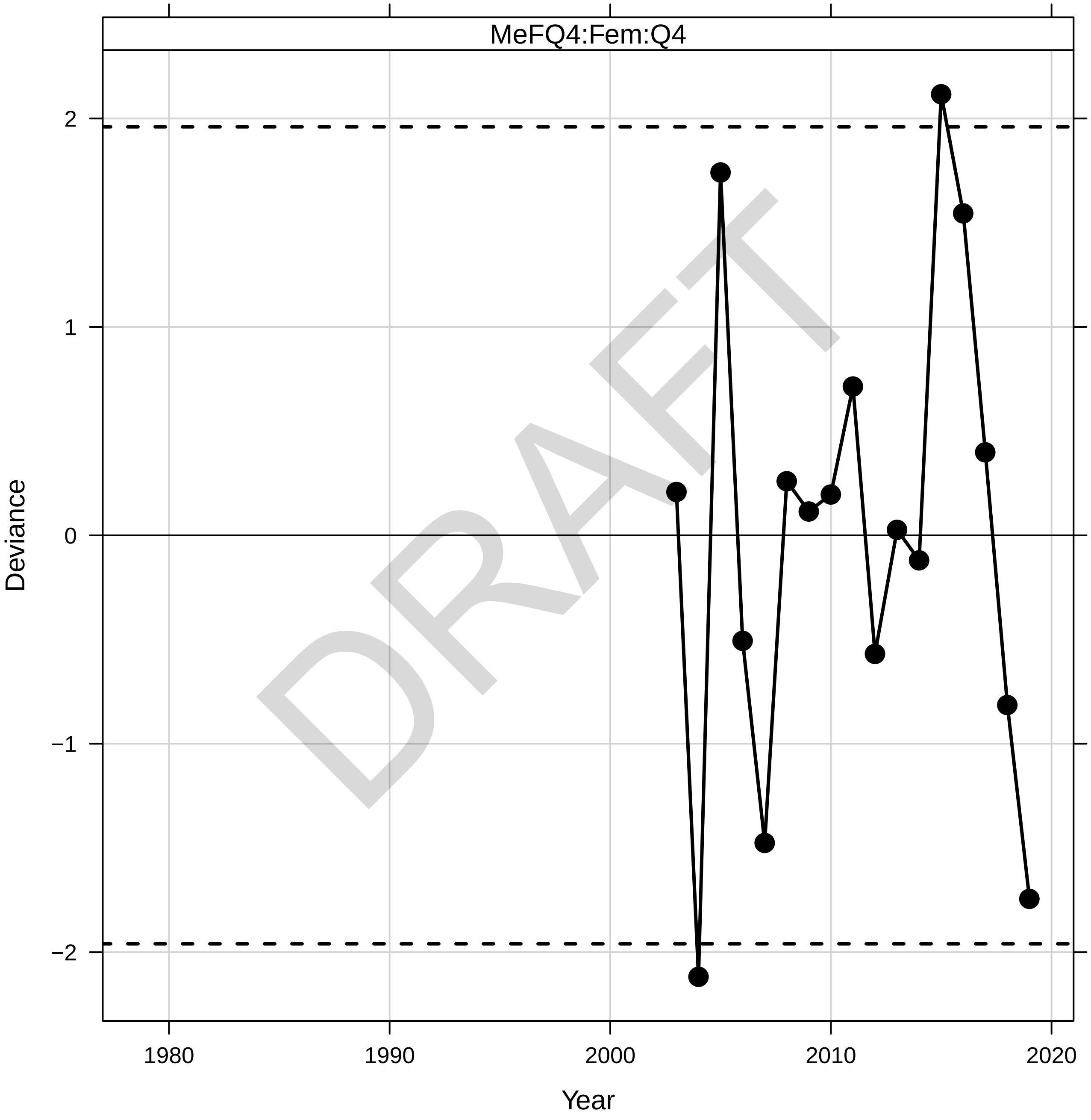
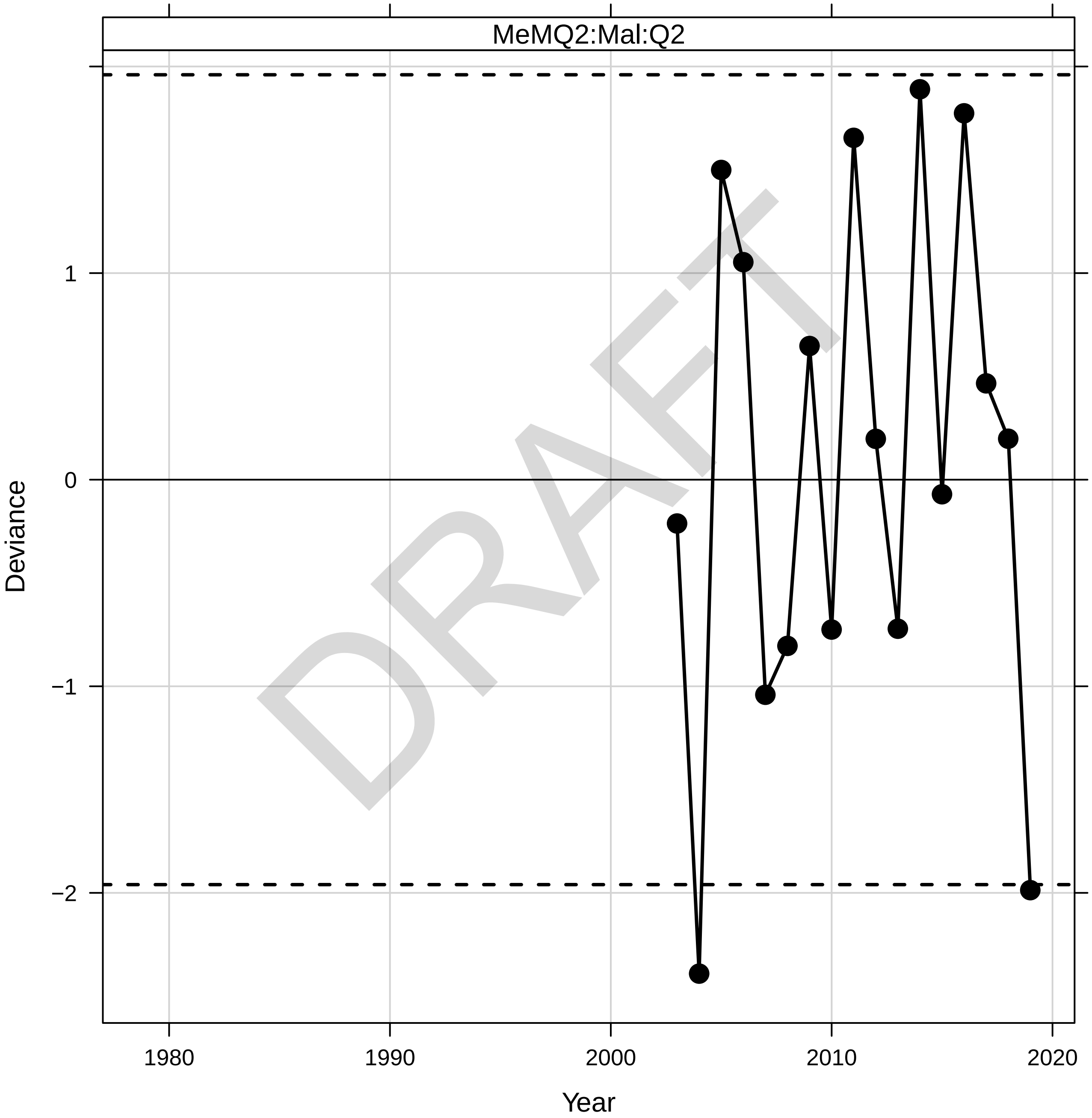
r60_ind_trawl_v6f6
deviance residuals for trend data MeFQ4

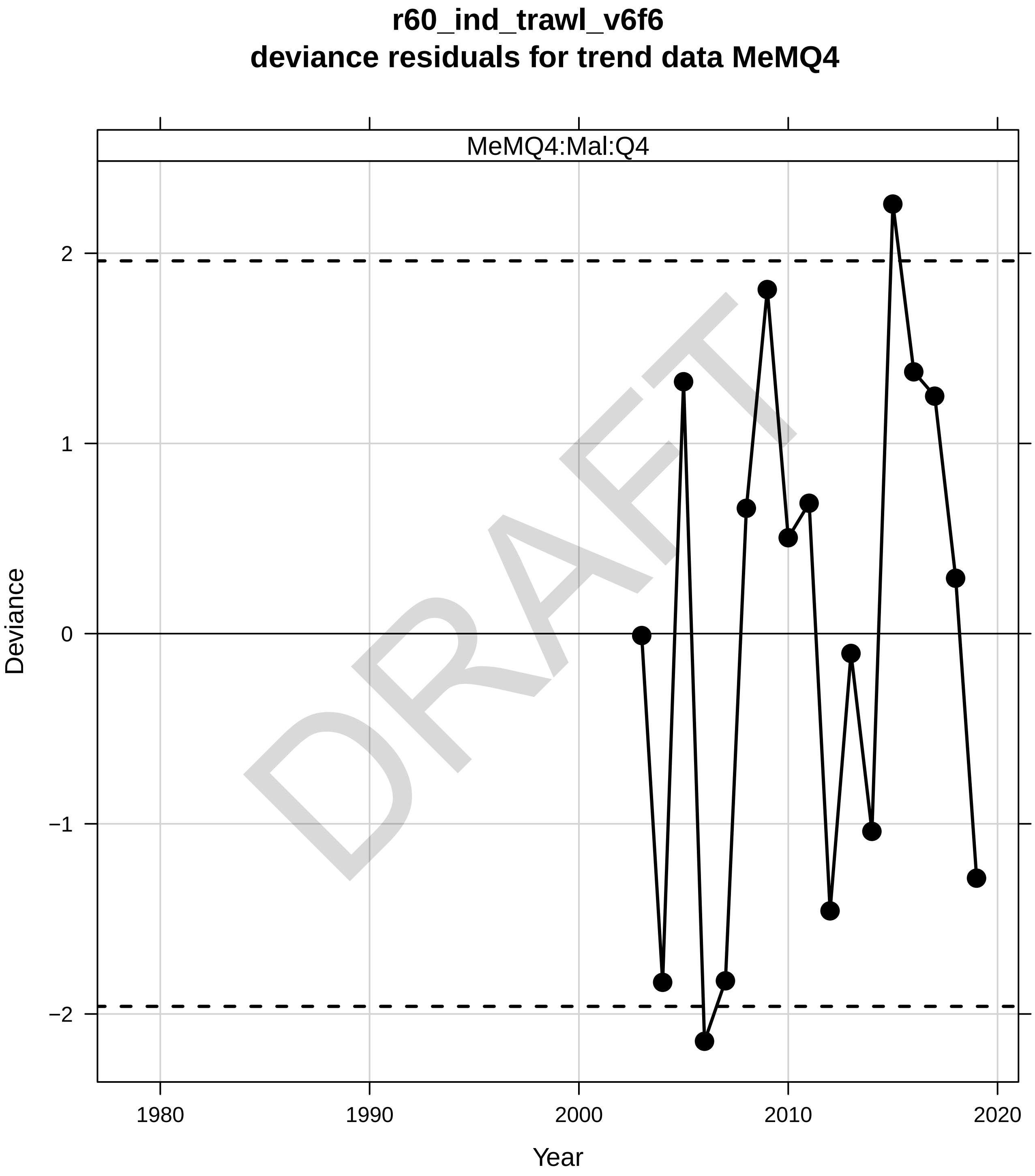


DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data MeMQ2

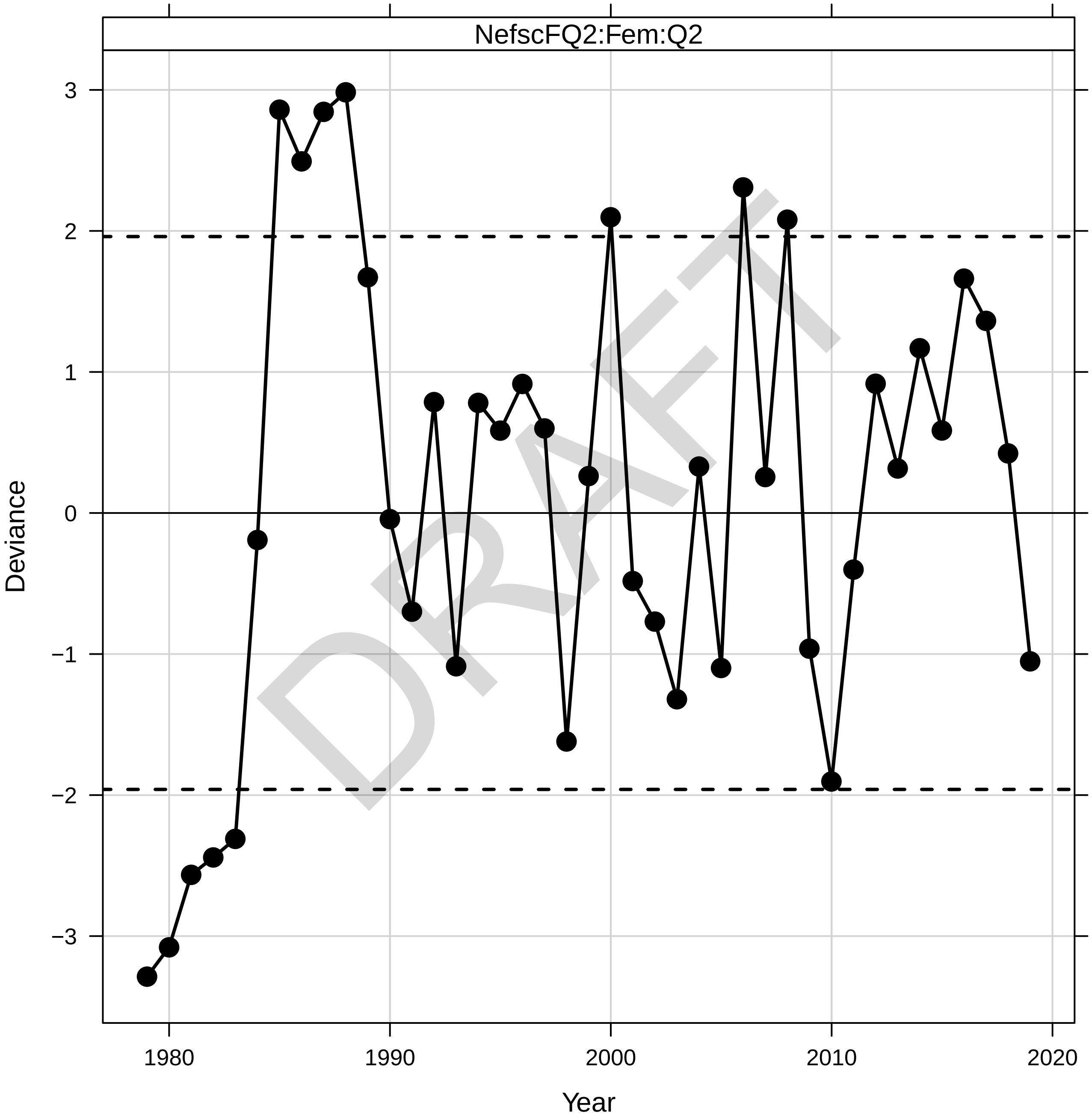


DRAFT


r60_ind_trawl_v6f6
deviance residuals for trend data MeMQ4
MeMQ4:Mal:Q4
Deviance
Year
2
1
0
−1
−2
1980
1990
2000
2010
2020

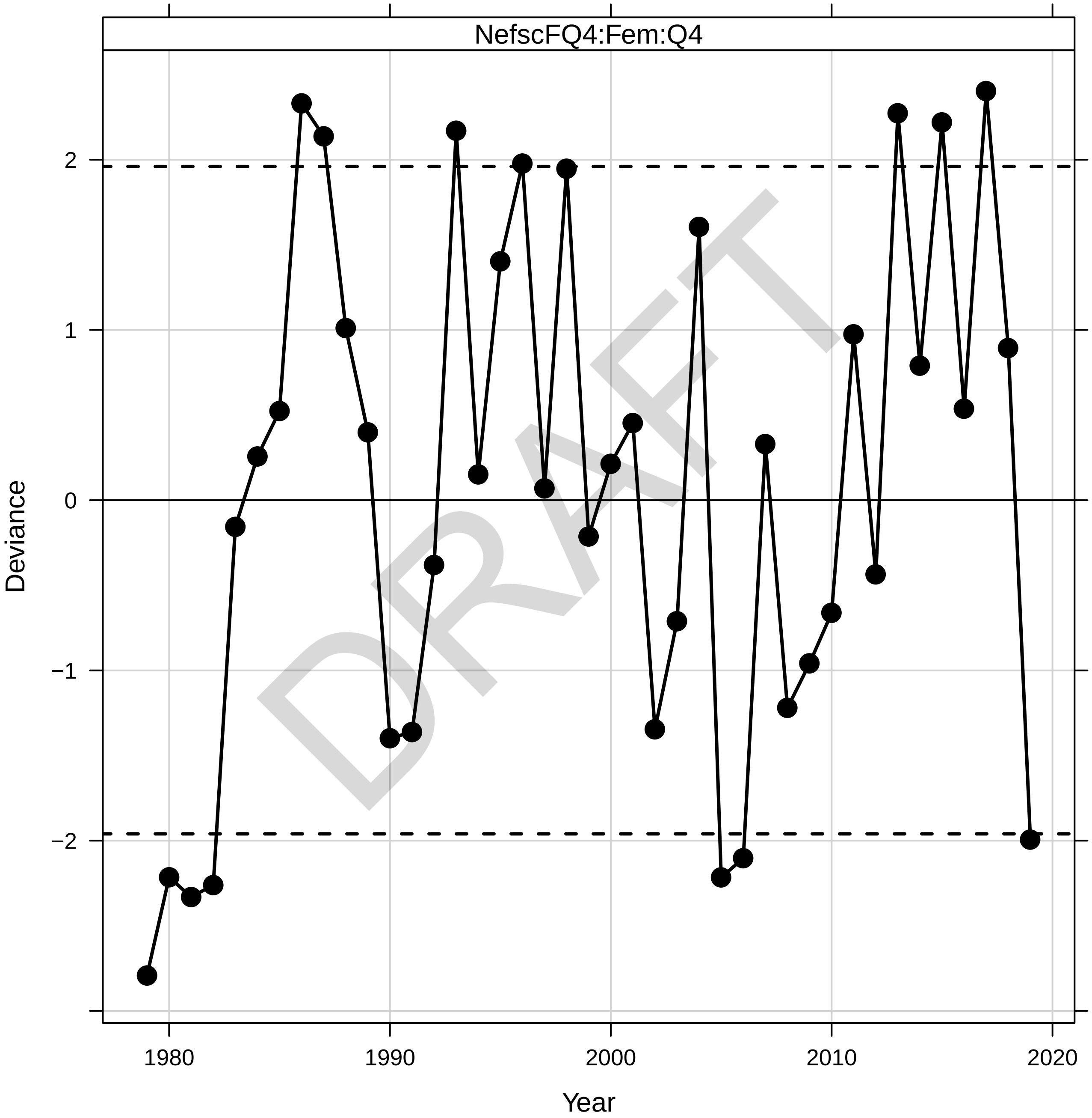
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data NefscFQ2



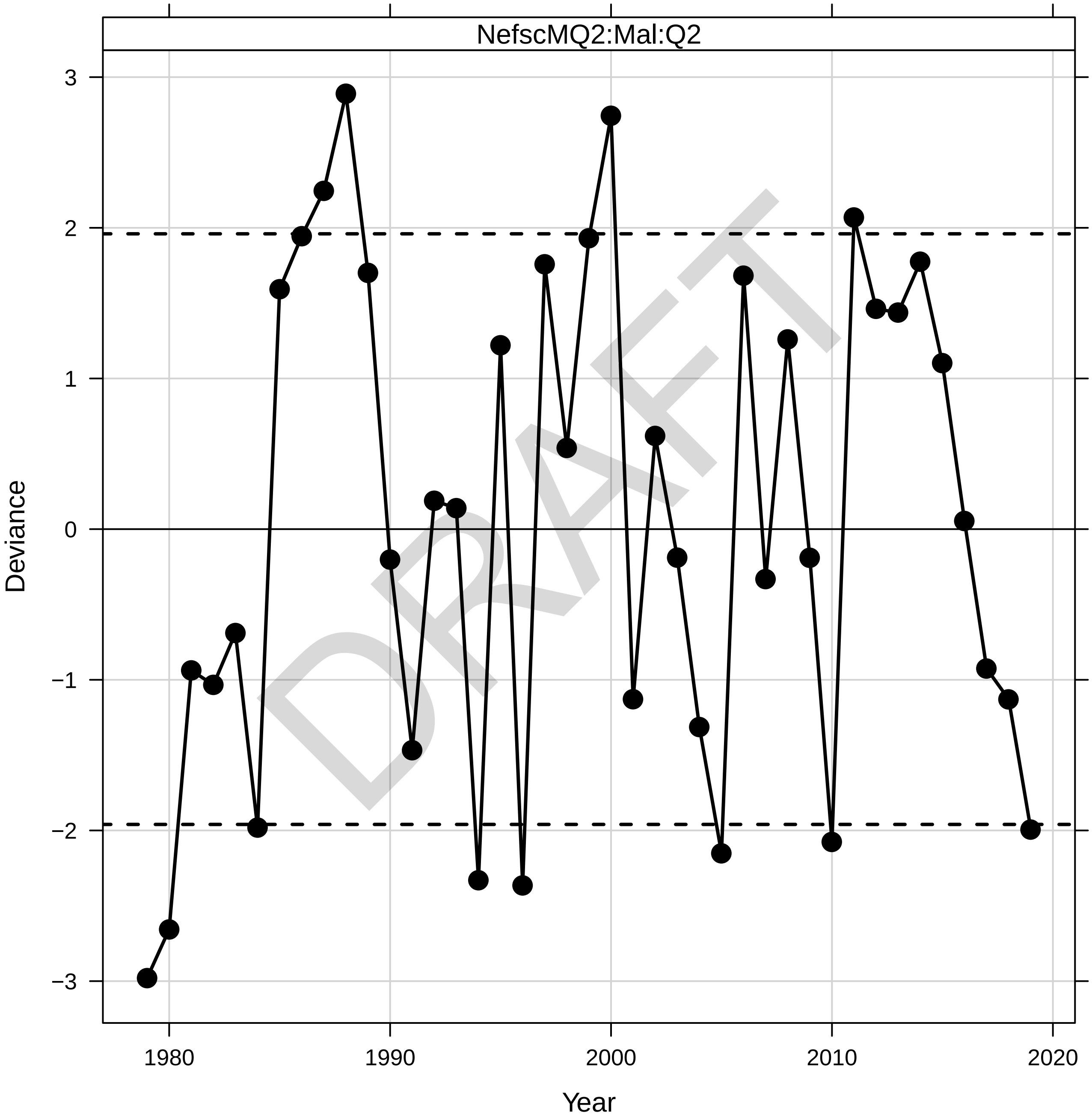
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data NefscFQ4



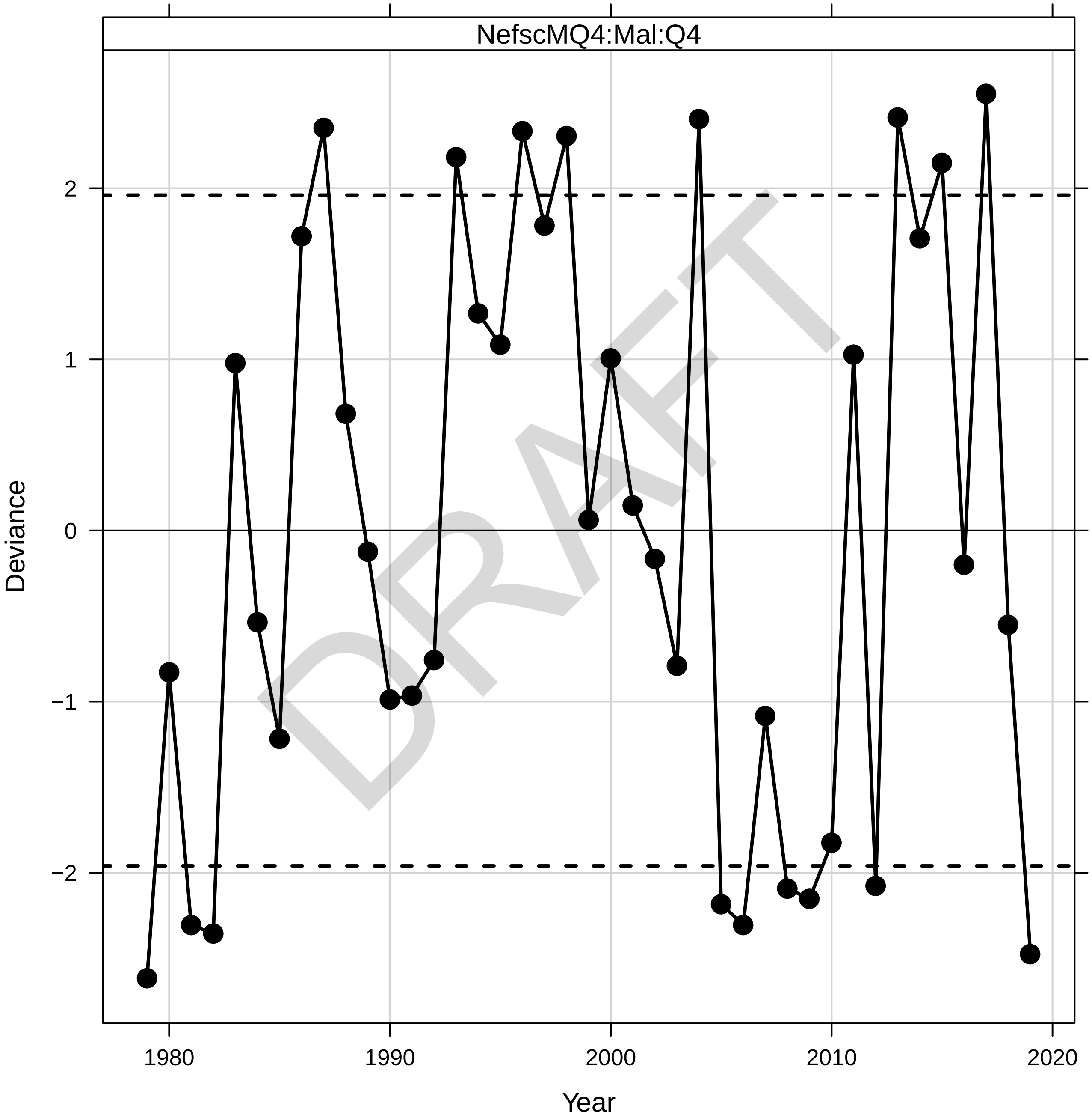
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data NefscMQ2



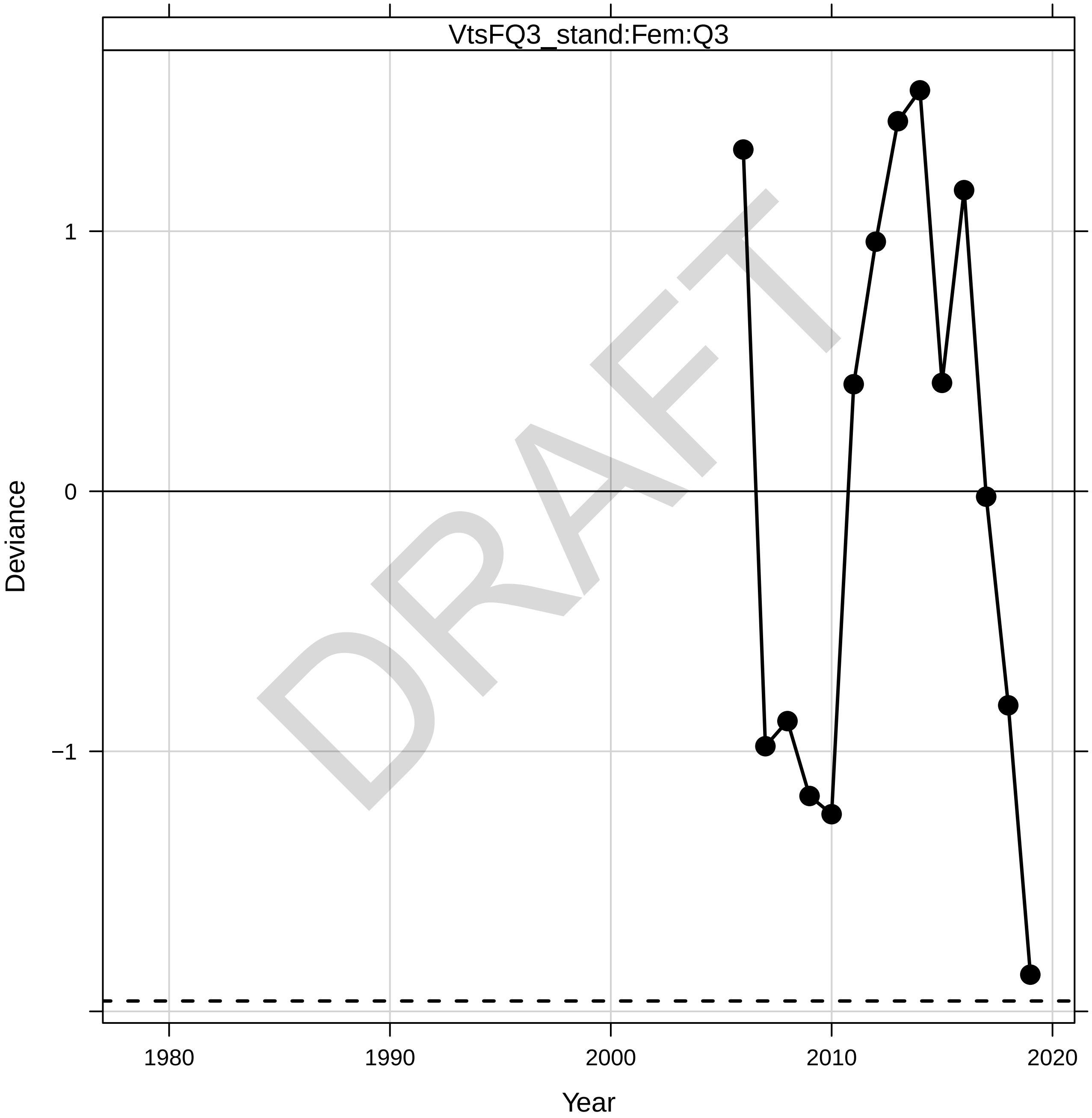
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data NefscMQ4



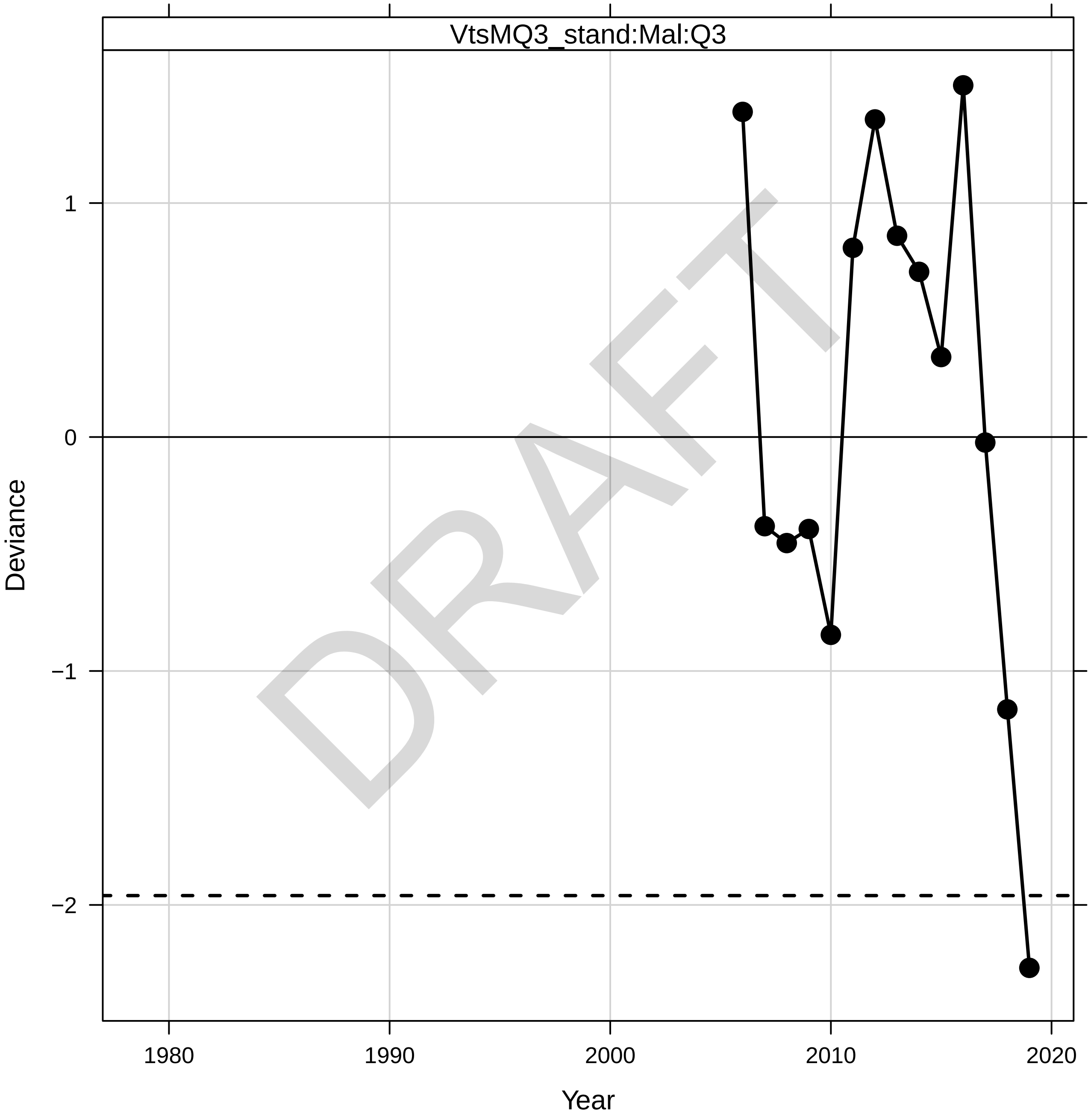
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data VtsFQ3_stand



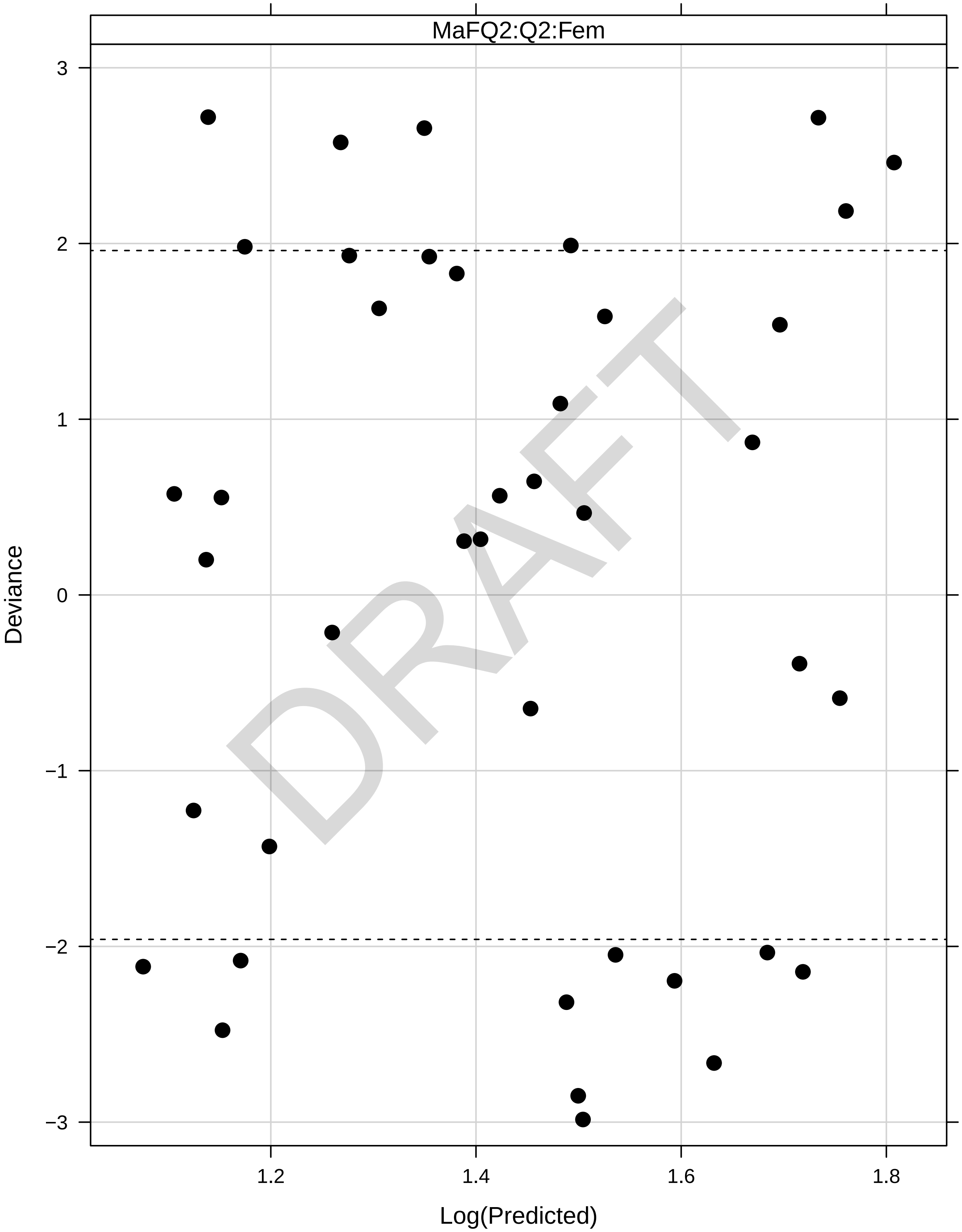
DRAFT

r60_ind_trawl_v6f6
deviance residuals for trend data VtsMQ3_stand



DRAFT

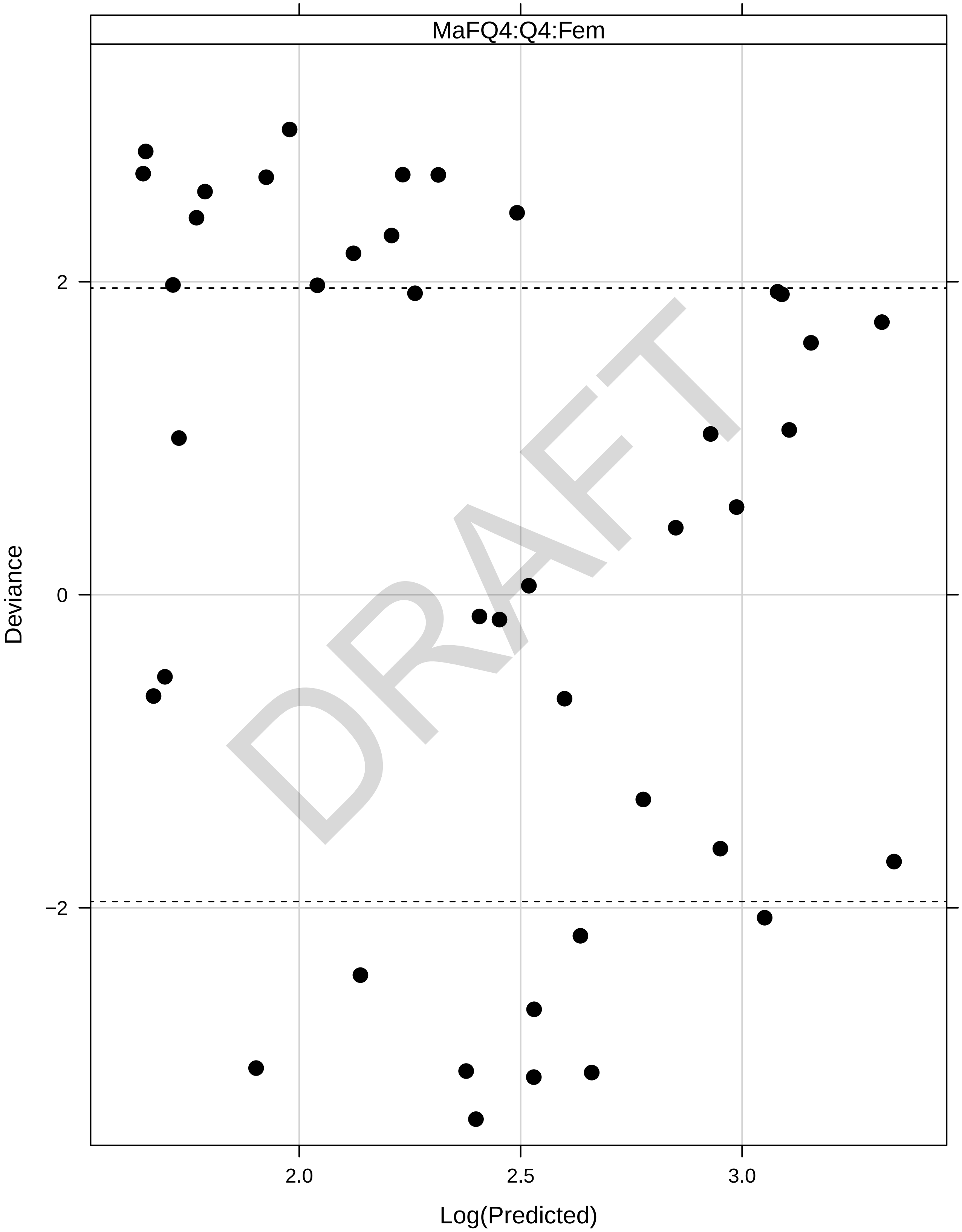
r60_ind_trawl_v6f6
MaFQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

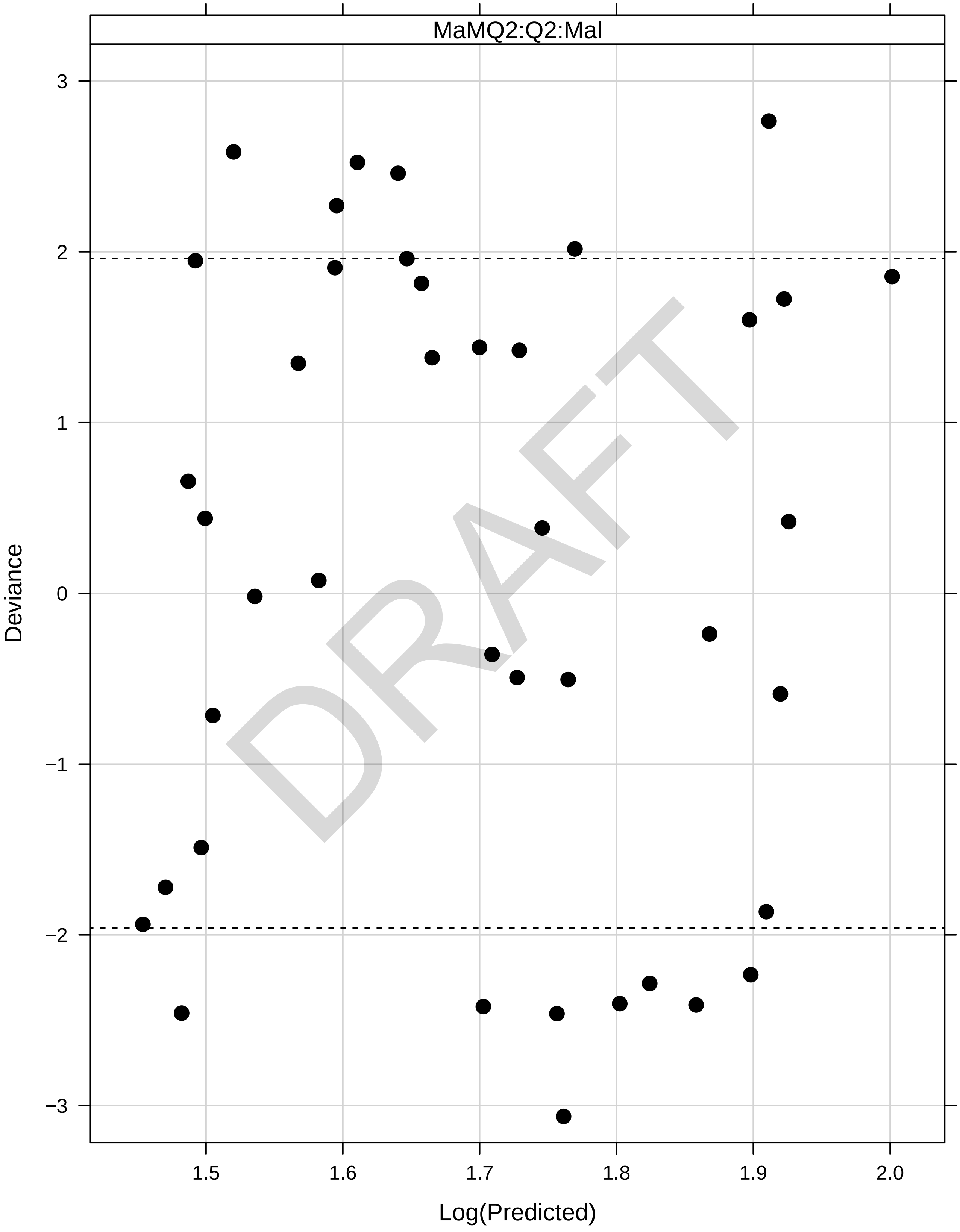
r60_ind_trawl_v6f6
MaFQ4 deviance residuals vs. predicted values



Symbols = observed / Solid line = predicted

DRAFT

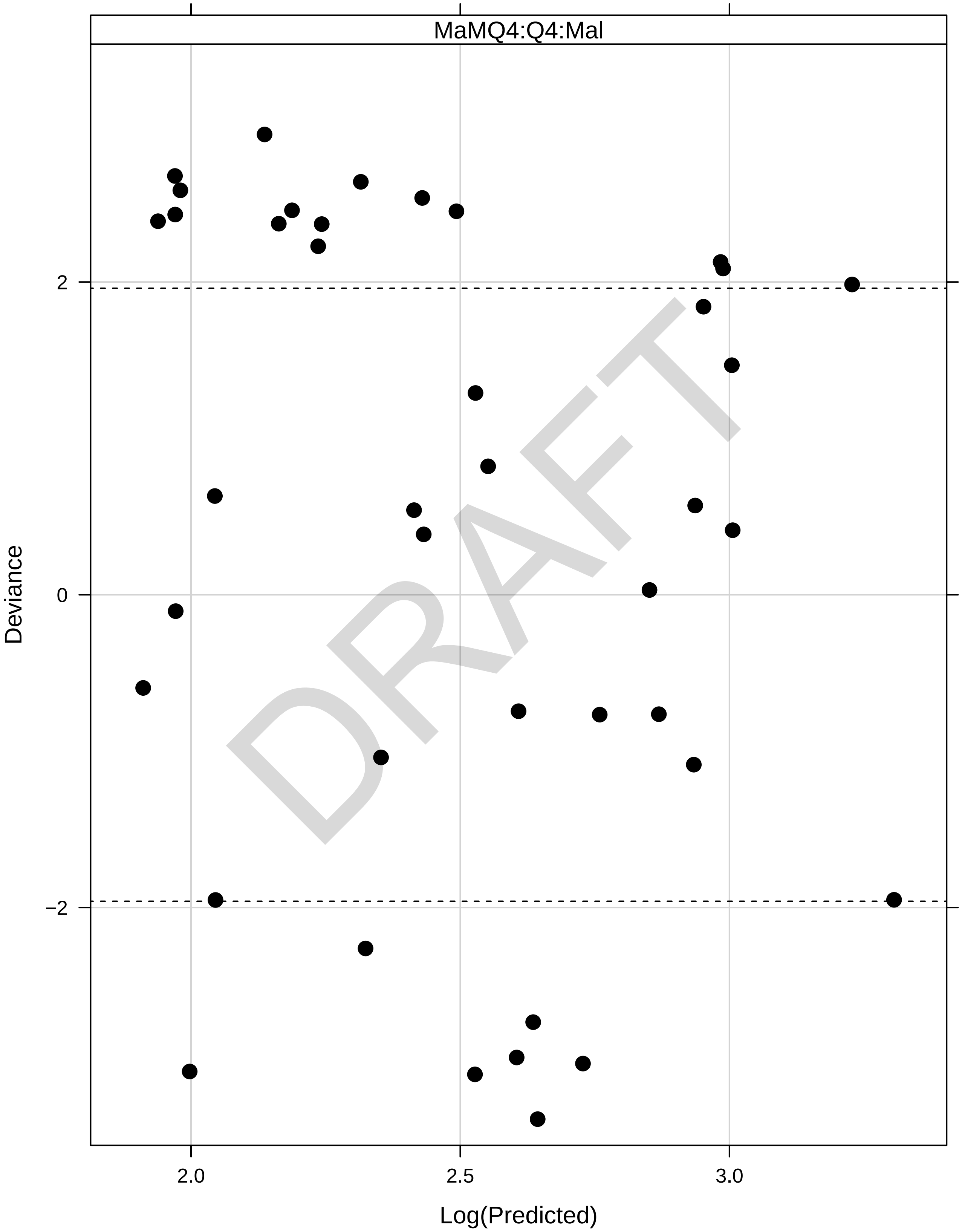
r60_ind_trawl_v6f6
MaMQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

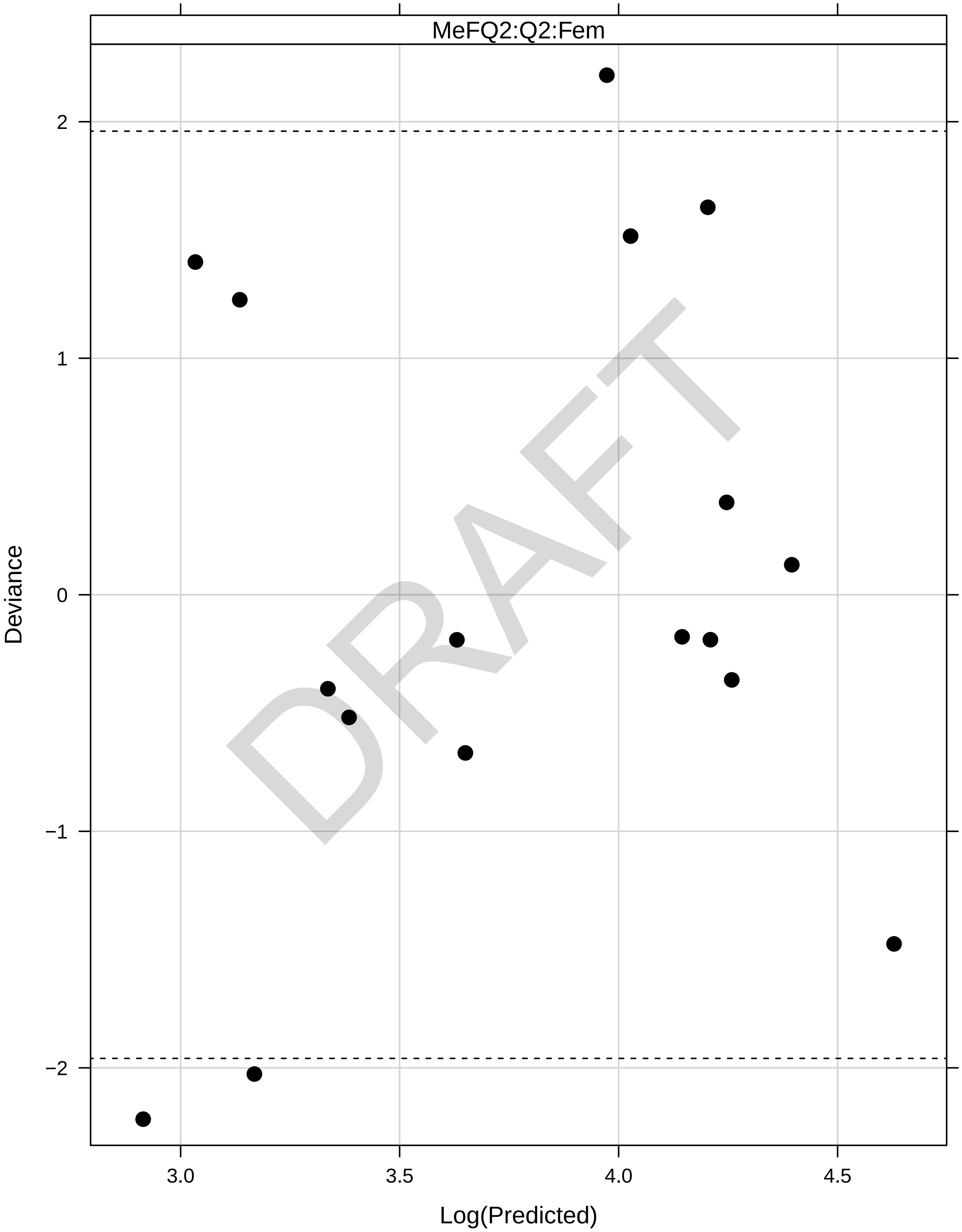
r60_ind_trawl_v6f6
MaMQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

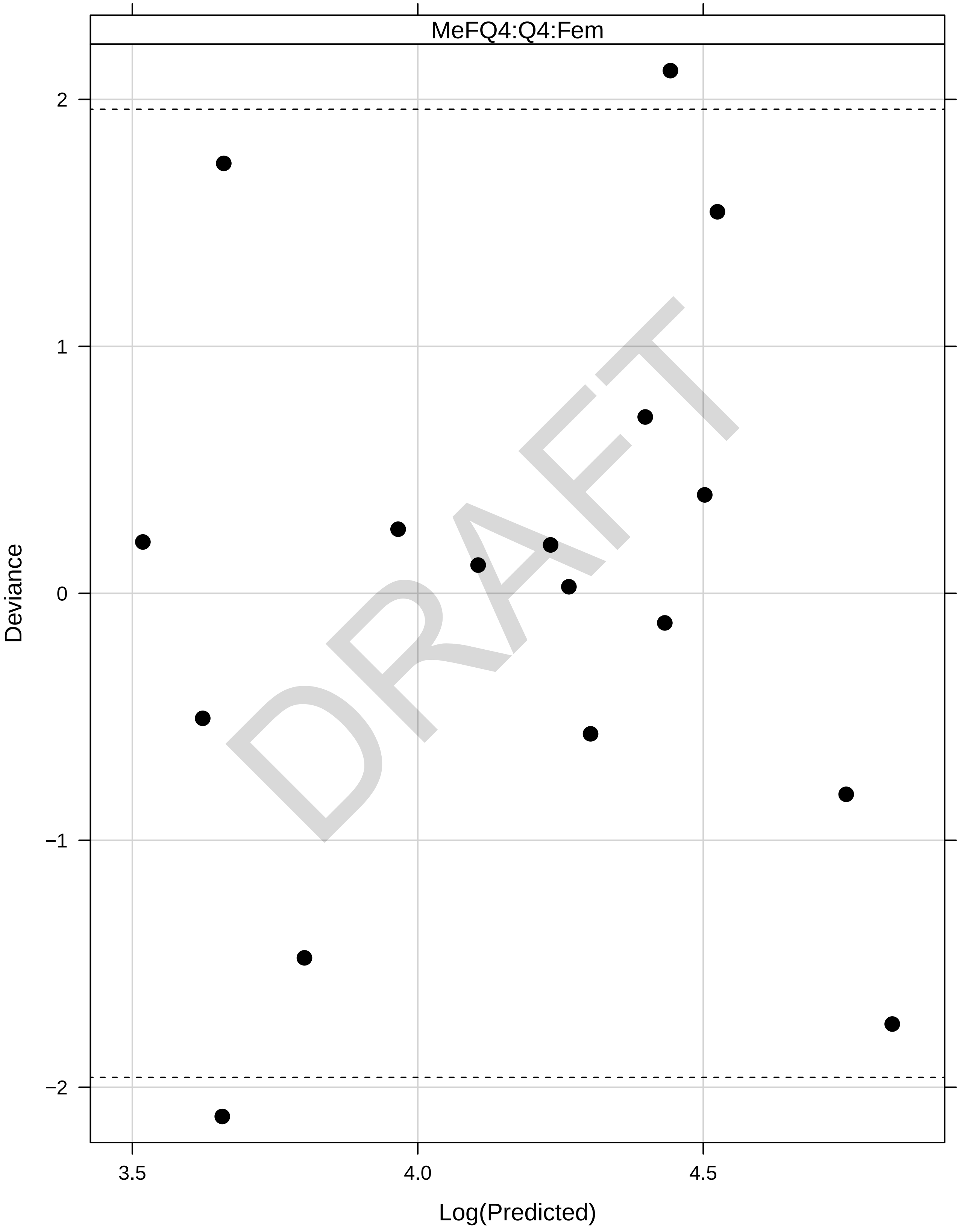
r60_ind_trawl_v6f6
MeFQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

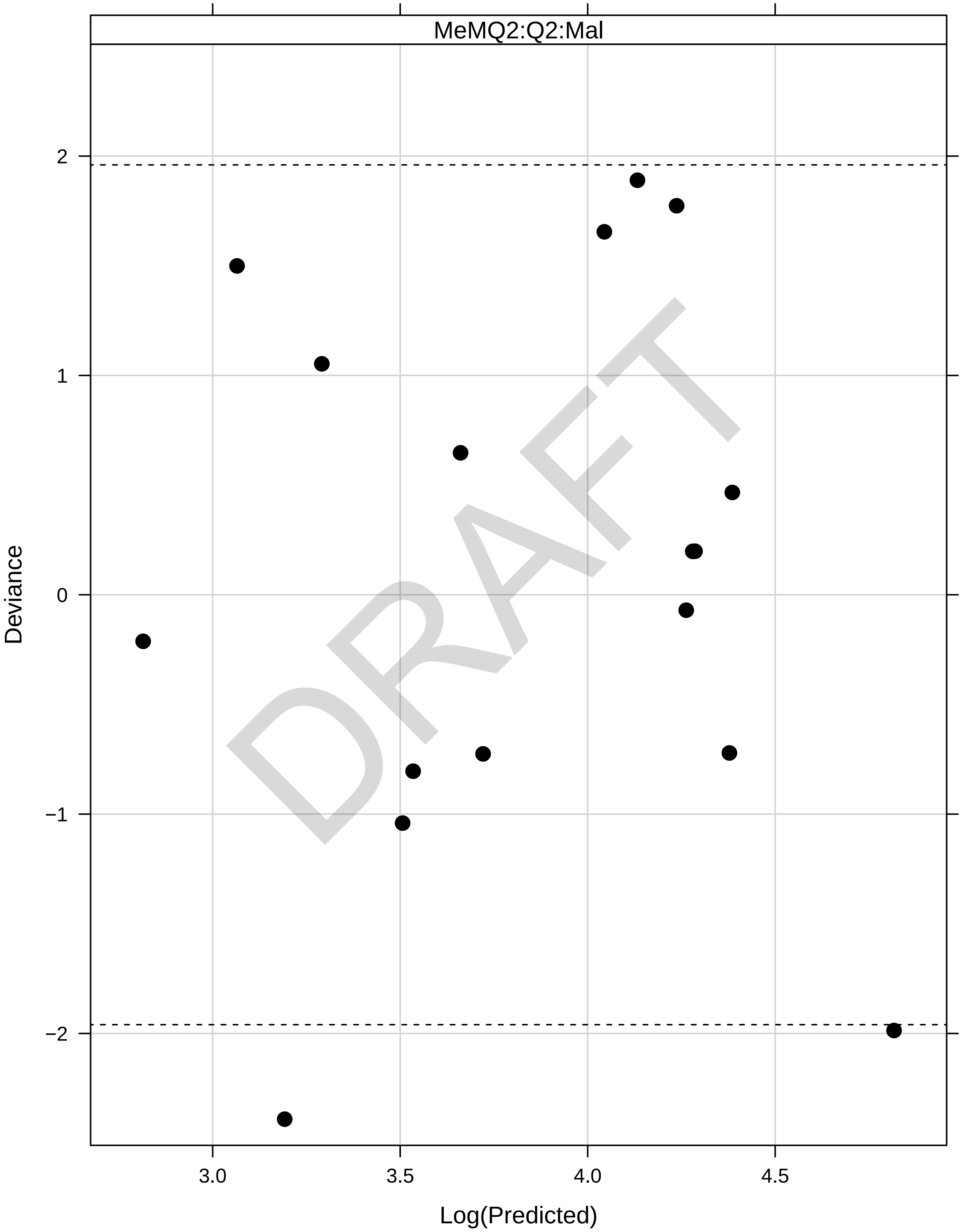
r60_ind_trawl_v6f6
MeFQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
MeMQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

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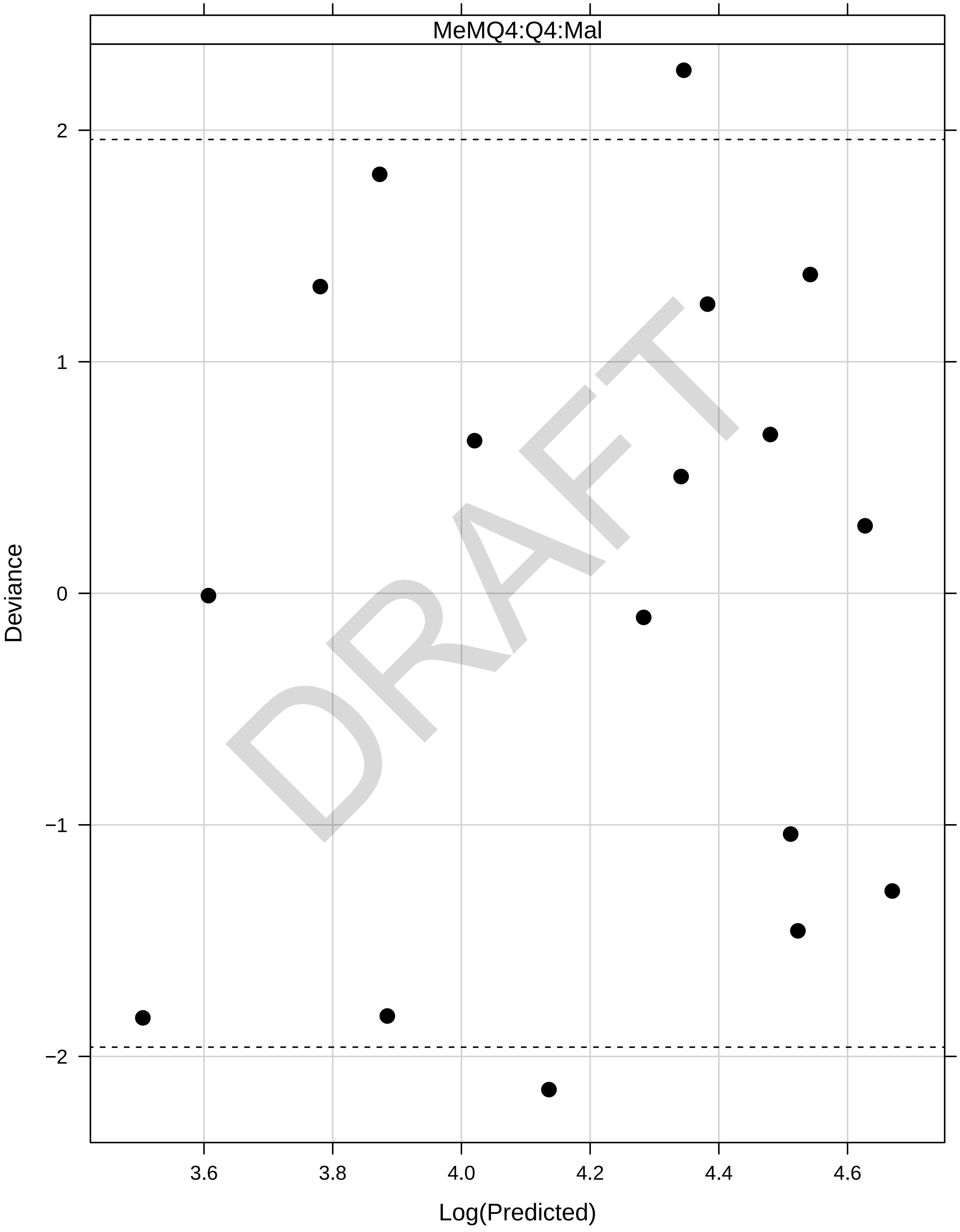
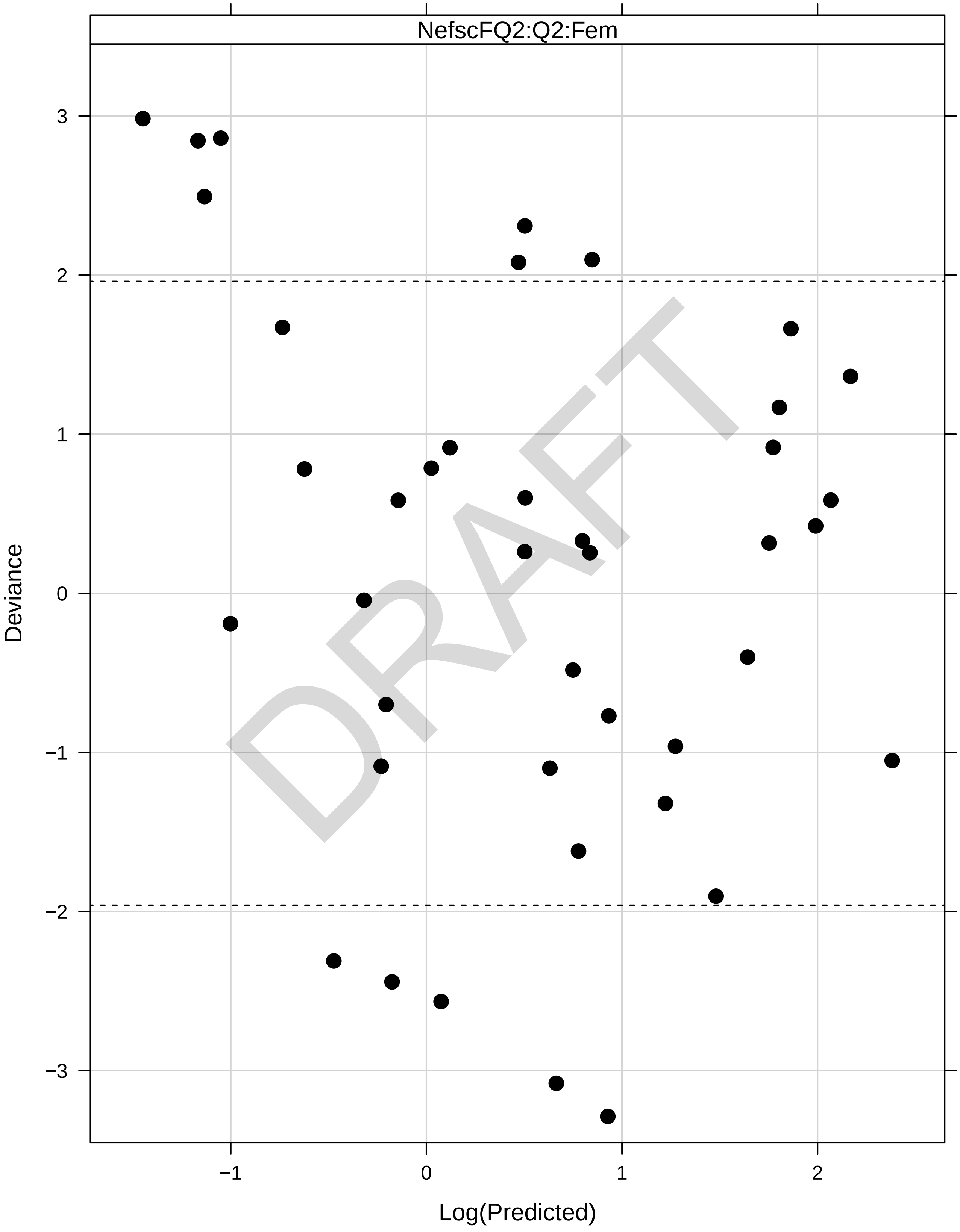
r60_ind_trawl_v6f6
MeMQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

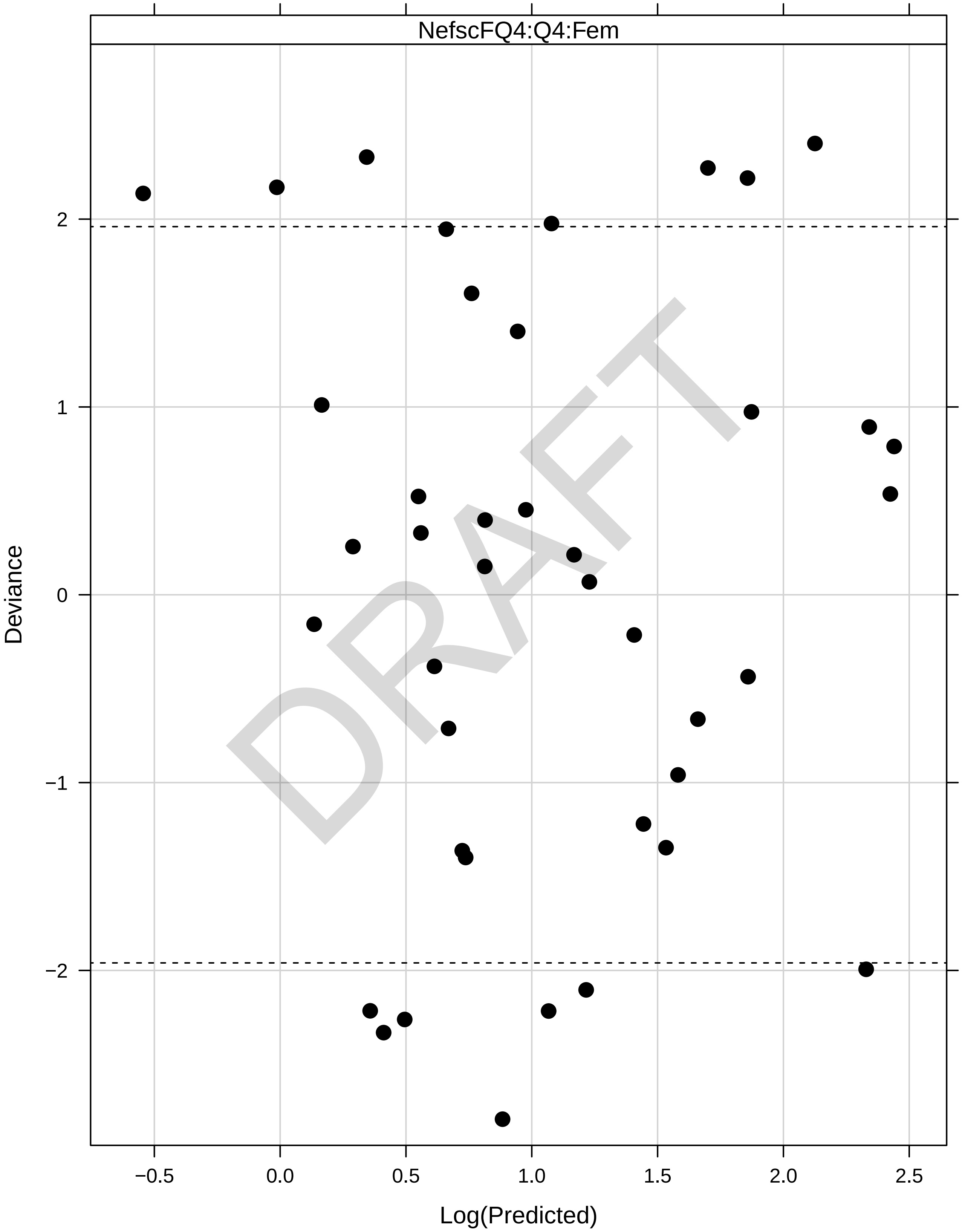
r60_ind_trawl_v6f6
NefscFQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

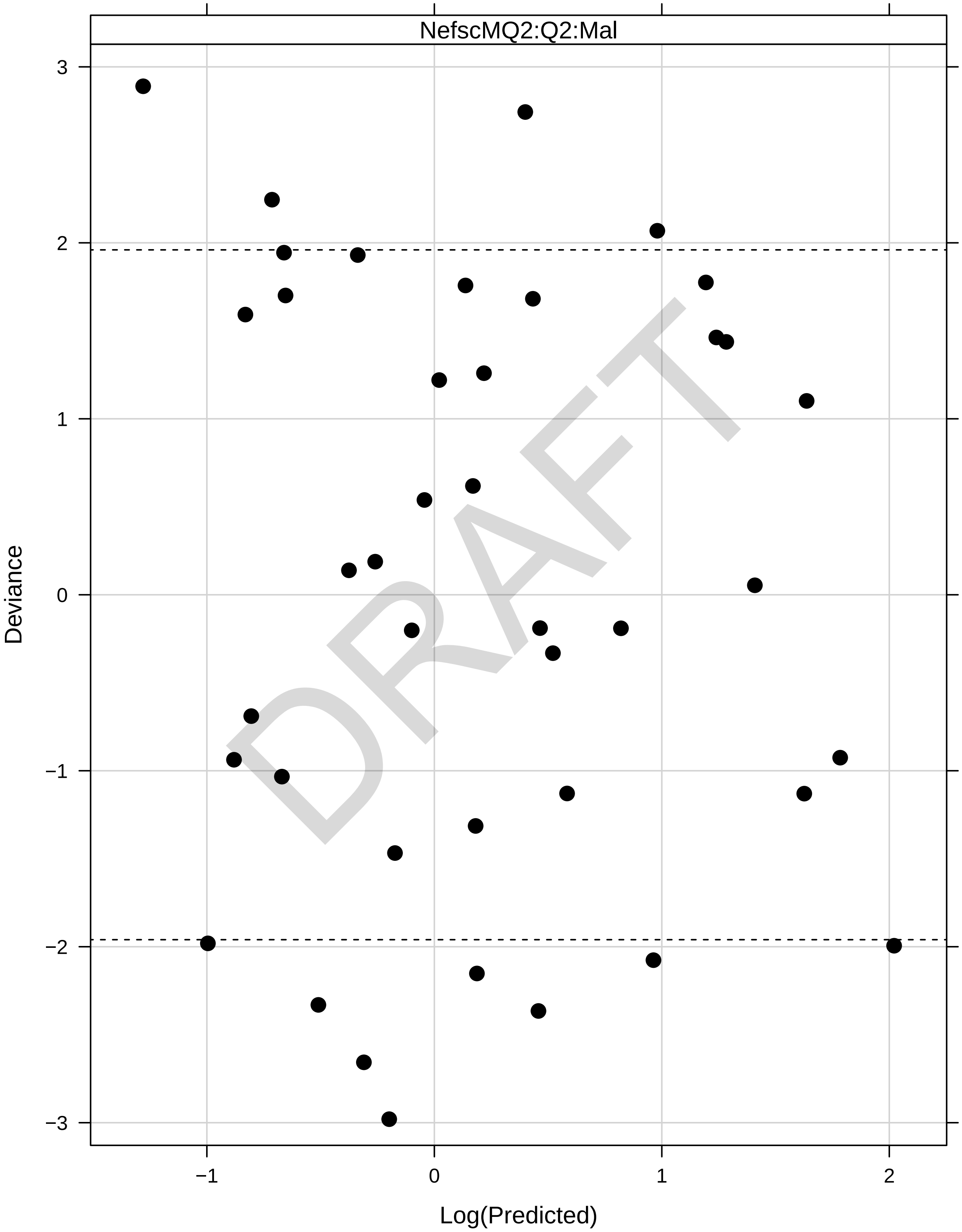
r60_ind_trawl_v6f6
NefscFQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
NefscMQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

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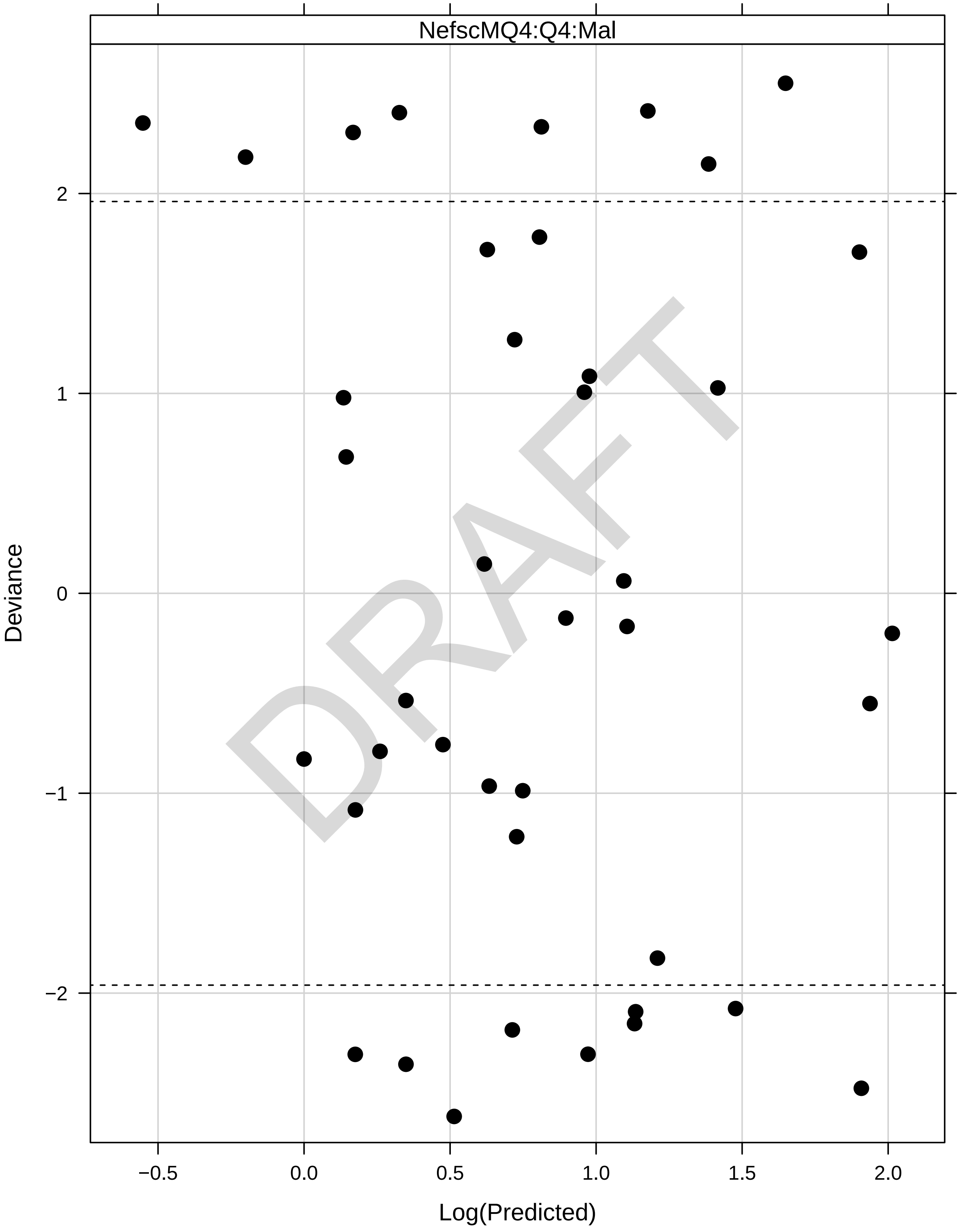
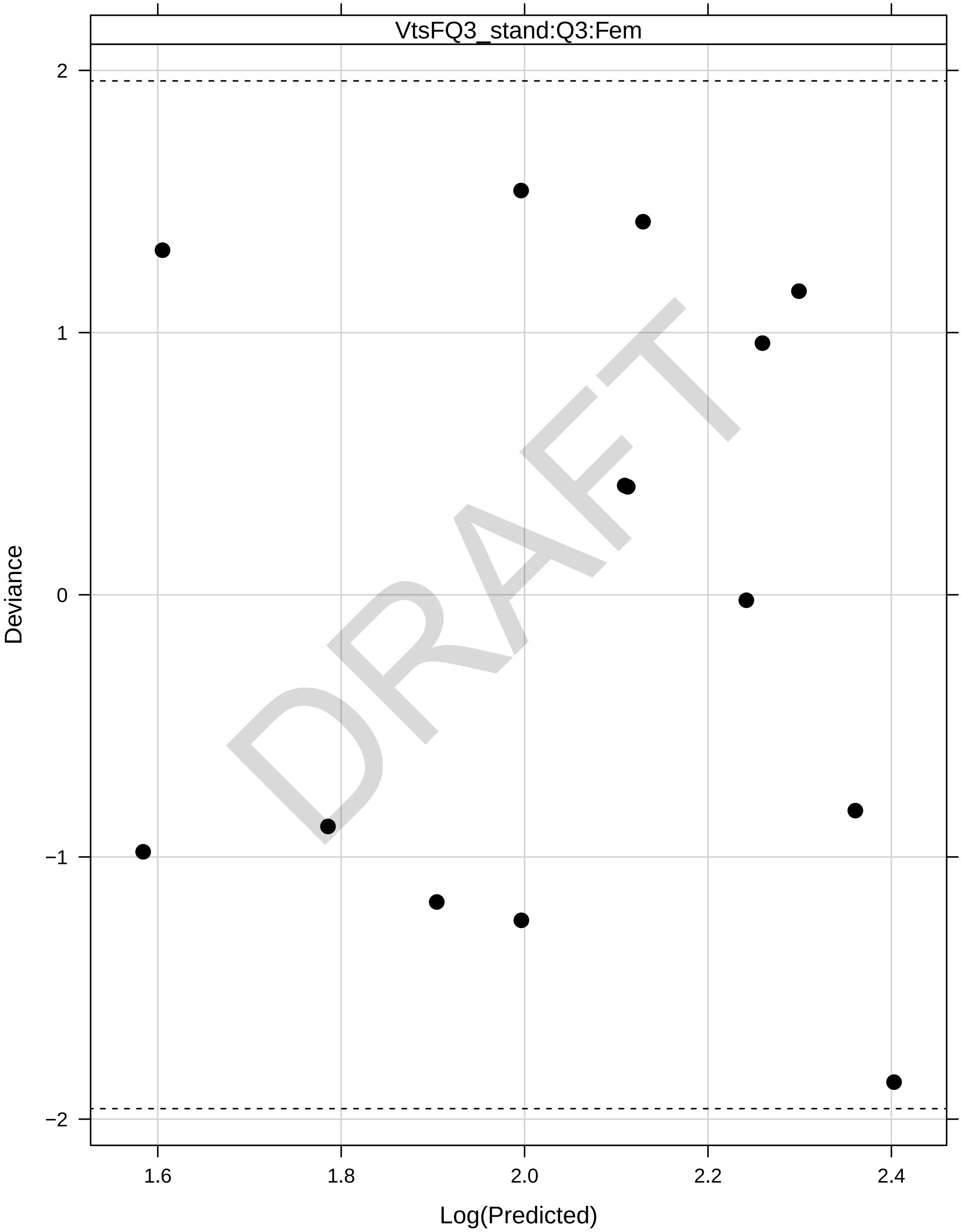
r60_ind_trawl_v6f6
NefscMQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

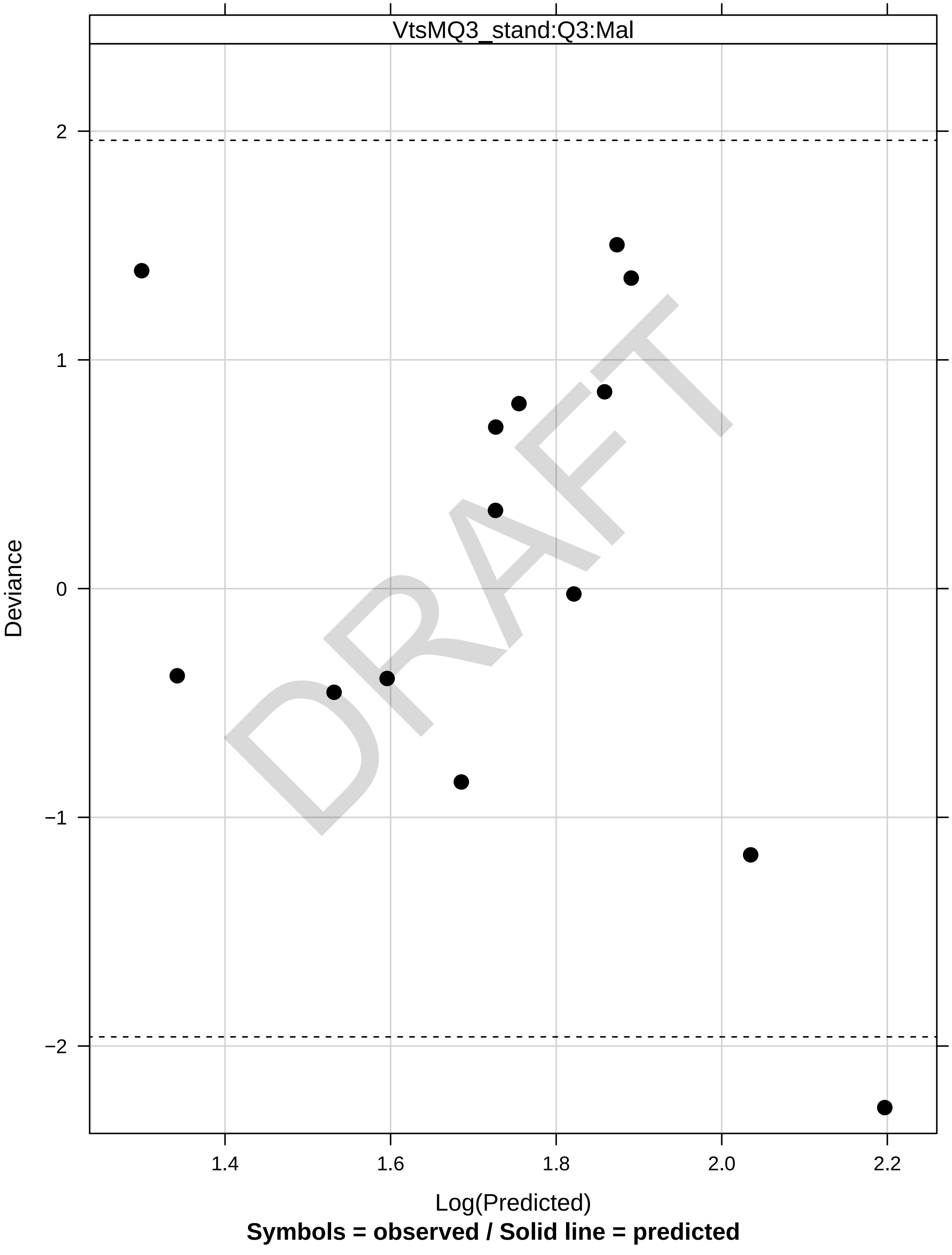
r60_ind_trawl_v6f6
VtsFQ3_stand deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

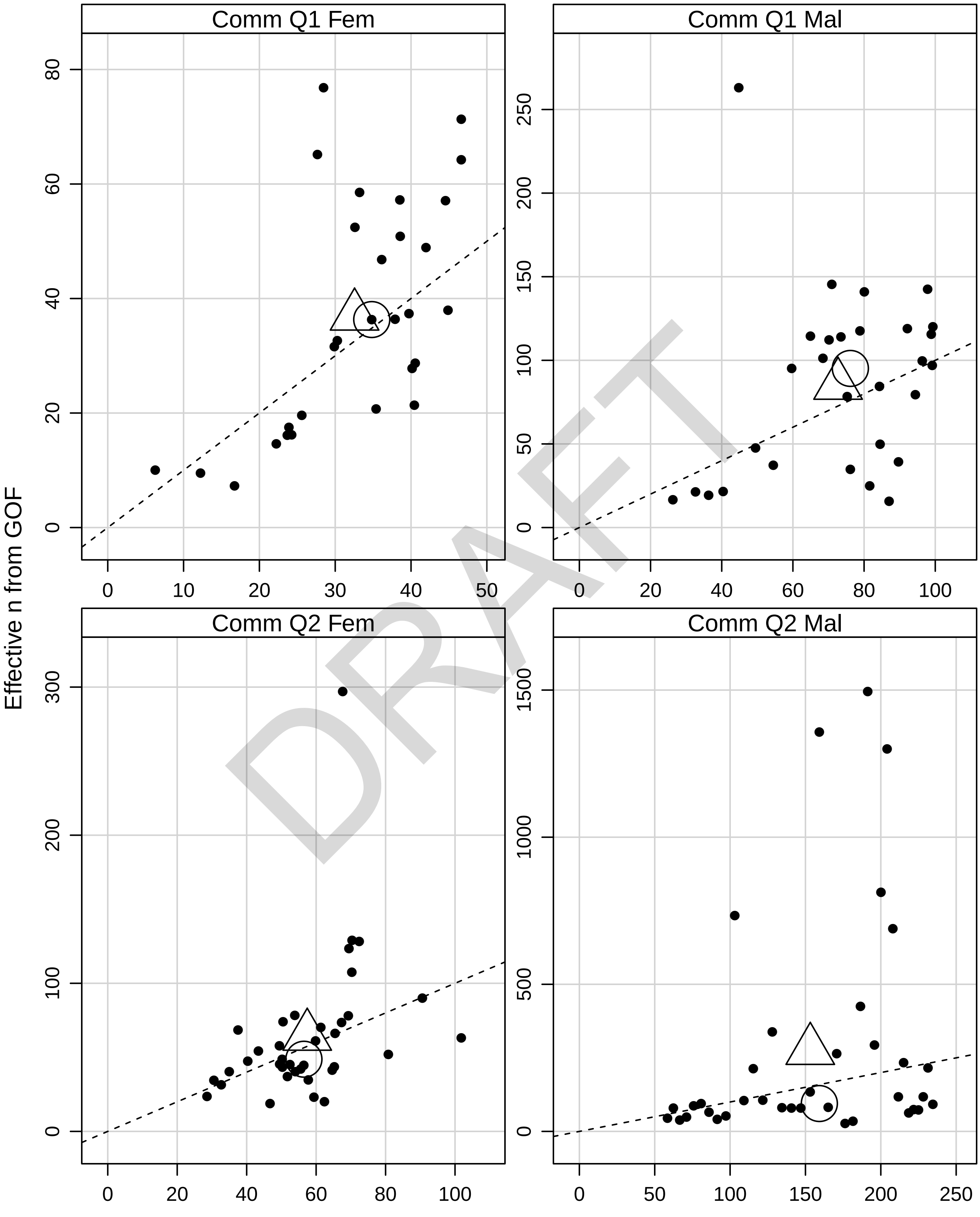
r60_ind_trawl_v6f6
VtsMQ3_stand deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

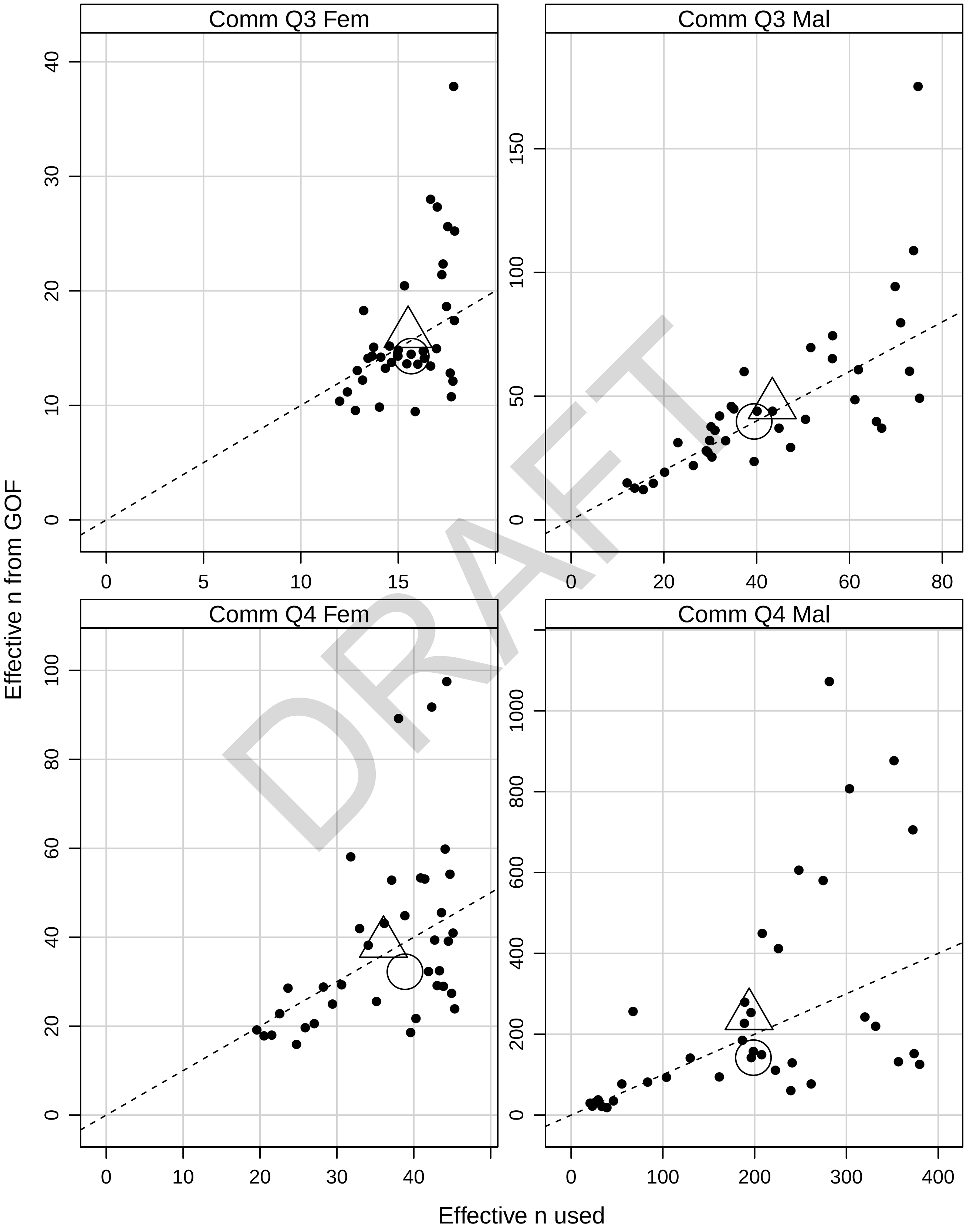
r60_ind_trawl_v6f6
Effective n for commercial length data



DRAFT

Large circle at bivariate medians, triangles at means

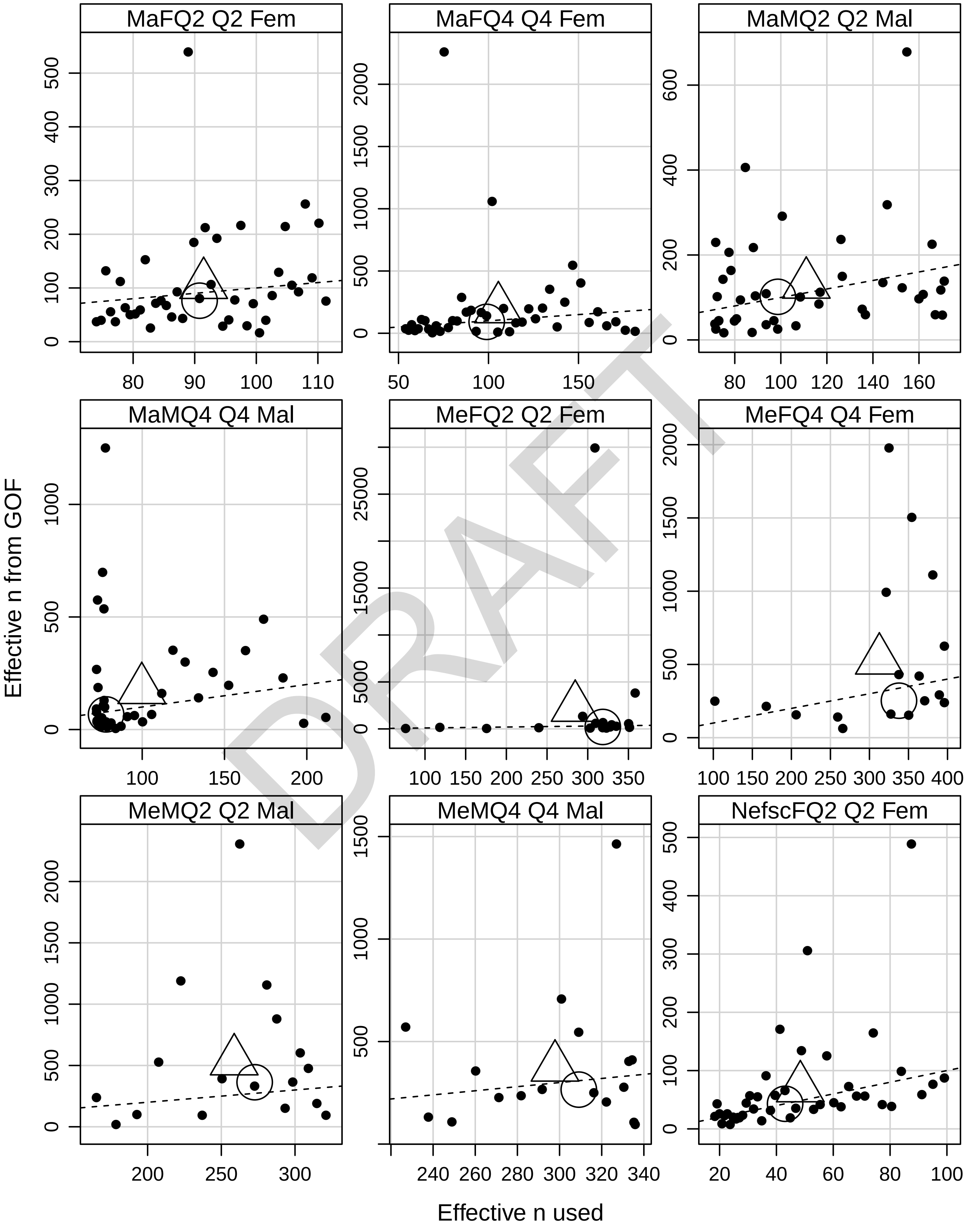
r60_ind_trawl_v6f6
Effective n for commercial length data



DRAFT

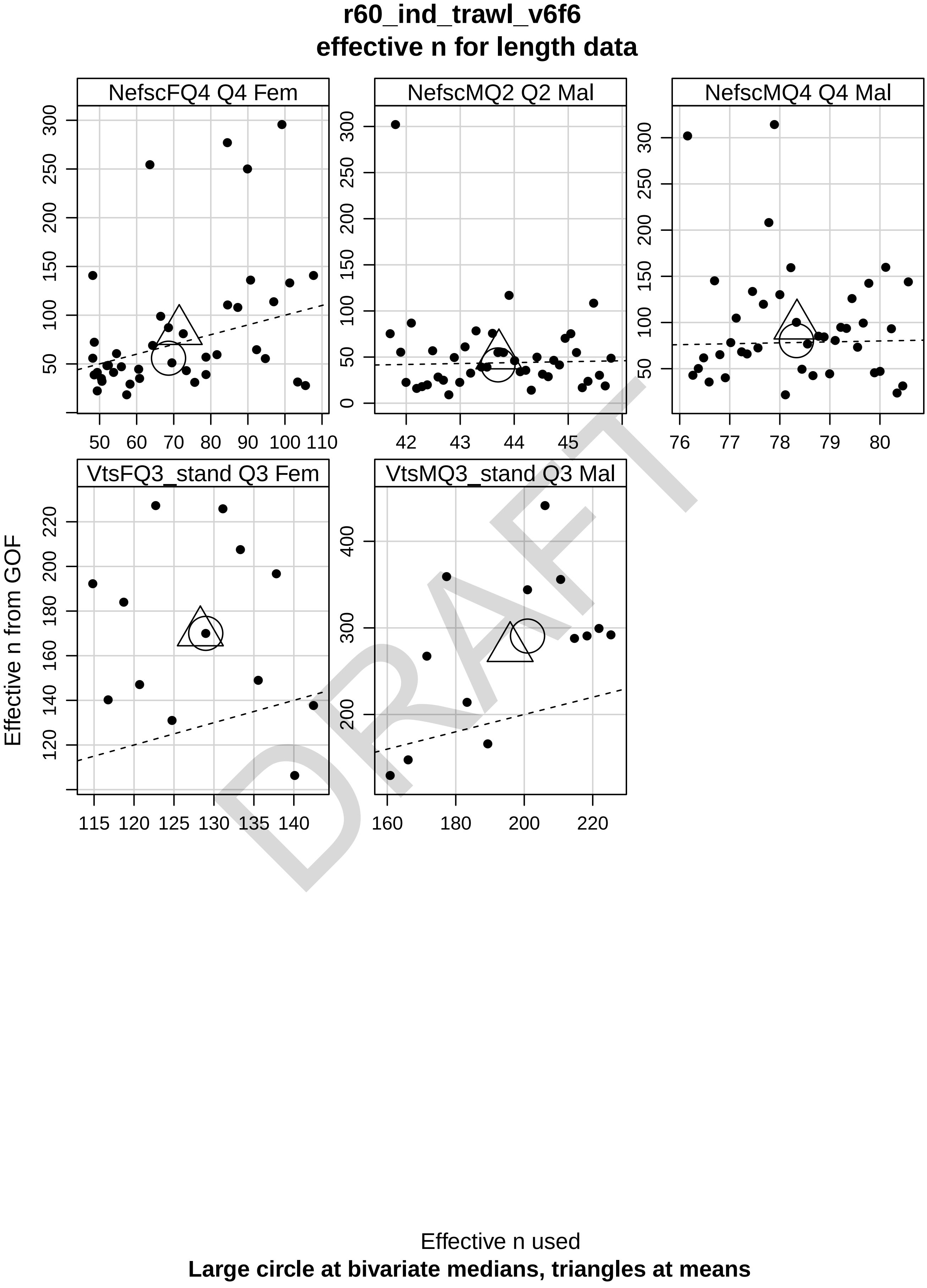
Large circle at bivariate medians, triangles at means

r60_ind_trawl_v6f6
effective n for length data



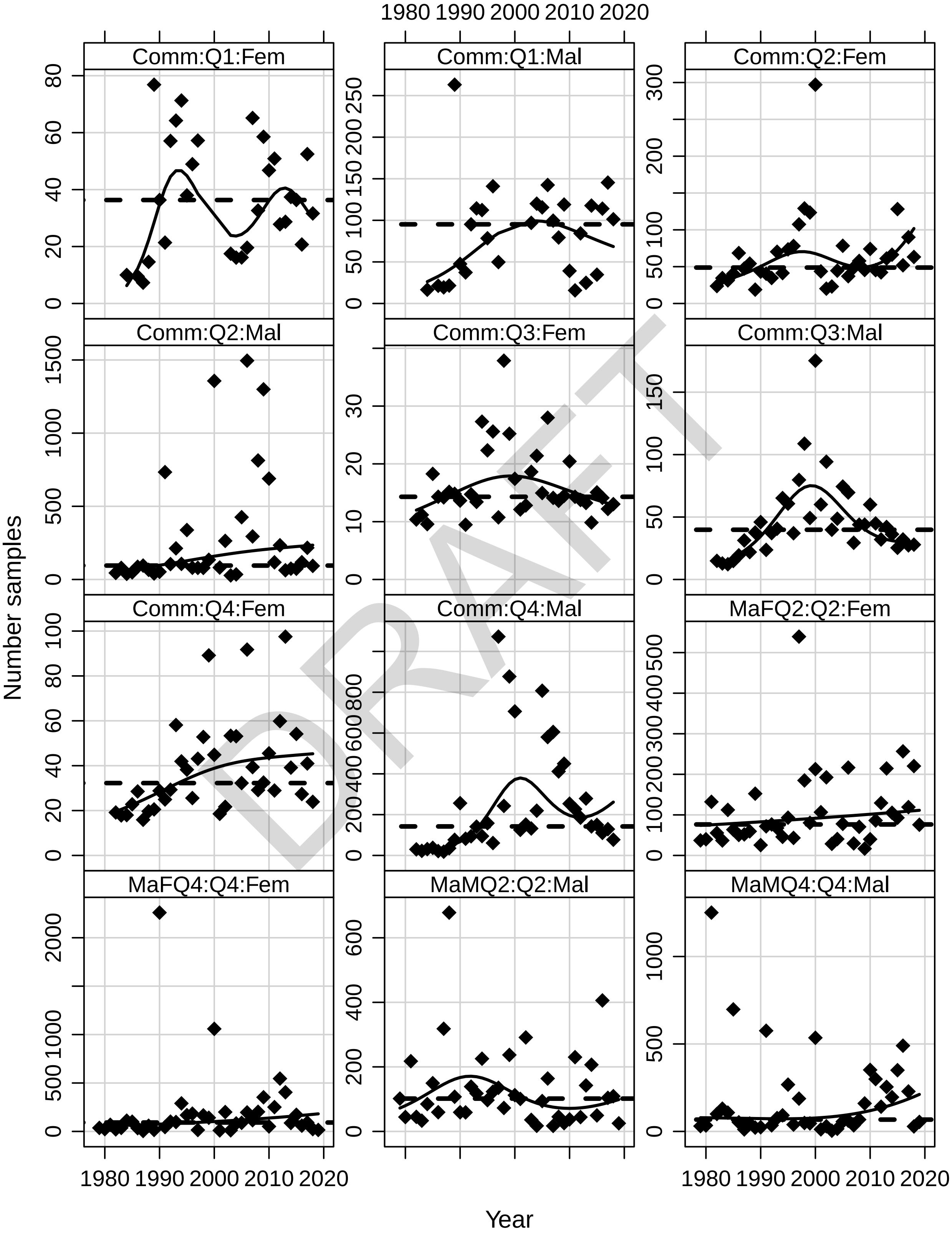
Large circle at bivariate medians, triangles at means

DRAFT


r60_ind_trawl_v6f6
effective n for length data
NefscFQ4 Q4 Fem
NefscMQ2 Q2 Mal
NefscMQ4 Q4 Mal
VtsFQ3_stand Q3 Fem
VtsMQ3_stand Q3 Mal
Effective n from GOF
50
100
150
200
250
300
0
120
140
160
180
200
220
400
50 60 70 80 90 100 110
42 43 44 45
76 77 78 79 80
115 120 125 130 135 140
160 180 200 220
Effective n used
Large circle at bivariate medians, triangles at means

DRAFT

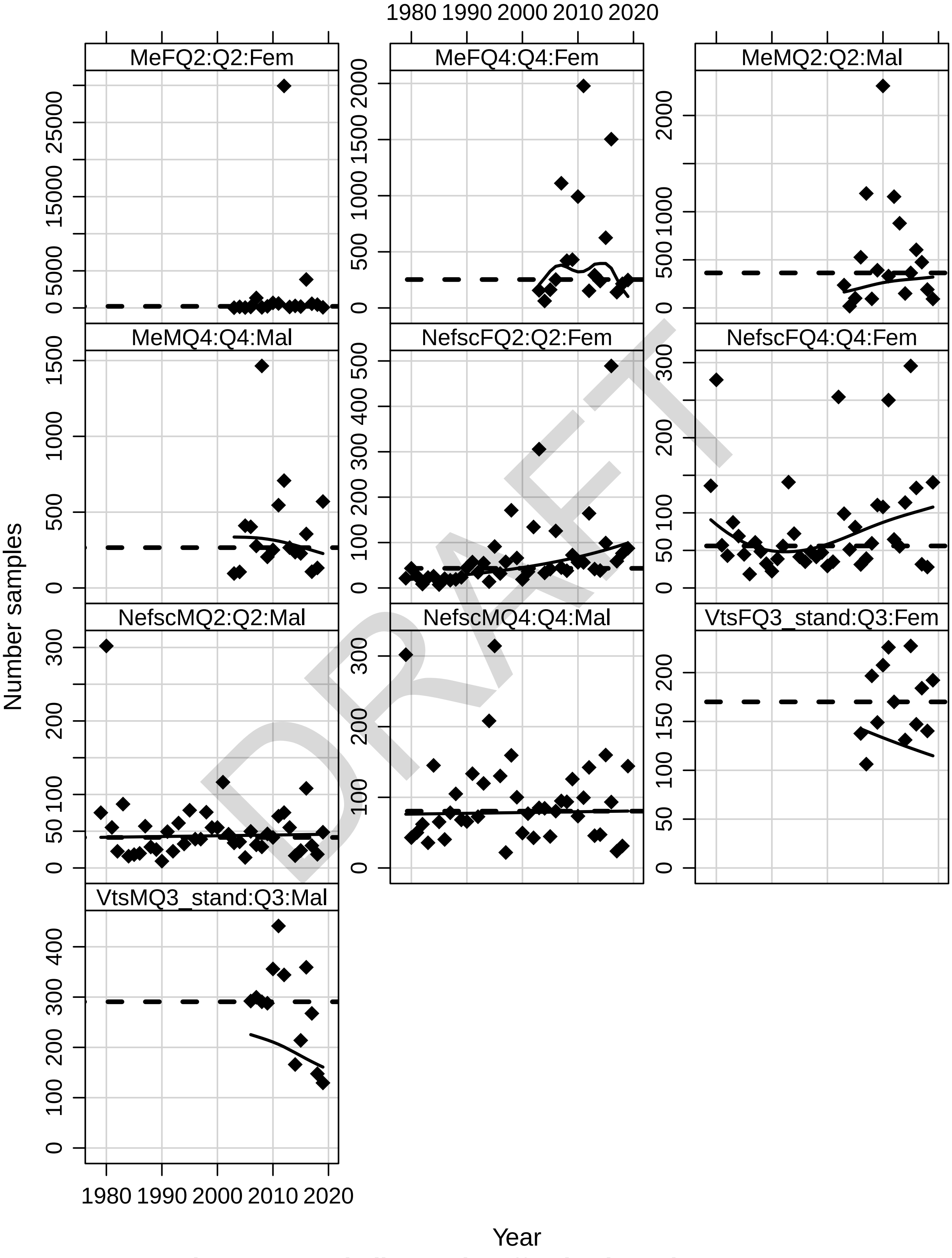
r60_ind_trawl_v6f6
Effective sample size for length data vs year



DRAFT

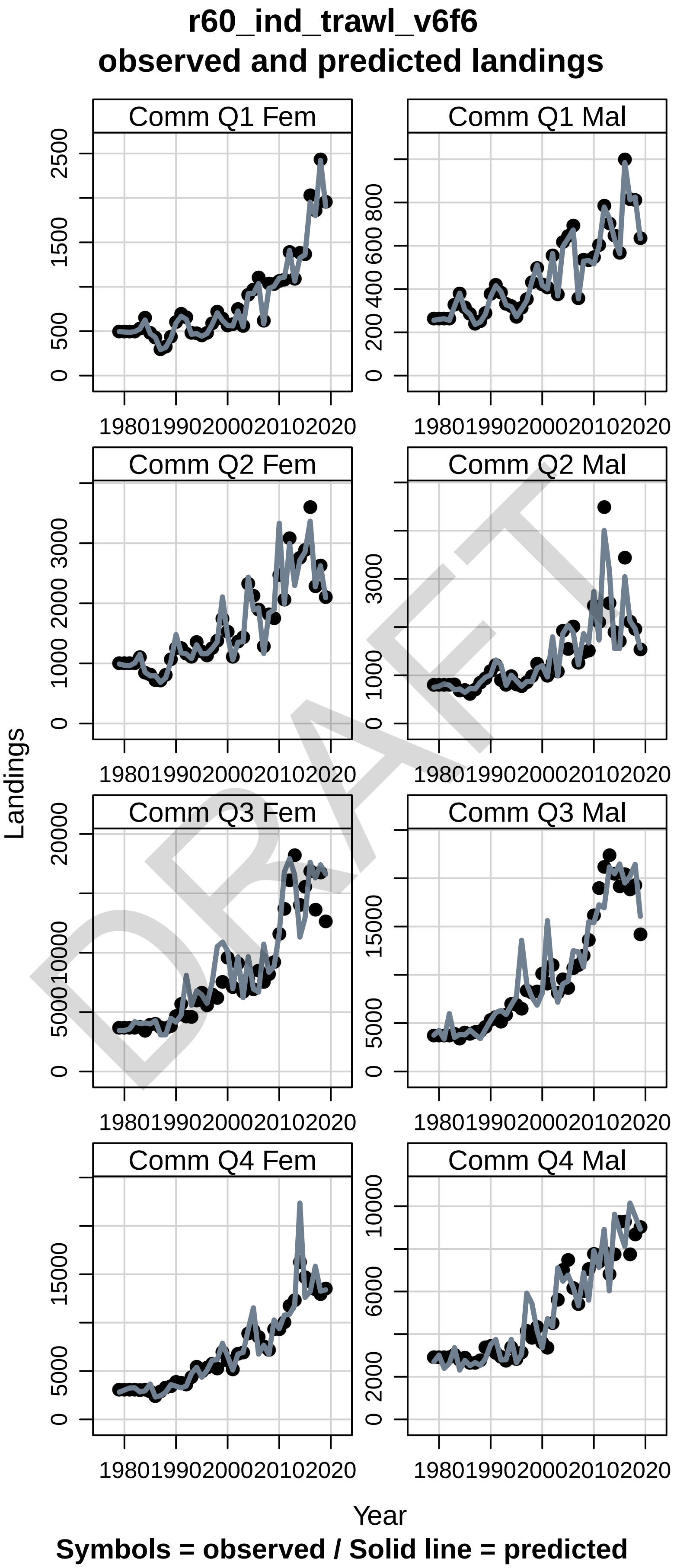
Line=assumed, diamonds=effective based on GOF, dotted line=median

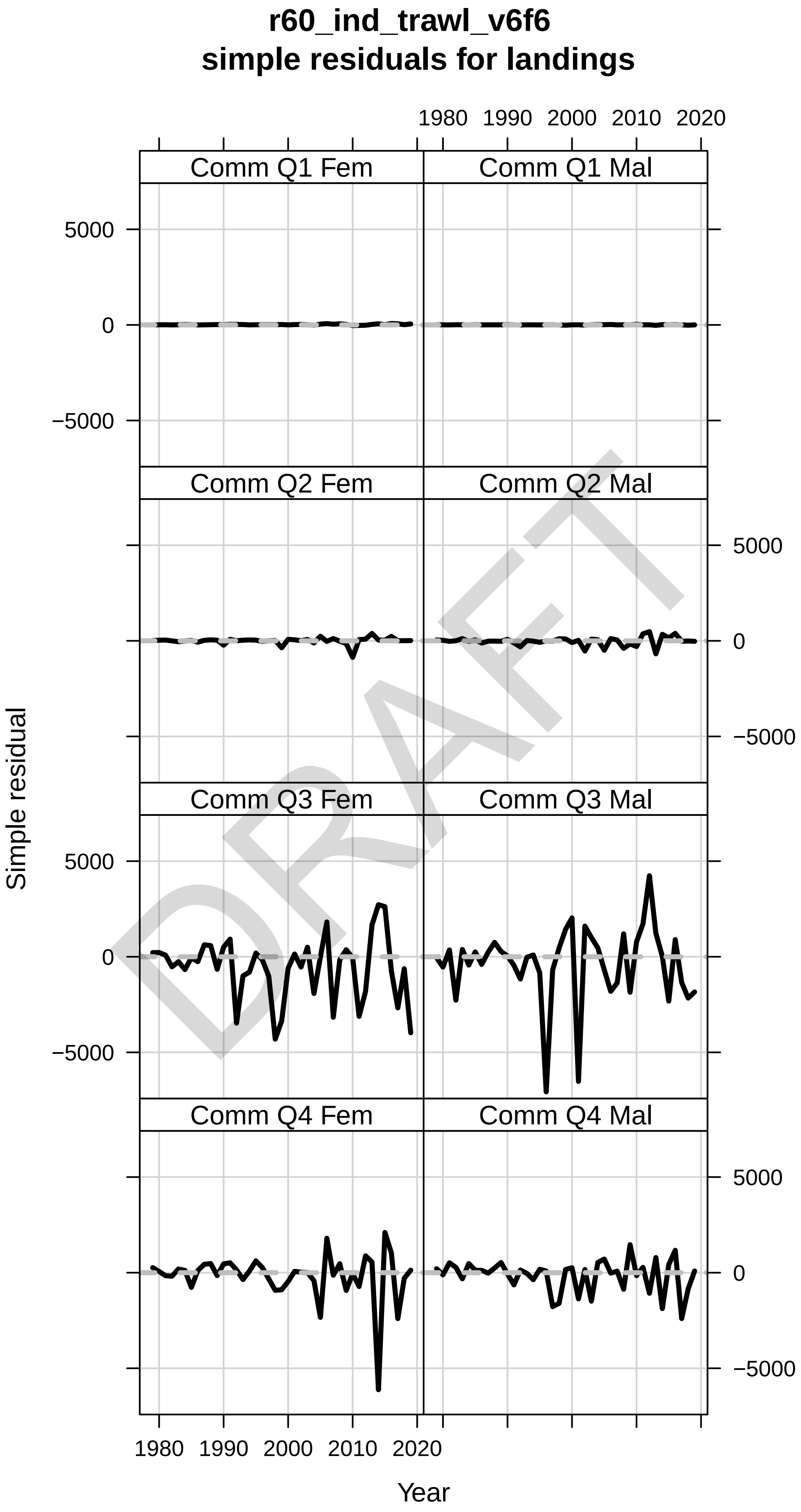
r60_ind_trawl_v6f6
Effective sample size for length data vs year



DRAFT

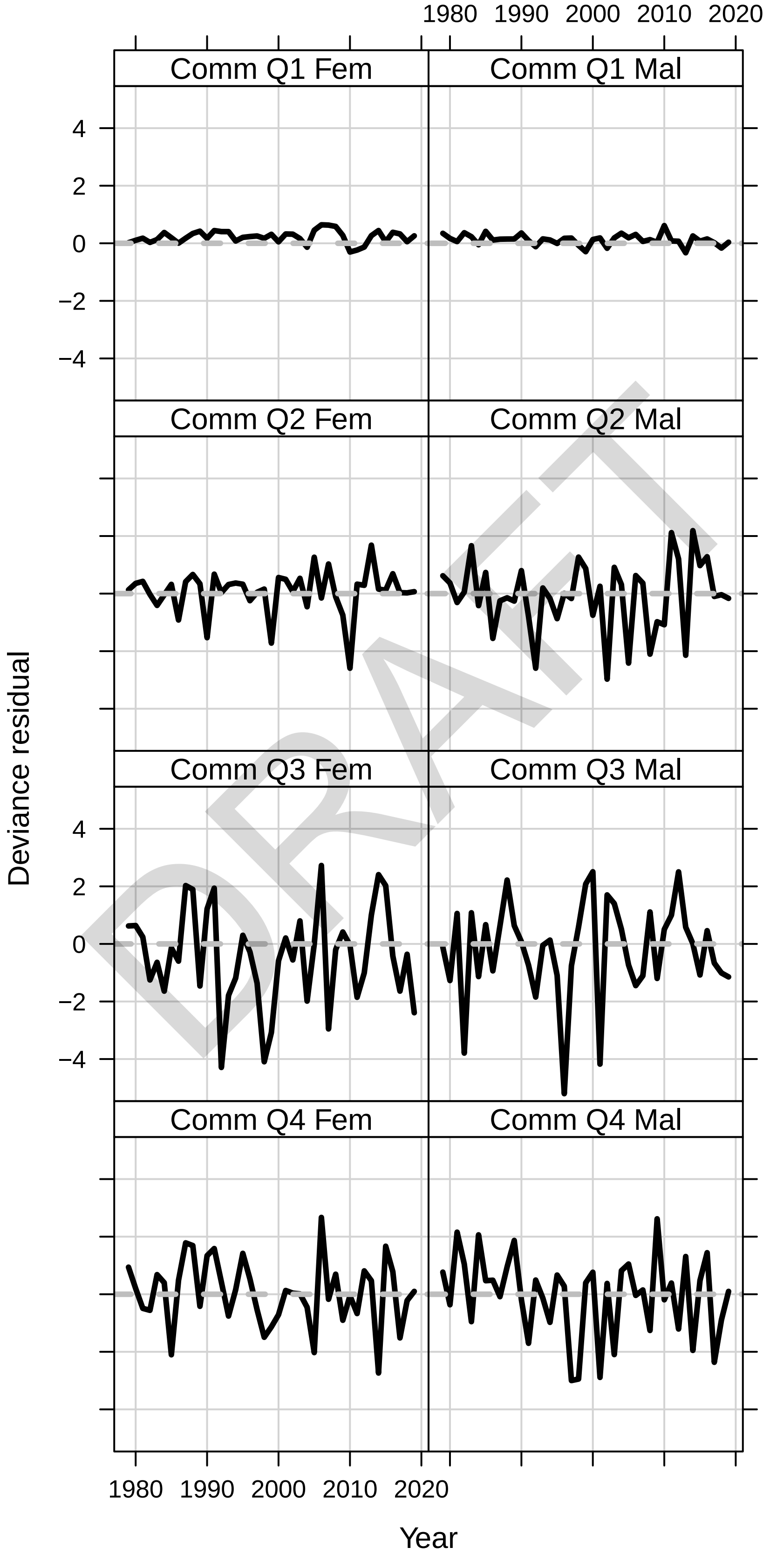
Line=assumed, diamonds=effective based on GOF,
dotted line=median


r60_ind_trawl_v6f6
observed and predicted landings
Comm Q1 Fem
Comm Q1 Mal
Comm Q2 Fem
Comm Q2 Mal
Comm Q3 Fem
Comm Q3 Mal
Comm Q4 Fem
Comm Q4 Mal
0
500
1500
2500
200 400 600 800
1000 2000 3000
1000
3000
500010000
20000
5000
15000
2000
6000
10000
1980199020002010 2020
Landings
Year
Symbols = observed / Solid line = predicted
DRAFT


r60_ind_trawl_v6f6
simple residuals for landings
Comm Q1 Fem
Comm Q1 Mal
Comm Q2 Fem
Comm Q2 Mal
Comm Q3 Fem
Comm Q3 Mal
Comm Q4 Fem
Comm Q4 Mal
5000
0
−5000
1980
1990
2000
2010
2020
Simple residual
Year

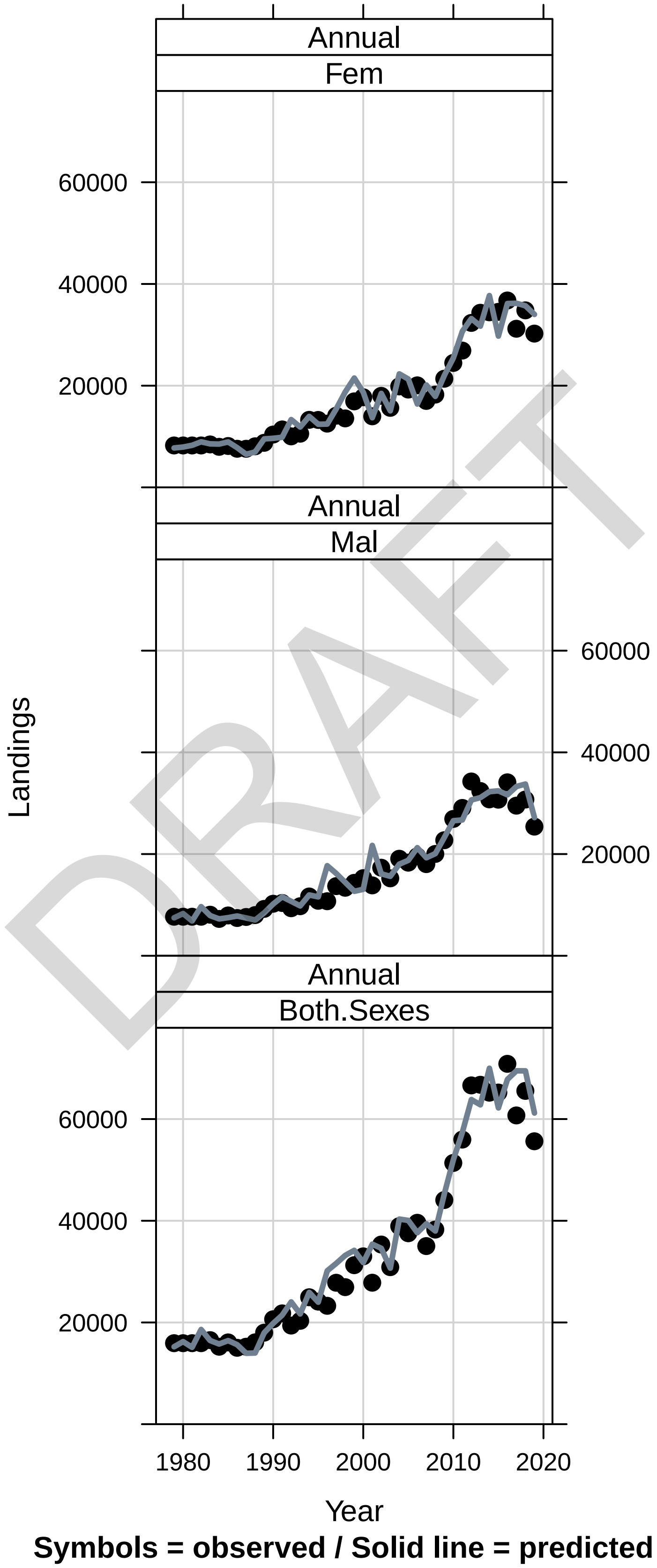
DRAFT

r60_ind_trawl_v6f6
deviance residuals for landings



DRAFT

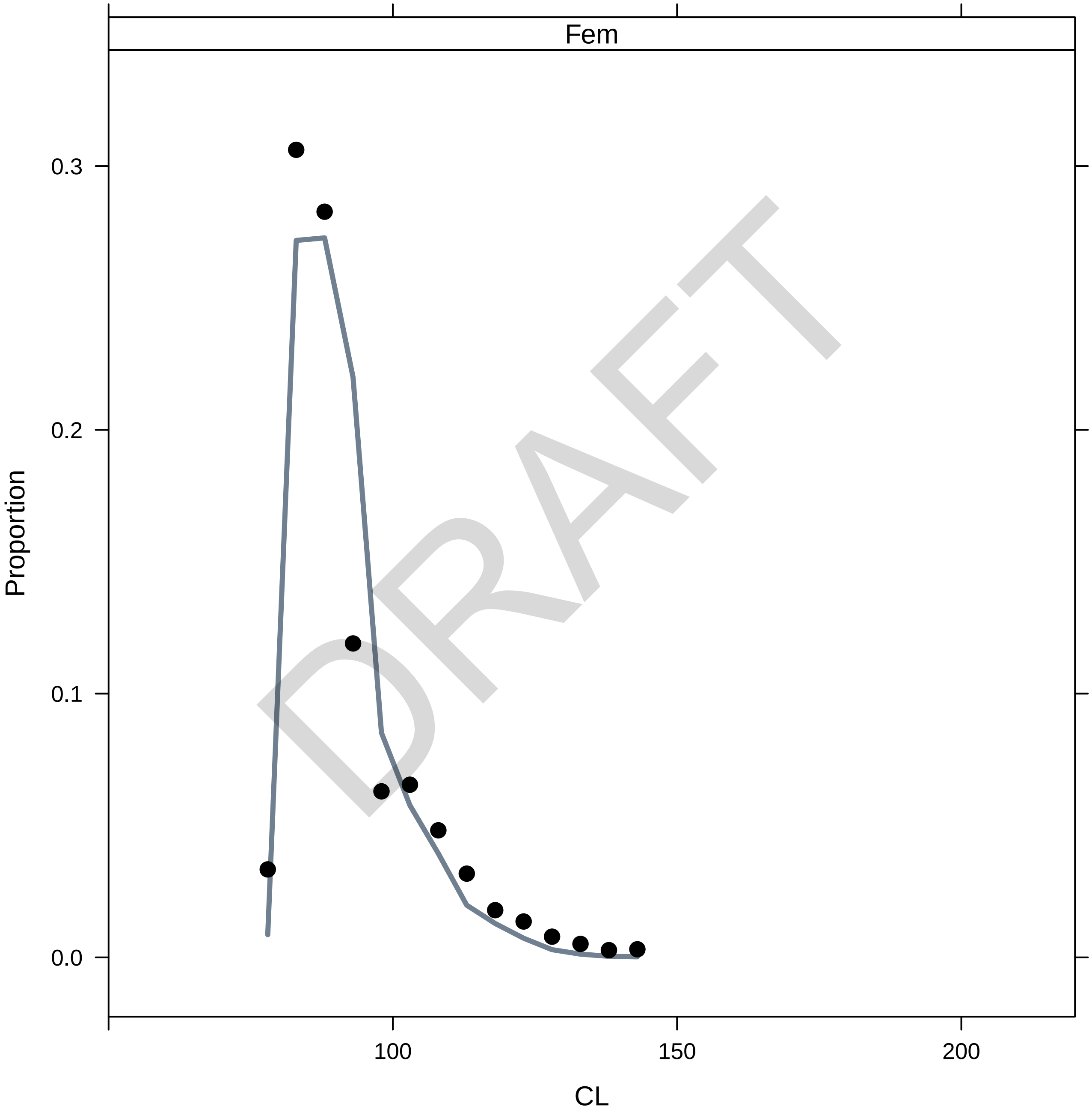
r60_ind_trawl_v6f6
observed and predicted landings



DRAFT

Symbols = observed / Solid line = predicted

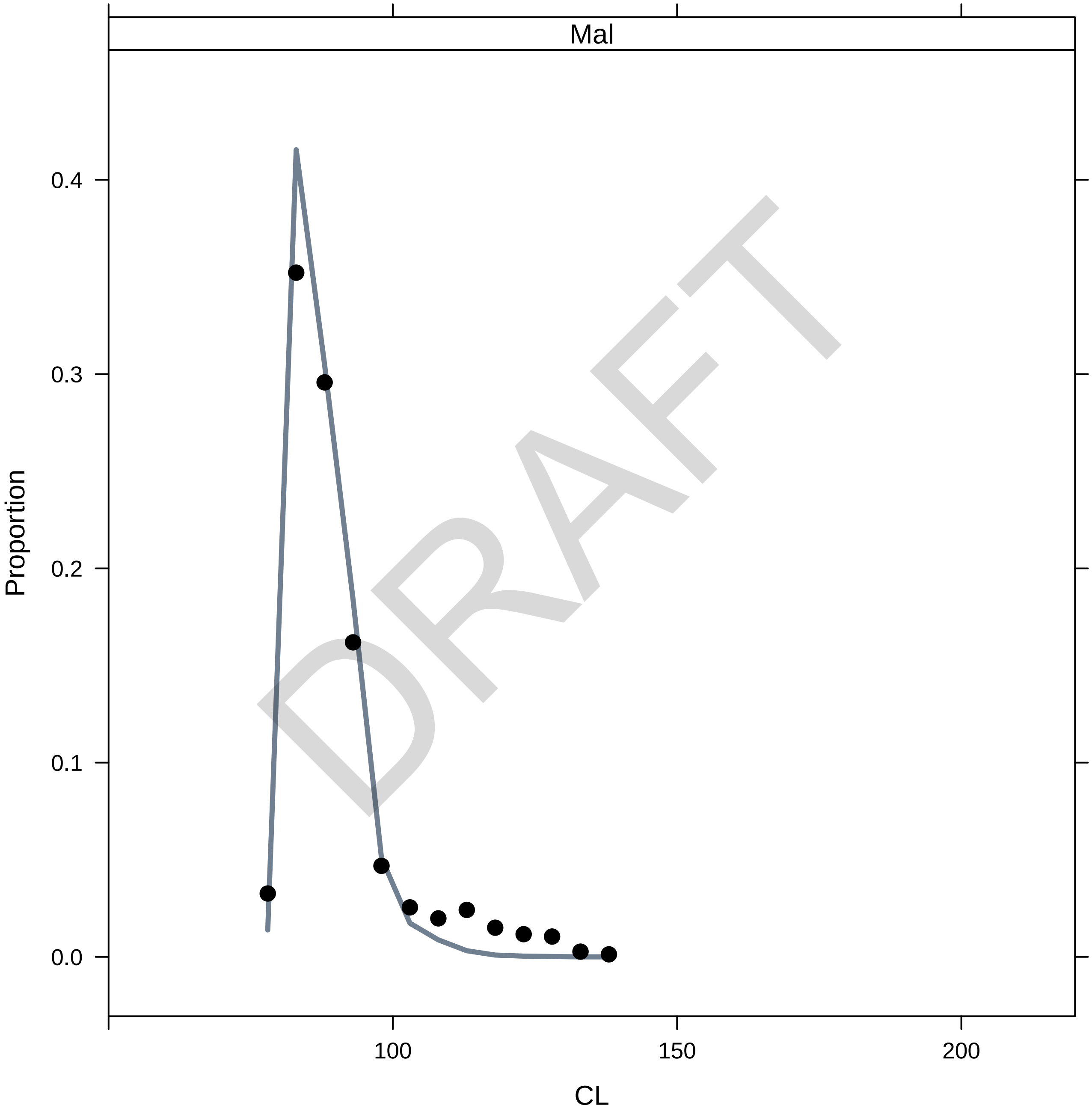
r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q1 Fem



DRAFT

Symbols = observed / Solid line = predicted

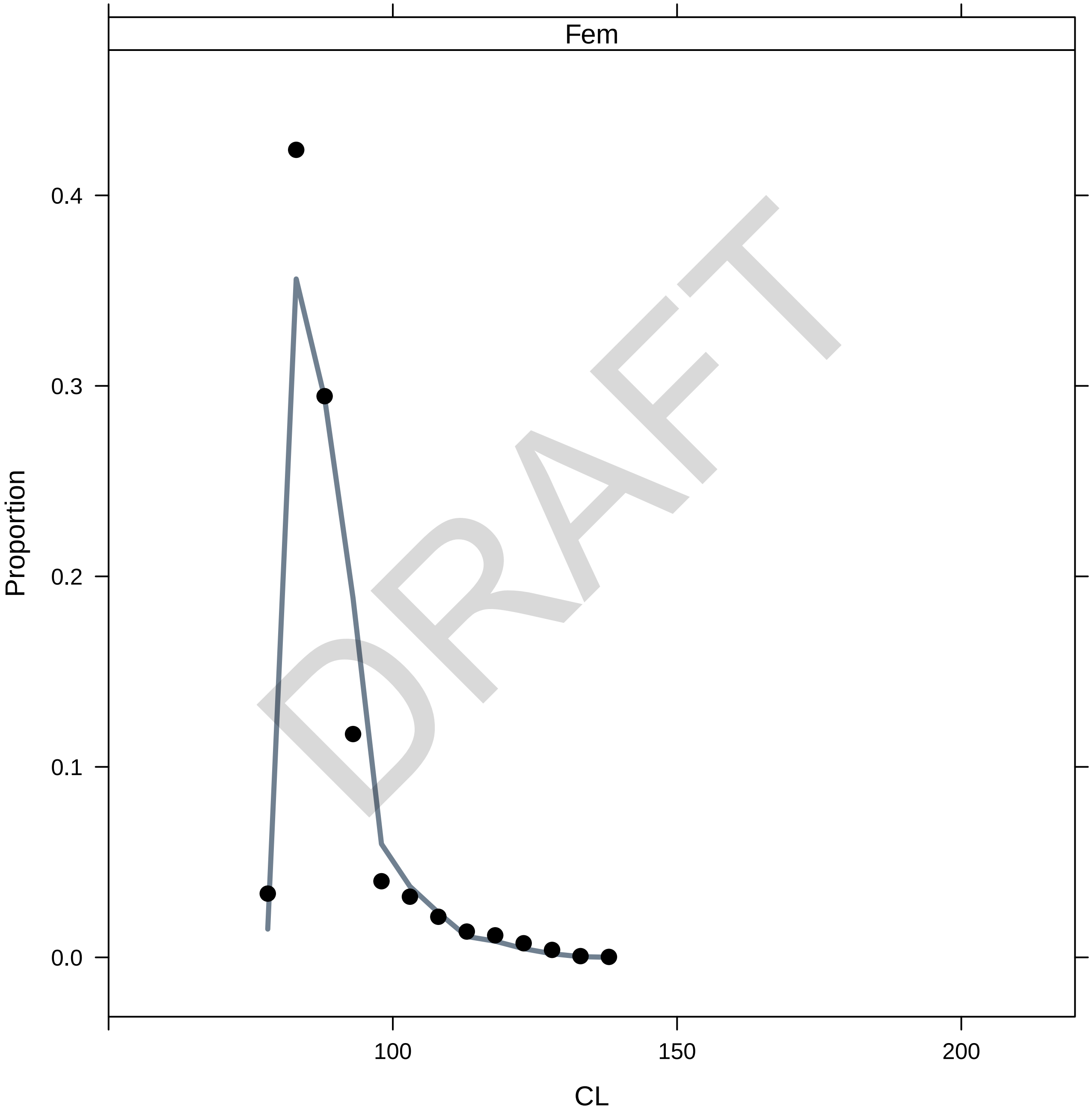
r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q1 Mal



Symbols = observed / Solid line = predicted

DRAFT

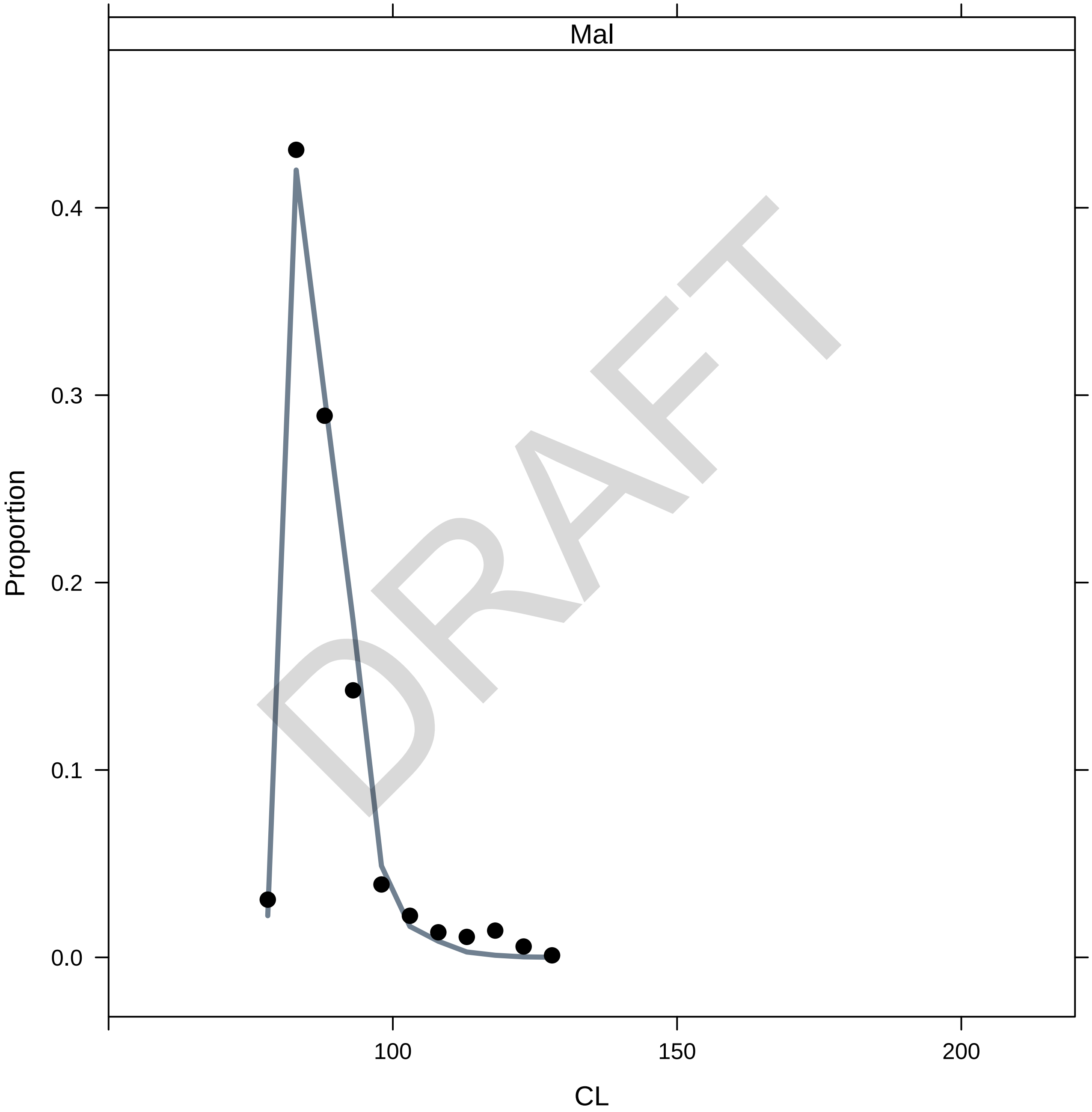
r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q2 Fem



DRAFT

Symbols = observed / Solid line = predicted

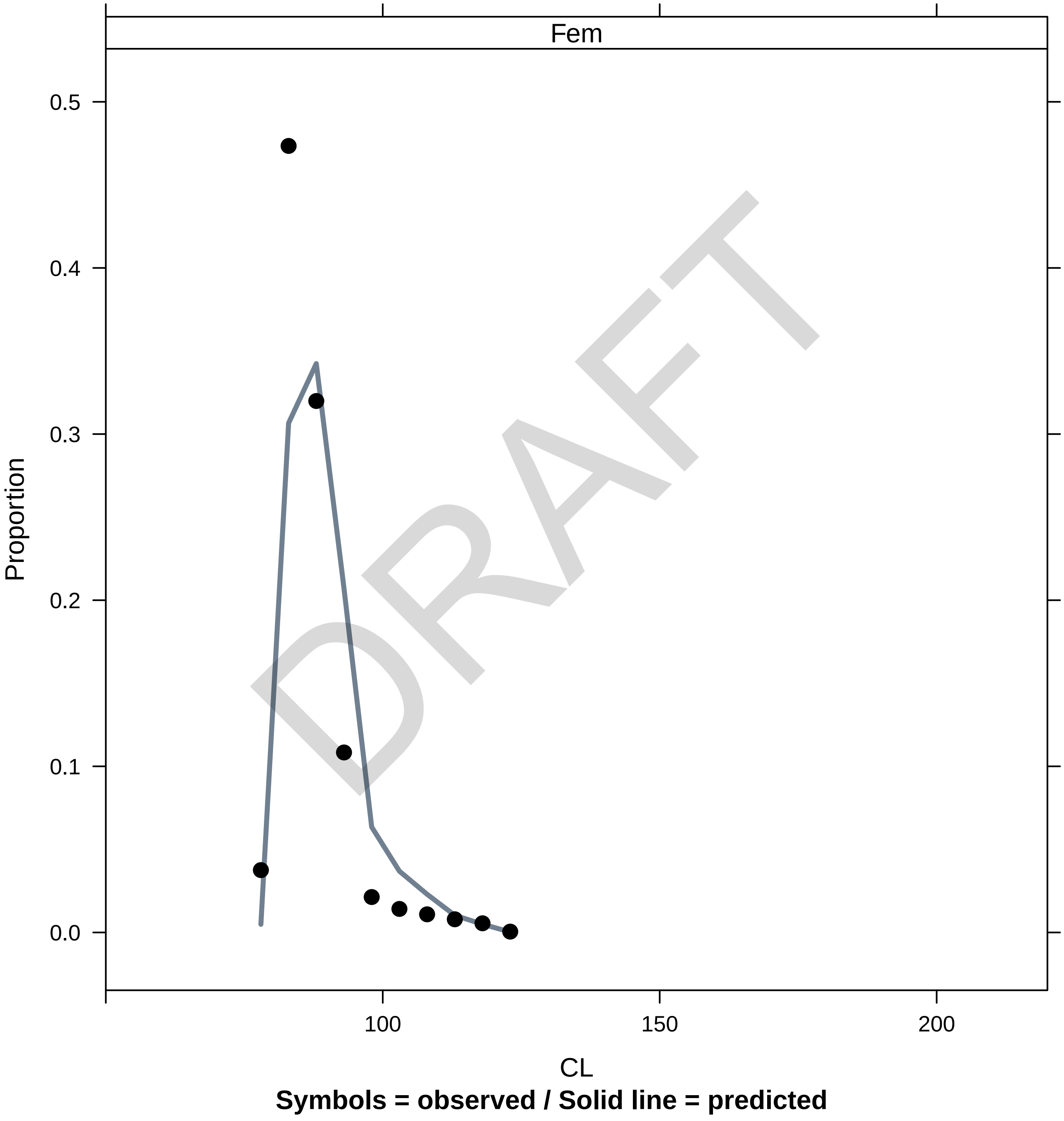
r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q2 Mal



DRAFT

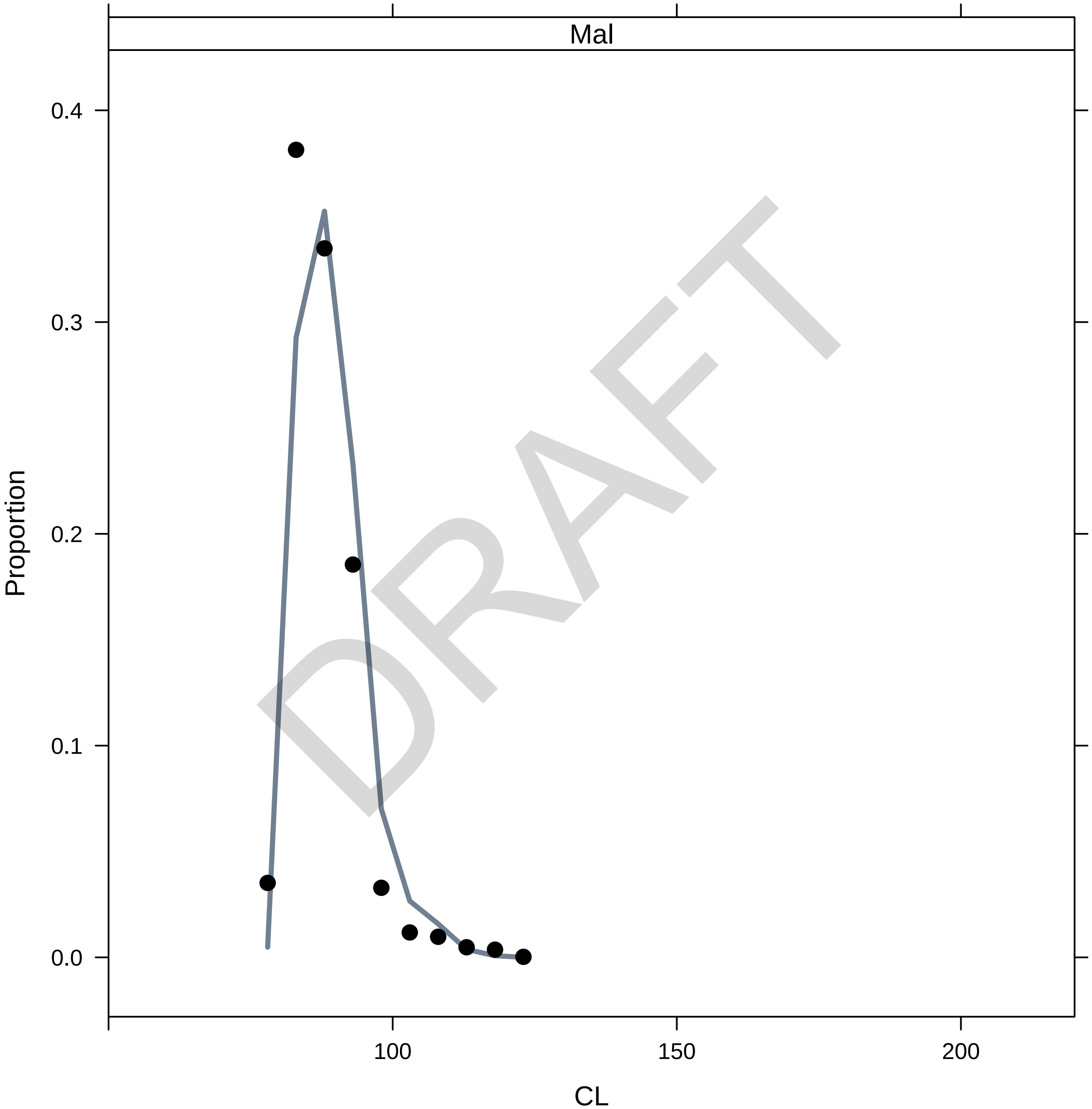
Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q3 Fem



DRAFT

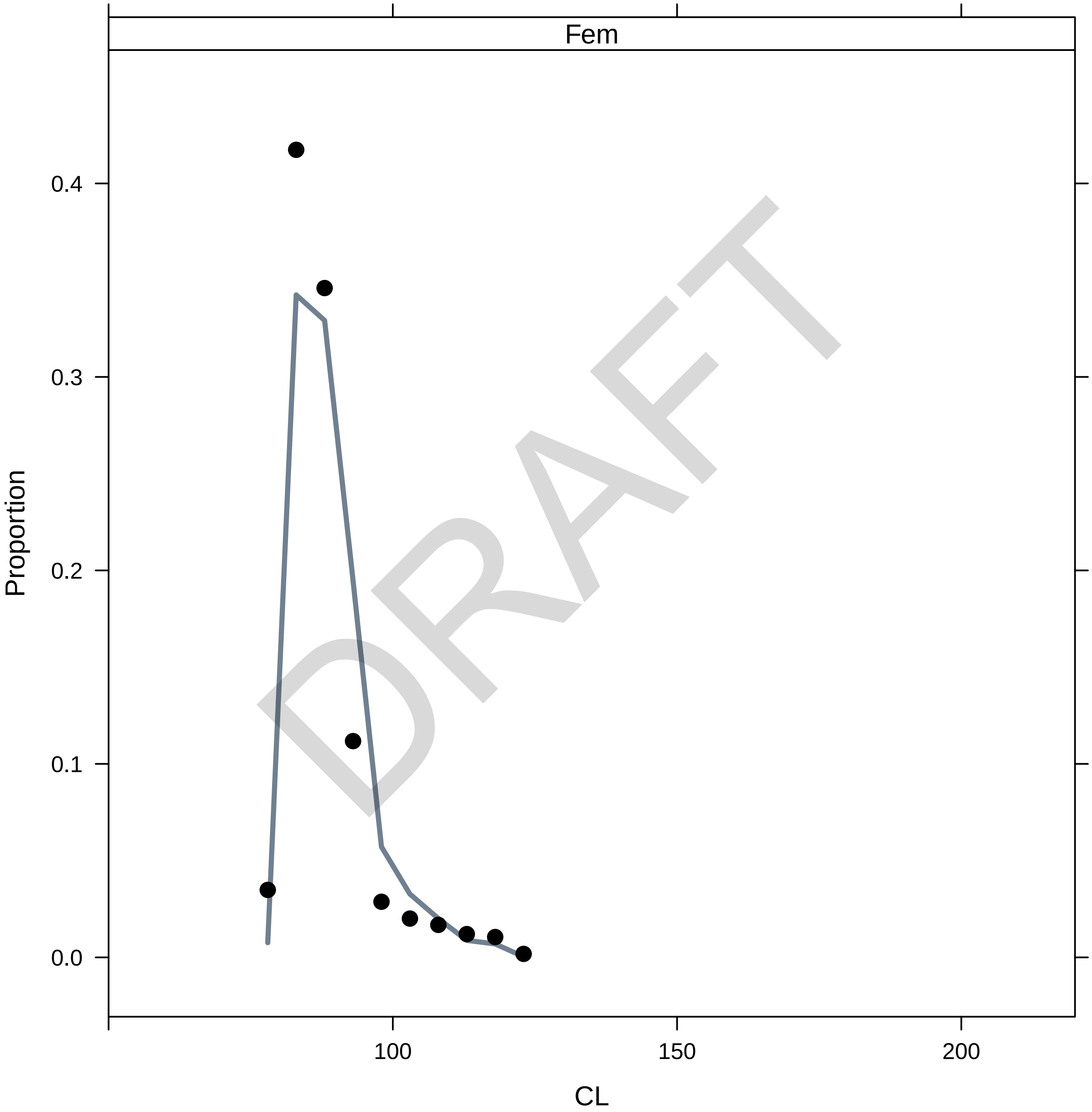
r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q3 Mal



DRAFT

Symbols = observed / Solid line = predicted

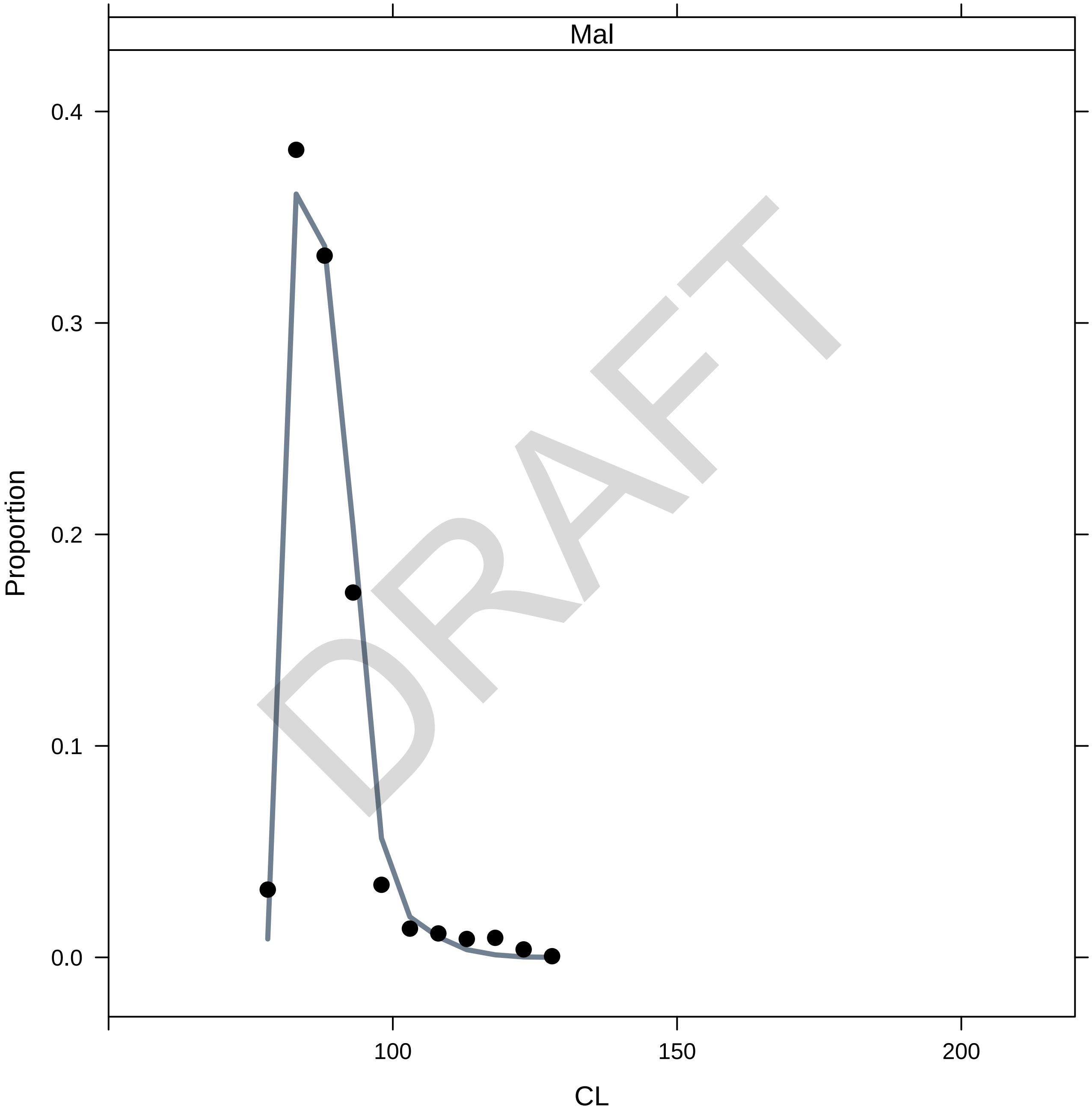
r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q4 Fem



Symbols = observed / Solid line = predicted

DRAFT

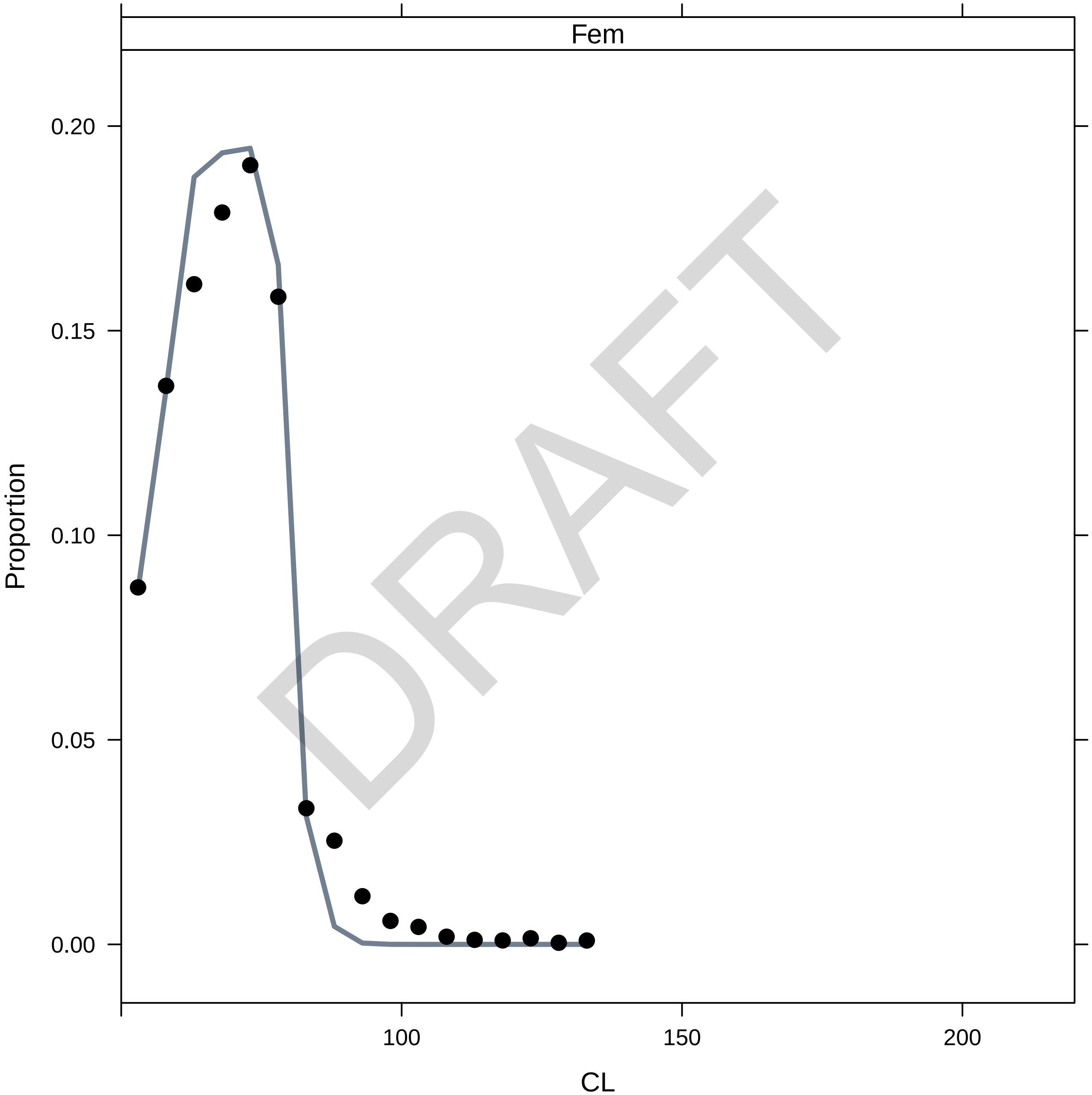
r60_ind_trawl_v6f6
Average observed and predicted length comps Comm Q4 Mal



DRAFT

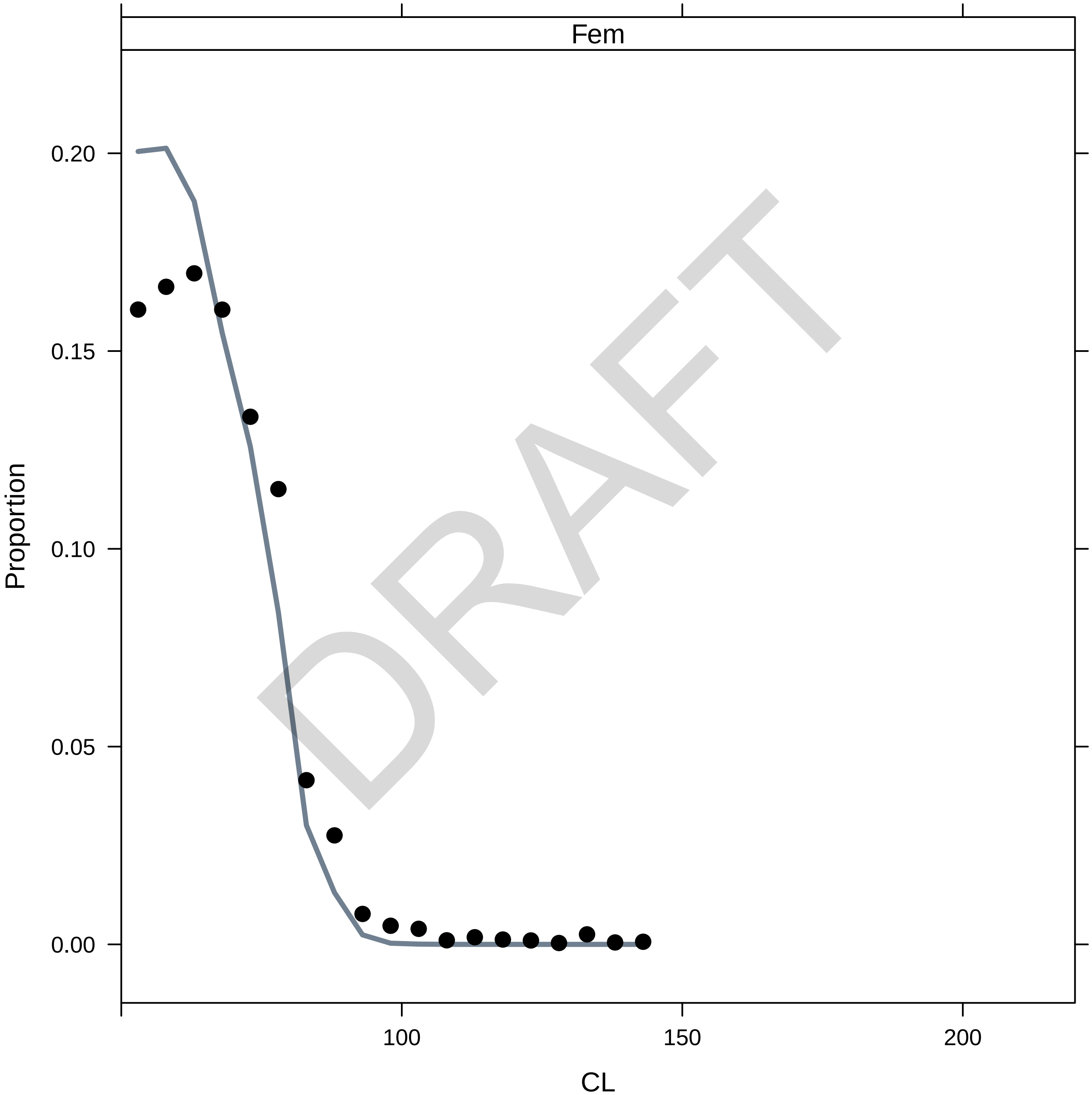
Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
Average observed and predicted length comps MaFQ2



Symbols = observed / Solid line = predicted

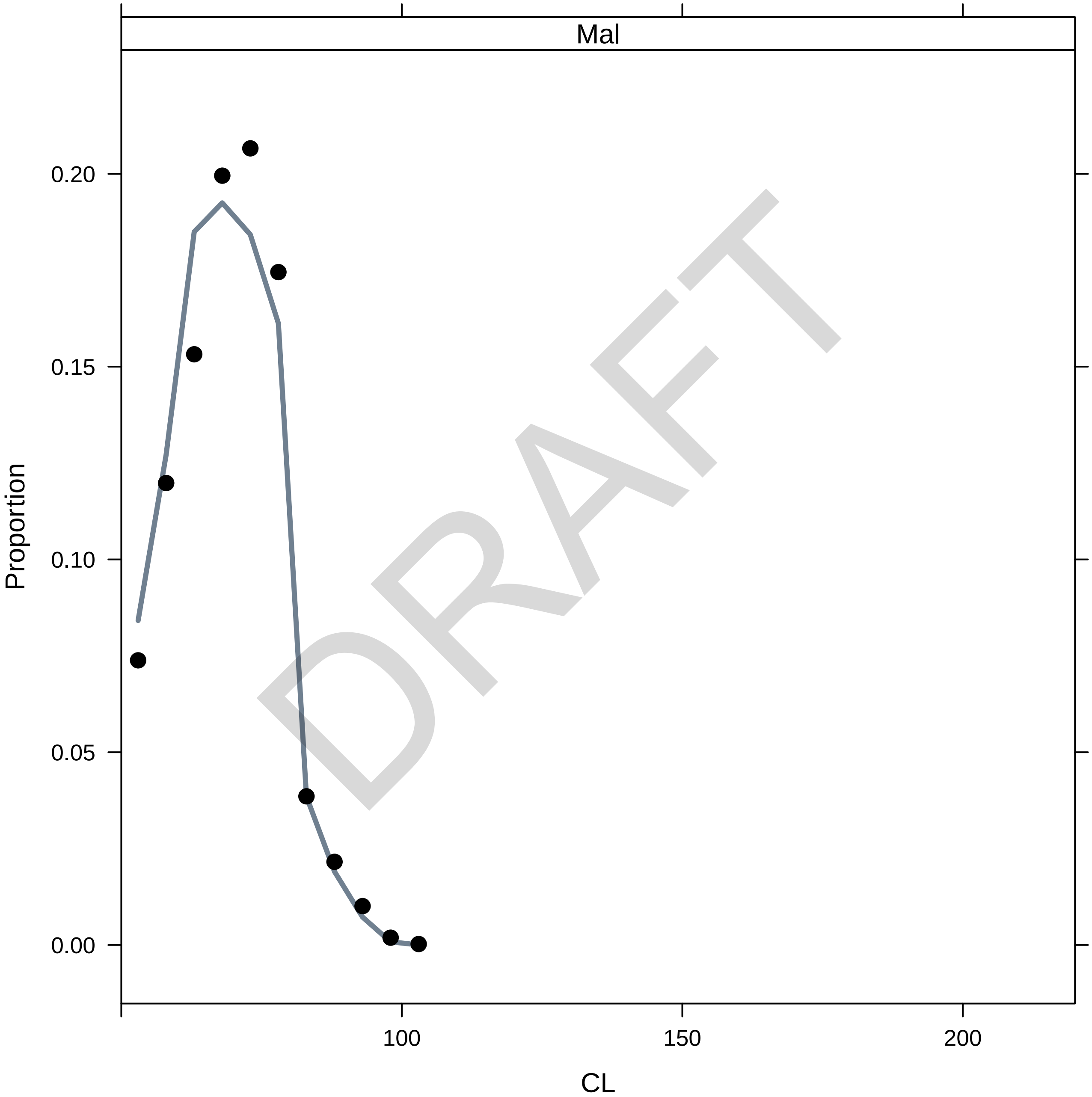
r60_ind_trawl_v6f6
Average observed and predicted length comps MaFQ4



DRAFT

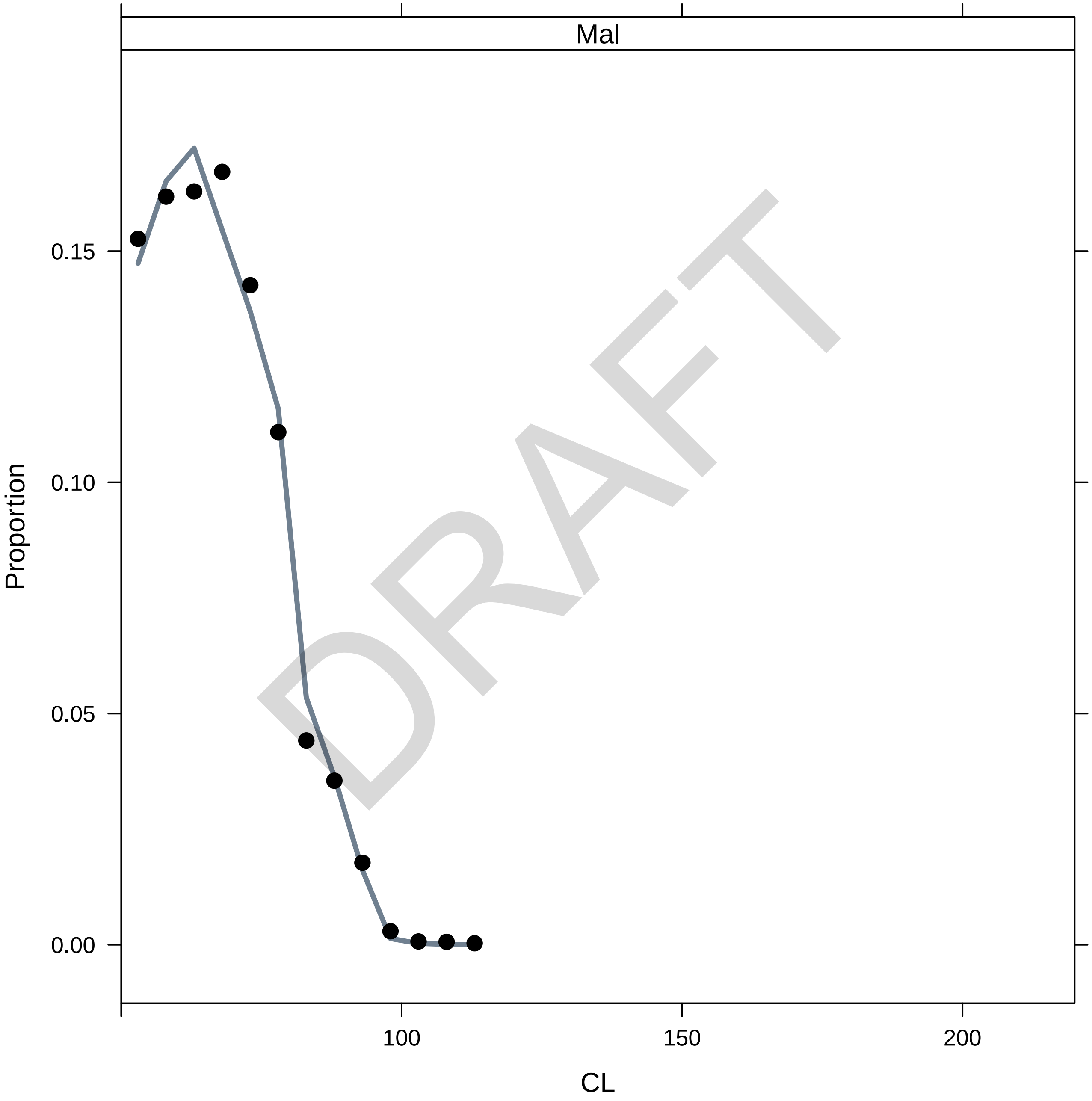
Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
Average observed and predicted length comps MaMQ2



Symbols = observed / Solid line = predicted

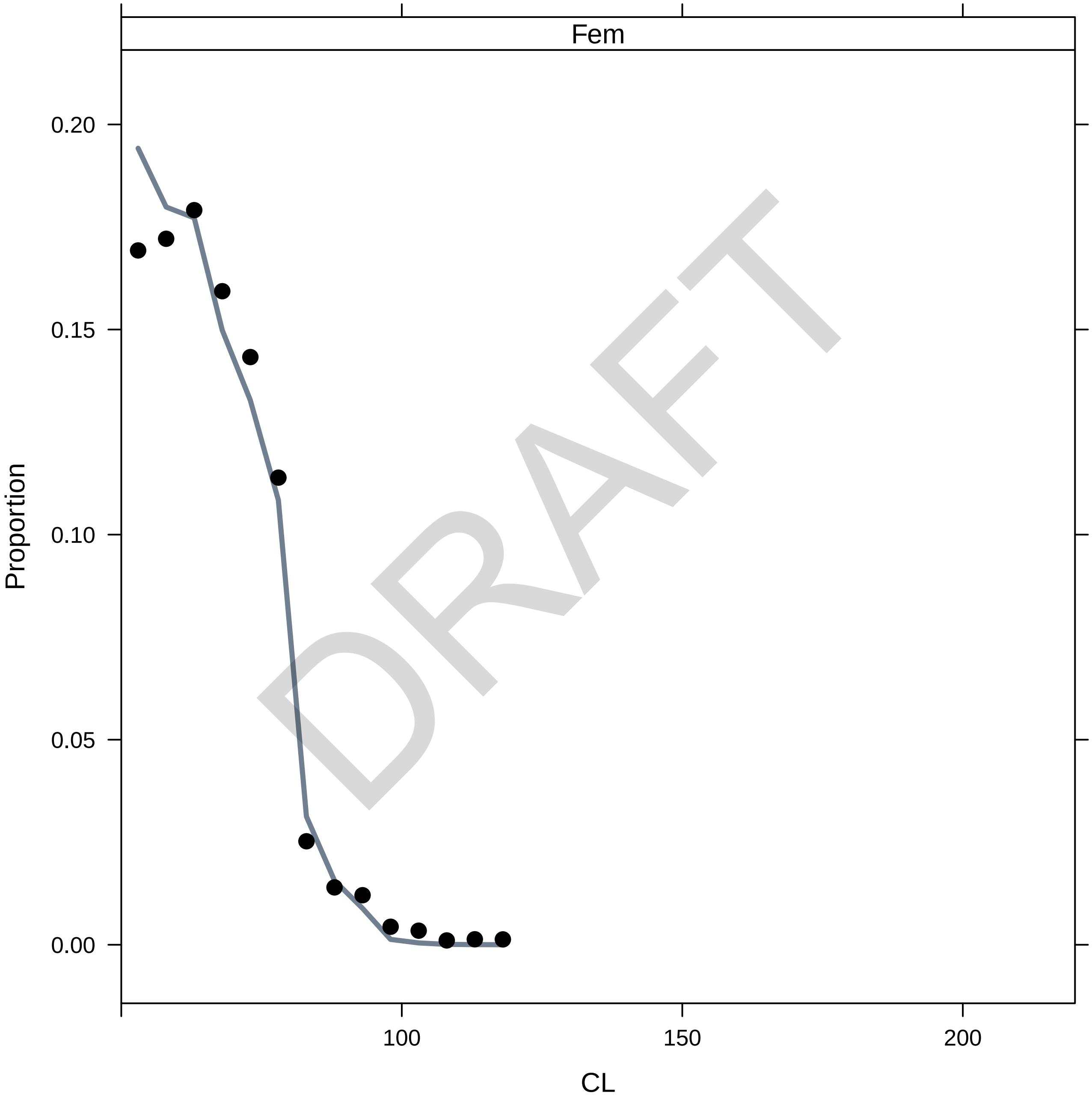
r60_ind_trawl_v6f6
Average observed and predicted length comps MaMQ4



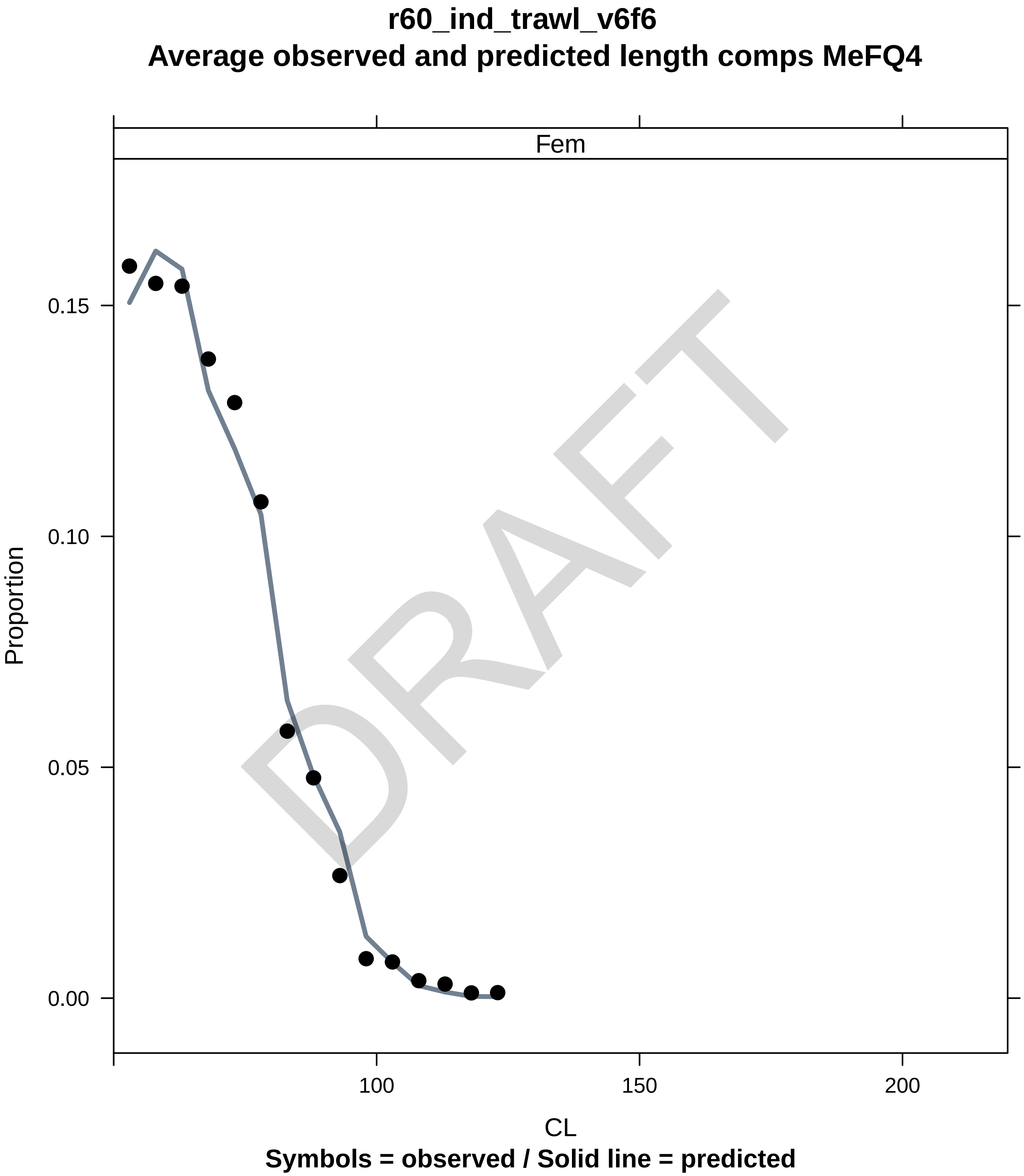
DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
Average observed and predicted length comps MeFQ2

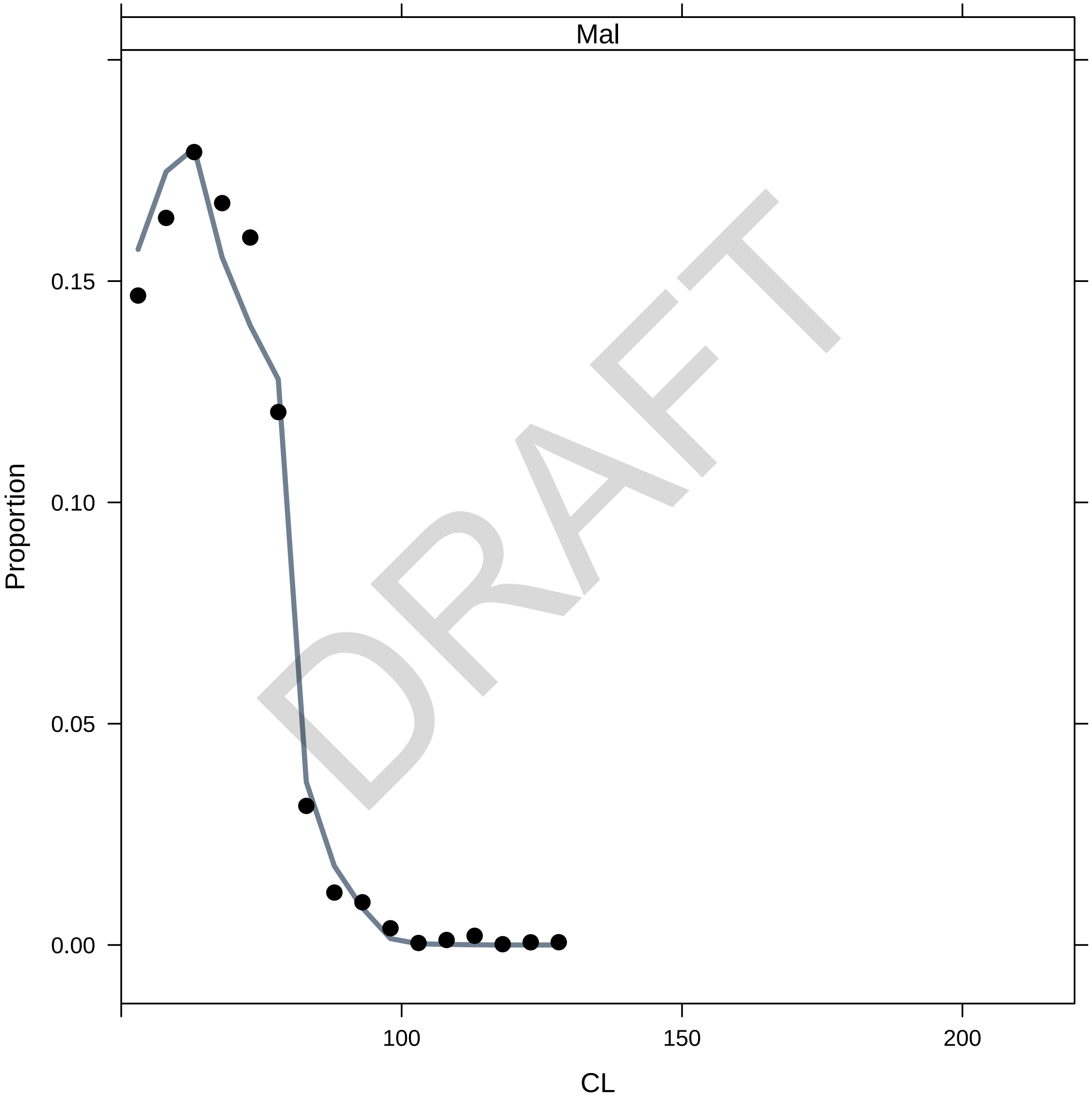


Symbols = observed / Solid line = predicted


r60_ind_trawl_v6f6
Average observed and predicted length comps MeFQ4
Fem
Proportion
0.00
0.05
0.10
0.15
100
150
200
CL
Symbols = observed / Solid line = predicted

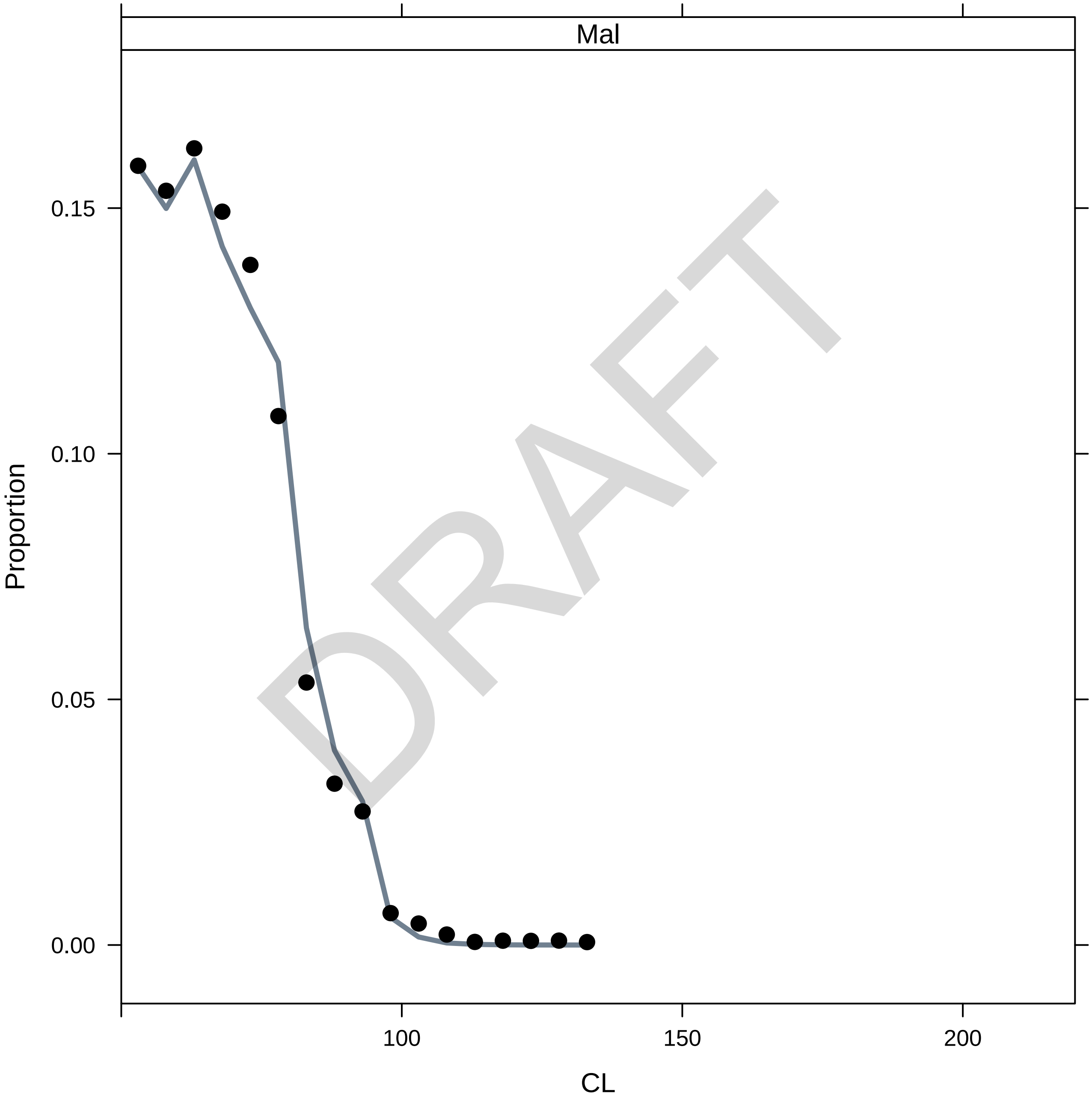
DRAFT

r60_ind_trawl_v6f6
Average observed and predicted length comps MeMQ2



Symbols = observed / Solid line = predicted

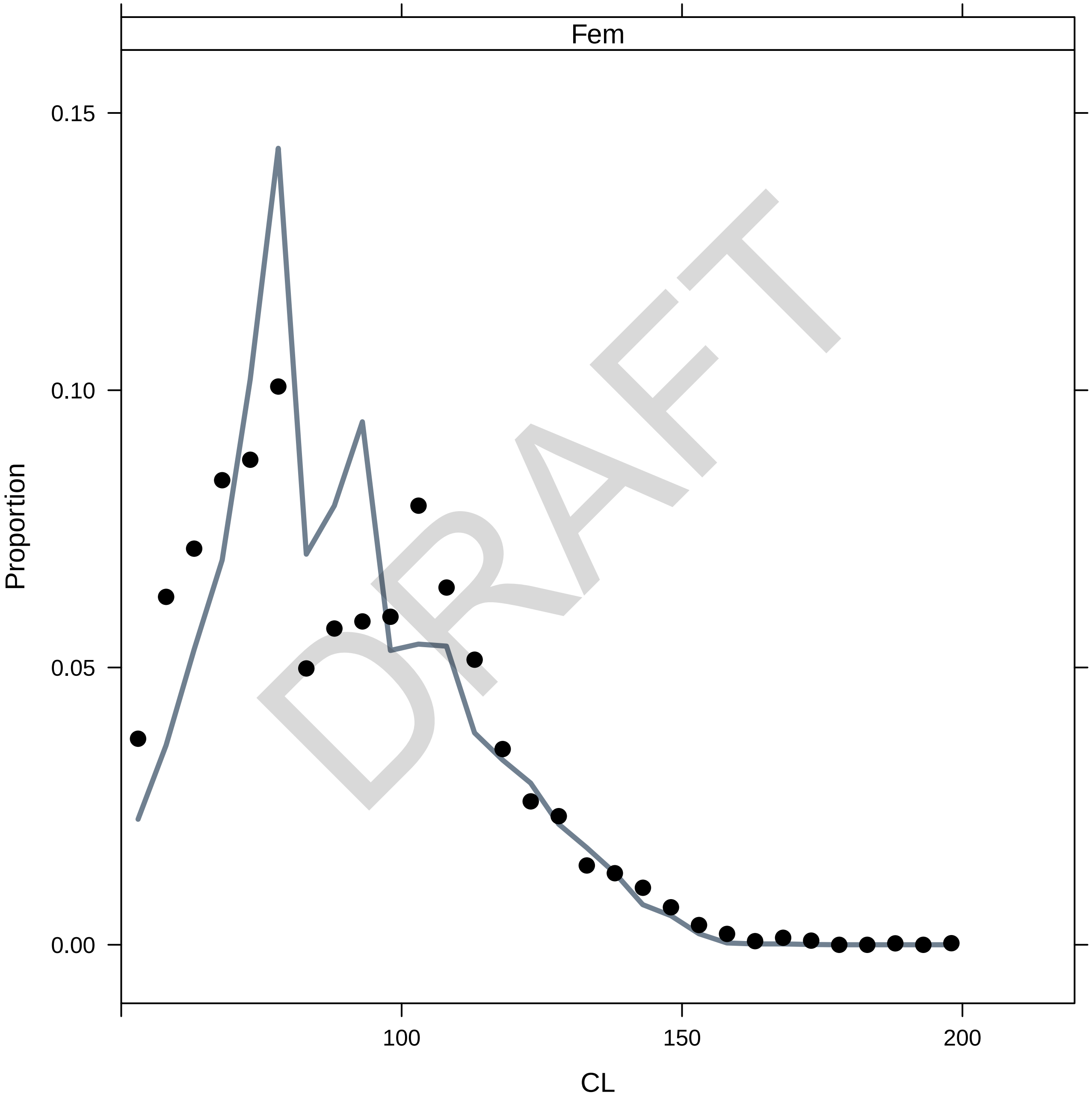
r60_ind_trawl_v6f6
Average observed and predicted length comps MeMQ4



DRAFT

Symbols = observed / Solid line = predicted

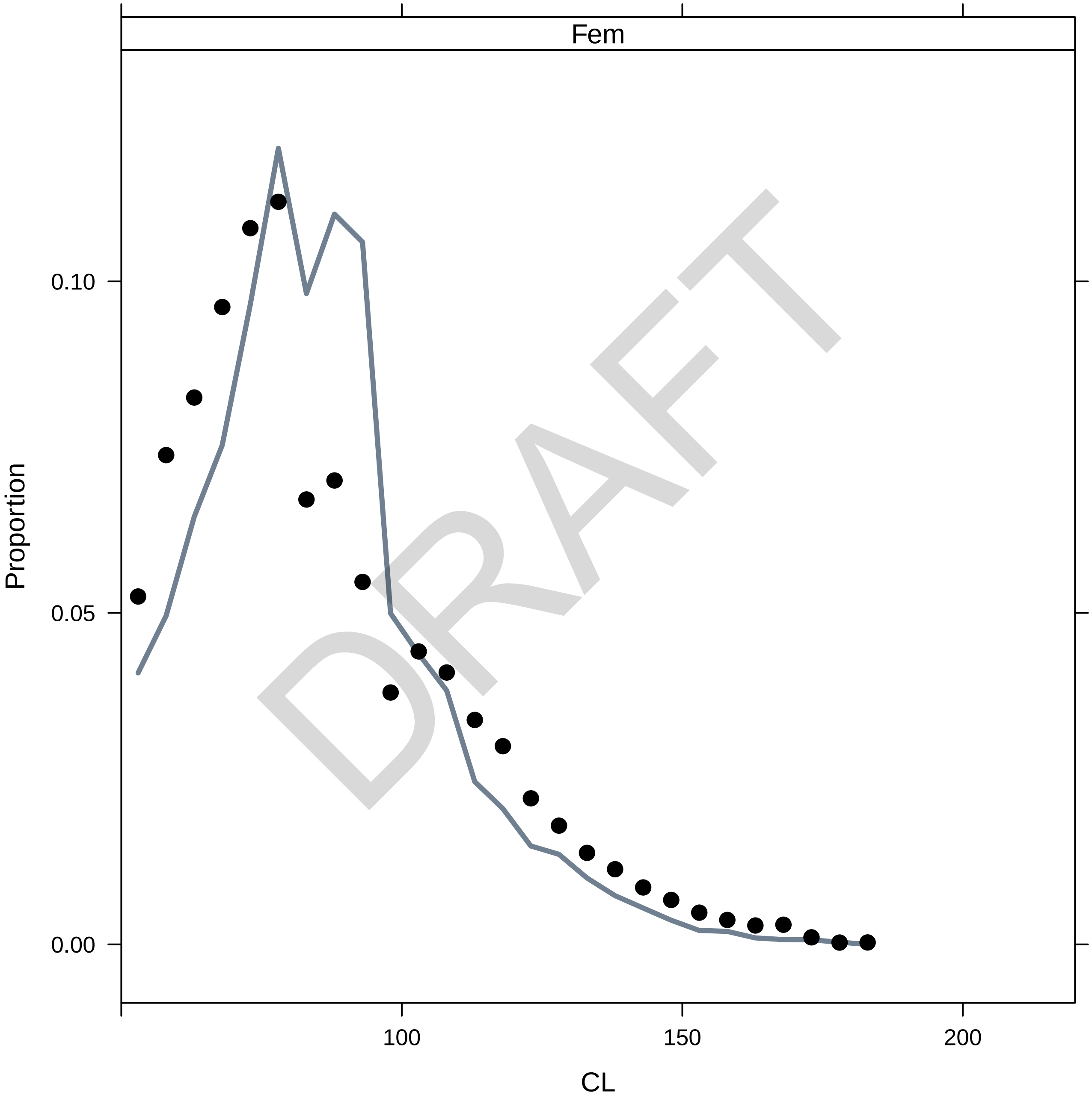
r60_ind_trawl_v6f6
Average observed and predicted length comps NefscFQ2



DRAFT

Symbols = observed / Solid line = predicted

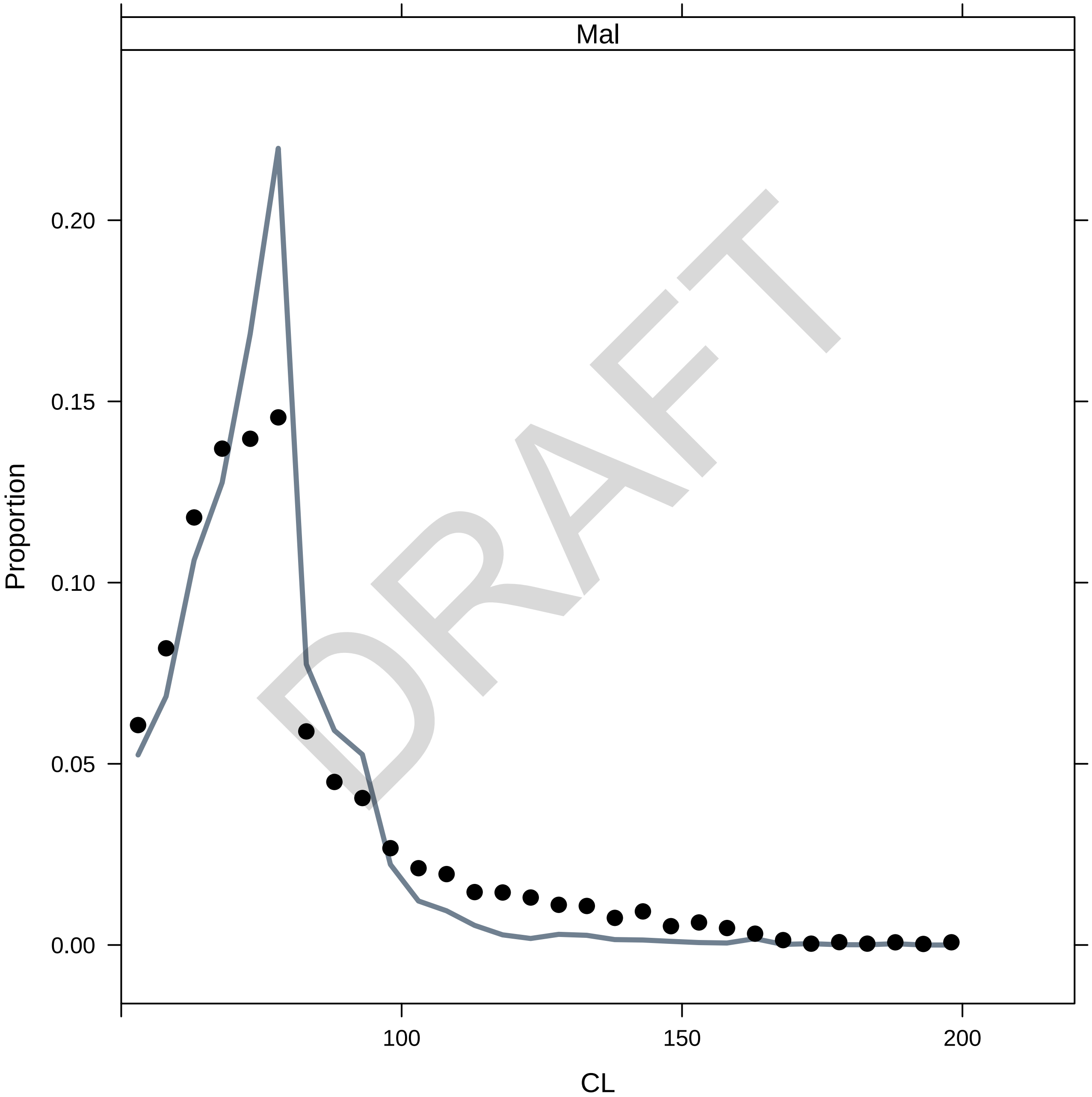
r60_ind_trawl_v6f6
Average observed and predicted length comps NefscFQ4



DRAFT

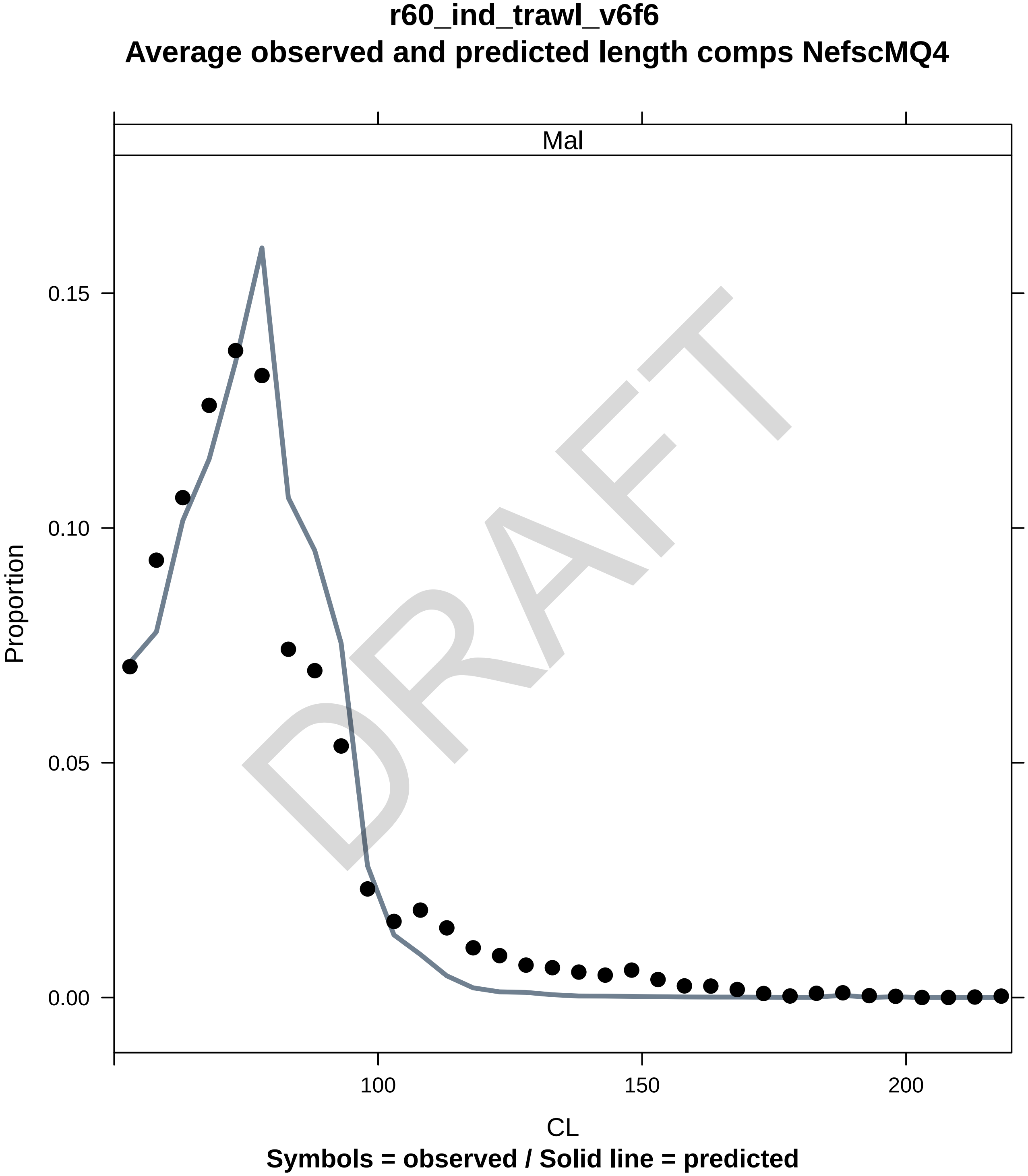
Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
Average observed and predicted length comps NefscMQ2



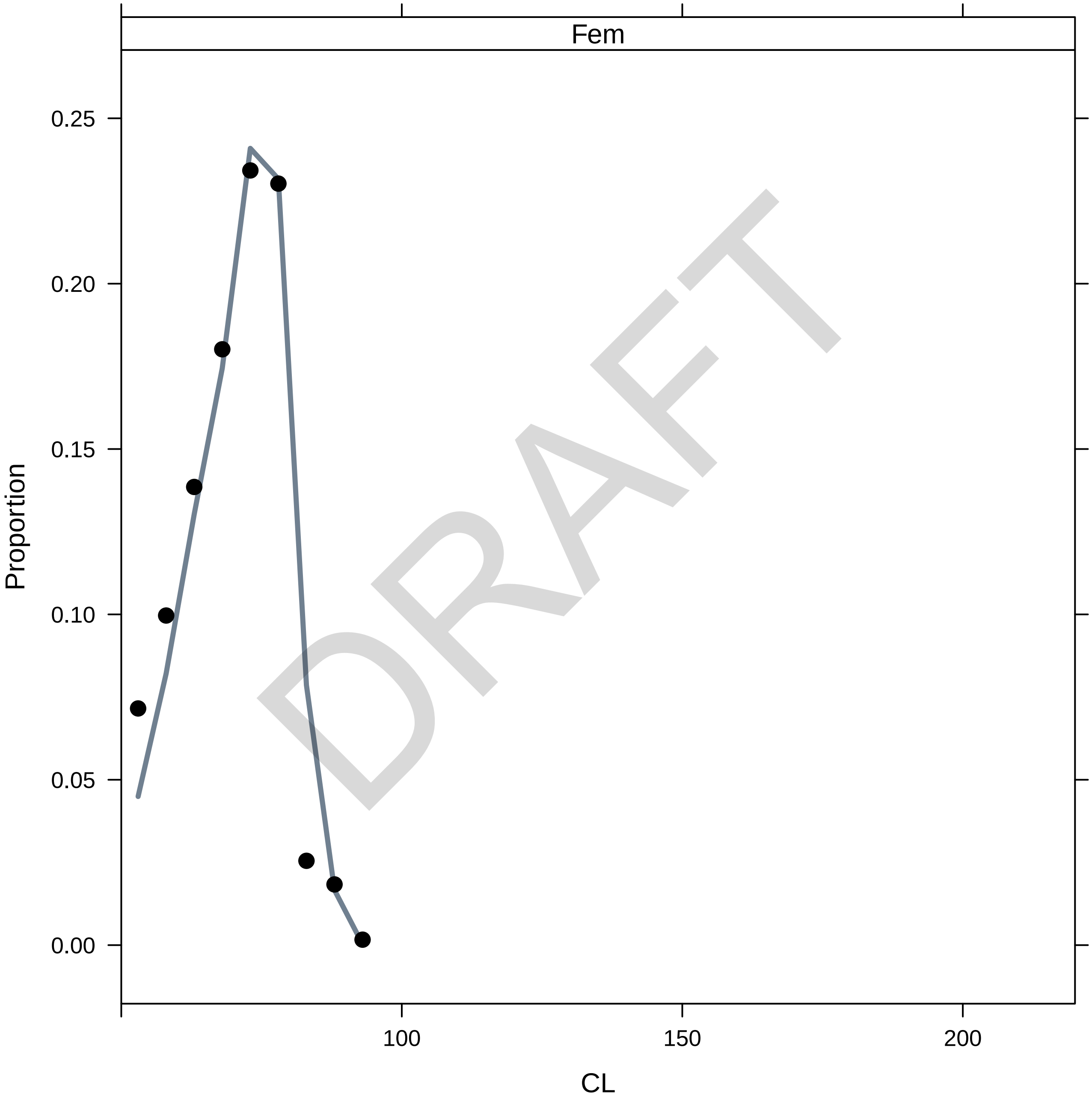
DRAFT

Symbols = observed / Solid line = predicted


r60_ind_trawl_v6f6
Average observed and predicted length comps NefscMQ4
Mal
Proportion
0.15
0.10
0.05
0.00
100
150
200
CL
Symbols = observed / Solid line = predicted

DRAFT

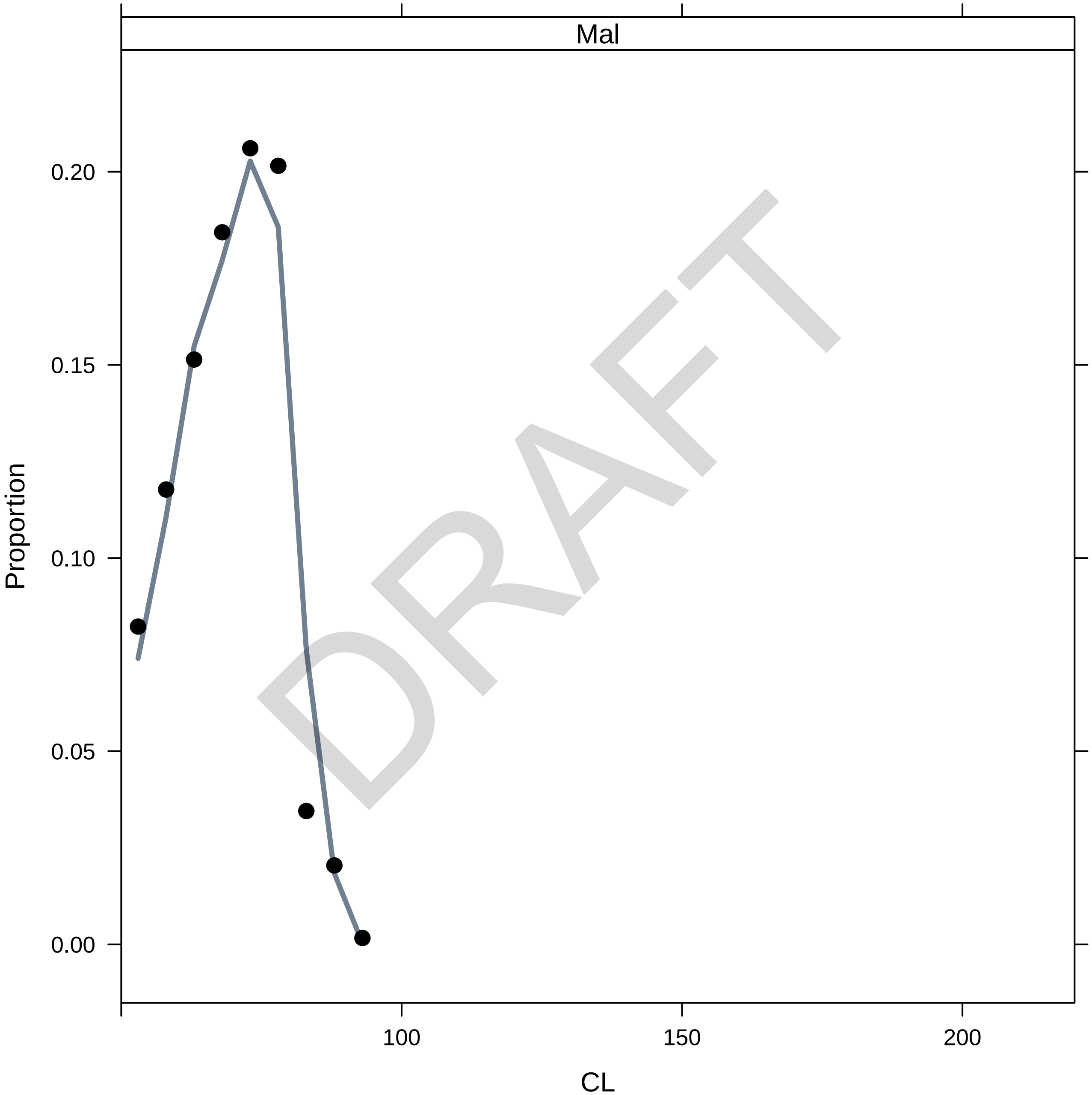
r60_ind_trawl_v6f6
Average observed and predicted length comps VtsFQ3_stand



DRAFT

Symbols = observed / Solid line = predicted

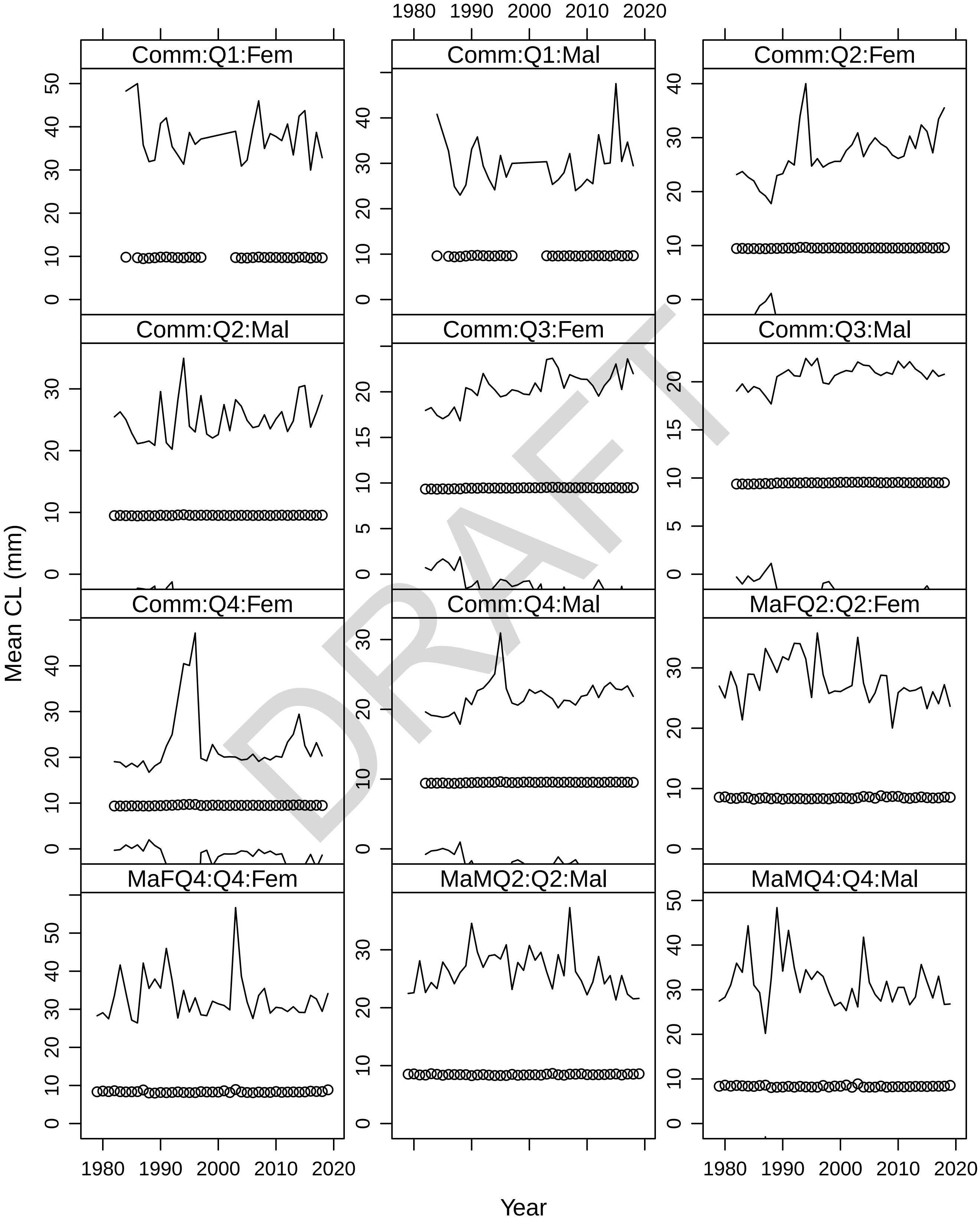
r60_ind_trawl_v6f6
Average observed and predicted length comps VtsMQ3_stand



DRAFT

Symbols = observed / Solid line = predicted

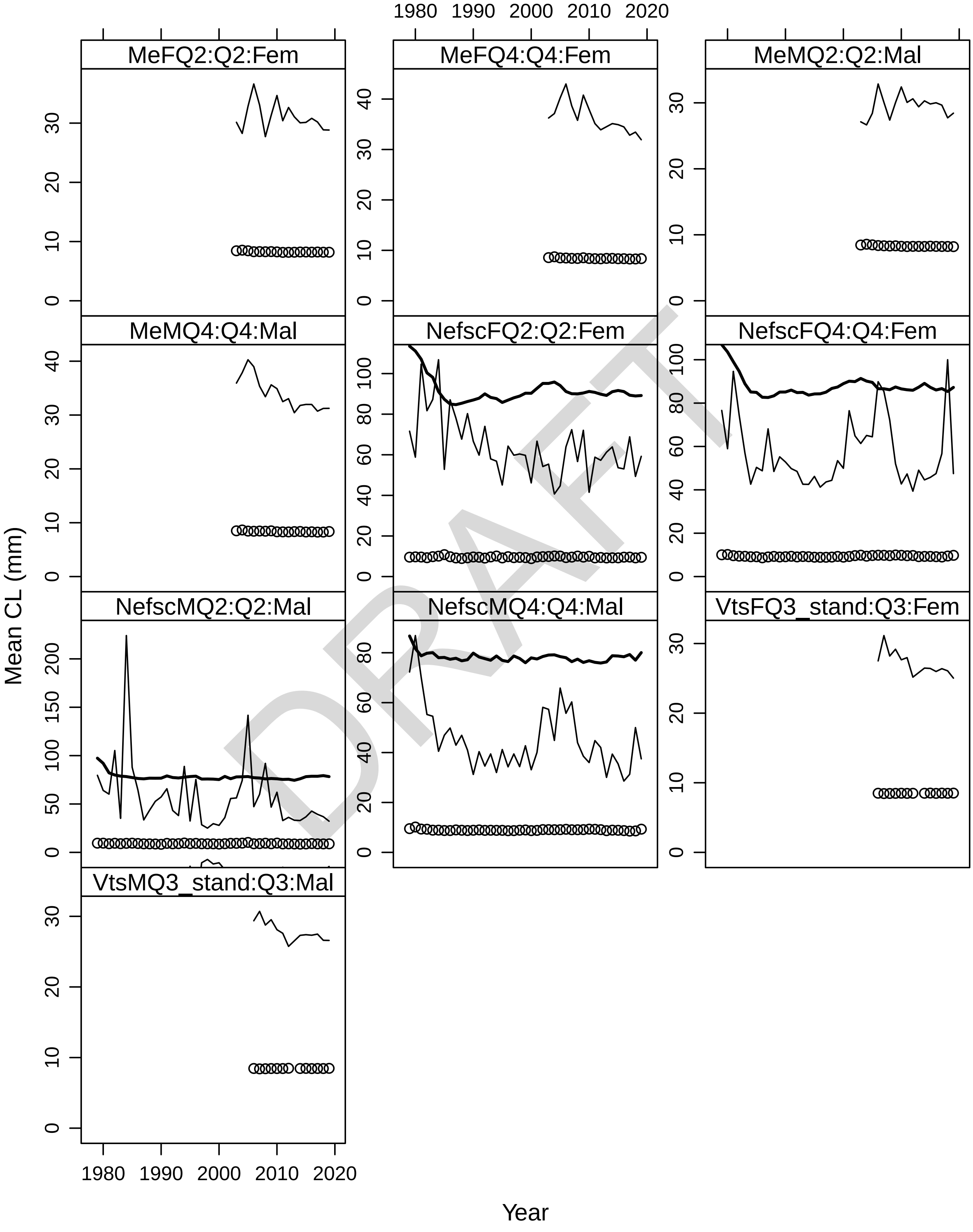
r60_ind_trawl_v6f6
Effective N/GOF plots for length data



Symbols=observed with 95% CI, heavy line=predicted

DRAFT

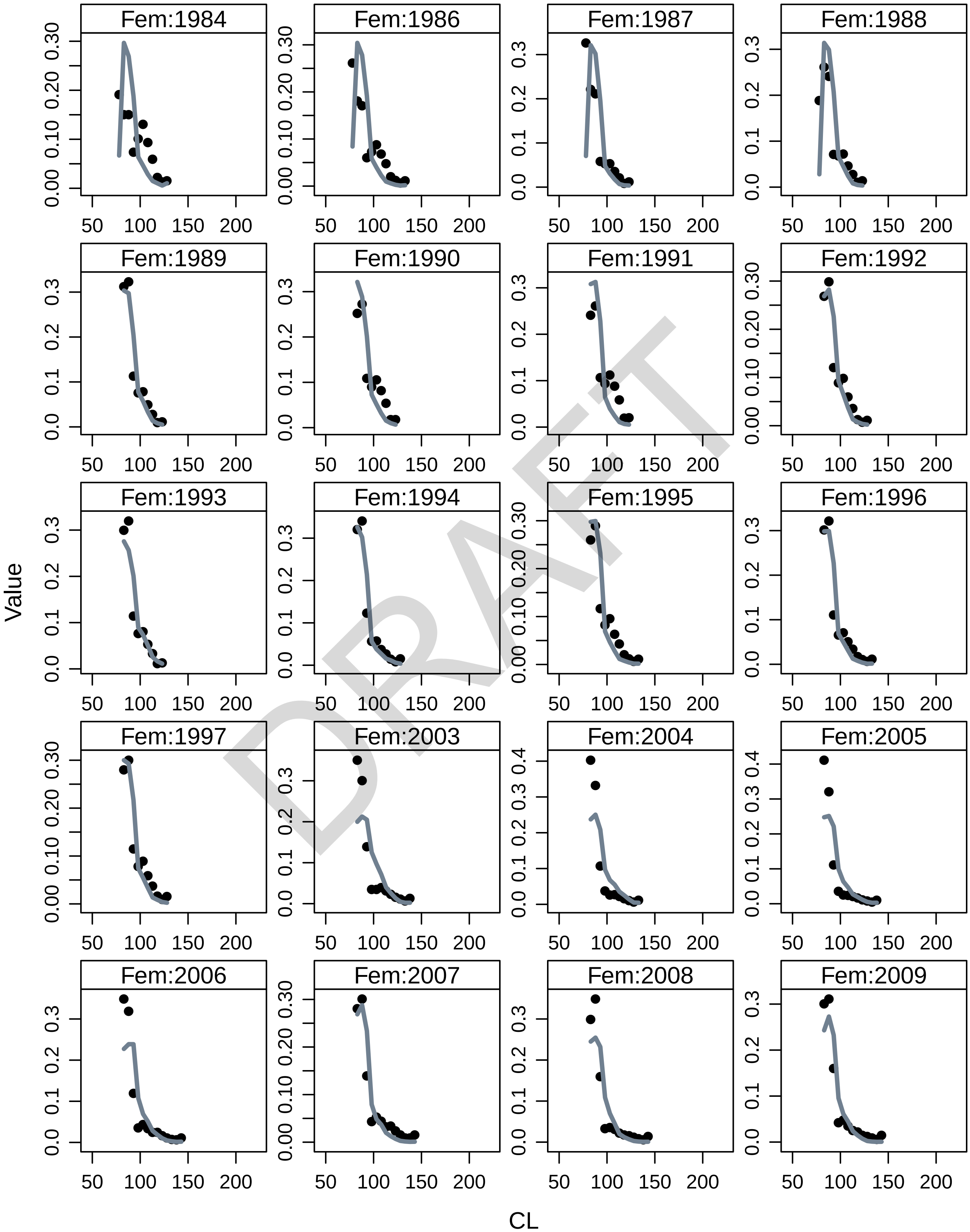
r60_ind_trawl_v6f6
Effective N/GOF plots for length data



DRAFT

Symbols=observed with 95% CI, heavy line=predicted

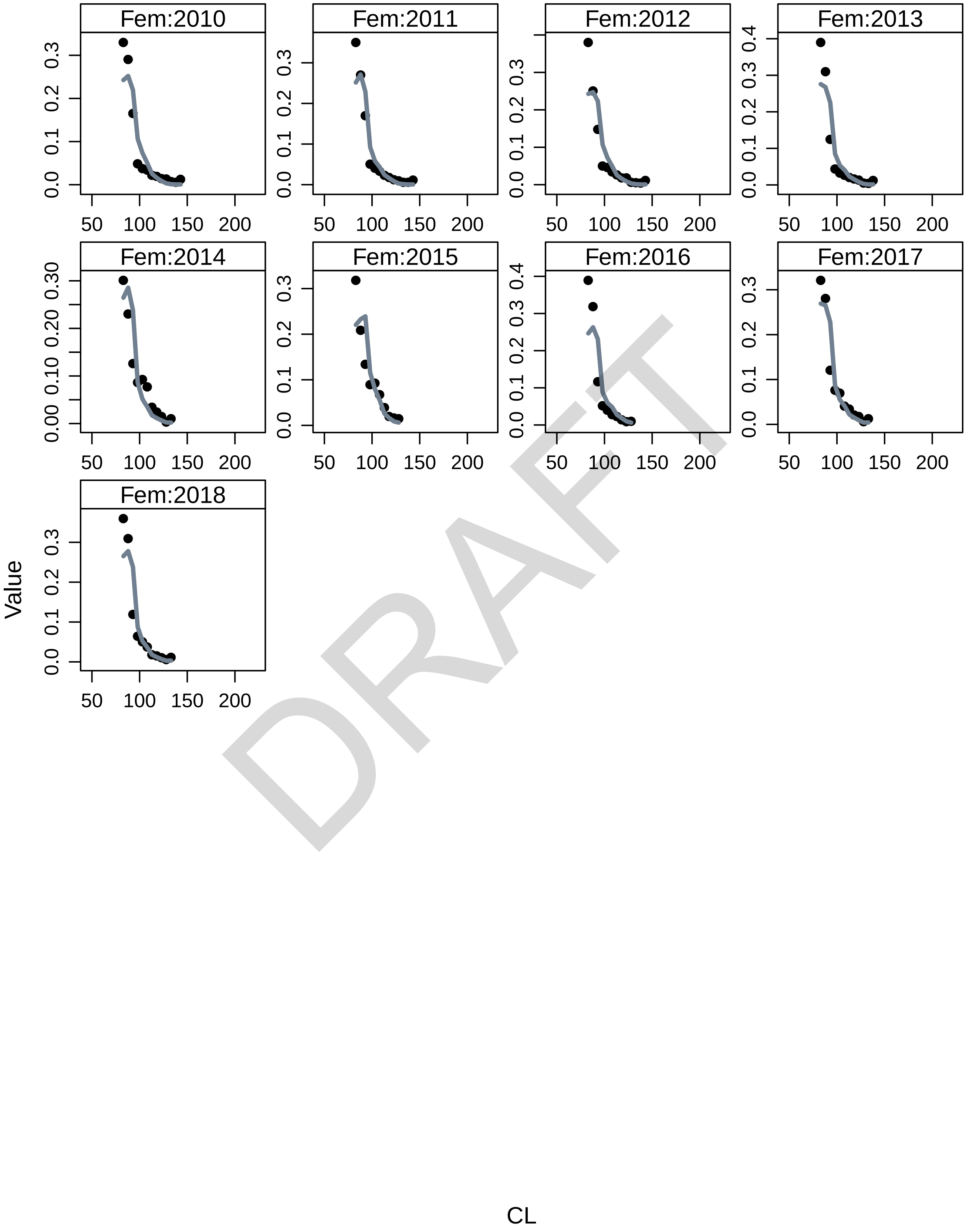
r60_ind_trawl_v6f6
Comm Q1 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

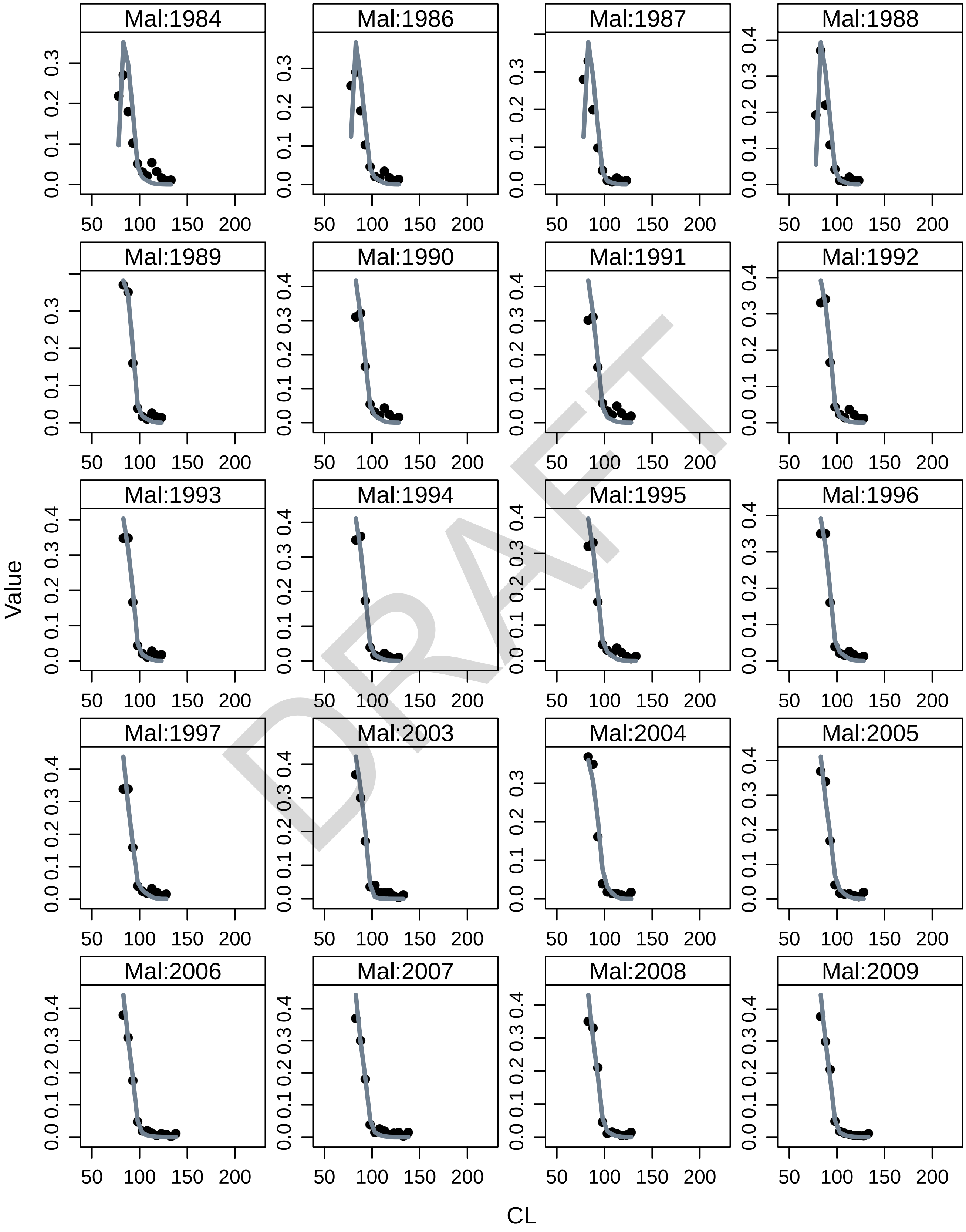
r60_ind_trawl_v6f6
Comm Q1 Fem observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

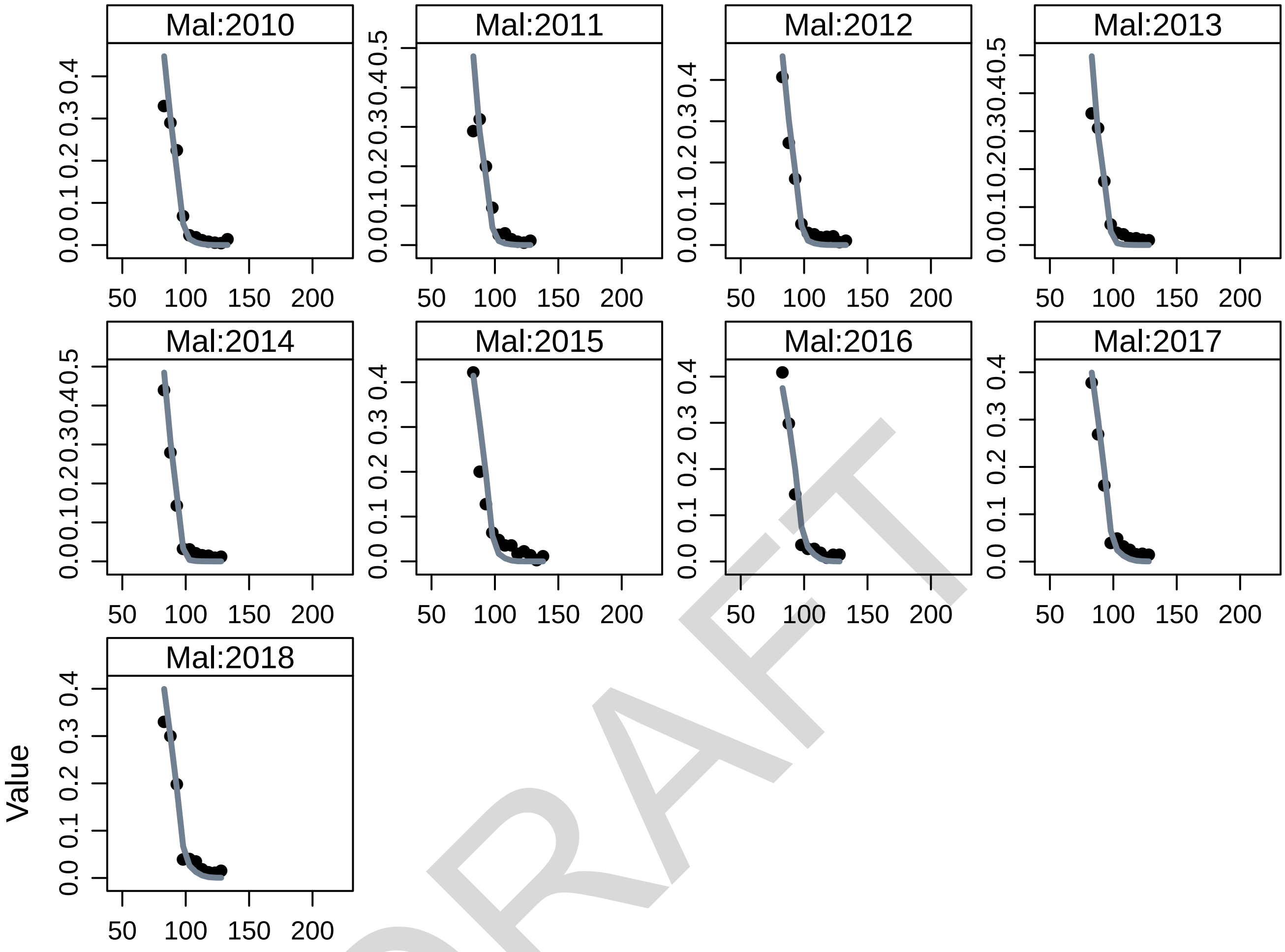
r60_ind_trawl_v6f6
Comm Q1 Mal observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

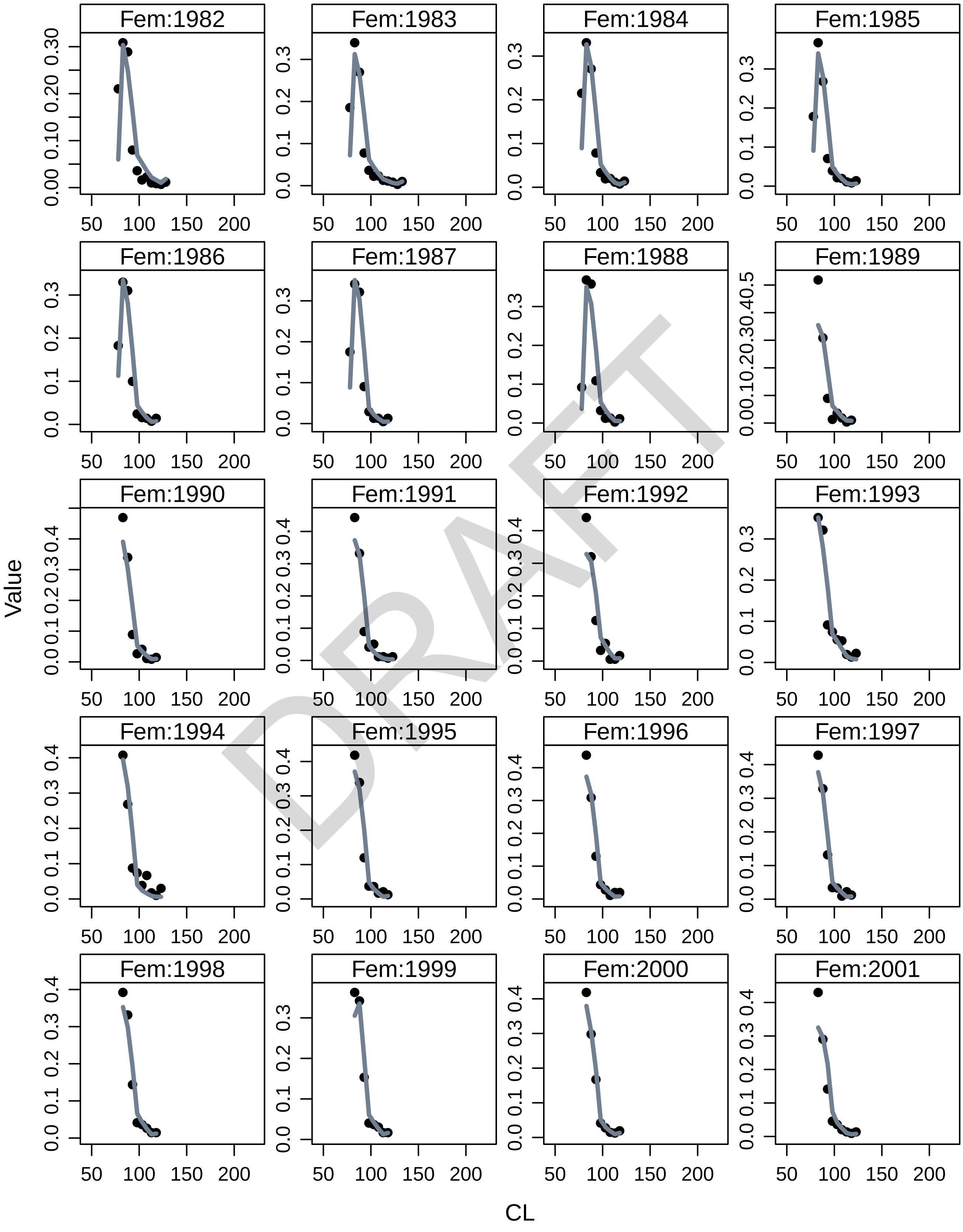
r60_ind_trawl_v6f6
Comm Q1 Mal observed and predicted length comps



DRAFT

CL
Symbols = observed / Solid line = predicted

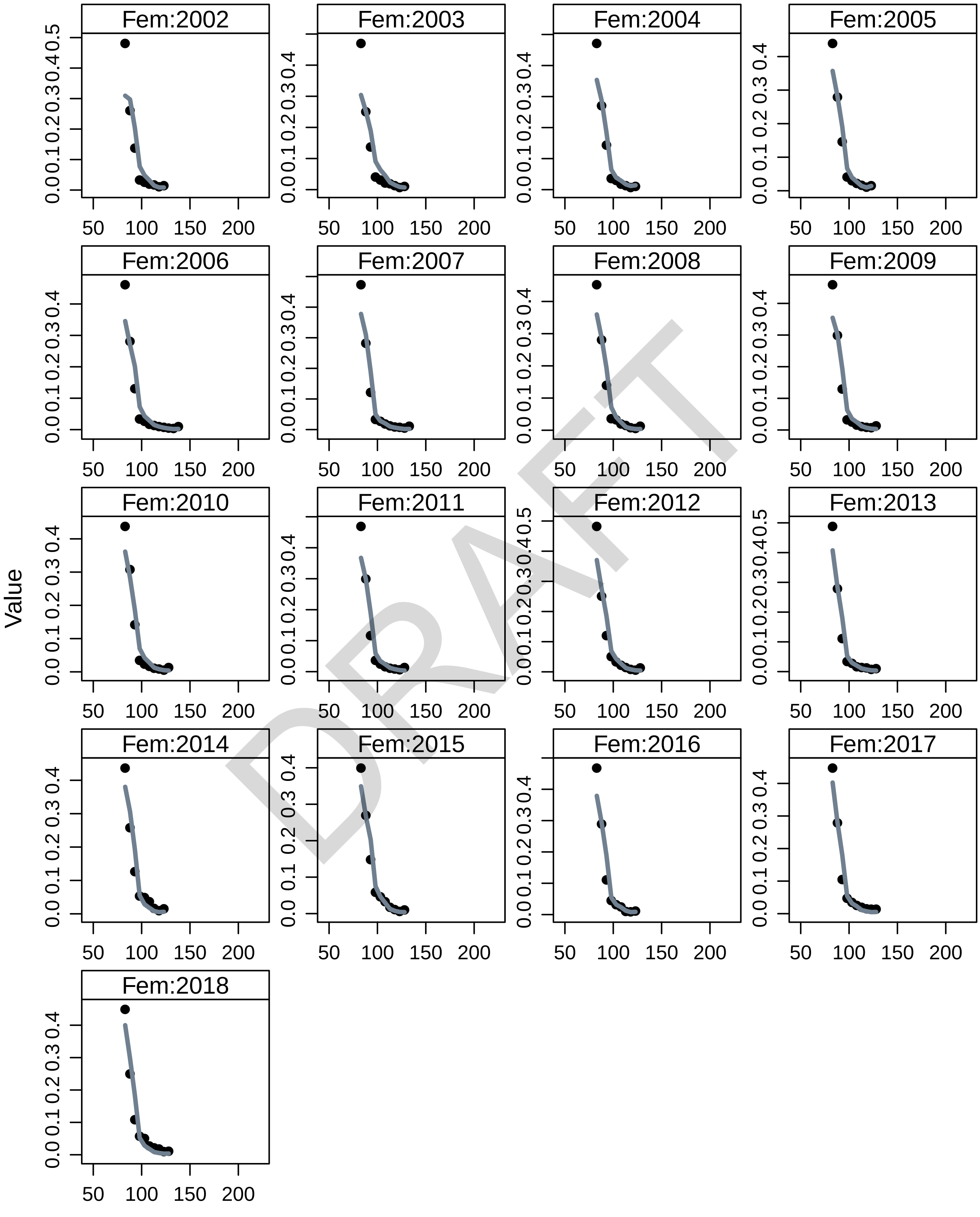
r60_ind_trawl_v6f6
Comm Q2 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

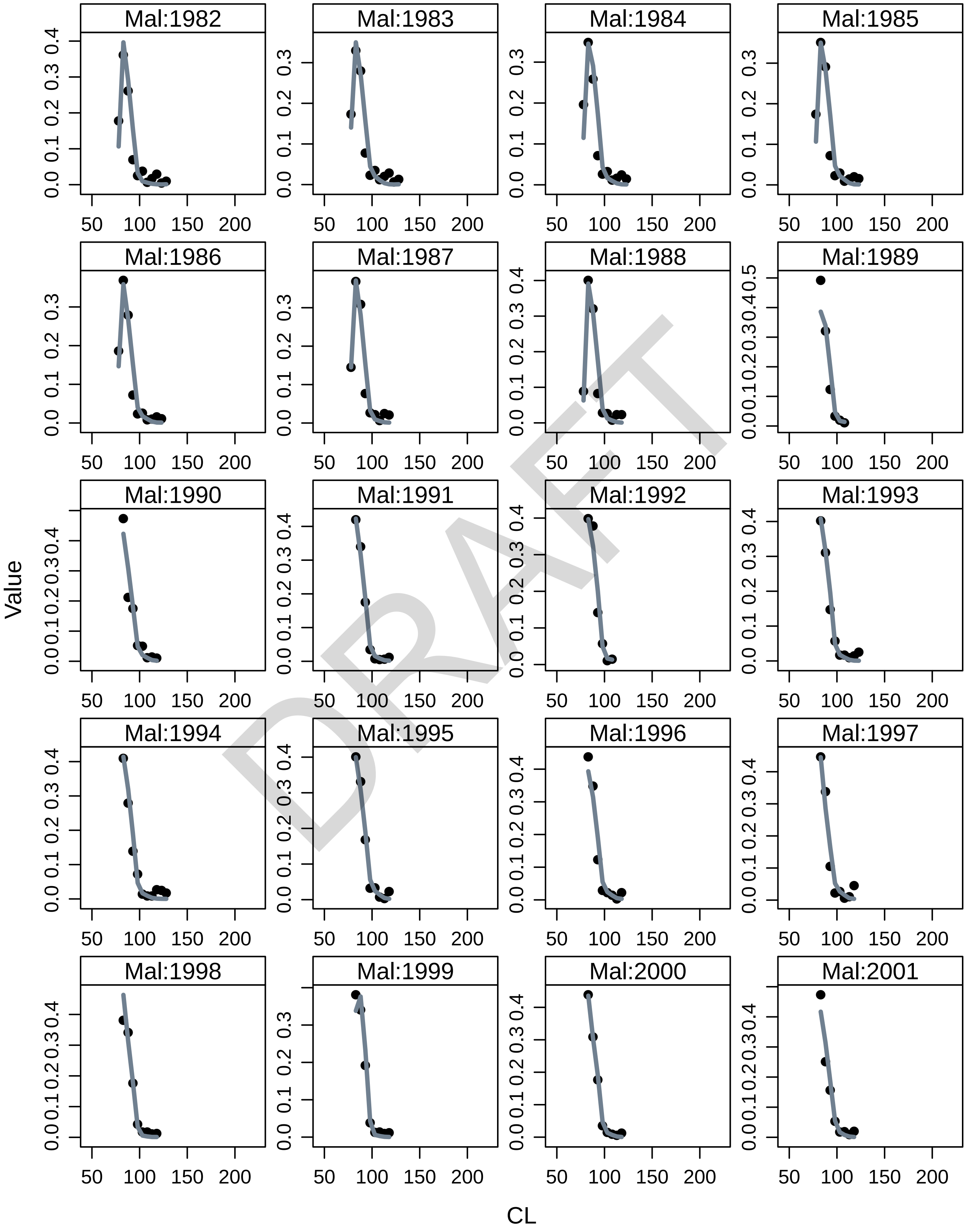
r60_ind_trawl_v6f6
Comm Q2 Fem observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
Comm Q2 Mal observed and predicted length comps

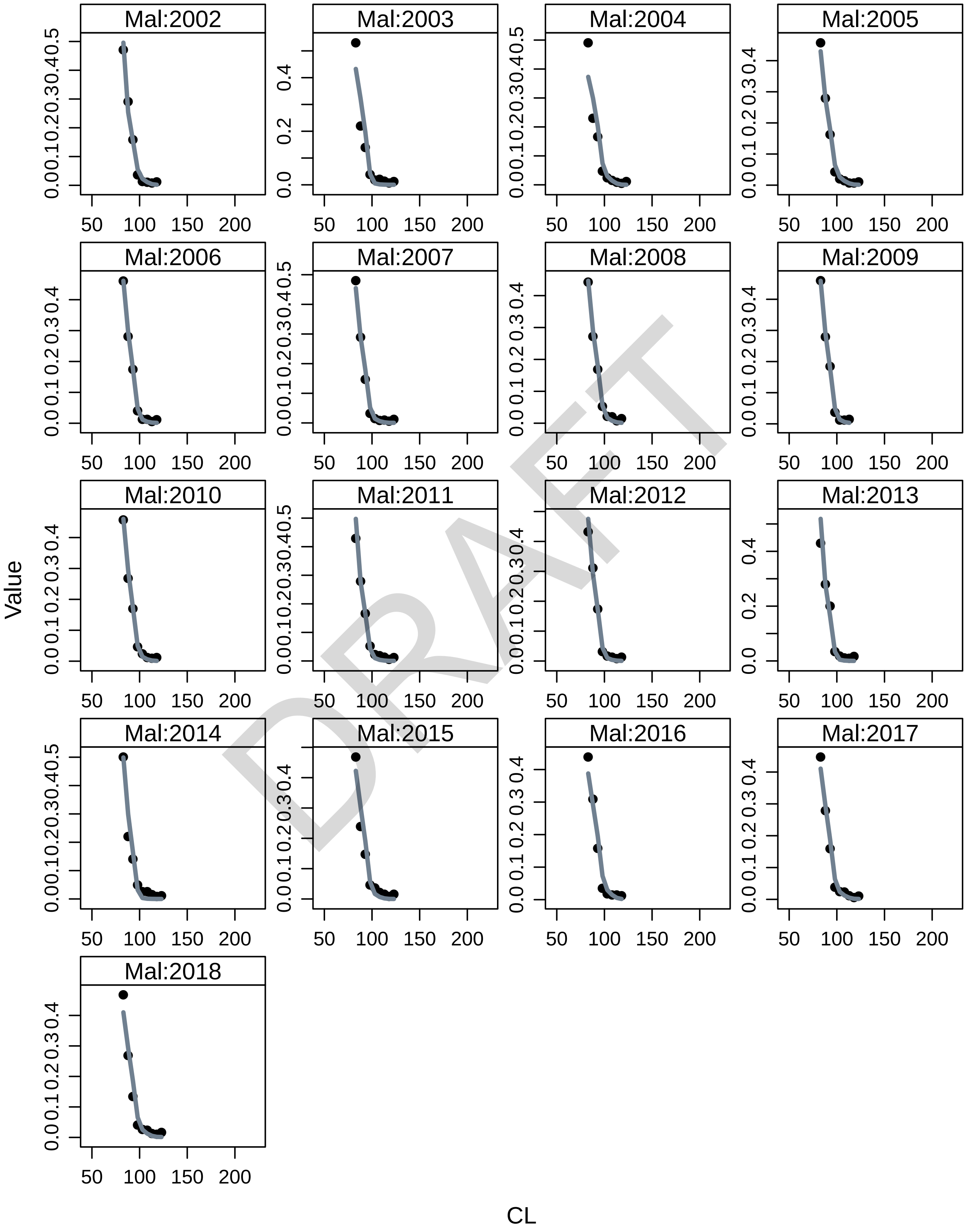


DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6

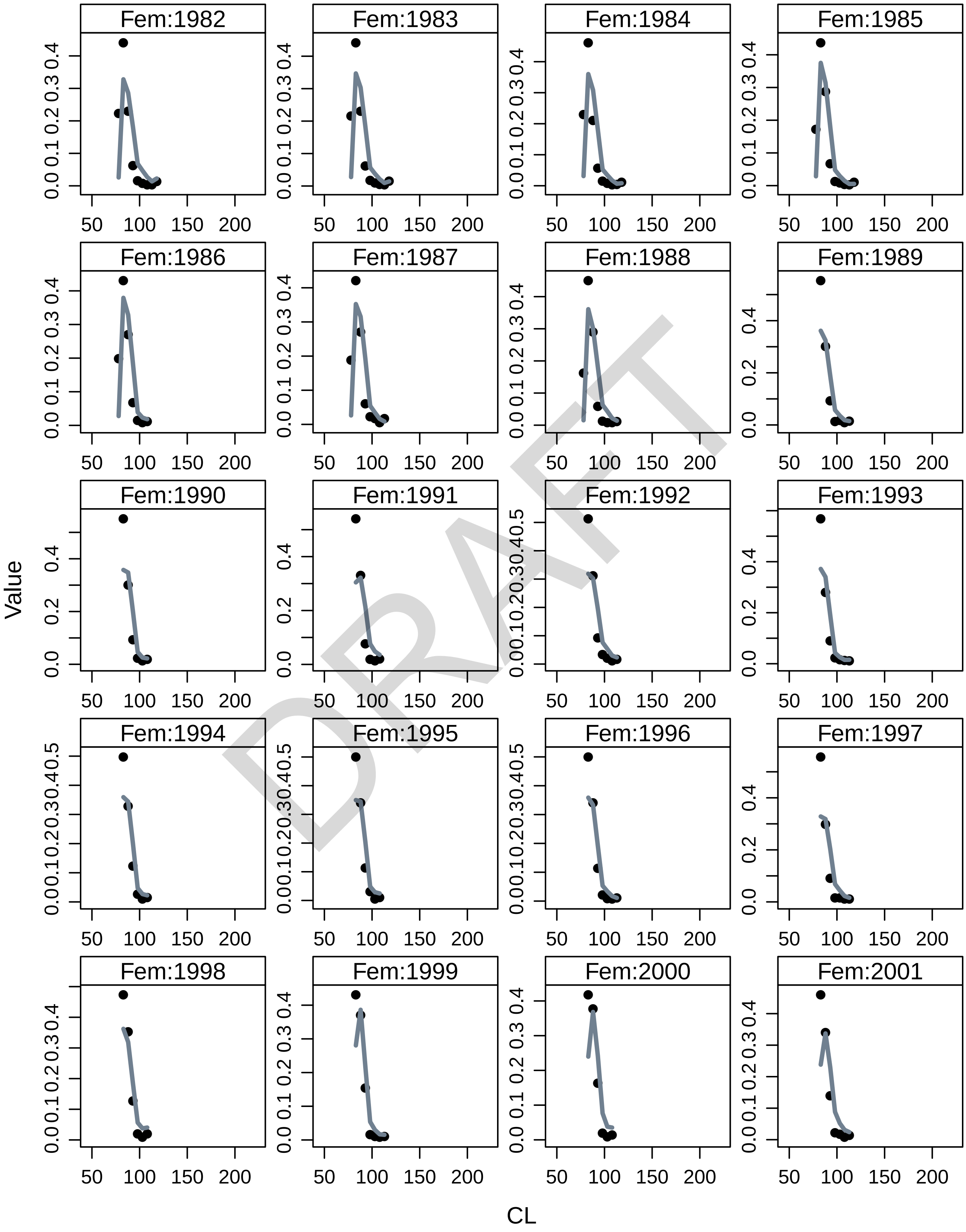
Comm Q2 Mal observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

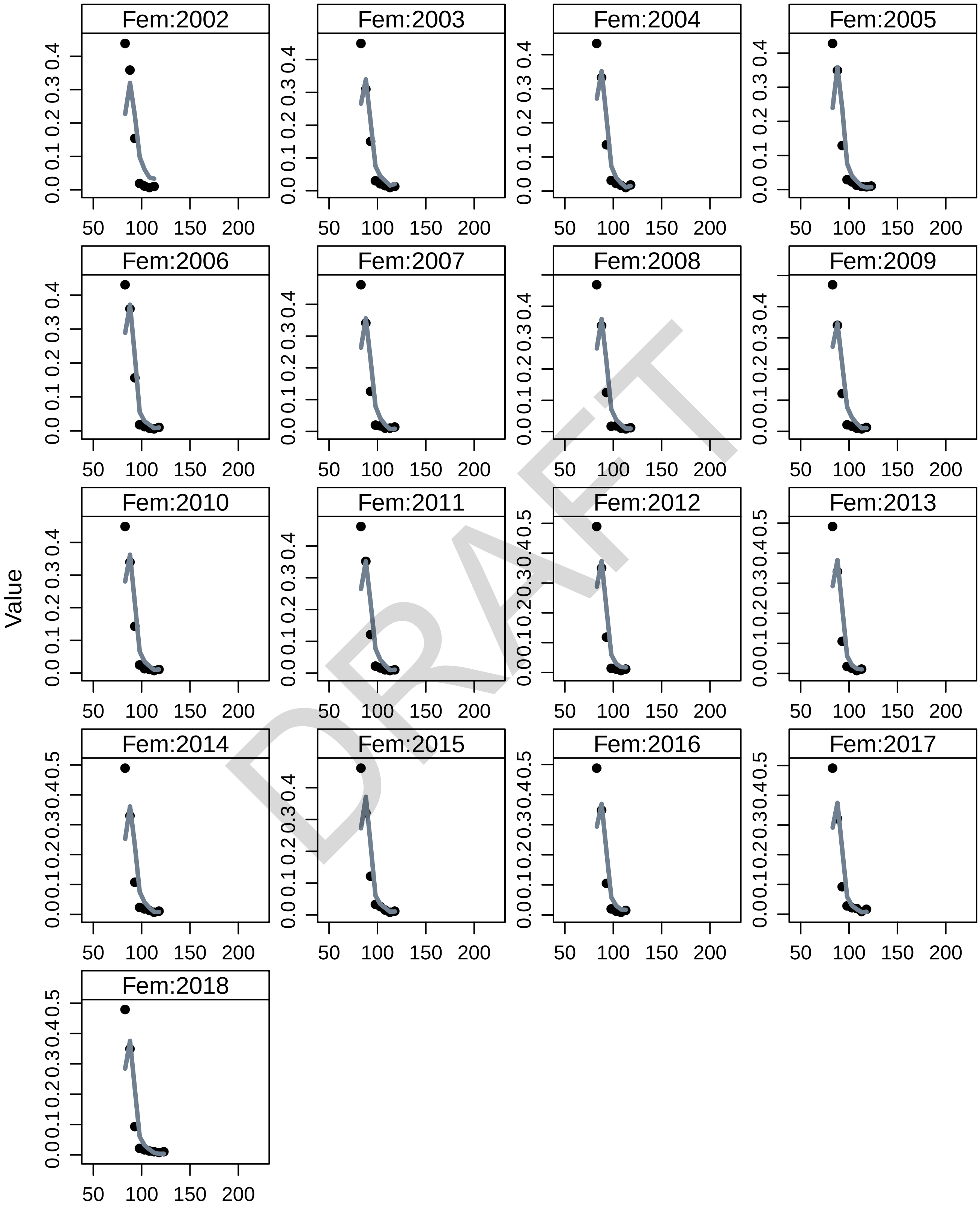
r60_ind_trawl_v6f6
Comm Q3 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
Comm Q3 Fem observed and predicted length comps

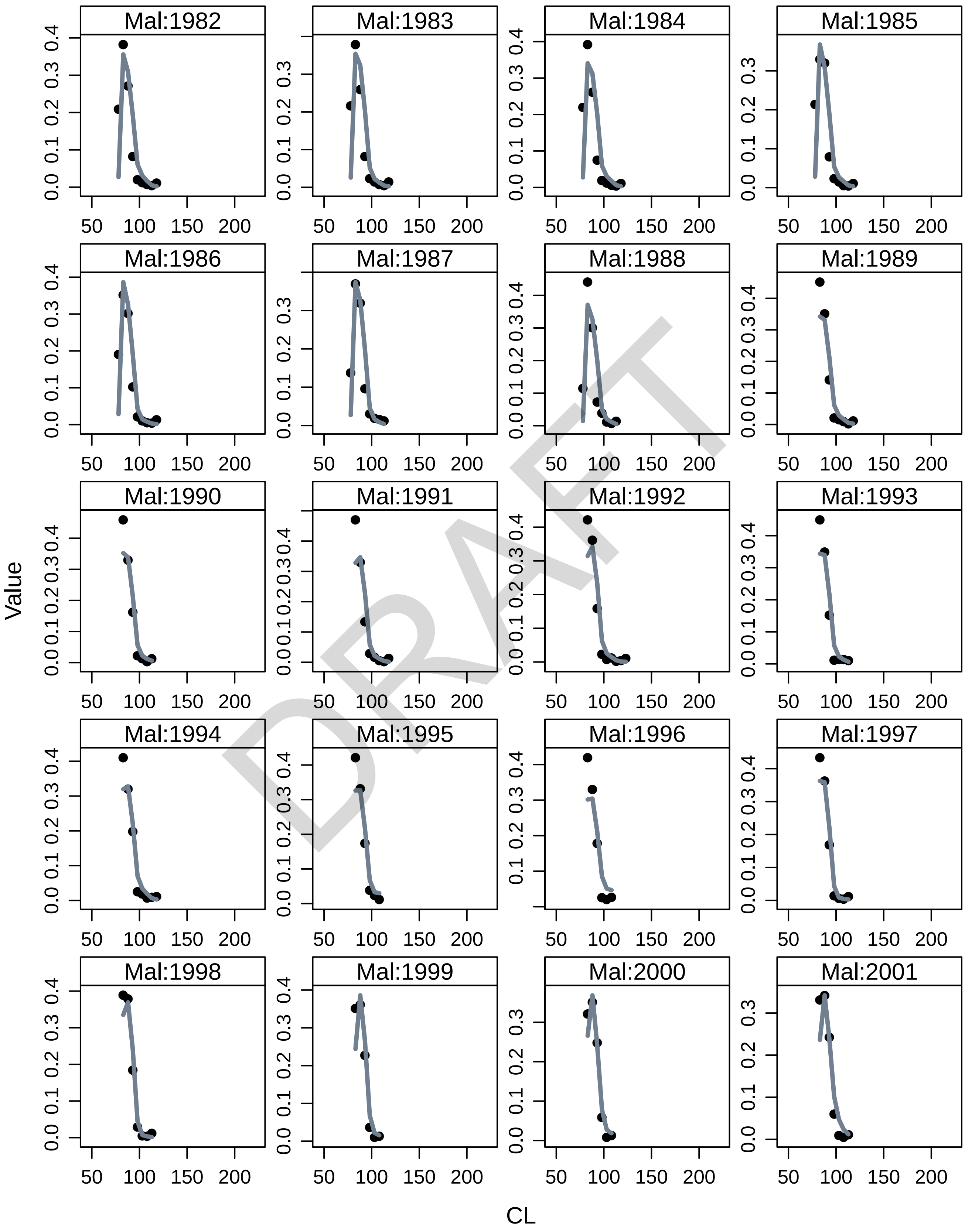


DRAFT

CL

Symbols = observed / Solid line = predicted

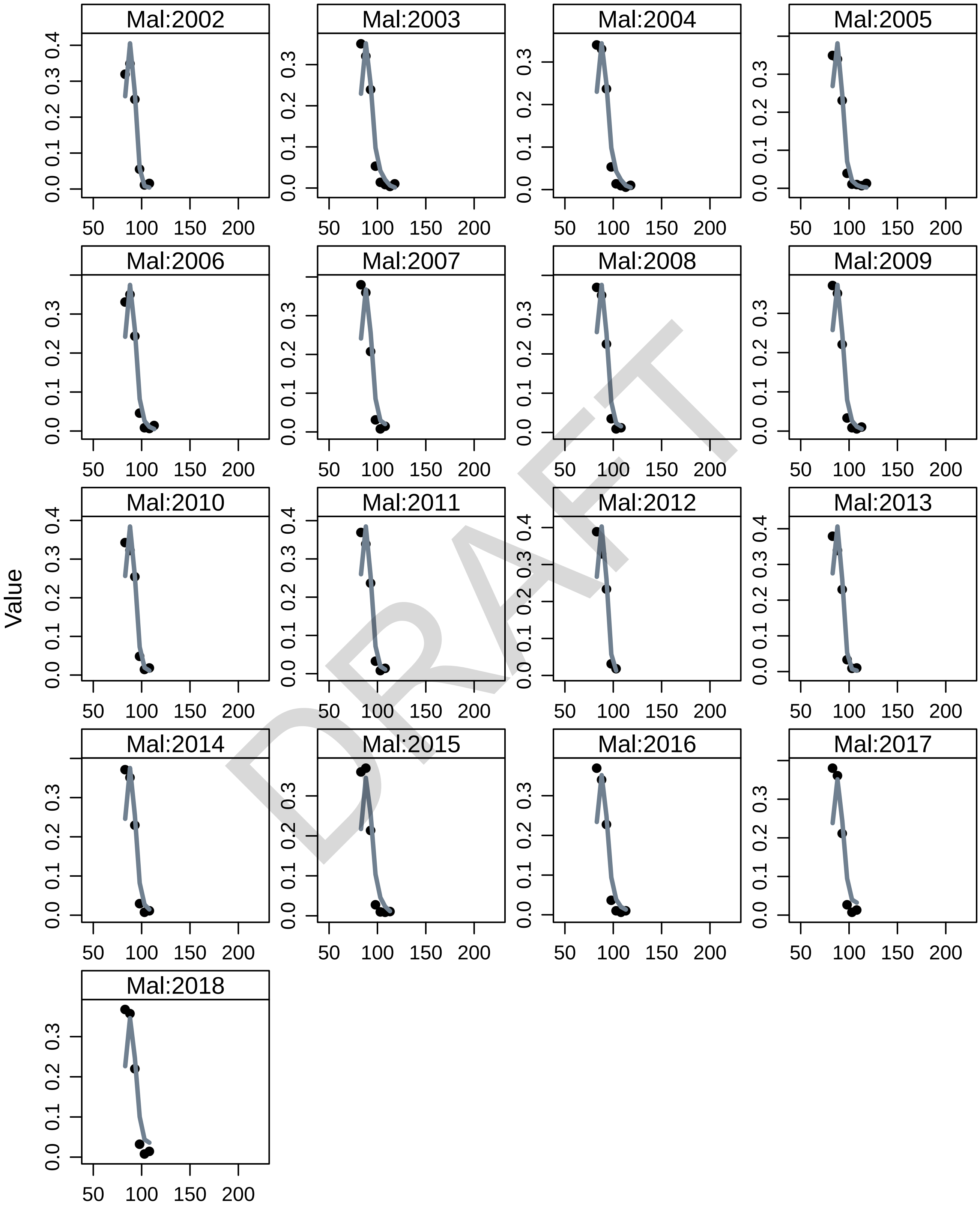
r60_ind_trawl_v6f6
Comm Q3 Mal observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
Comm Q3 Mal observed and predicted length comps

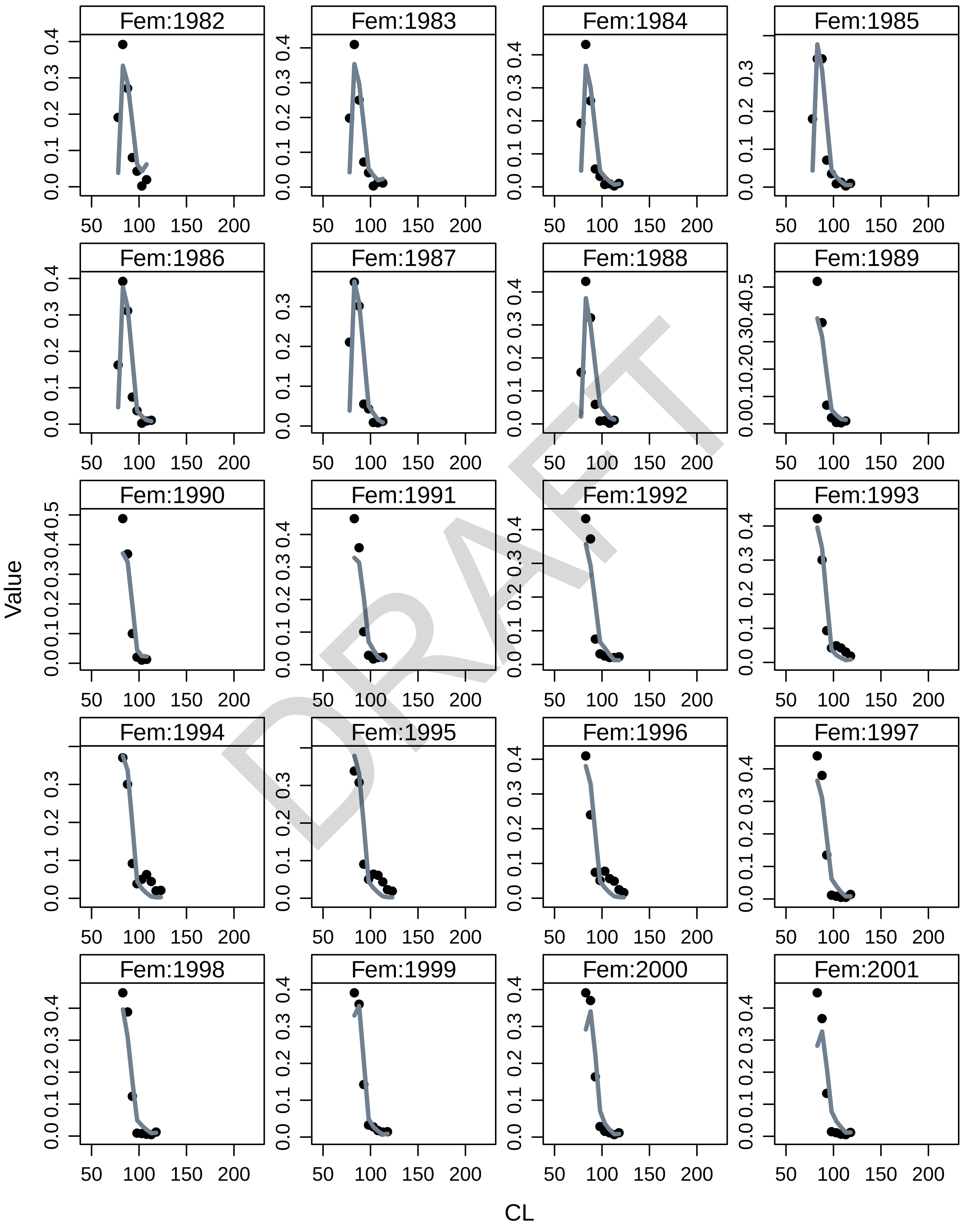


CL

Symbols = observed / Solid line = predicted

DRAFT

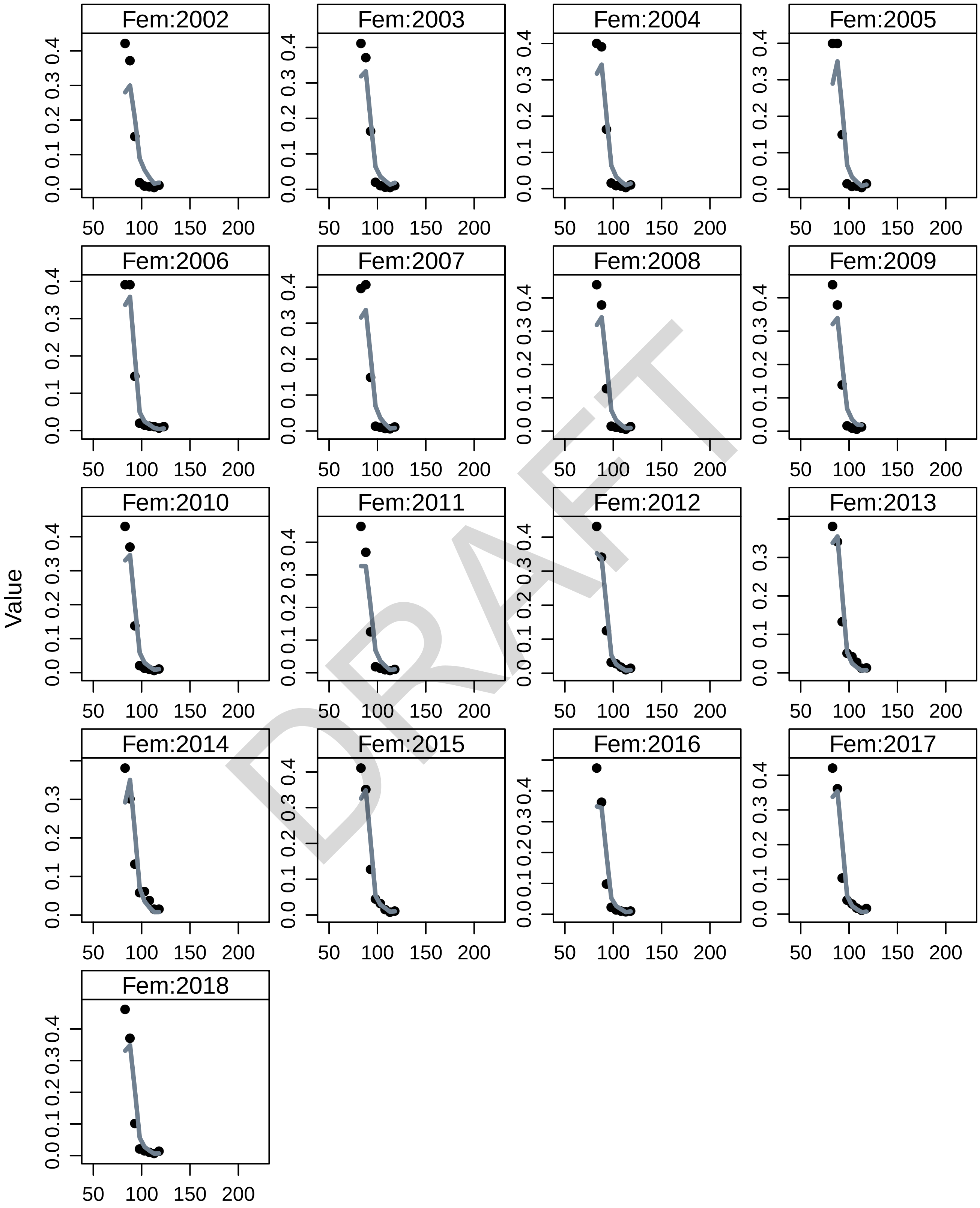
r60_ind_trawl_v6f6
Comm Q4 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

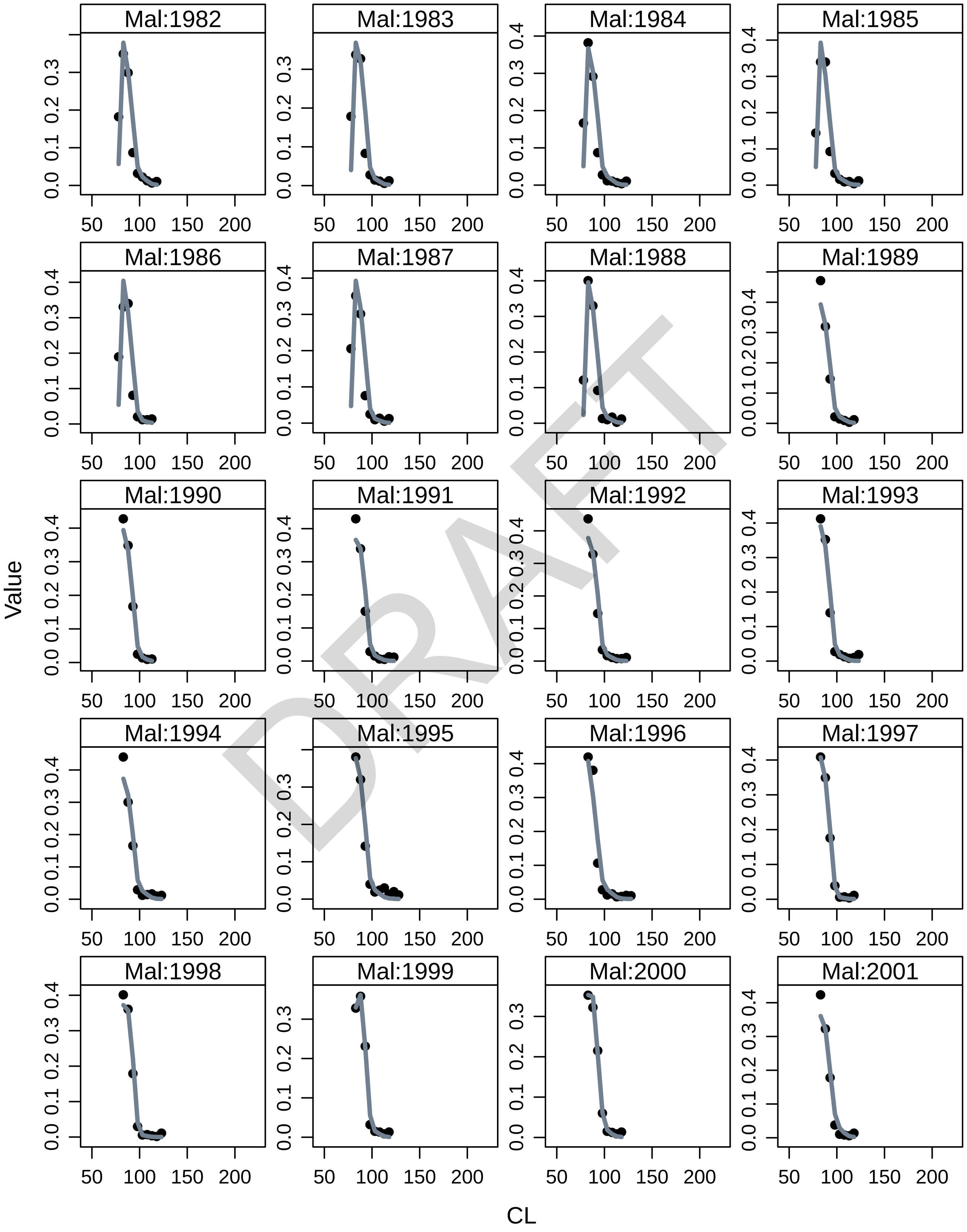
r60_ind_trawl_v6f6
Comm Q4 Fem observed and predicted length comps



CL
Symbols = observed / Solid line = predicted

DRAFT

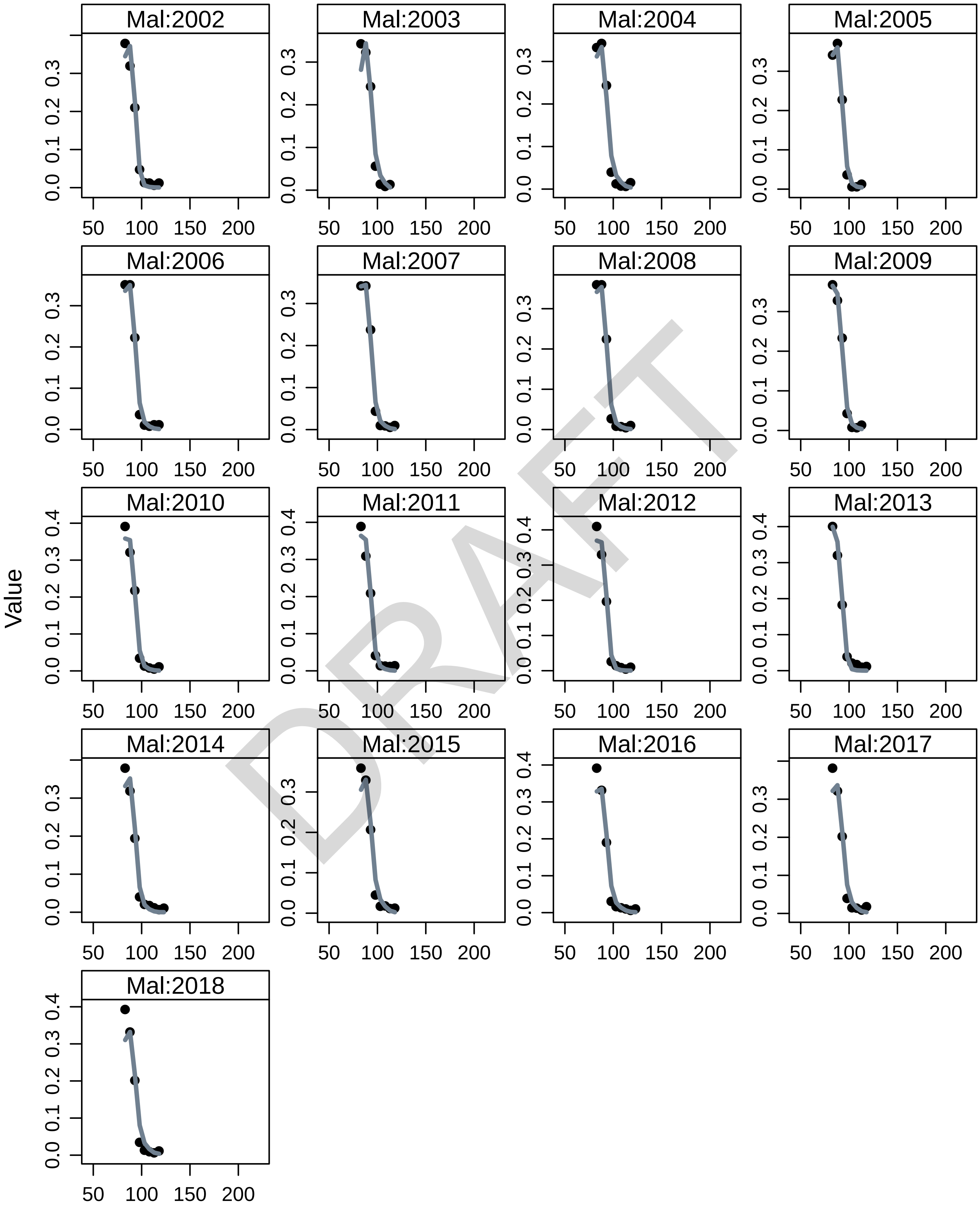
r60_ind_trawl_v6f6
Comm Q4 Mal observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
Comm Q4 Mal observed and predicted length comps

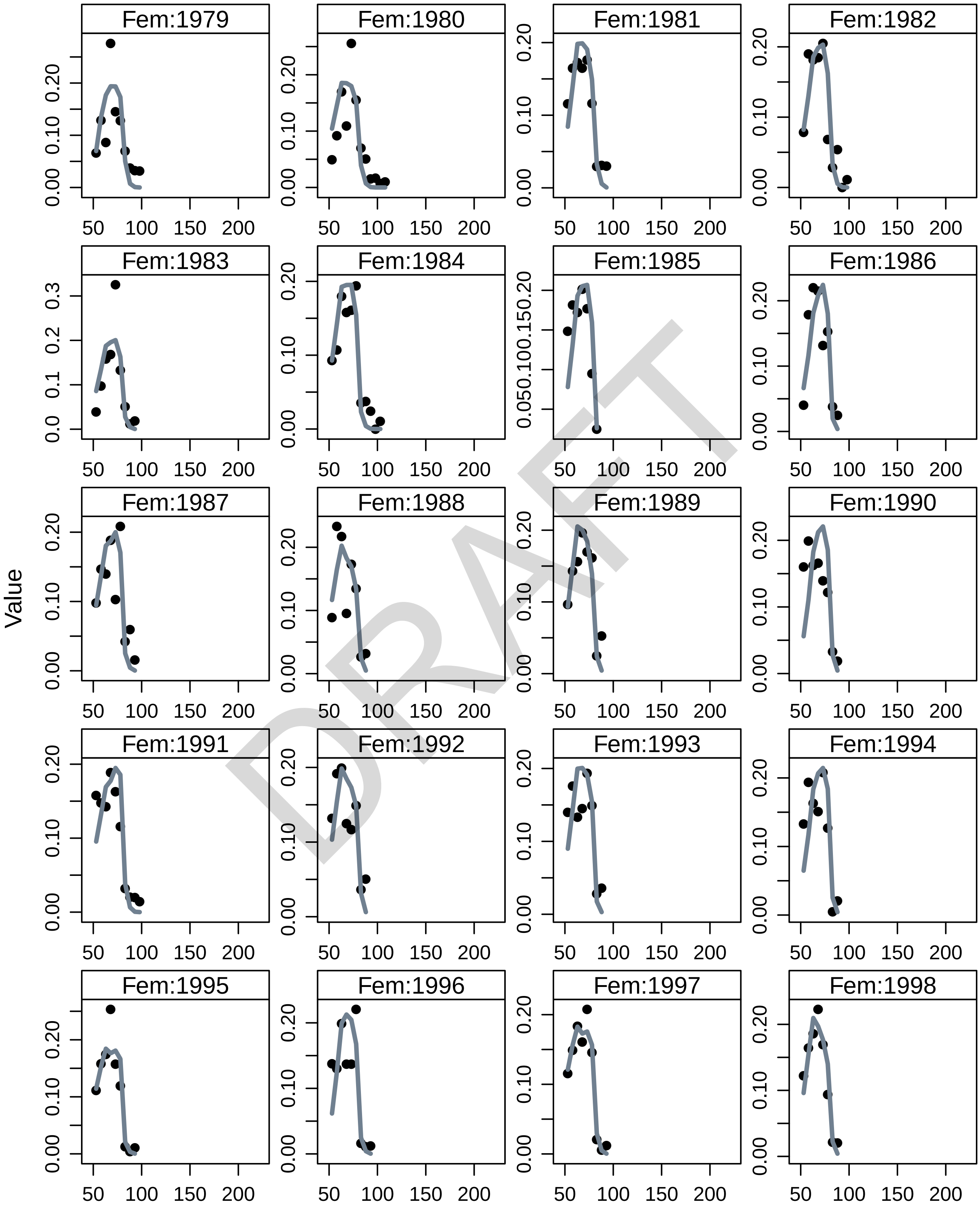


CL

Symbols = observed / Solid line = predicted

DRAFT

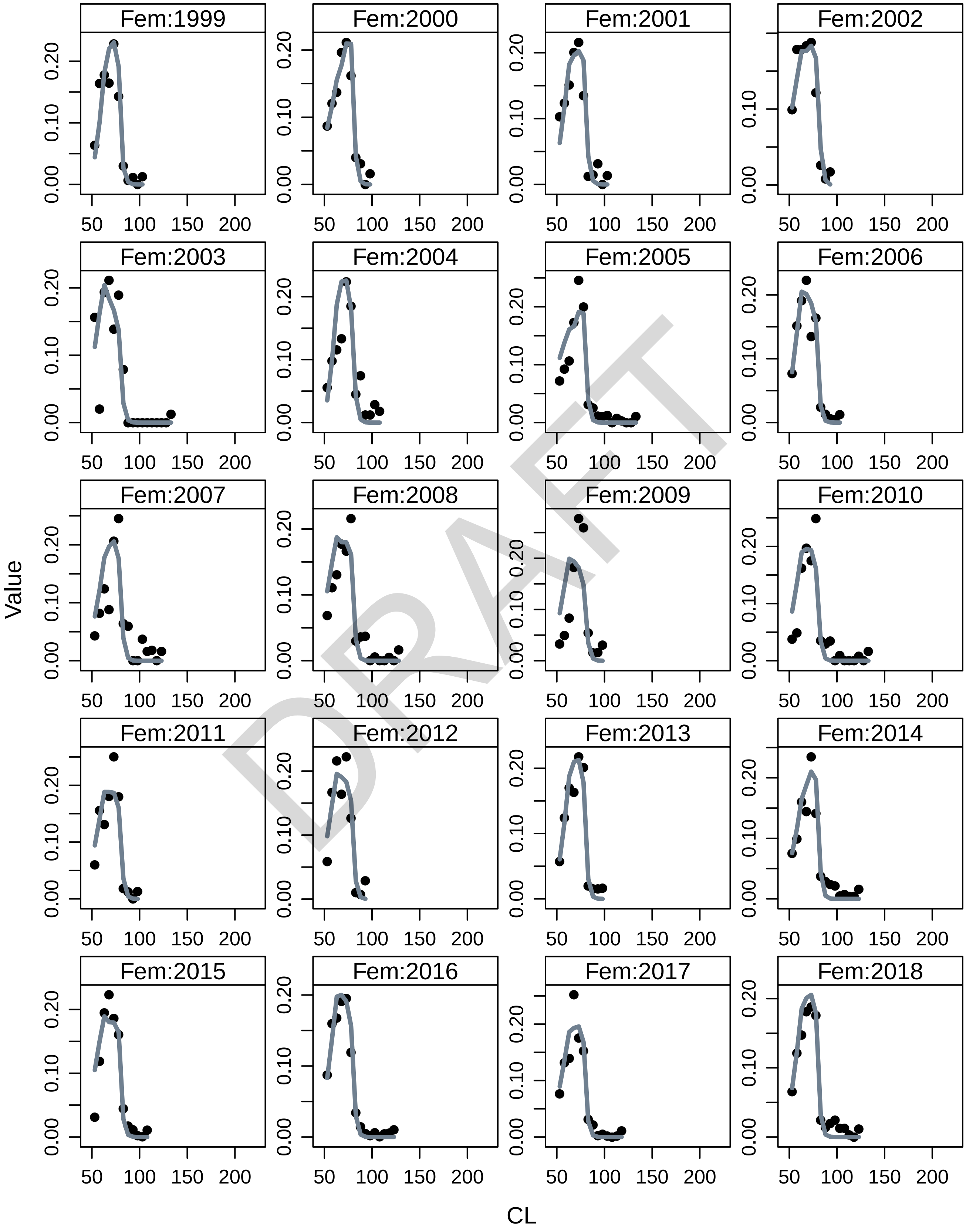
r60_ind_trawl_v6f6
MaFQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

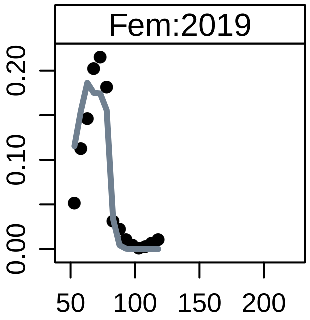
r60_ind_trawl_v6f6
MaFQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
MaFQ2 observed and predicted length comps



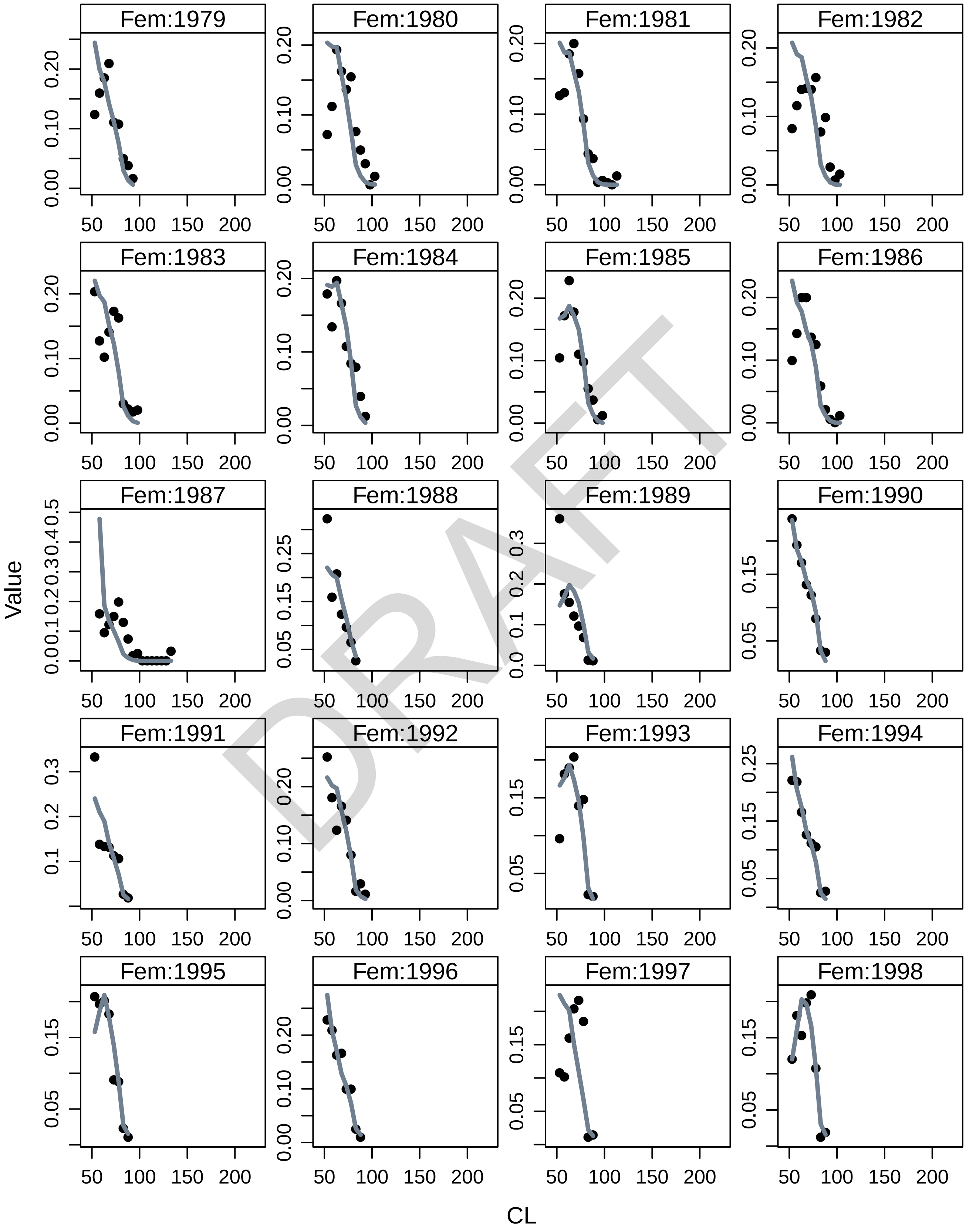
DRAFT

Value

CL

Symbols = observed / Solid line = predicted

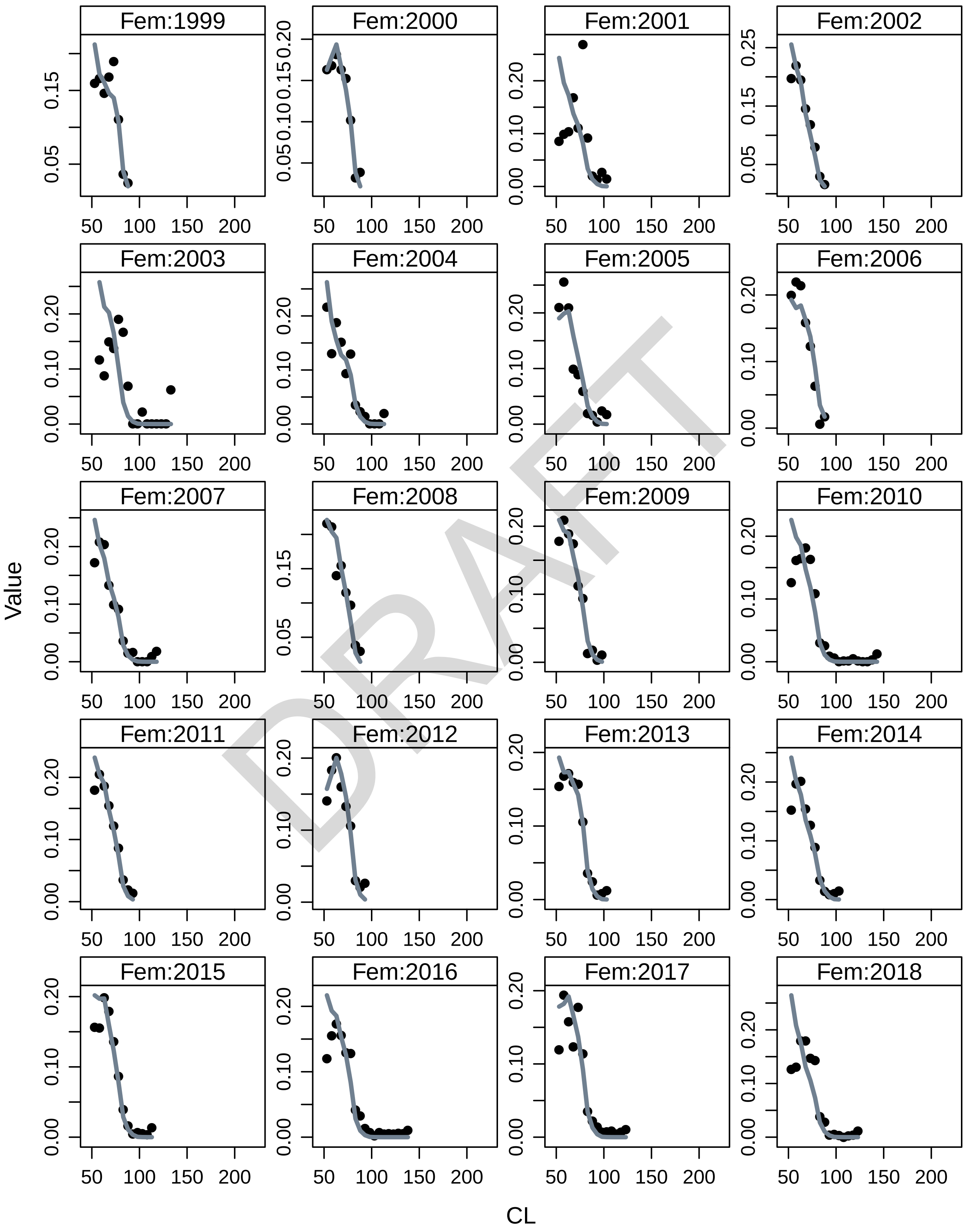
r60_ind_trawl_v6f6
MaFQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

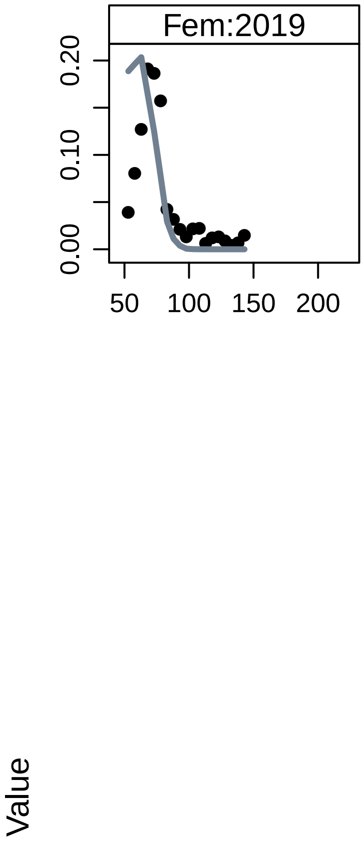
r60_ind_trawl_v6f6
MaFQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
MaFQ4 observed and predicted length comps

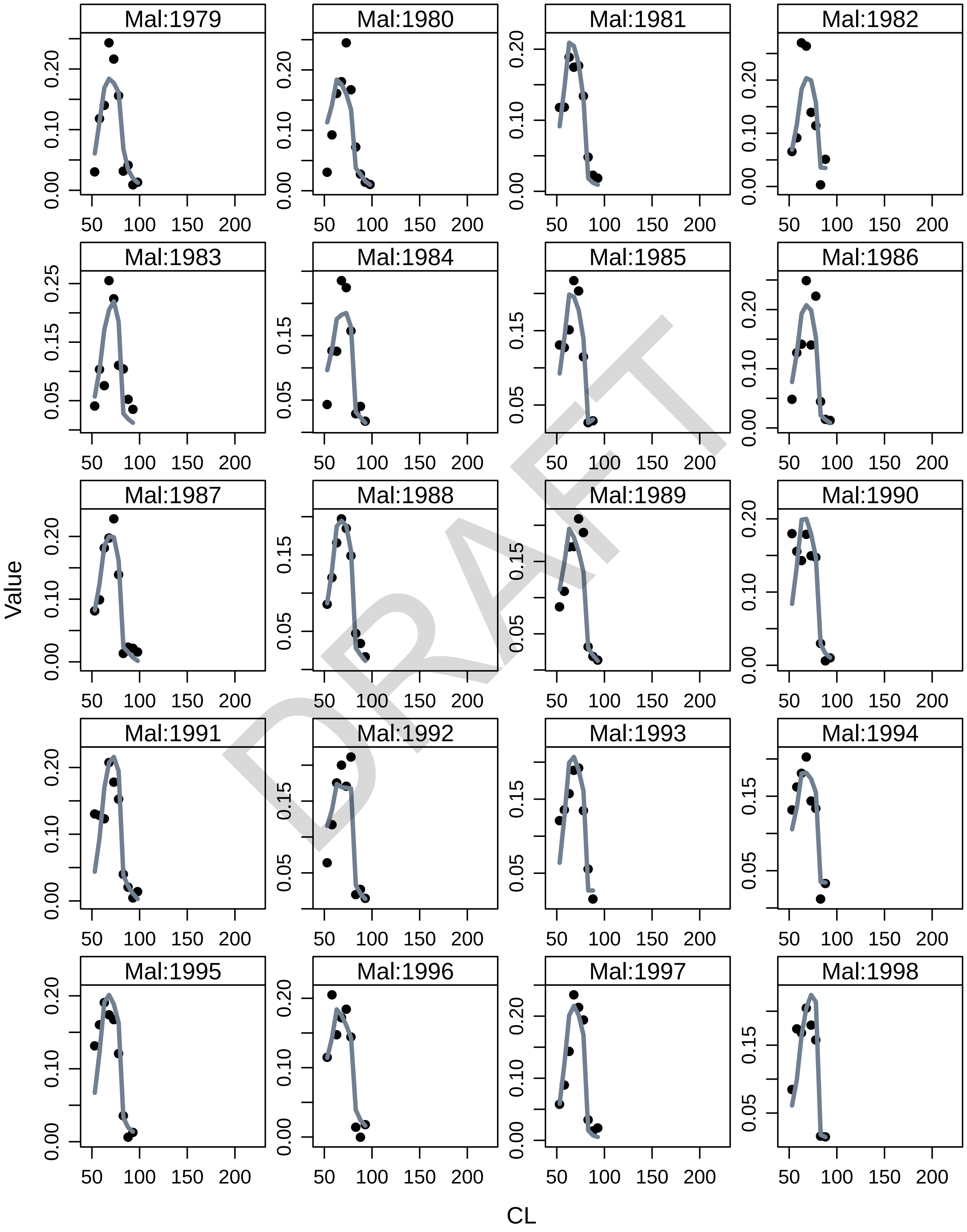


DRAFT

CL

Symbols = observed / Solid line = predicted

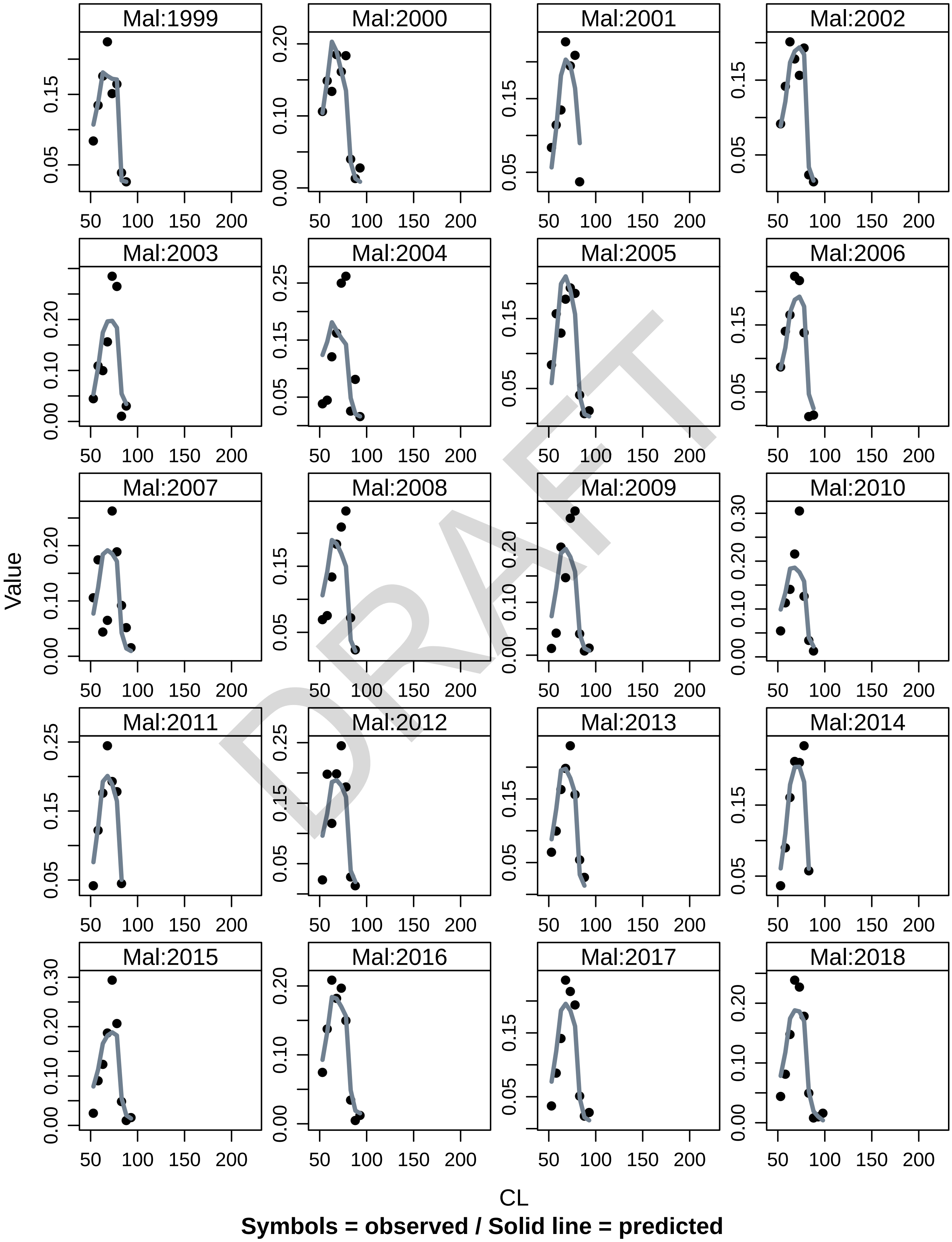
r60_ind_trawl_v6f6
MaMQ2 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

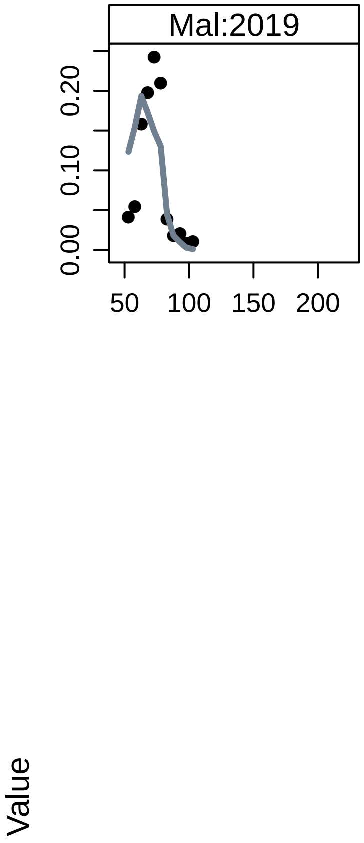
r60_ind_trawl_v6f6
MaMQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
MaMQ2 observed and predicted length comps

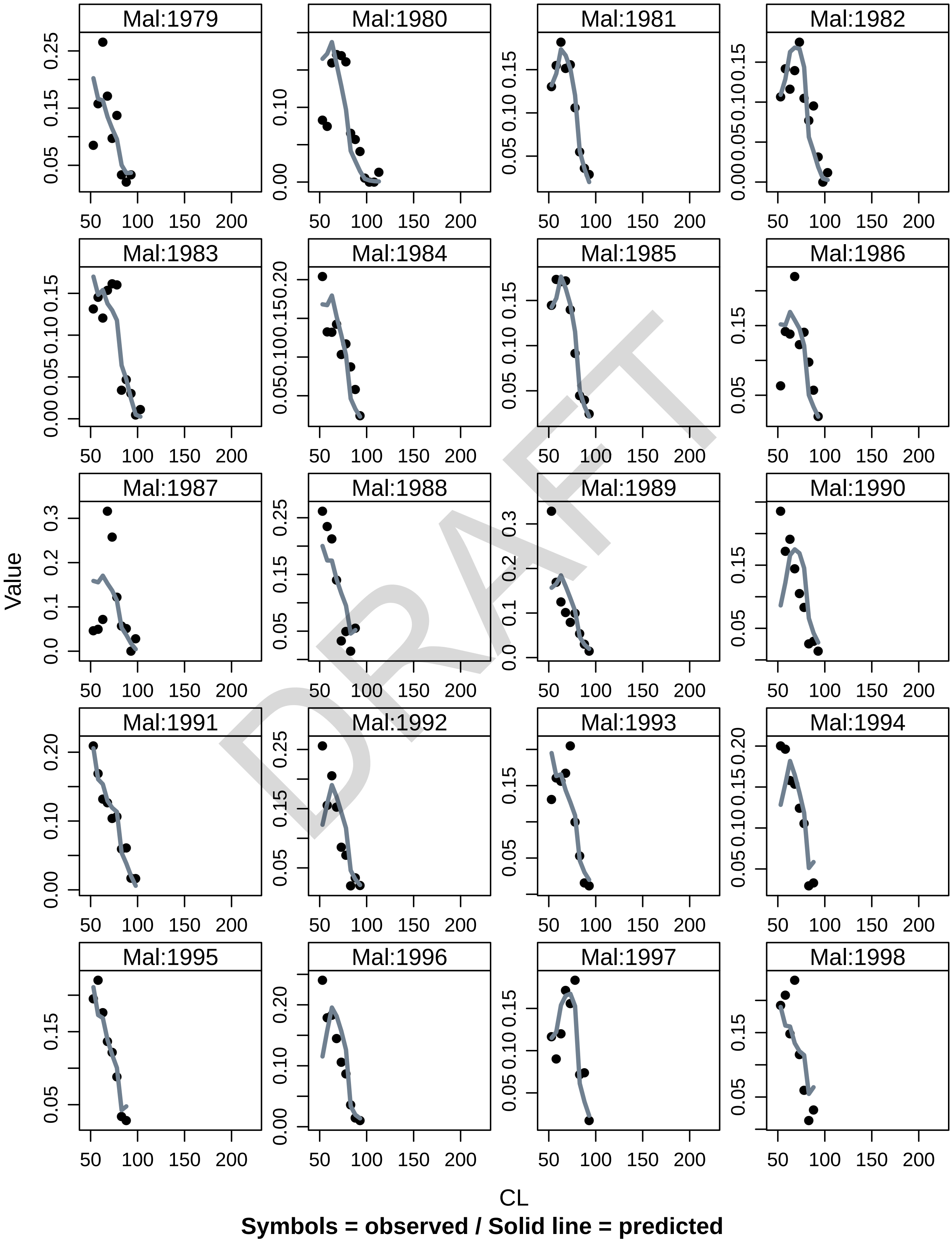


DRAFT

CL

Symbols = observed / Solid line = predicted

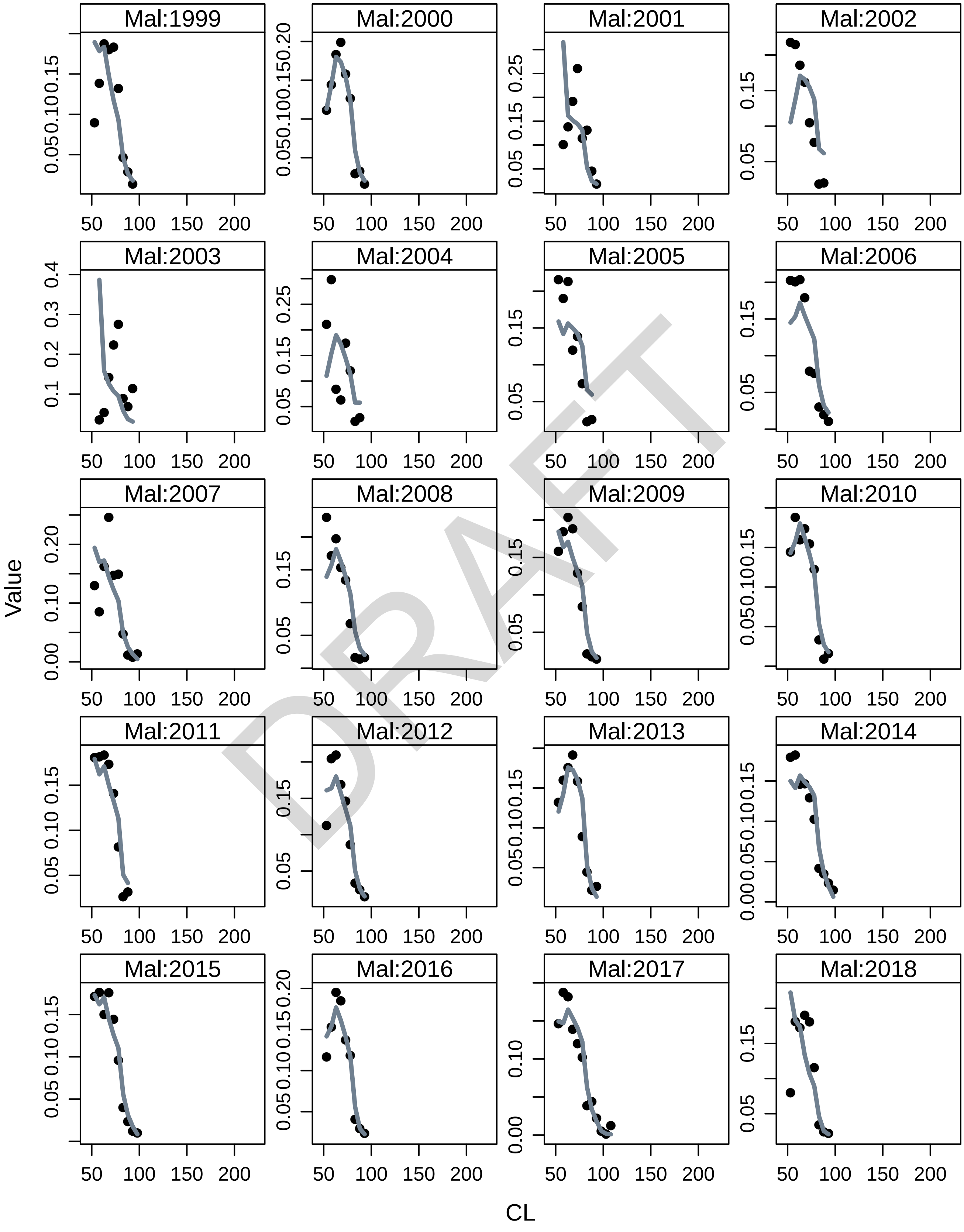
r60_ind_trawl_v6f6
MaMQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

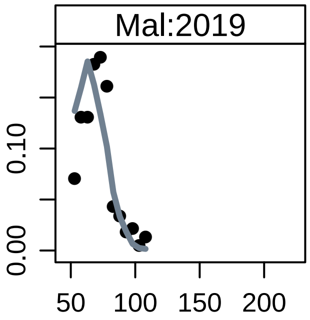
r60_ind_trawl_v6f6
MaMQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
MaMQ4 observed and predicted length comps



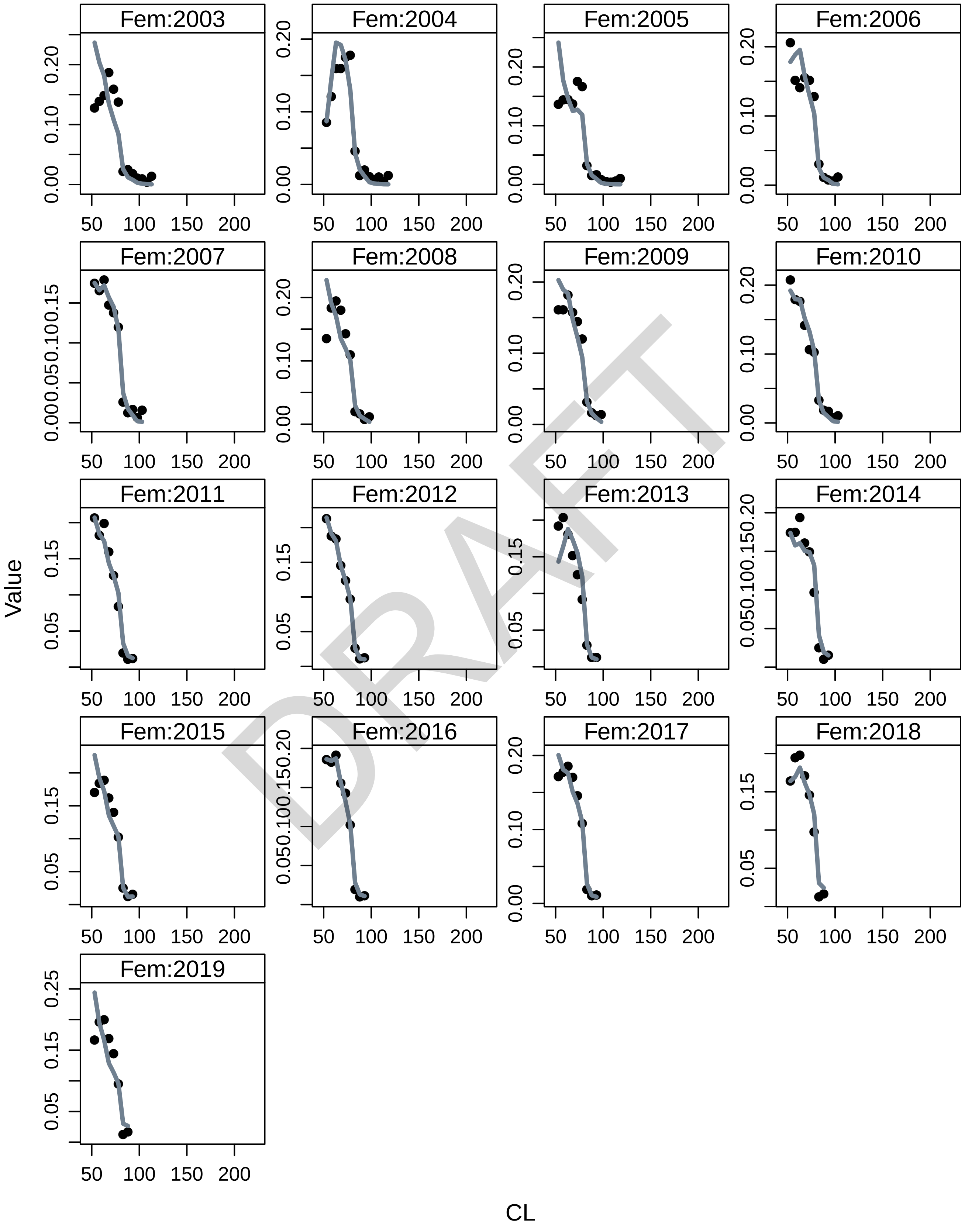
Value

DRAFT

CL

Symbols = observed / Solid line = predicted

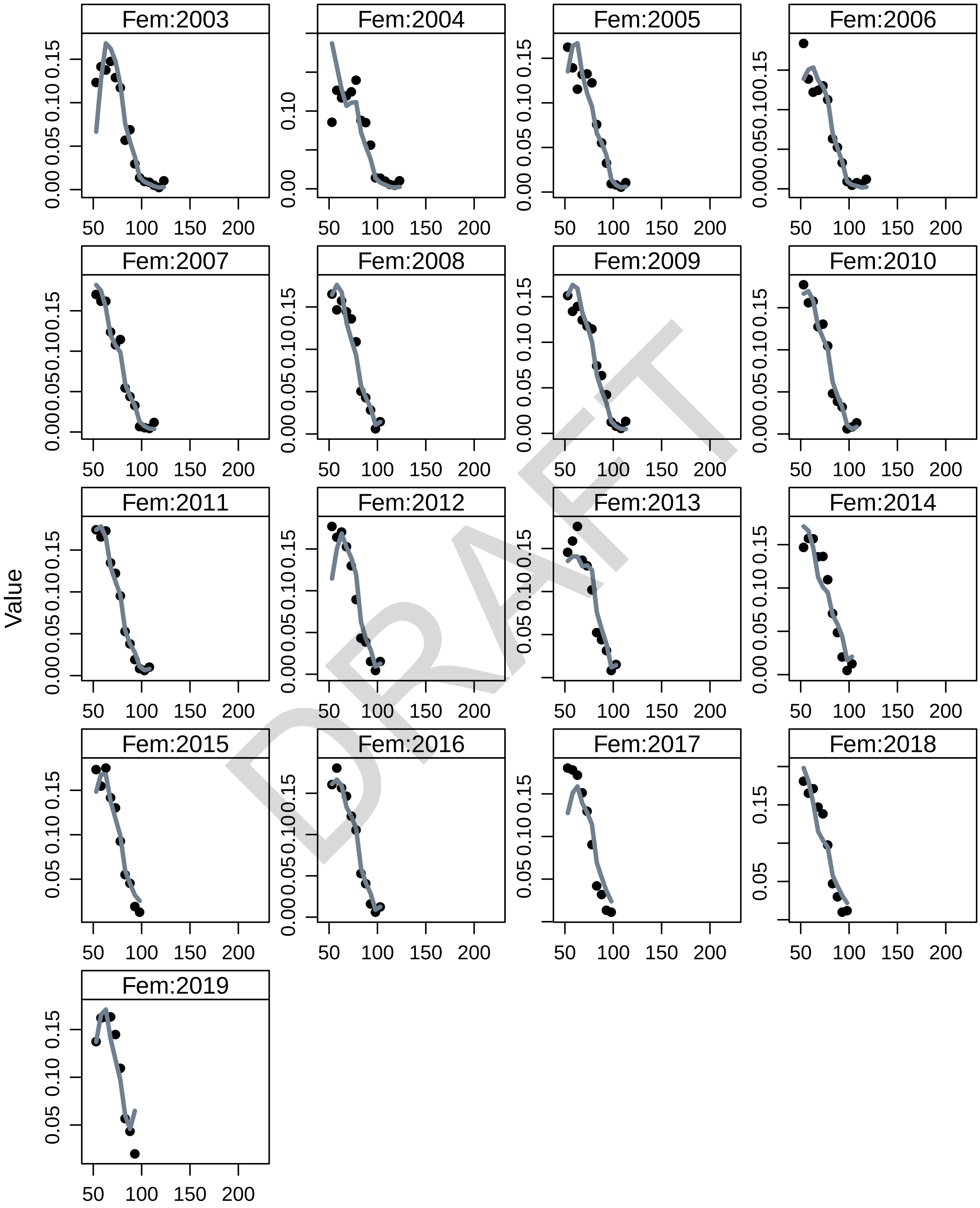
r60_ind_trawl_v6f6
MeFQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
MeFQ4 observed and predicted length comps

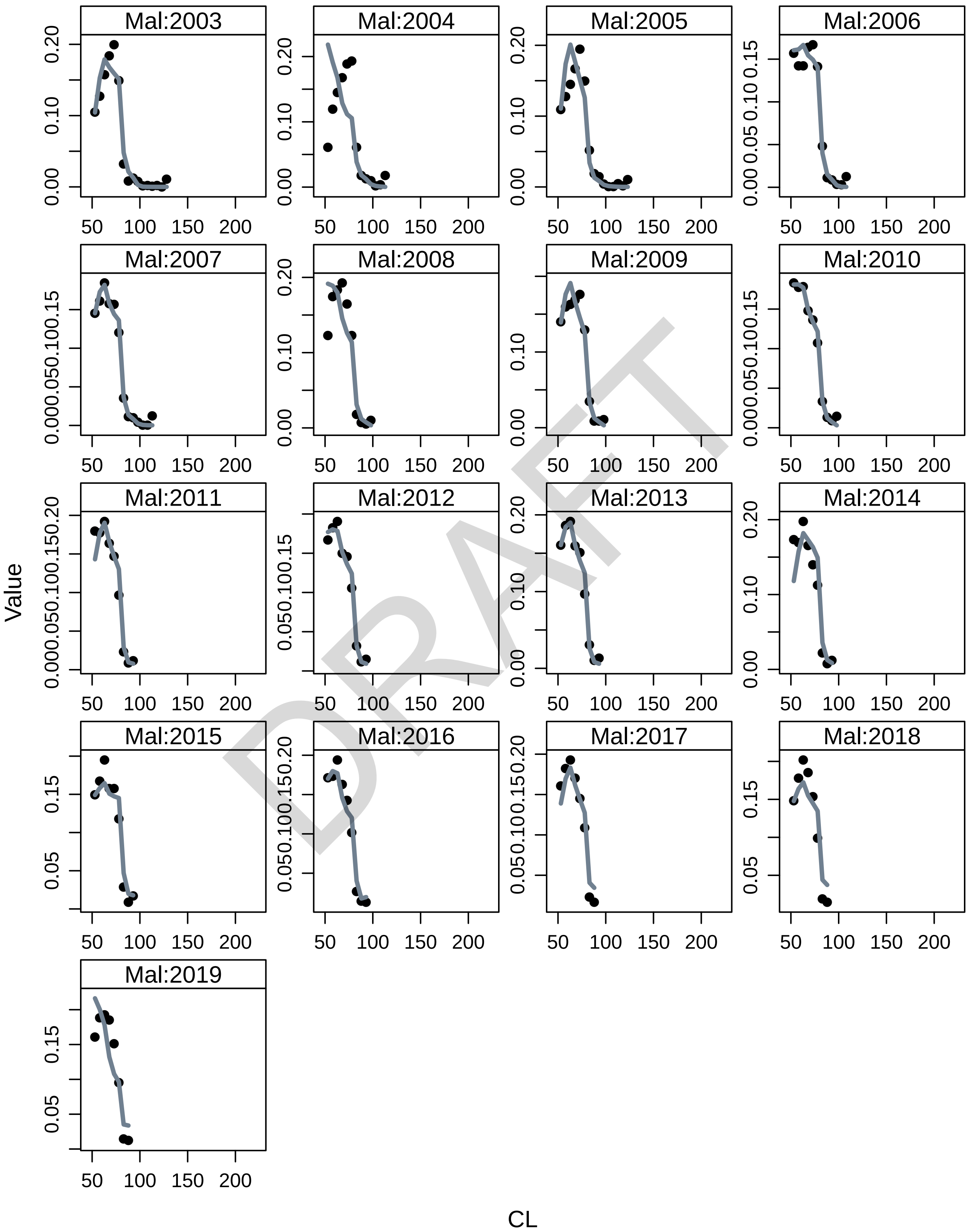


CL

Symbols = observed / Solid line = predicted

DRAFT

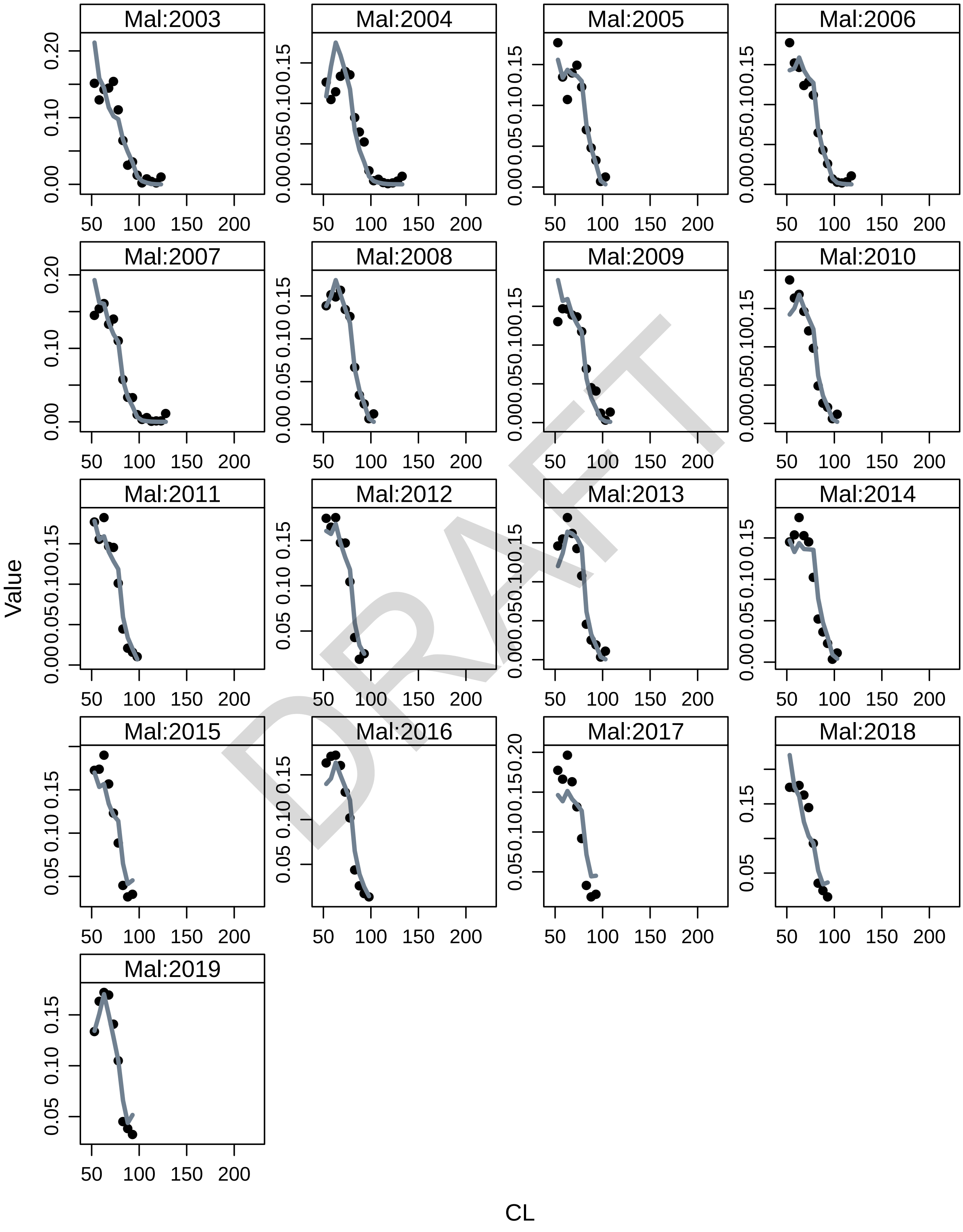
r60_ind_trawl_v6f6
MeMQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
MeMQ4 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

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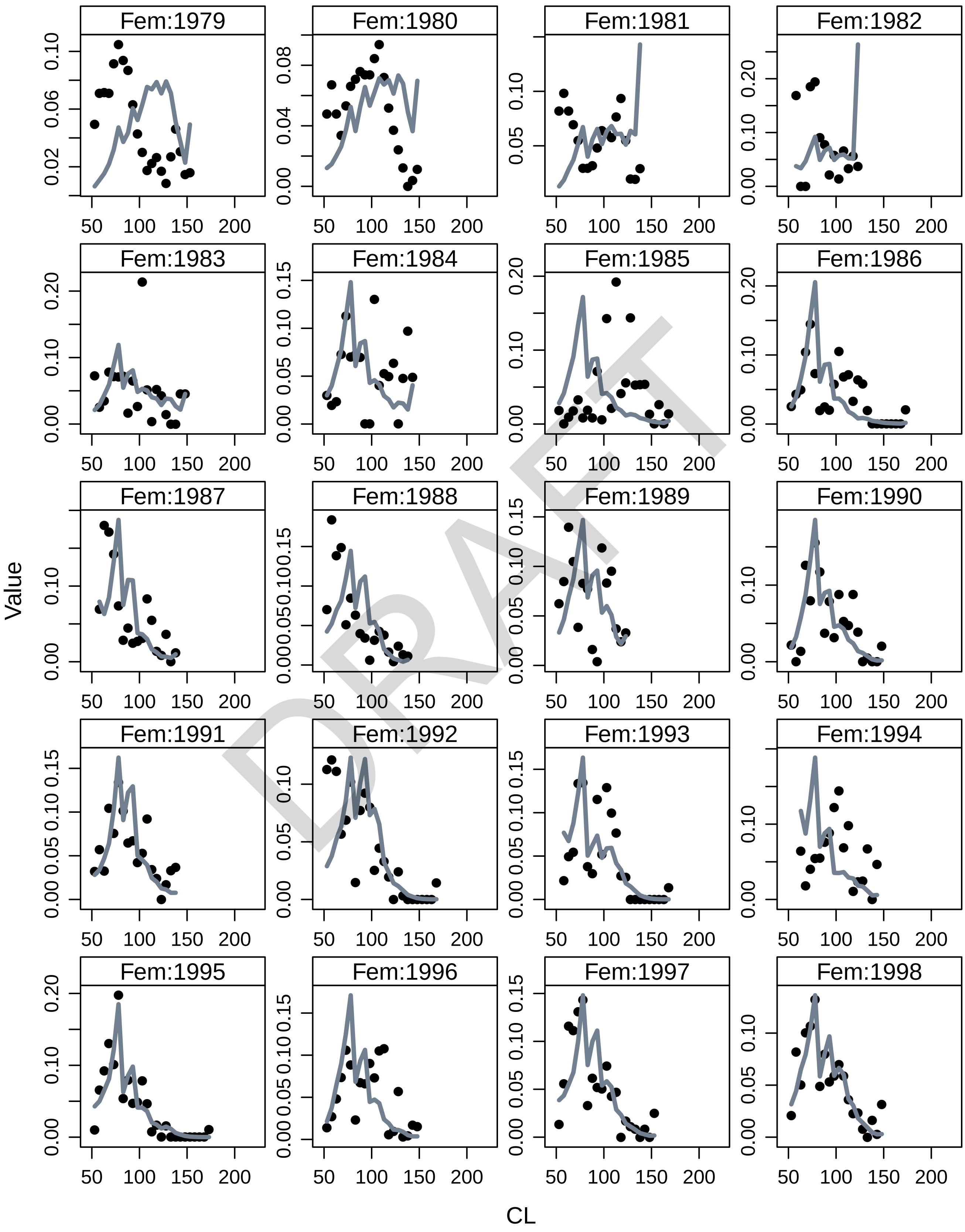
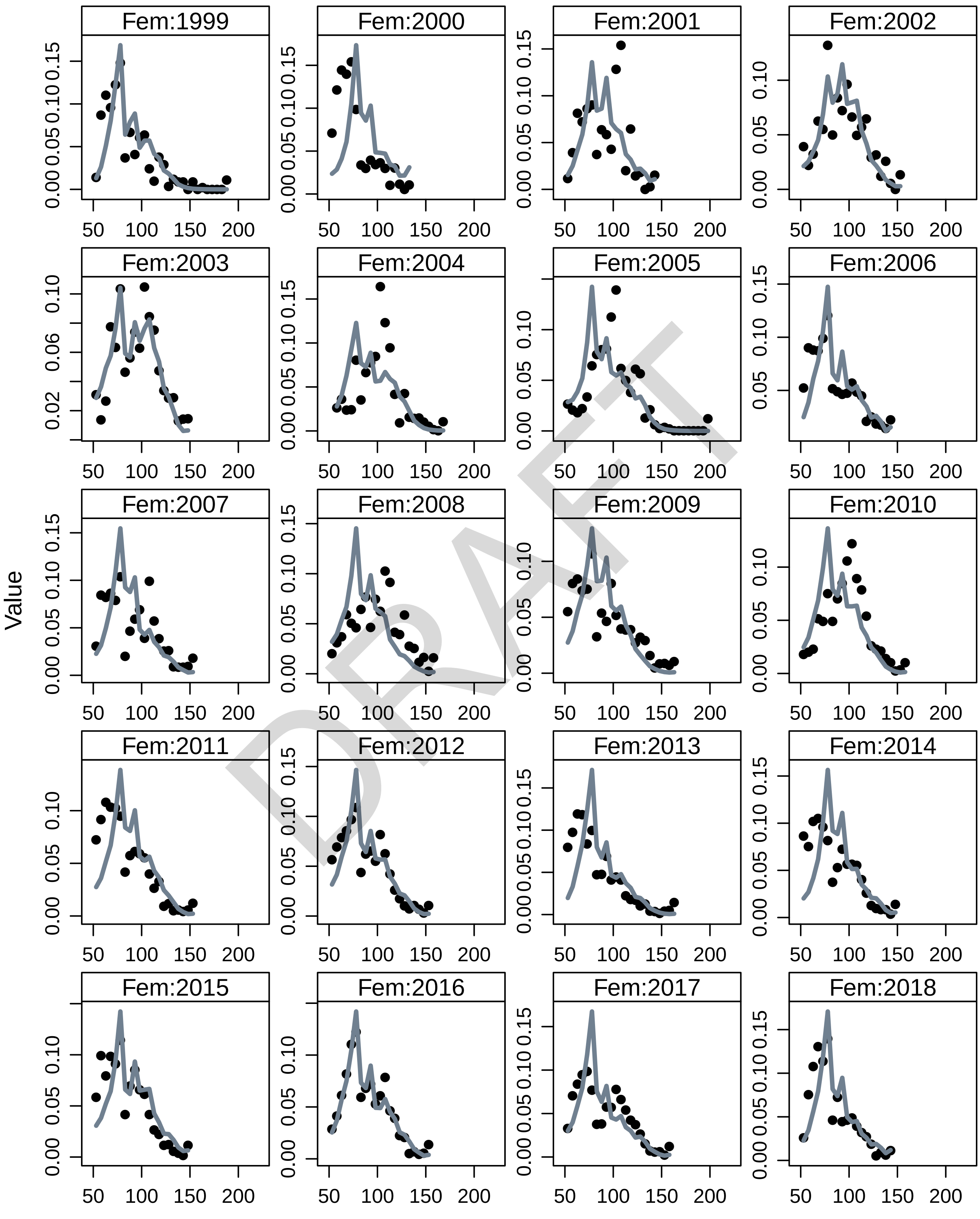
r60_ind_trawl_v6f6
NefscFQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
NefscFQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

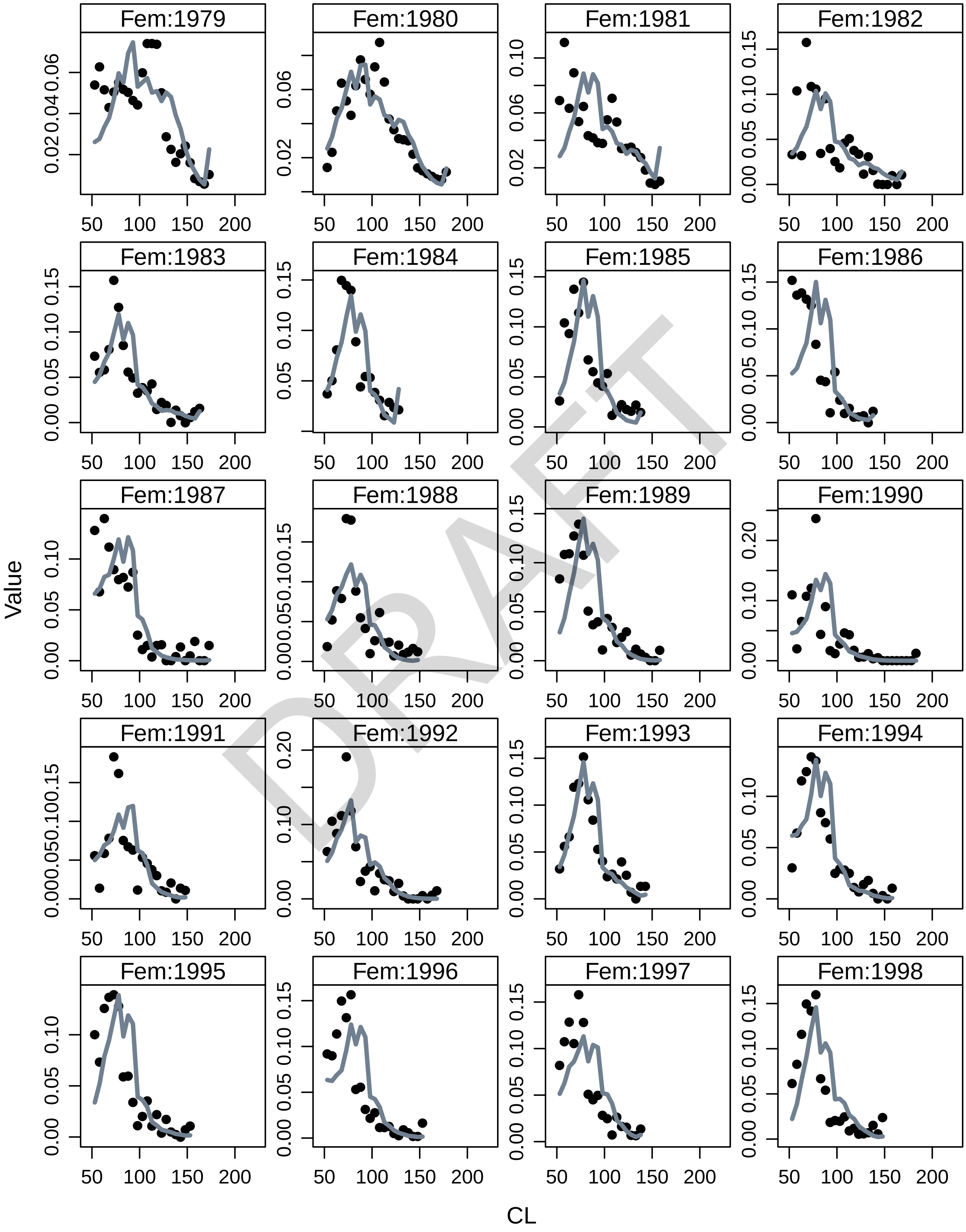
DRAFT

r60_ind_trawl_v6f6
NefscFQ2 observed and predicted length comps

DRAFT

Symbols = observed / Solid line = predicted

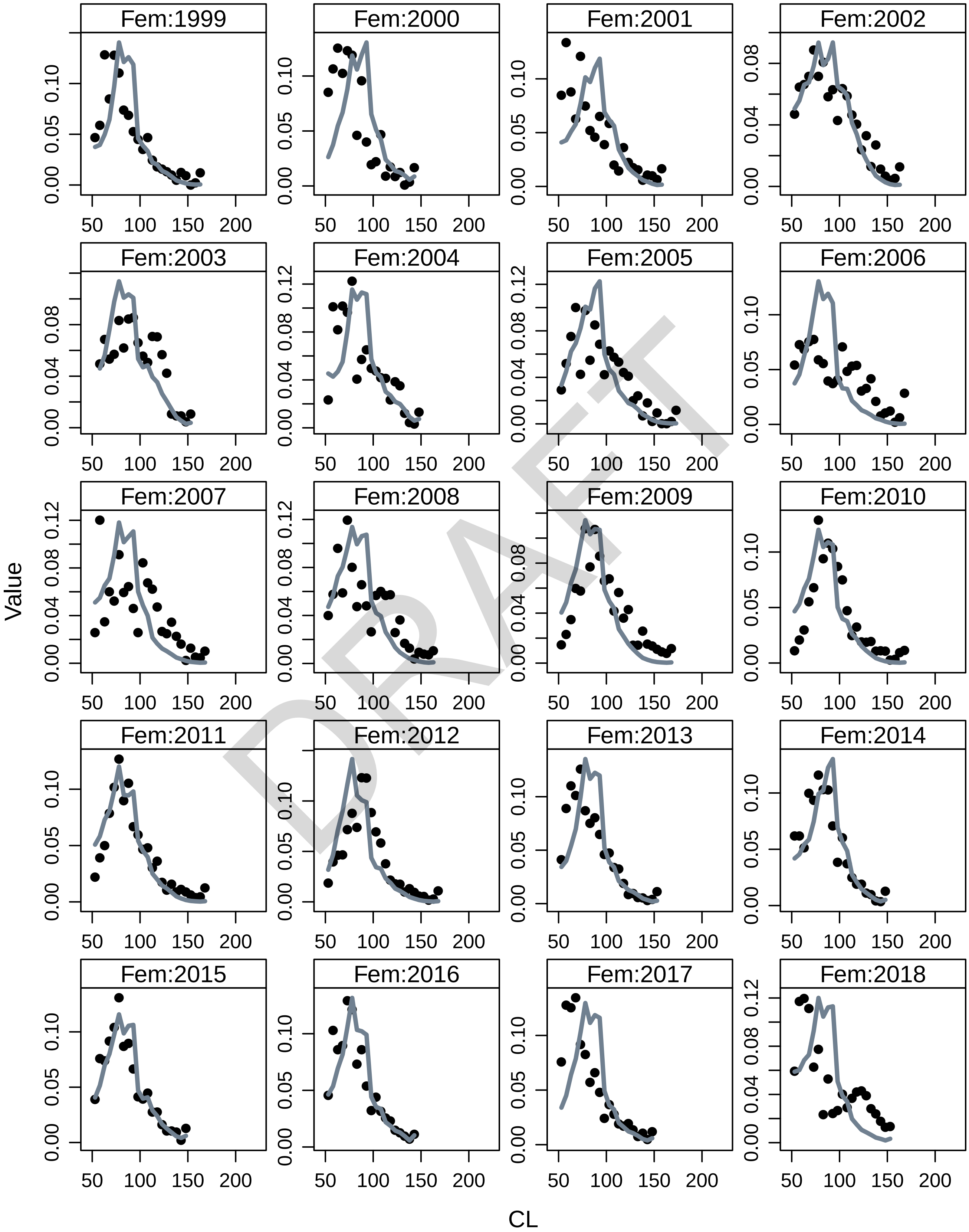
r60_ind_trawl_v6f6
NefscFQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

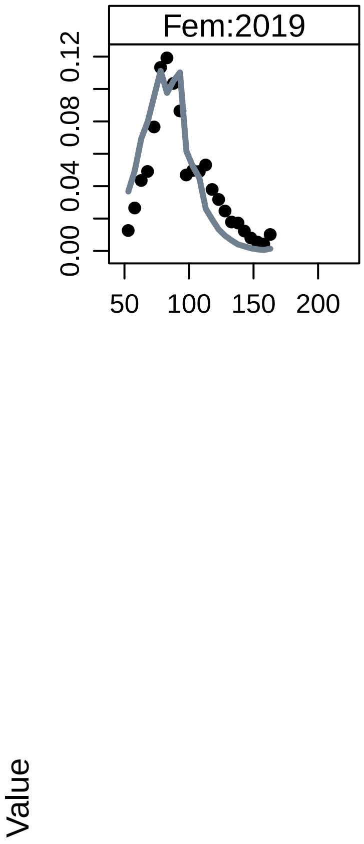
r60_ind_trawl_v6f6
NefscFQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

r60_ind_trawl_v6f6
NefscFQ4 observed and predicted length comps

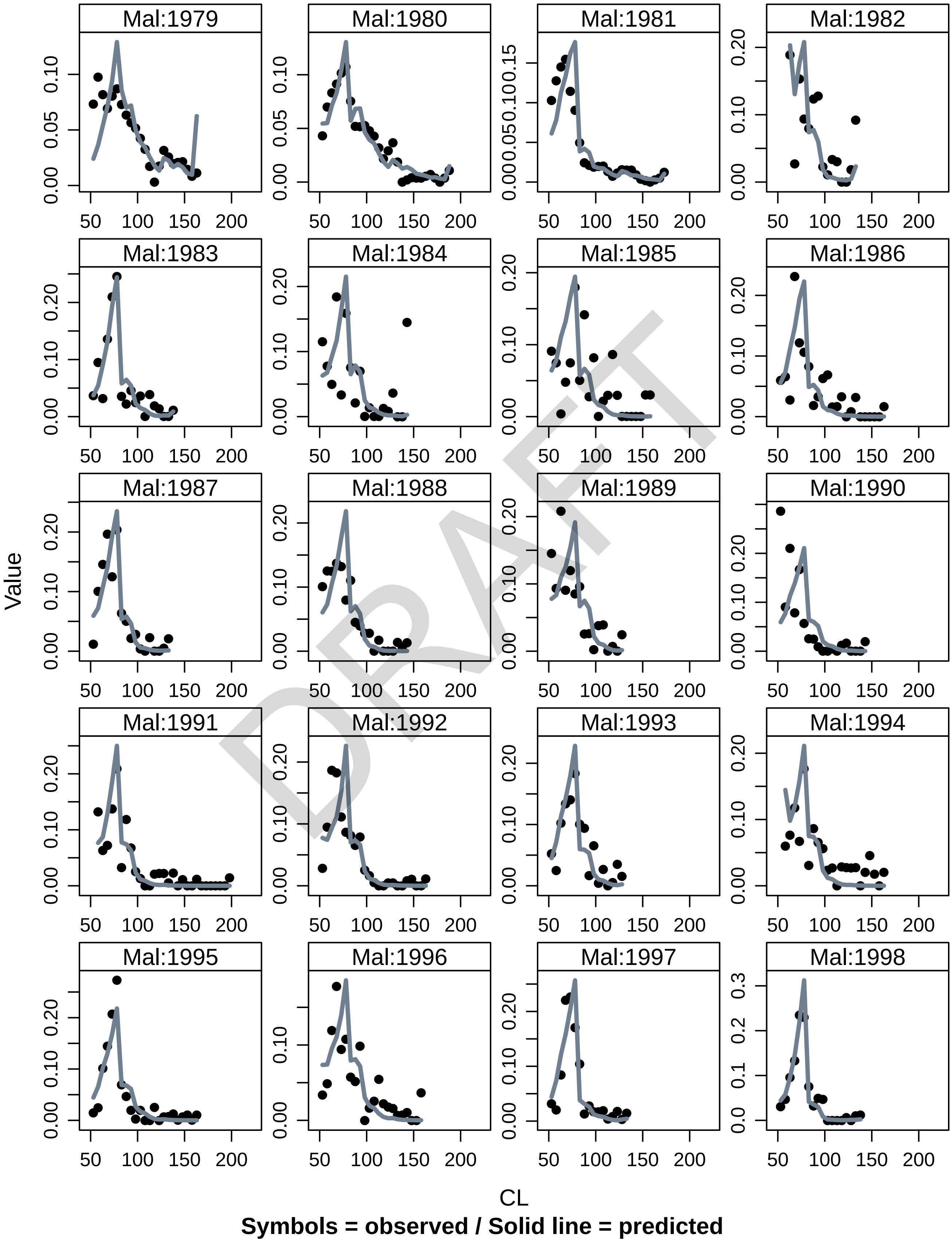


DRAFT

CL

Symbols = observed / Solid line = predicted

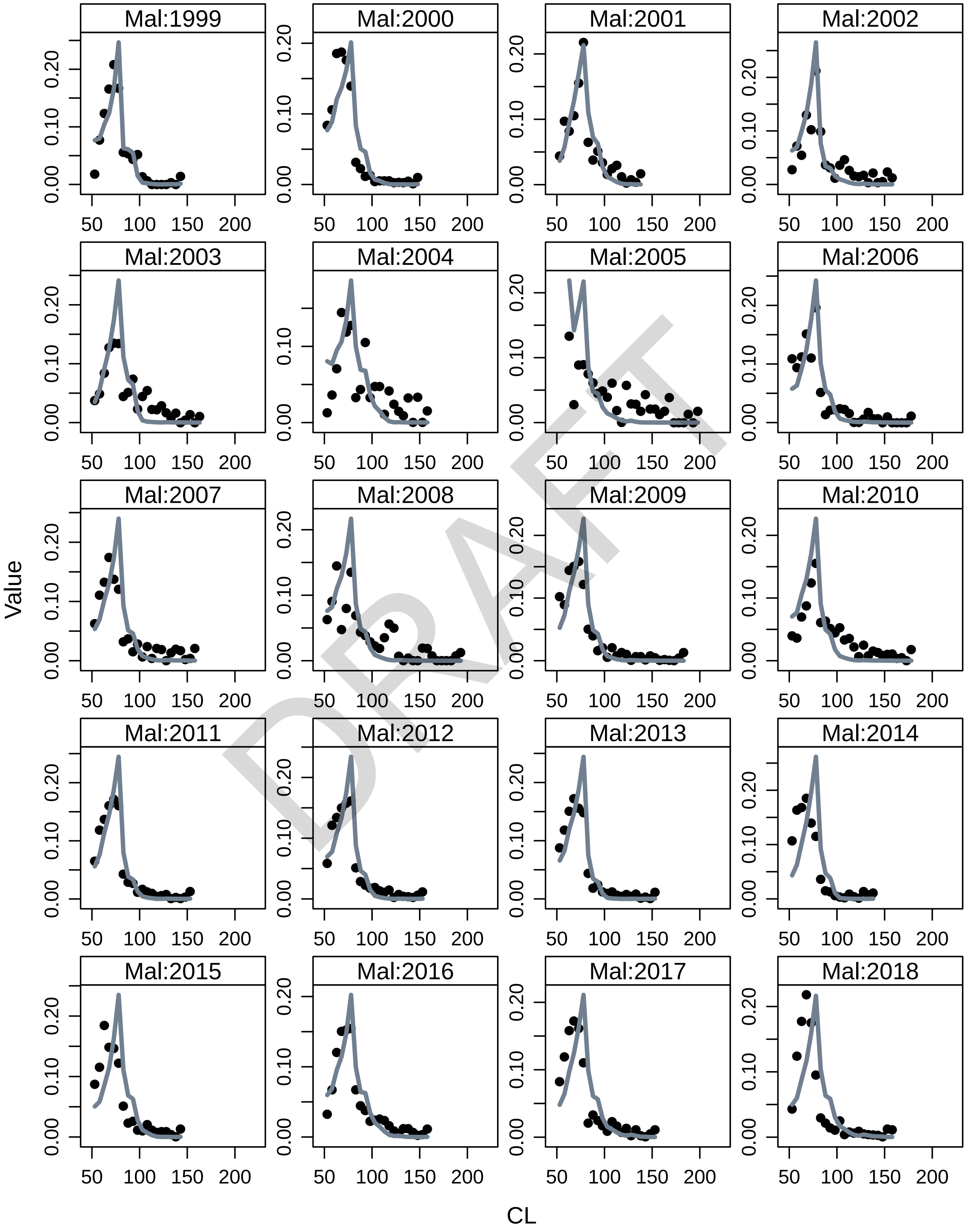
r60_ind_trawl_v6f6
NefscMQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

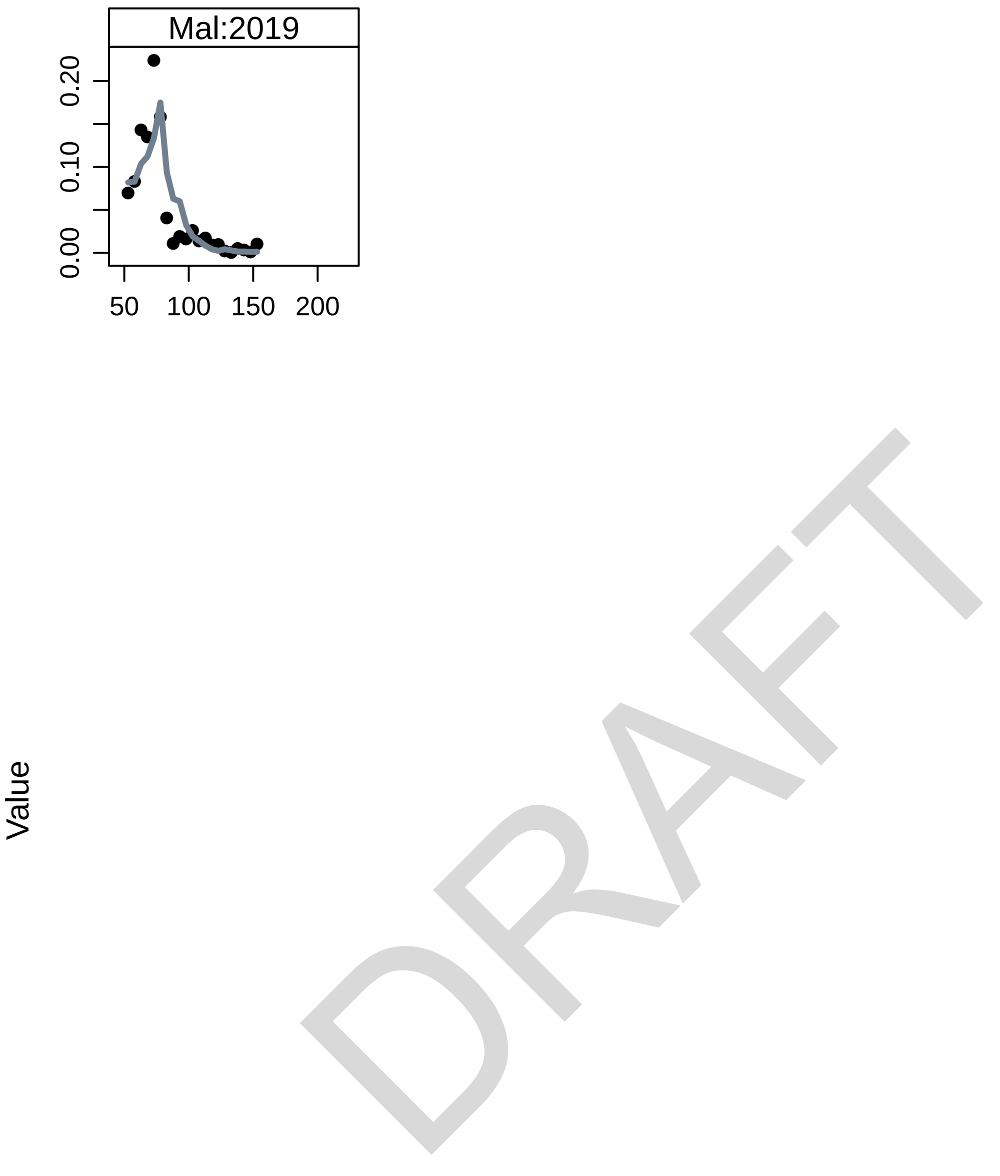
r60_ind_trawl_v6f6
NefscMQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

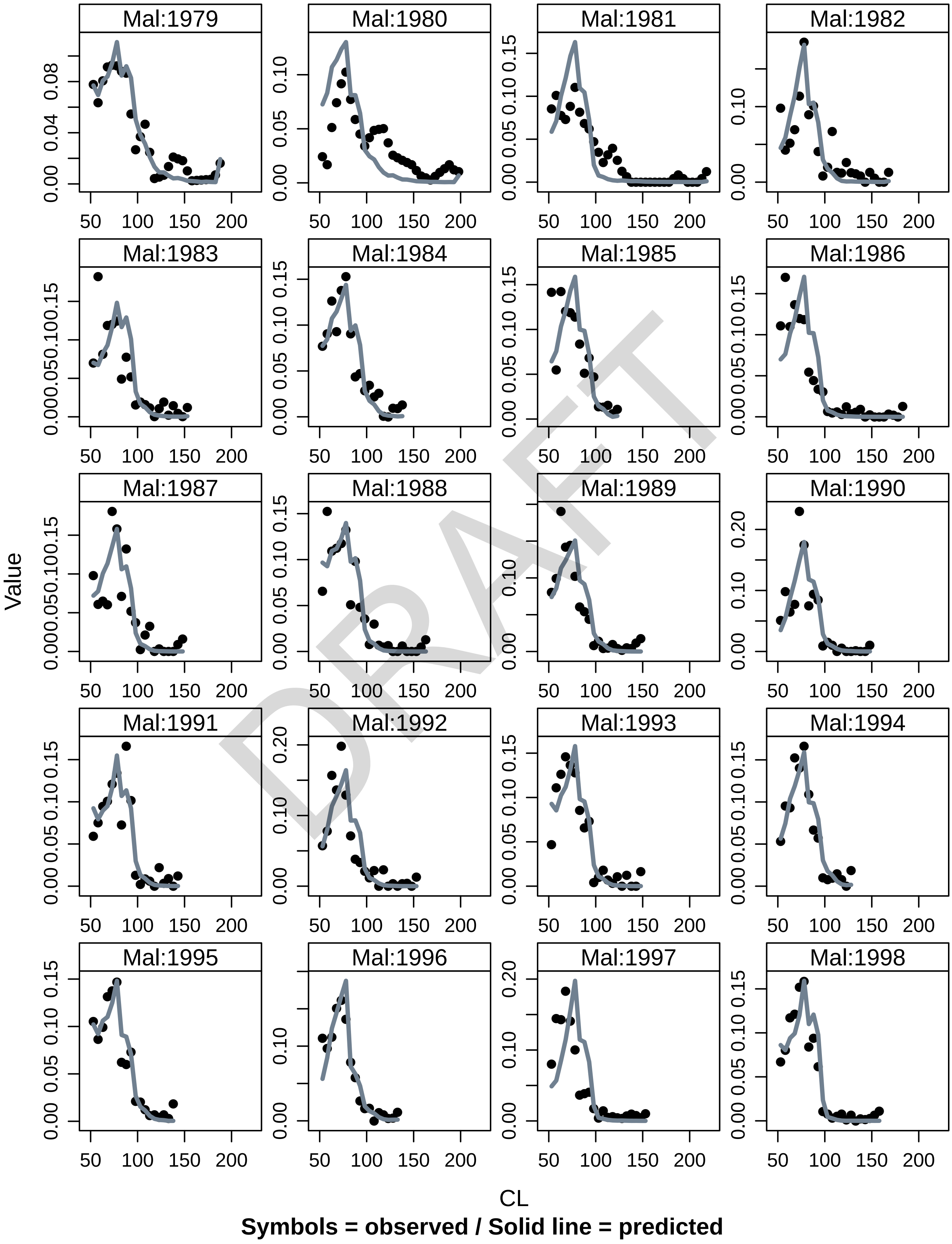
r60_ind_trawl_v6f6
NefscMQ2 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

r60_ind_trawl_v6f6
NefscMQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

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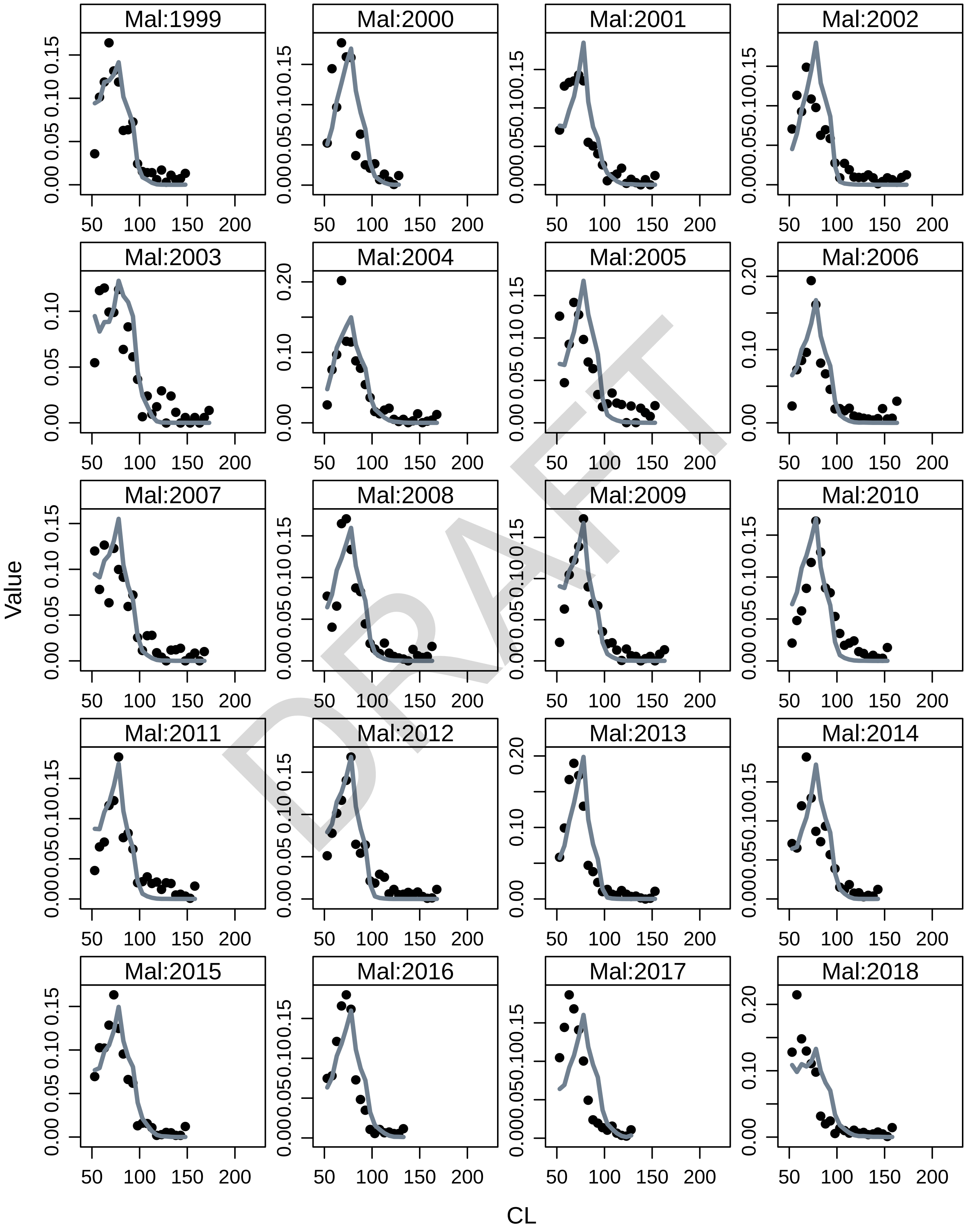
r60_ind_trawl_v6f6
NefscMQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

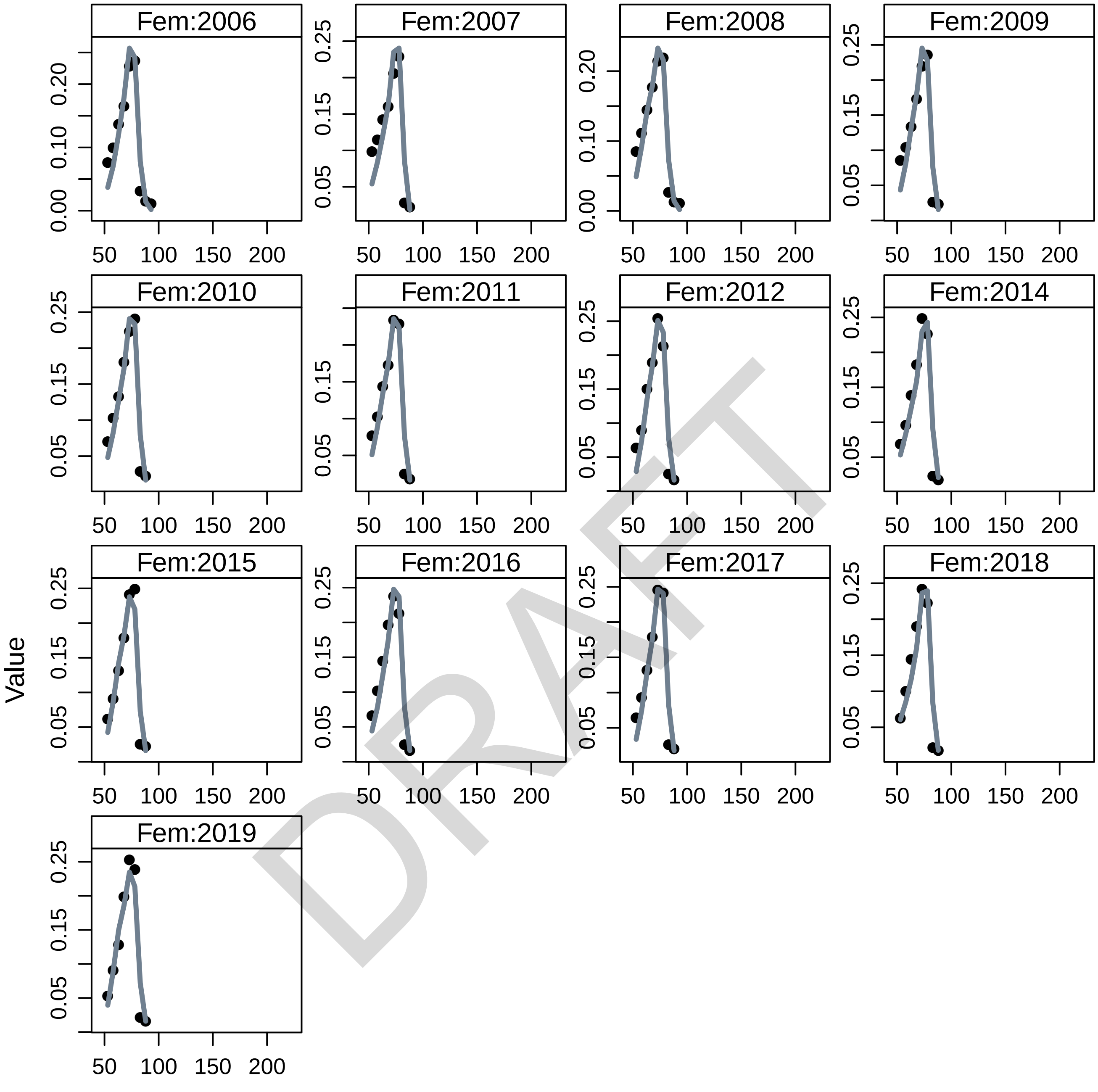
DRAFT

r60_ind_trawl_v6f6
NefscMQ4 observed and predicted length comps

DRAFT

Symbols = observed / Solid line = predicted

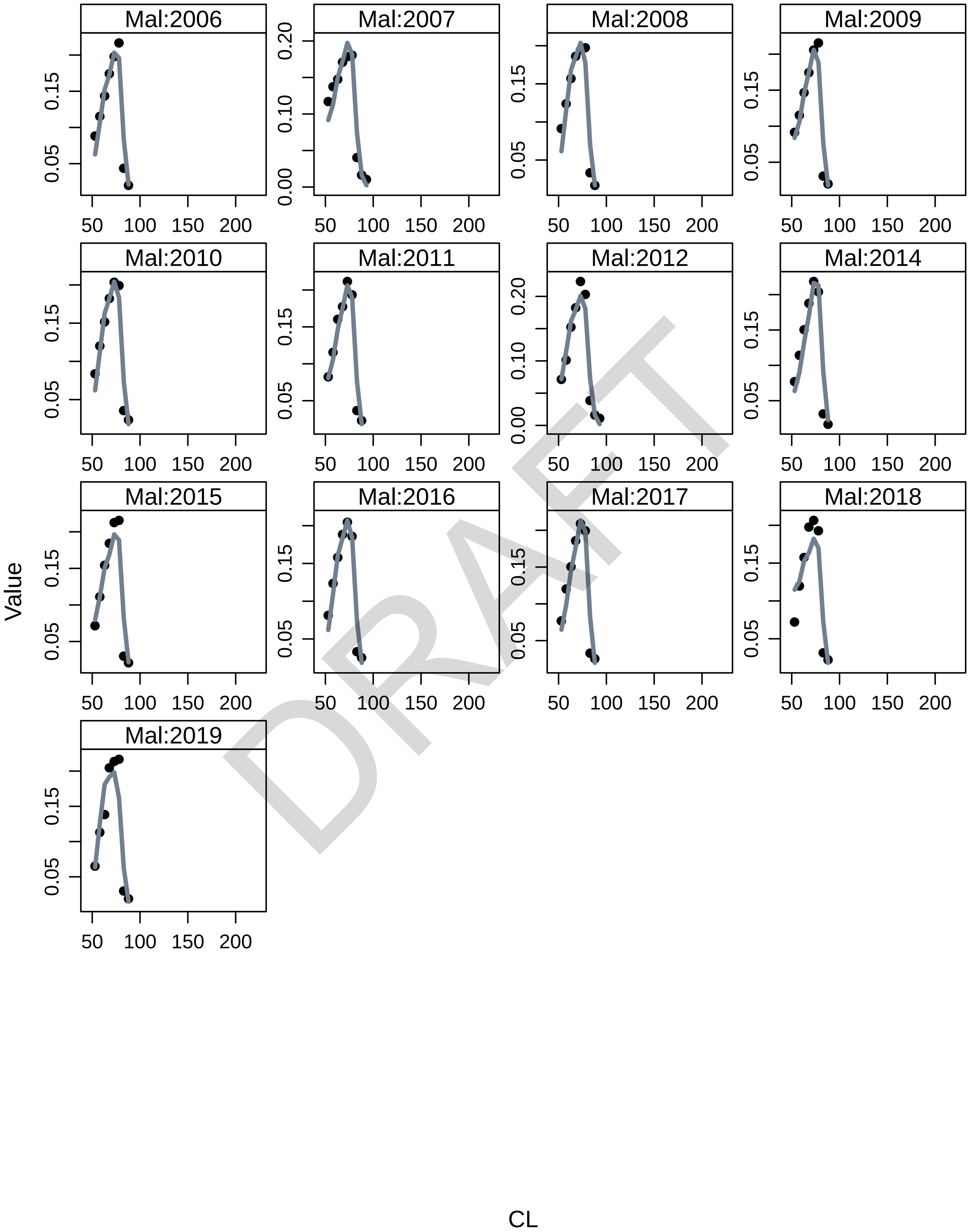
r60_ind_trawl_v6f6
VtsFQ3_stand observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

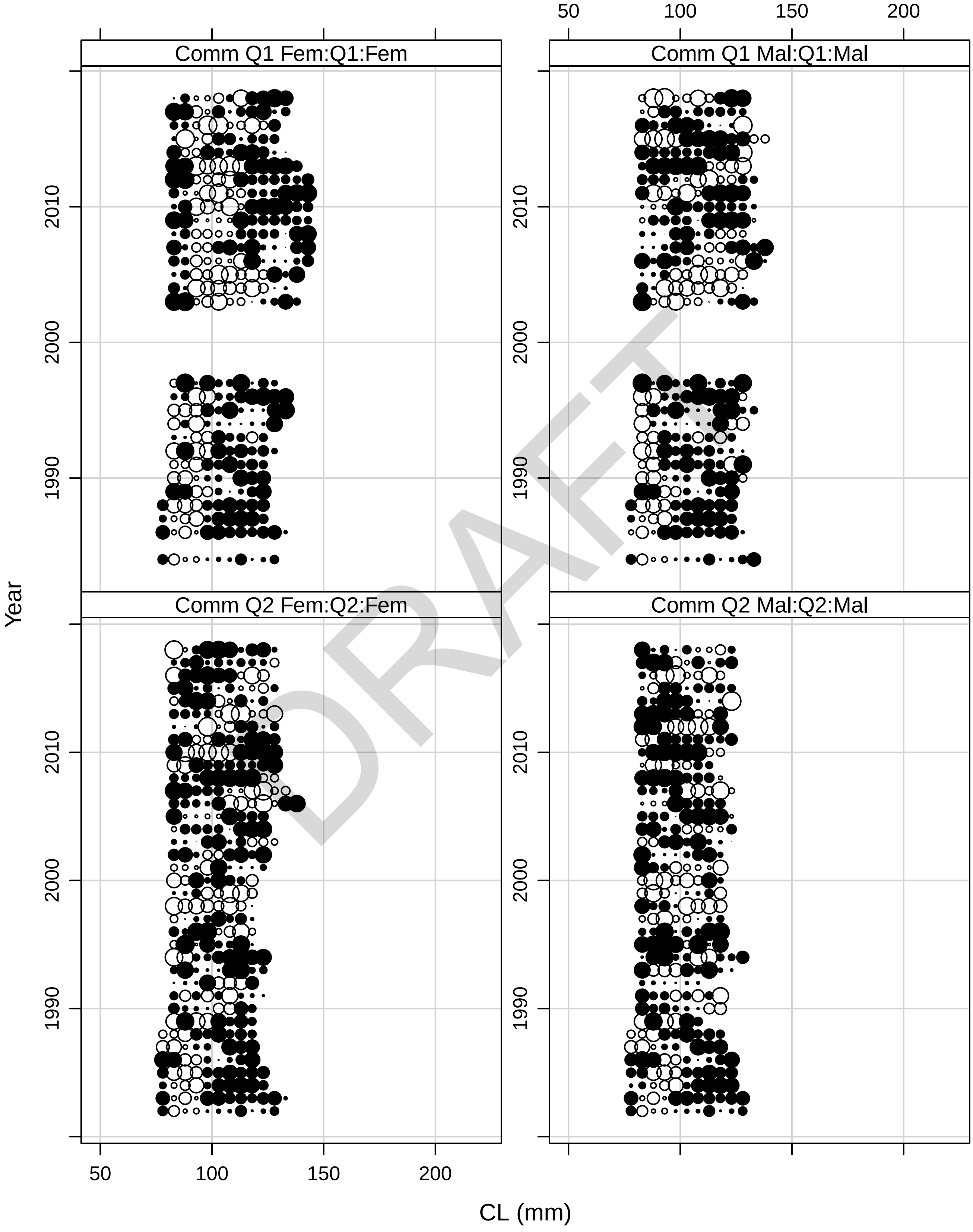
r60_ind_trawl_v6f6
VtsMQ3_stand observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

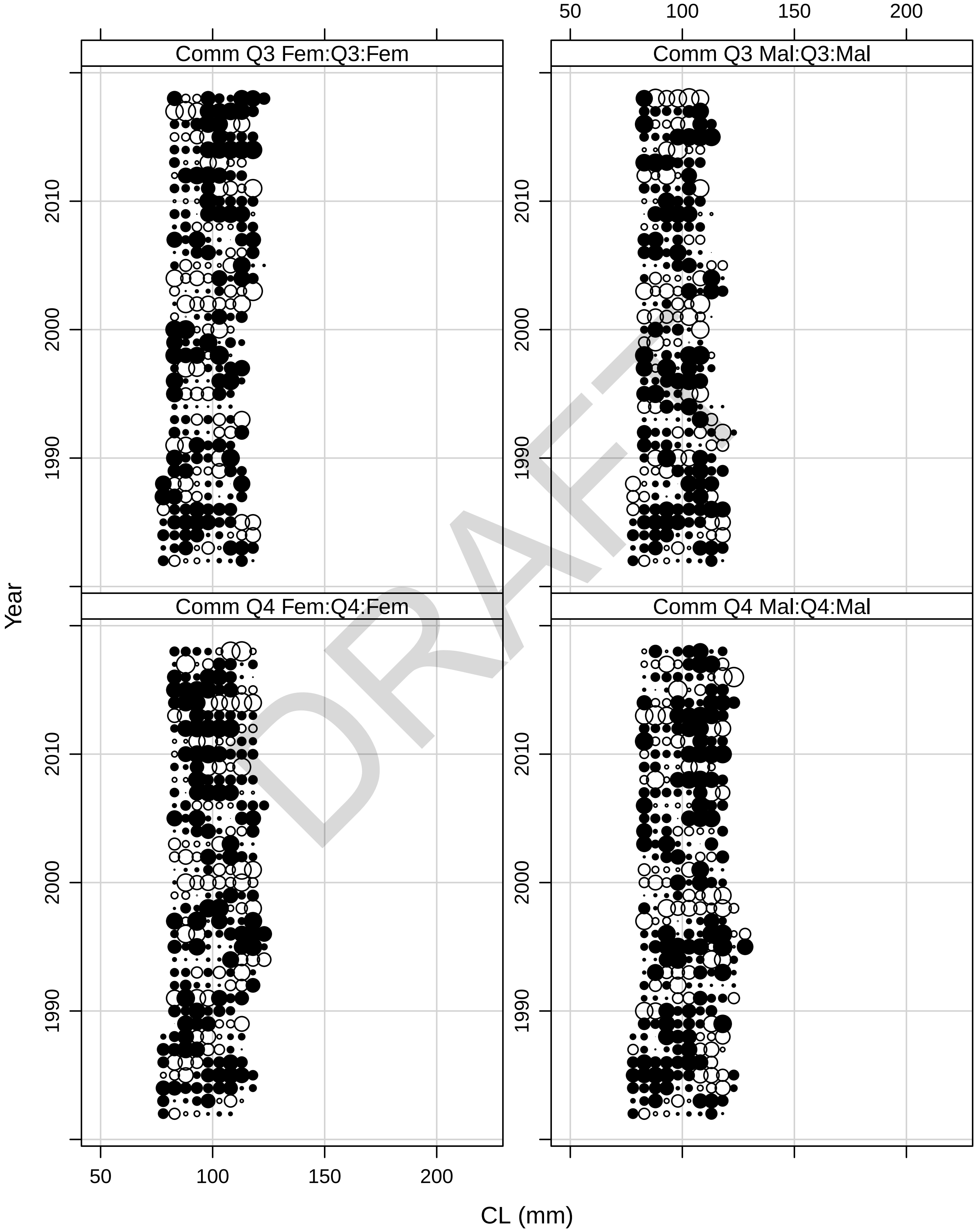
r60_ind_trawl_v6f6
Length composition deviance residuals



Negative residuals clear; postive residuals solid

DRAFT

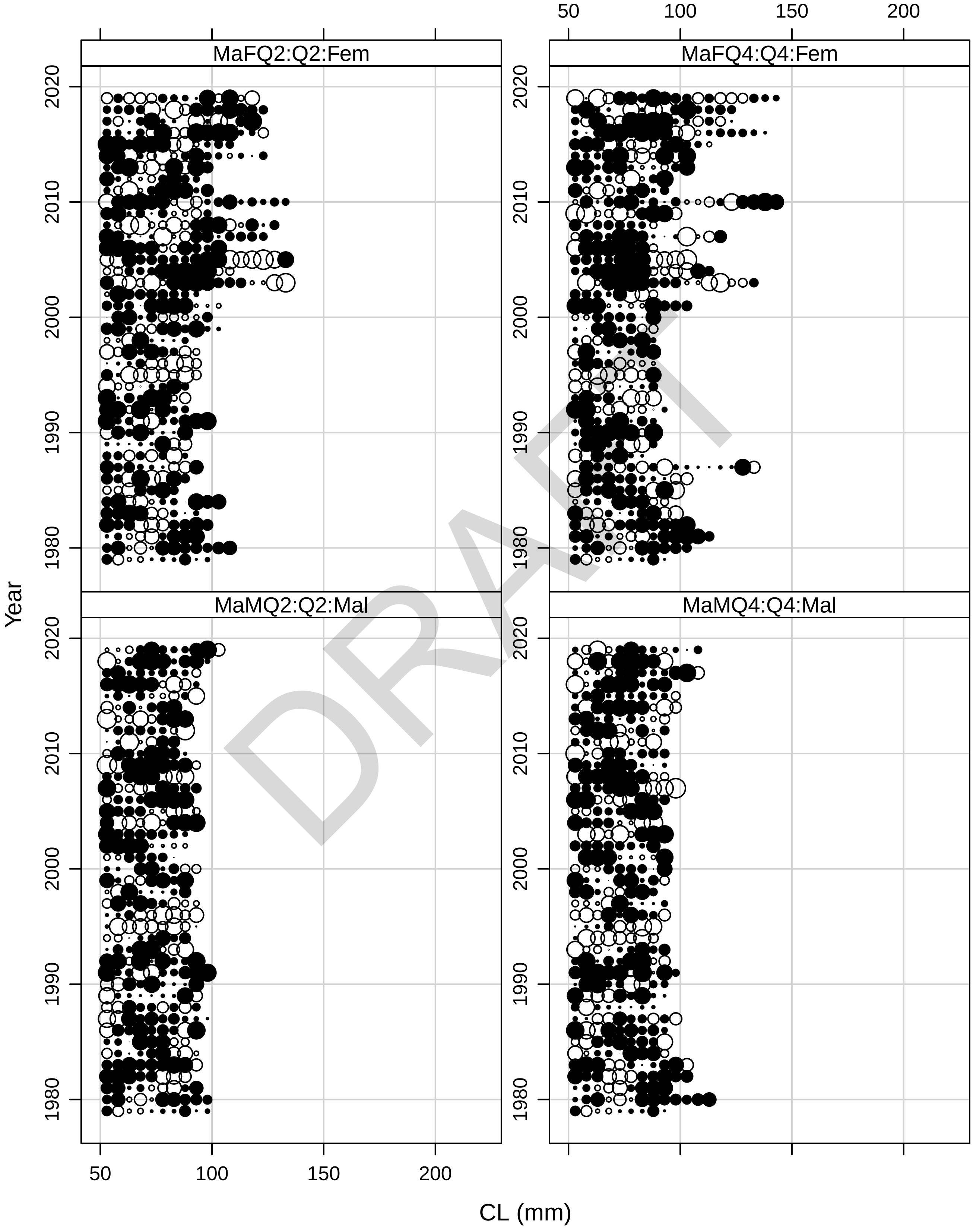
r60_ind_trawl_v6f6
Length composition deviance residuals



Negative residuals clear; postive residuals solid

DRAFT

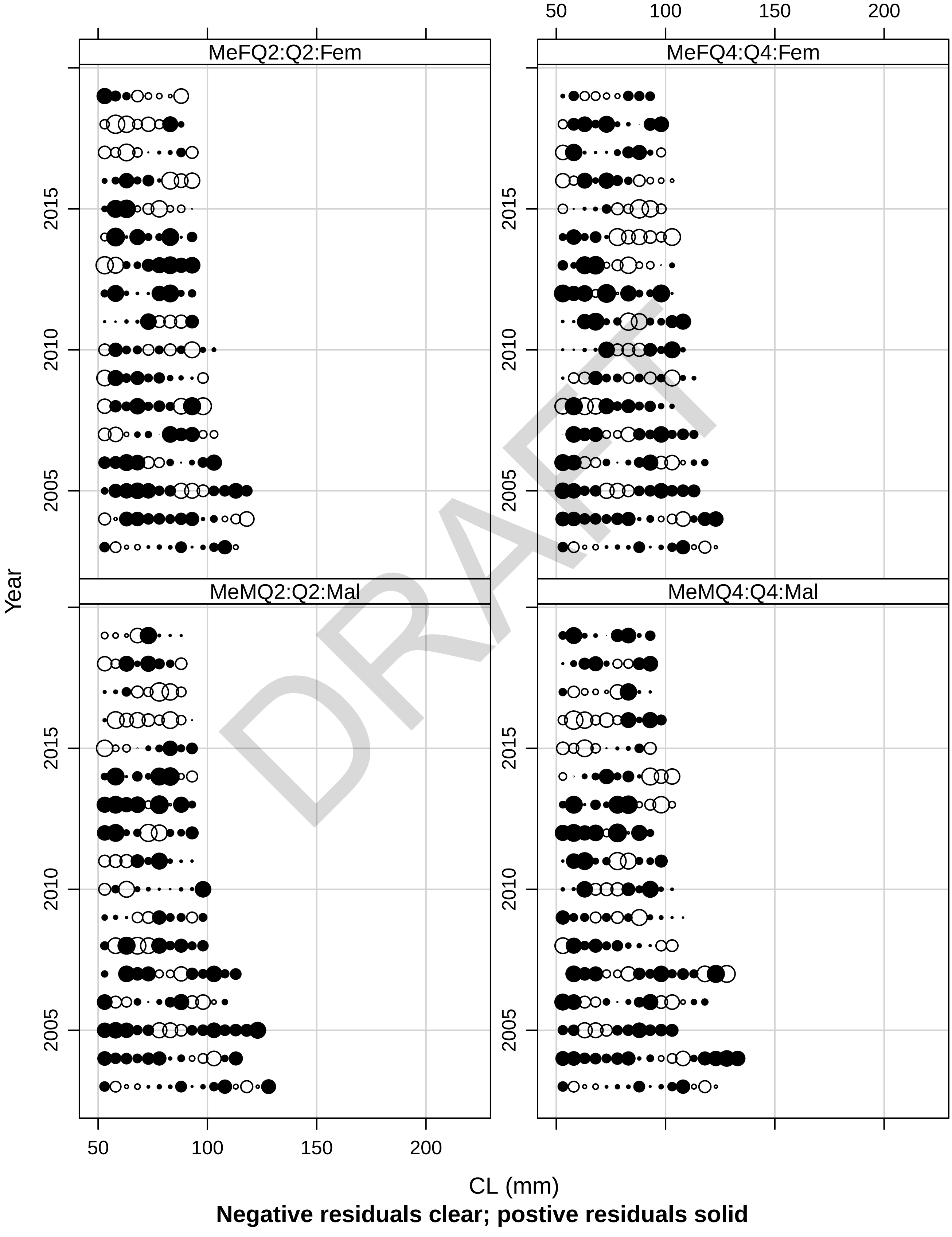
r60_ind_trawl_v6f6
Length composition deviance residuals



Negative residuals clear; postive residuals solid

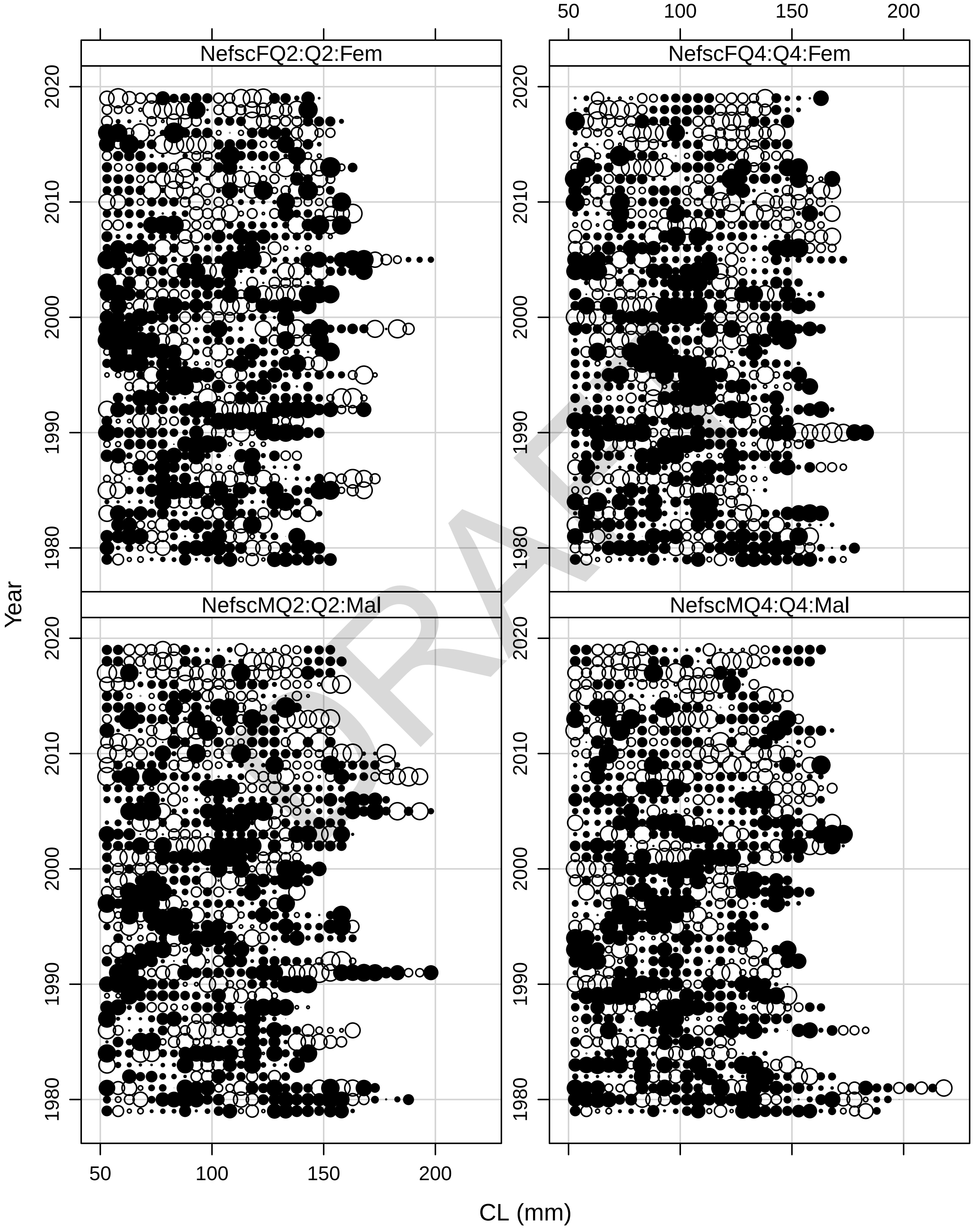
DRAFT

r60_ind_trawl_v6f6
Length composition deviance residuals



DRAFT

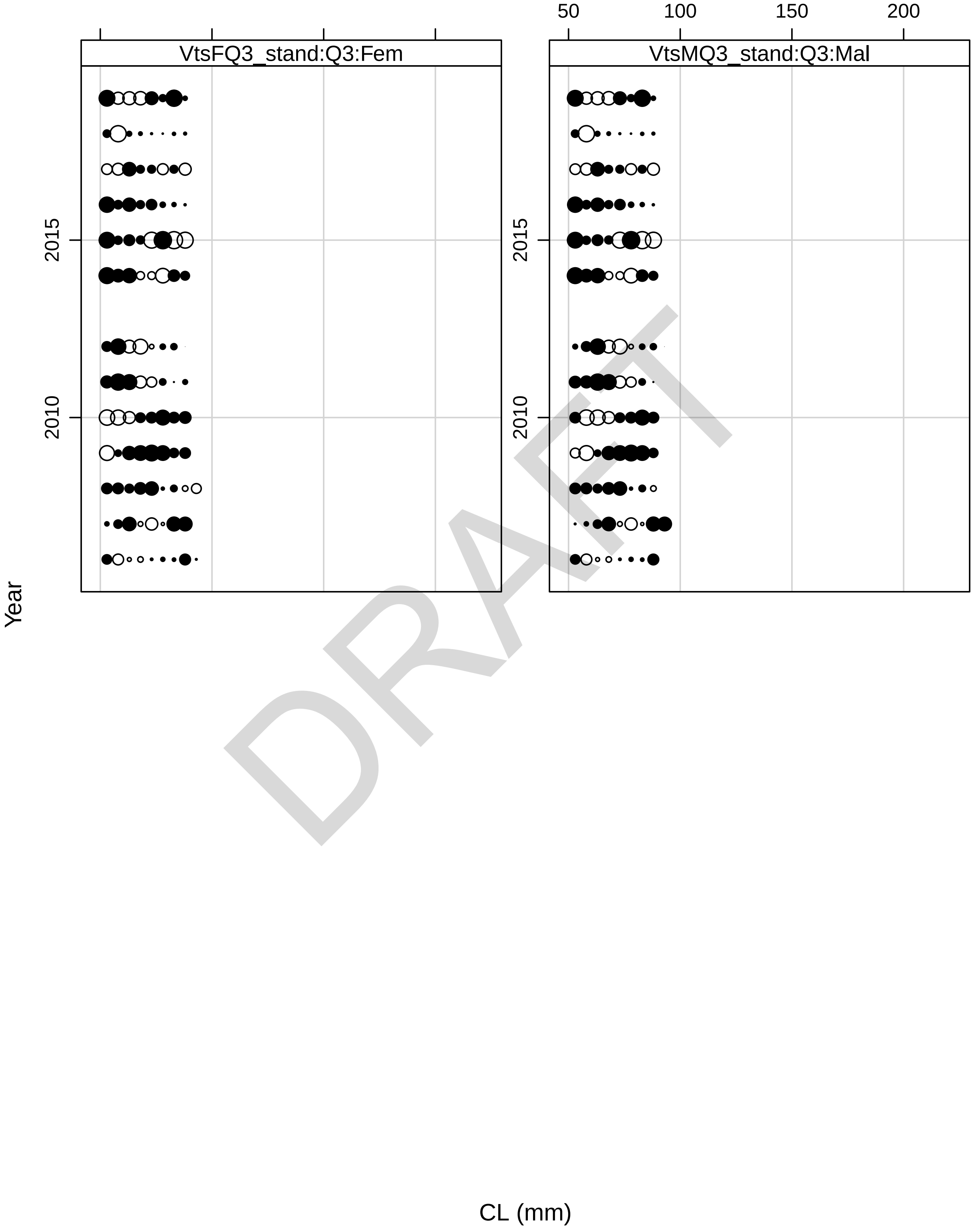
r60_ind_trawl_v6f6
Length composition deviance residuals



Negative residuals clear; postive residuals solid

DRAFT

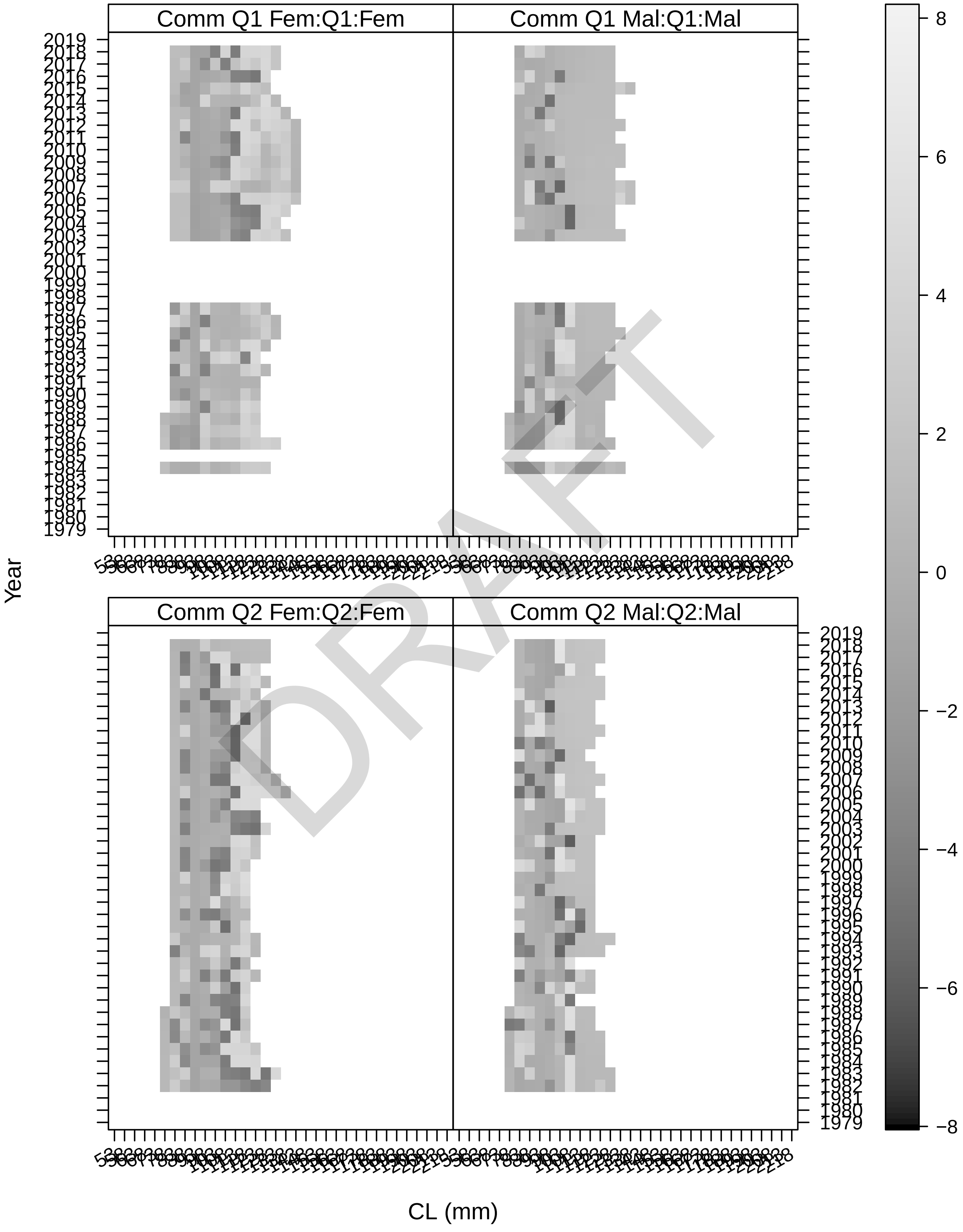
r60_ind_trawl_v6f6
Length composition deviance residuals



Negative residuals clear; postive residuals solid

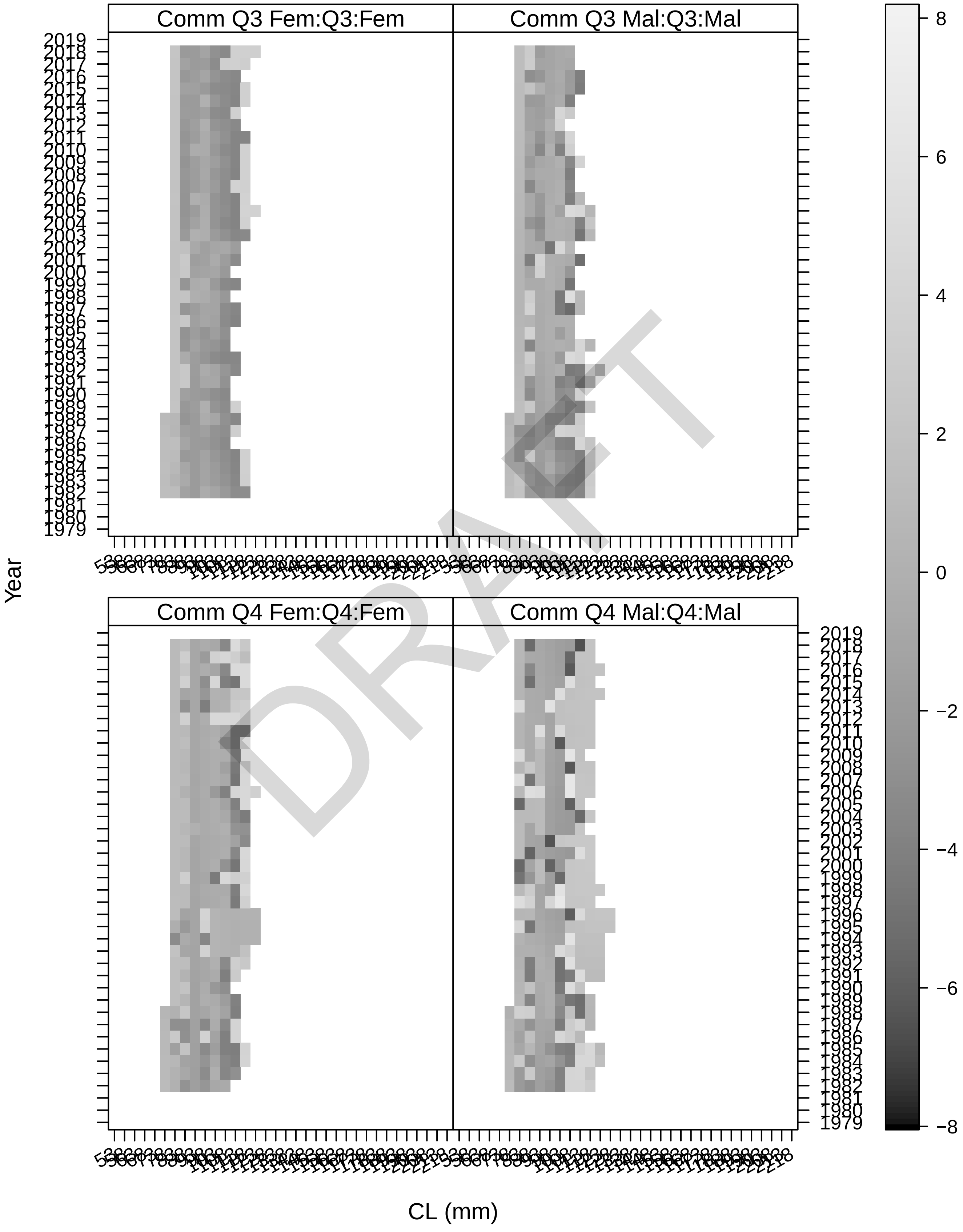
DRAFT

r60_ind_trawl_v6f6
Length composition deviance residuals



DRAFT

r60_ind_trawl_v6f6
Length composition deviance residuals



DRAFT

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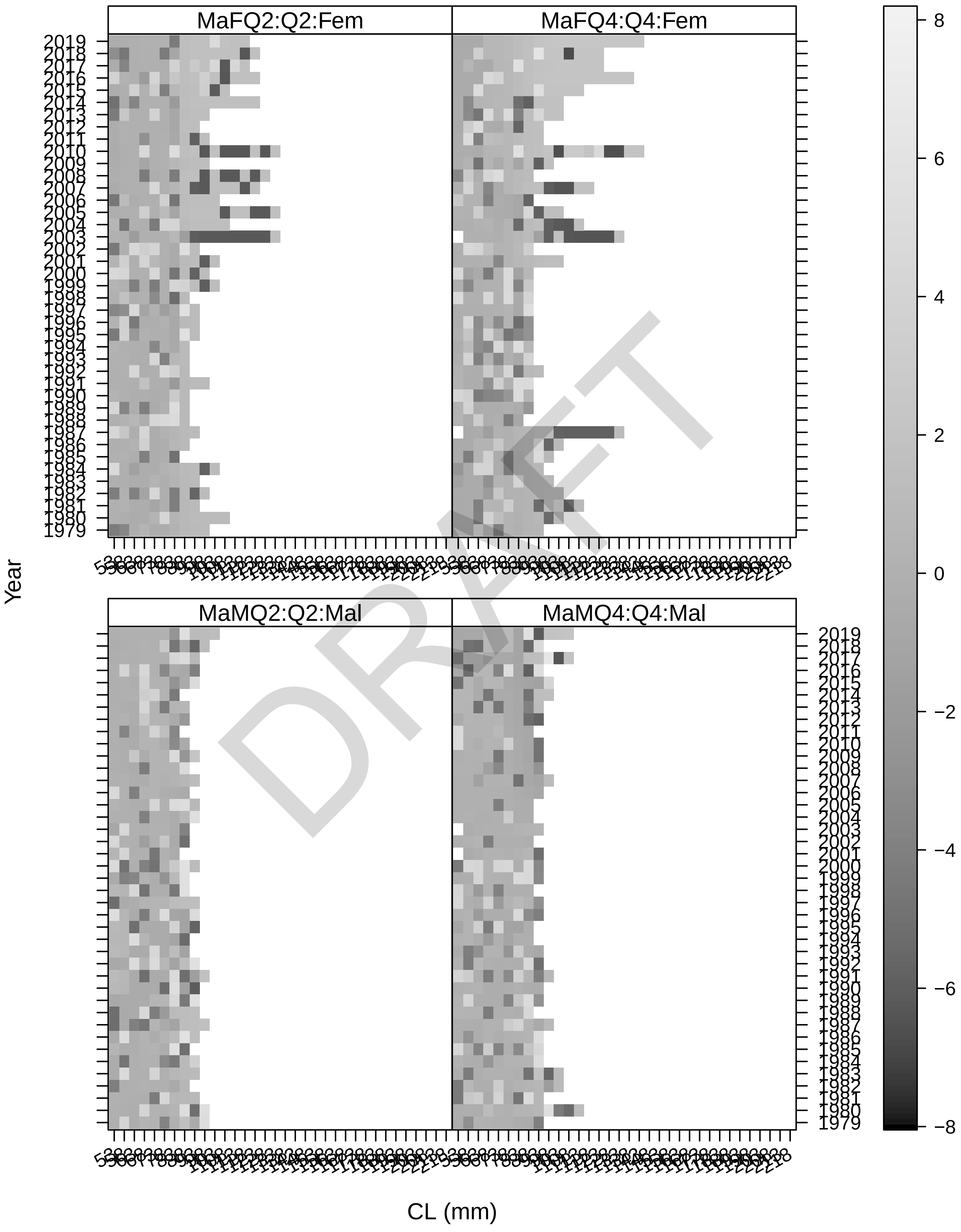
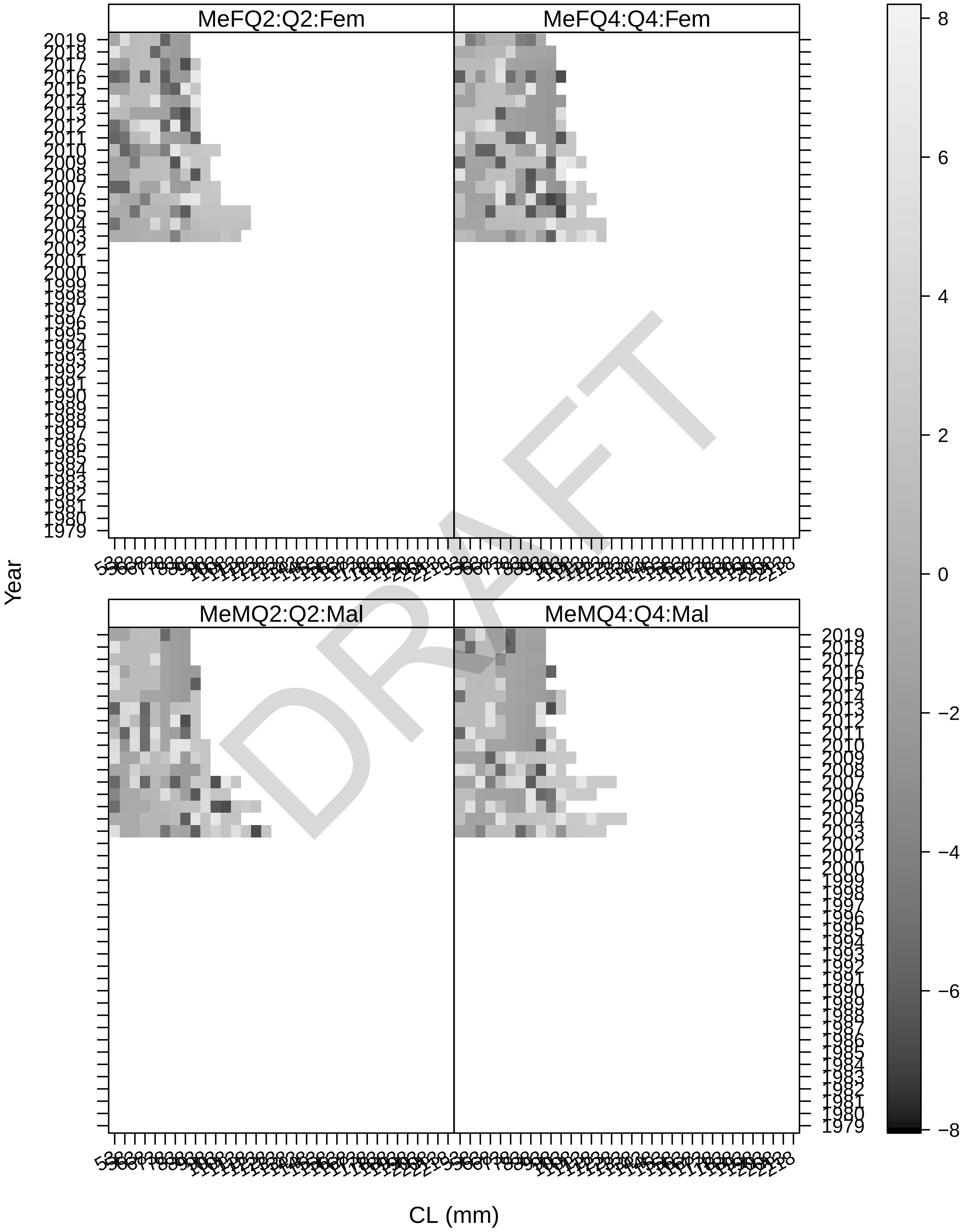


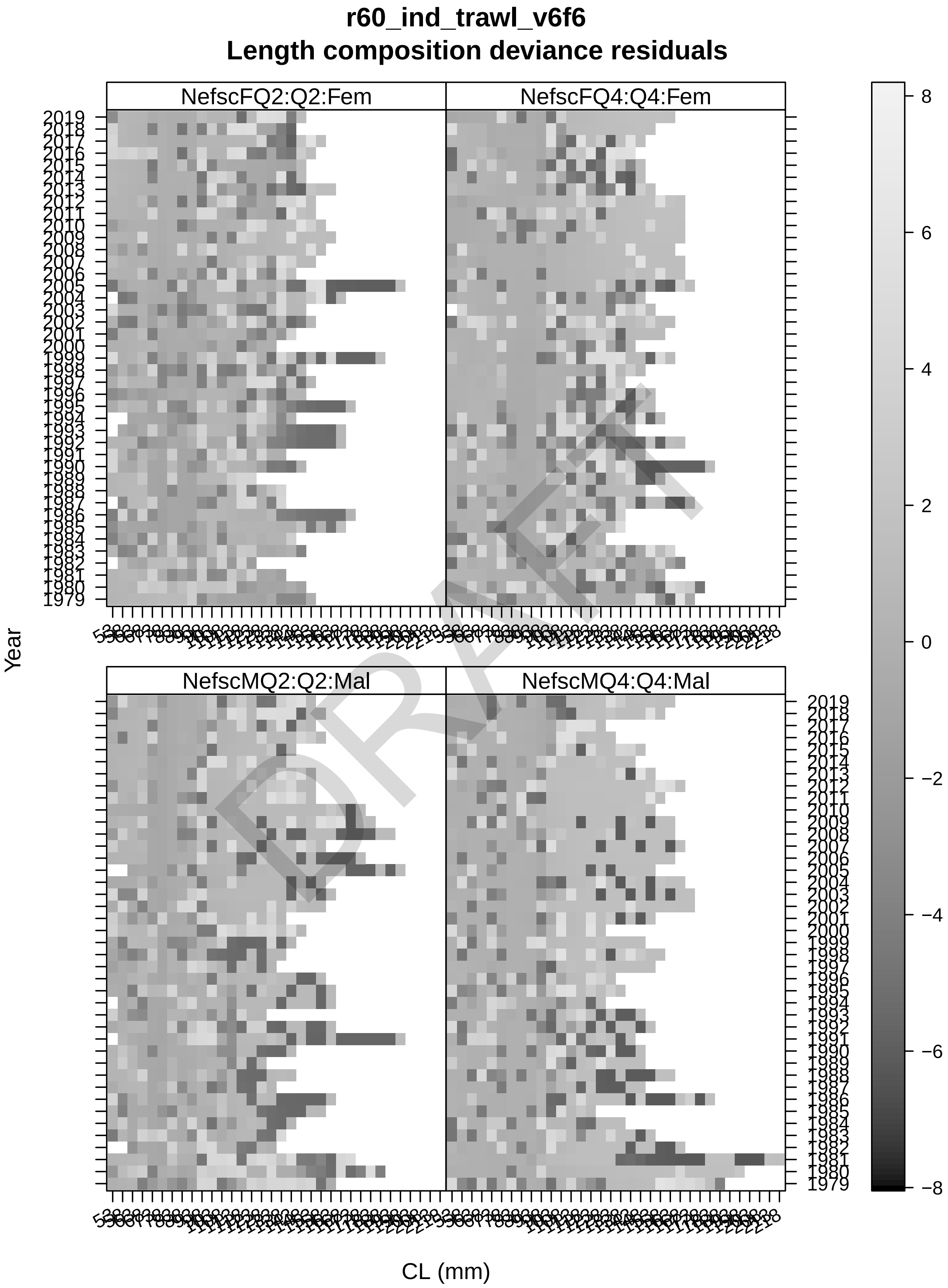
r60_ind_trawl_v6f6
Length composition deviance residuals

DRAFT

r60_ind_trawl_v6f6
Length composition deviance residuals

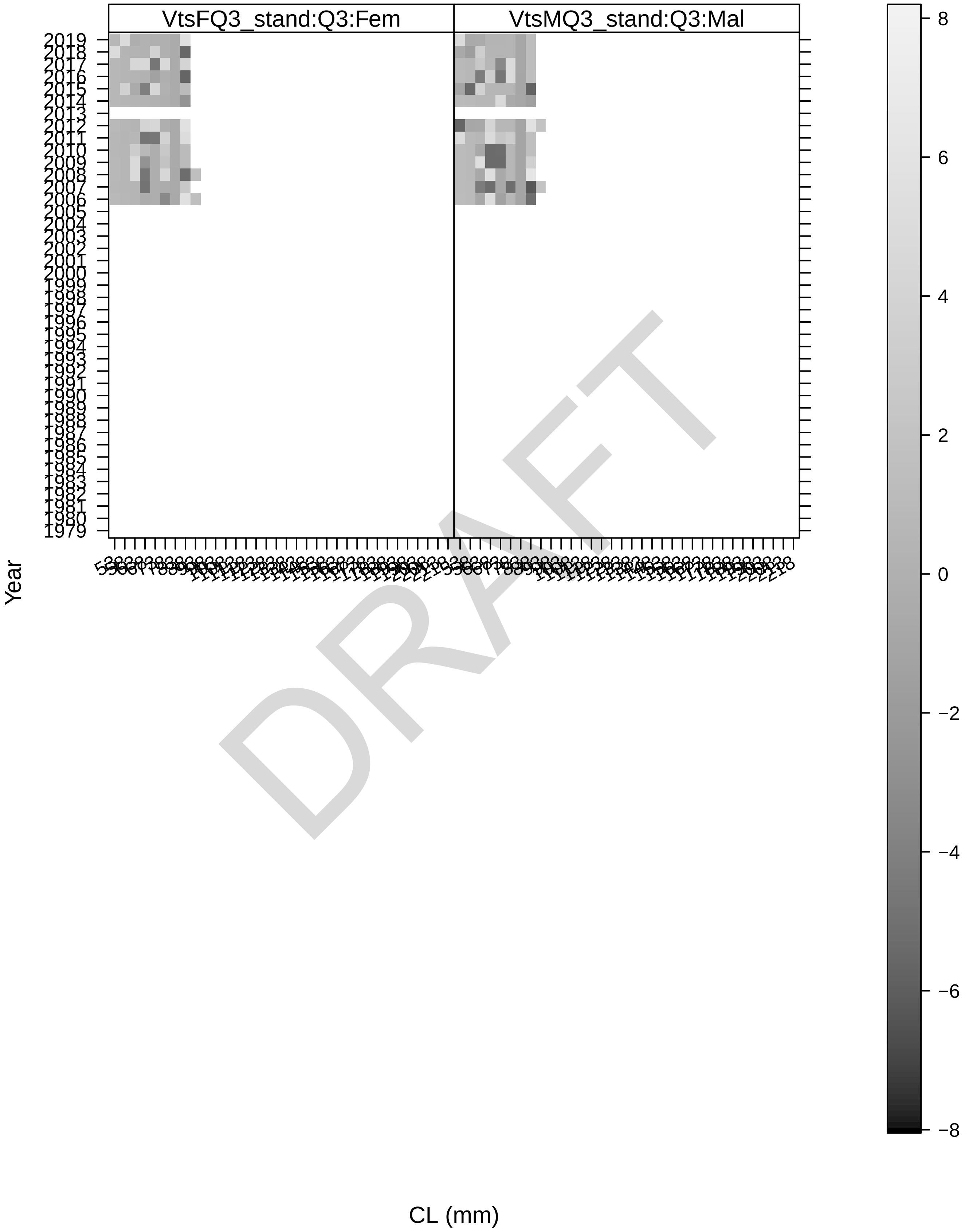


DRAFT


r60_ind_trawl_v6f6
Length composition deviance residuals
NefscFQ2:Q2:Fem
NefscFQ4:Q4:Fem
NefscMQ2:Q2:Mal
NefscMQ4:Q4:Mal
Year
CL (mm)
2019
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
1993
1992
1991
1990
1989
1988
1987
1986
1985
1984
1983
1982
1981
1980
1979
8
6
4
2
0
−2
−4
−6
−8

DRAFT

r60_ind_trawl_v6f6
Length composition deviance residuals



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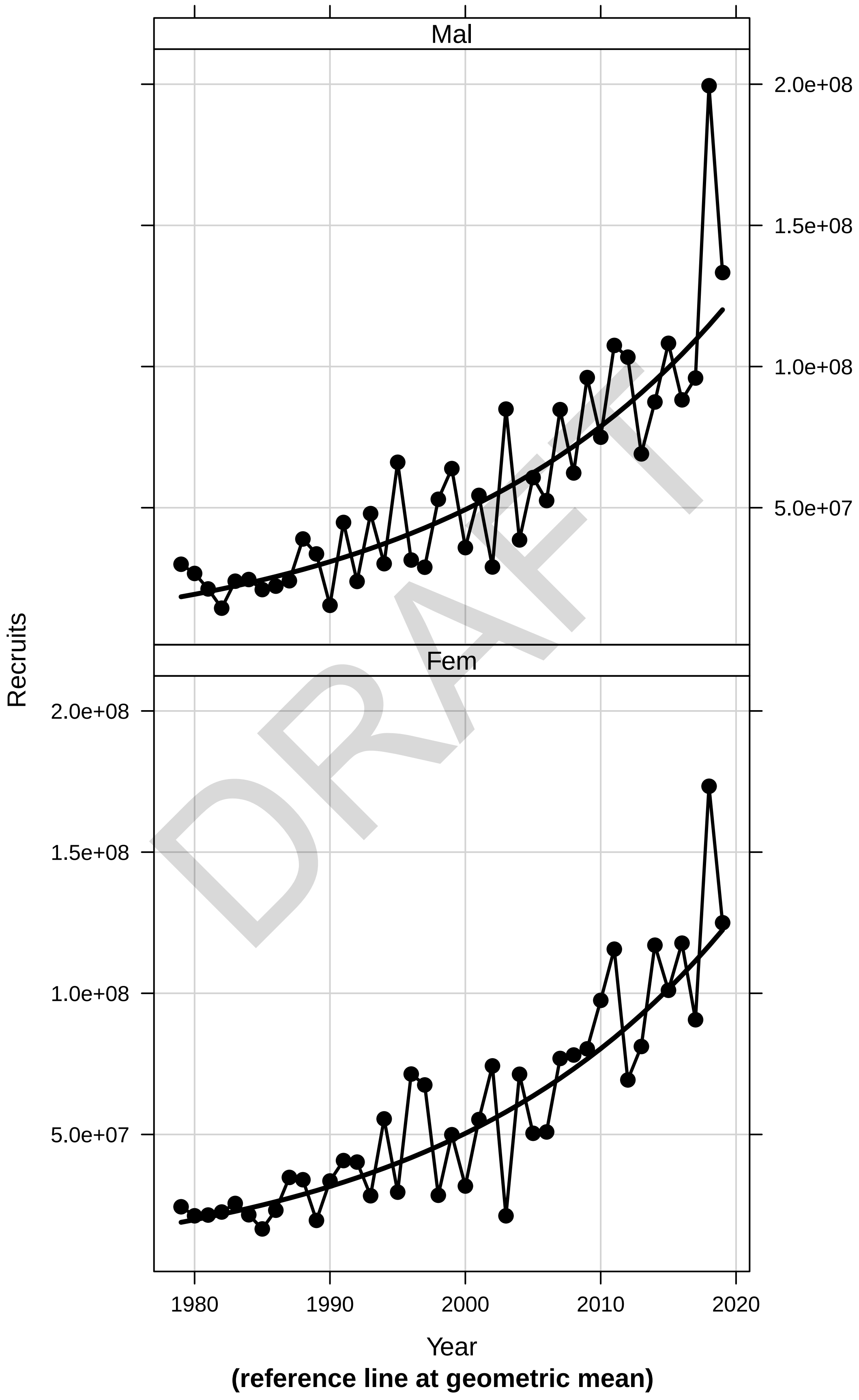
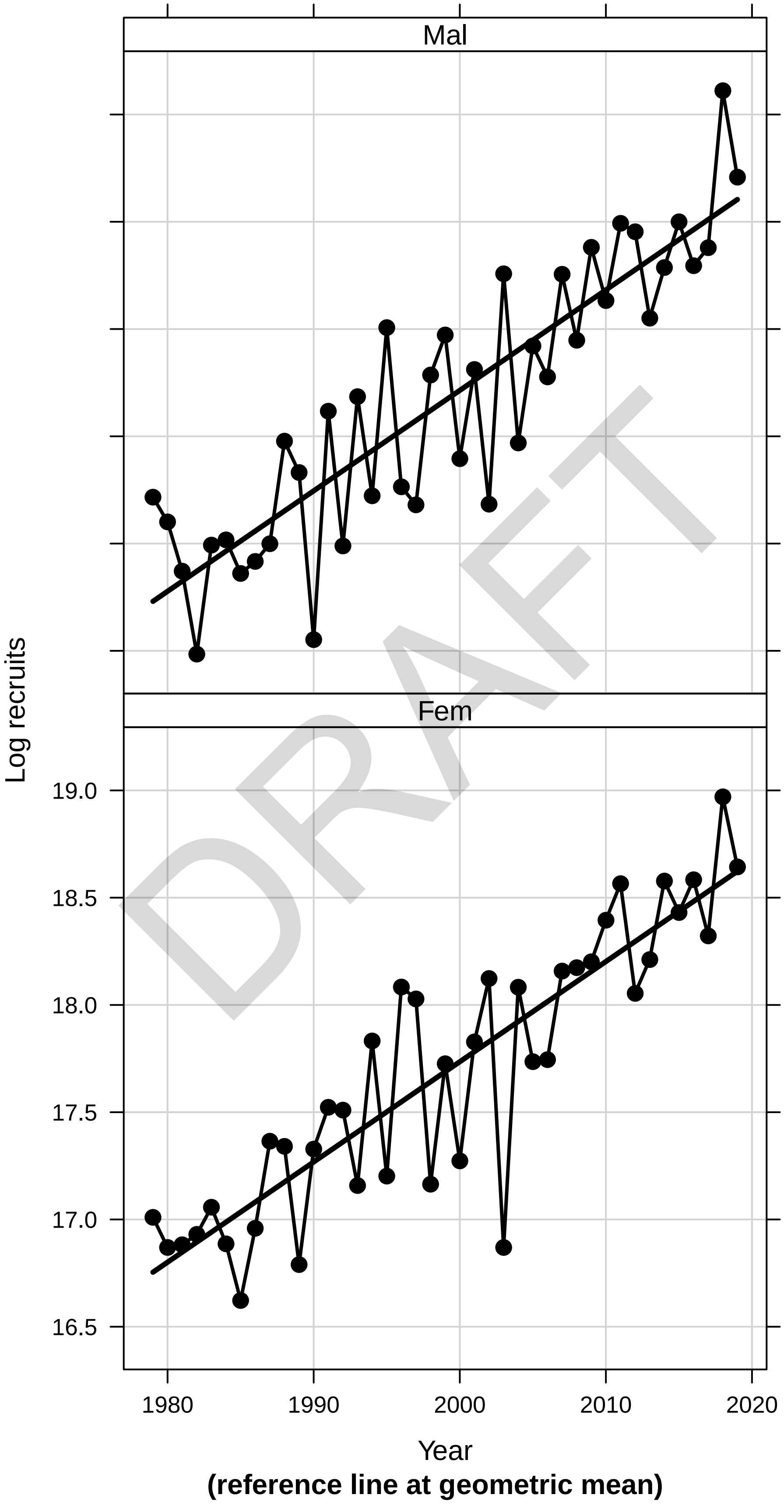
r60_ind_trawl_v6f6 recruitment



DRAFT

r60_ind_trawl_v6f6 recruitment



(reference line at geometric mean)

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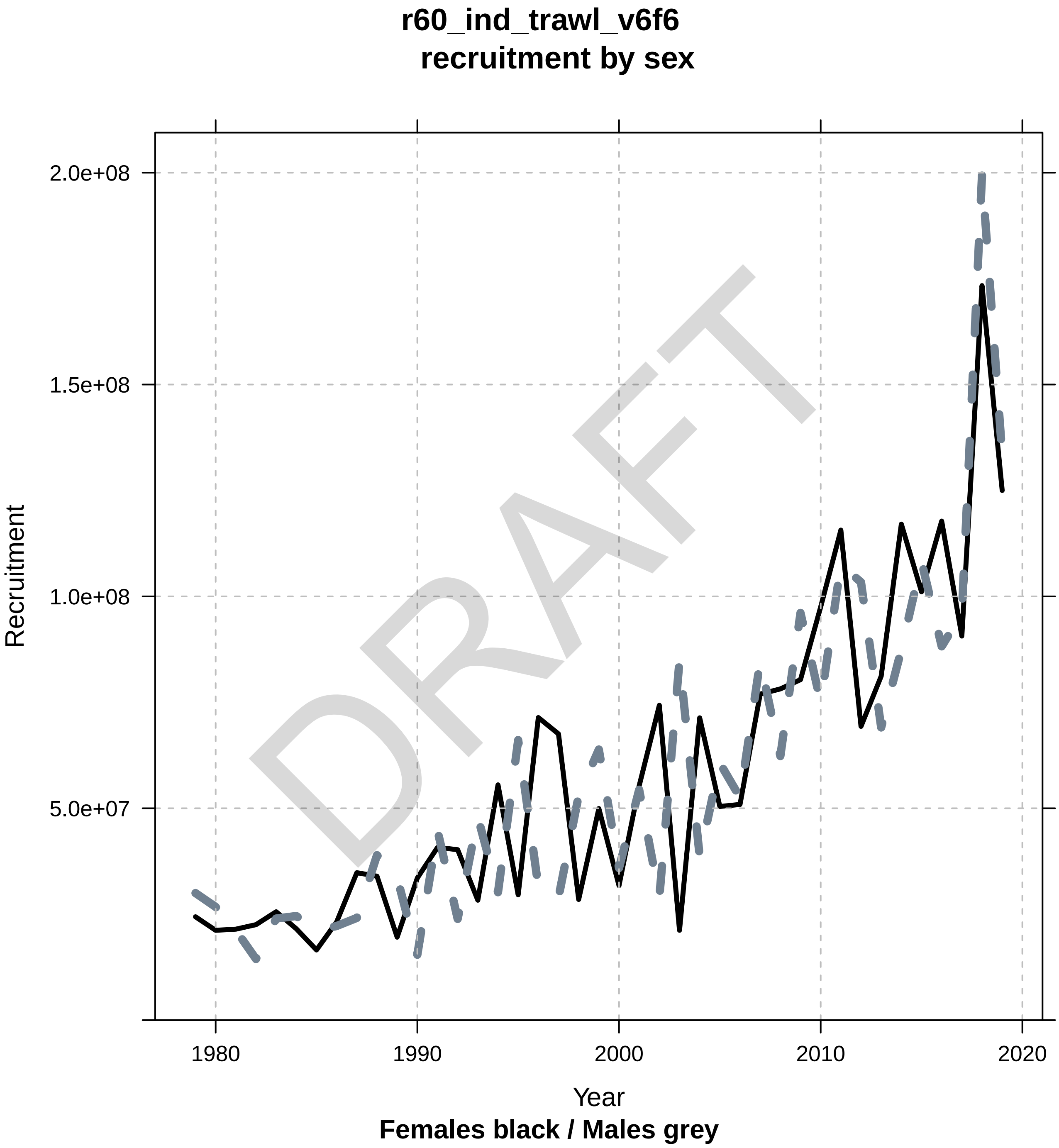
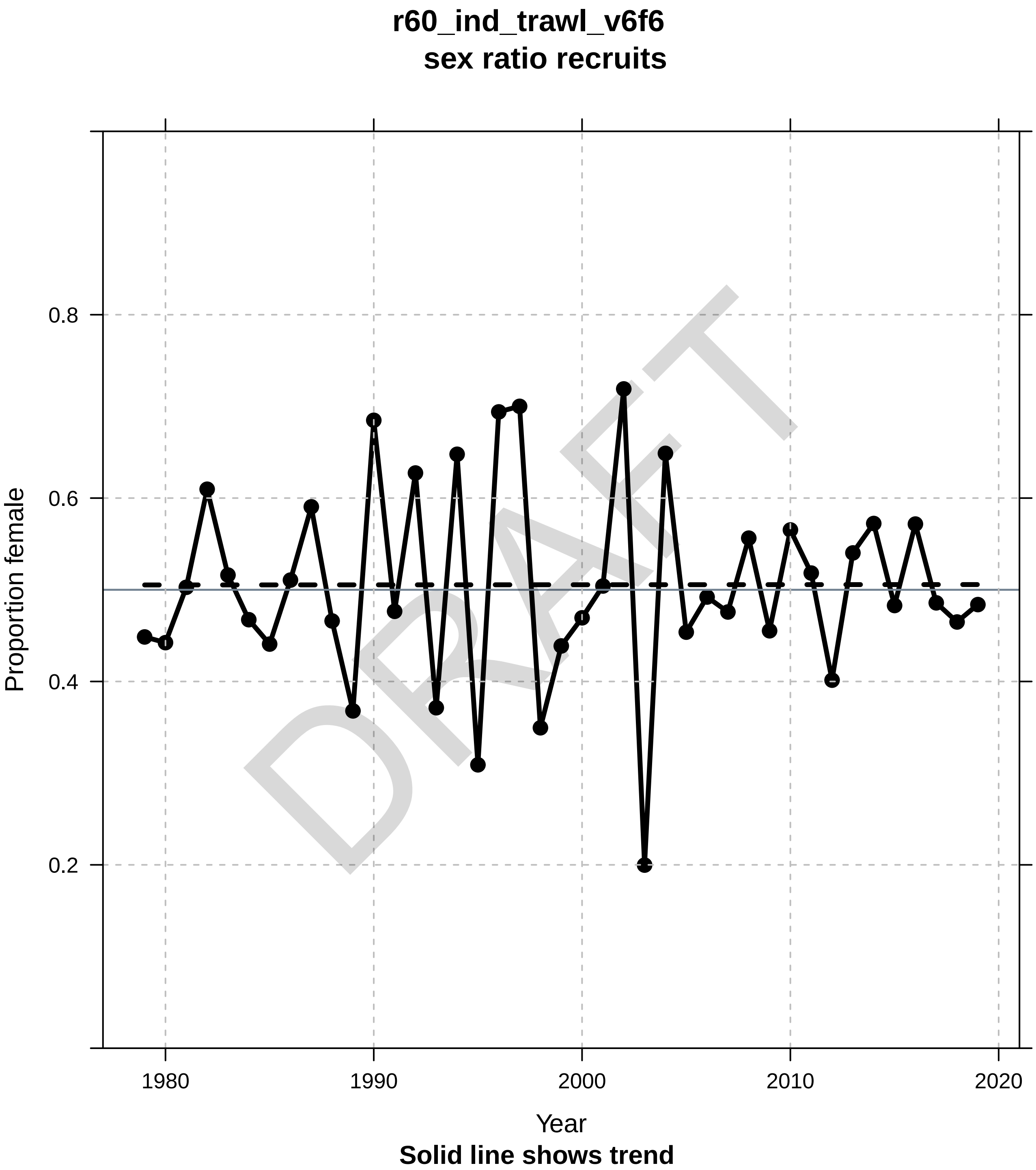


DRAFT


r60_ind_trawl_v6f6
sex ratio recruits
Proportion female
0.2
0.4
0.6
0.8
1980
1990
2000
2010
2020
Year
Solid line shows trend

DRAFT

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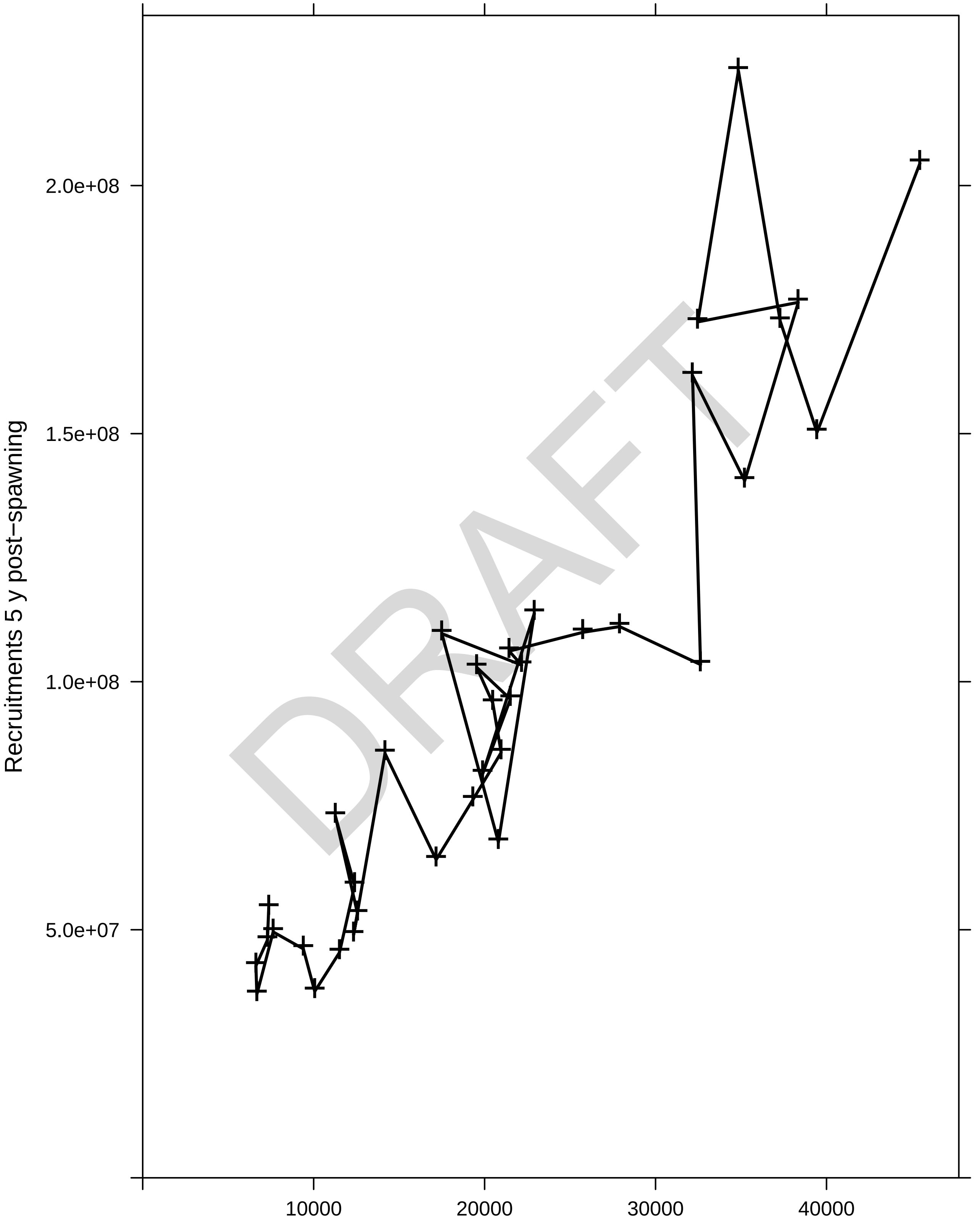
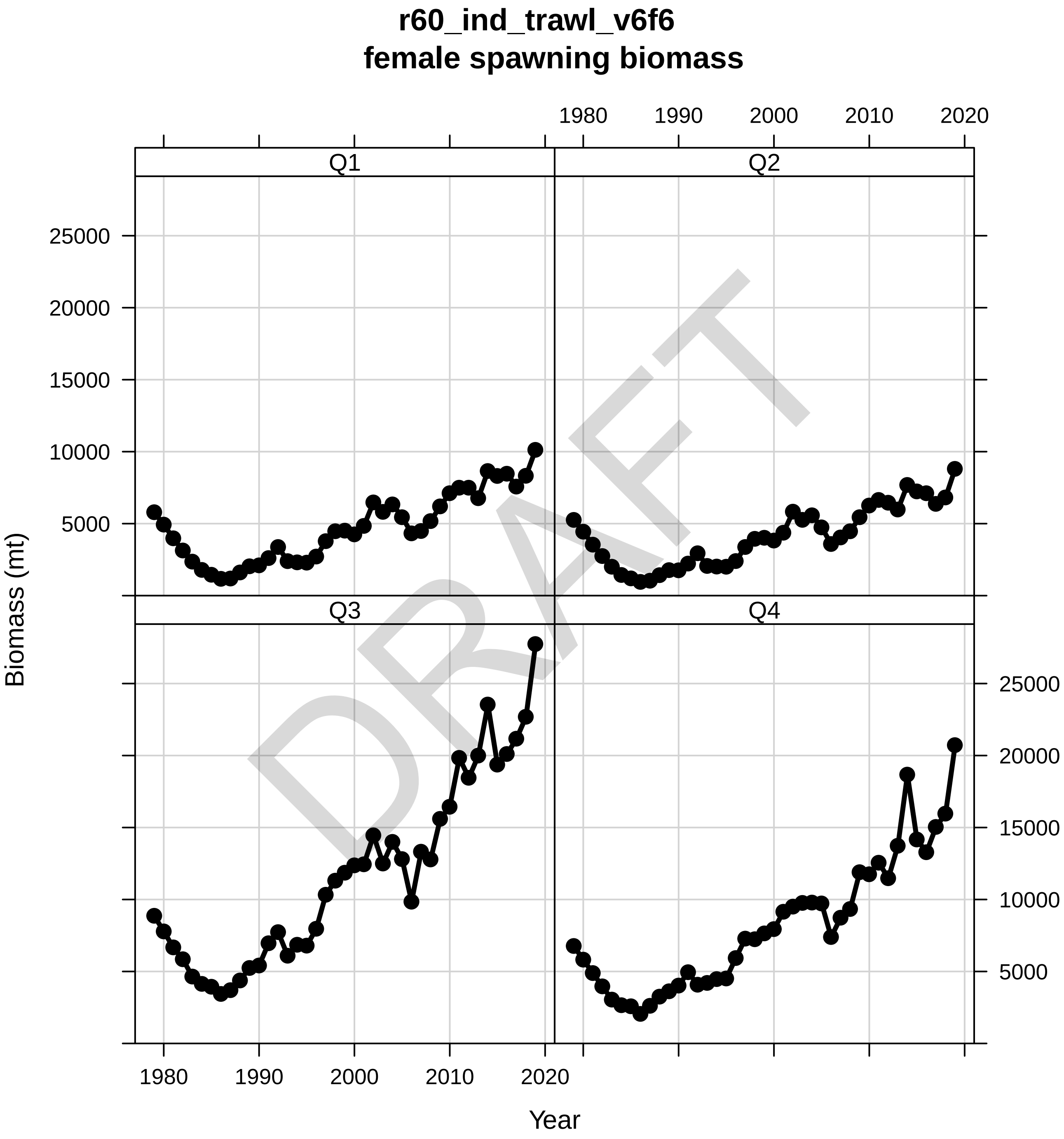
r60_ind_trawl_v6f6
spawning biomass−recruitment plot (recruits lag 5 y)



DRAFT


r60_ind_trawl_v6f6
female spawning biomass
Q1
Q2
Q3
Q4
Biomass (mt)
Year
5000
10000
15000
20000
25000
1980
1990
2000
2010
2020

DRAFT

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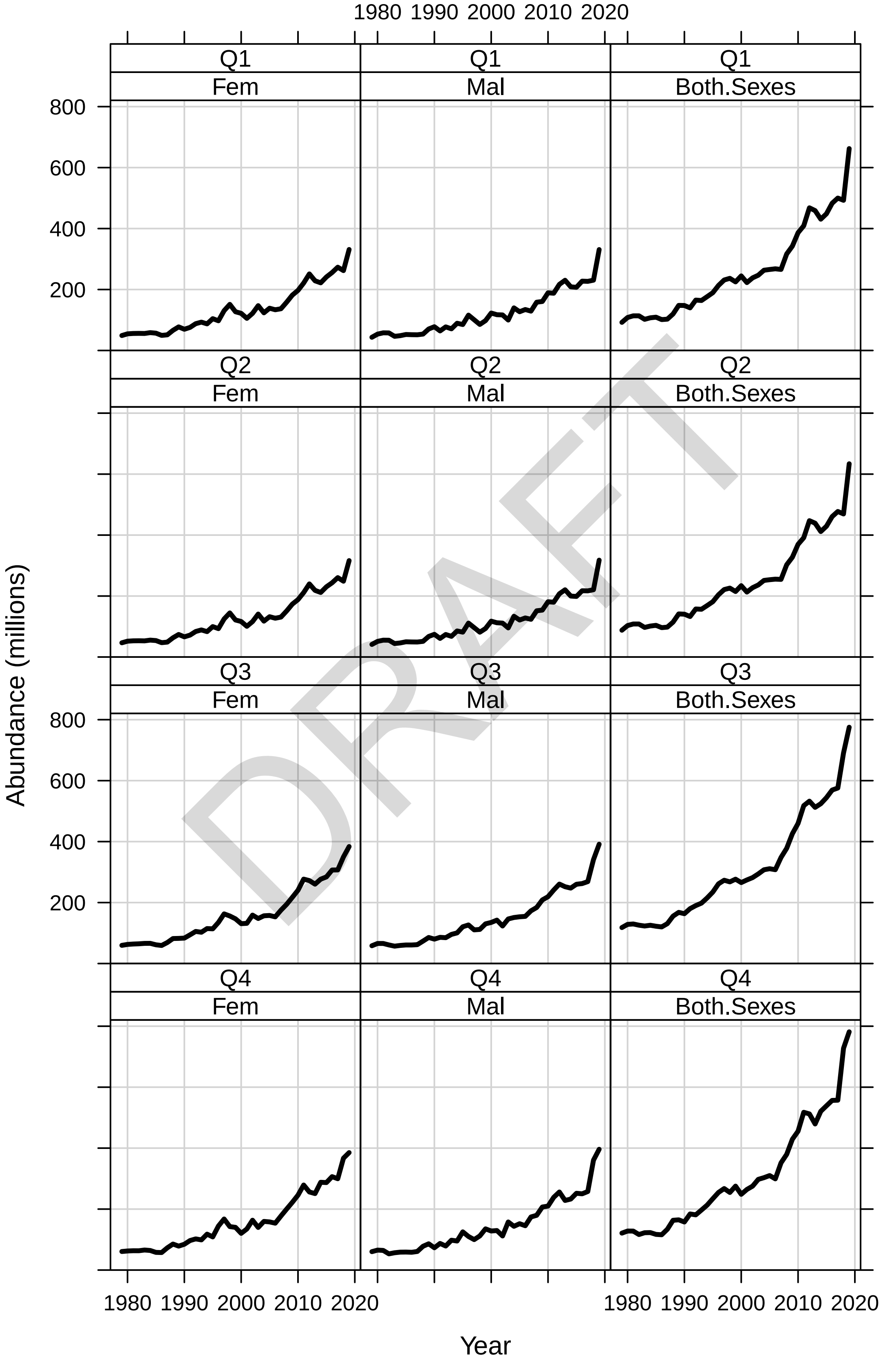
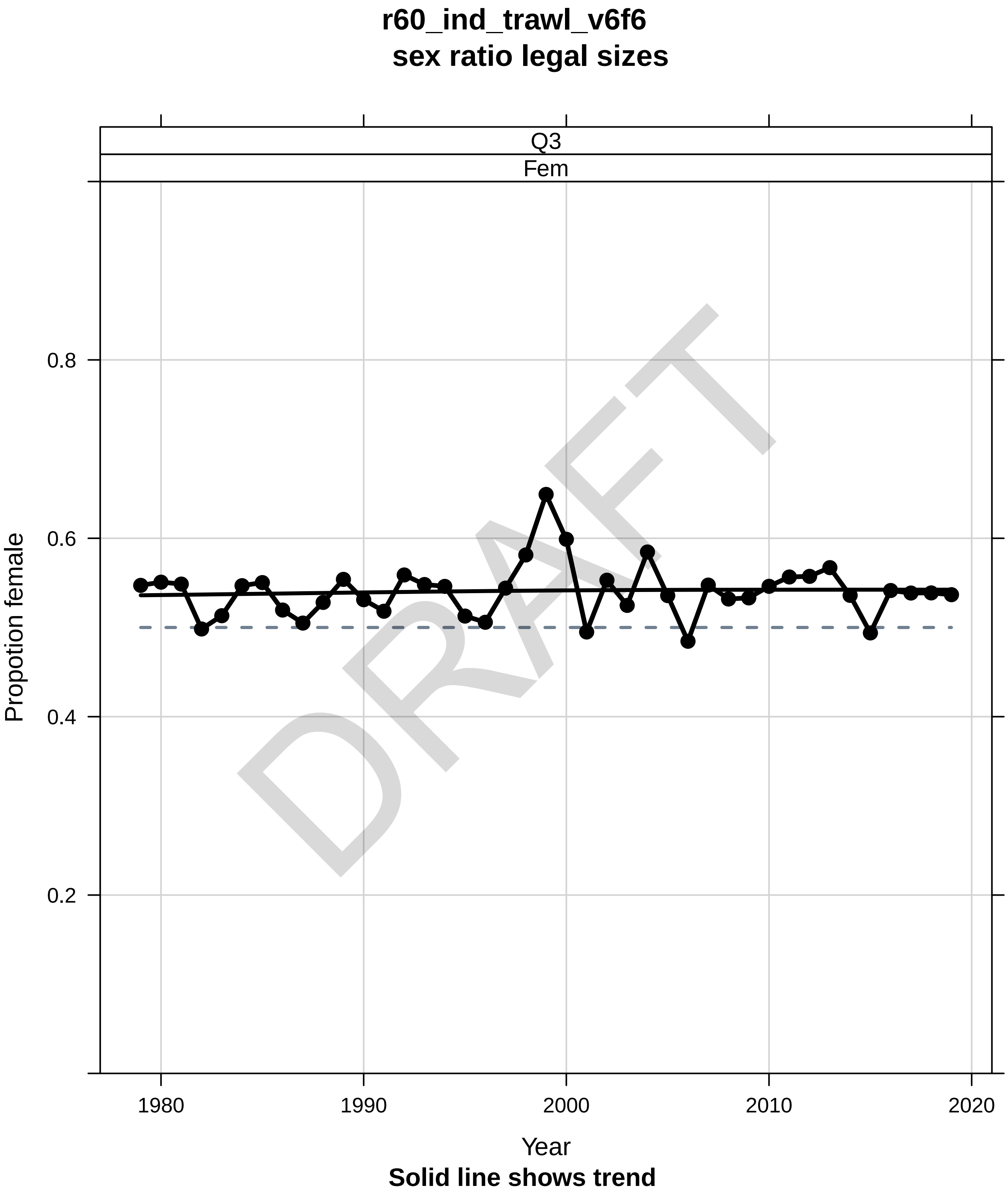
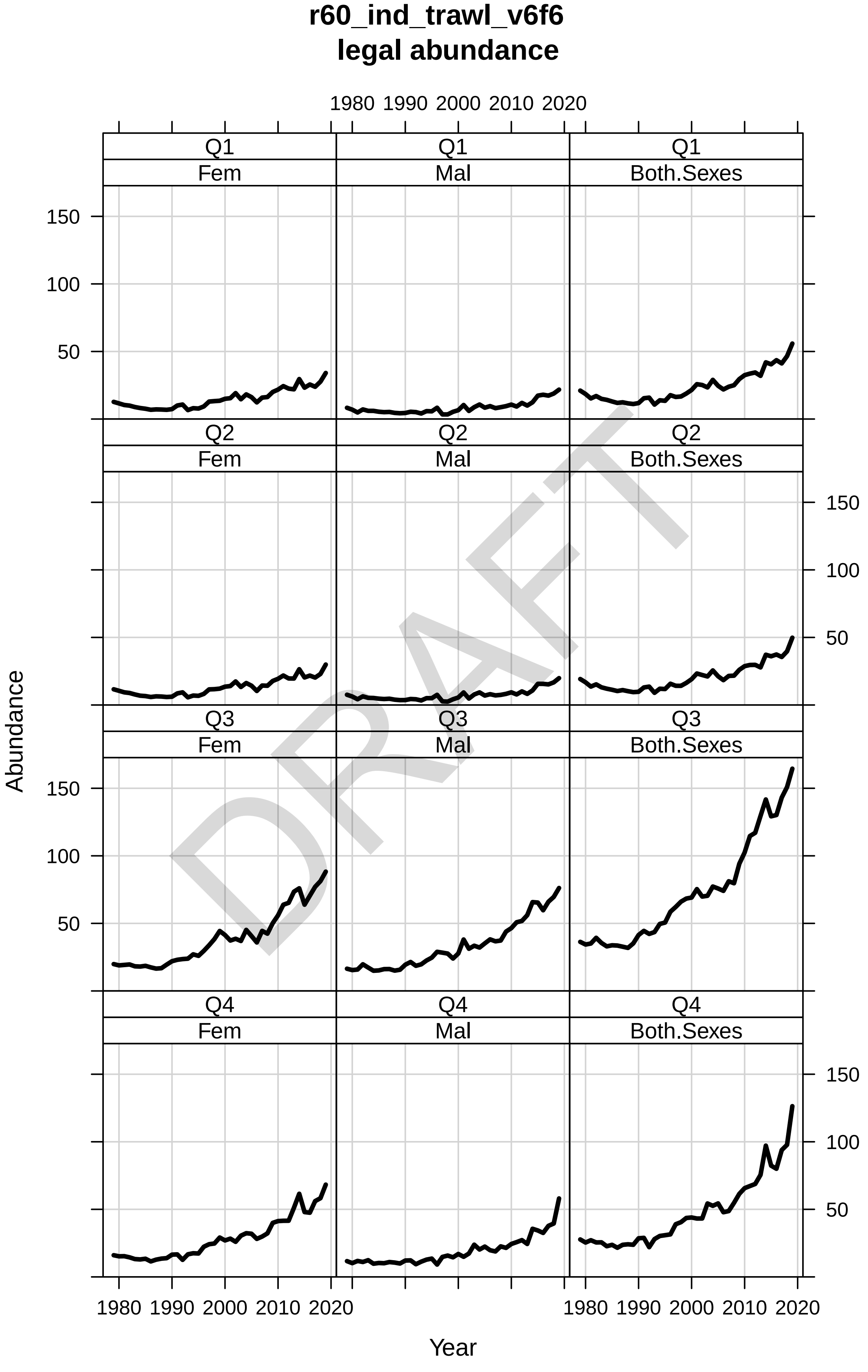
r60_ind_trawl_v6f6
estimated total abundance



DRAFT

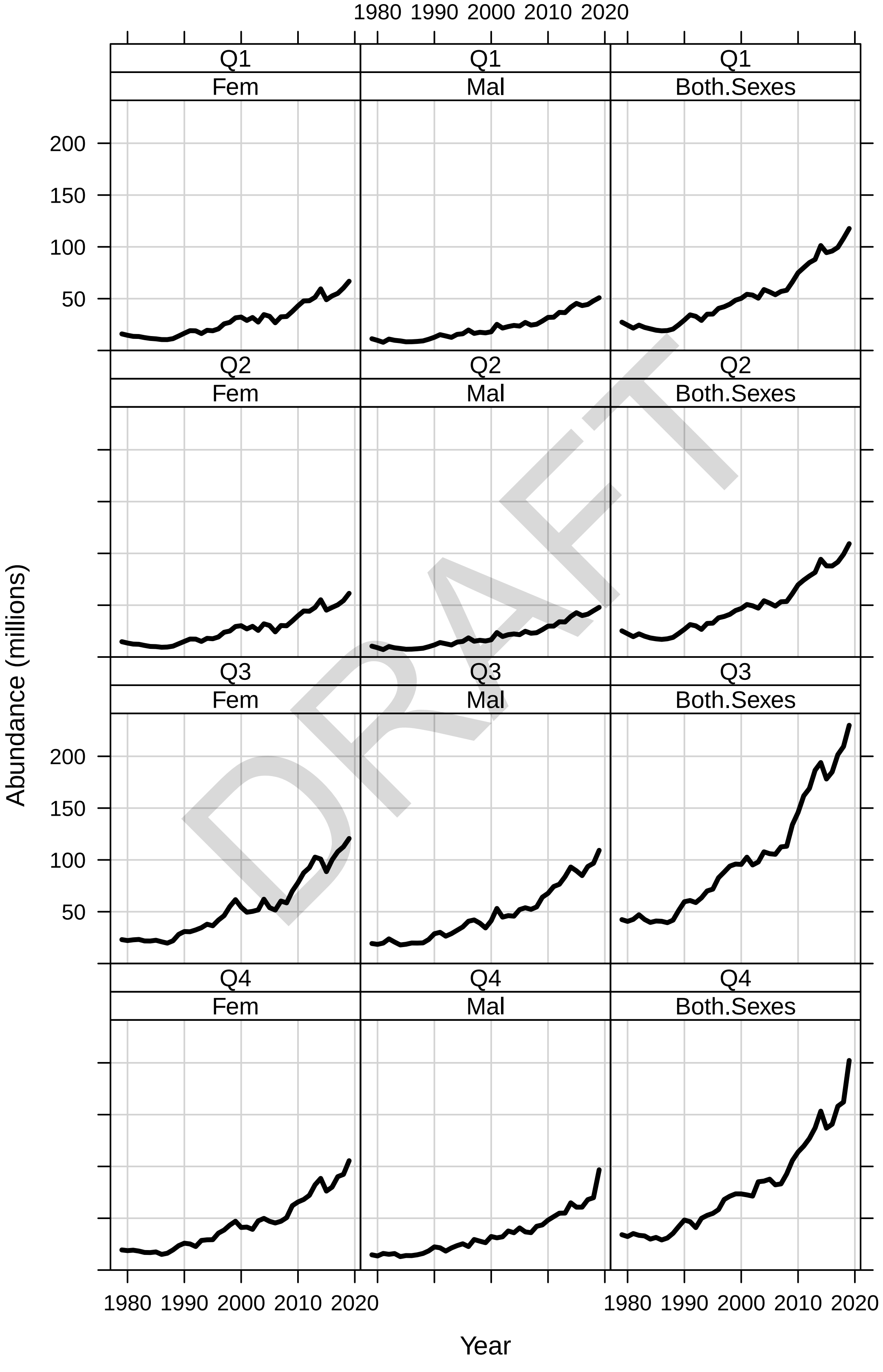

r60_ind_trawl_v6f6
sex ratio legal sizes
Q3
Fem
0.8
0.6
0.4
0.2
Propotion female
1980
1990
2000
2010
2020
Year
Solid line shows trend

DRAFT


r60_ind_trawl_v6f6
legal abundance
Q1
Fem
Mal
Both.Sexes
Q2
Q3
Q4
Abundance
Year
50
100
150
1980
1990
2000
2010
2020

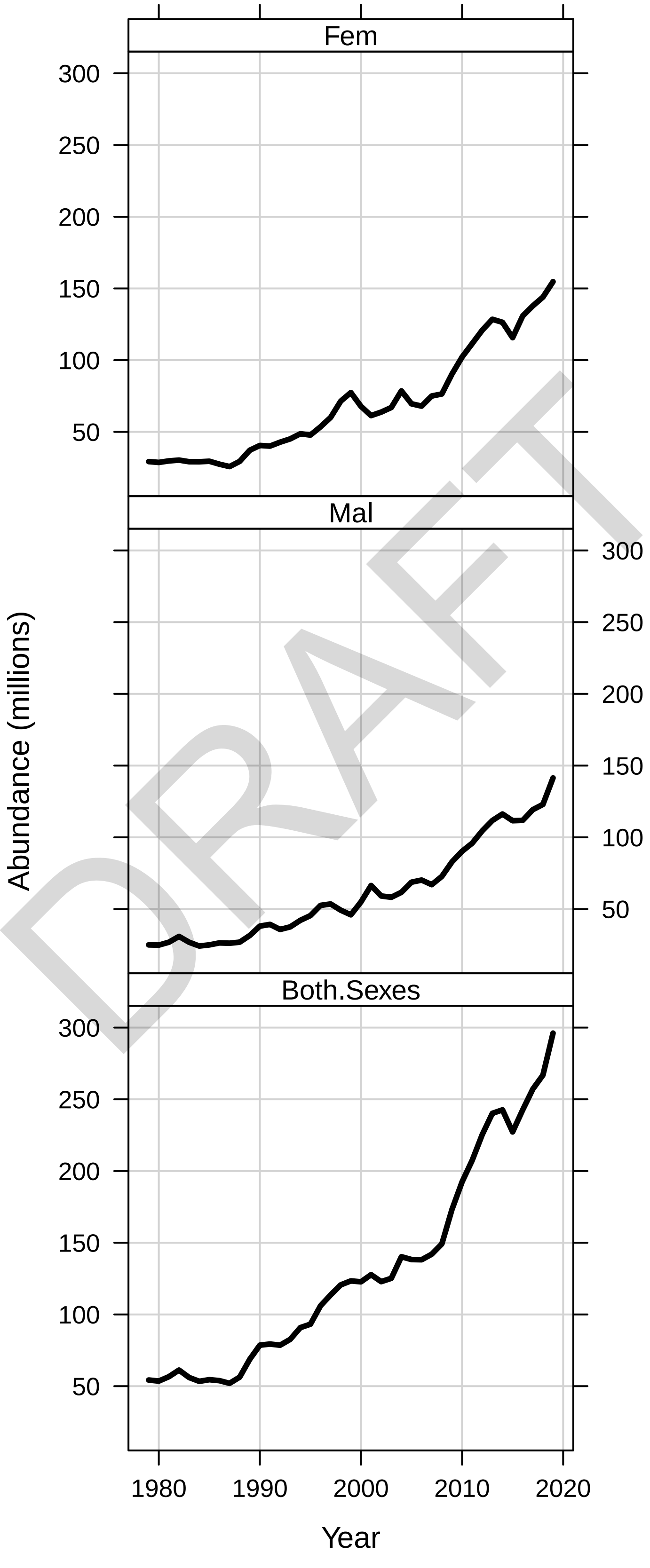
DRAFT

r60_ind_trawl_v6f6
abundance 78 + mm CL



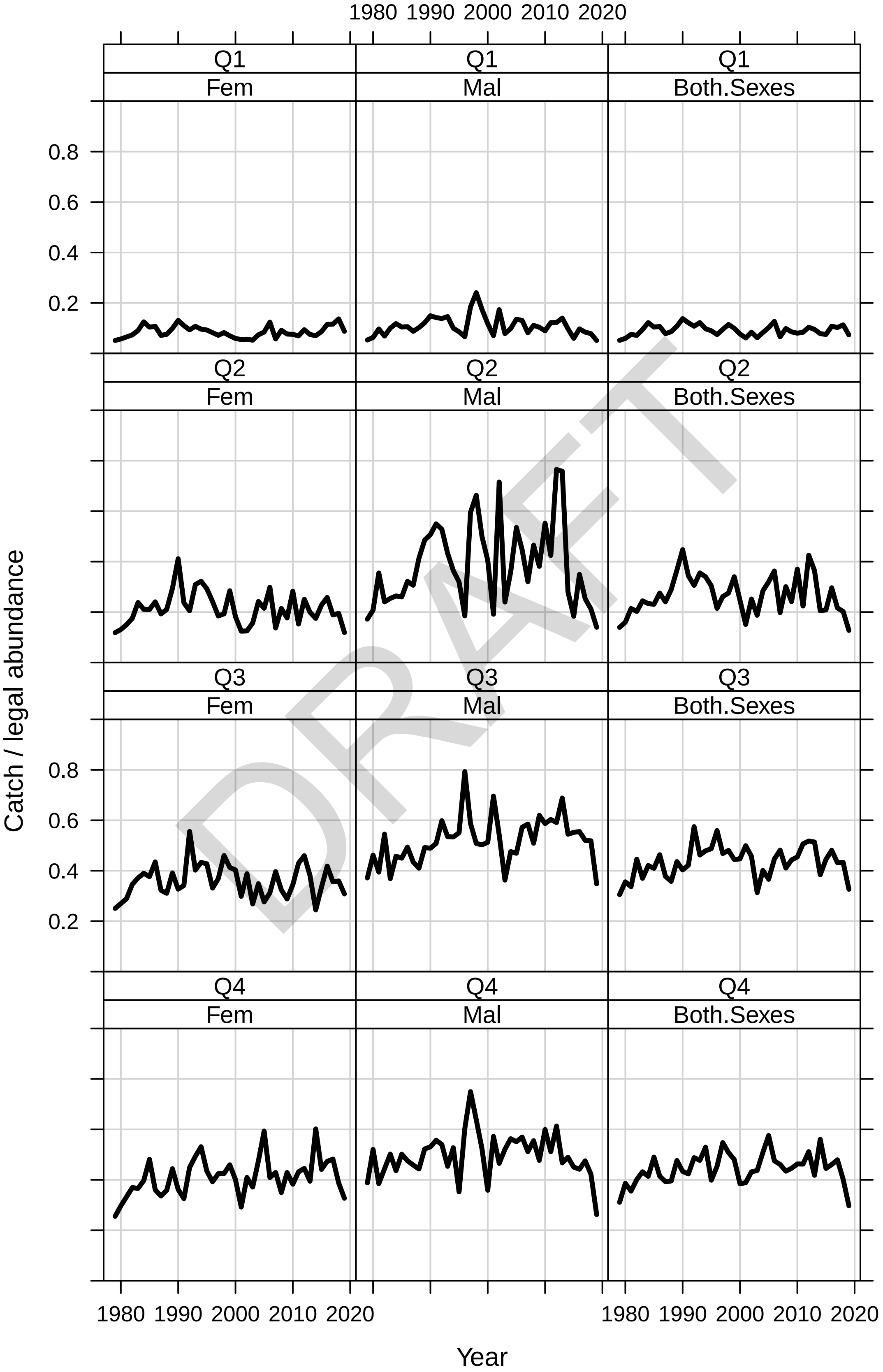
DRAFT

r60_ind_trawl_v6f6
abundance reference population on Jan. 1



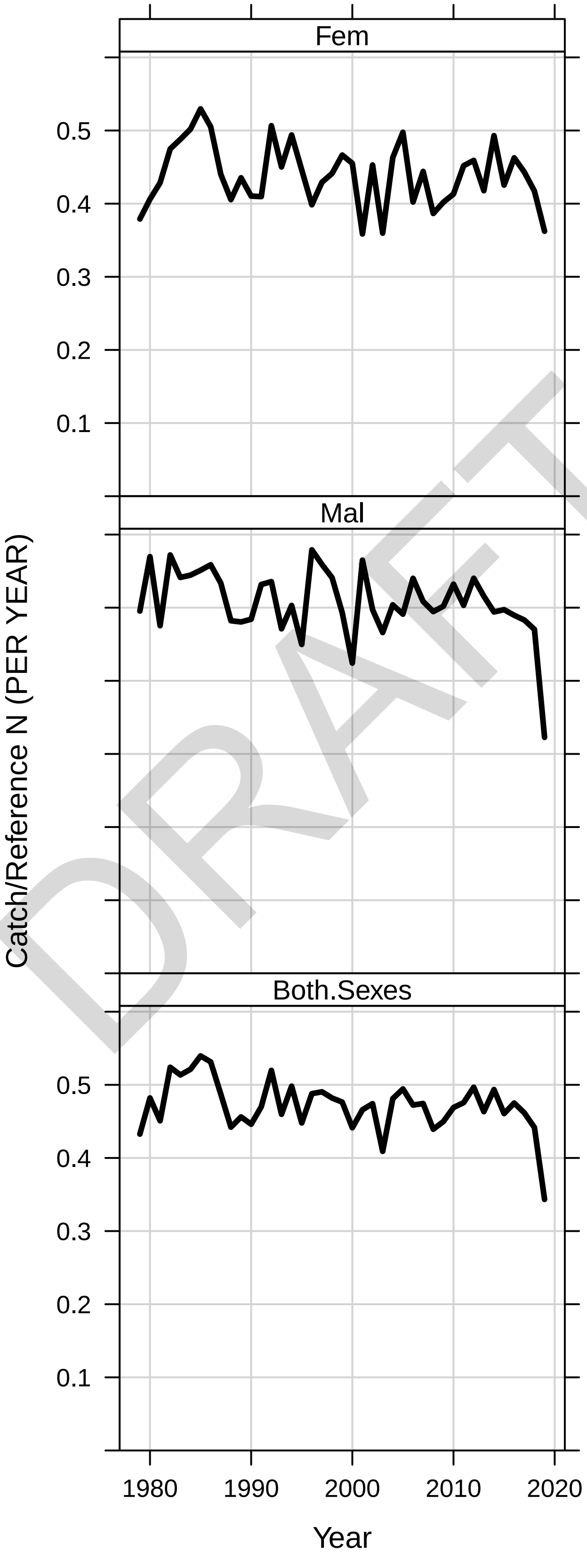
DRAFT

r60_ind_trawl_v6f6
quarterly exploitation rate (catch/legal abundance)

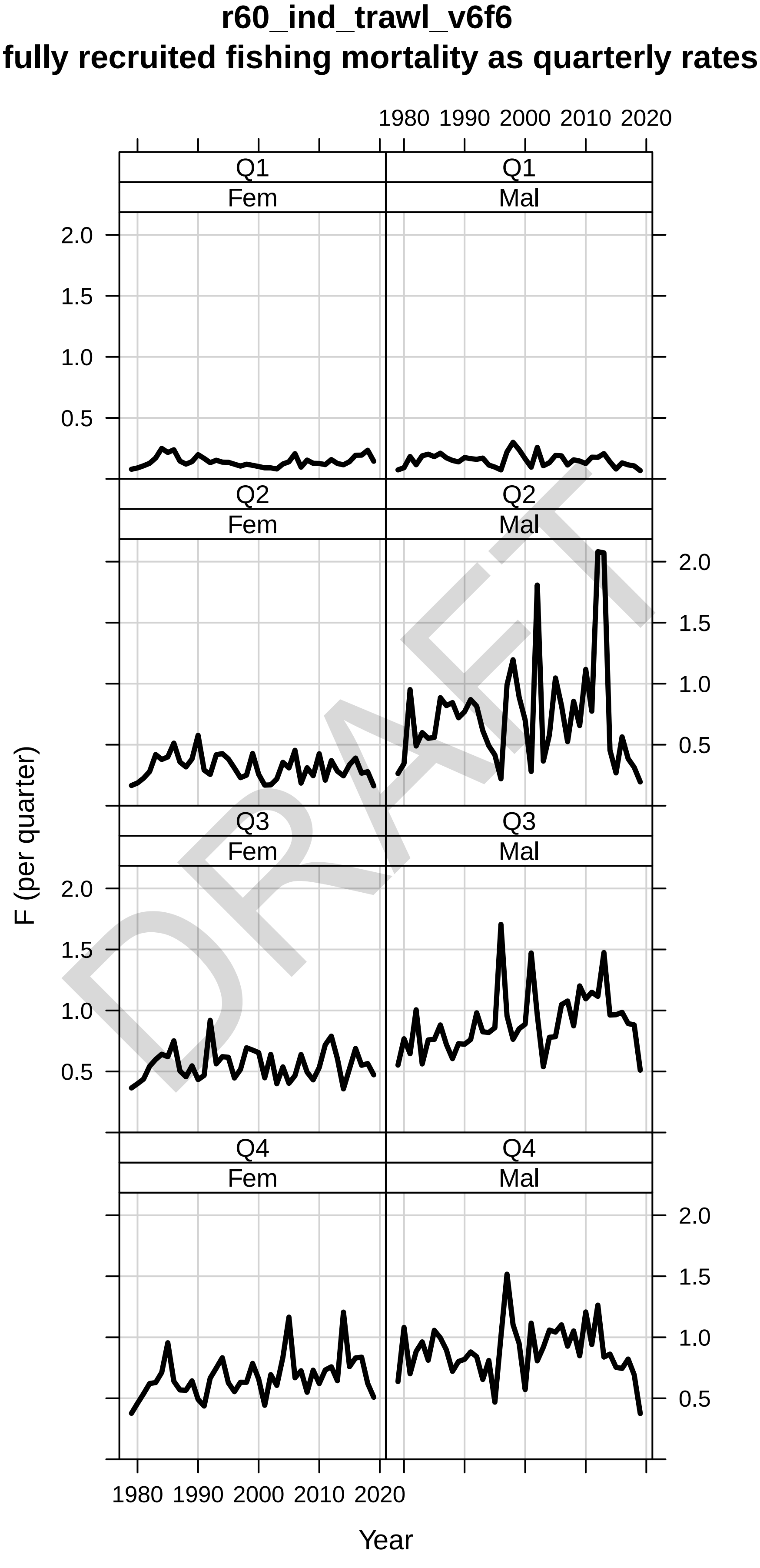


DRAFT

r60_ind_trawl_v6f6
annual effective exploitation rate

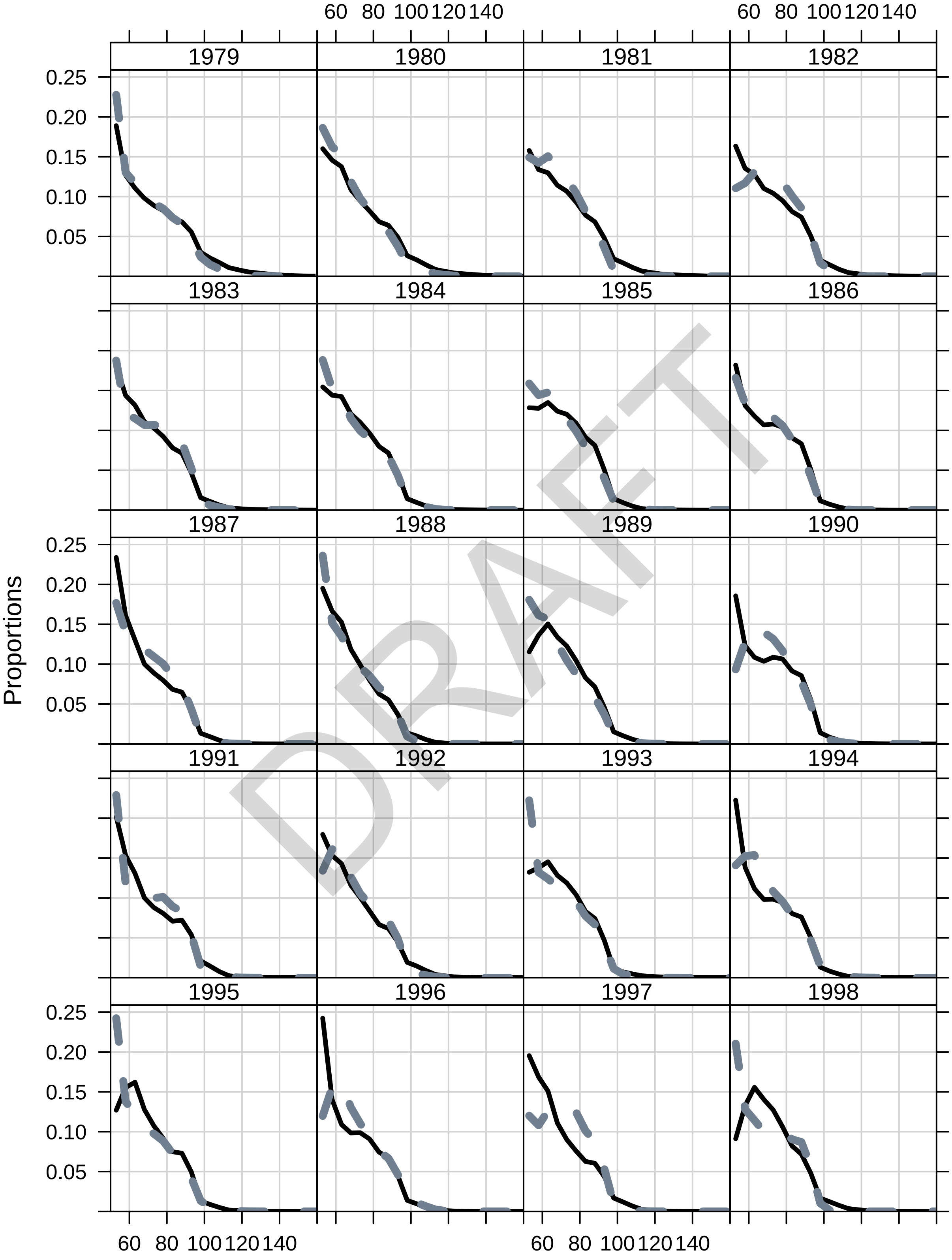


DRAFT


r60_ind_trawl_v6f6
fully recruited fishing mortality as quarterly rates
Q1
Fem
Q1
Mal
Q2
Fem
Q2
Mal
Q3
Fem
Q3
Mal
Q4
Fem
Q4
Mal
F (per quarter)
Year
0.5
1.0
1.5
2.0
1980
1990
2000
2010
2020

DRAFT

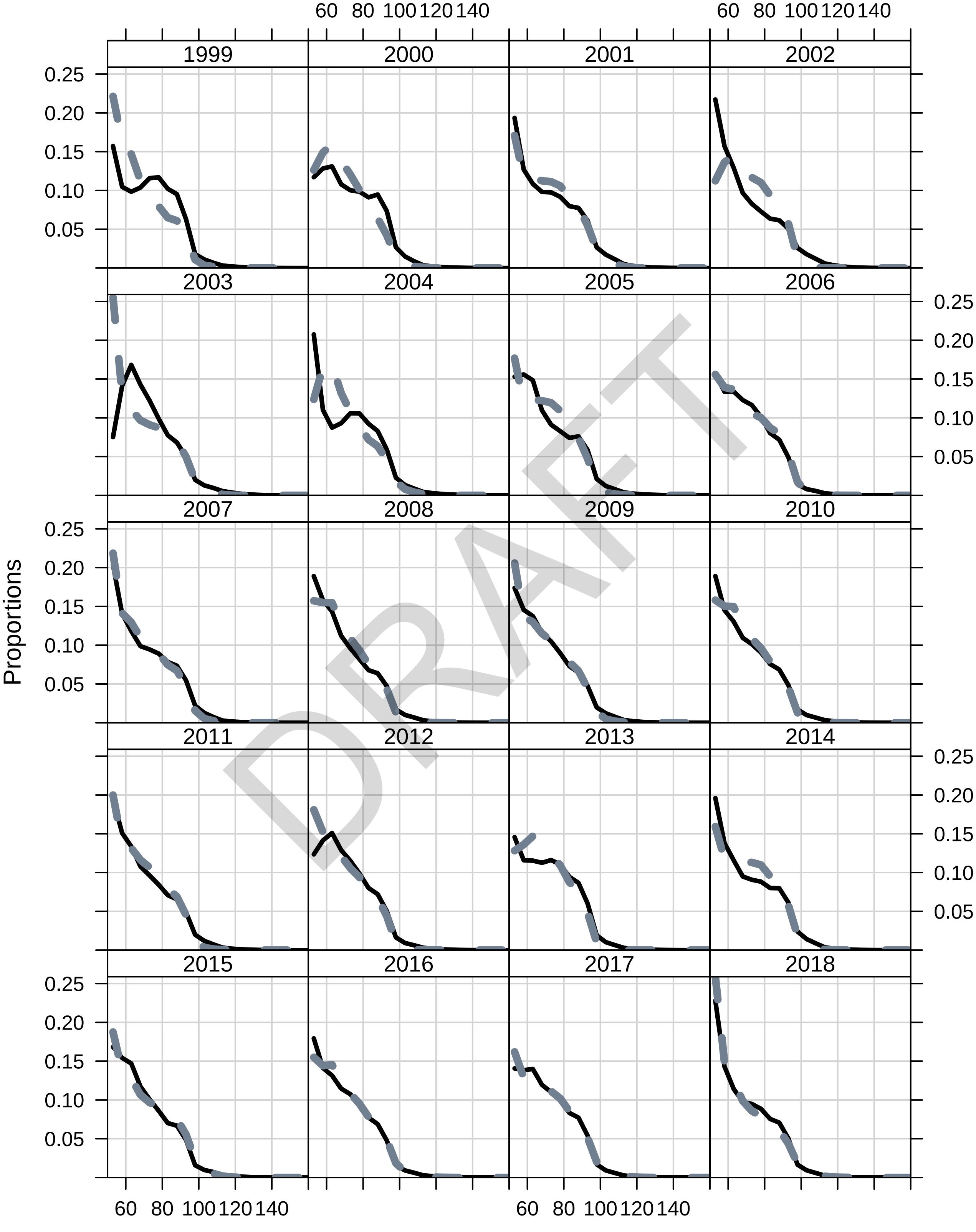
r60_ind_trawl_v6f6
summer population size composition



Females black / Males grey

DRAFT

r60_ind_trawl_v6f6
summer population size composition

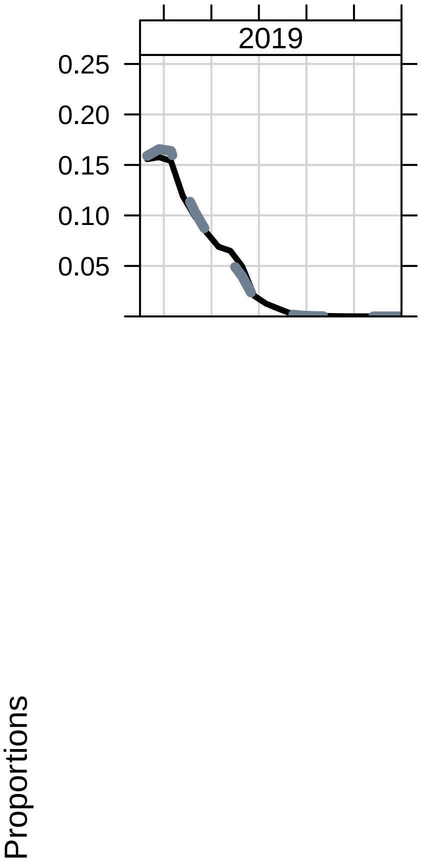


CL (mm)

Females black / Males grey

DRAFT

r60_ind_trawl_v6f6
summer population size composition

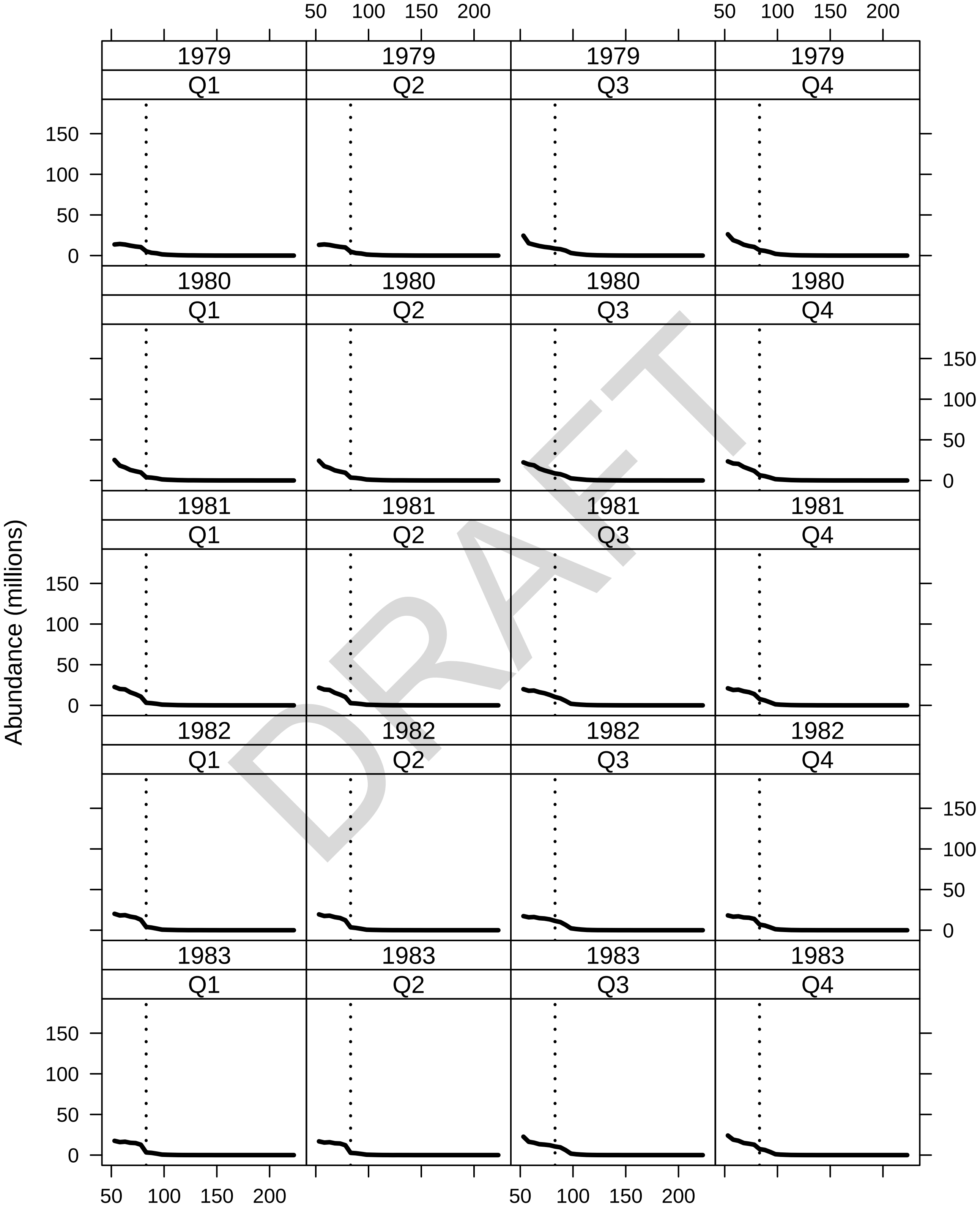


DRAFT

CL (mm)

Females black / Males grey

r60_ind_trawl_v6f6
combined sex abundance at length



DRAFT

Vertical line at 83 mm

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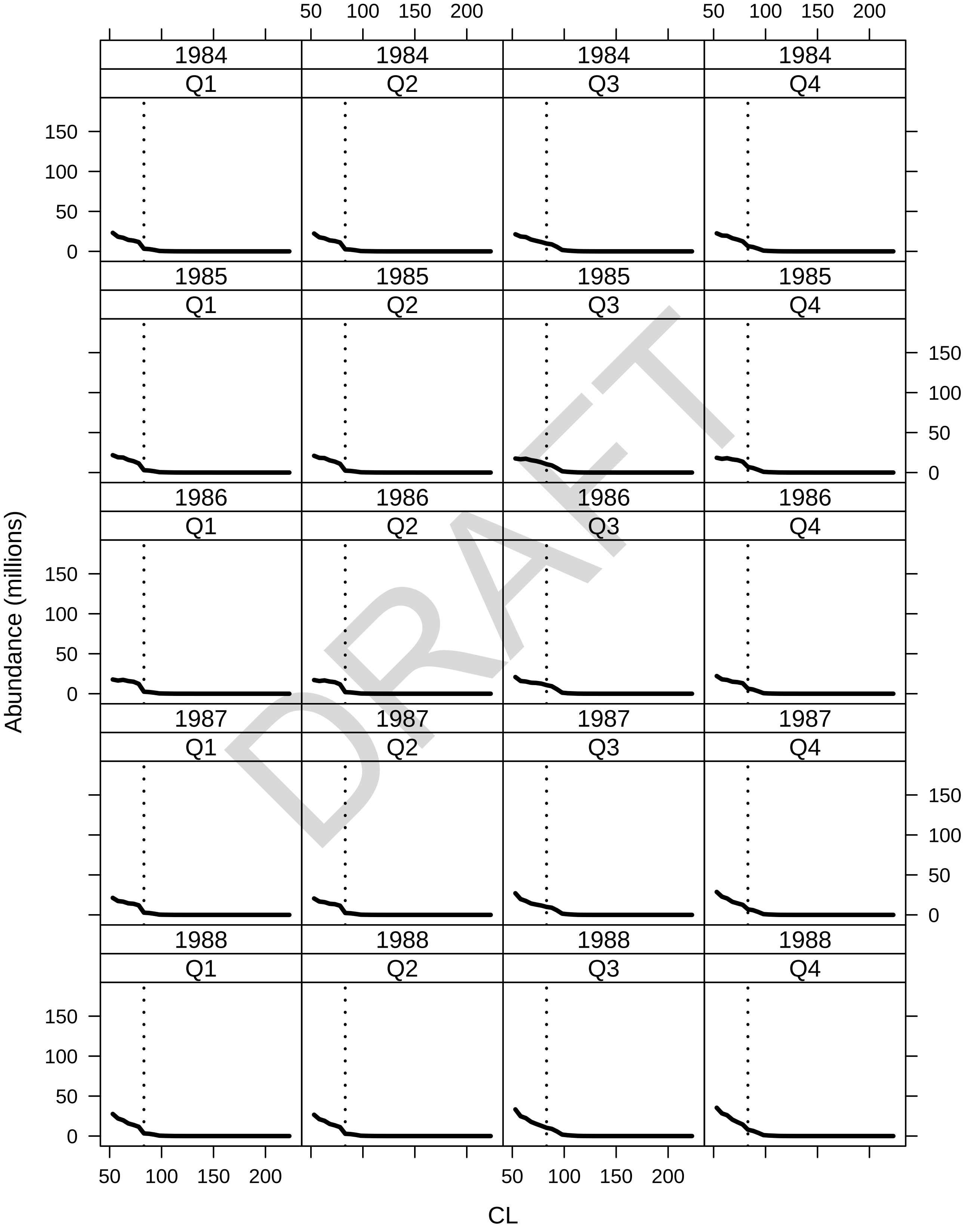
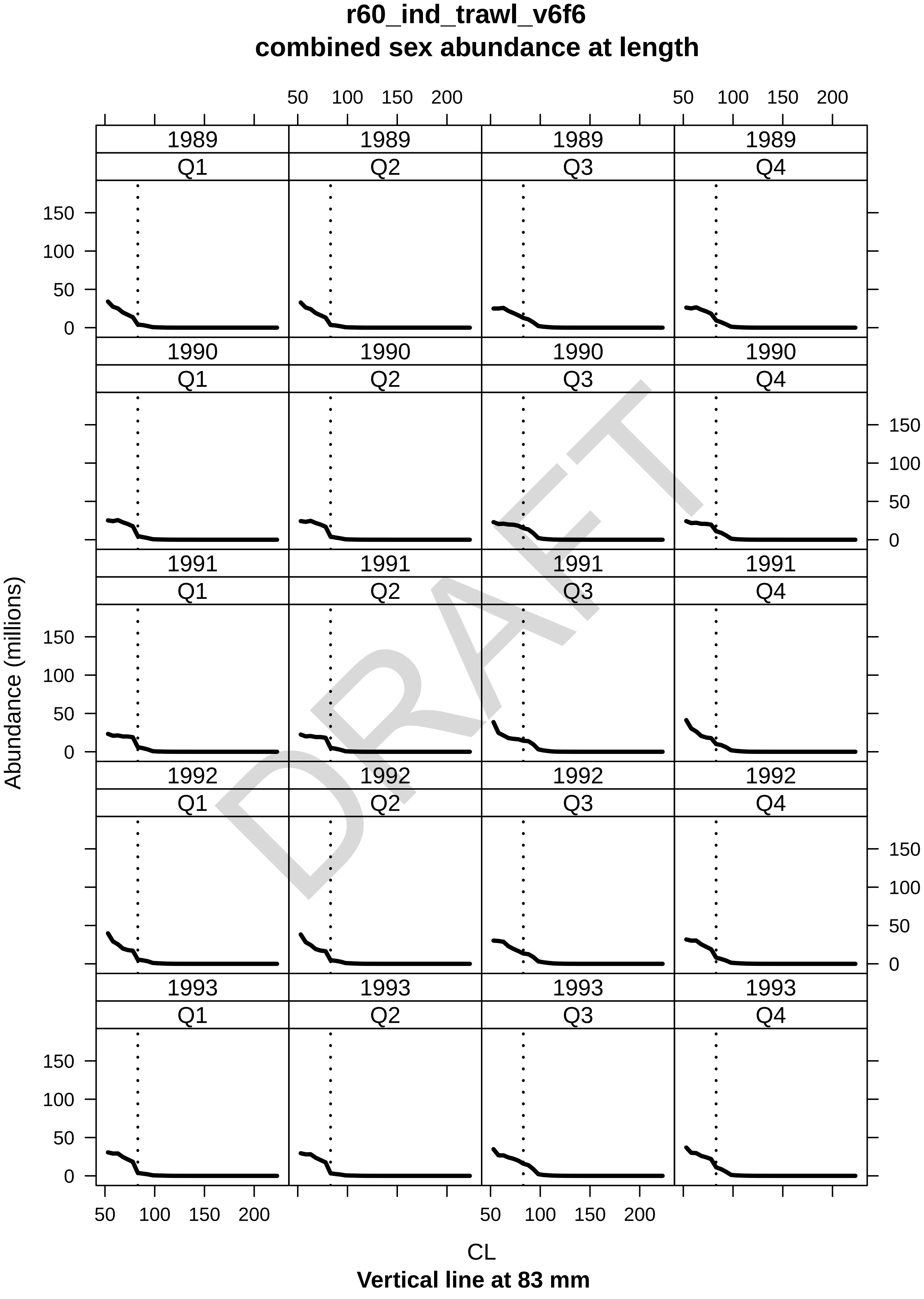
r60_ind_trawl_v6f6
combined sex abundance at length

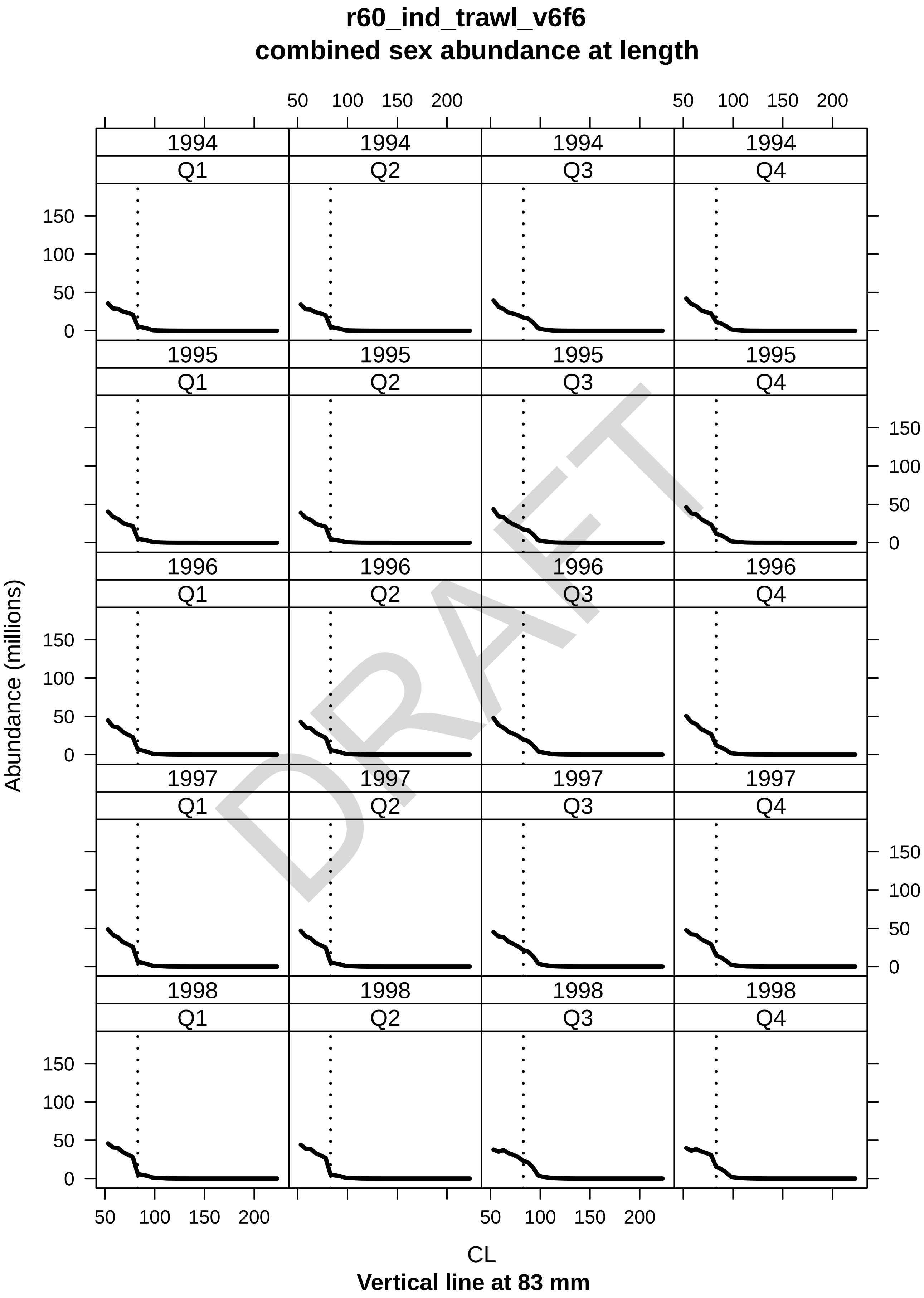


DRAFT

Vertical line at 83 mm

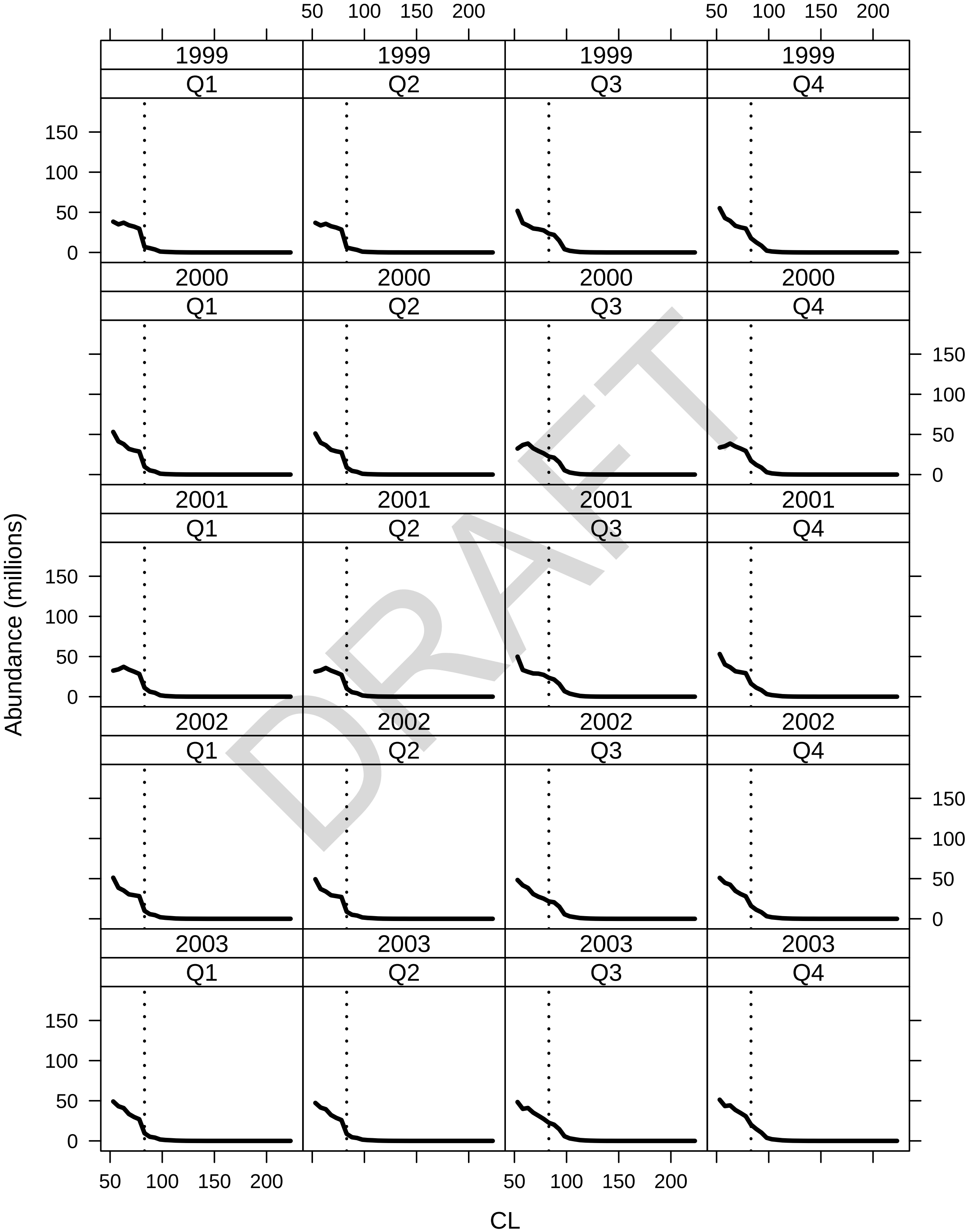

r60_ind_trawl_v6f6
combined sex abundance at length
1989
1990
1991
1992
1993
Q1
Q2
Q3
Q4
Abundance (millions)
0
50
100
150
50
100
150
200
CL
Vertical line at 83 mm

DRAFT


r60_ind_trawl_v6f6
combined sex abundance at length
1994
1995
1996
1997
1998
Q1
Q2
Q3
Q4
Abundance (millions)
0
50
100
150
50
100
150
200
CL
Vertical line at 83 mm

DRAFT

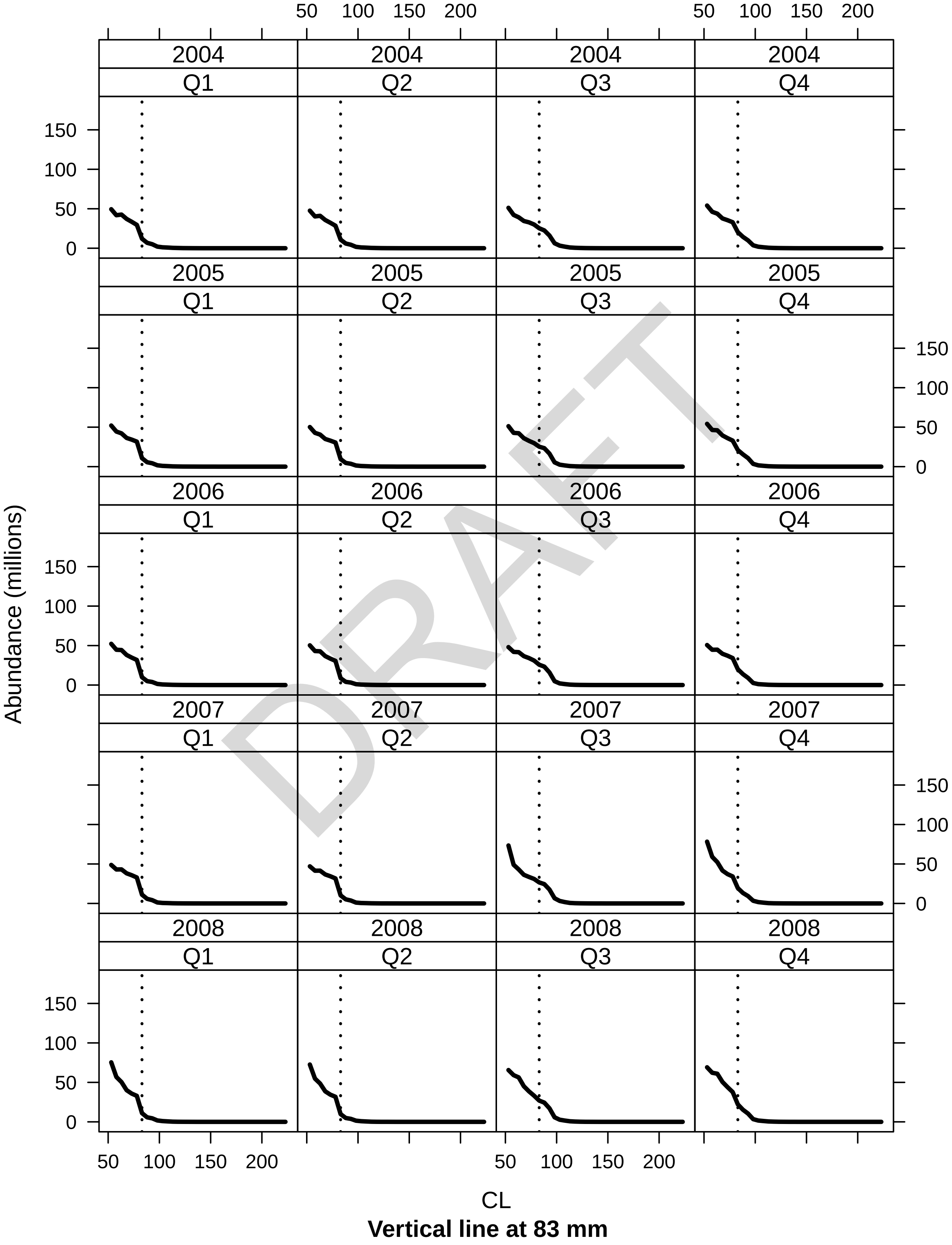
r60_ind_trawl_v6f6
combined sex abundance at length



DRAFT

Vertical line at 83 mm

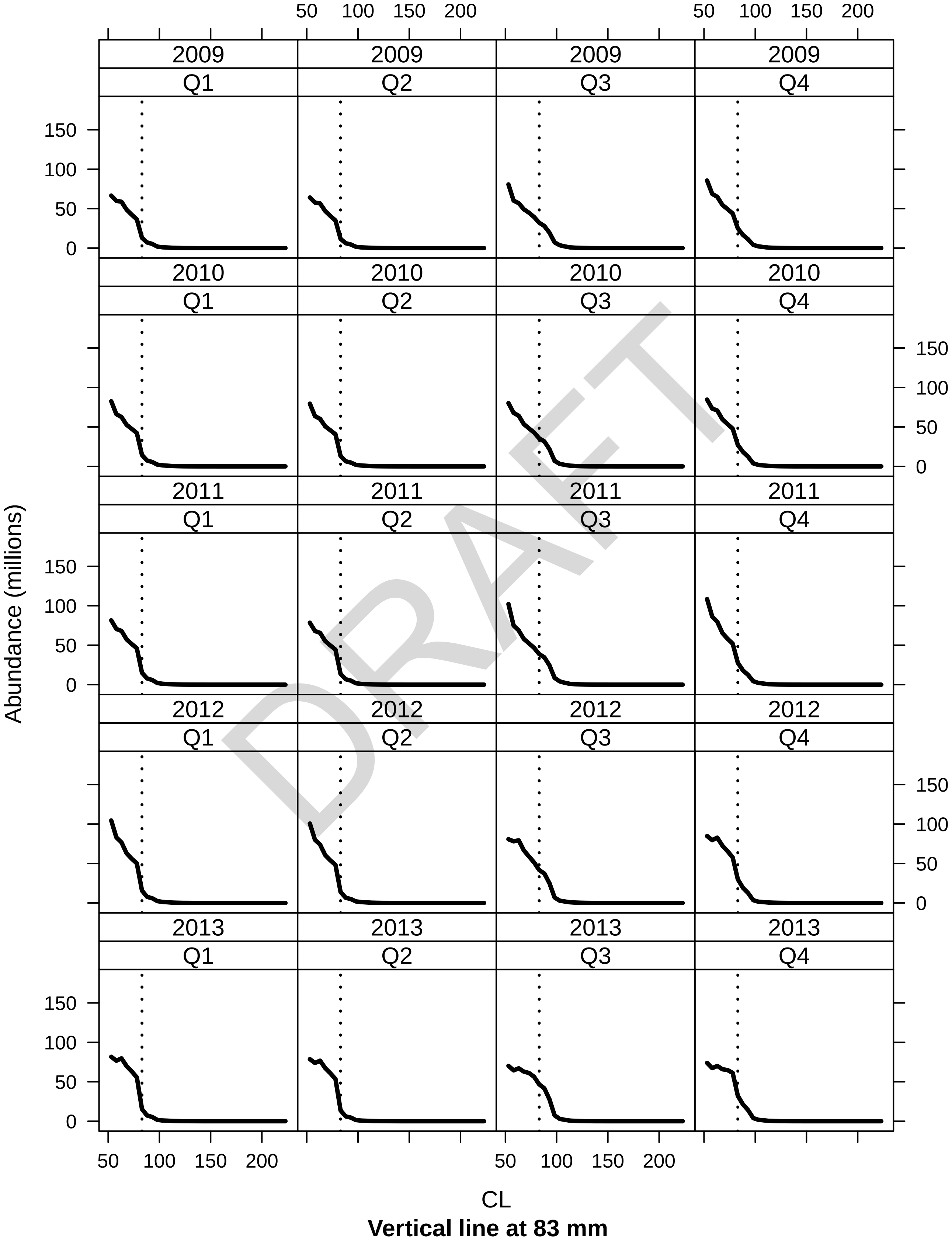
r60_ind_trawl_v6f6
combined sex abundance at length



Vertical line at 83 mm

DRAFT

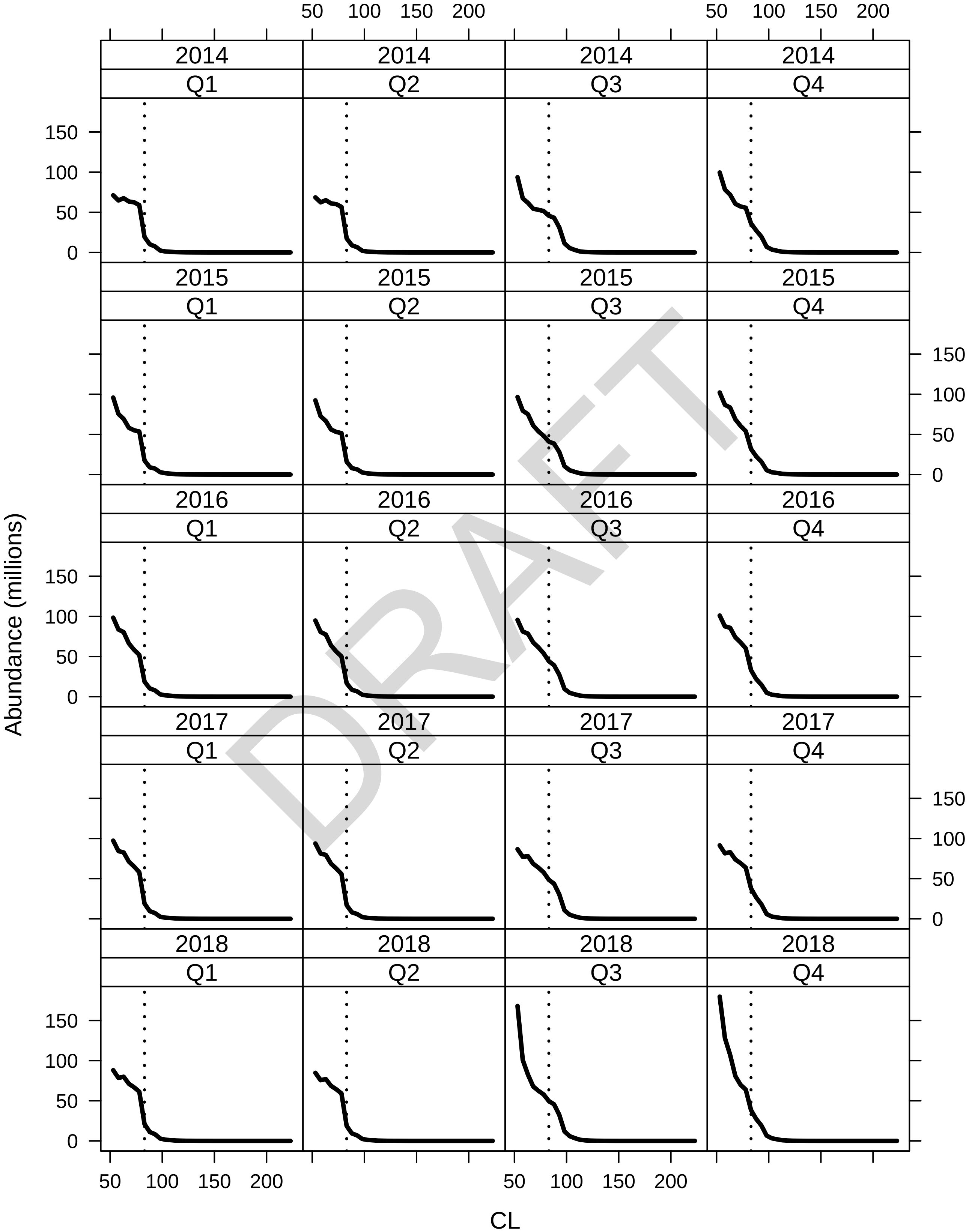
r60_ind_trawl_v6f6
combined sex abundance at length



Vertical line at 83 mm

DRAFT

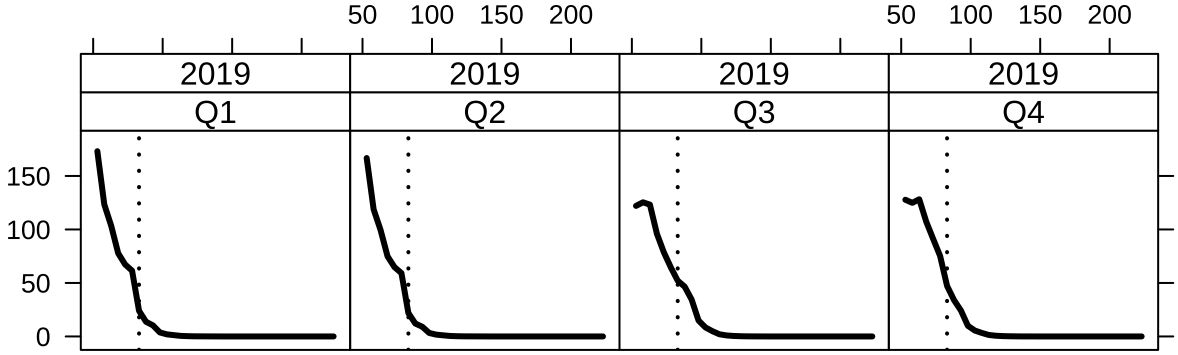
r60_ind_trawl_v6f6
combined sex abundance at length



Vertical line at 83 mm

DRAFT

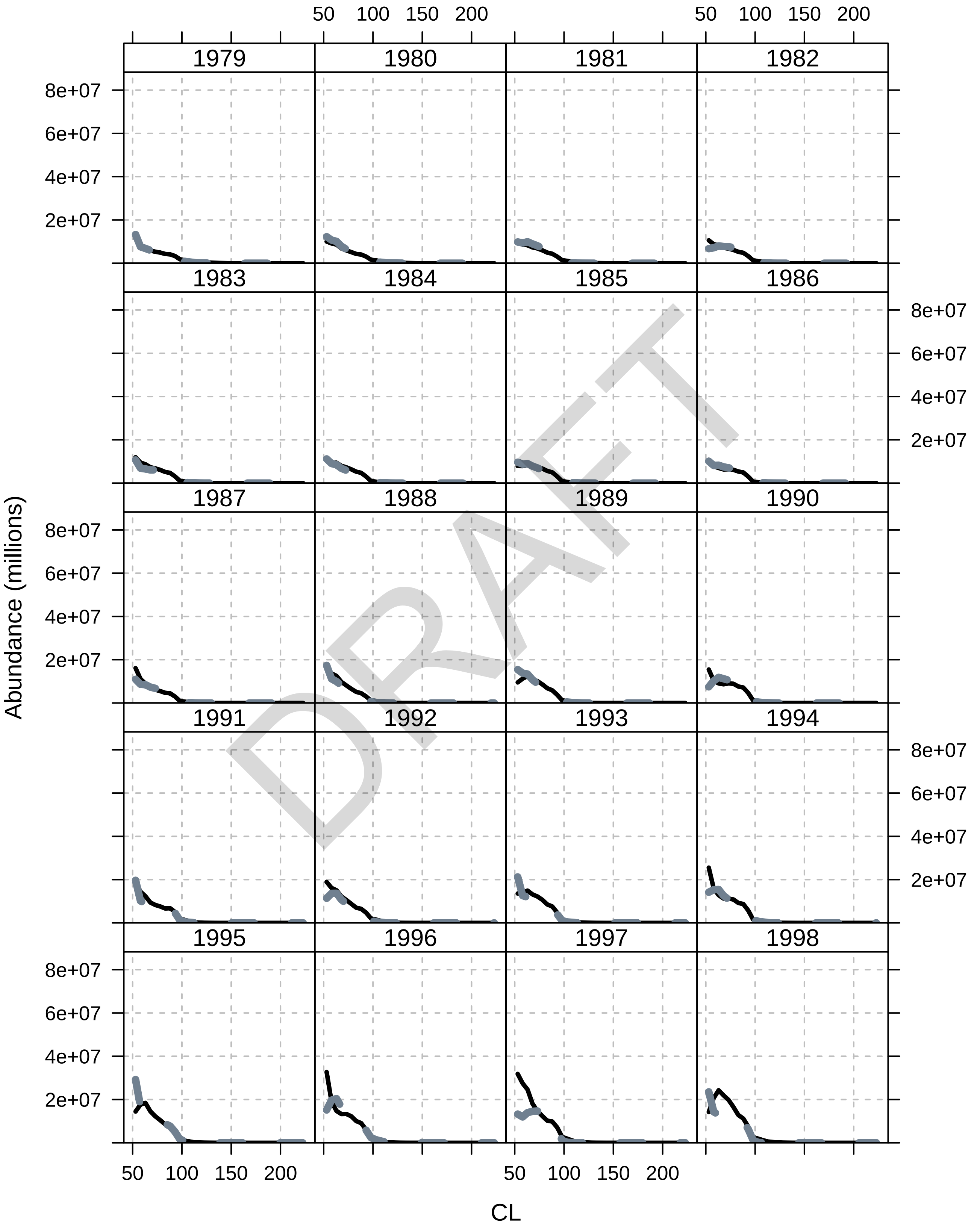
r60_ind_trawl_v6f6
combined sex abundance at length



Vertical line at 83 mm

DRAFT

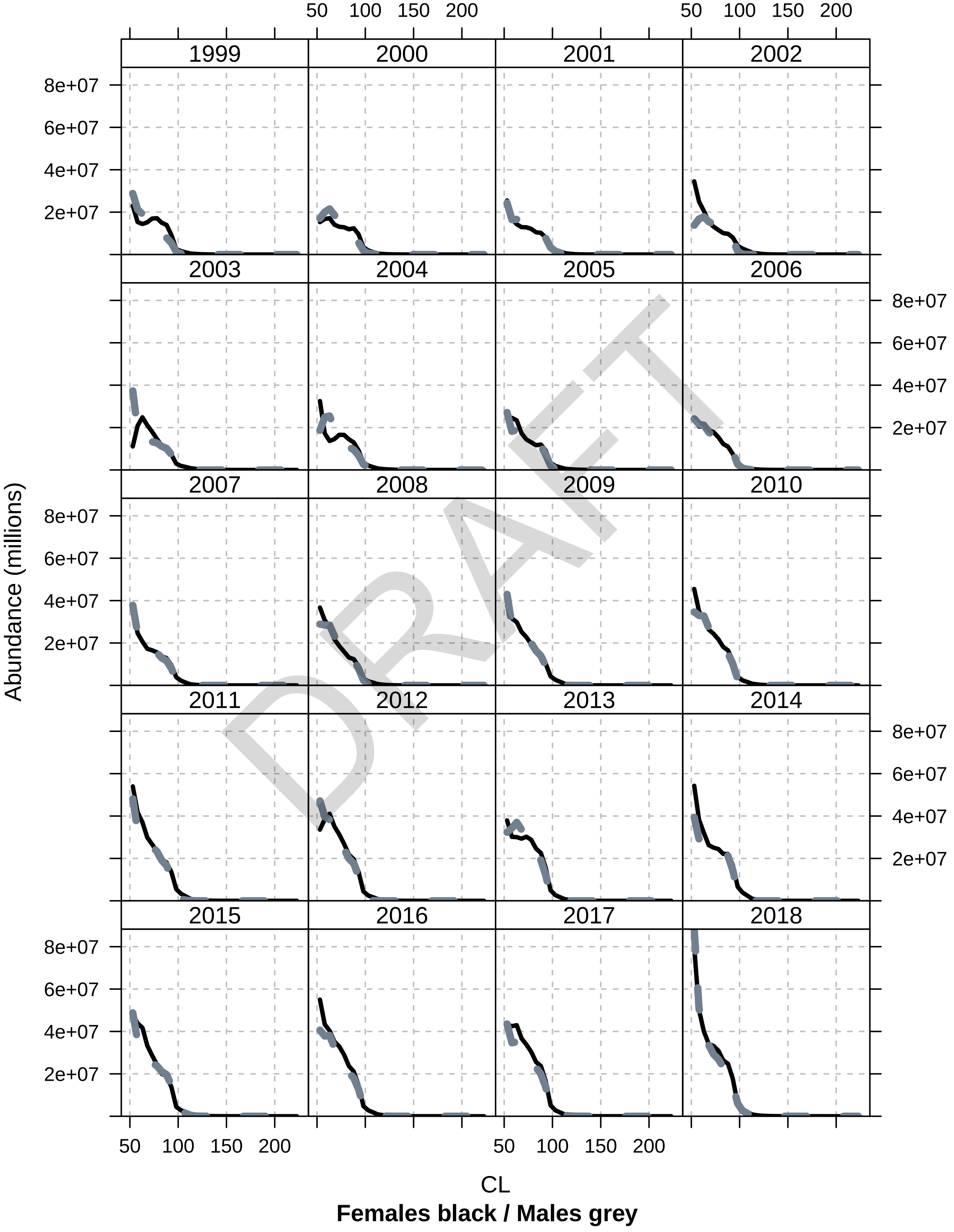
r60_ind_trawl_v6f6
summer size and sex specific abundance



Females black / Males grey

DRAFT

r60_ind_trawl_v6f6
summer size and sex specific abundance



Females black / Males grey

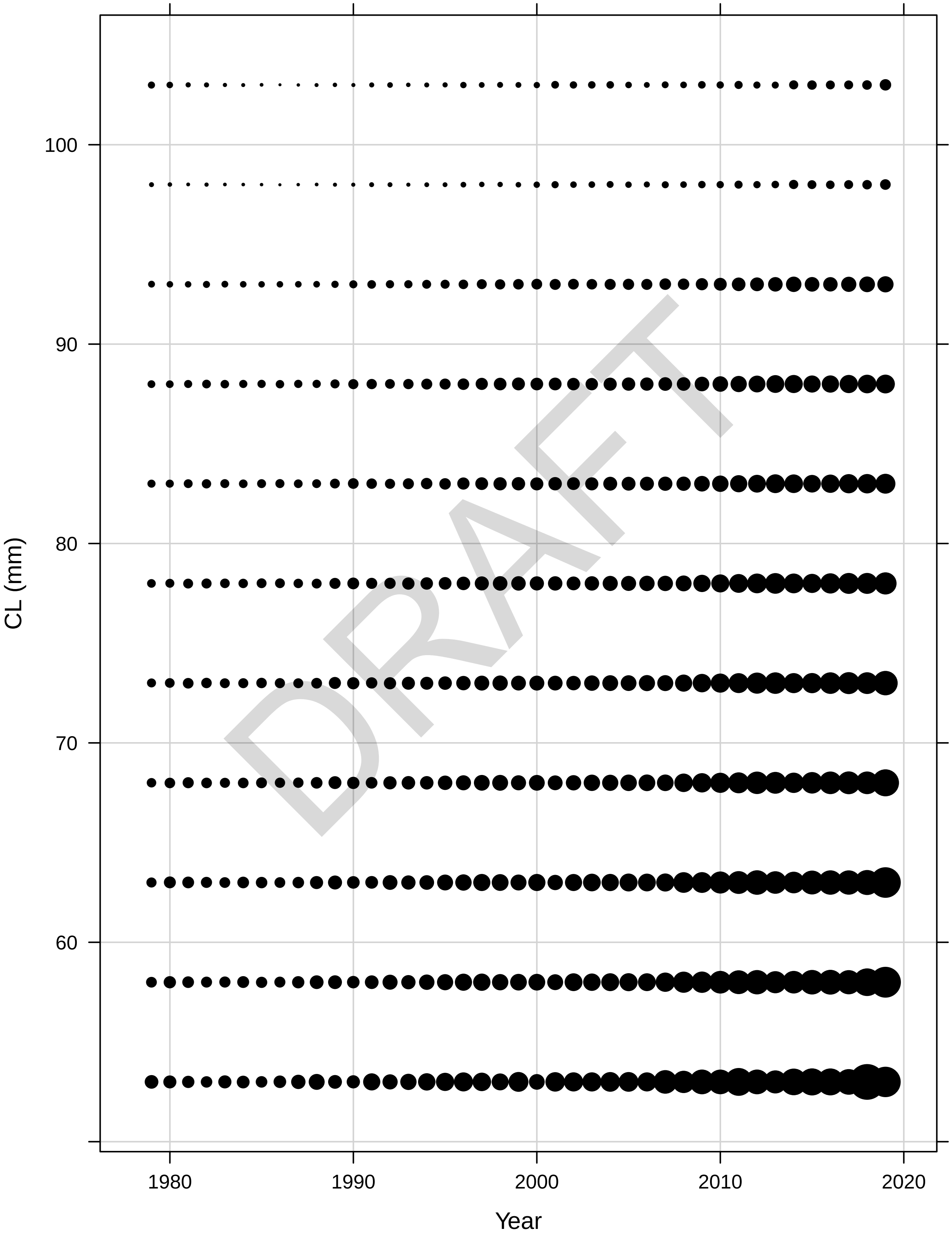
DRAFT

r60_ind_trawl_v6f6
summer size and sex specific abundance

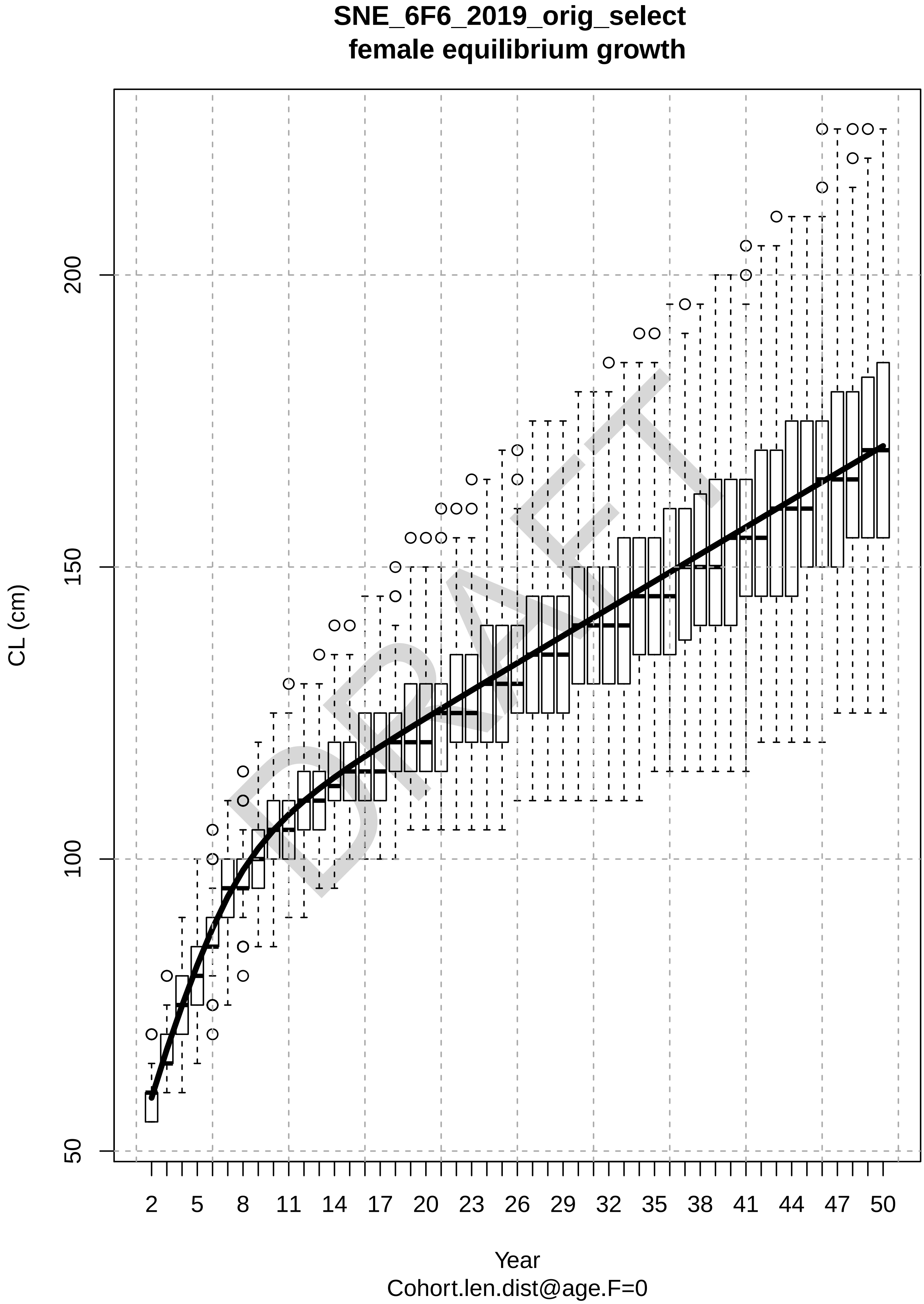
Females black / Males grey

DRAFT

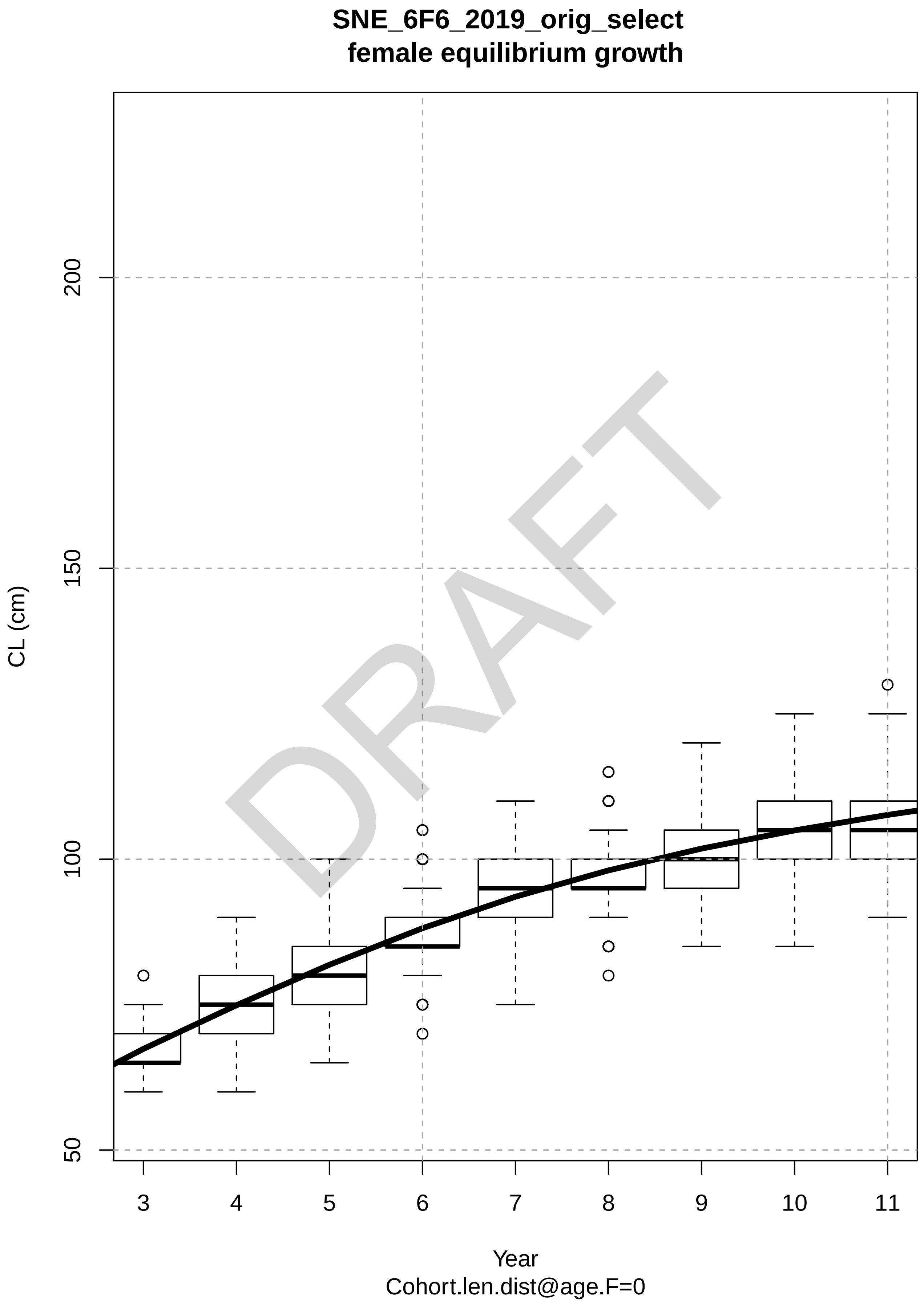
r60_ind_trawl_v6f6
June 1 Abundance by year at size



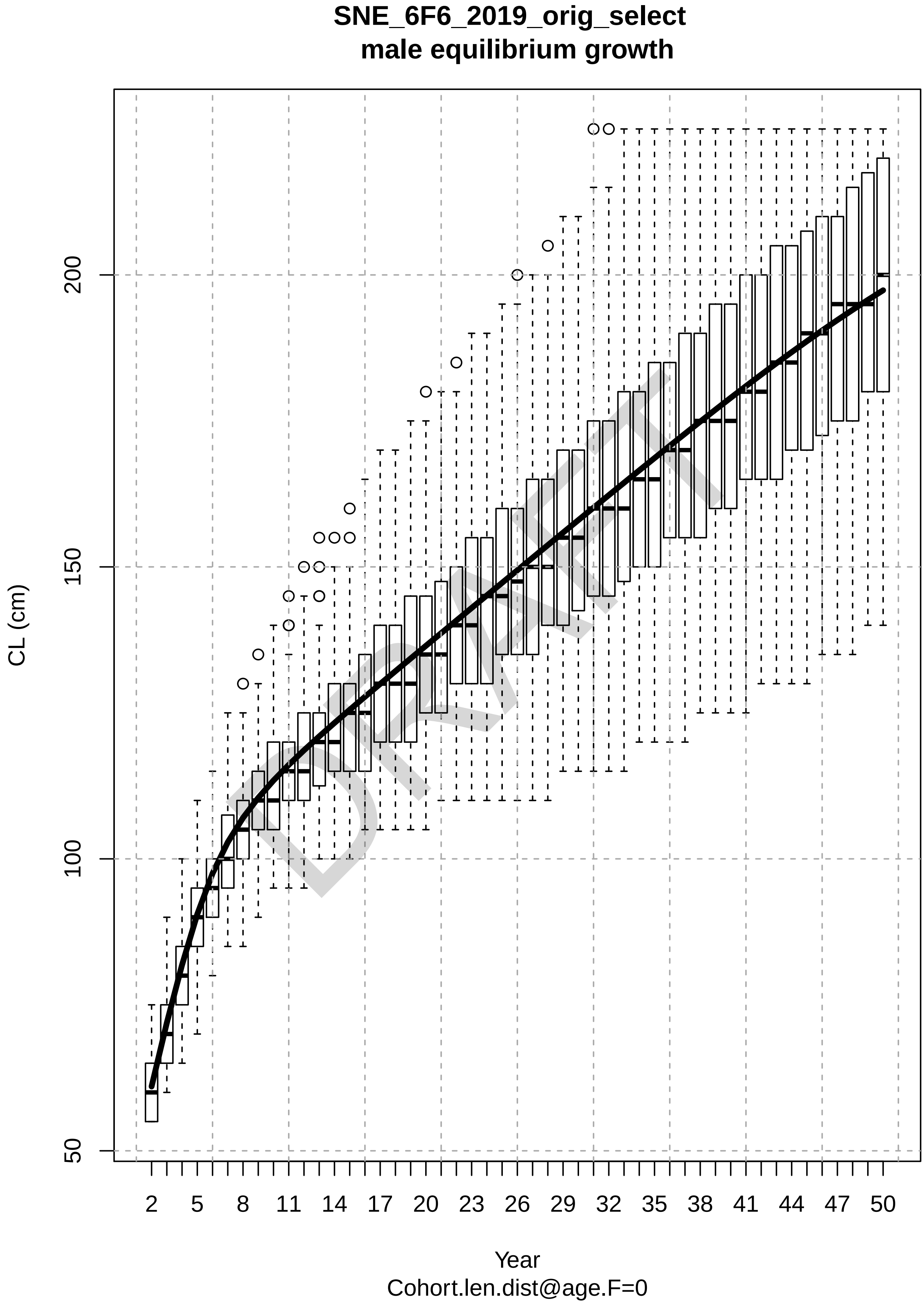
DRAFT


SNE_6F6_2019_orig_select
female equilibrium growth
CL (cm)
50
100
150
200
2
5
8
11
14
17
20
23
26
29
32
35
38
41
44
47
50
Year
Cohort.len.dist@age.F=0

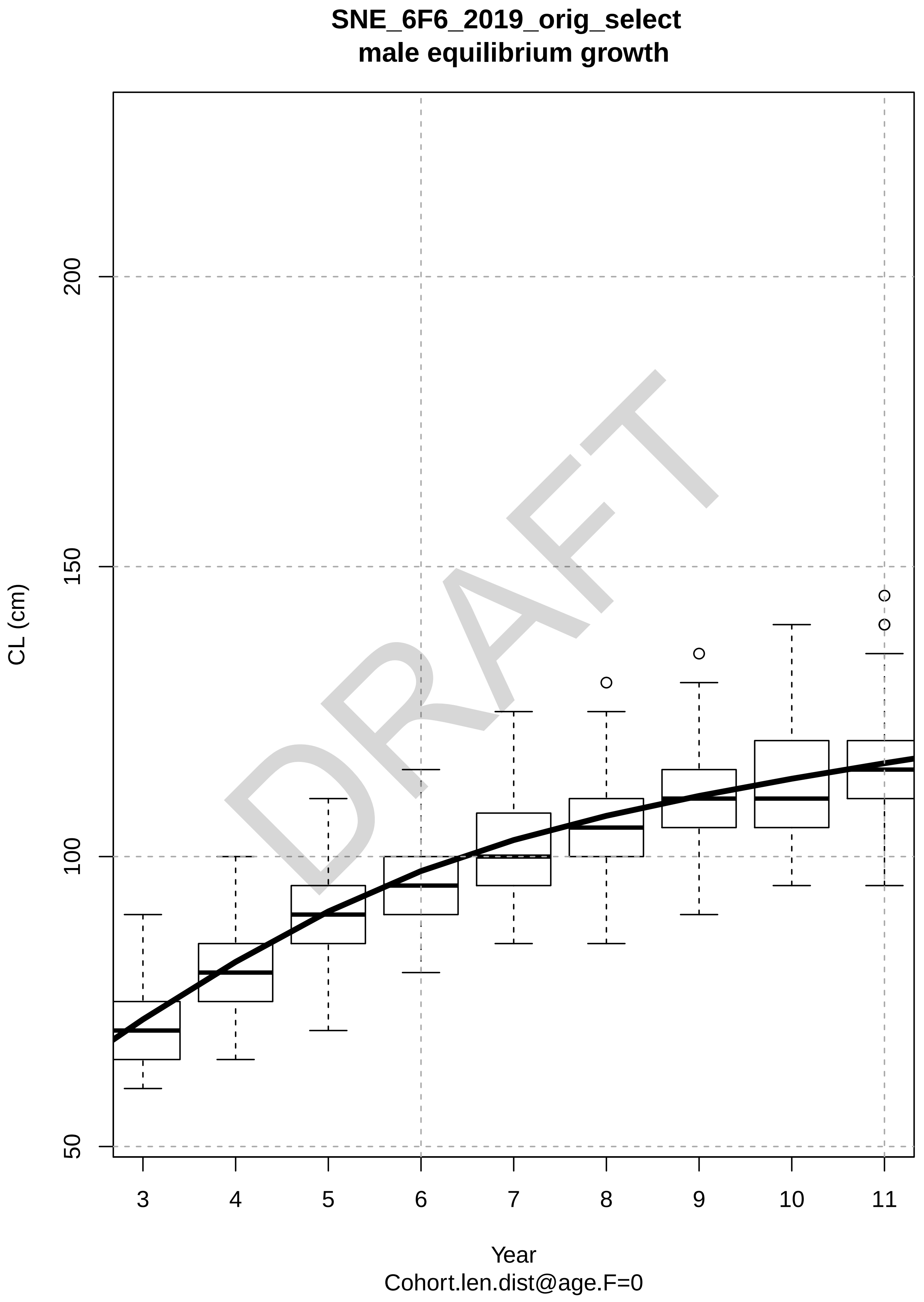
DRAFT


SNE_6F6_2019_orig_select
female equilibrium growth
CL (cm)
50
100
150
200
3
4
5
6
7
8
9
10
11
Year
Cohort.len.dist@age.F=0

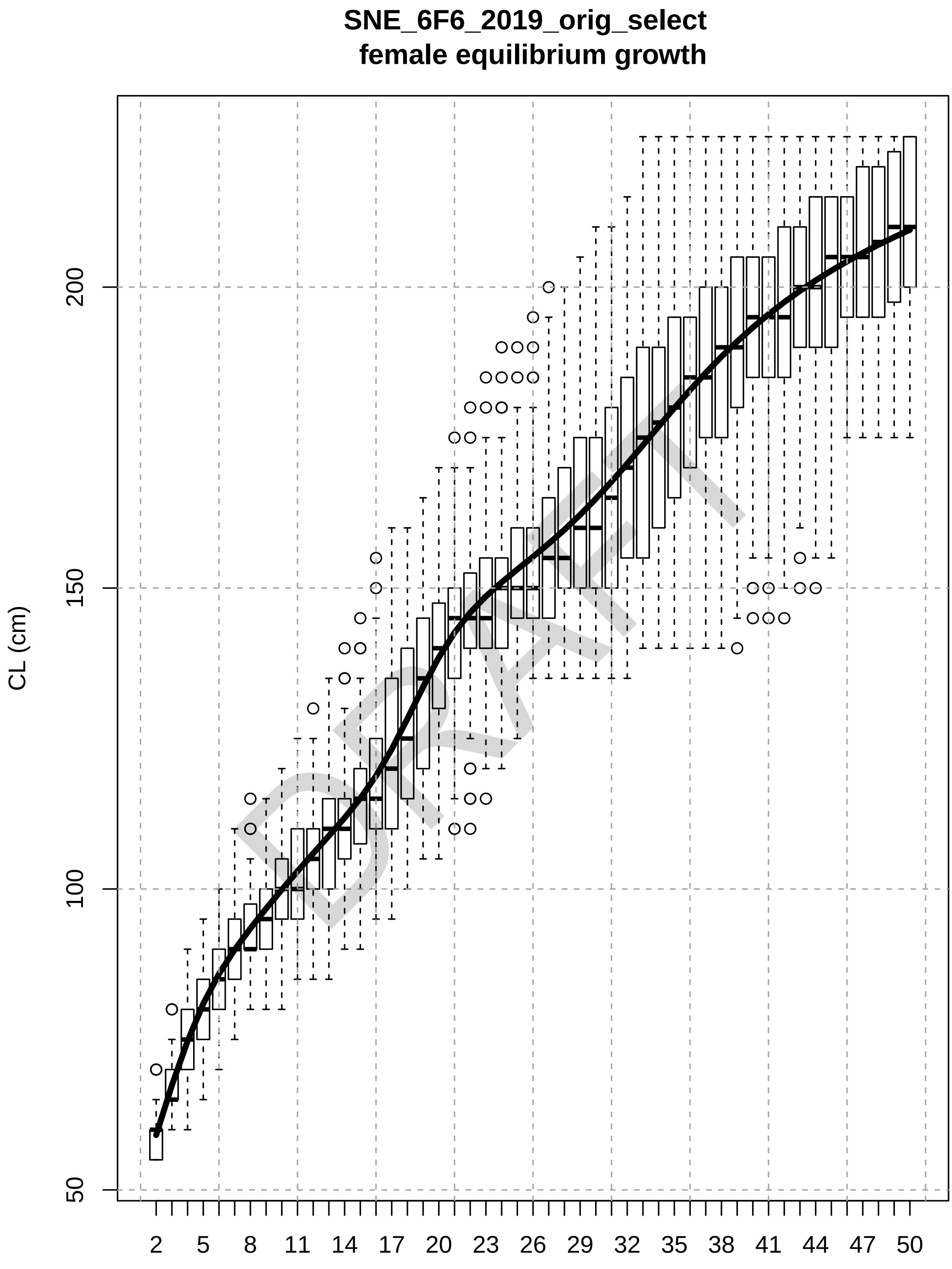
DRAFT


SNE_6F6_2019_orig_select
male equilibrium growth
CL (cm)
50
100
150
200
2
5
8
11
14
17
20
23
26
29
32
35
38
41
44
47
50
Year
Cohort.len.dist@age.F=0

DRAFT


SNE_6F6_2019_orig_select
male equilibrium growth
CL (cm)
50
100
150
200
3
4
5
6
7
8
9
10
11
Year
Cohort.len.dist@age.F=0

DRAFT


SNE_6F6_2019_orig_select
female equilibrium growth
CL (cm)
50
100
150
200
2
5
8
11
14
17
20
23
26
29
32
35
38
41
44
47
50
Year
Cohort.len.dist@age.F=First5Yrs
DRAFT

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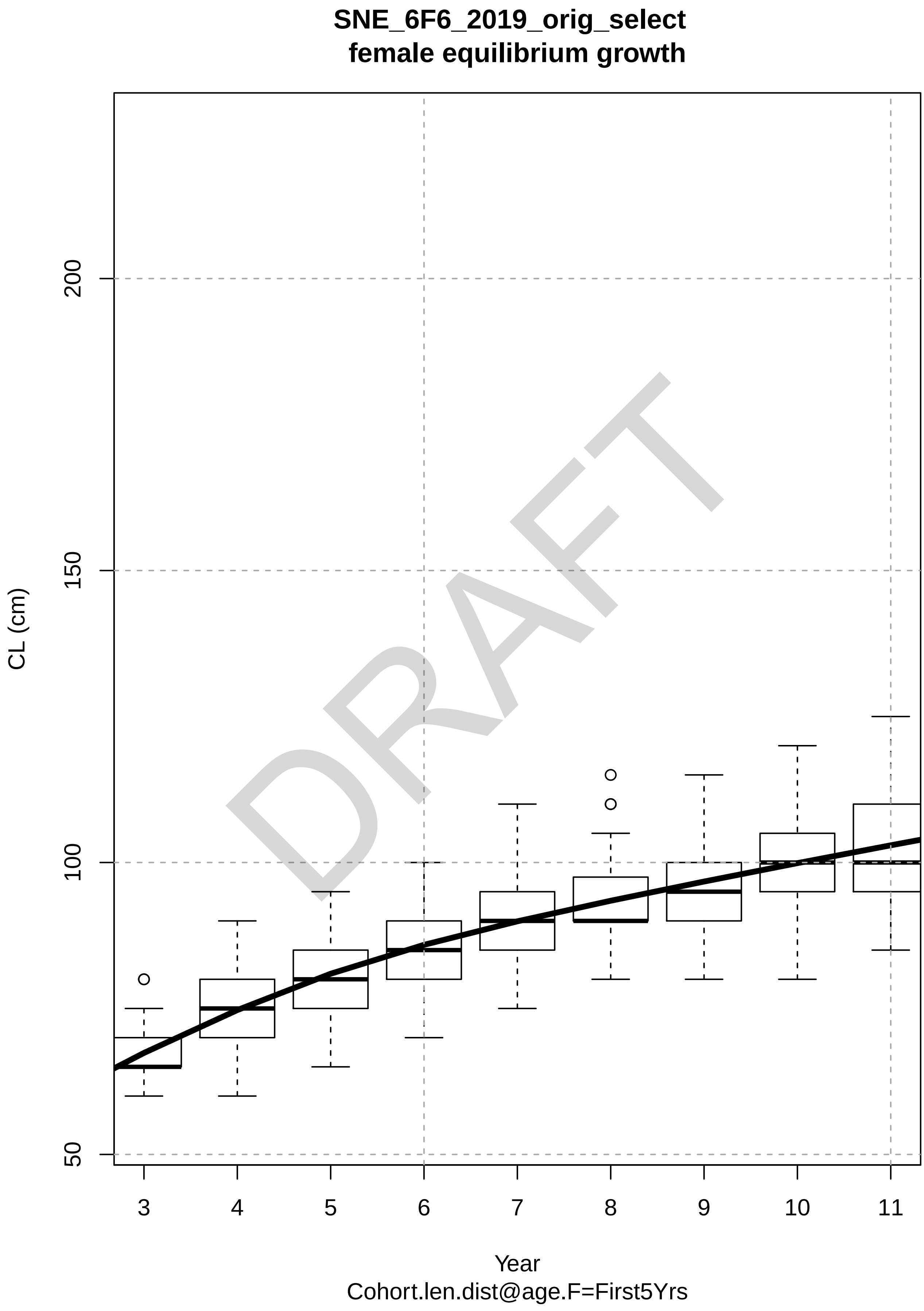
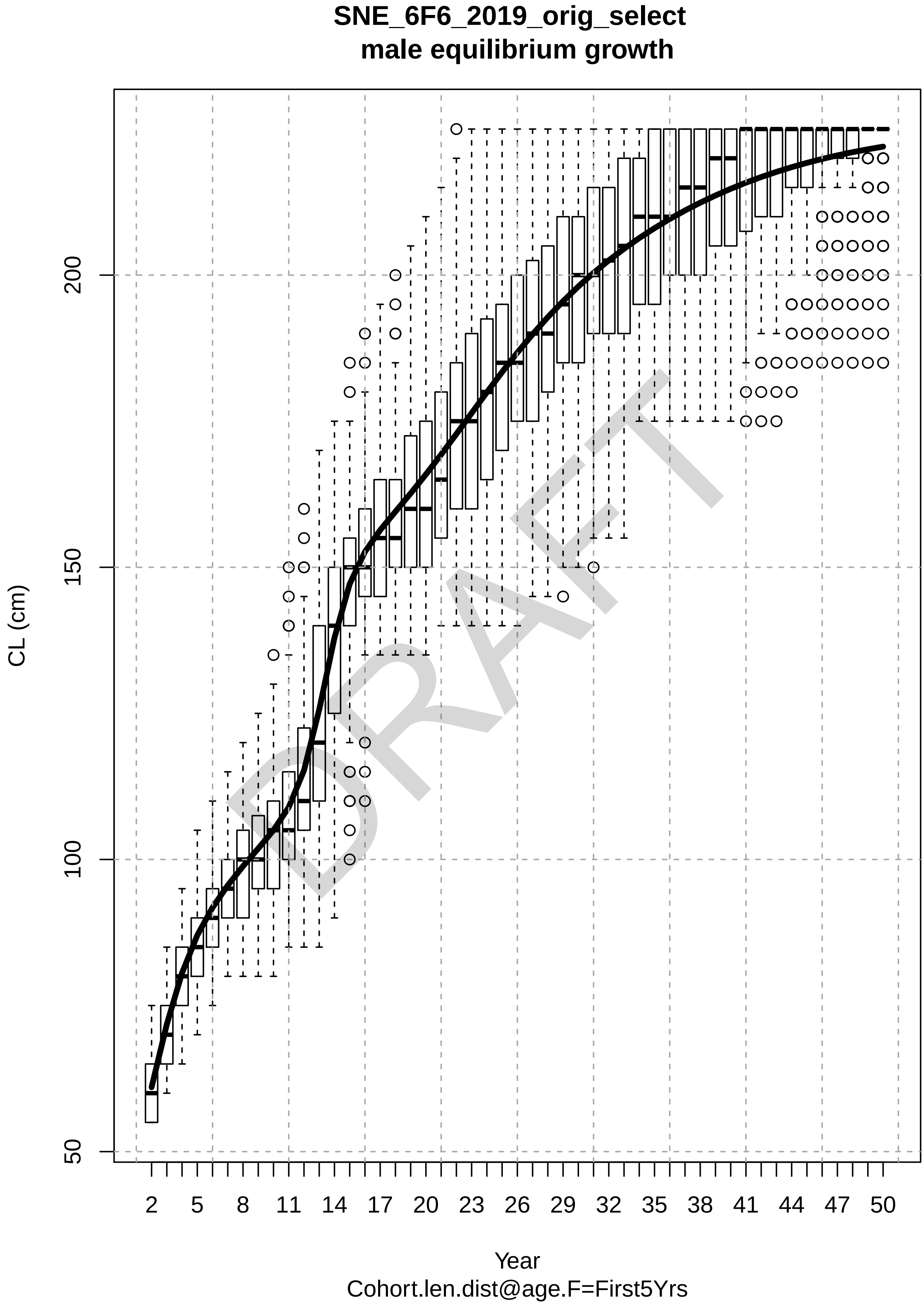
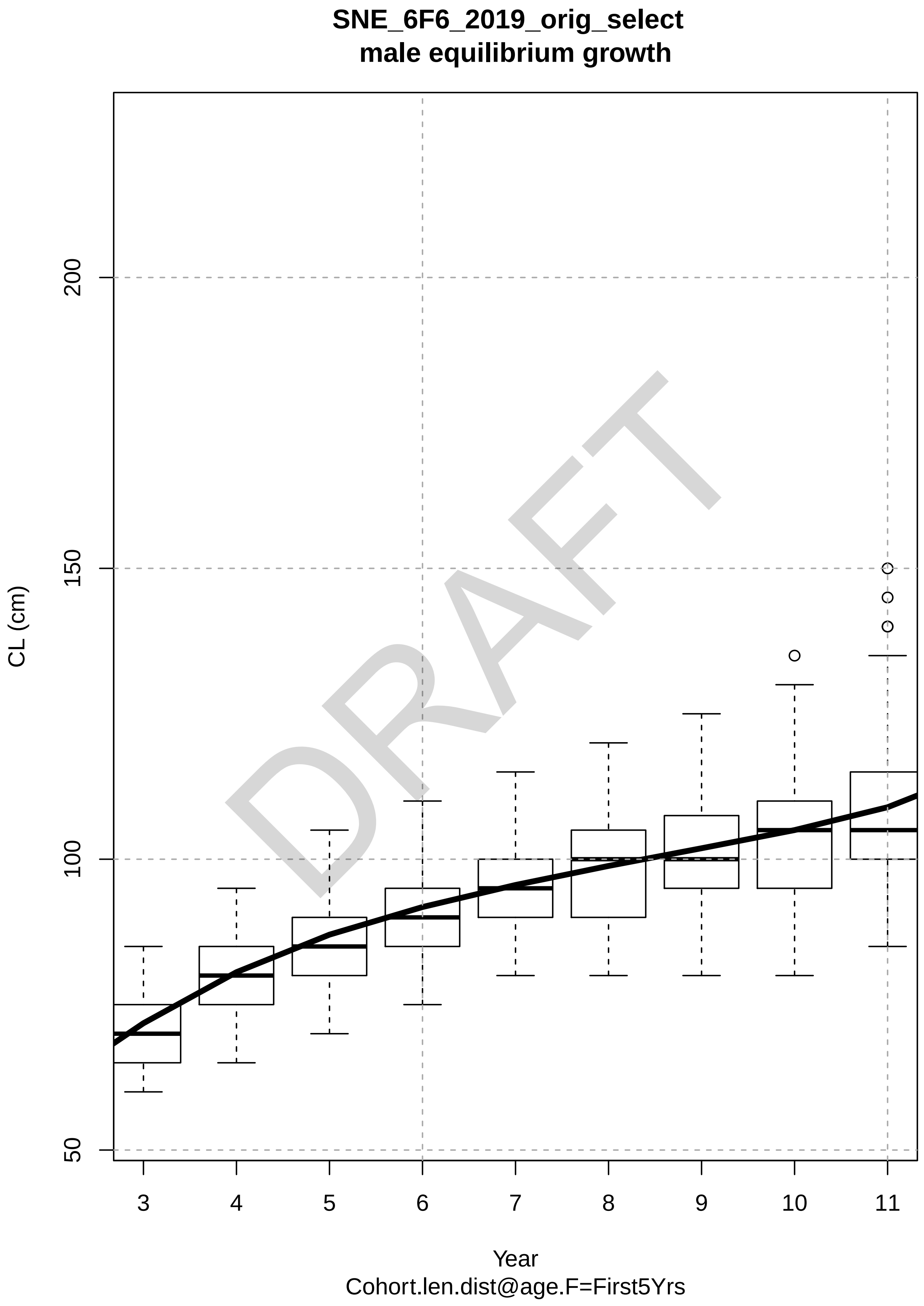


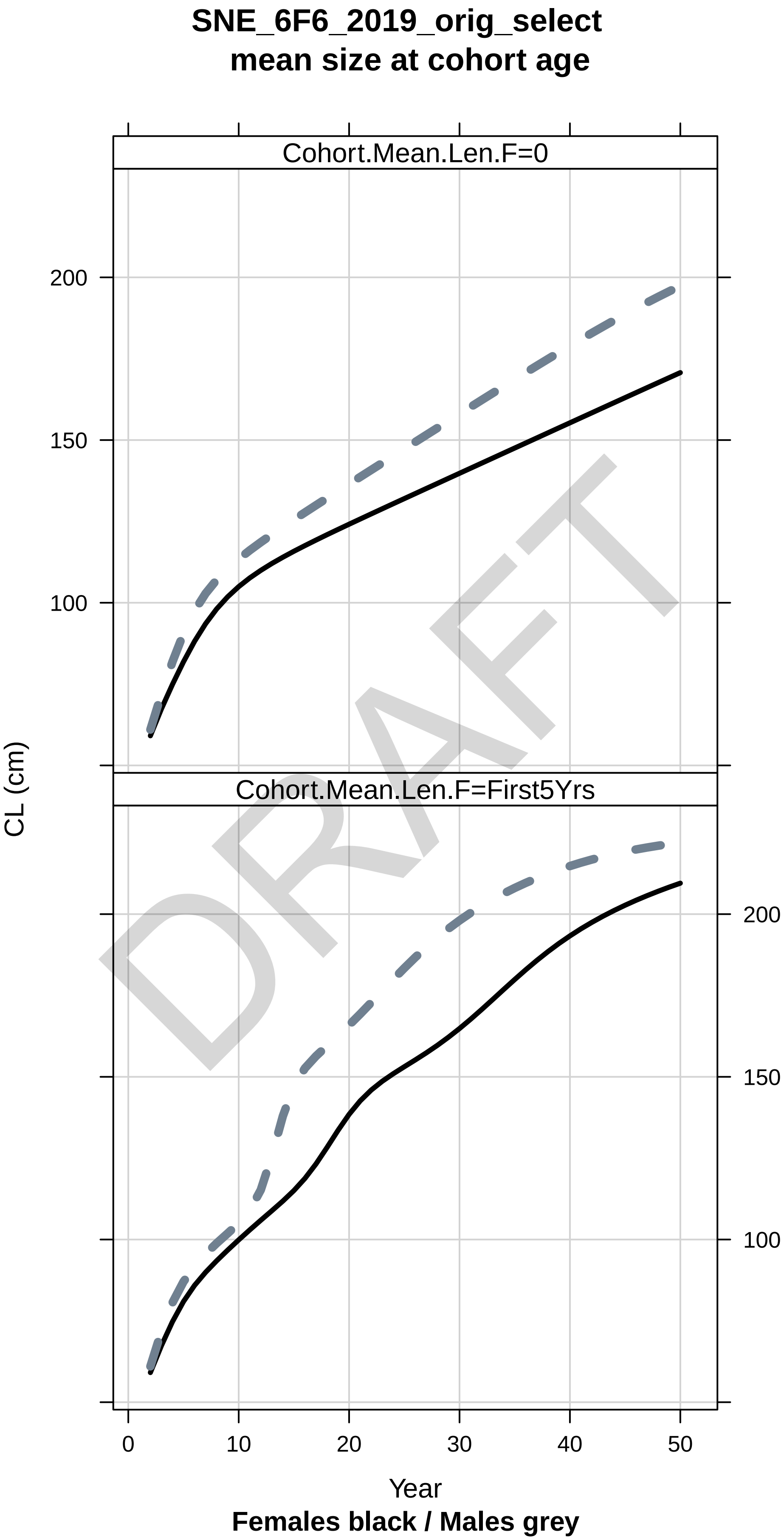
DRAFT


SNE_6F6_2019_orig_select
male equilibrium growth
CL (cm)
50
100
150
200
2
5
8
11
14
17
20
23
26
29
32
35
38
41
44
47
50
Year
Cohort.len.dist@age.F=First5Yrs

DRAFT

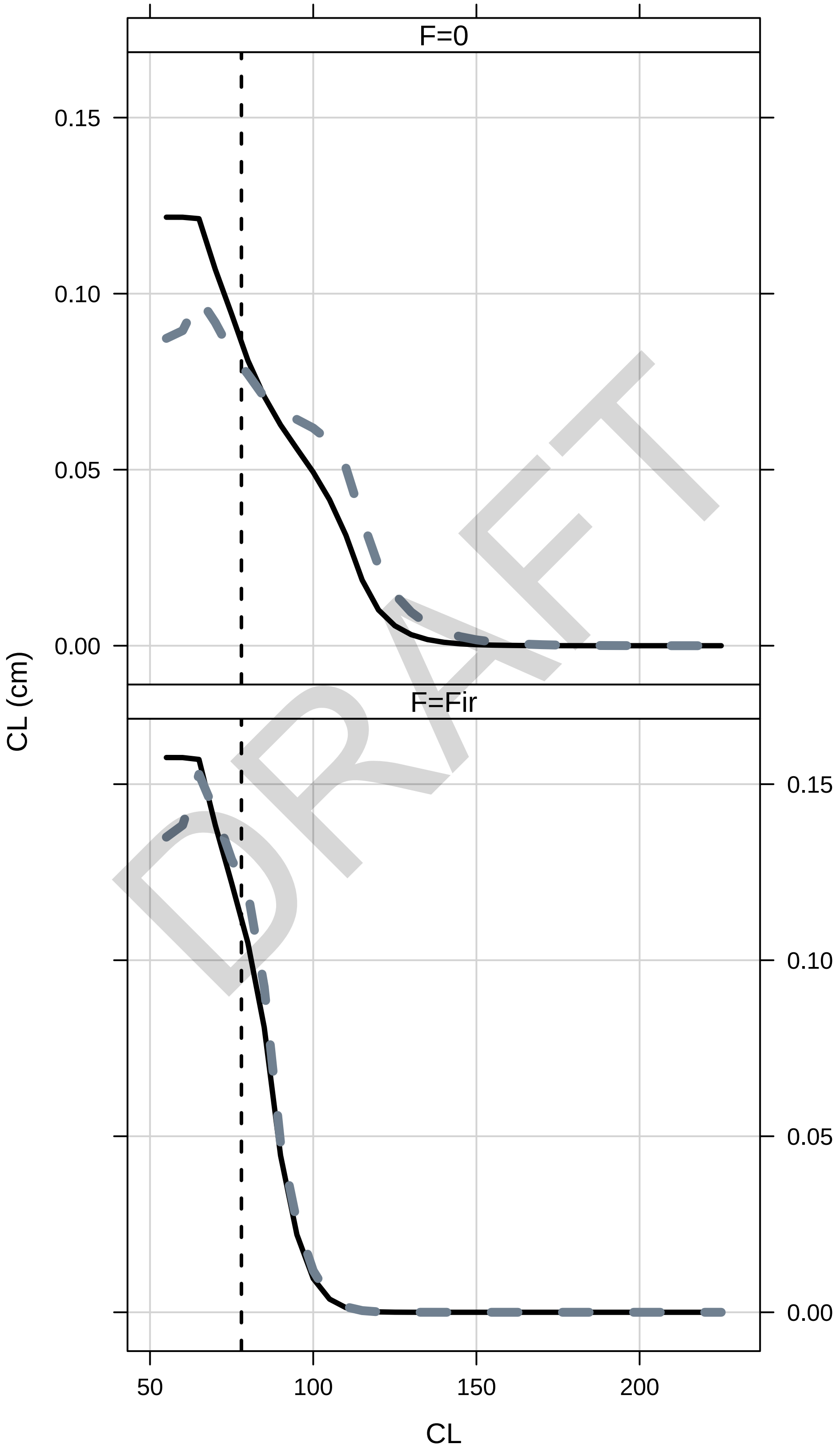

SNE_6F6_2019_orig_select
male equilibrium growth
CL (cm)
50
100
150
200
3
4
5
6
7
8
9
10
11
Year
Cohort.len.dist@age.F=First5Yrs

DRAFT


SNE_6F6_2019_orig_select
mean size at cohort age
Cohort.Mean.Len.F=0
Cohort.Mean.Len.F=First5Yrs
200
150
100
CL (cm)
0
10
20
30
40
50
Year
Females black / Males grey

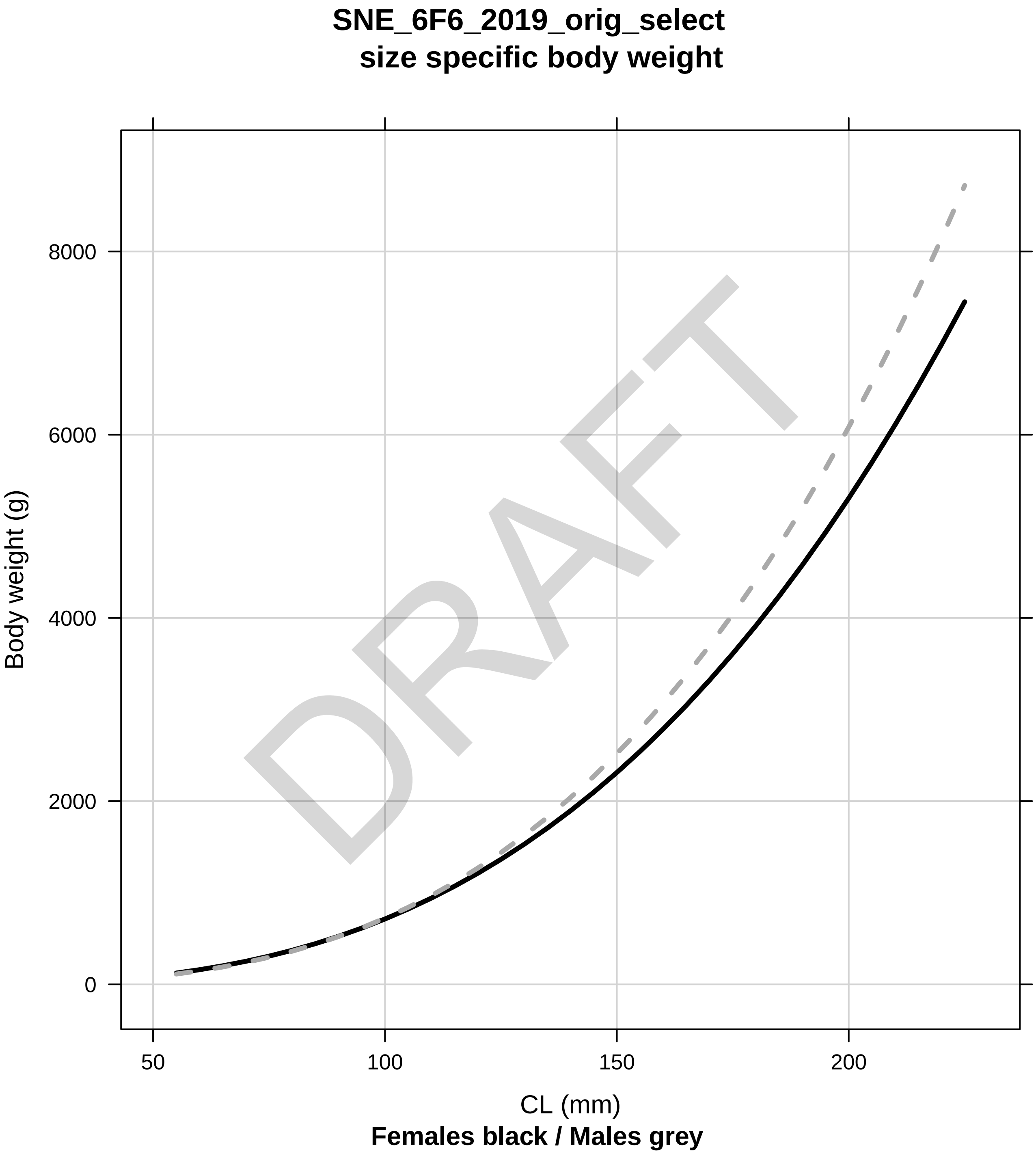
DRAFT

SNE_6F6_2019_orig_select
equilbrium size composition (beginning of winter)



DRAFT

Females black / Males grey − vertical line at 78 mm CL


SNE_6F6_2019_orig_select
size specific body weight
Body weight (g)
0
2000
4000
6000
8000
50
100
150
200
CL (mm)
Females black / Males grey

DRAFT

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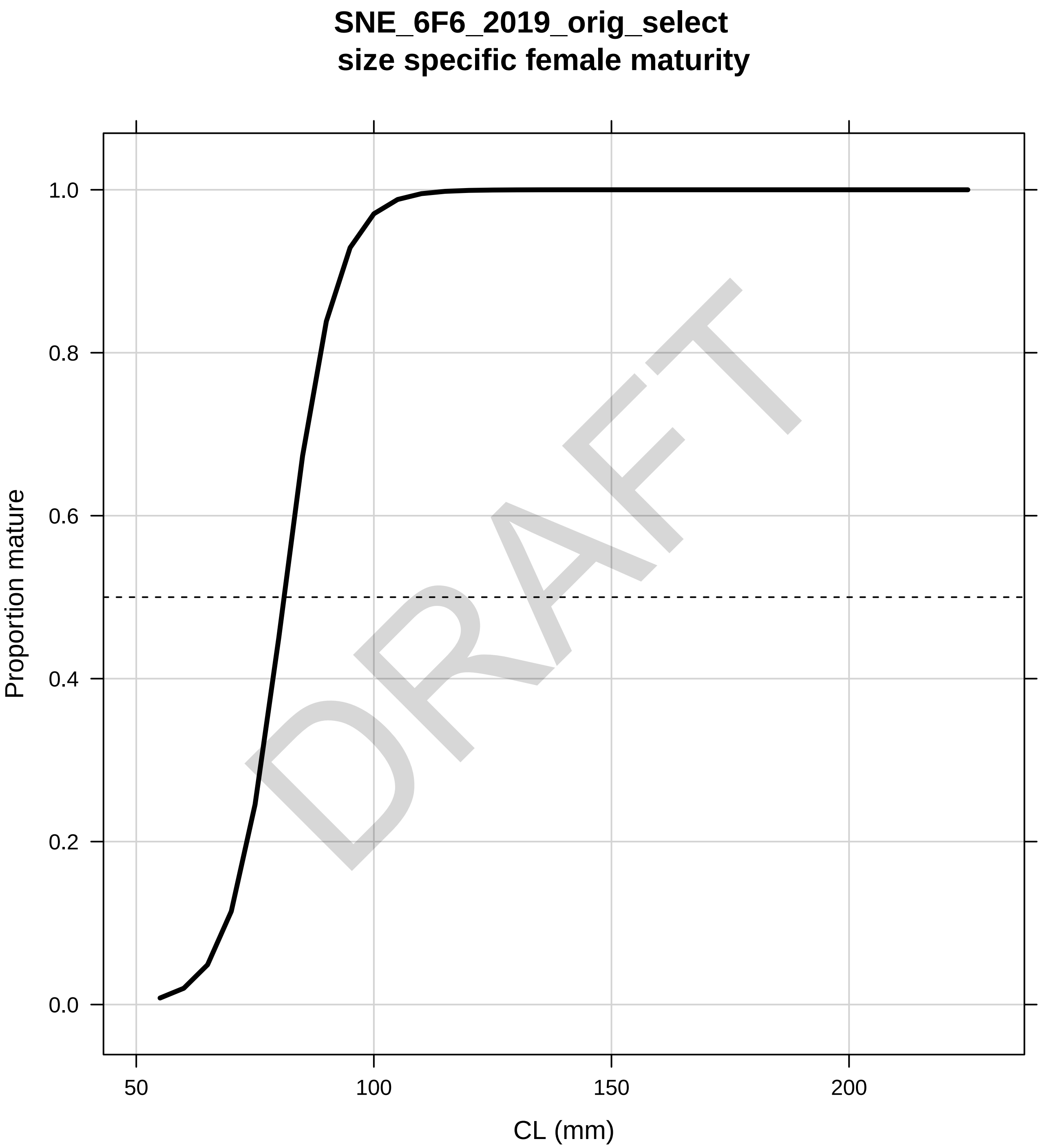

DRAFT

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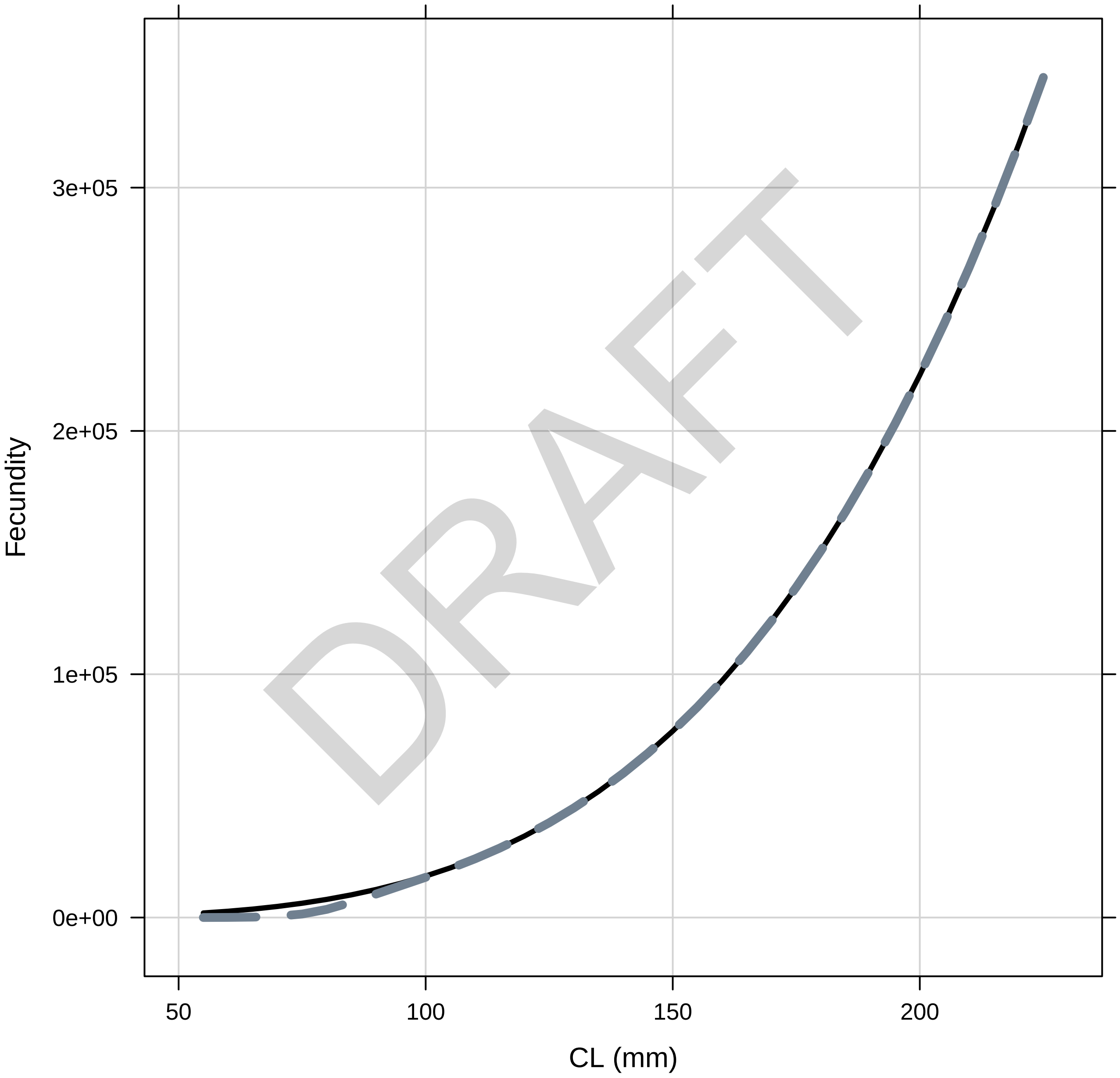
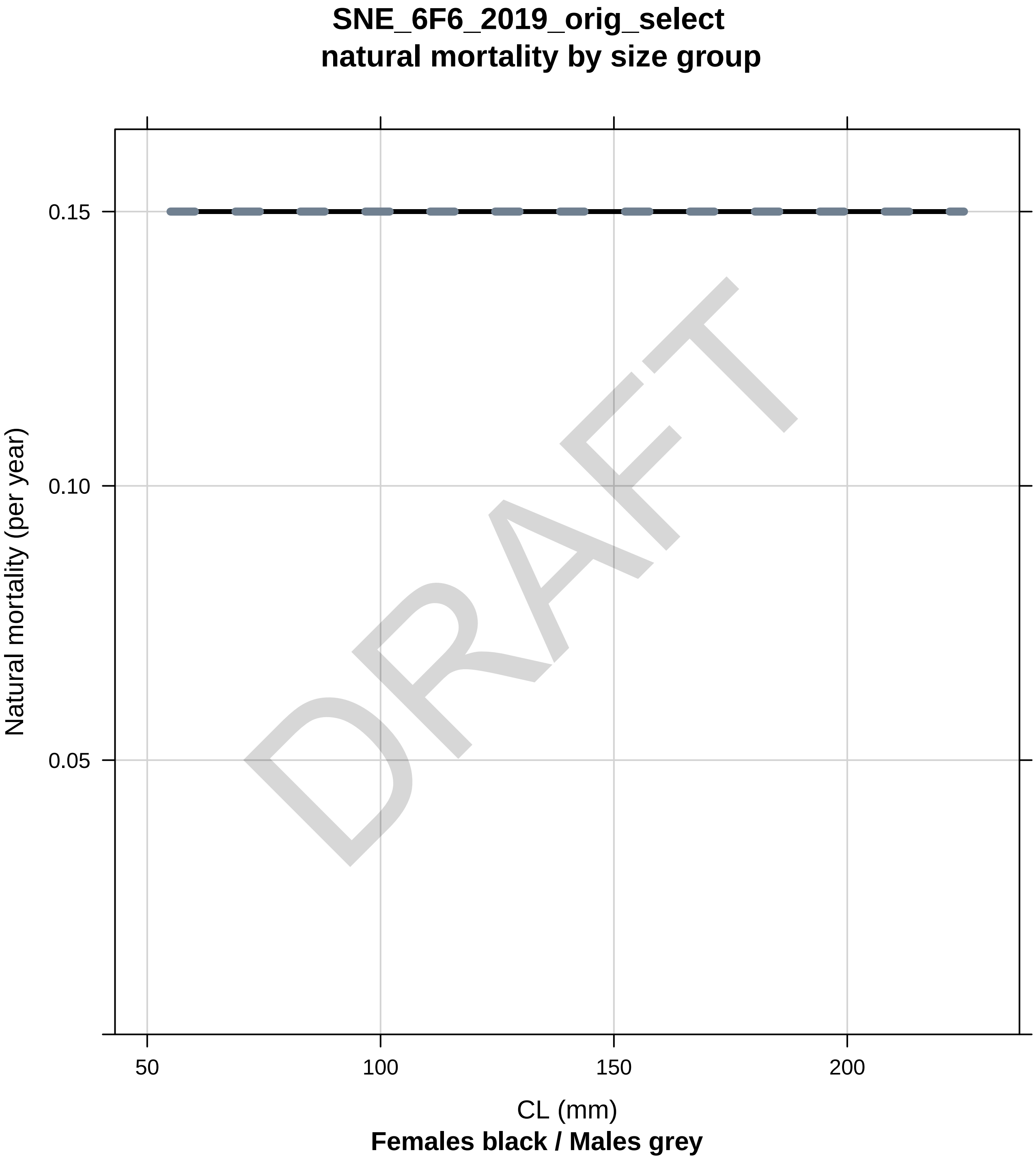
SNE_6F6_2019_orig_select
size specific fecundity

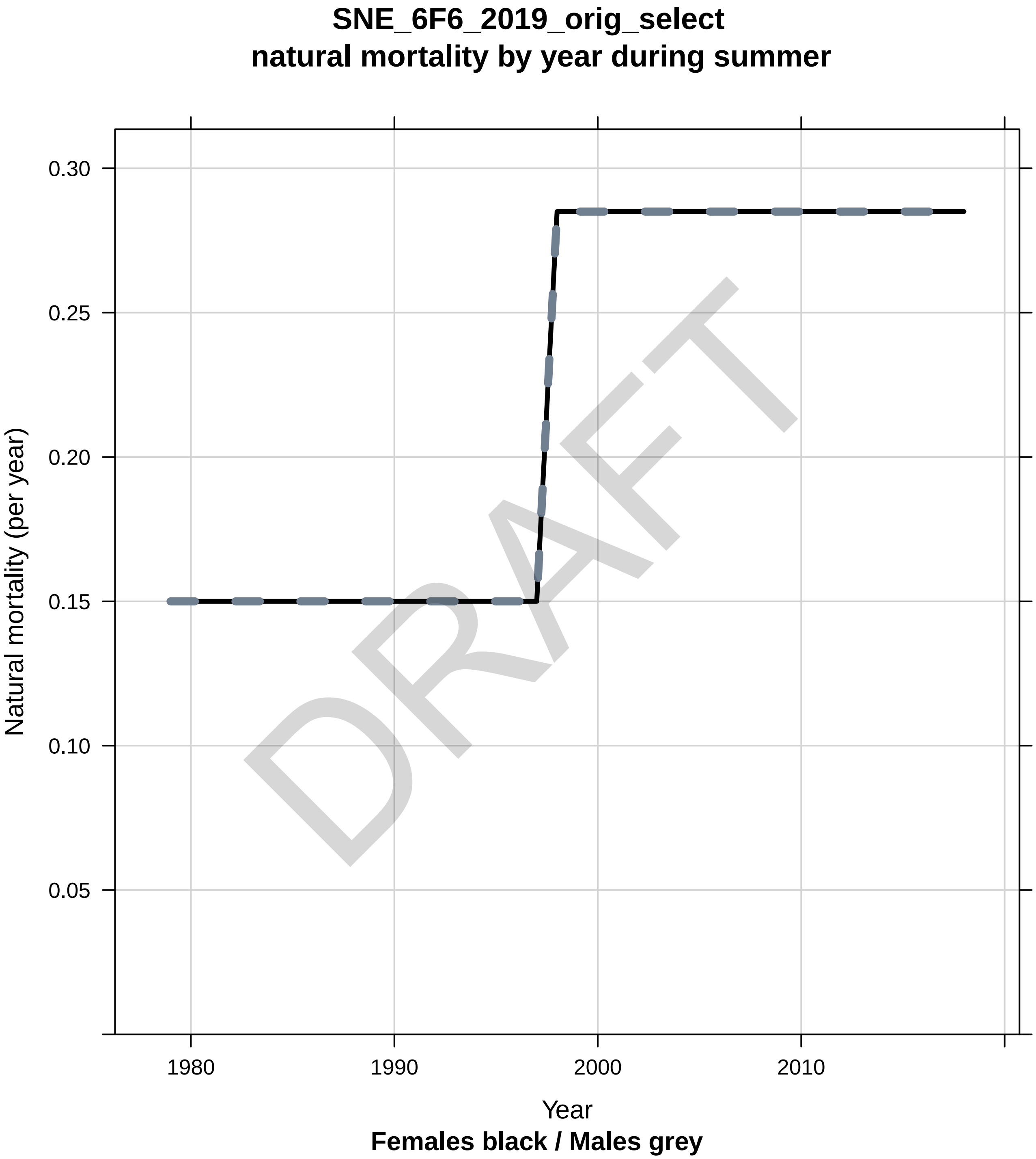


DRAFT

Fecudinty solid line / Effective Fecundity dash line

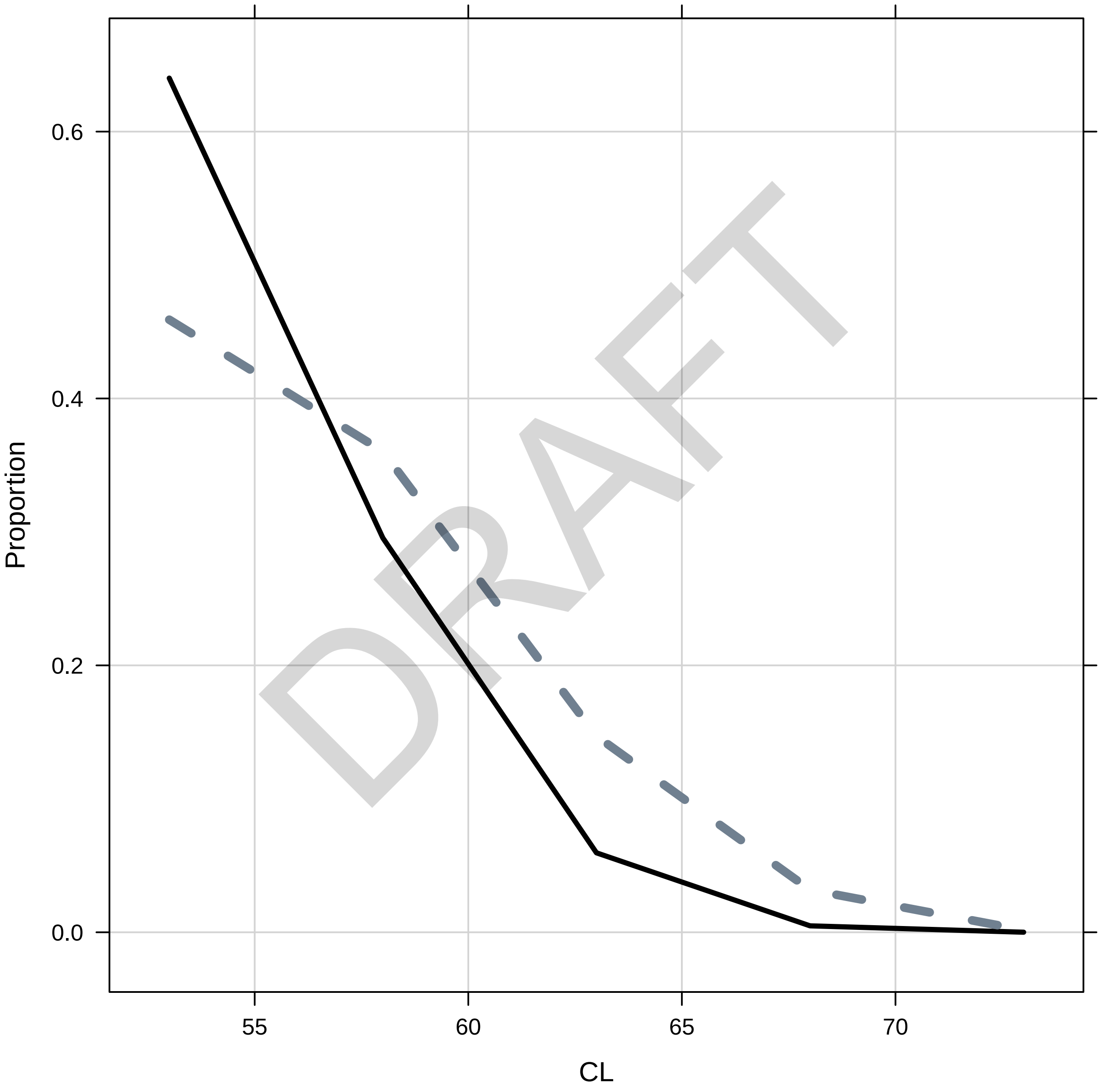

SNE_6F6_2019_orig_select
natural mortality by size group
Natural mortality (per year)
0.15
0.10
0.05
50
100
150
200
CL (mm)
Females black / Males grey

DRAFT


SNE_6F6_2019_orig_select
natural mortality by year during summer
Natural mortality (per year)
0.30
0.25
0.20
0.15
0.10
0.05
1980
1990
2000
2010
Year
Females black / Males grey

DRAFT

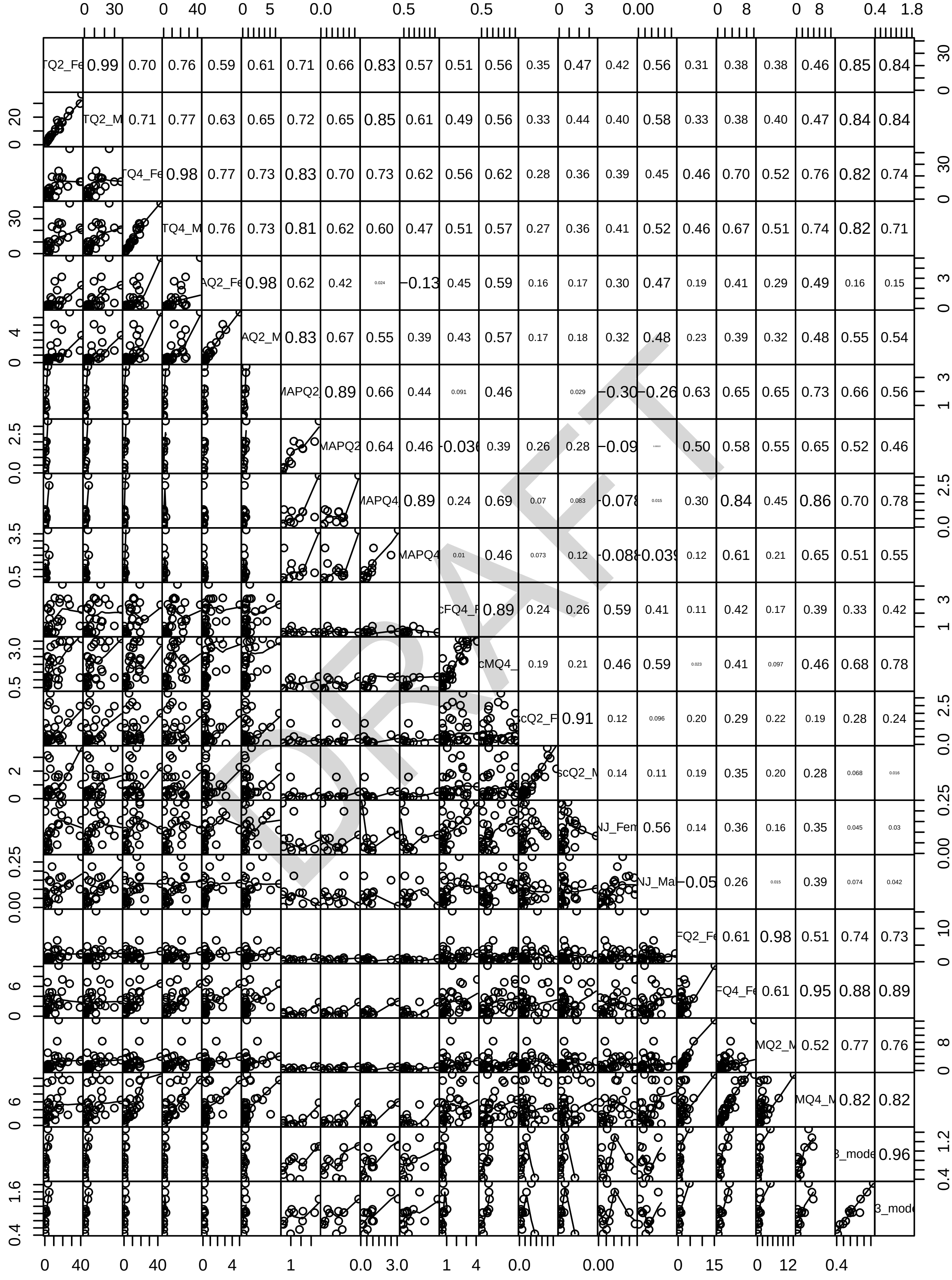
SNE_6F6_2019_orig_select
recruit size composition



Females black / Males grey

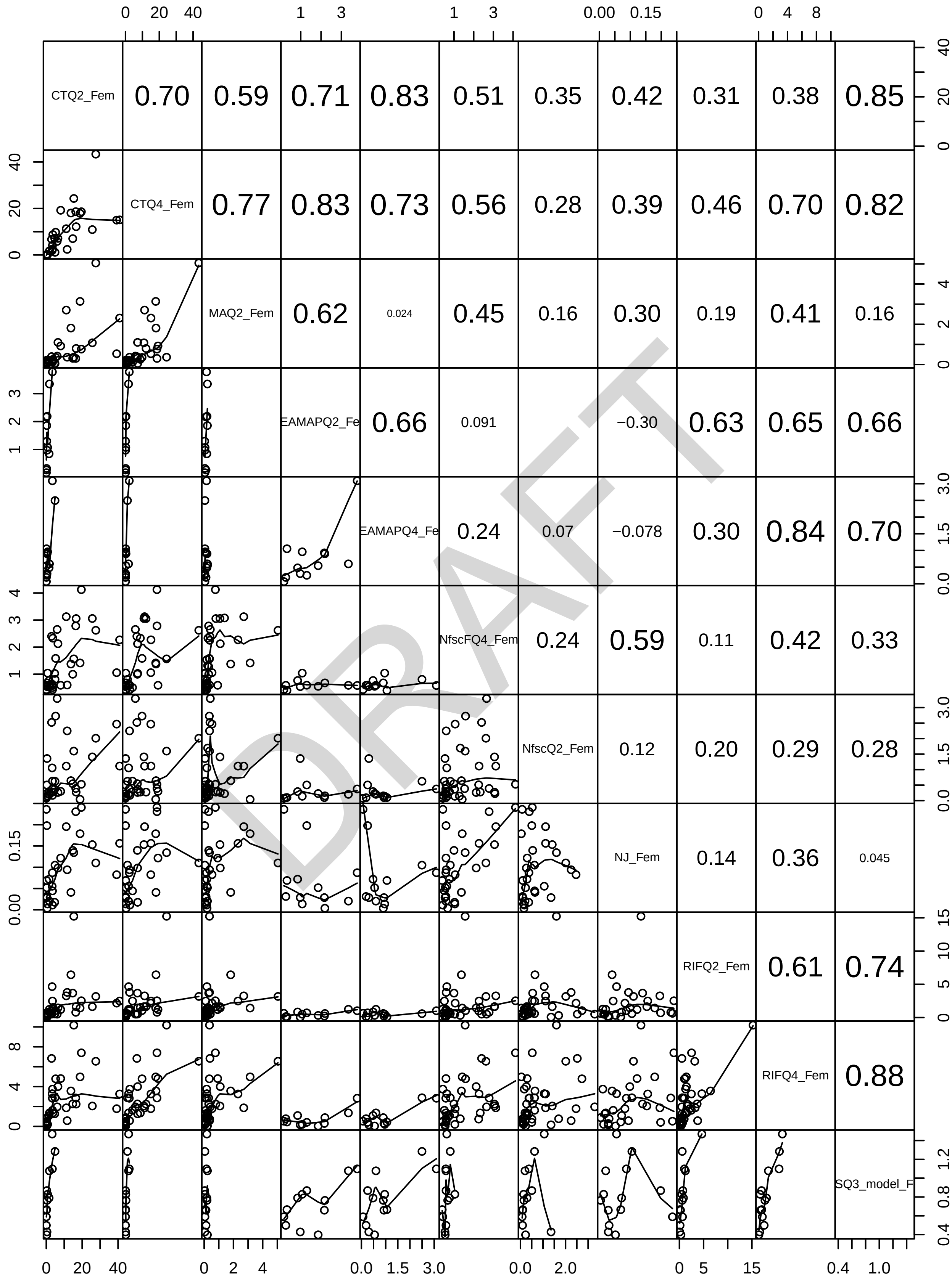
DRAFT

SNE_6F6_2019_orig_select
Pairwise scatterplots for survey trend data



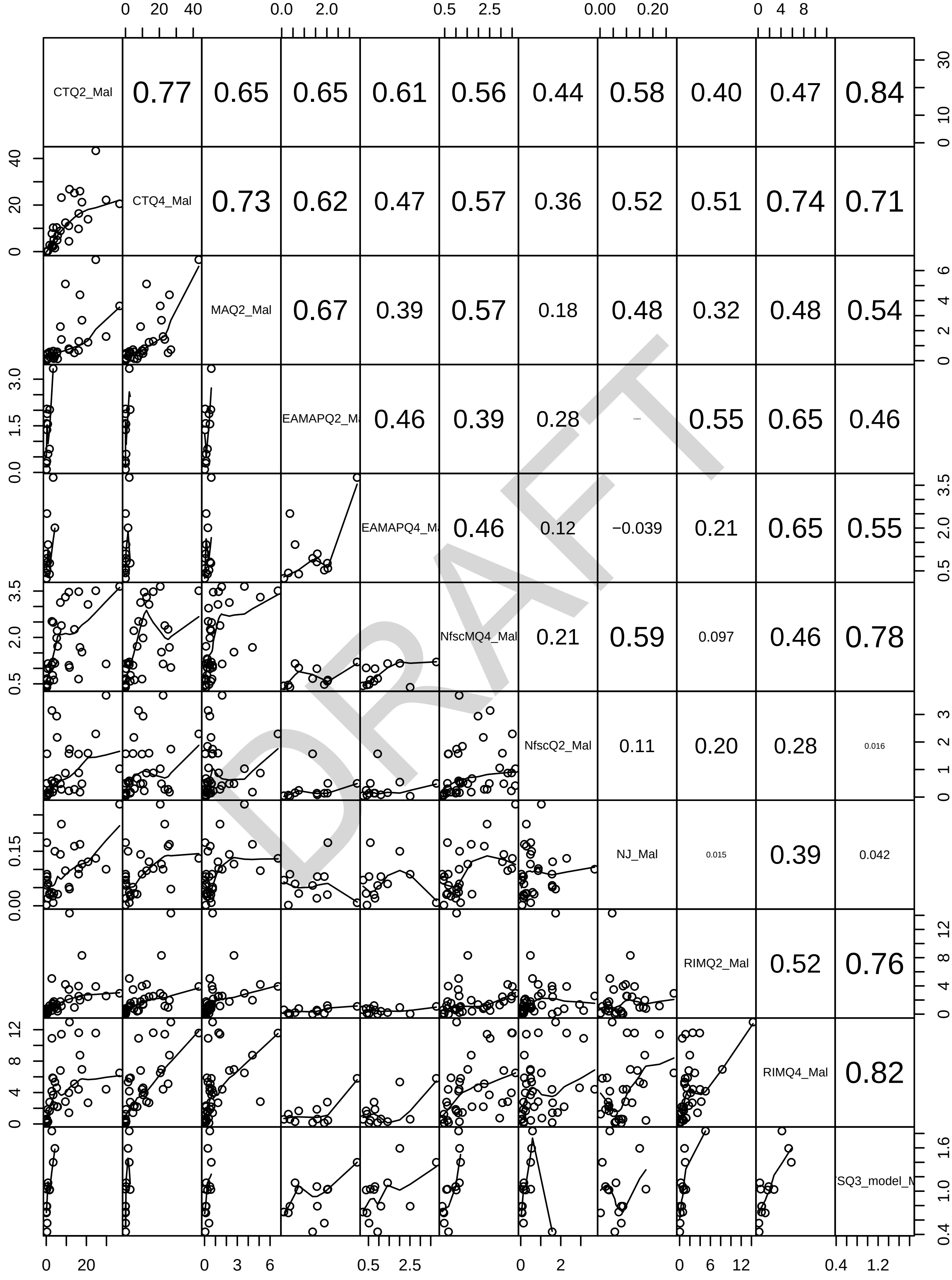
DRAFT

SNE_6F6_2019_orig_select
Pairwise scatterplots for survey trend data (Female)



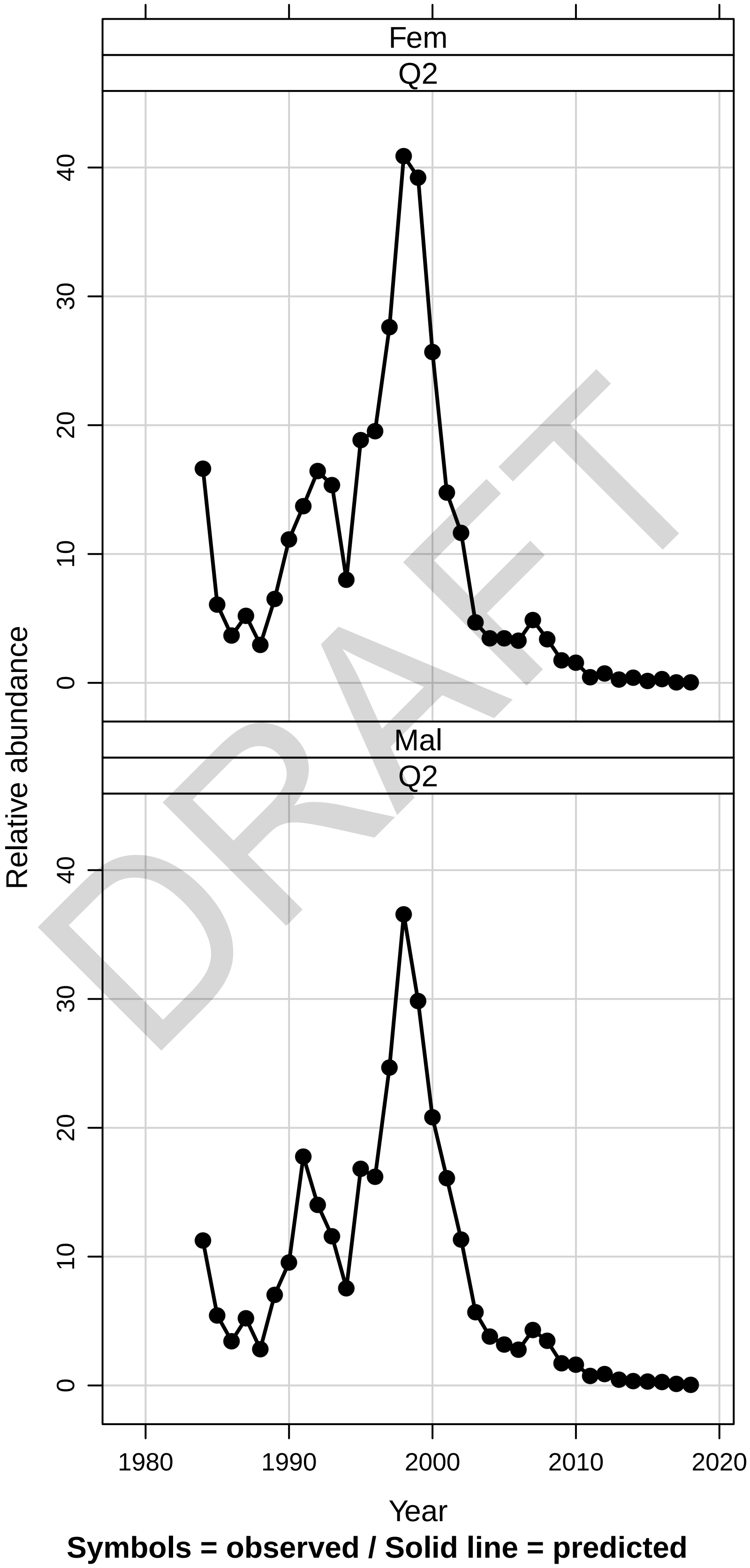
DRAFT

SNE_6F6_2019_orig_select
Pairwise scatterplots for survey trend data (Male)



DRAFT

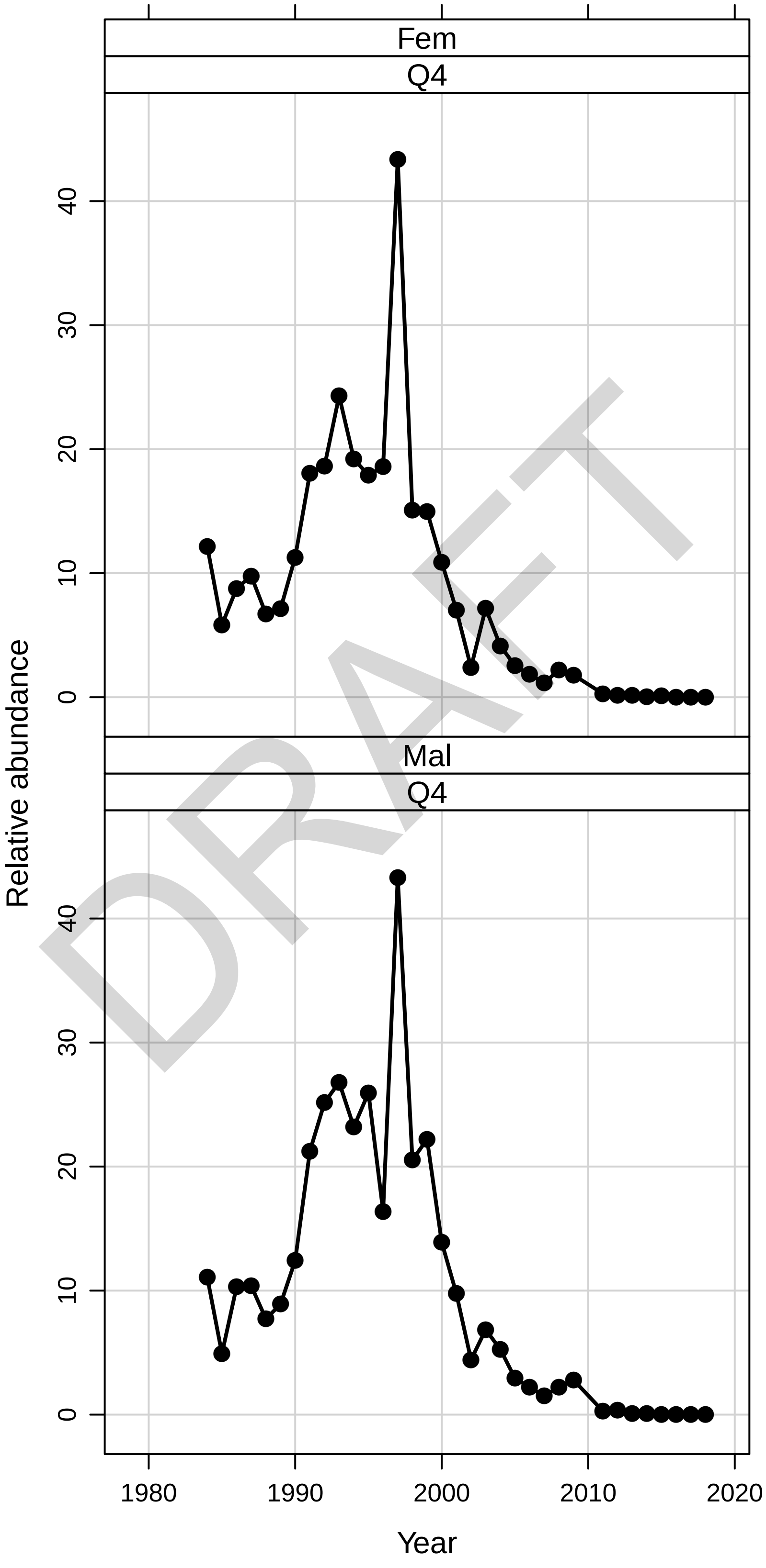
SNE_6F6_2019_orig_select
CTQ2 Survey trend data



Symbols = observed / Solid line = predicted

DRAFT

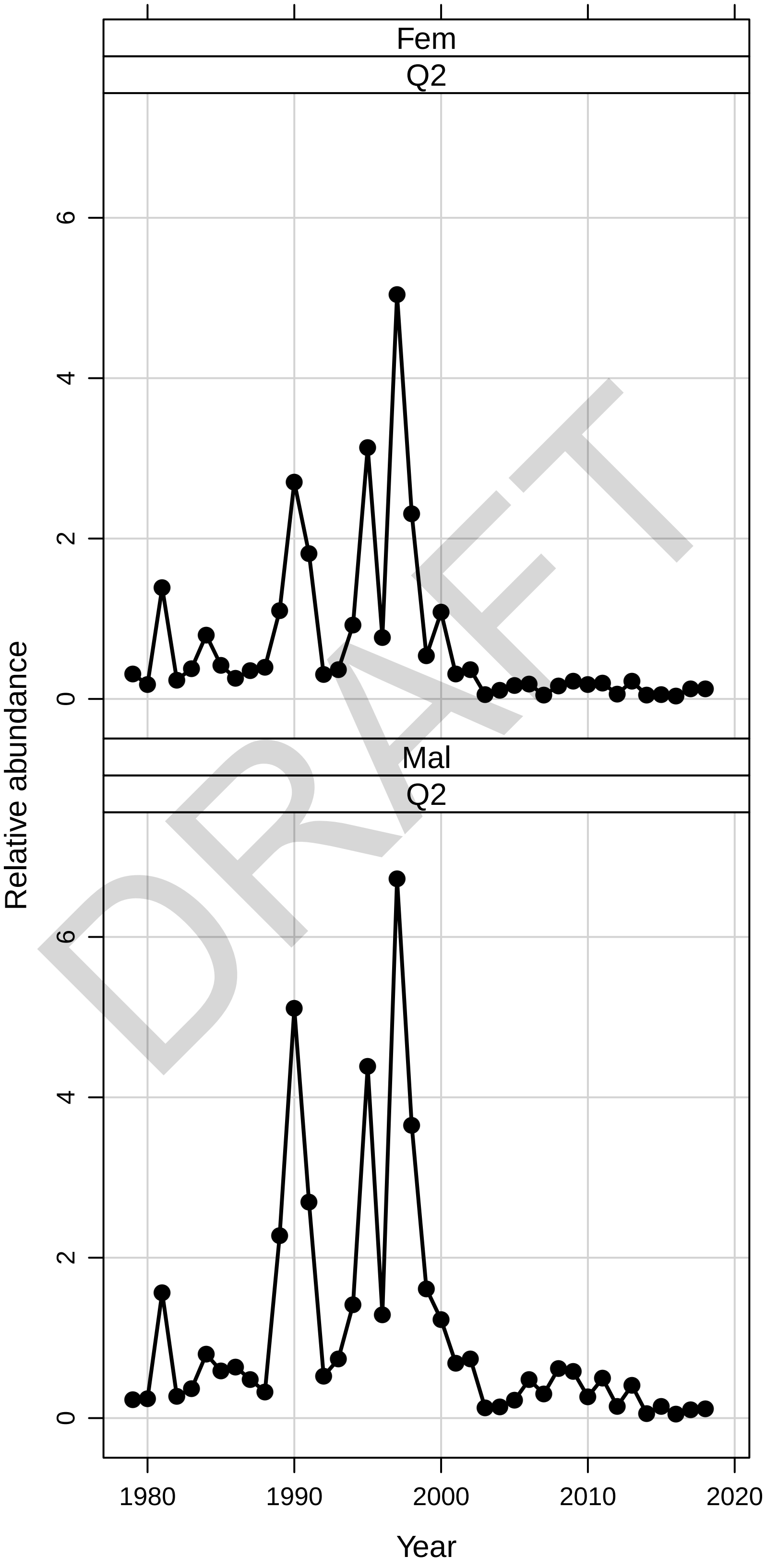
SNE_6F6_2019_orig_select
CTQ4 Survey trend data



Symbols = observed / Solid line = predicted

DRAFT

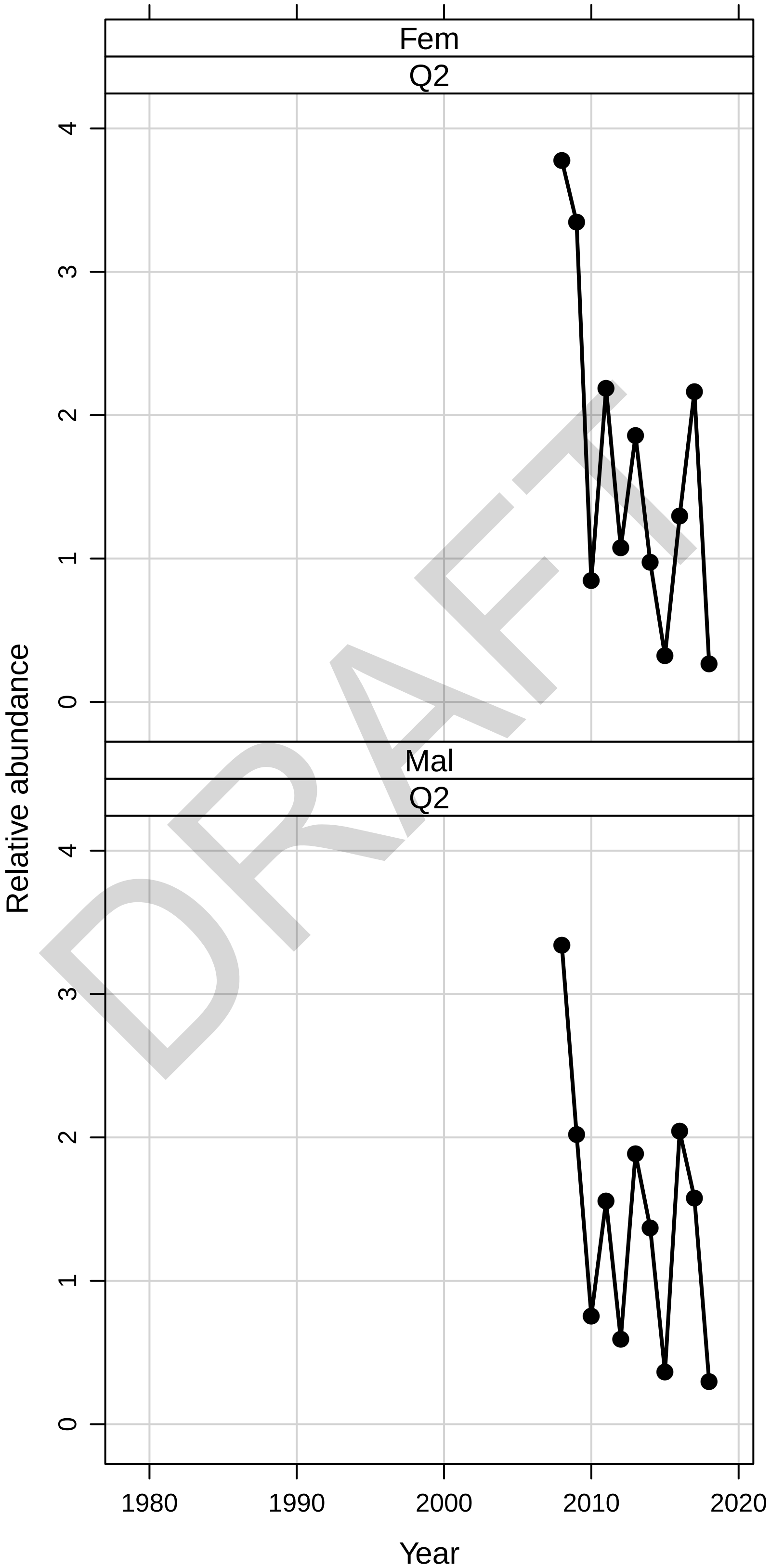
SNE_6F6_2019_orig_select
MAQ2 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

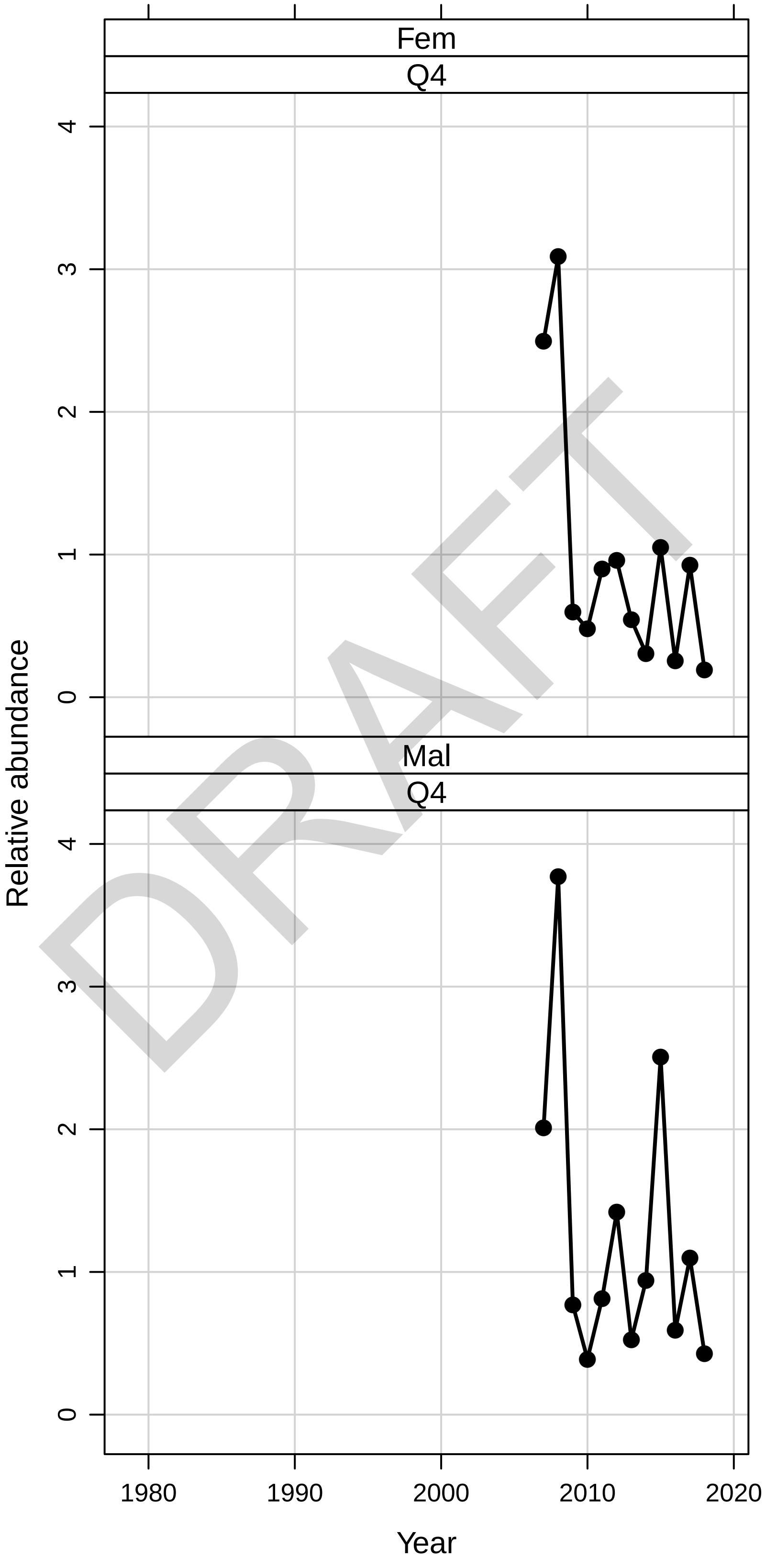
SNE_6F6_2019_orig_select
NEAMAPQ2 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

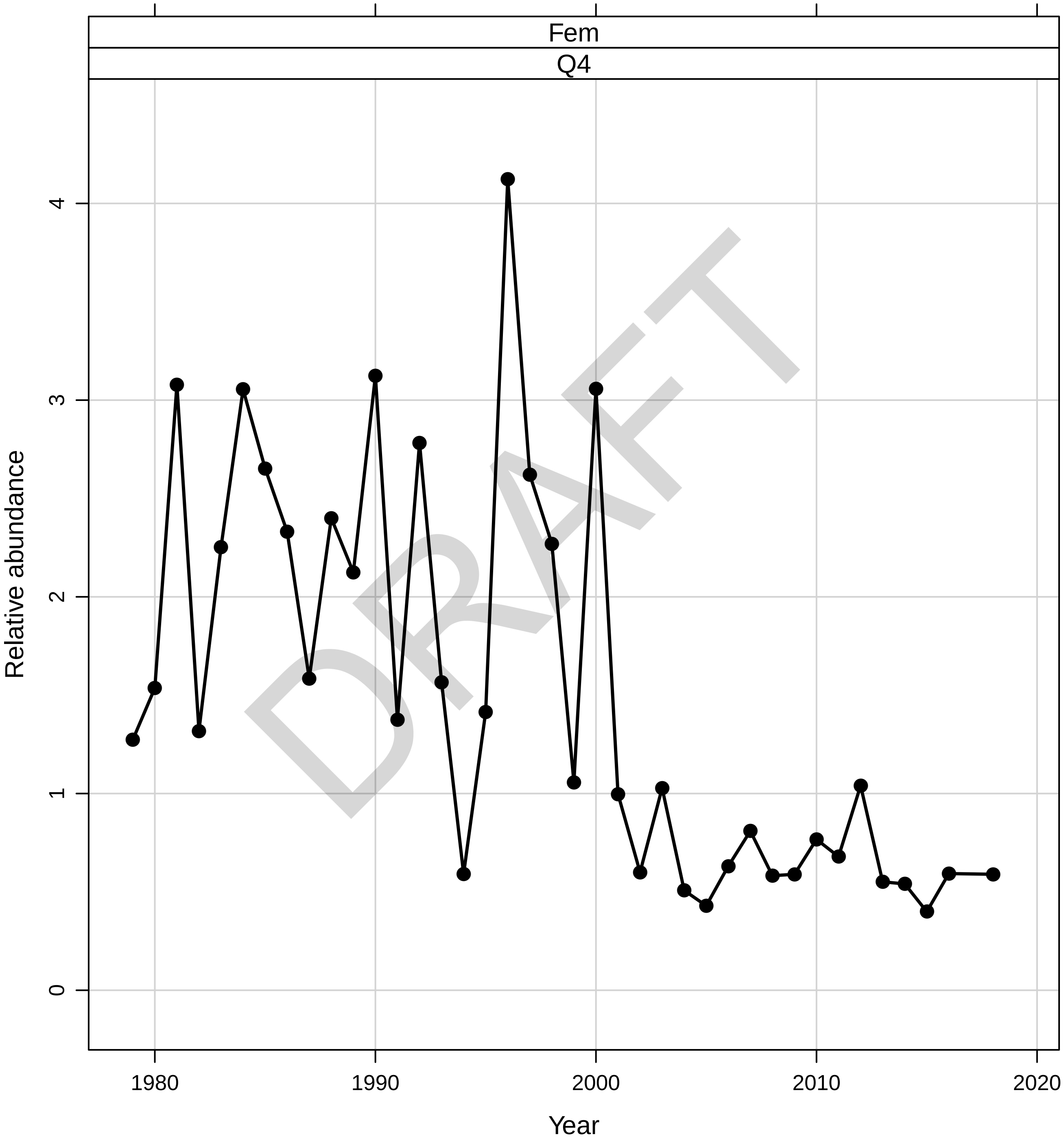
SNE_6F6_2019_orig_select
NEAMAPQ4 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

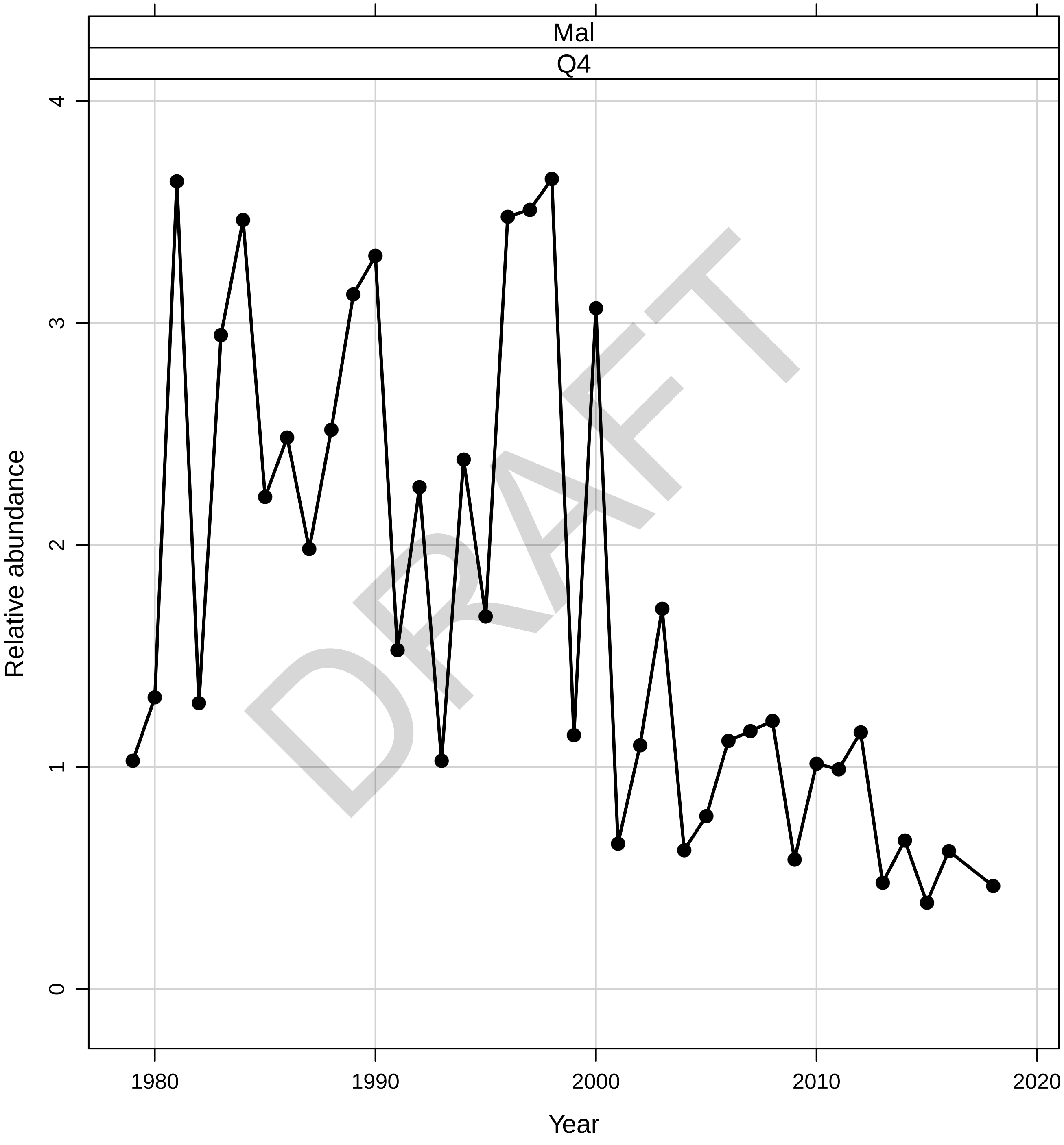
SNE_6F6_2019_orig_select
NfscFQ4 Survey trend data



DRAFT

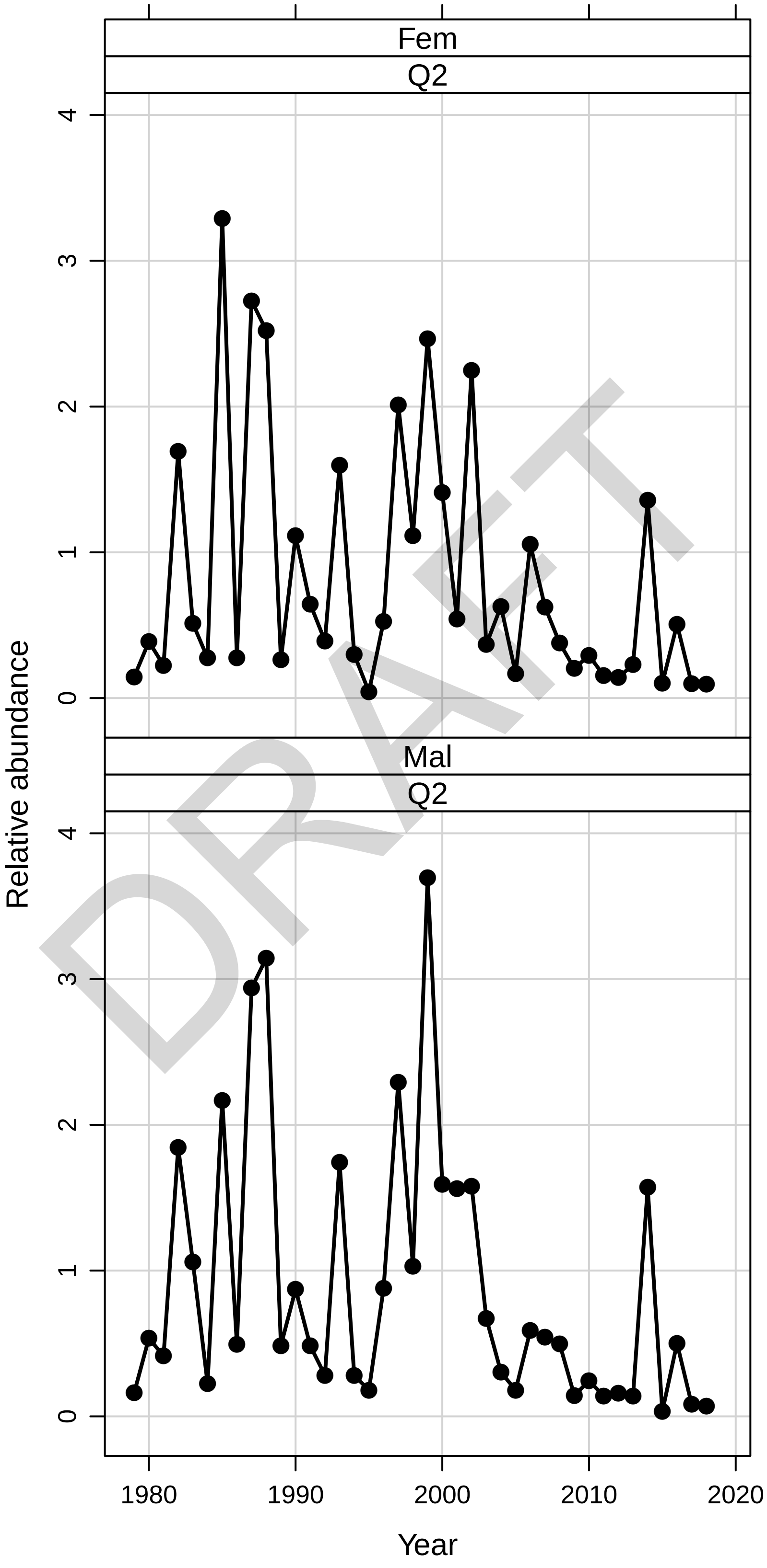
Symbols = observed / Solid line = predicted

SNE_6F6_2019_orig_select
NfscMQ4 Survey trend data



Symbols = observed / Solid line = predicted

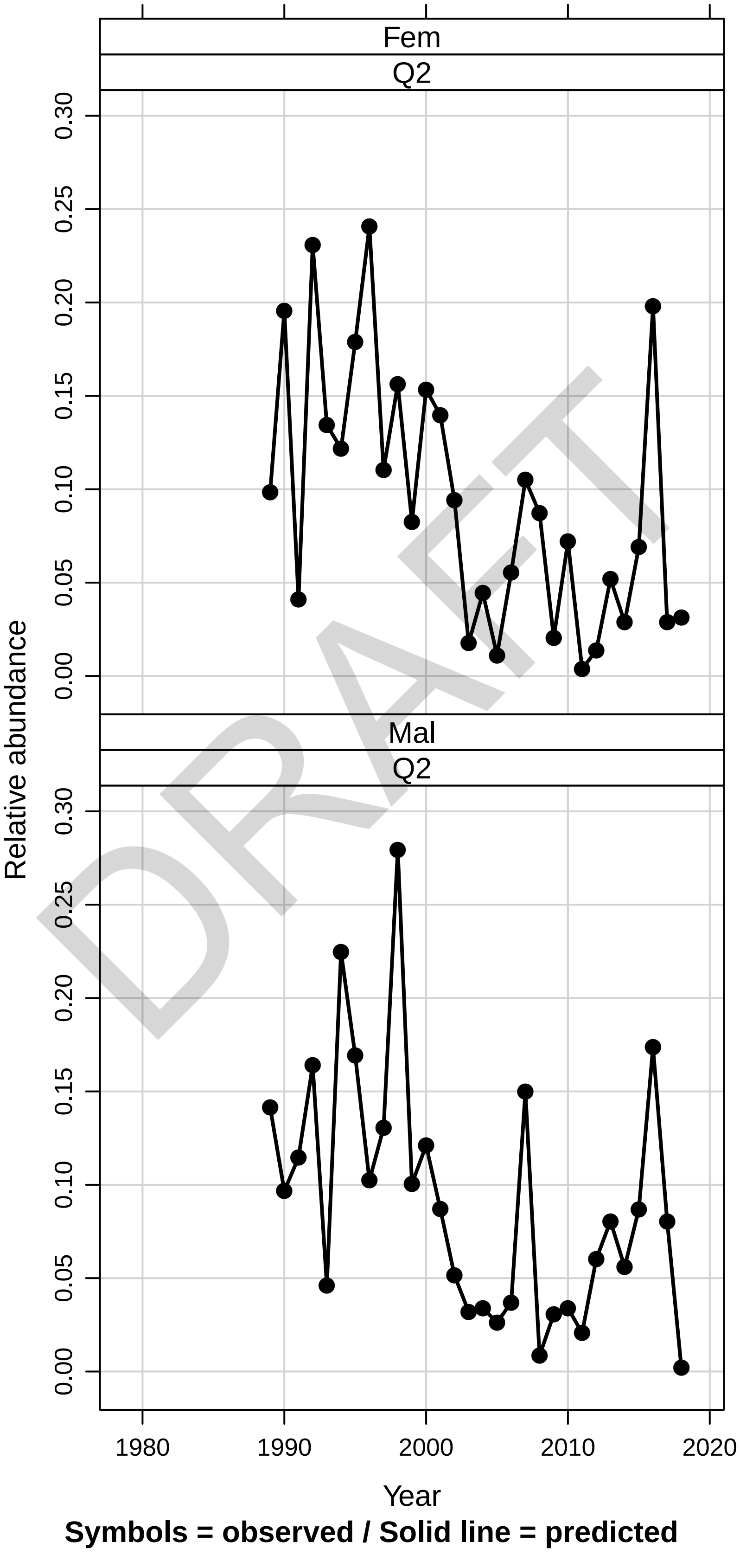
SNE_6F6_2019_orig_select
NfscQ2 Survey trend data



Symbols = observed / Solid line = predicted

DRAFT

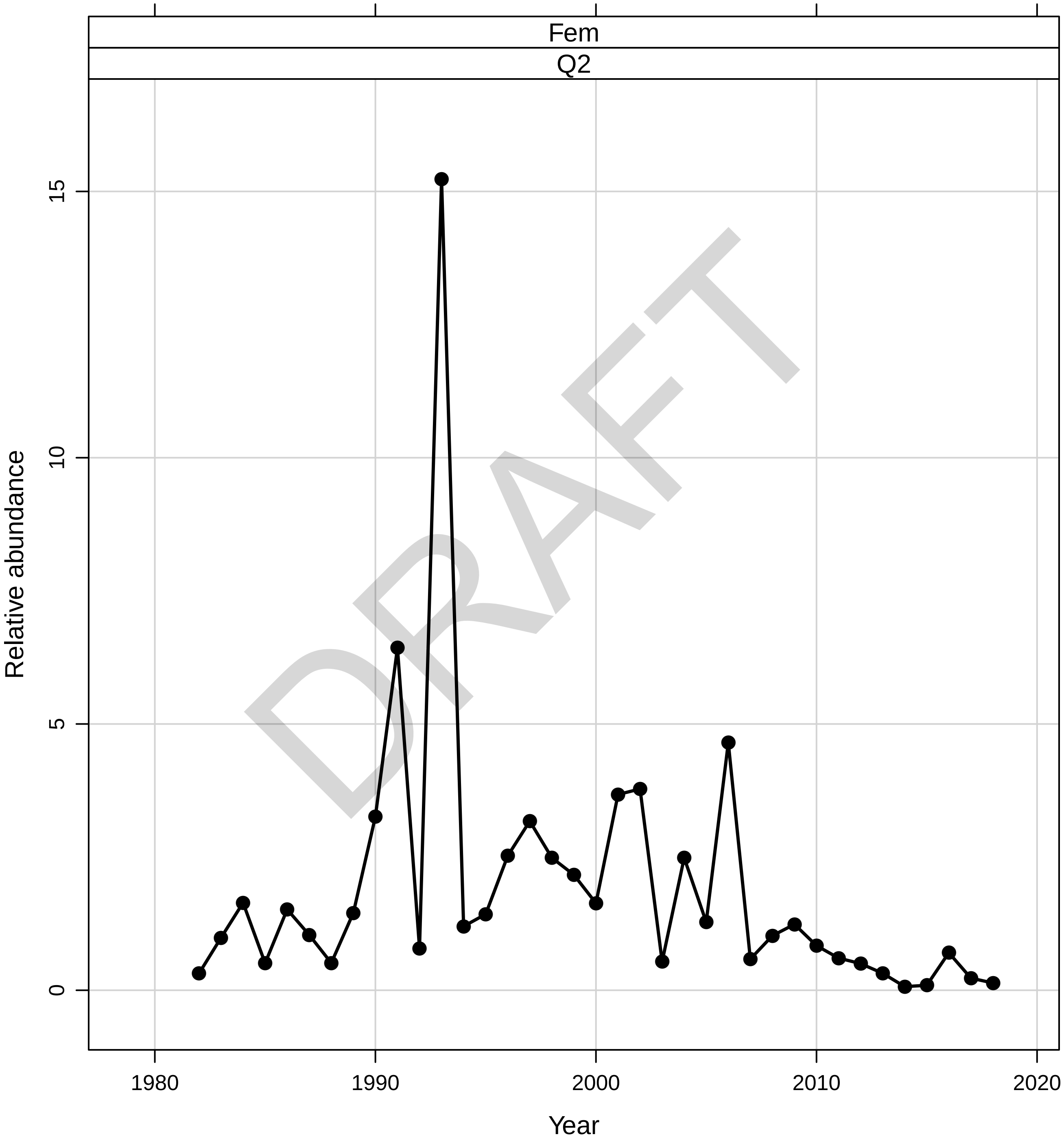
SNE_6F6_2019_orig_select
NJ Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

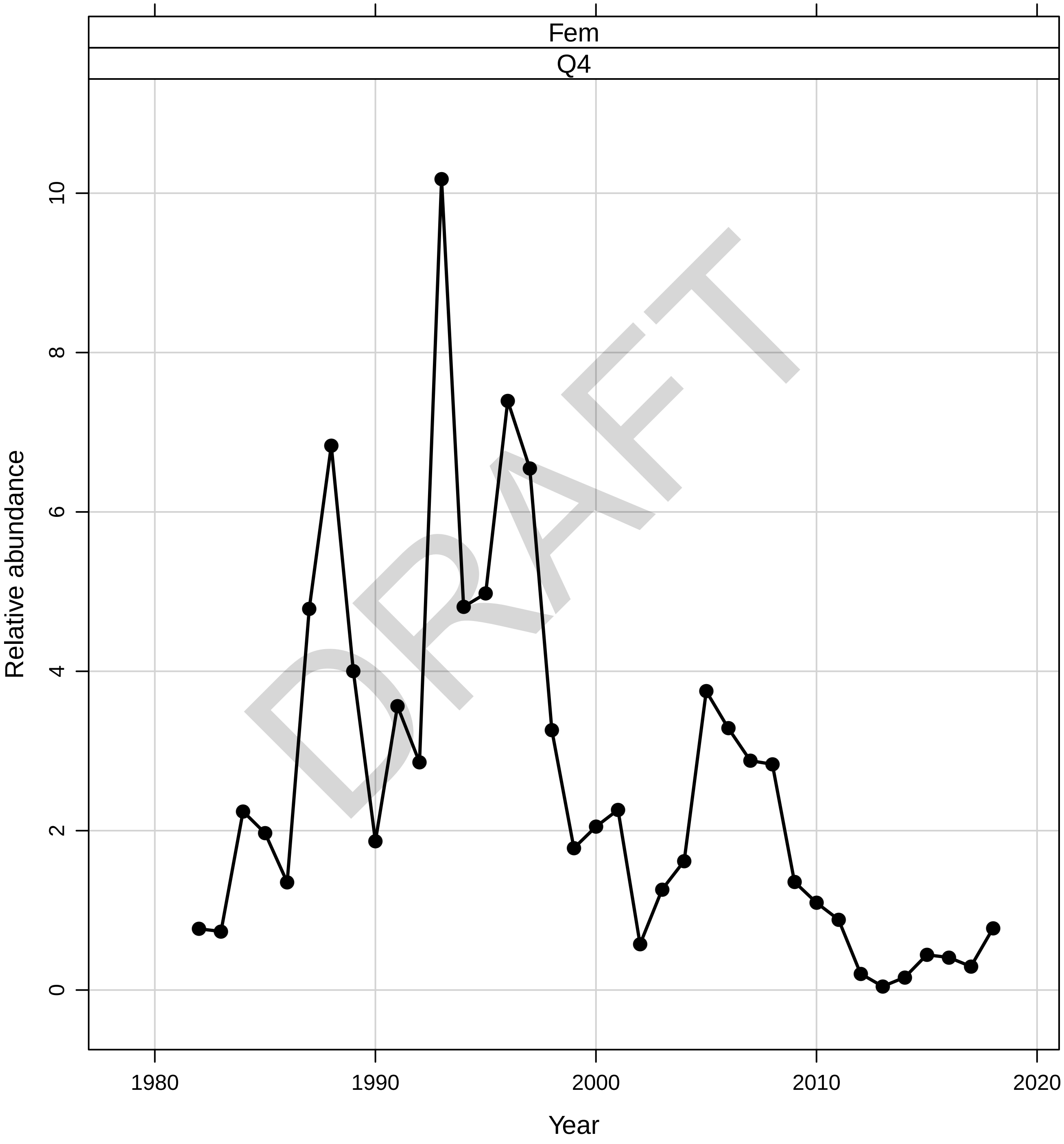
SNE_6F6_2019_orig_select
RIFQ2 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

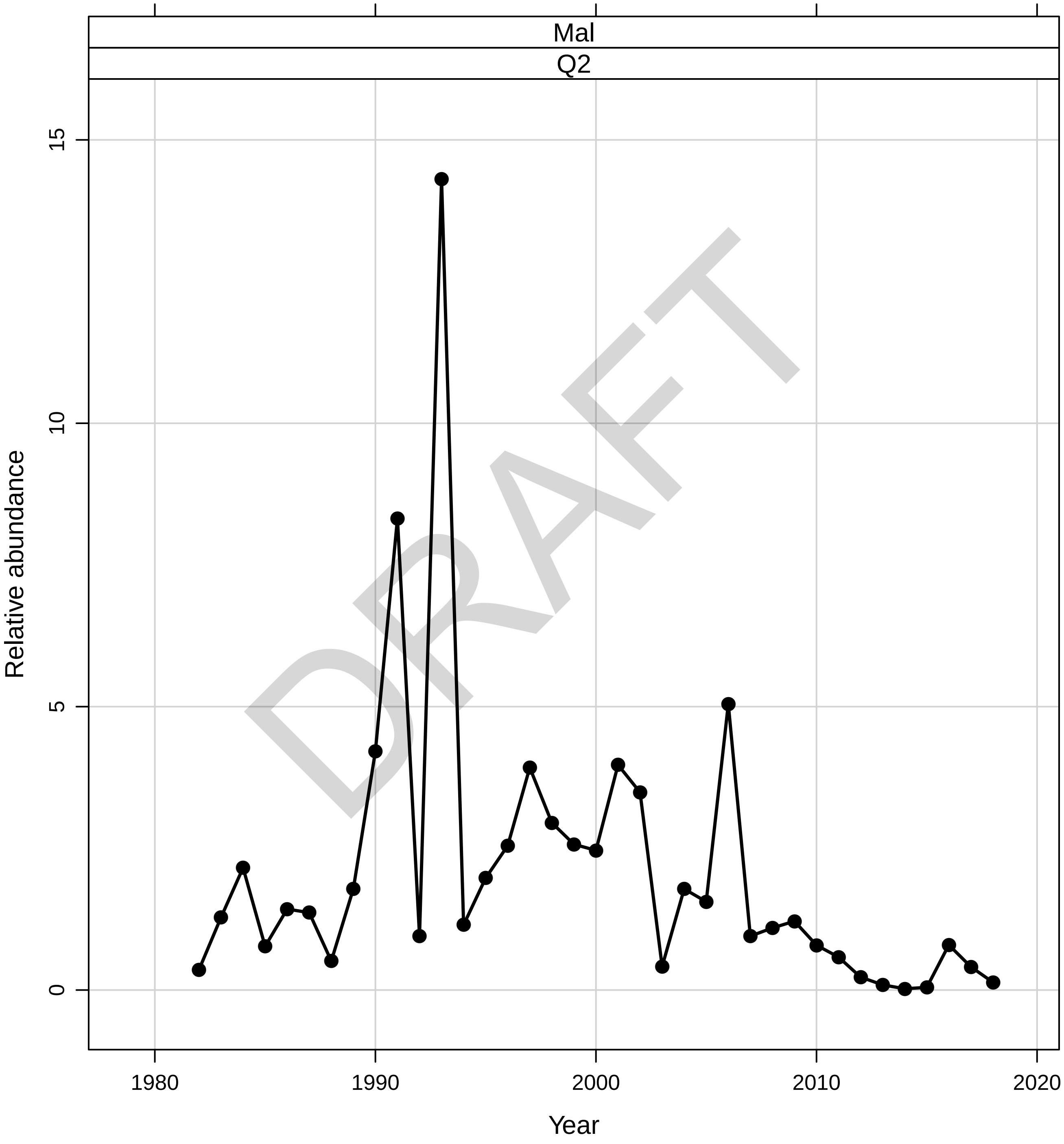
SNE_6F6_2019_orig_select
RIFQ4 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

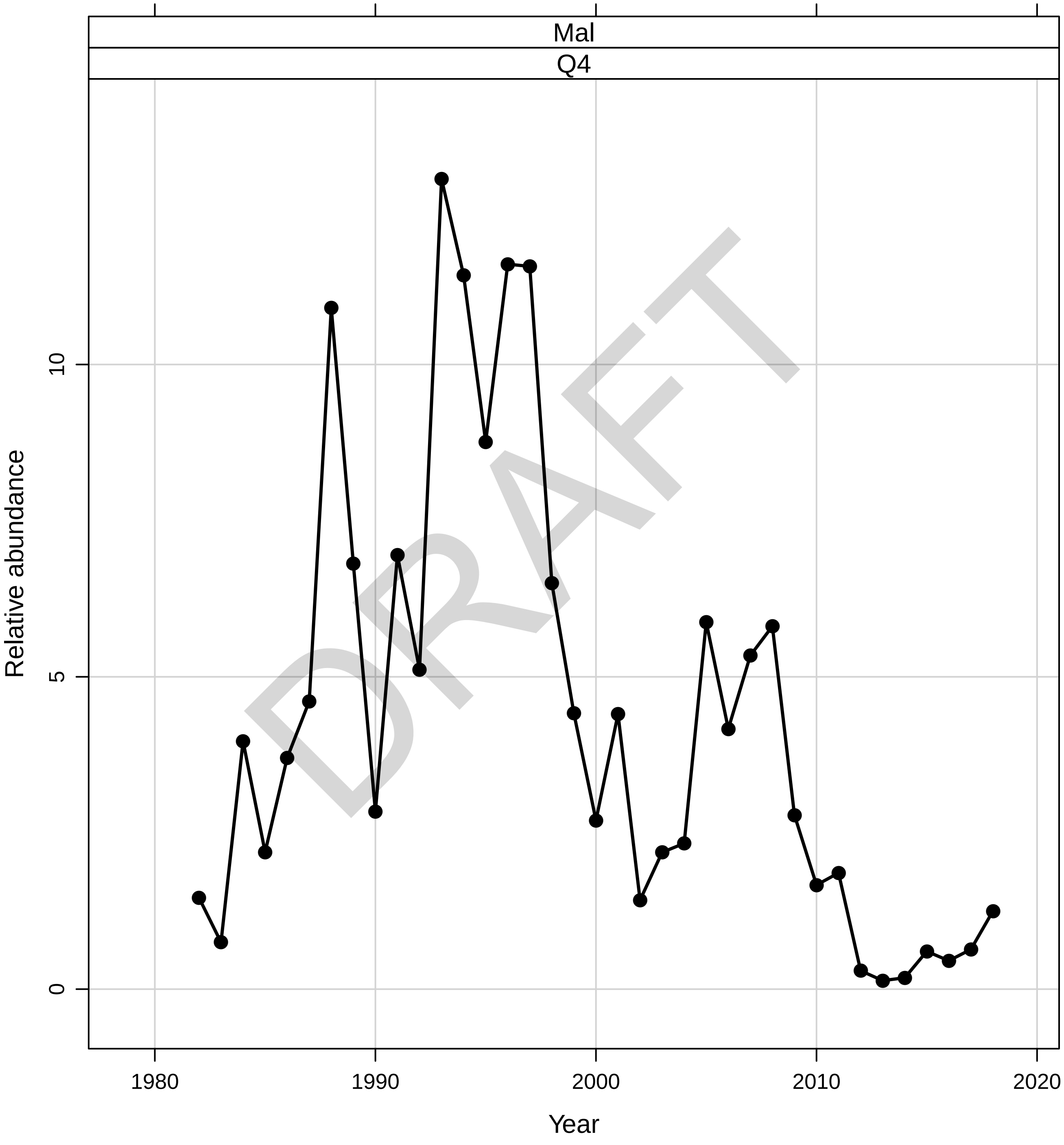
SNE_6F6_2019_orig_select
RIMQ2 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

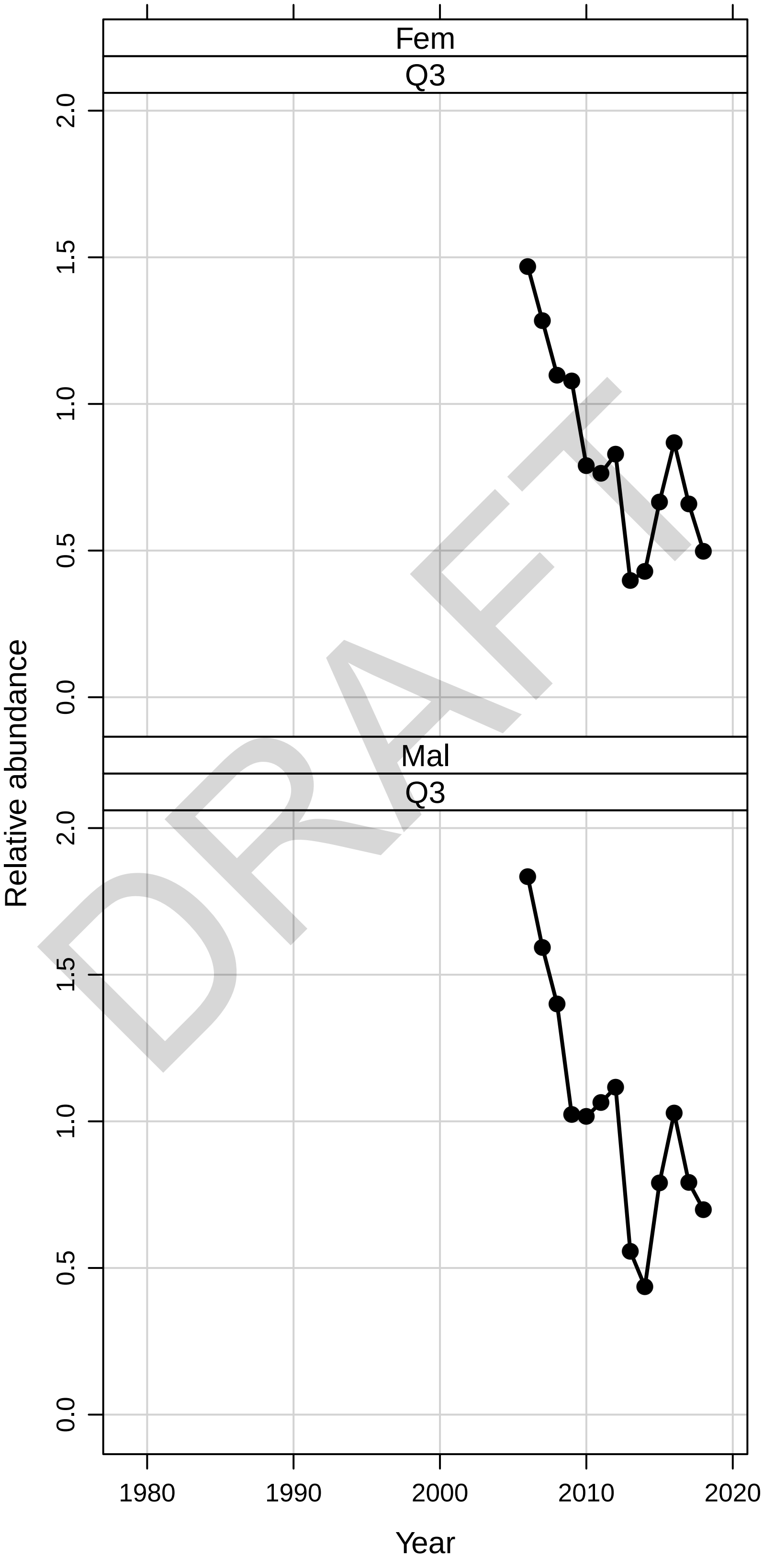
SNE_6F6_2019_orig_select
RIMQ4 Survey trend data



DRAFT

Symbols = observed / Solid line = predicted

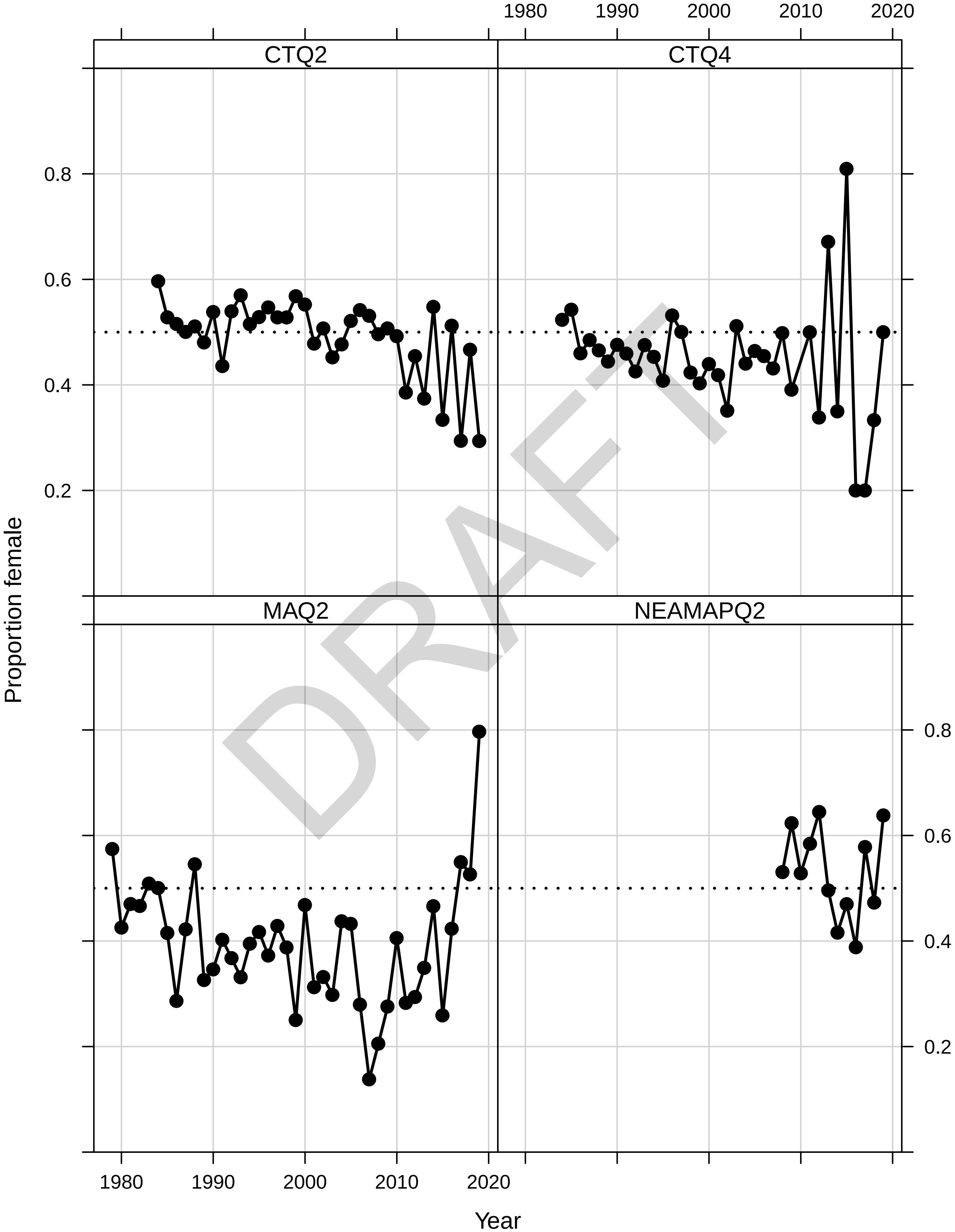
SNE_6F6_2019_orig_select VTSQ3_model Survey trend data



DRAFT

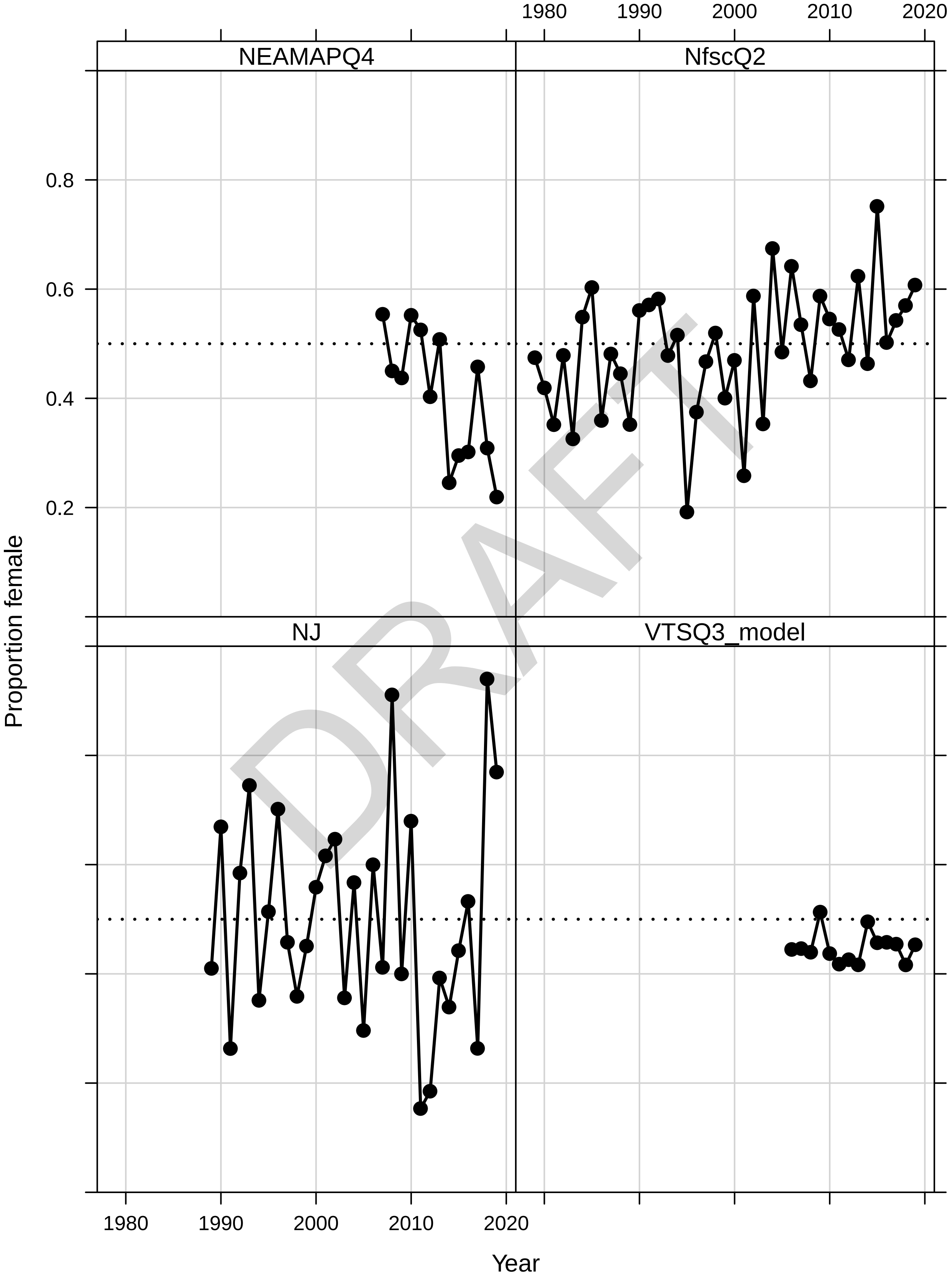
Symbols = observed / Solid line = predicted

SNE_6F6_2019_orig_select
Survey sex ratio data



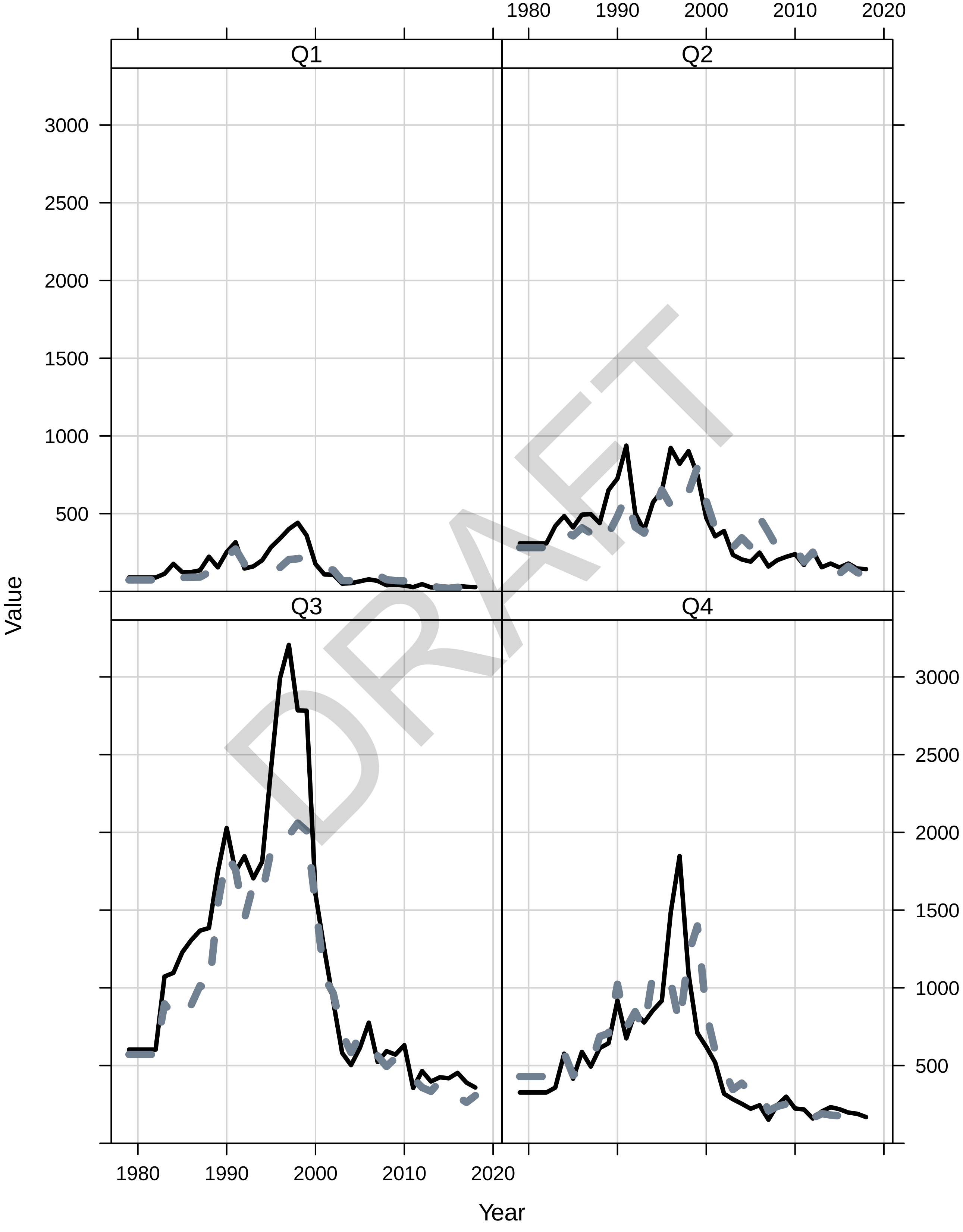
DRAFT

SNE_6F6_2019_orig_select
Survey sex ratio data



DRAFT

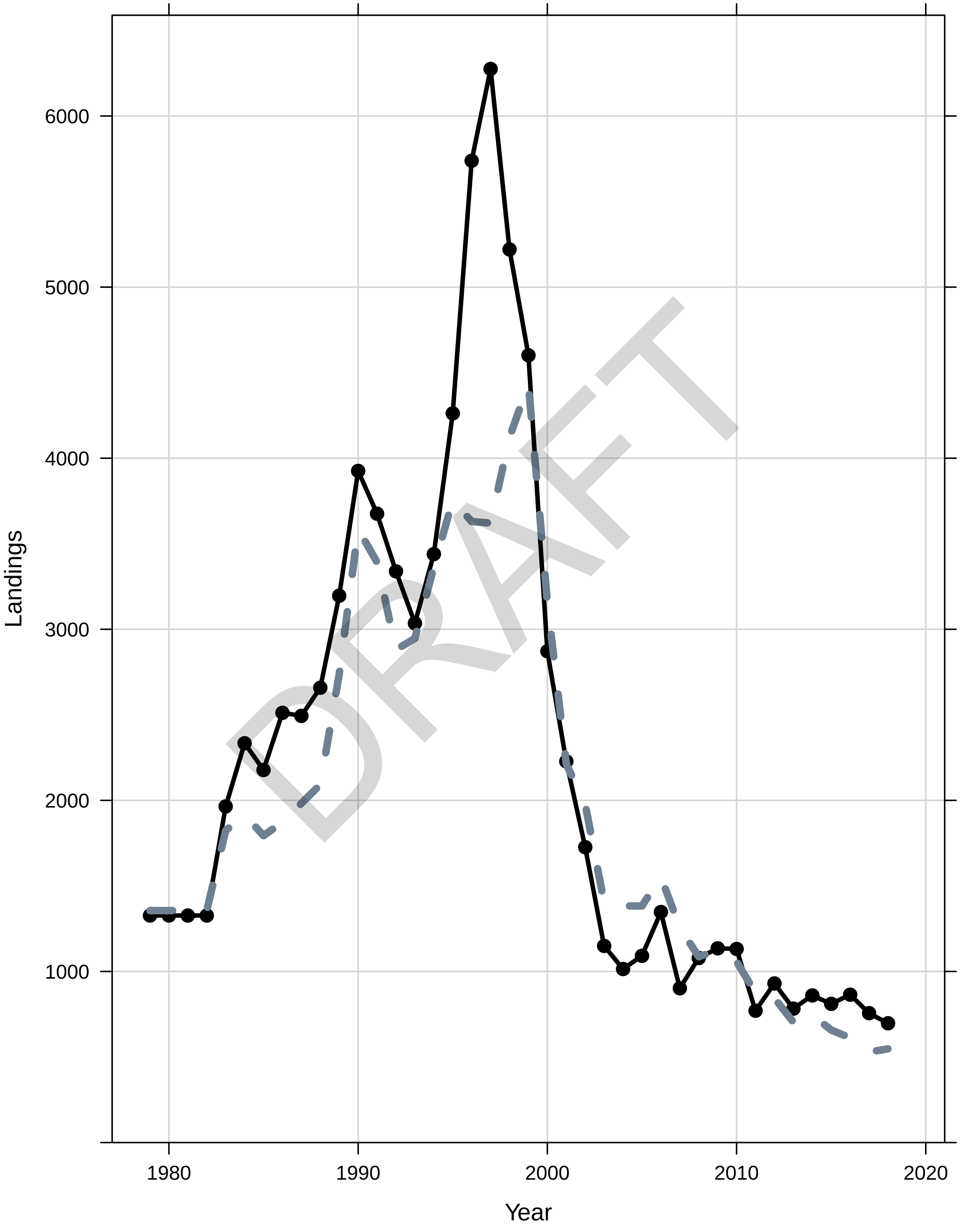
SNE_6F6_2019_orig_select
landings



DRAFT

Females black / Males grey

SNE_6F6_2019_orig_select
landings



DRAFT

Females black / Males grey

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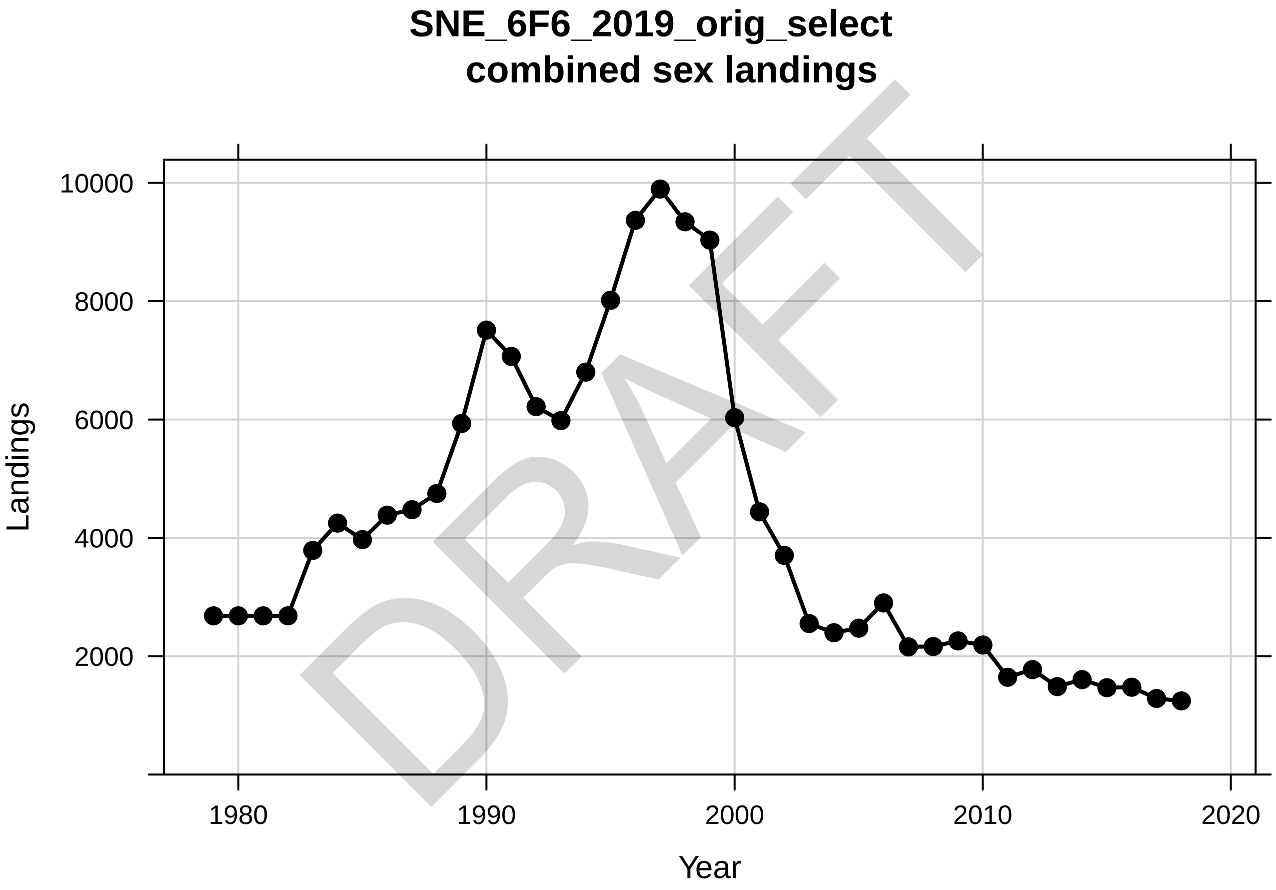
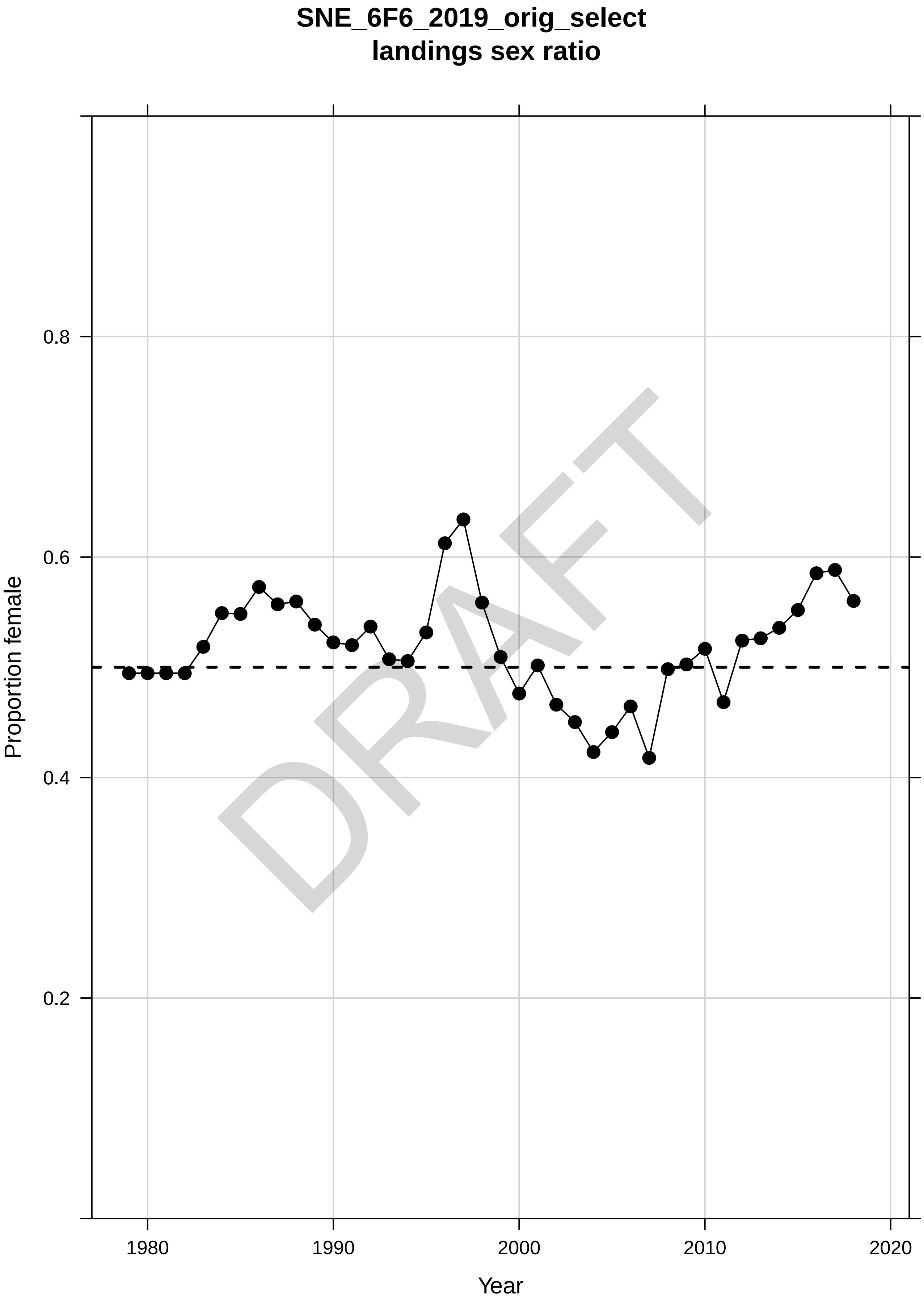
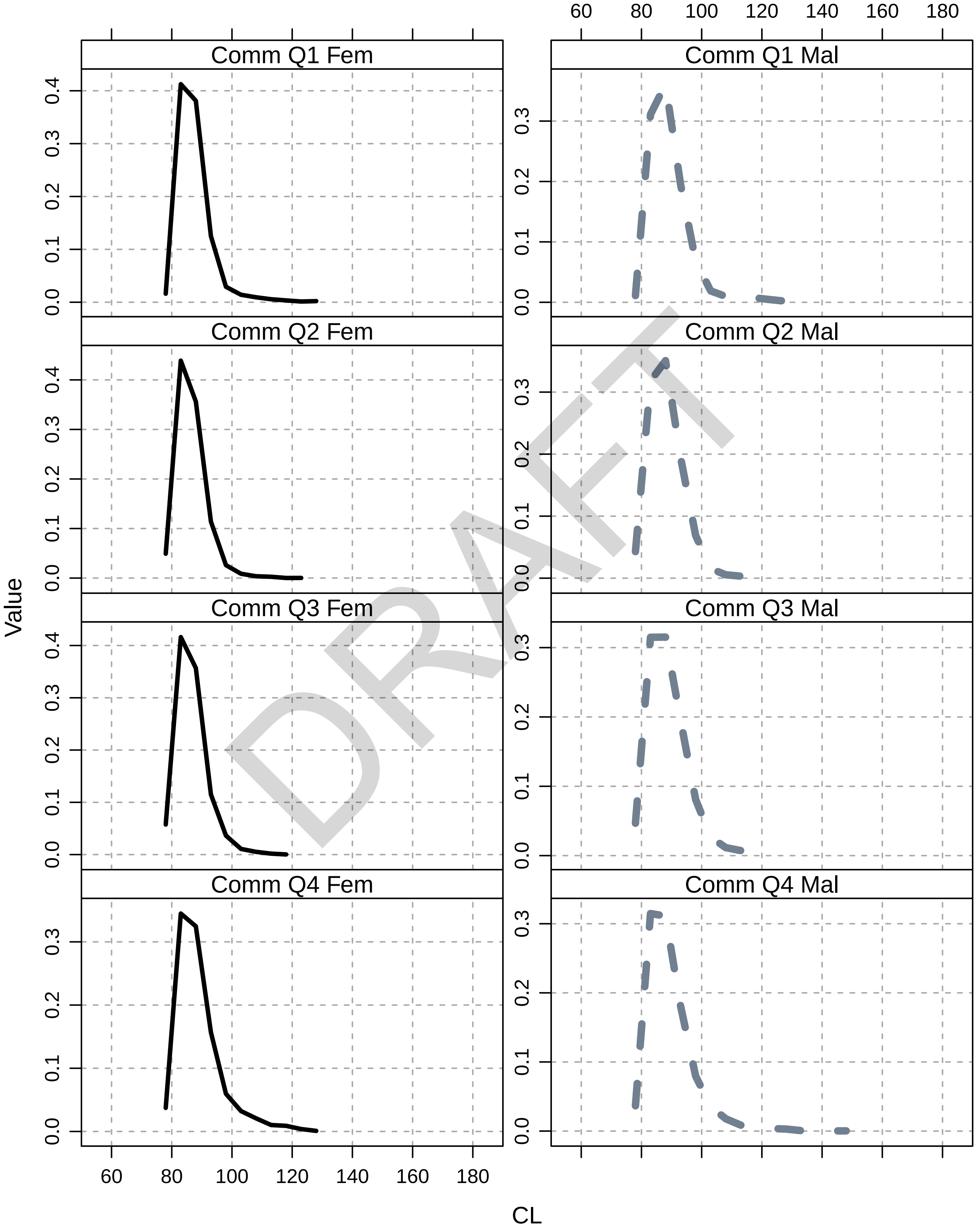


DRAFT


SNE_6F6_2019_orig_select
landings sex ratio
Proportion female
0.2
0.4
0.6
0.8
1980
1990
2000
2010
2020
Year

DRAFT

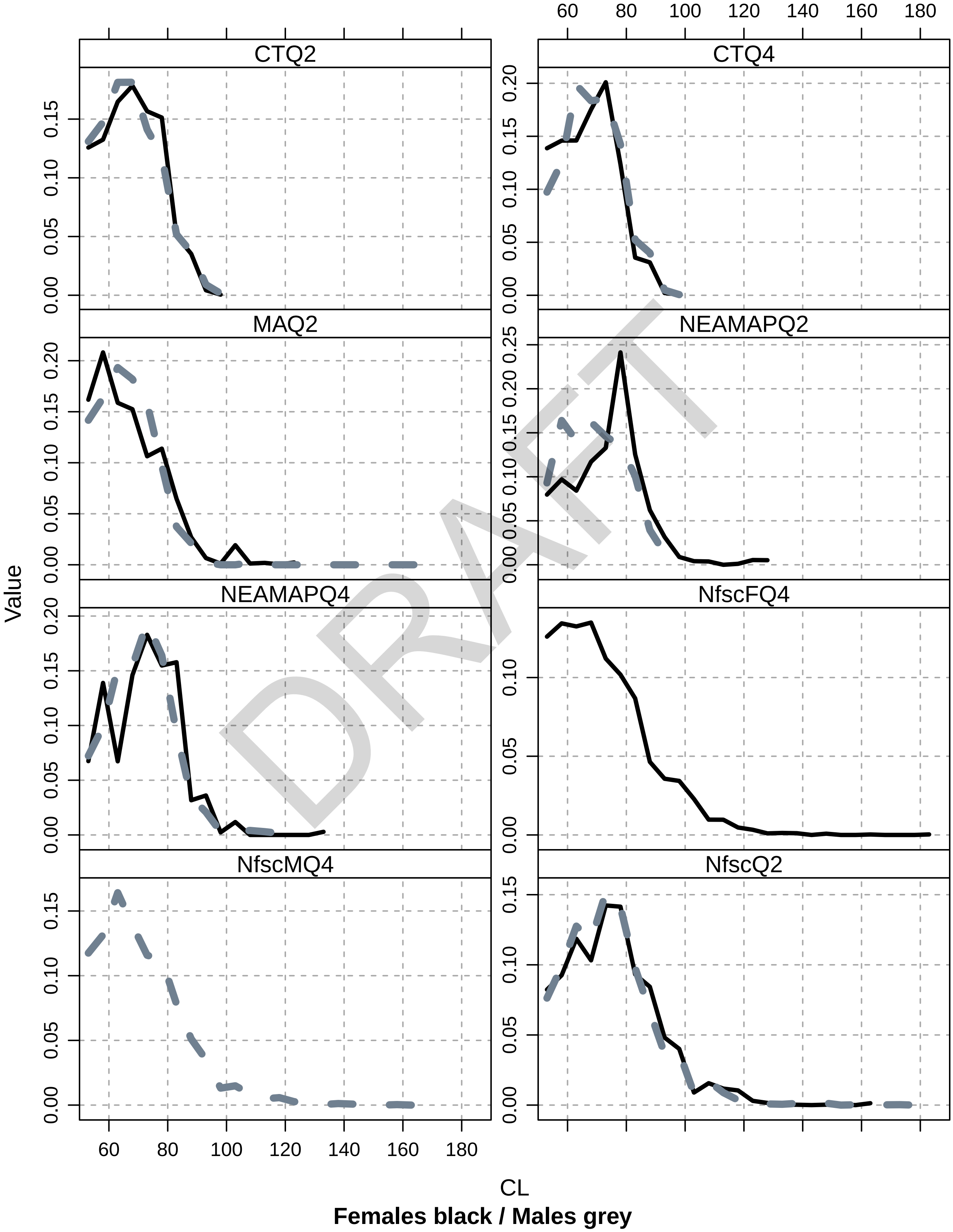
SNE_6F6_2019_orig_select
Average length data by season and sex



DRAFT

Females black / Males grey

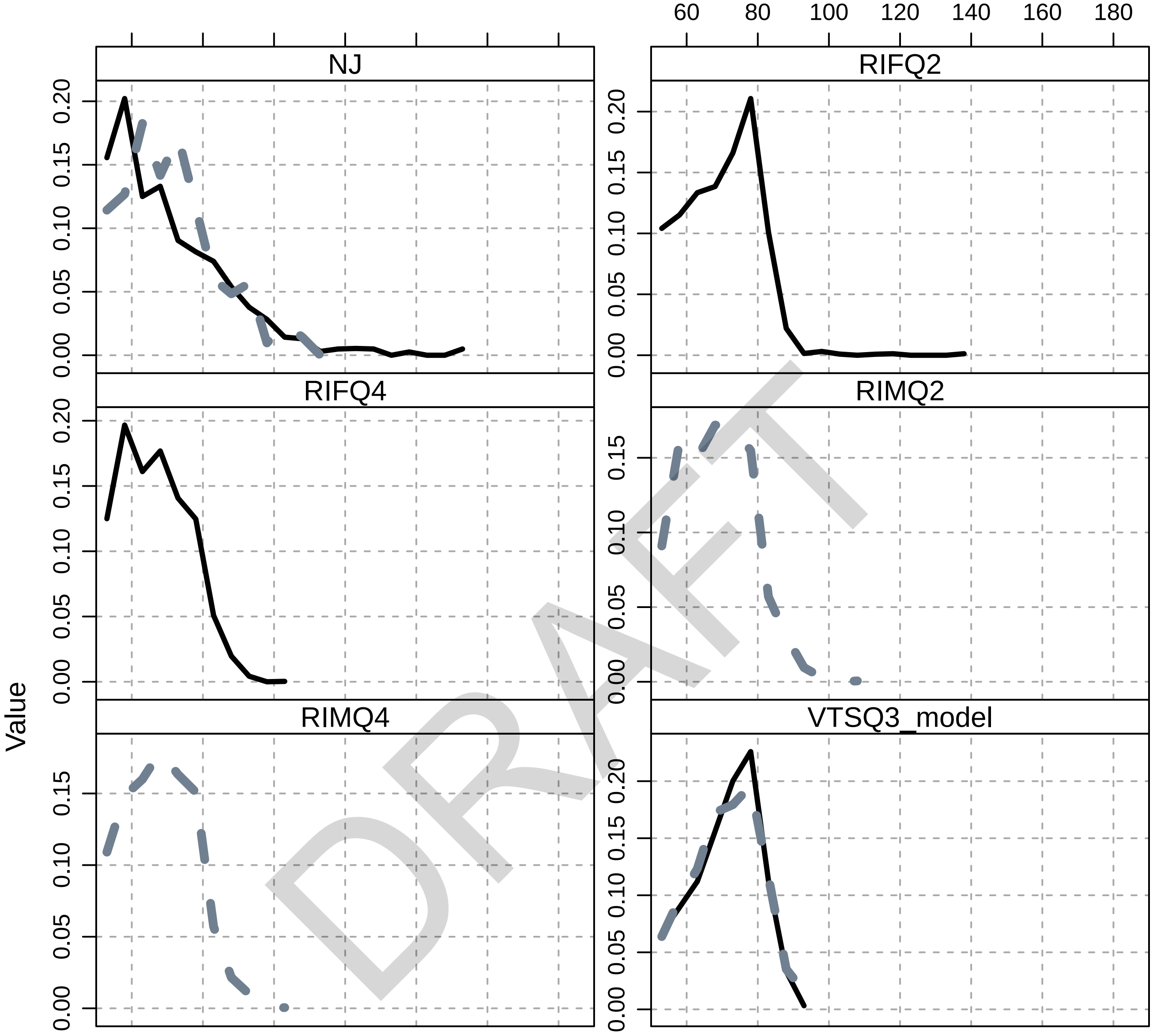
SNE_6F6_2019_orig_select
Average length data by season and sex



Females black / Males grey

DRAFT

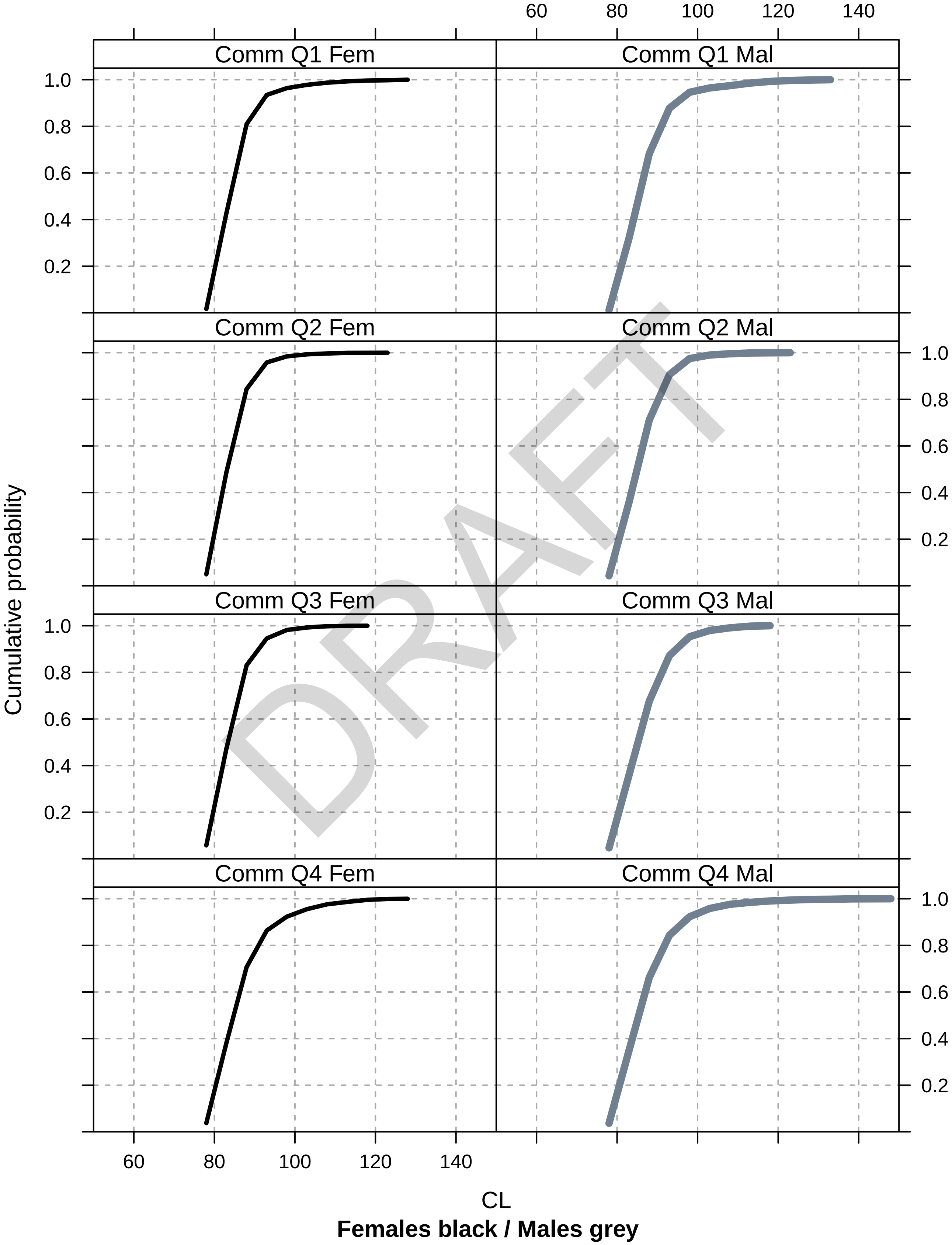
SNE_6F6_2019_orig_select
Average length data by season and sex



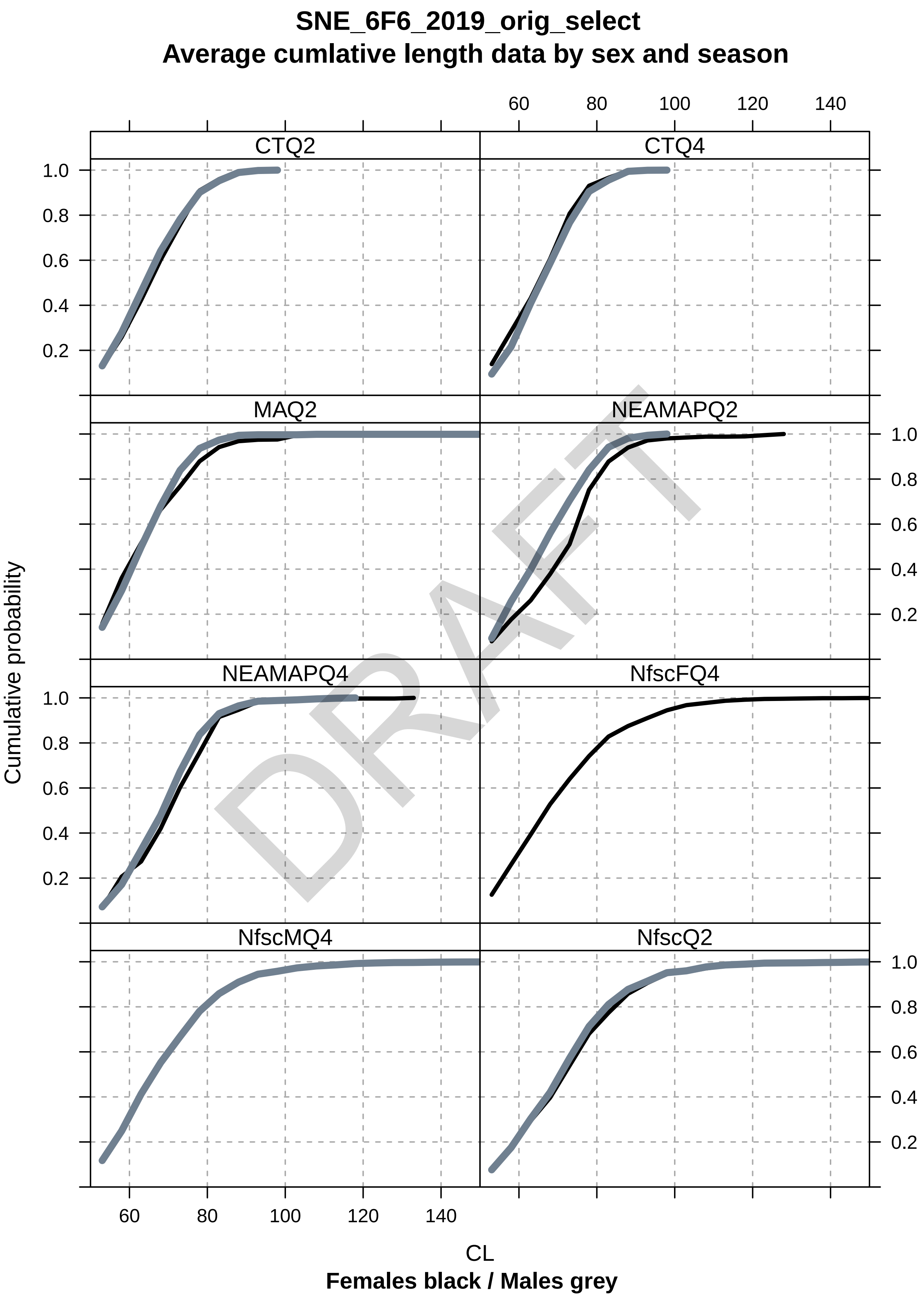
CL

Females black / Males grey

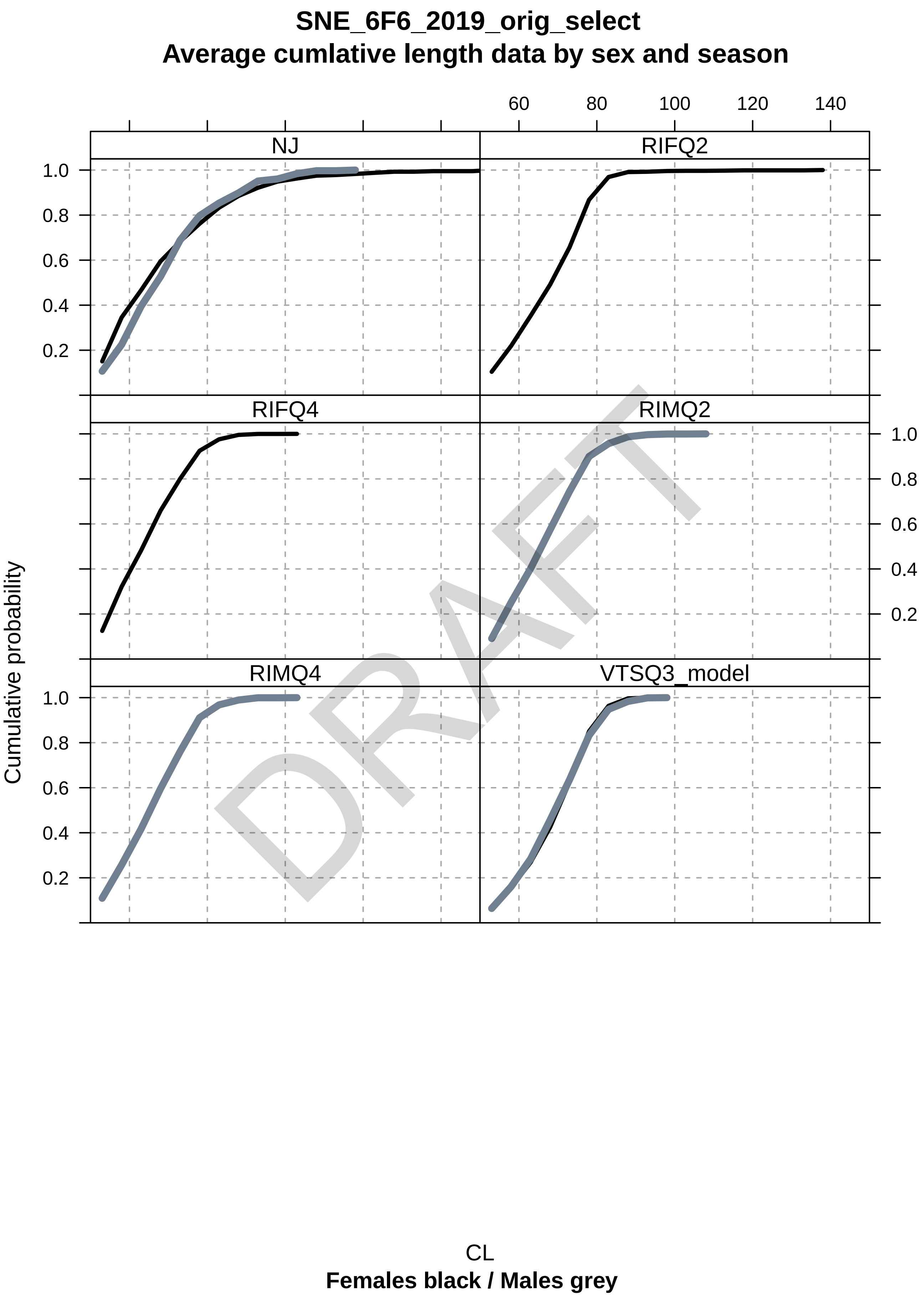
SNE_6F6_2019_orig_select
Average cumlative length data by sex and season



DRAFT

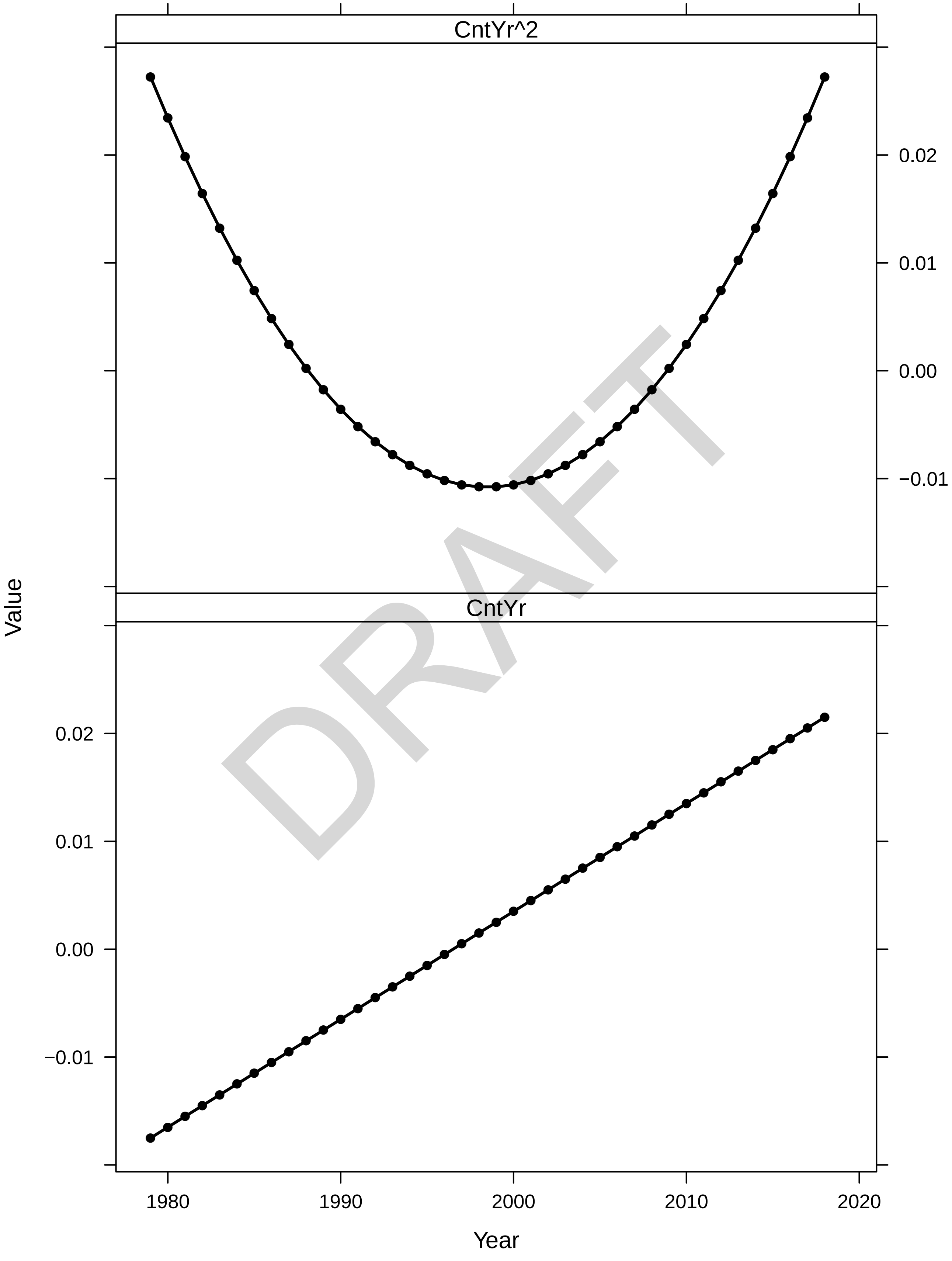

SNE_6F6_2019_orig_select
Average cumlative length data by sex and season
CTQ2
CTQ4
MAQ2
NEAMAPQ2
NEAMAPQ4
NfscFQ4
NfscMQ4
NfscQ2
Cumulative probability
0.2
0.4
0.6
0.8
1.0
60
80
100
120
140
CL
Females black / Males grey

DRAFT


SNE_6F6_2019_orig_select
Average cumlative length data by sex and season
NJ
RIFQ2
RIFQ4
RIMQ2
RIMQ4
VTSQ3_model
60
80
100
120
140
0.2
0.4
0.6
0.8
1.0
Cumulative probability
CL
Females black / Males grey

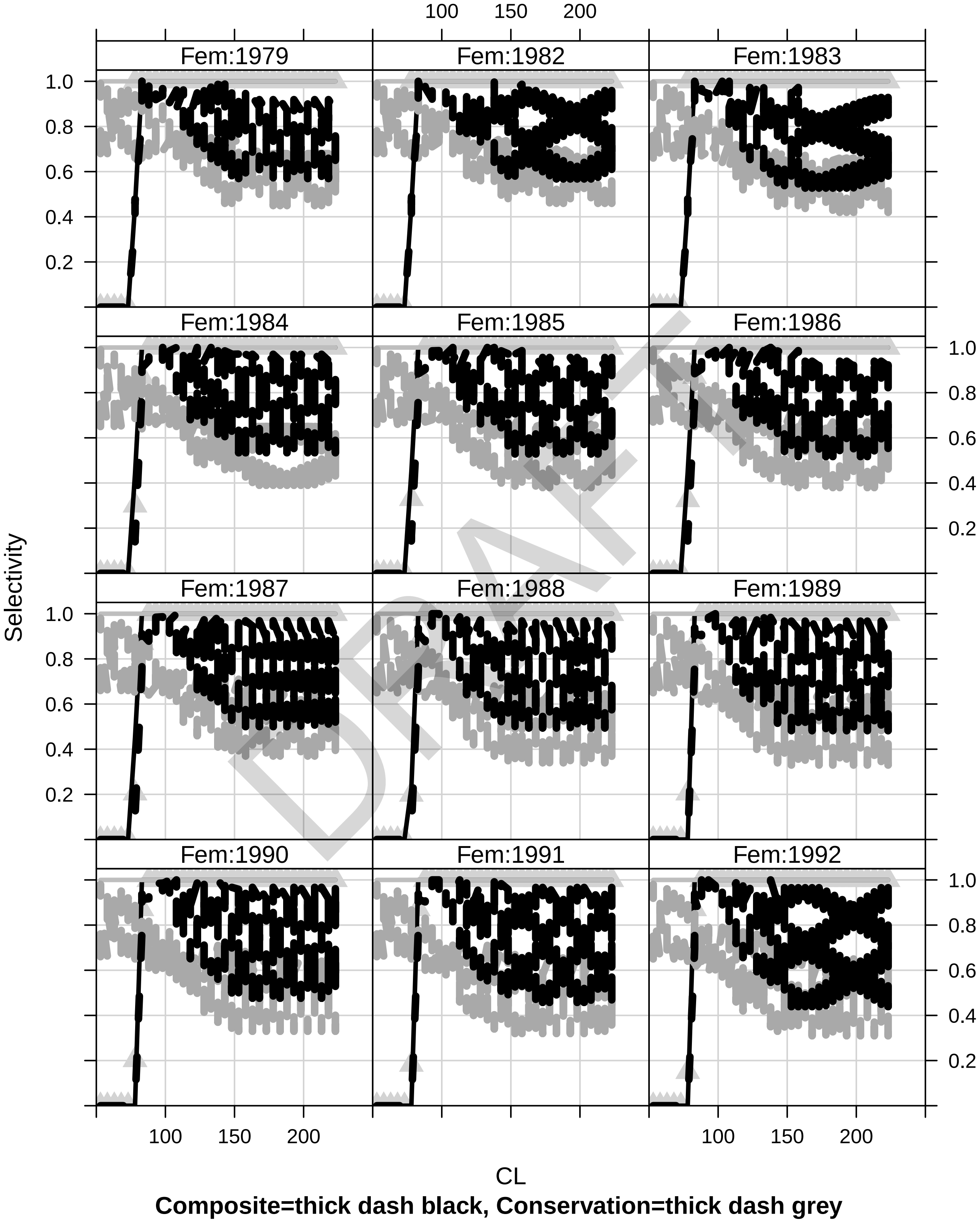
DRAFT

Recruitment covariates used in model Year Covariate



DRAFT

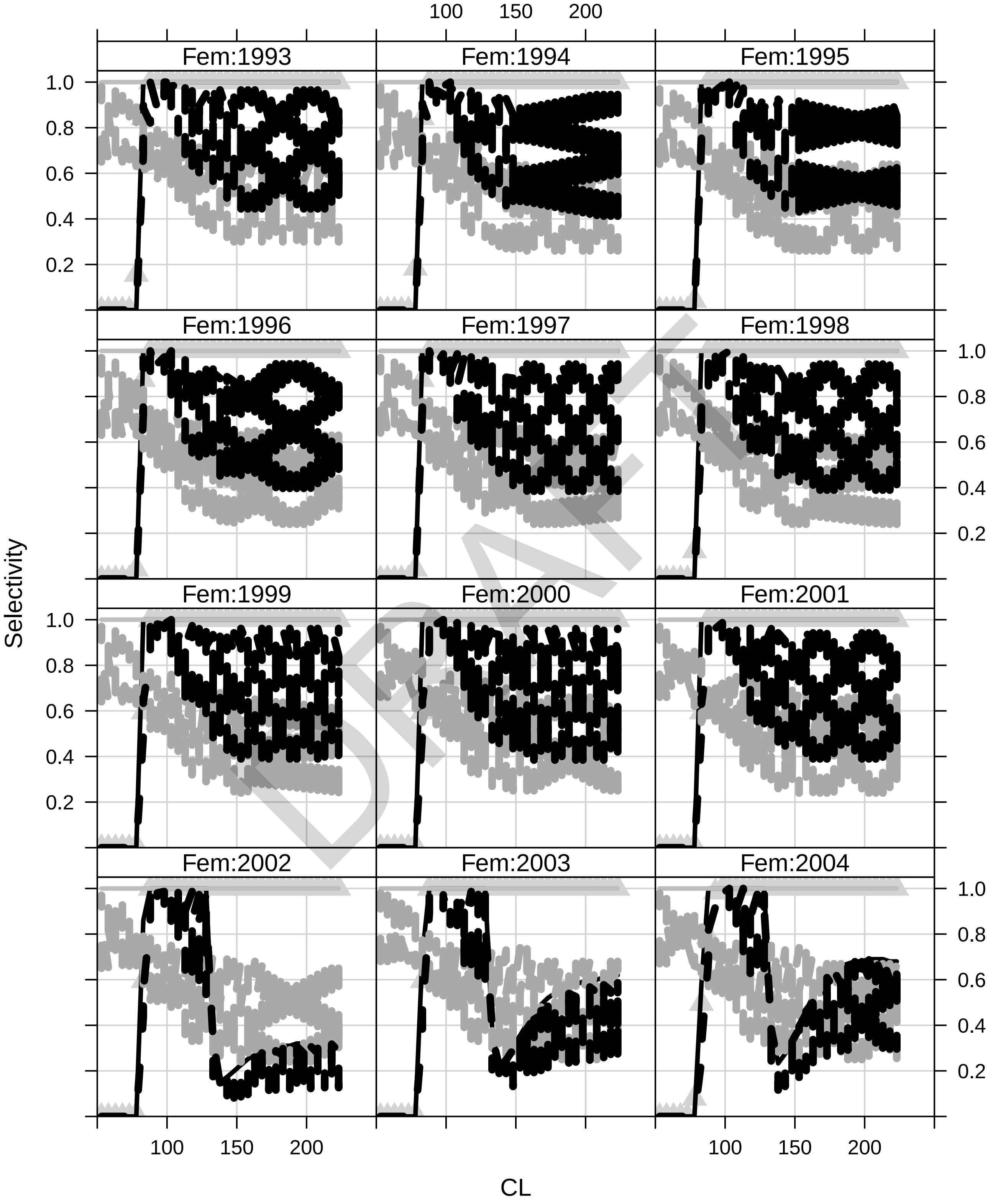
SNE_6F6_2019_orig_select commercial Selectivity (3rd quarter)



DRAFT

Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

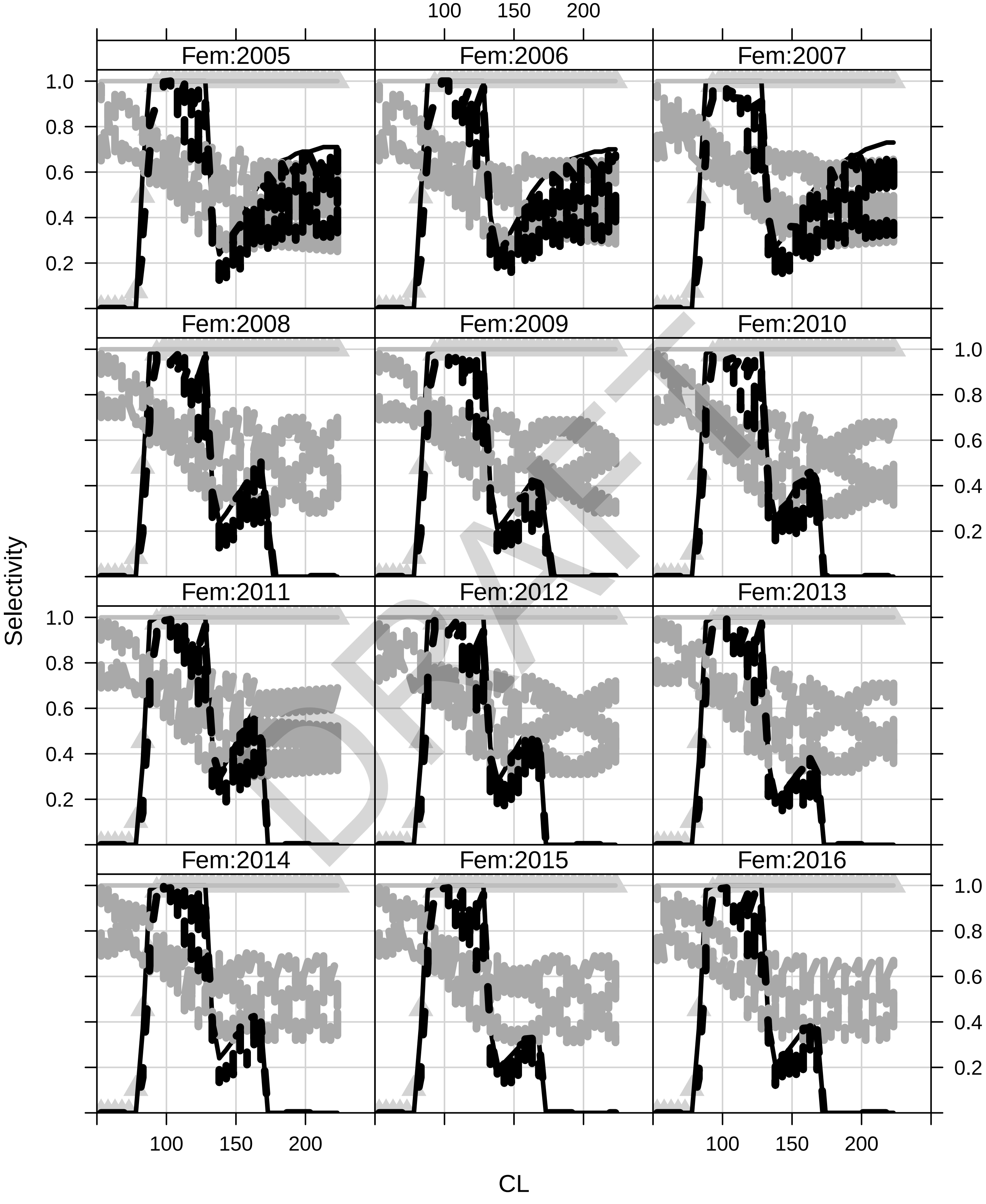
SNE_6F6_2019_orig_select commercial Selectivity (3rd quarter)



DRAFT

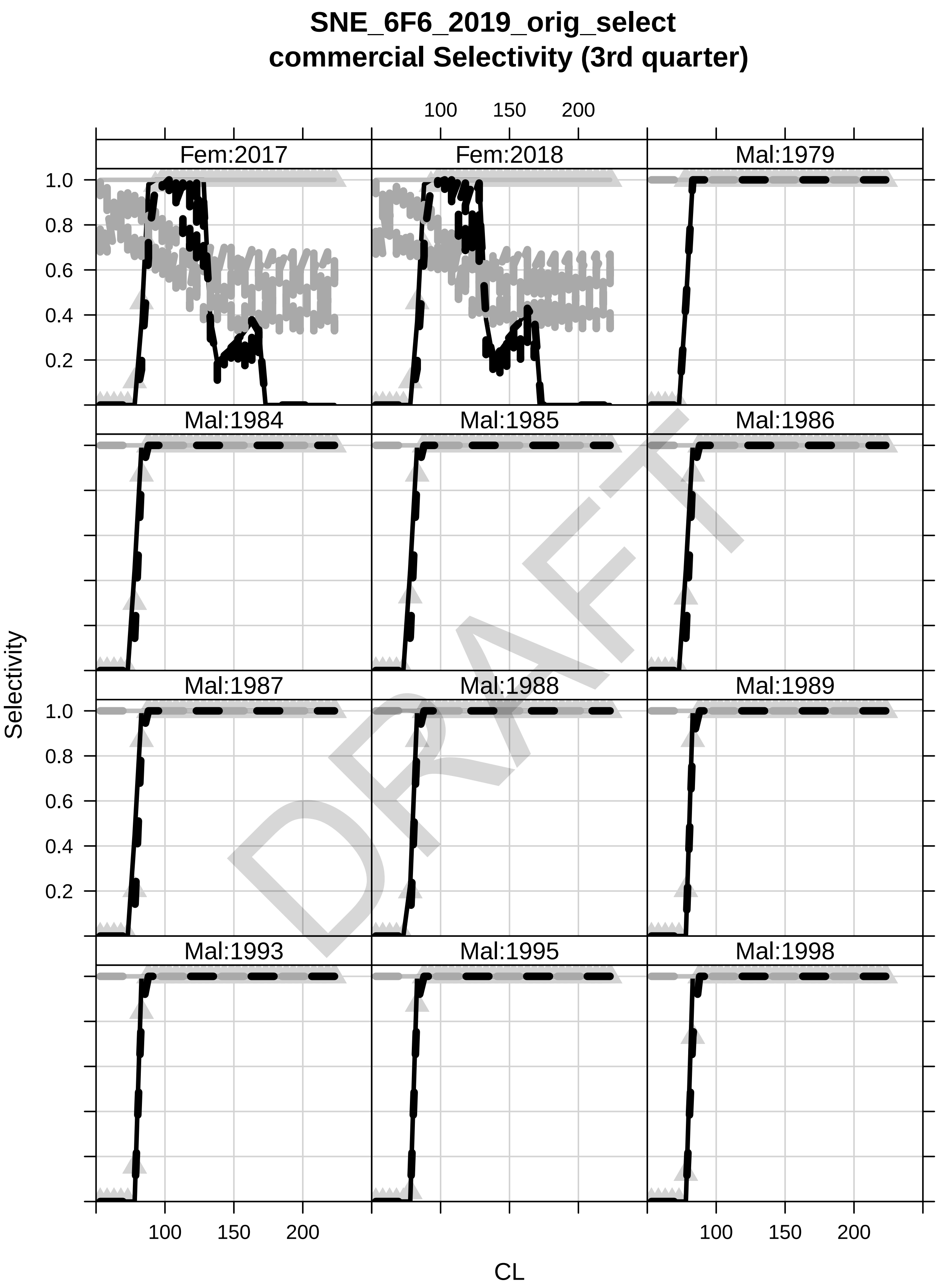
Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

SNE_6F6_2019_orig_select commercial Selectivity (3rd quarter)



DRAFT

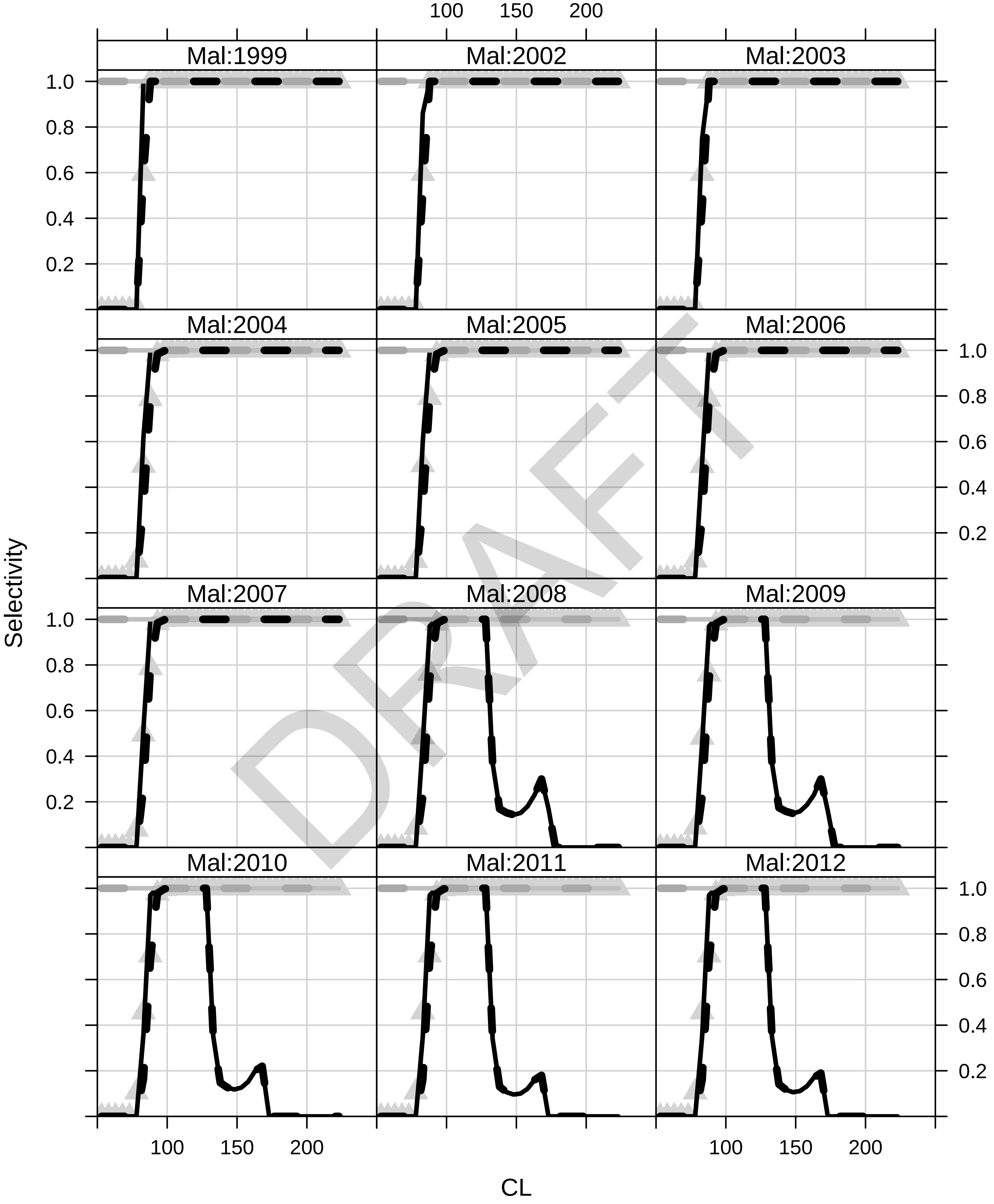
Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)



DRAFT

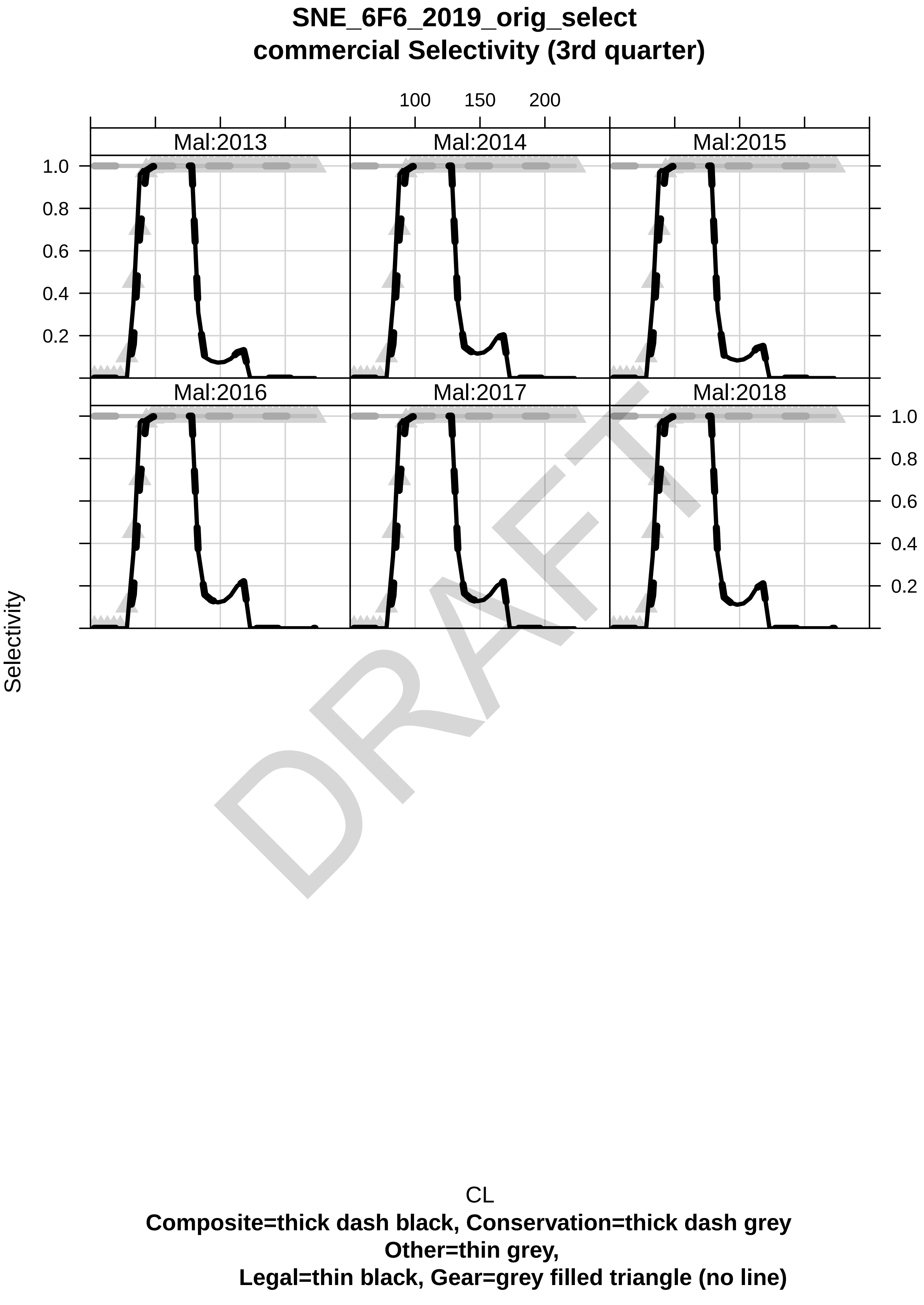
Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

SNE_6F6_2019_orig_select
commercial Selectivity (3rd quarter)

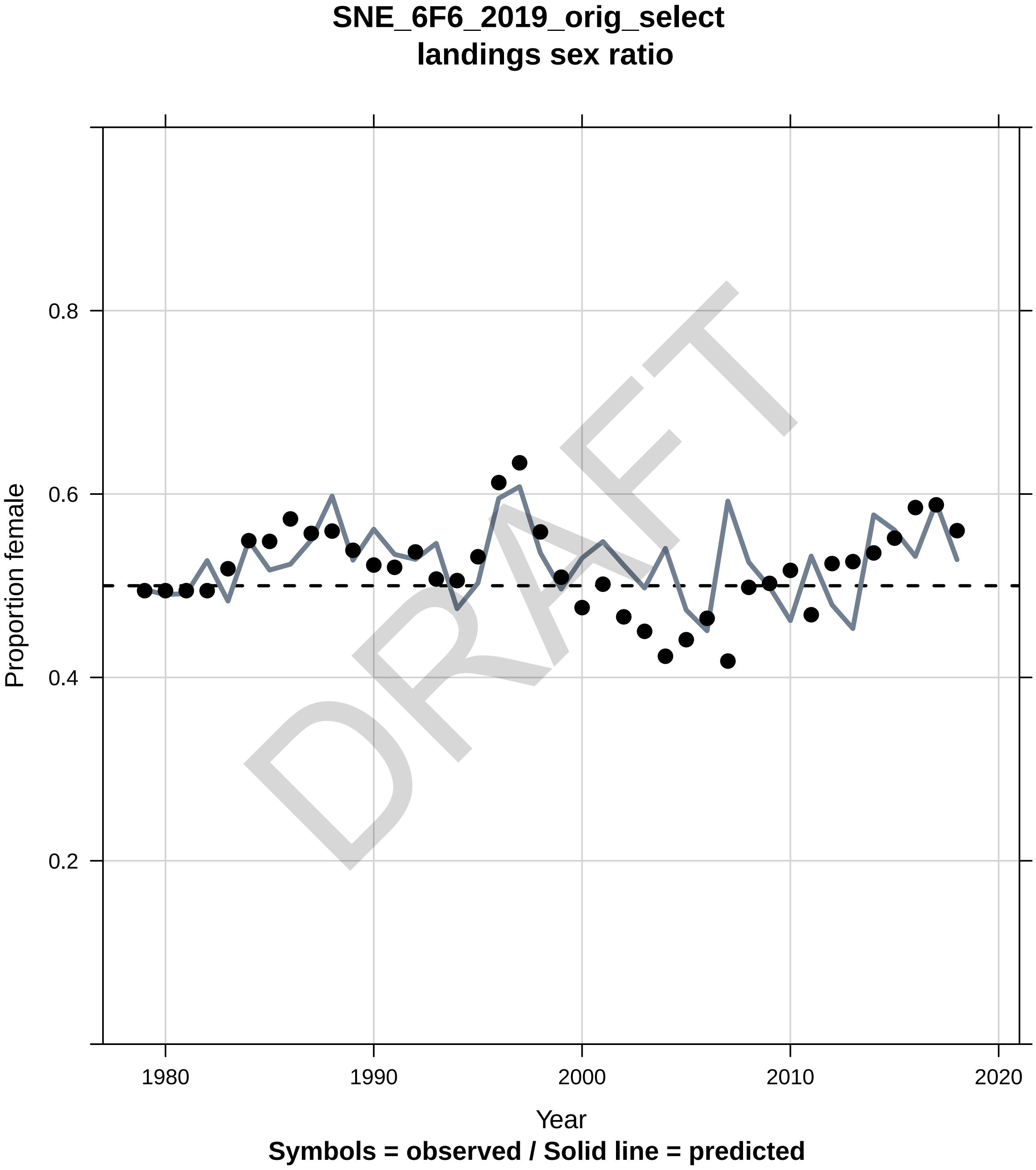


DRAFT

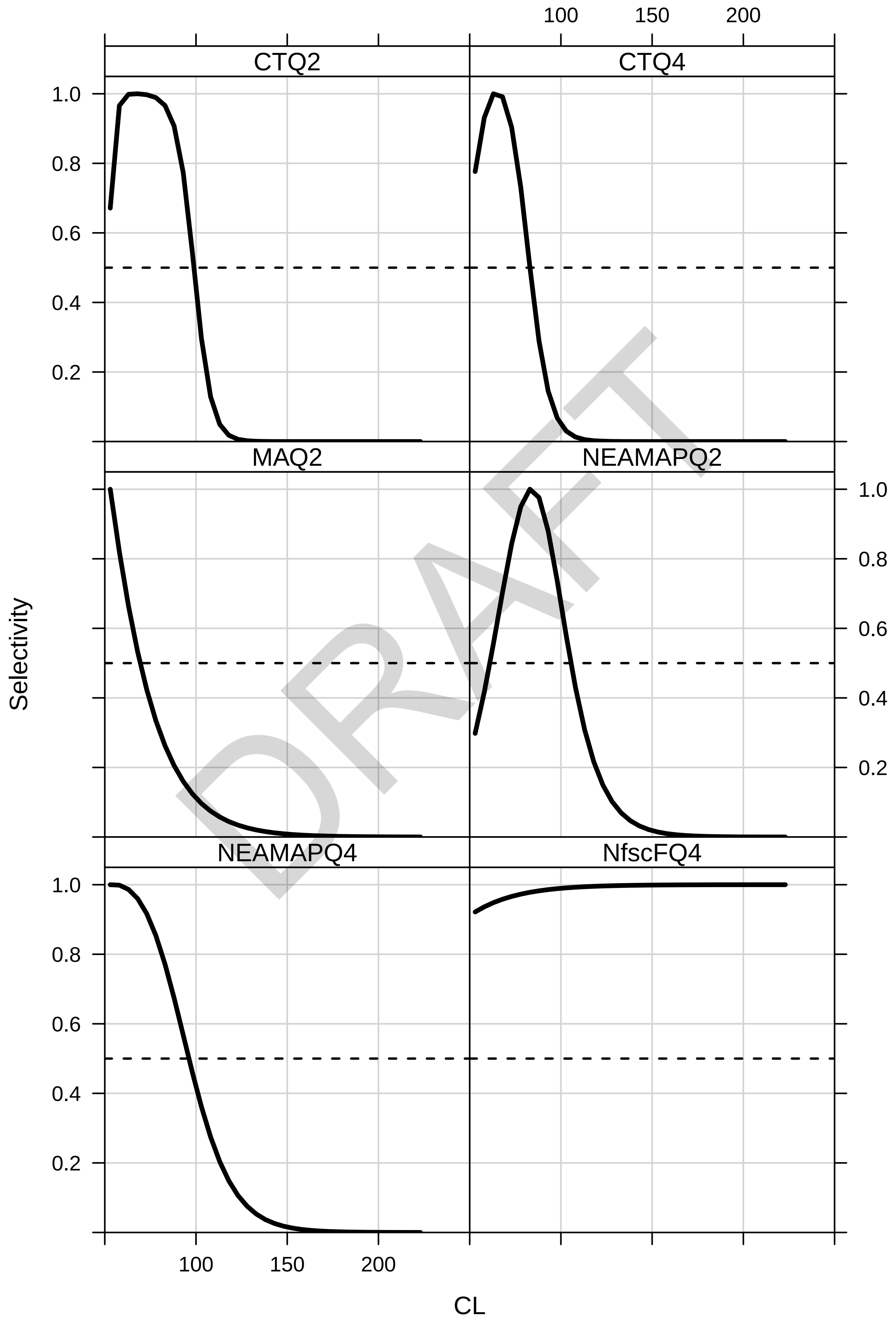
Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)


SNE_6F6_2019_orig_select
commercial Selectivity (3rd quarter)
100
150
200
Mal:2013
Mal:2014
Mal:2015
Mal:2016
Mal:2017
Mal:2018
1.0
0.8
0.6
0.4
0.2
Selectivity
CL
Composite=thick dash black, Conservation=thick dash grey
Other=thin grey,
Legal=thin black, Gear=grey filled triangle (no line)

DRAFT

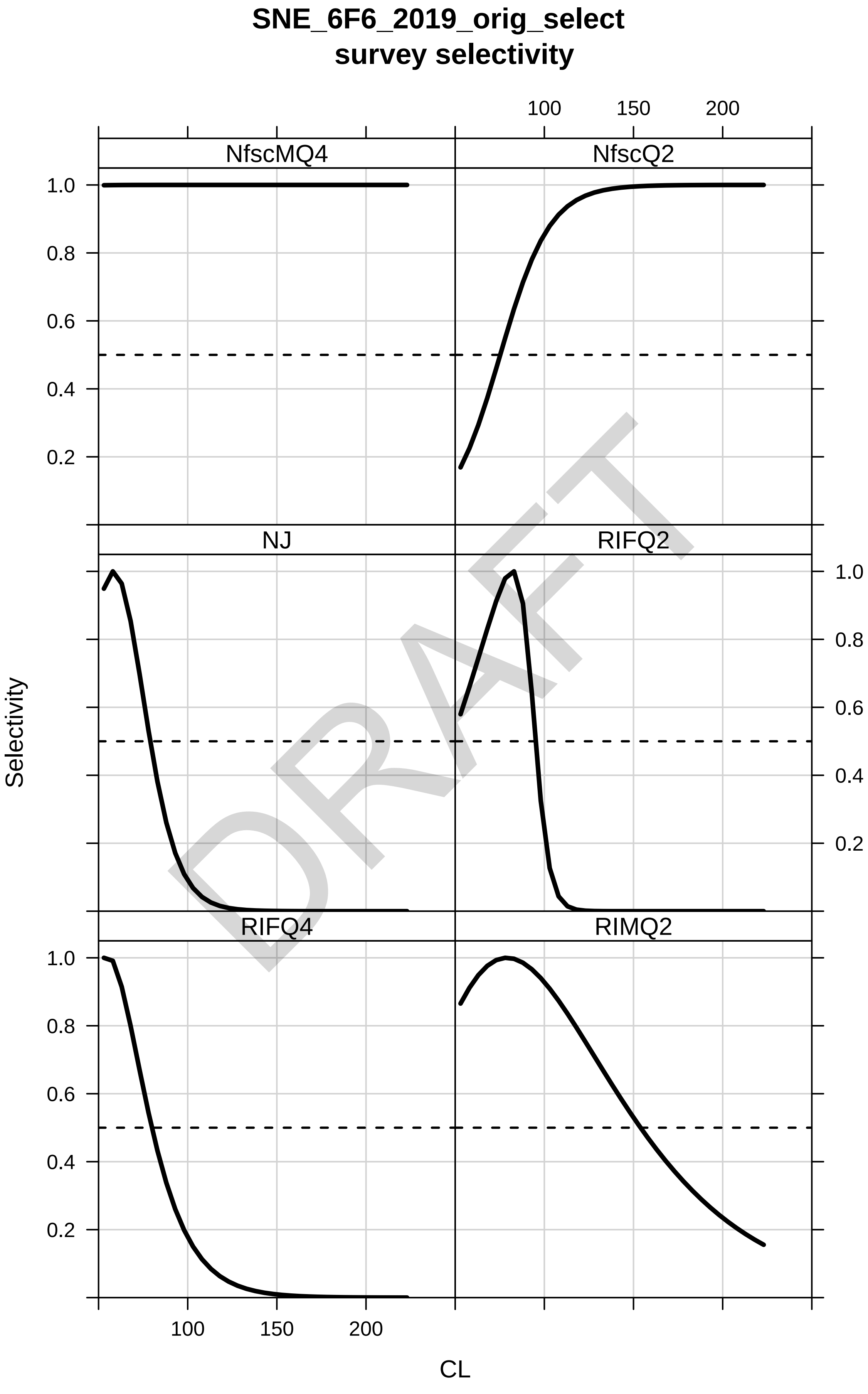

SNE_6F6_2019_orig_select
landings sex ratio
0.8
0.6
0.4
0.2
Proportion female
1980
1990
2000
2010
2020
Year
Symbols = observed / Solid line = predicted

DRAFT



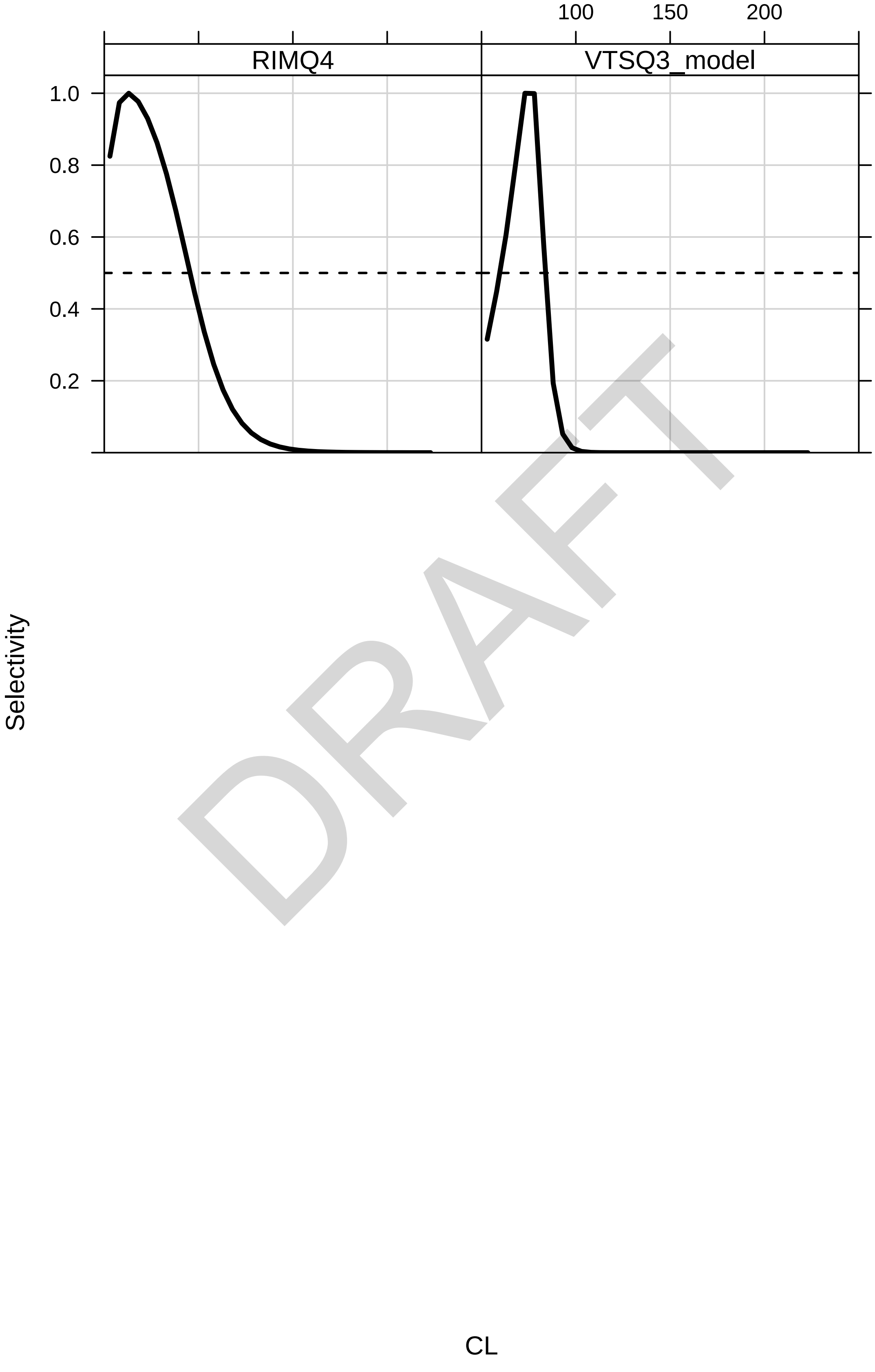
SNE_6F6_2019_orig_select
survey selectivity

DRAFT

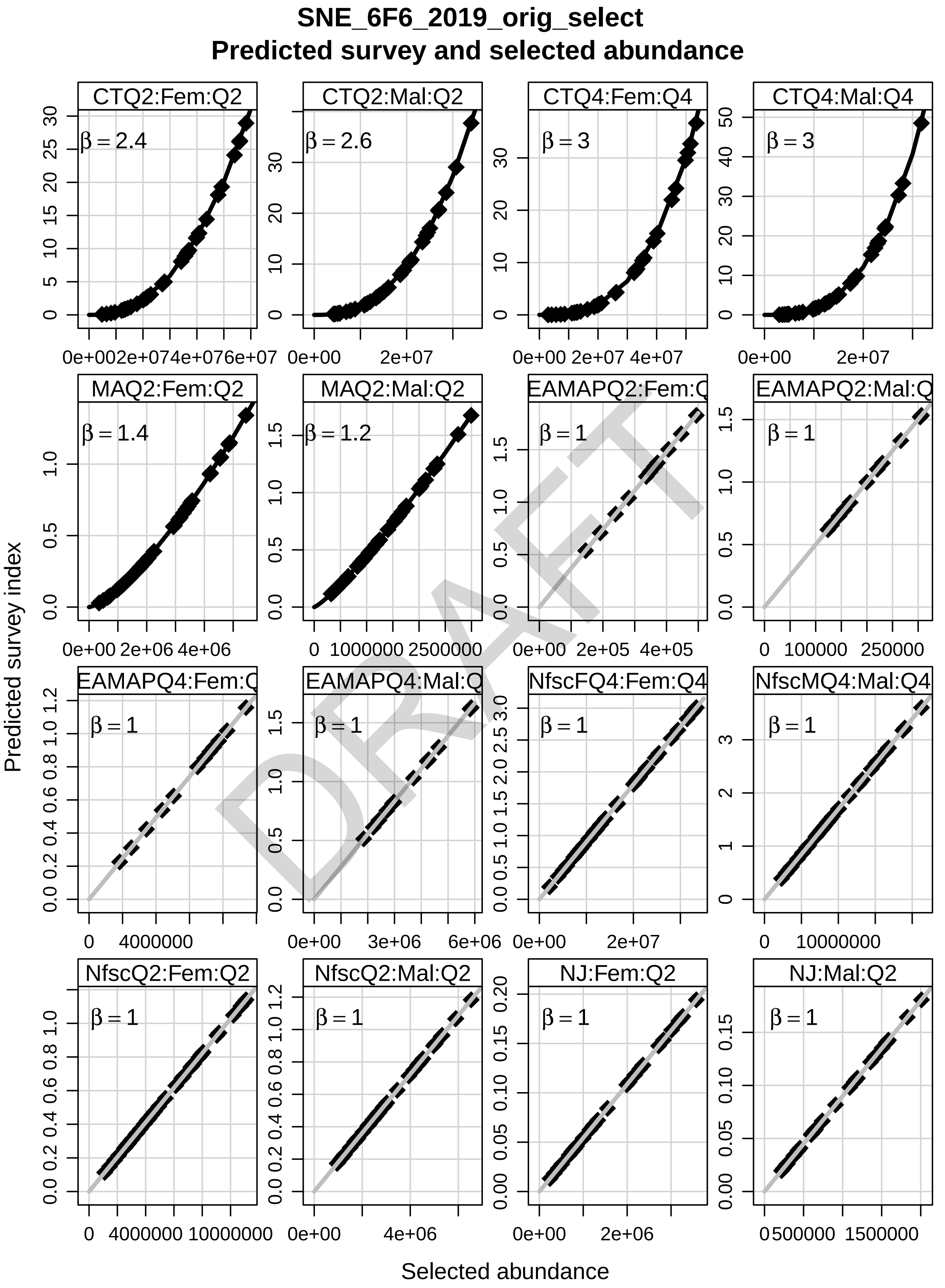

SNE_6F6_2019_orig_select
survey selectivity
NfscMQ4
NfscQ2
NJ
RIFQ2
RIFQ4
RIMQ2
Selectivity
CL
1.0
0.8
0.6
0.4
0.2
100
150
200

DRAFT

SNE_6F6_2019_orig_select
survey selectivity

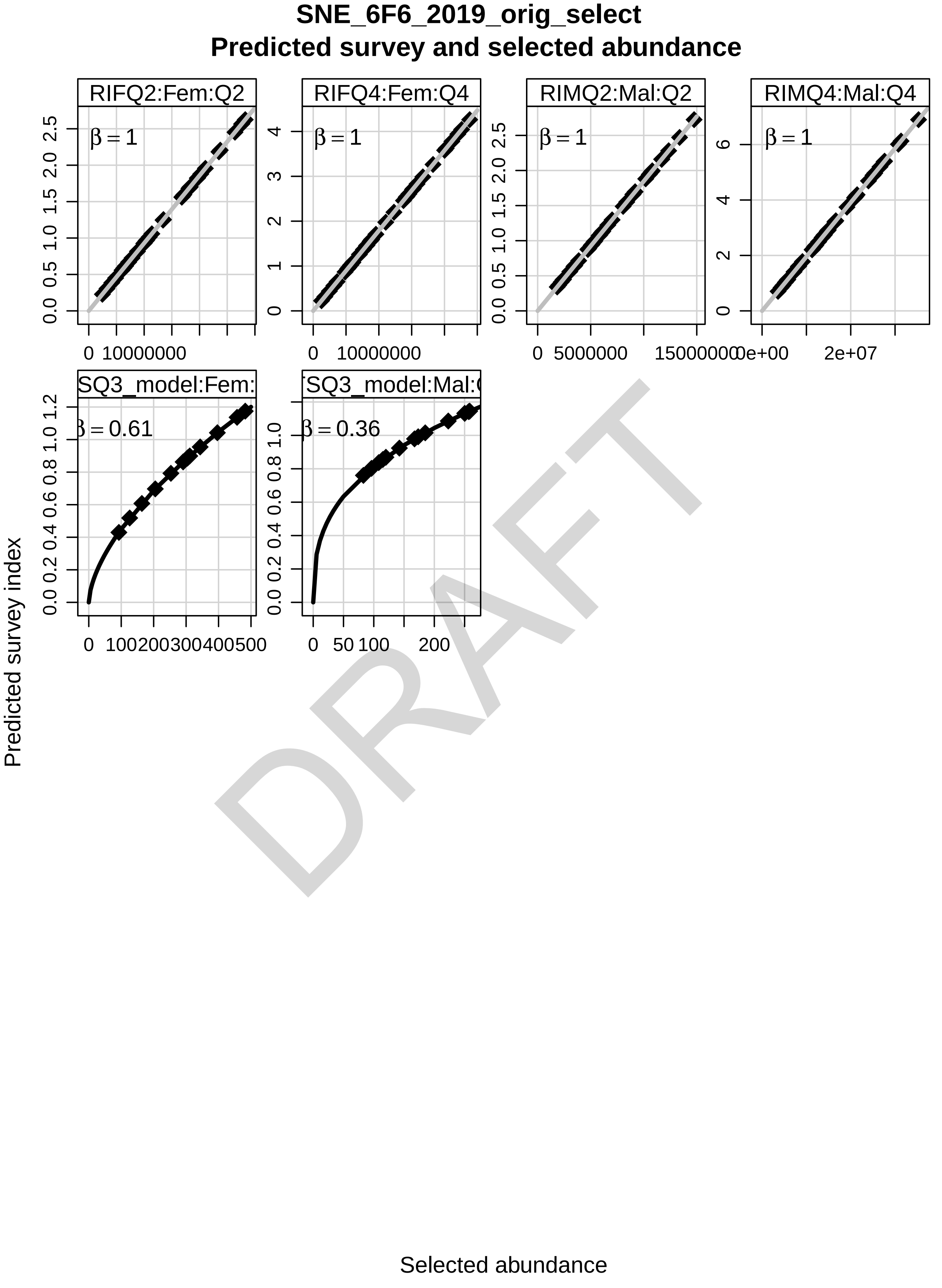


DRAFT



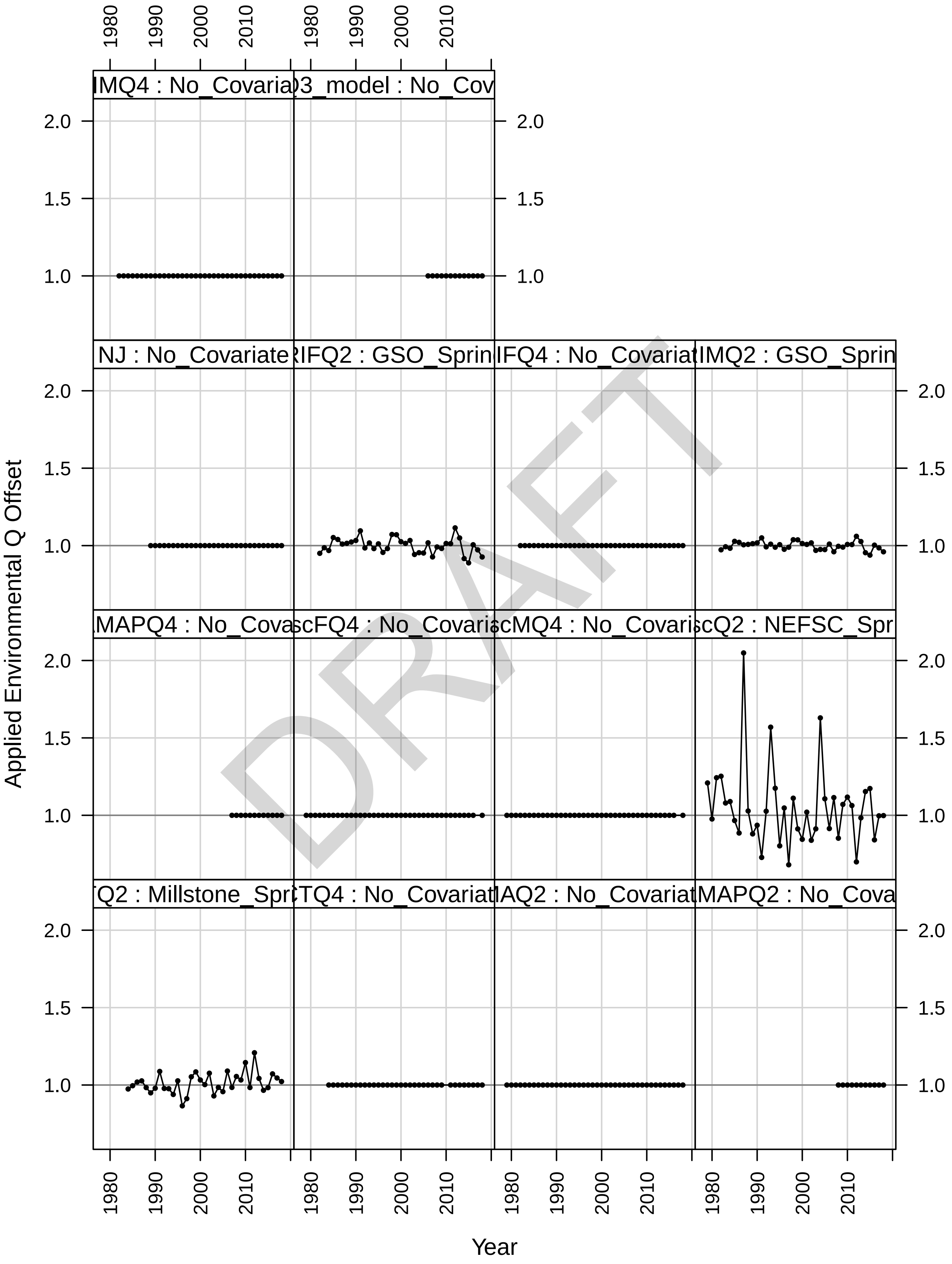
SNE_6F6_2019_orig_select
Predicted survey and selected abundance

DRAFT


SNE_6F6_2019_orig_select
Predicted survey and selected abundance
RIFQ2:Fem:Q2
$\beta = 1$
RIFQ4:Fem:Q4
$\beta = 1$
RIMQ2:Mal:Q2
$\beta = 1$
RIMQ4:Mal:Q4
$\beta = 1$
0 10000000
0 10000000
0 5000000 15000000
0e+00 2e+07
SQ3_model:Fem:
$\beta = 0.61$
SQ3_model:Mal:
$\beta = 0.36$
0 100 200 300 400 500
0 50 100 200
Predicted survey index
Selected abundance

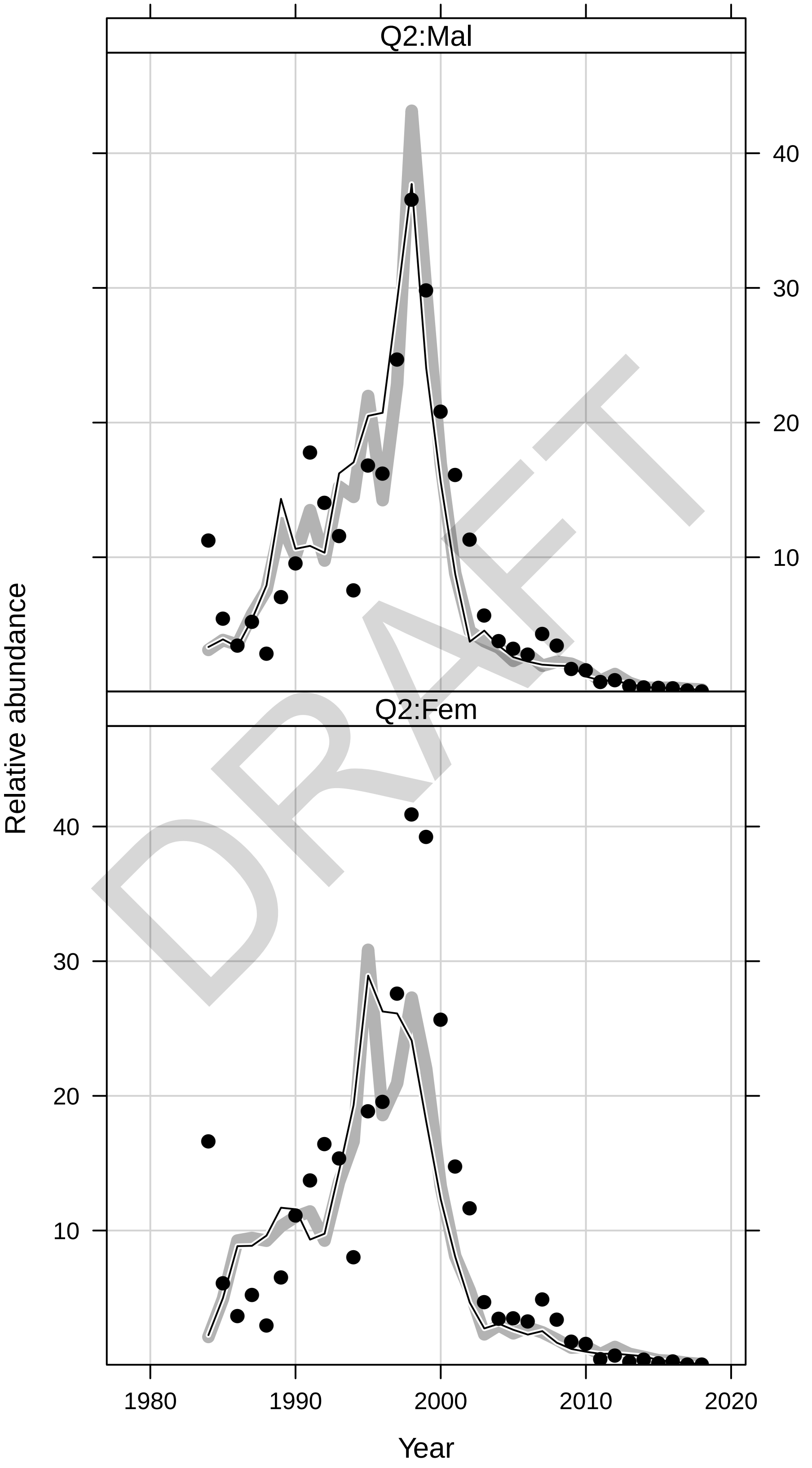
DRAFT

Survey Q As Modified by Environmental Covariates



DRAFT

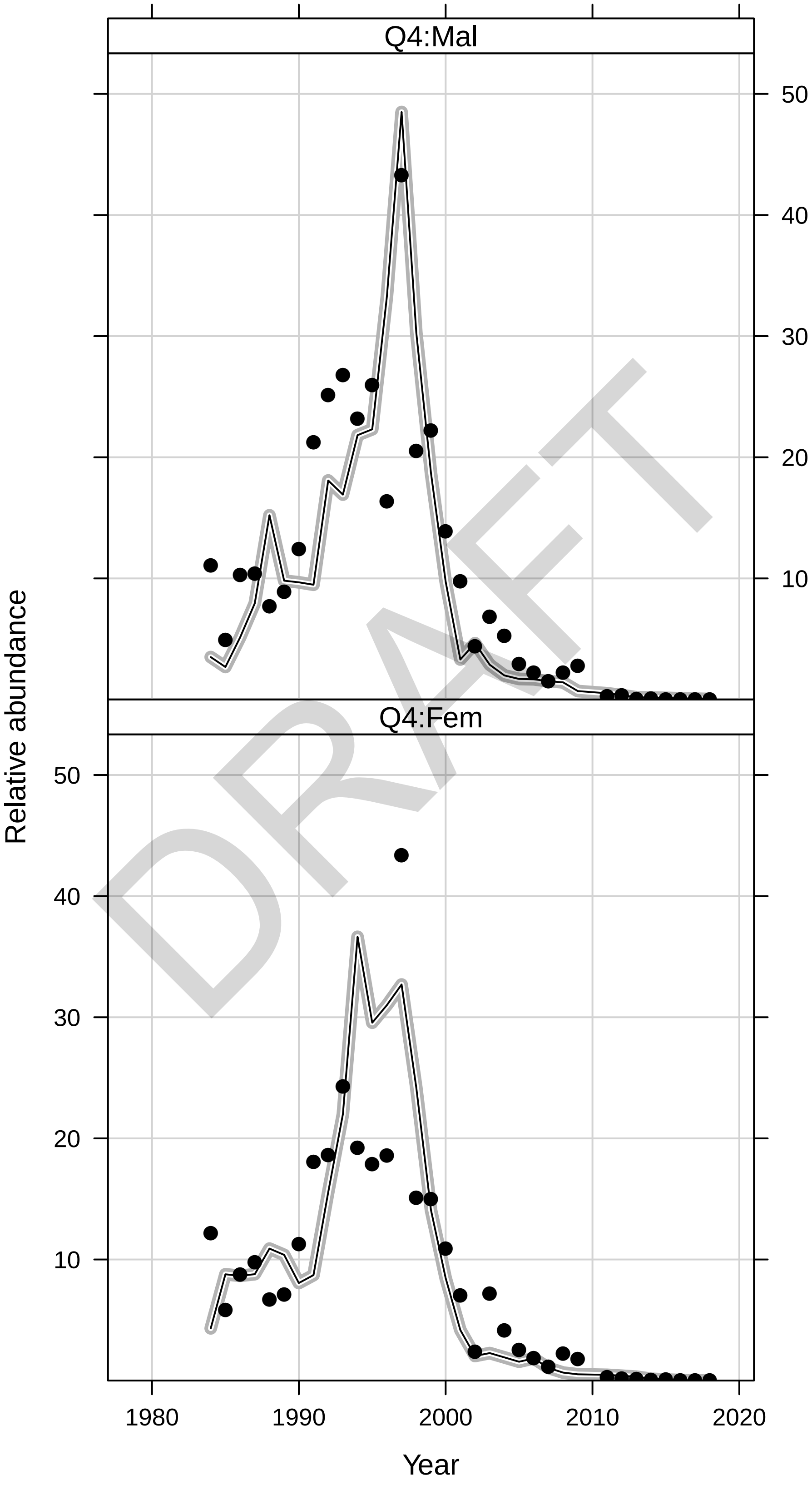
SNE_6F6_2019_orig_select
CTQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

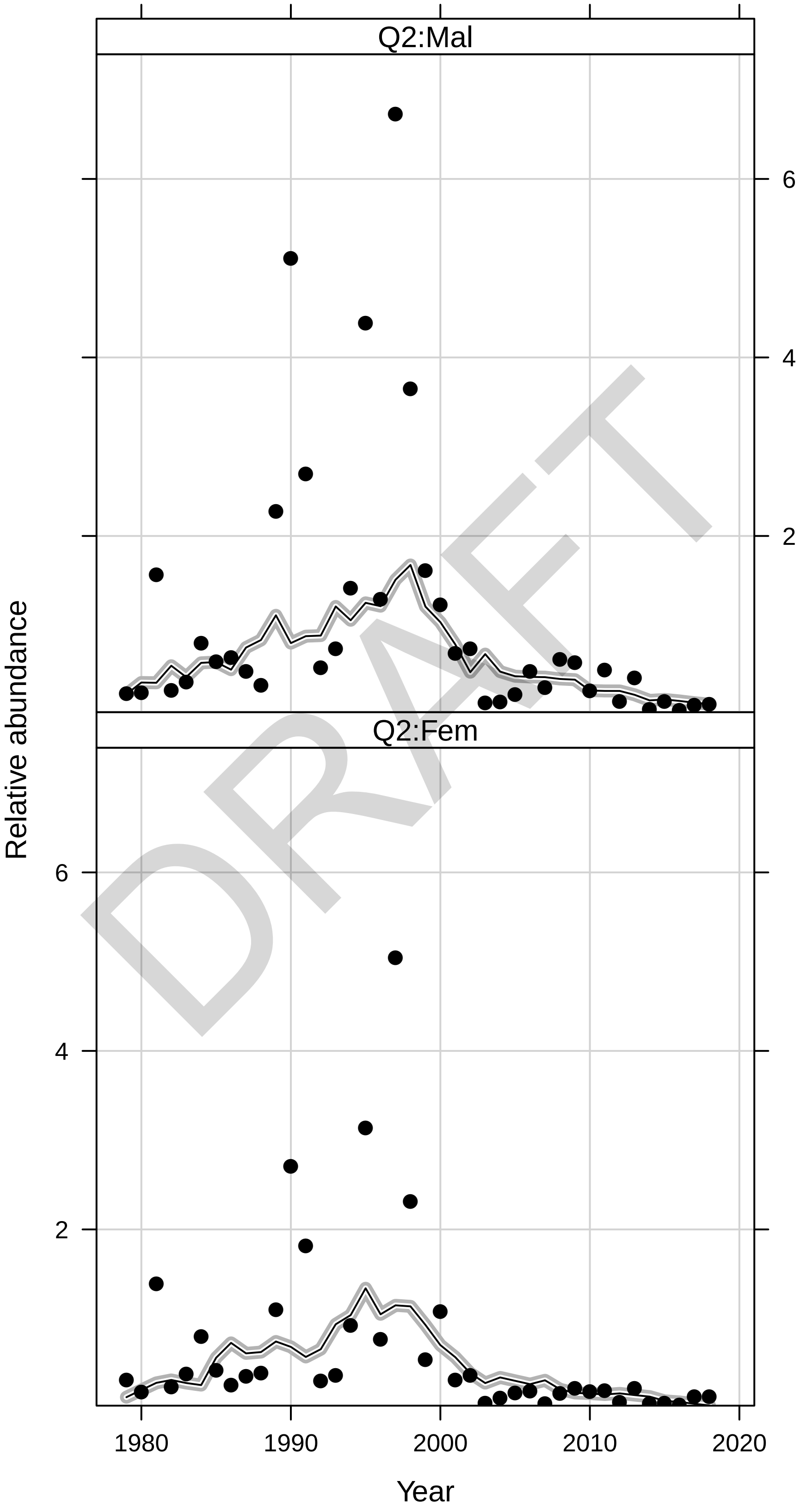
SNE_6F6_2019_orig_select
CTQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

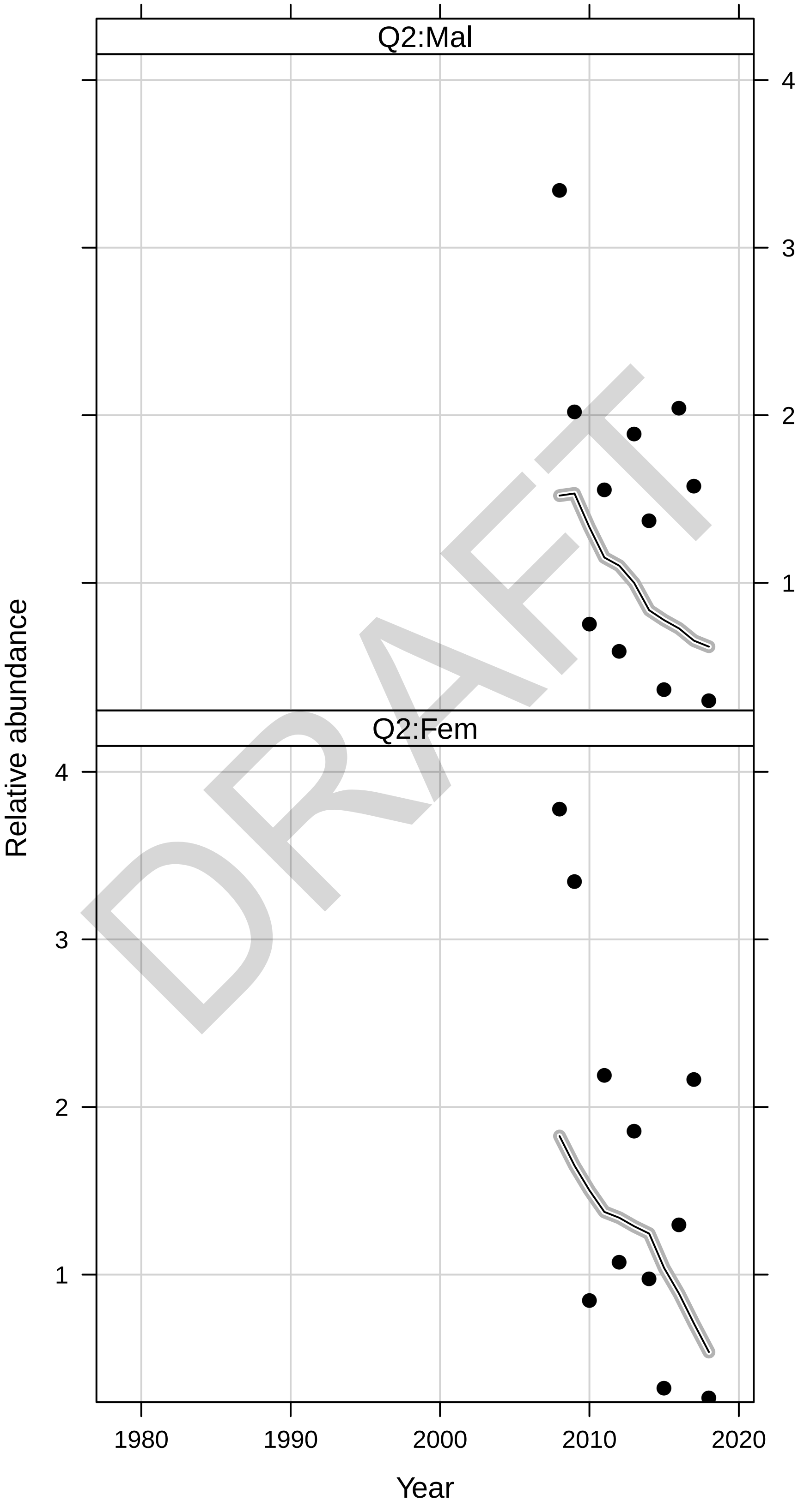
SNE_6F6_2019_orig_select
MAQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

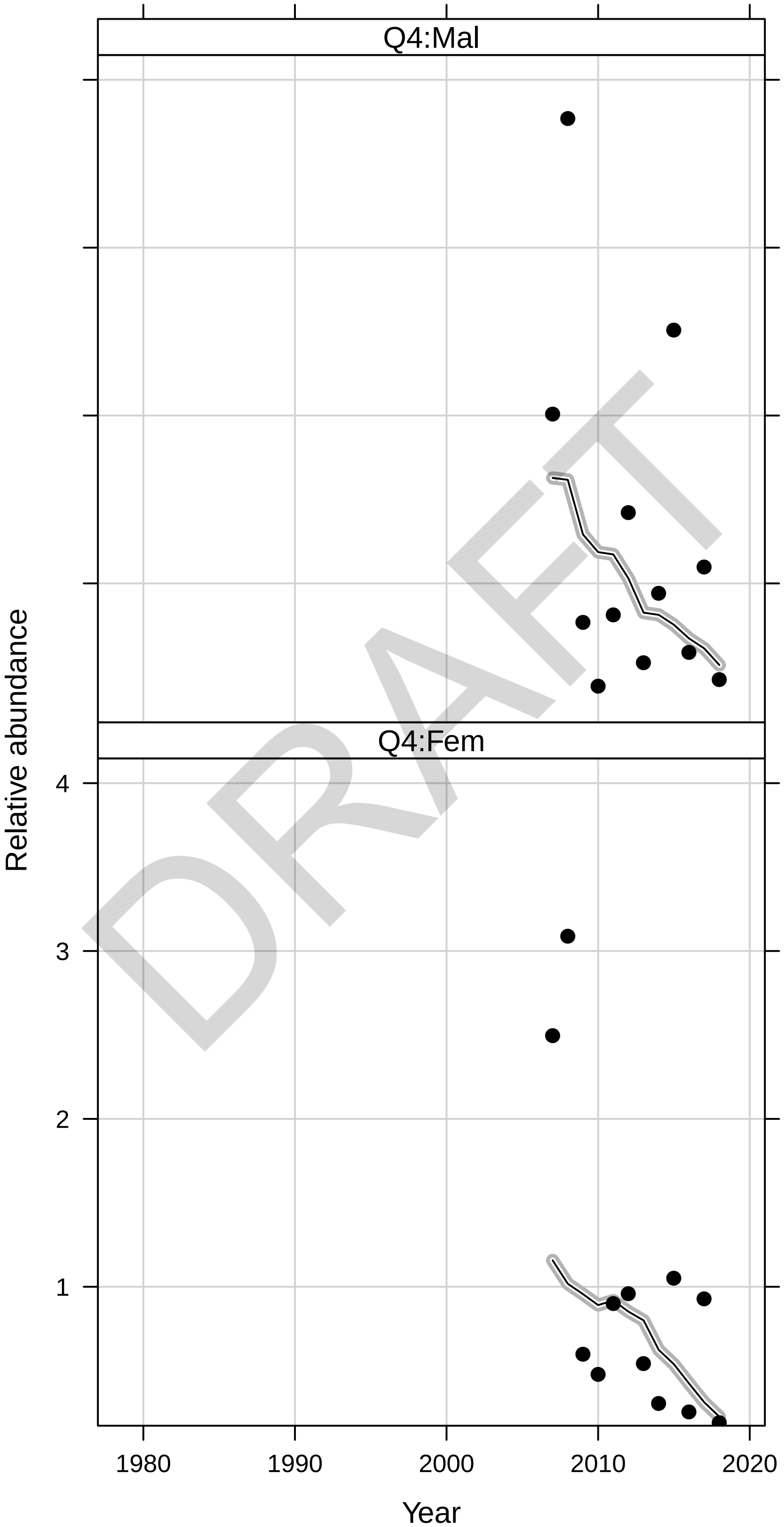
SNE_6F6_2019_orig_select
NEAMAPQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

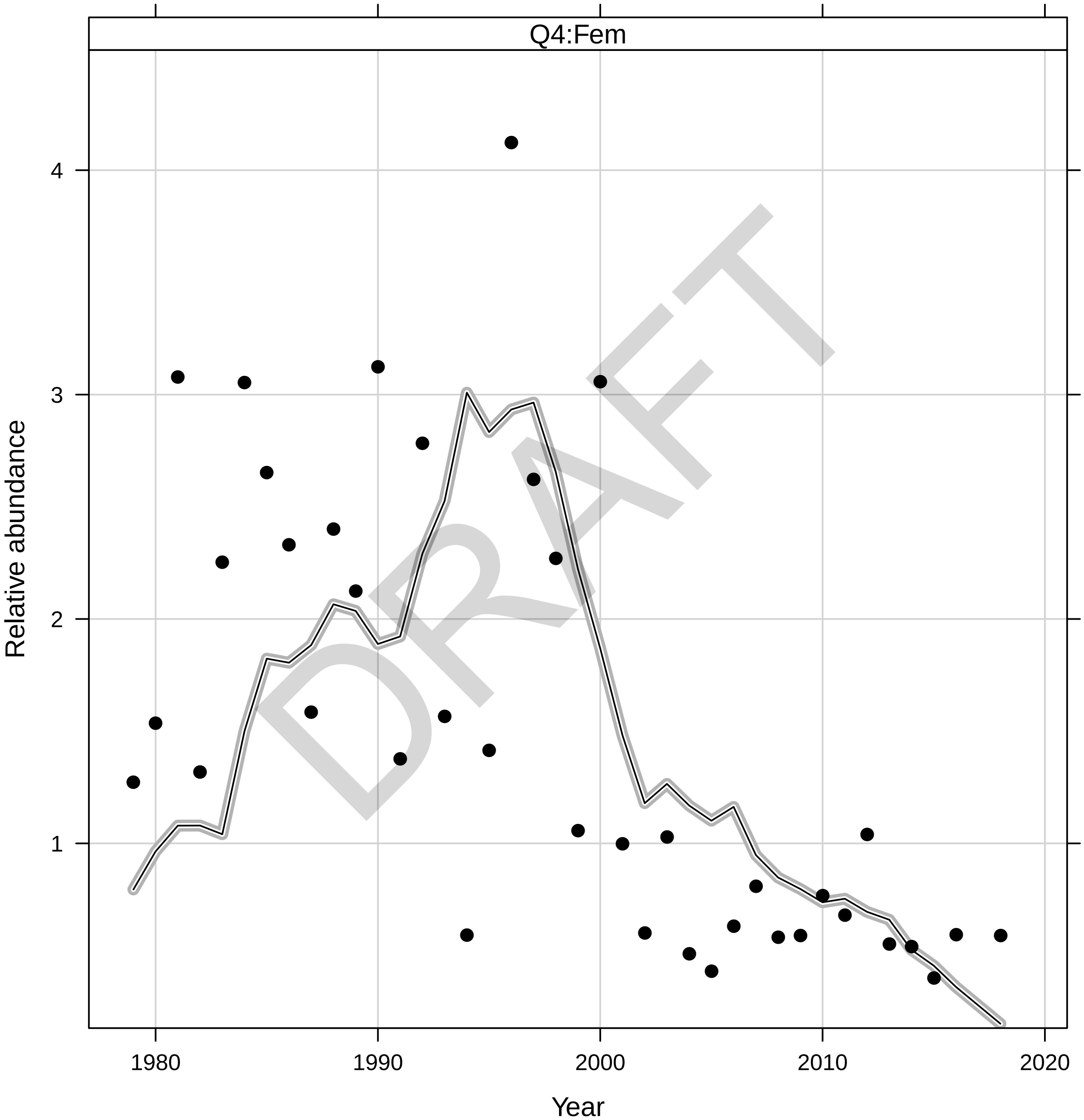
SNE_6F6_2019_orig_select
NEAMAPQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

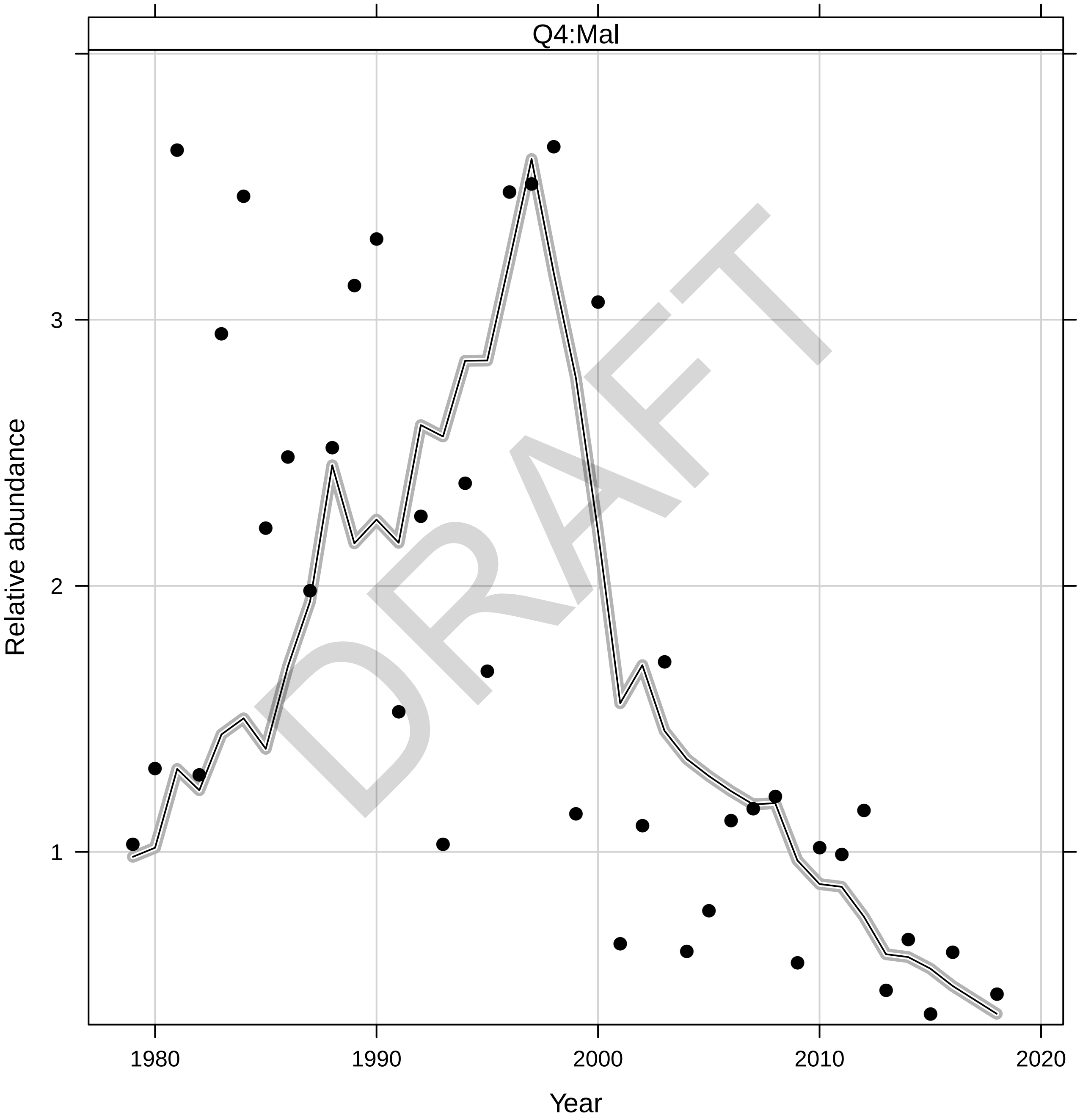
SNE_6F6_2019_orig_select
NfscFQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

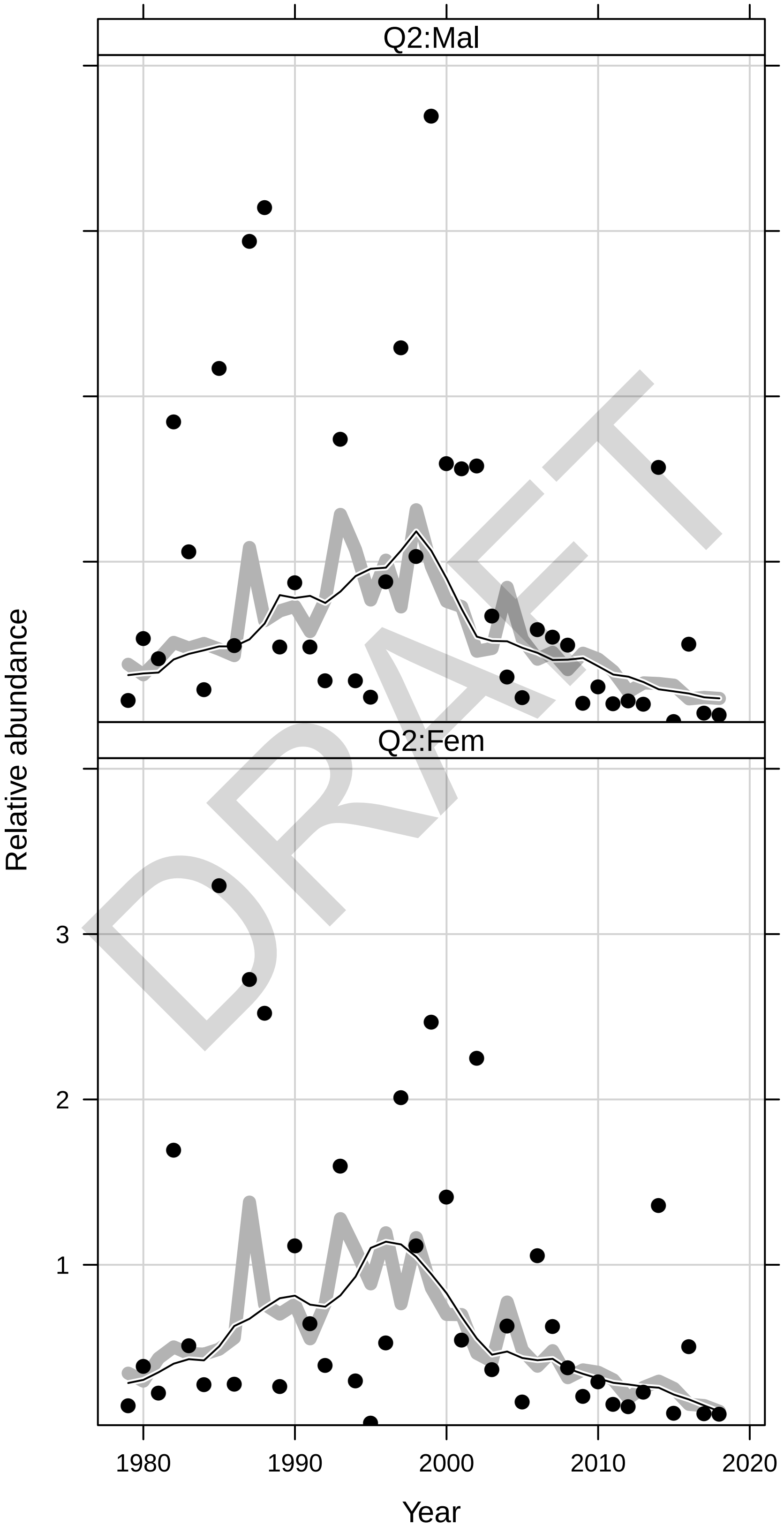
SNE_6F6_2019_orig_select
NfscMQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

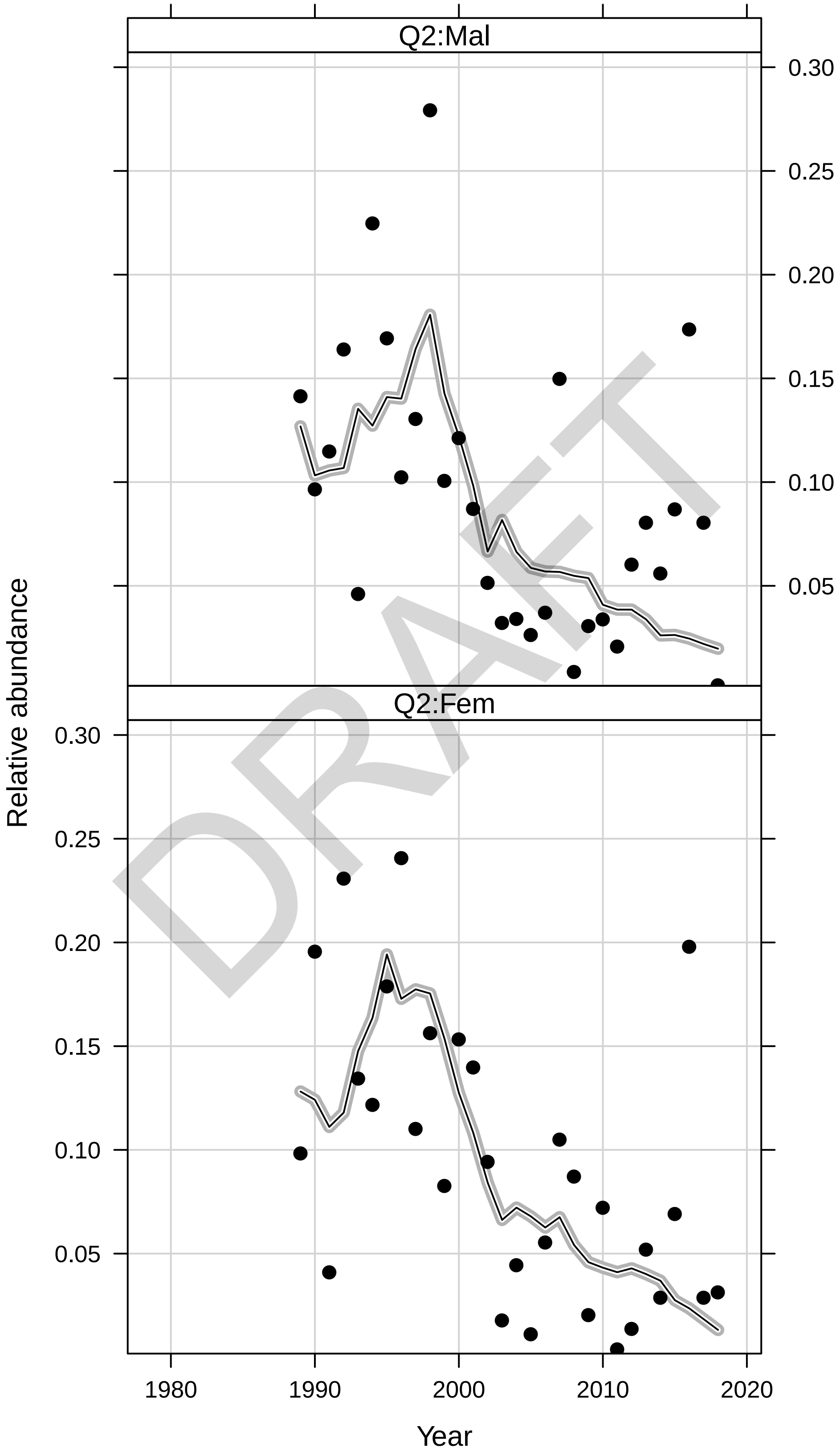
SNE_6F6_2019_orig_select
NfscQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

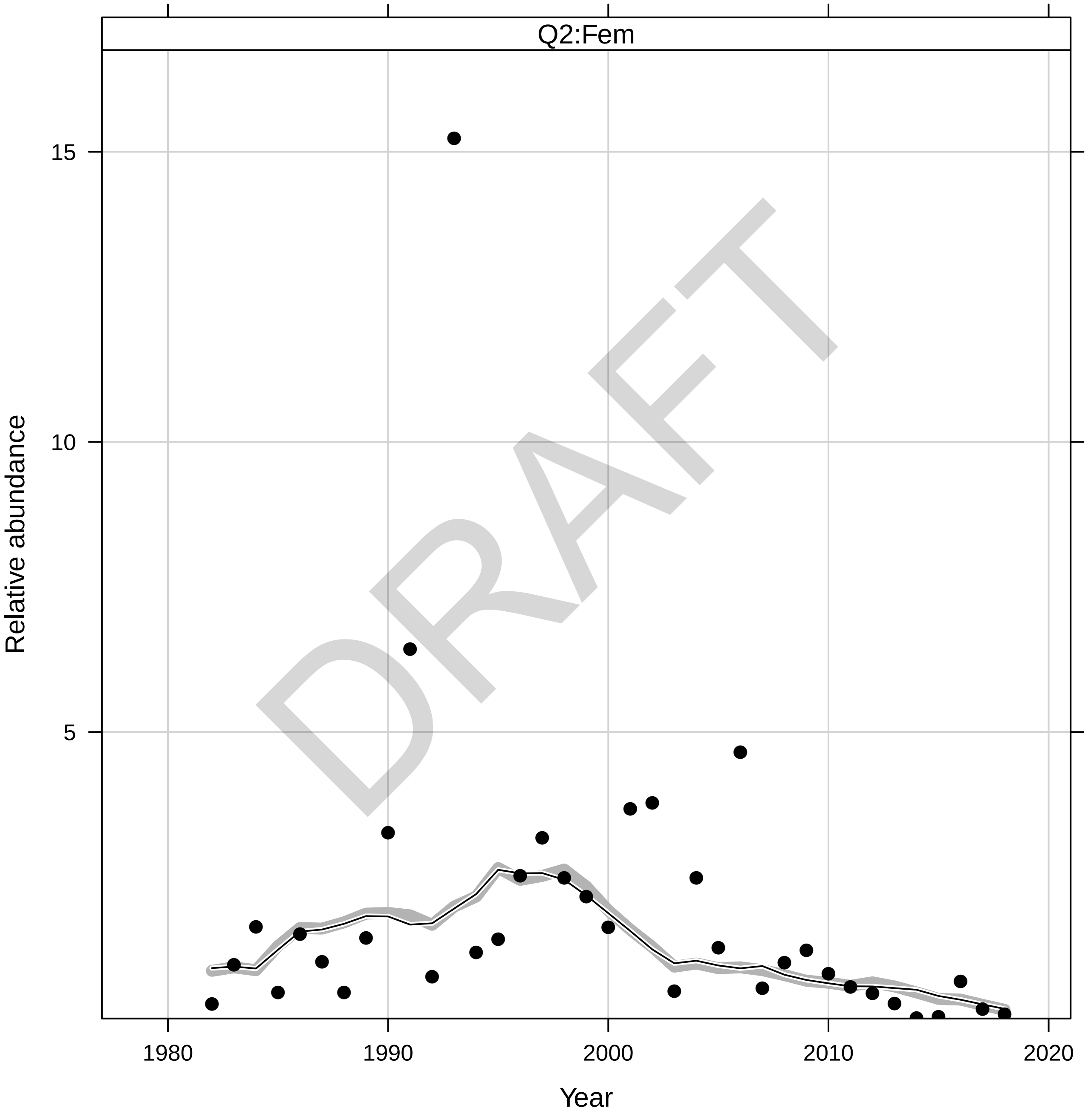
SNE_6F6_2019_orig_select
NJ observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

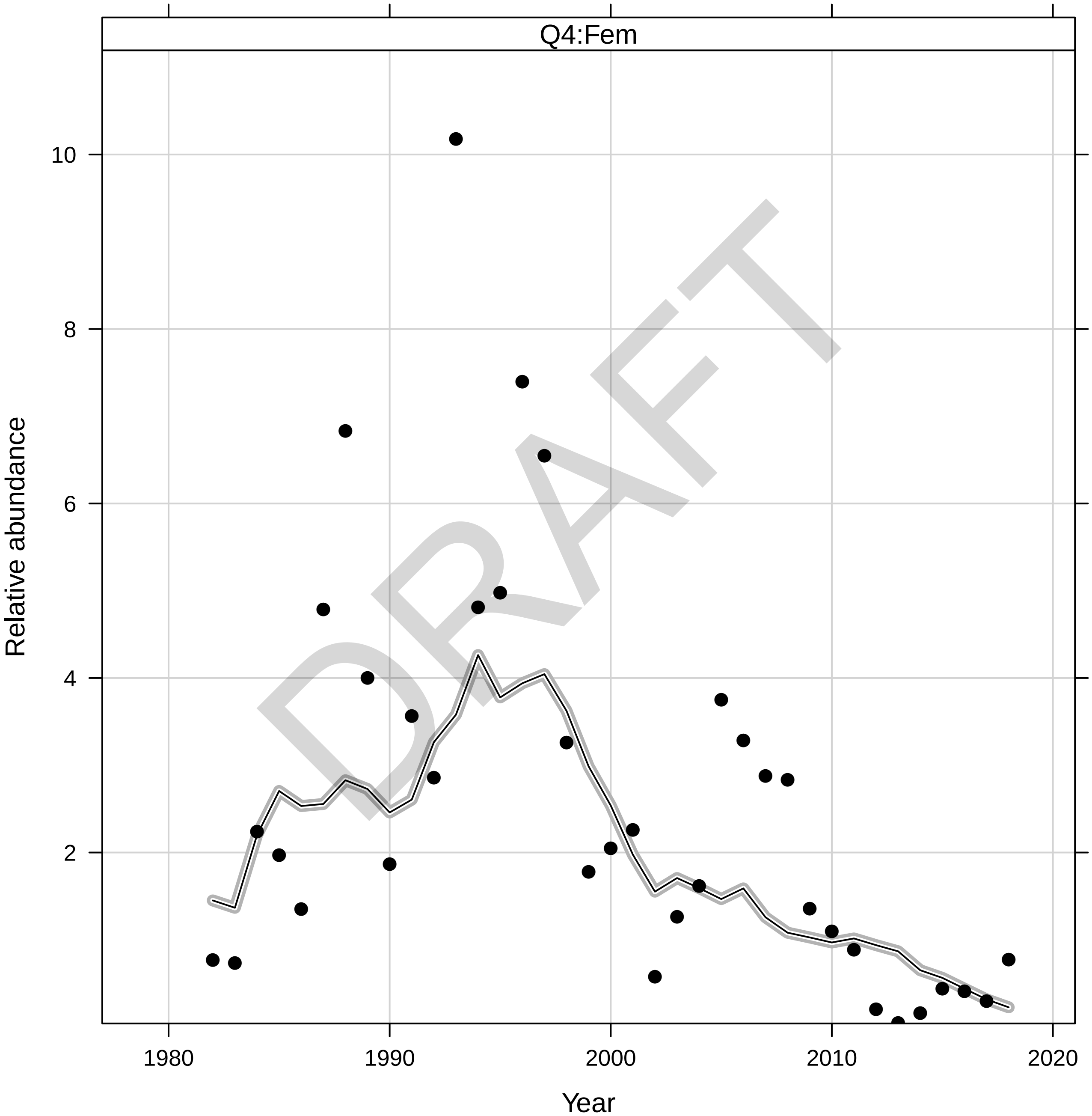
SNE_6F6_2019_orig_select
RIFQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

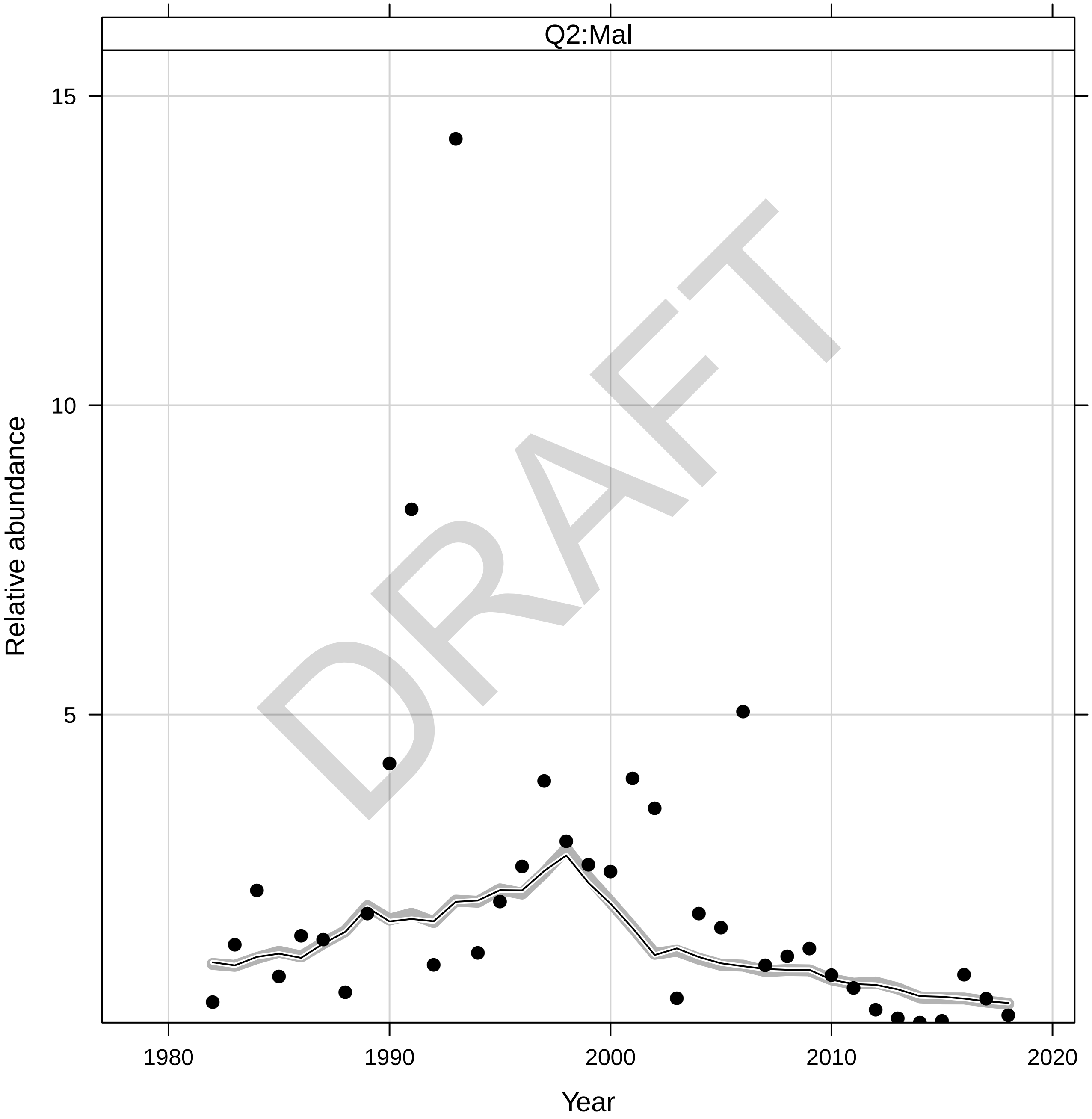
SNE_6F6_2019_orig_select
RIFQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

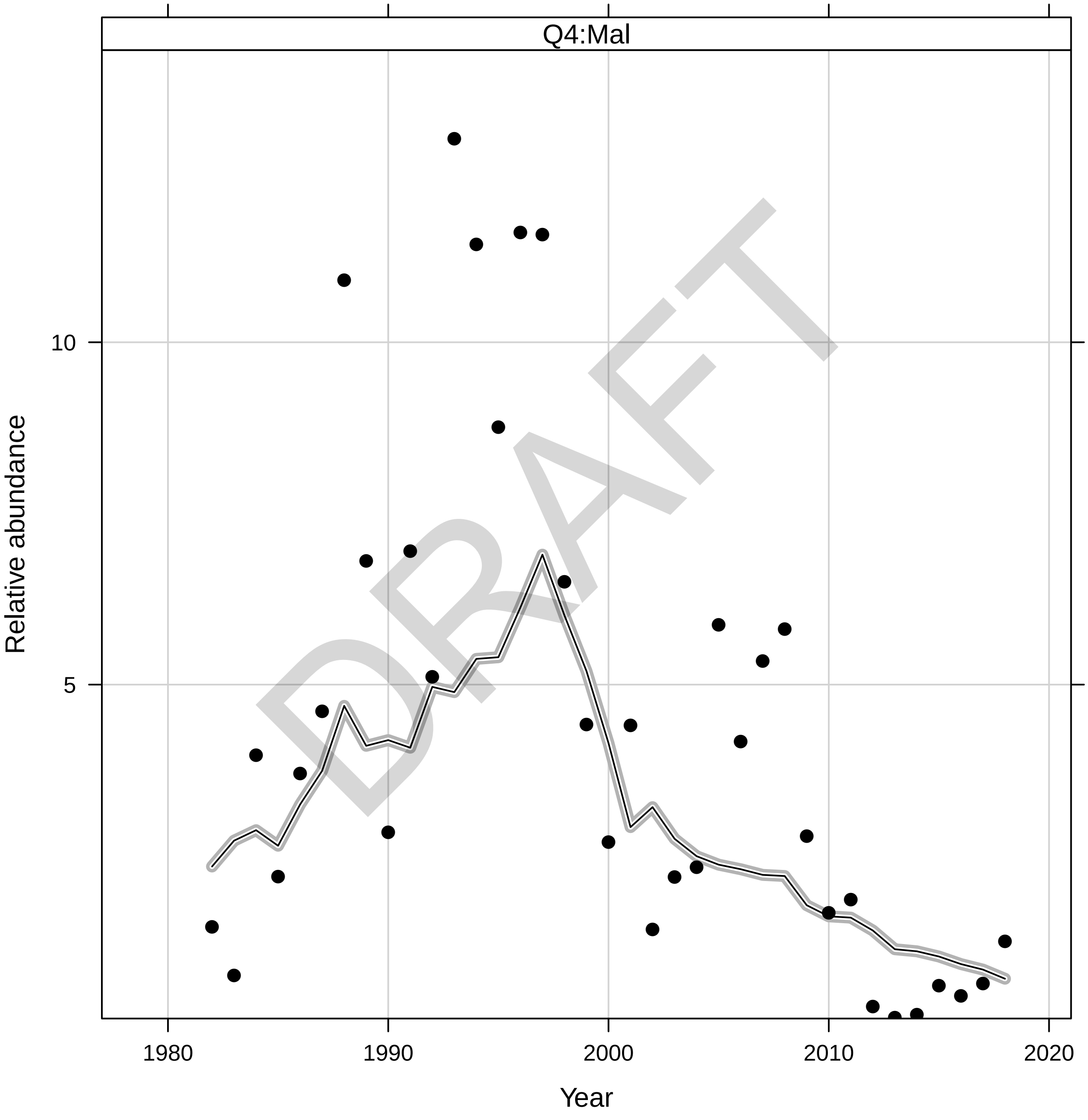
SNE_6F6_2019_orig_select
RIMQ2 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

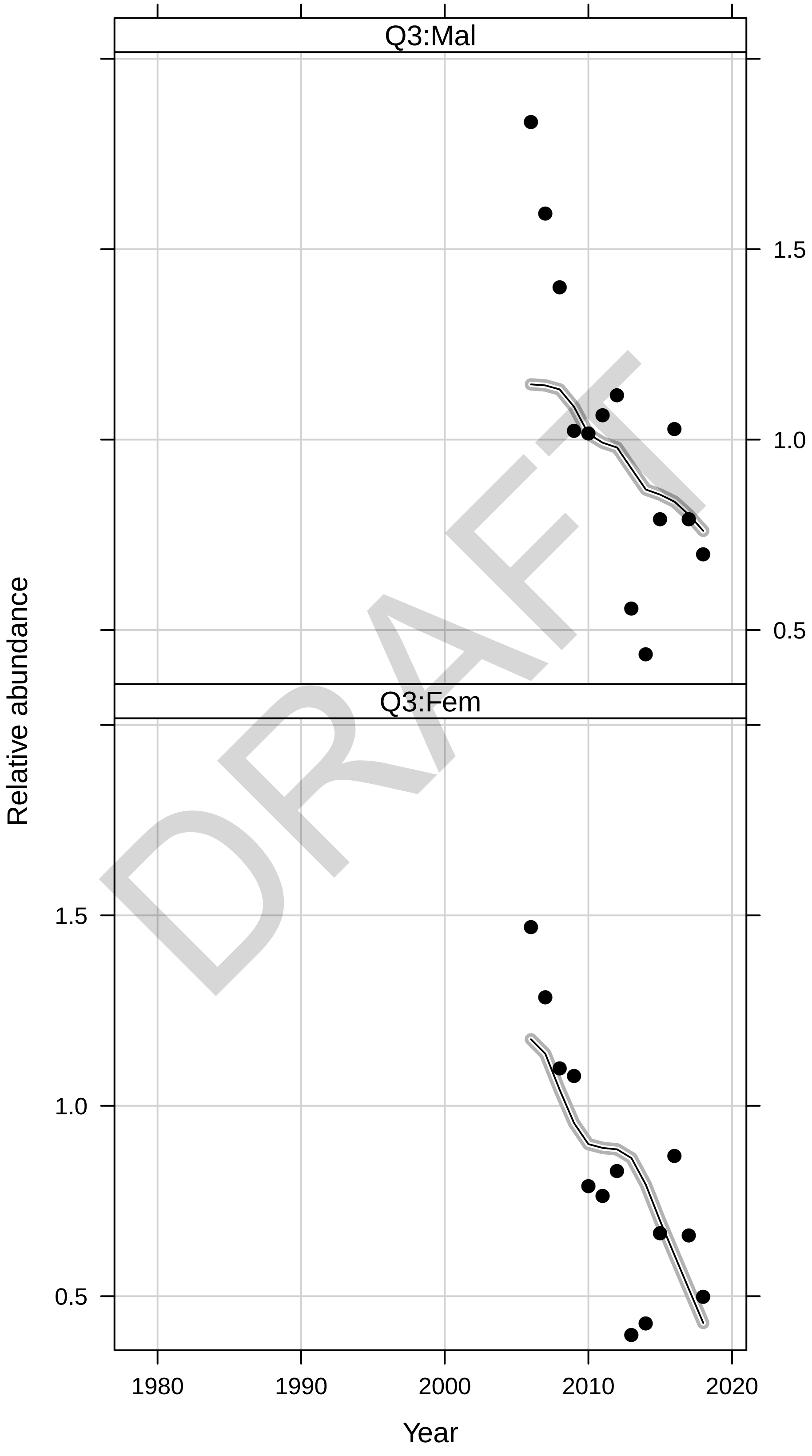
SNE_6F6_2019_orig_select
RIMQ4 observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

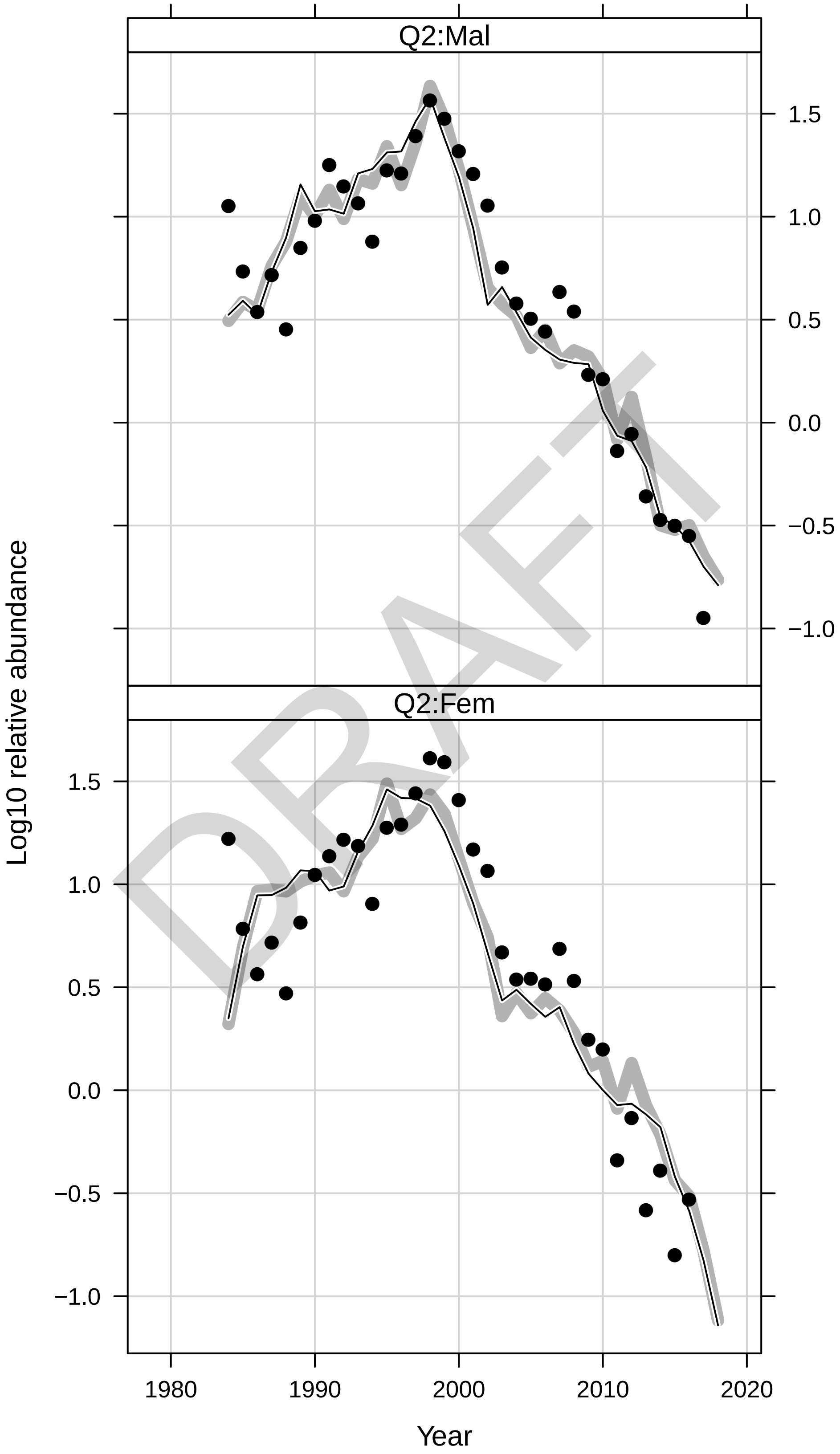
SNE_6F6_2019_orig_select
VTSQ3_model observed and predicted survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

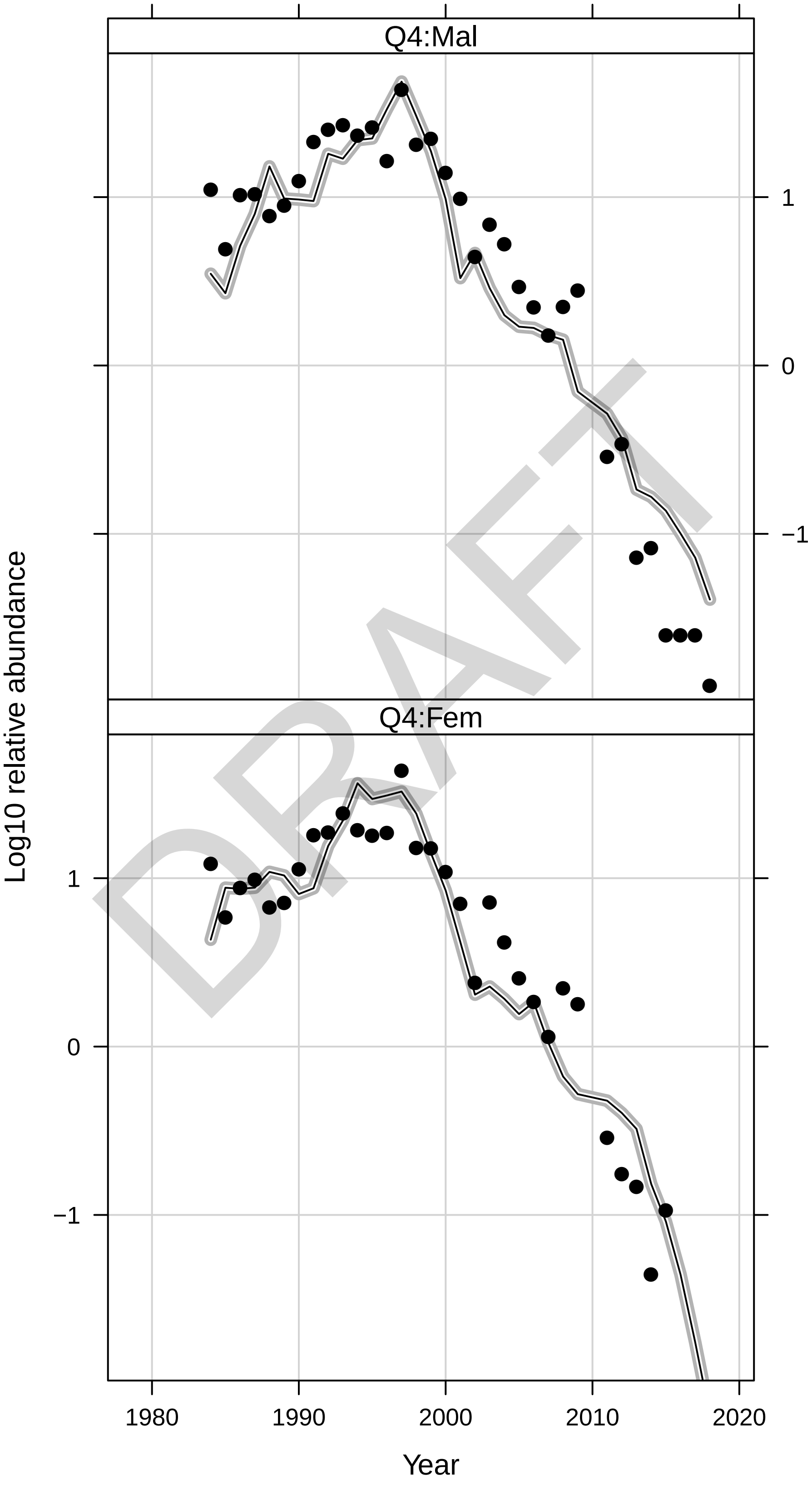
SNE_6F6_2019_orig_select
CTQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

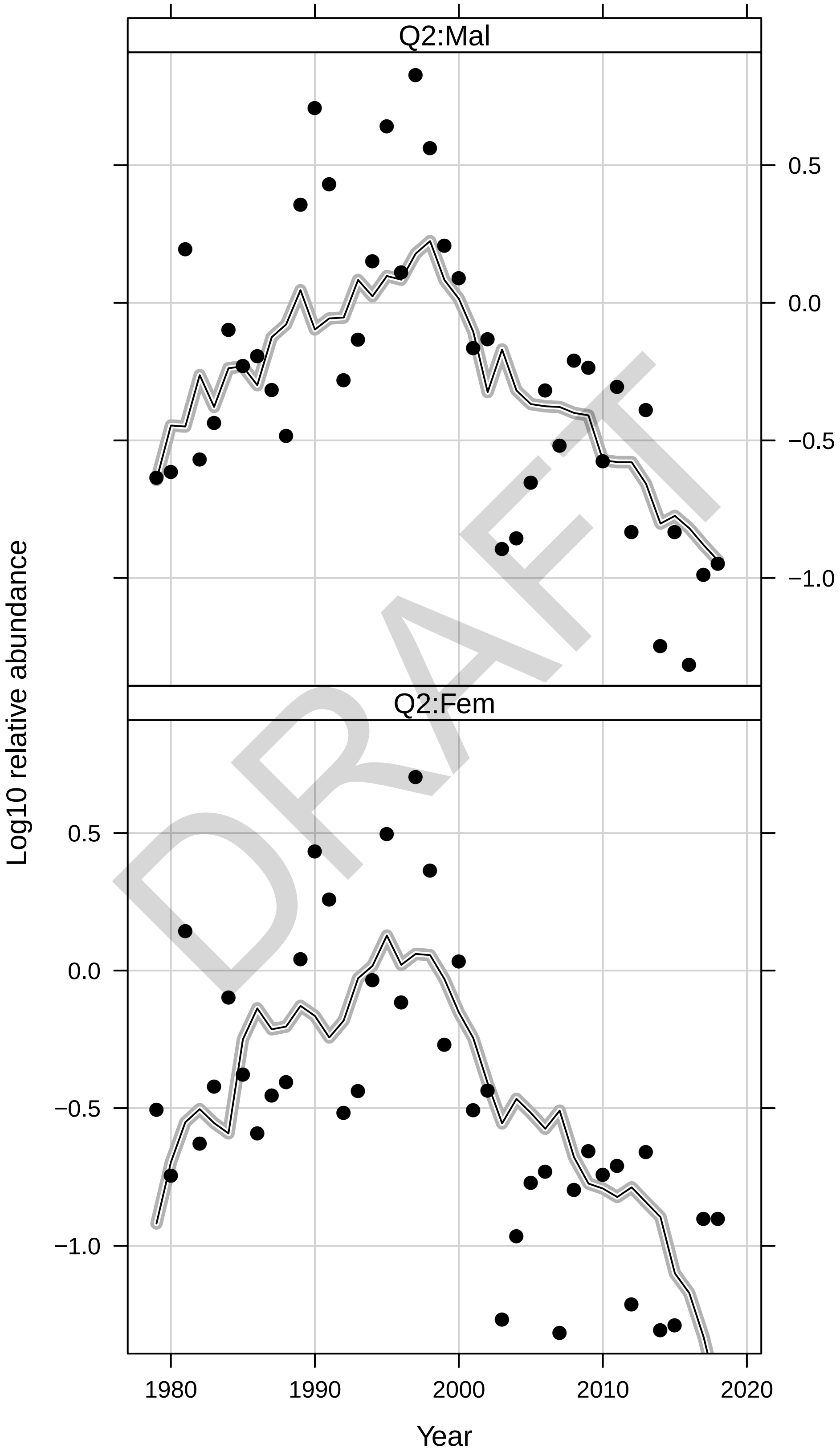
SNE_6F6_2019_orig_select
CTQ4 observed and predicted log survey trends



DRAFT

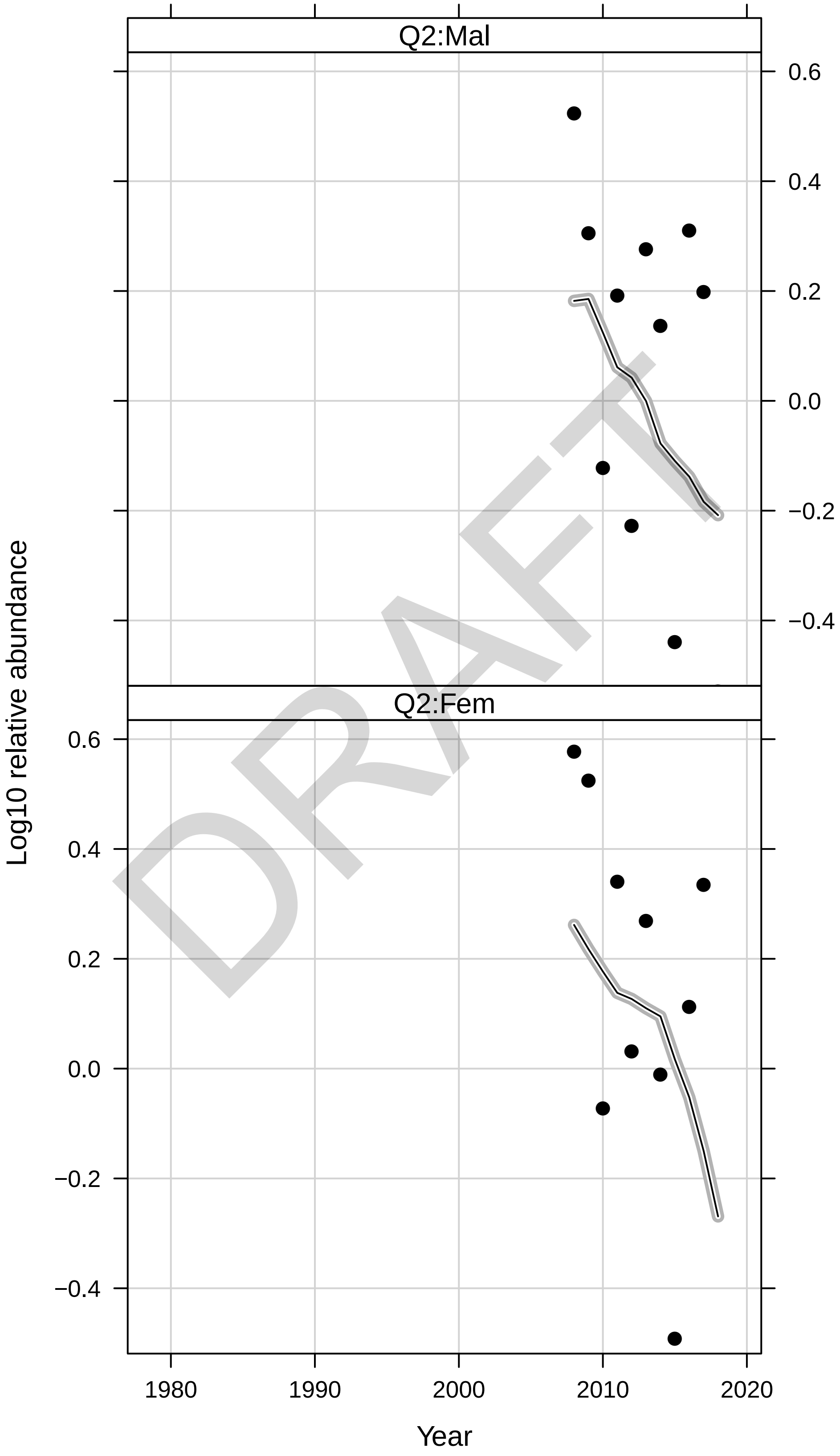
Symbols = observed; Dark line = predicted; Light line = predicted adjust

SNE_6F6_2019_orig_select
MAQ2 observed and predicted log survey trends



Symbols = observed; Dark line = predicted; Light line = predicted adjust

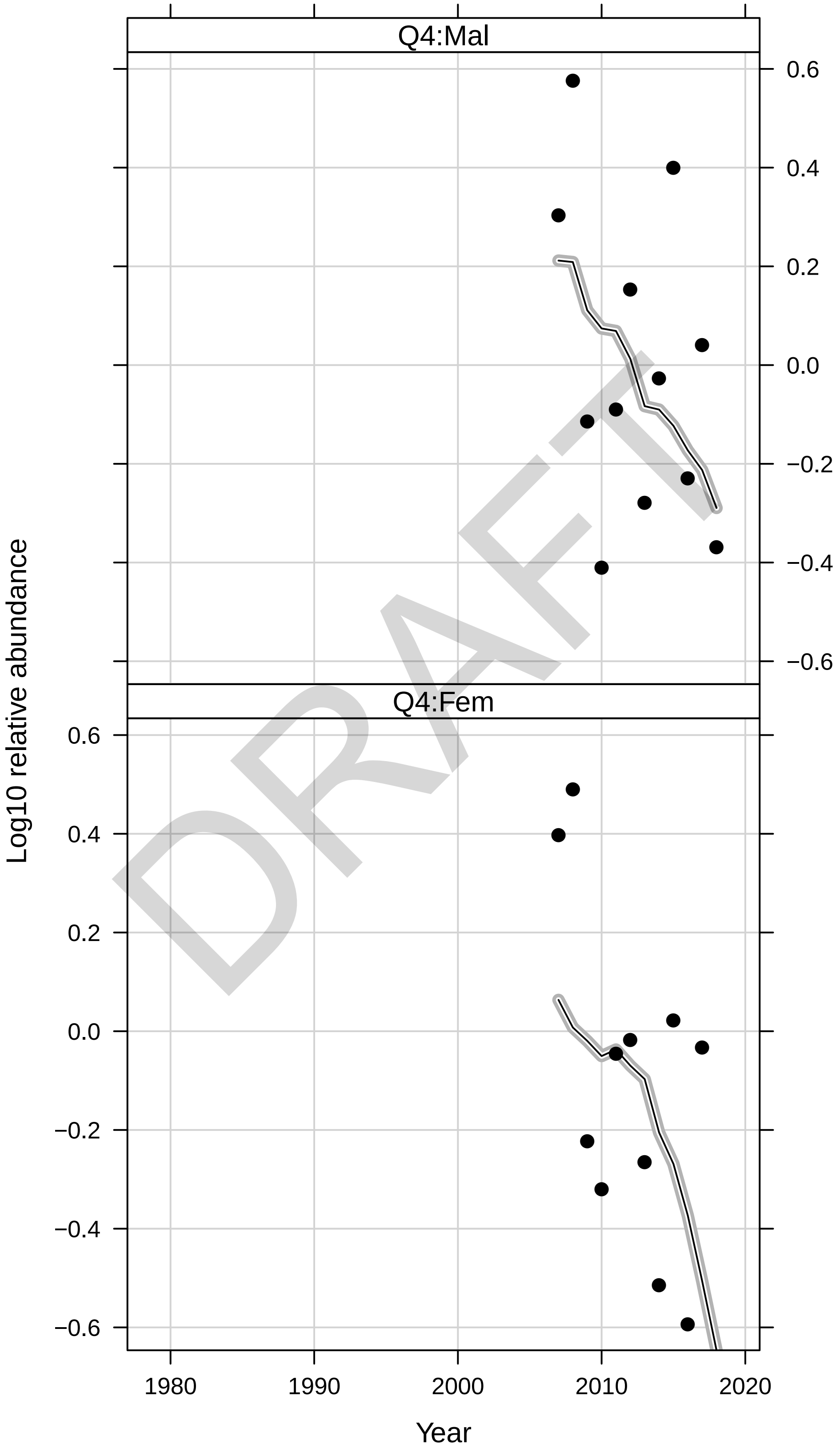
SNE_6F6_2019_orig_select
NEAMAPQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

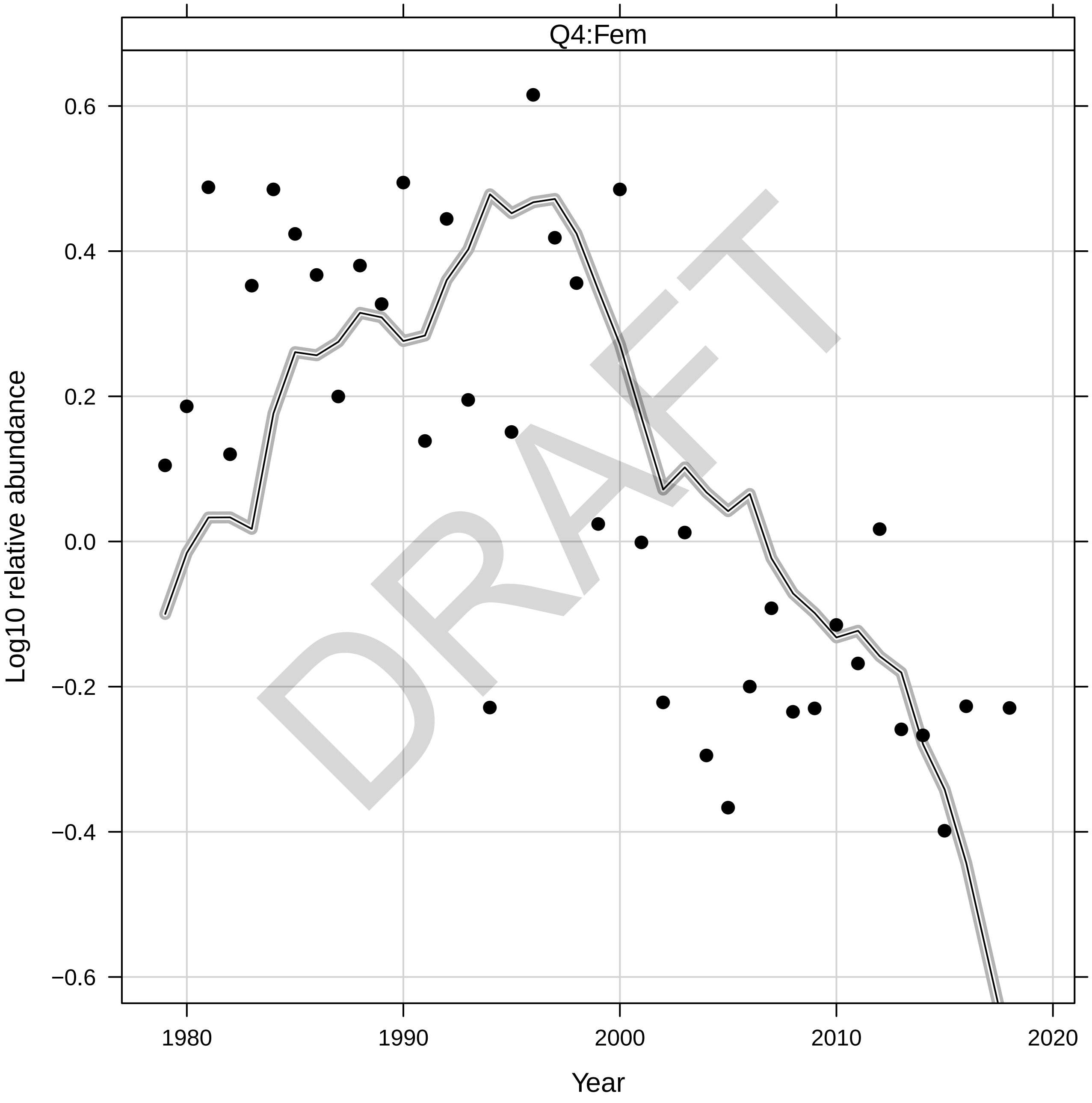
SNE_6F6_2019_orig_select
NEAMAPQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

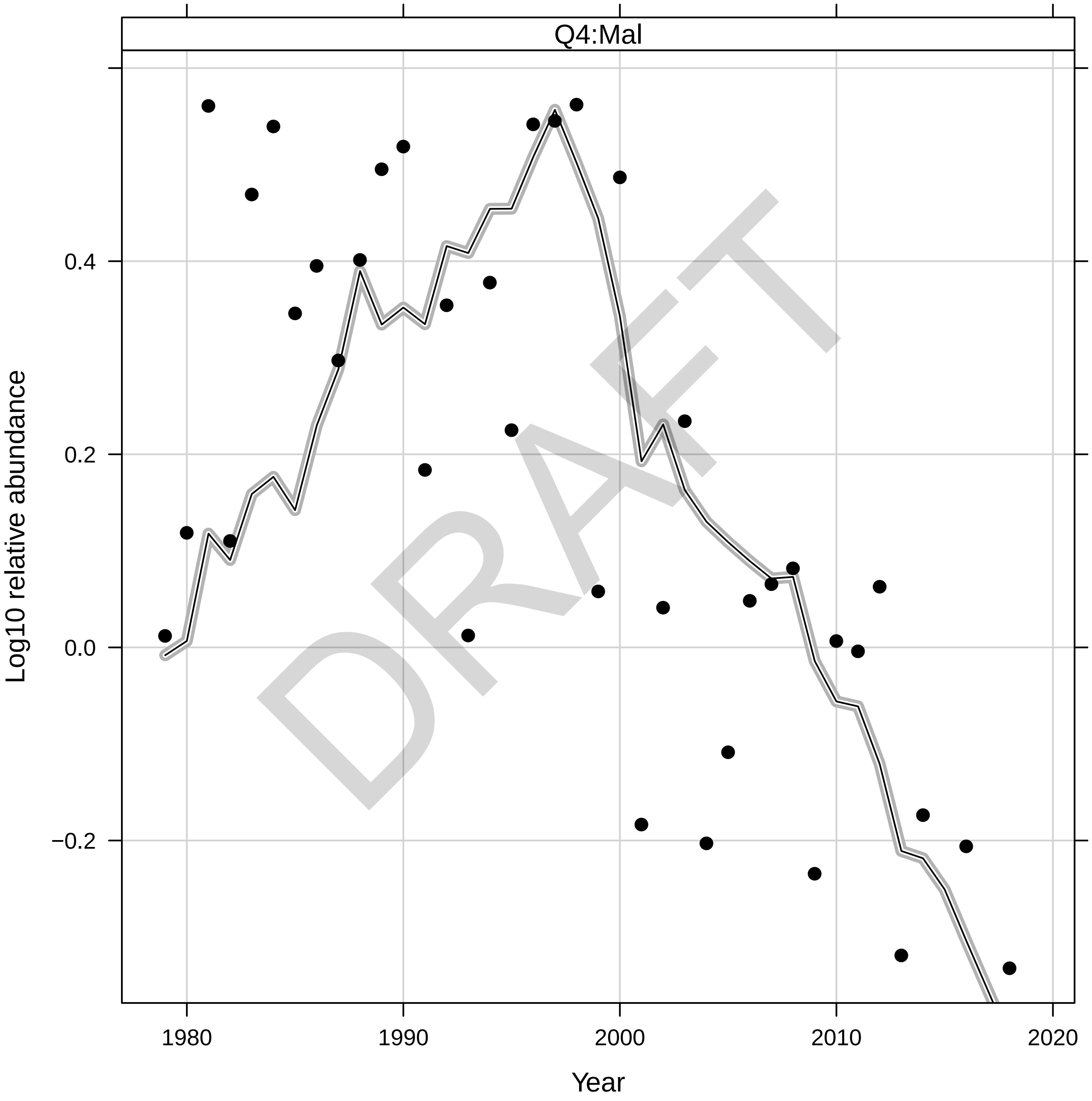
SNE_6F6_2019_orig_select
NfscFQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

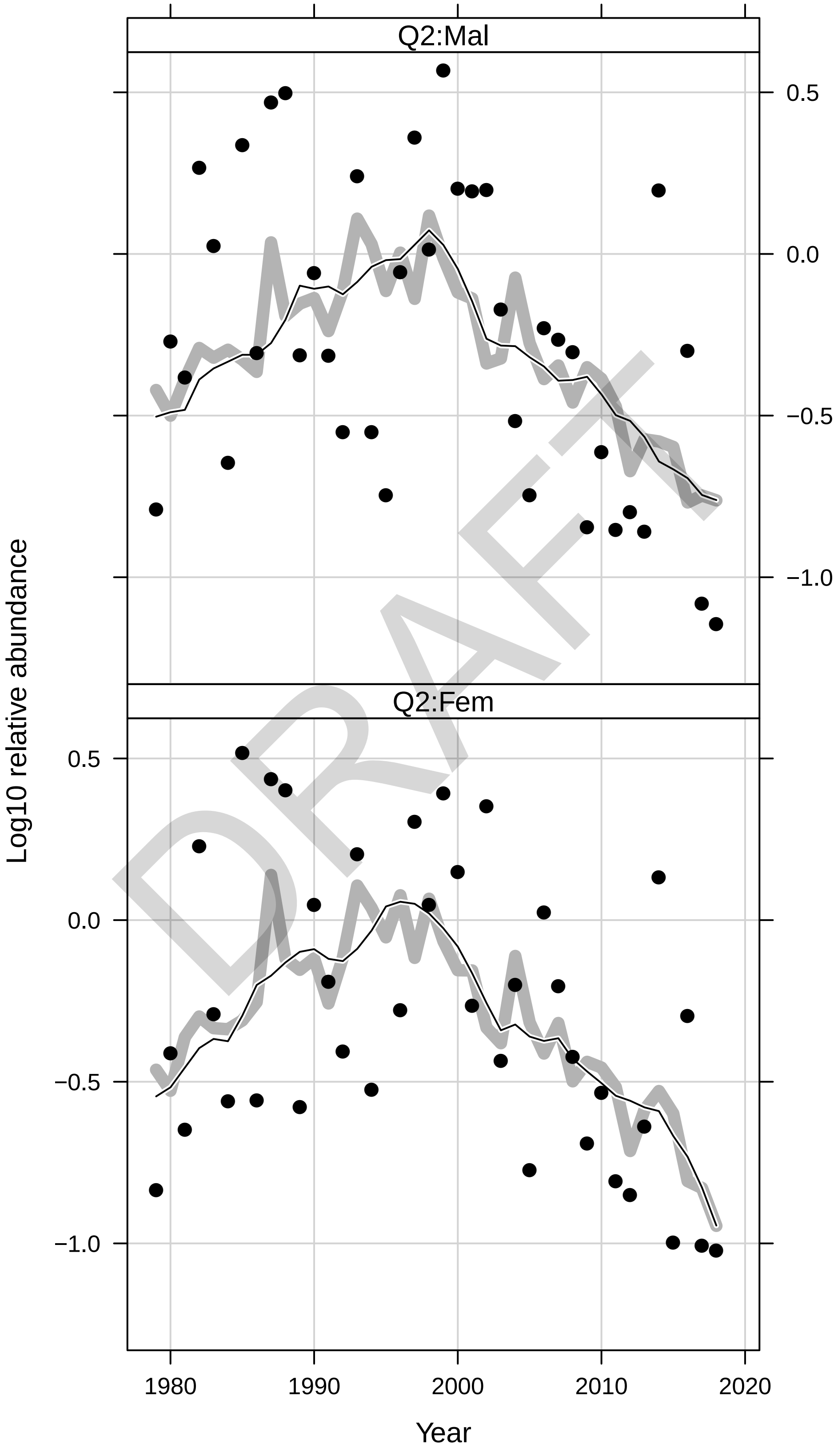
SNE_6F6_2019_orig_select
NfscMQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

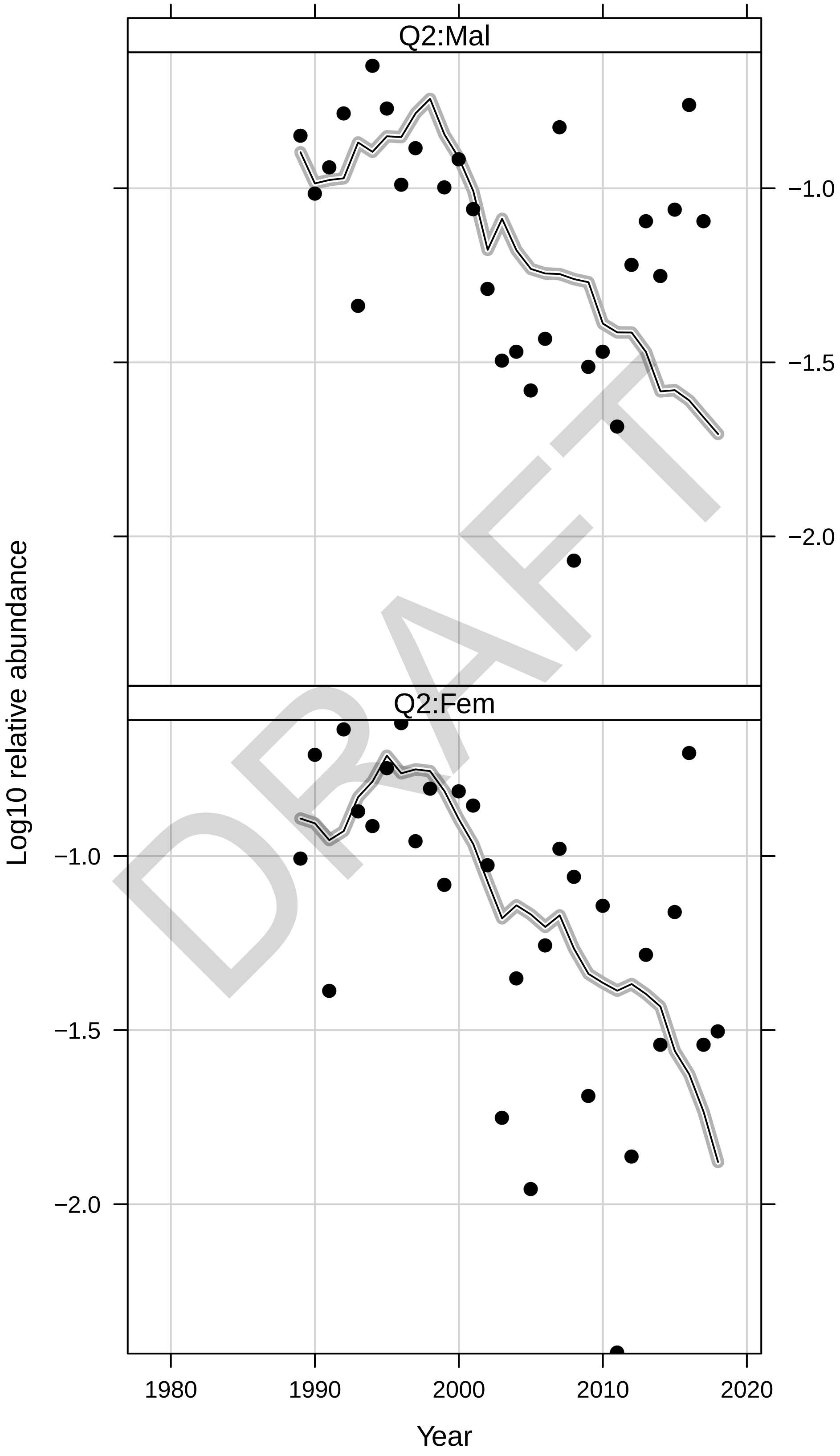
SNE_6F6_2019_orig_select
NfscQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

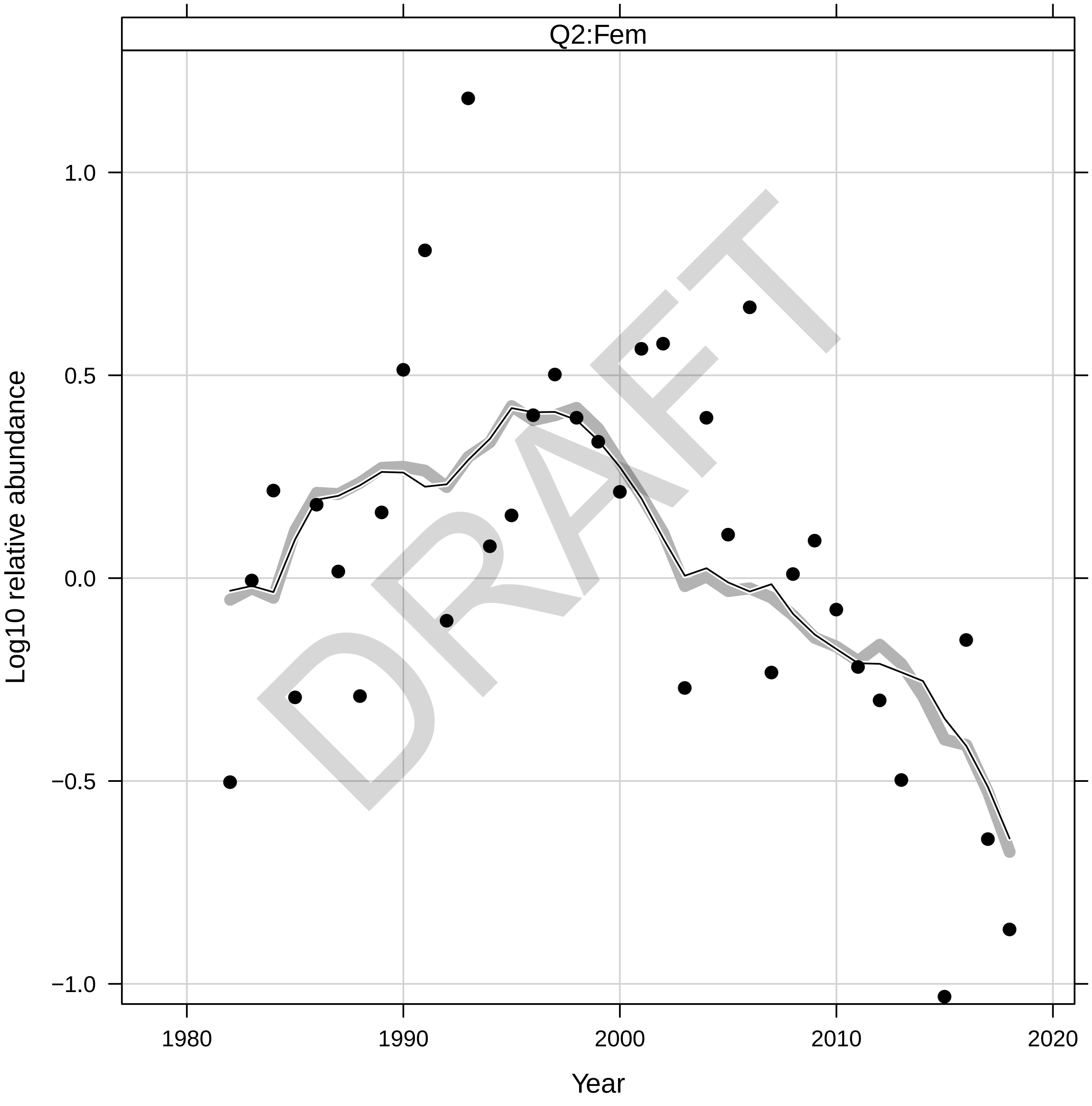
SNE_6F6_2019_orig_select
NJ observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

SNE_6F6_2019_orig_select
RIFQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

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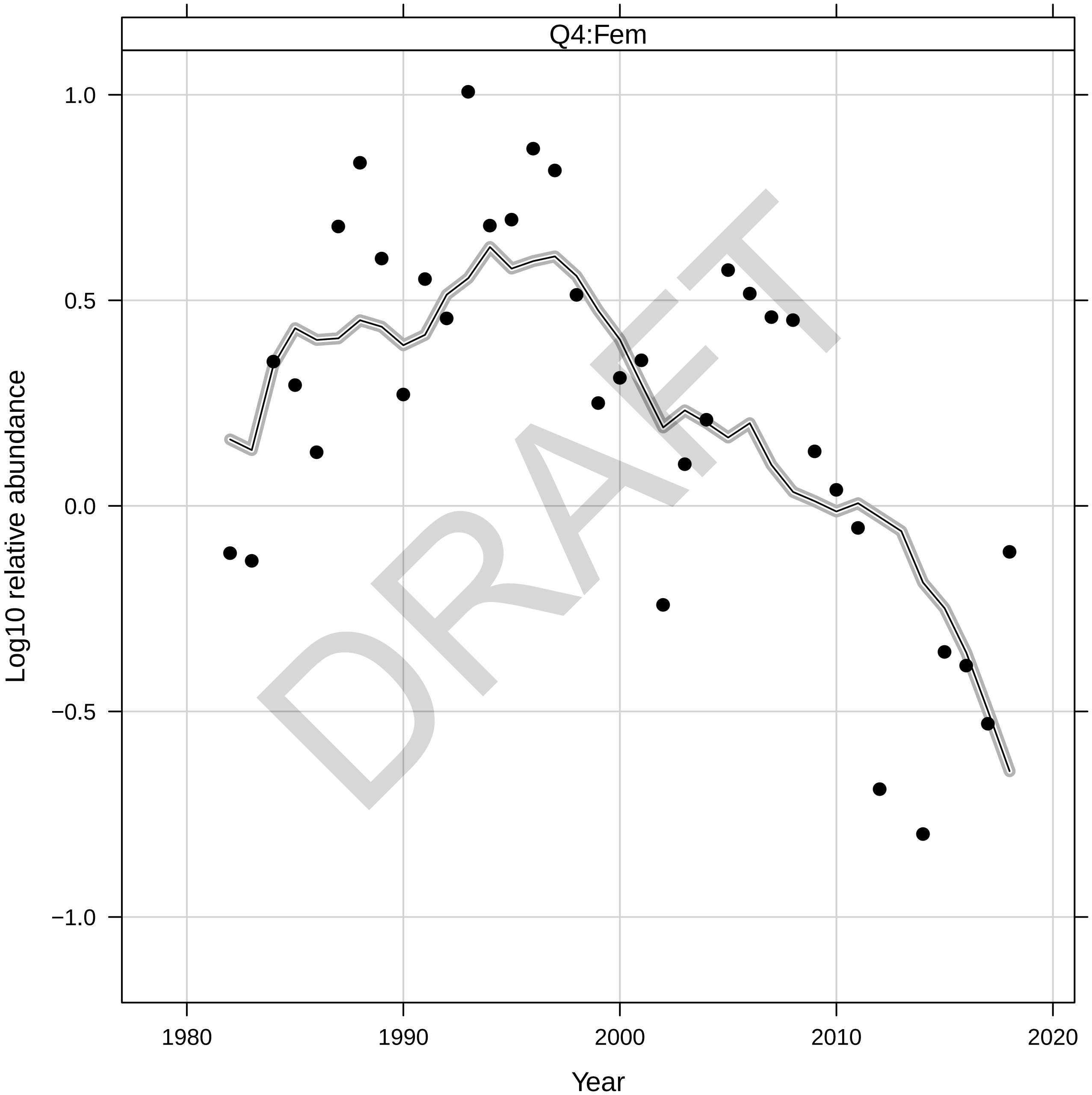
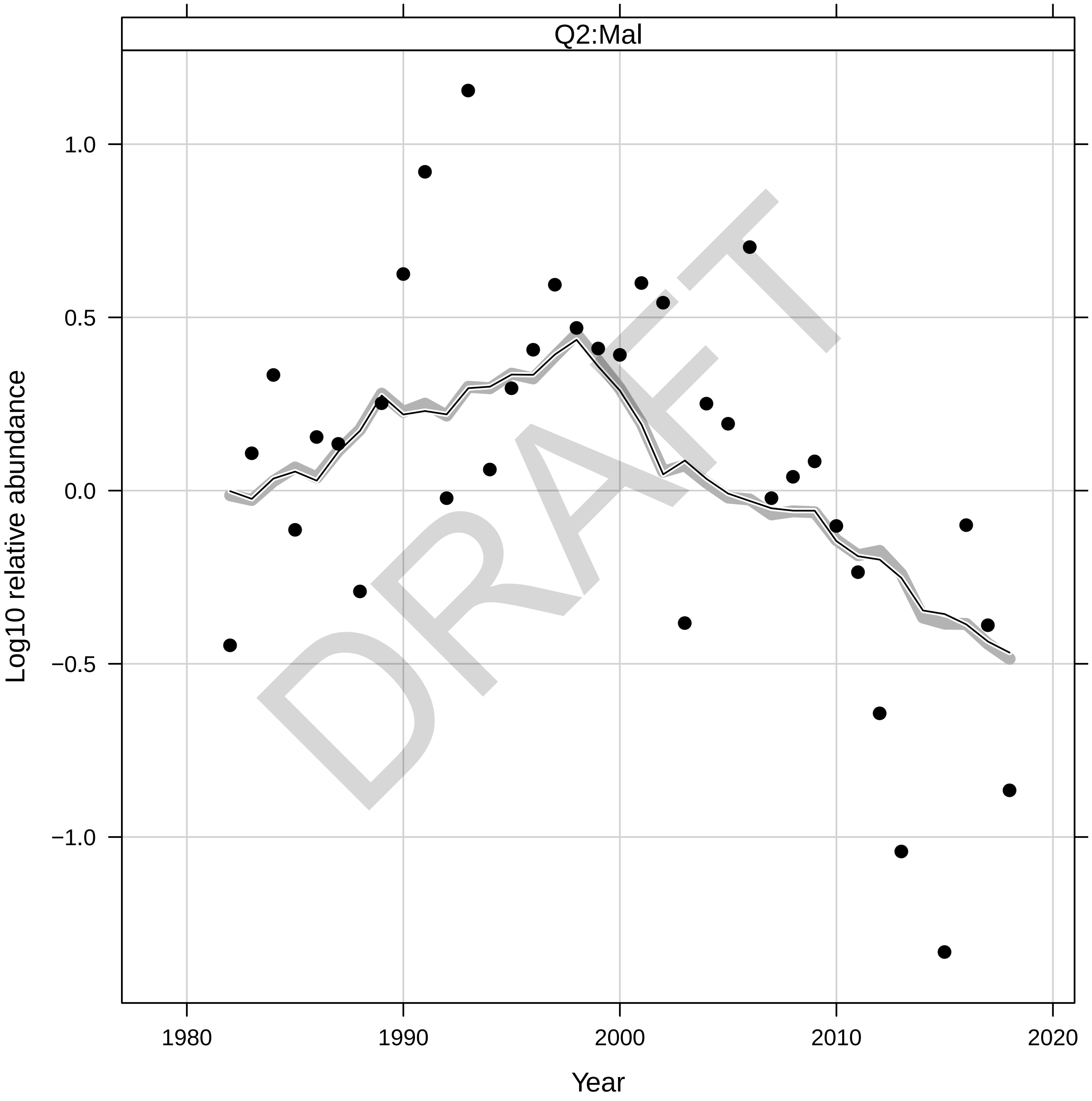
SNE_6F6_2019_orig_select
RIFQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

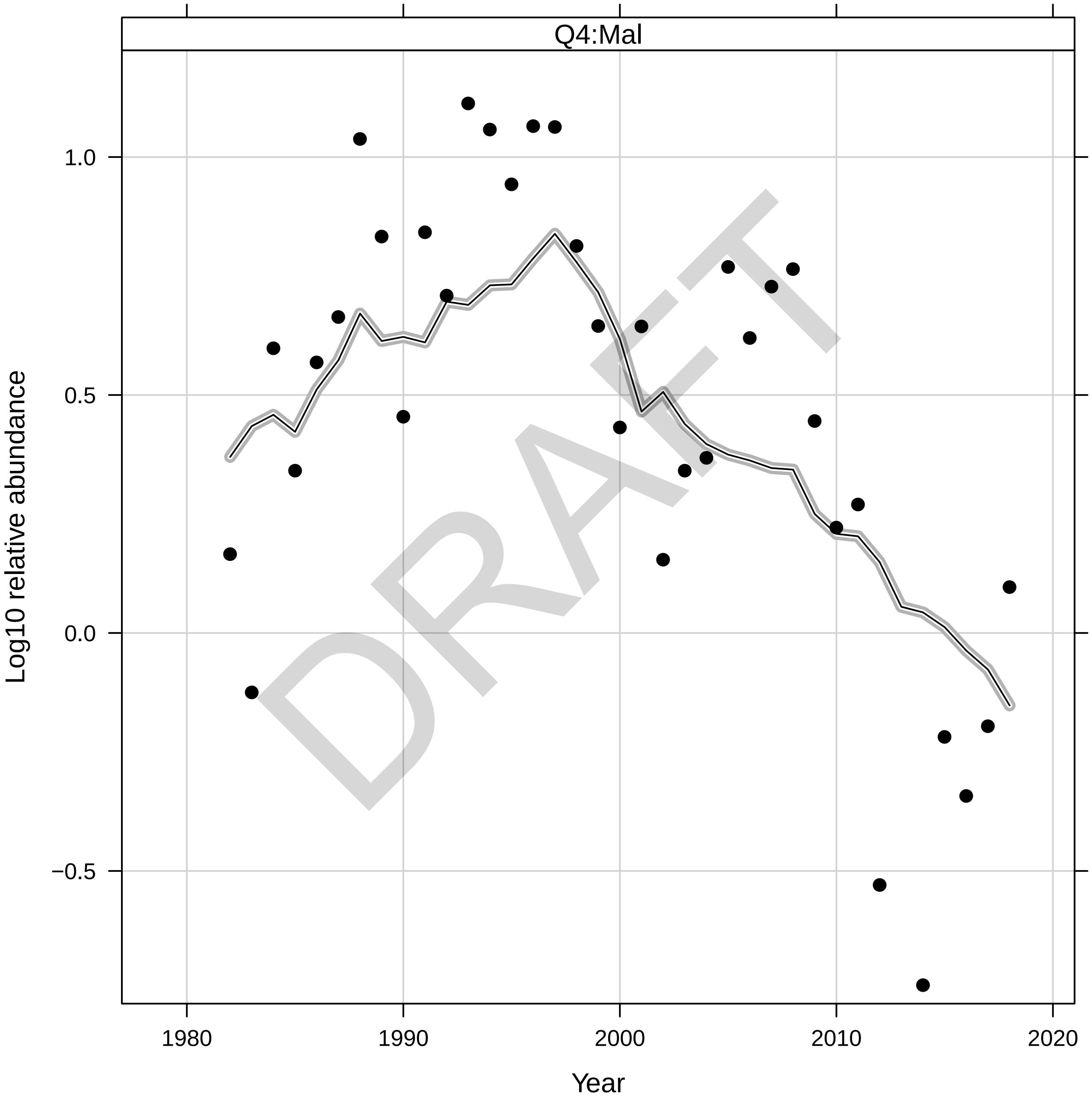
SNE_6F6_2019_orig_select
RIMQ2 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

SNE_6F6_2019_orig_select
RIMQ4 observed and predicted log survey trends



DRAFT

Symbols = observed; Dark line = predicted; Light line = predicted adjust

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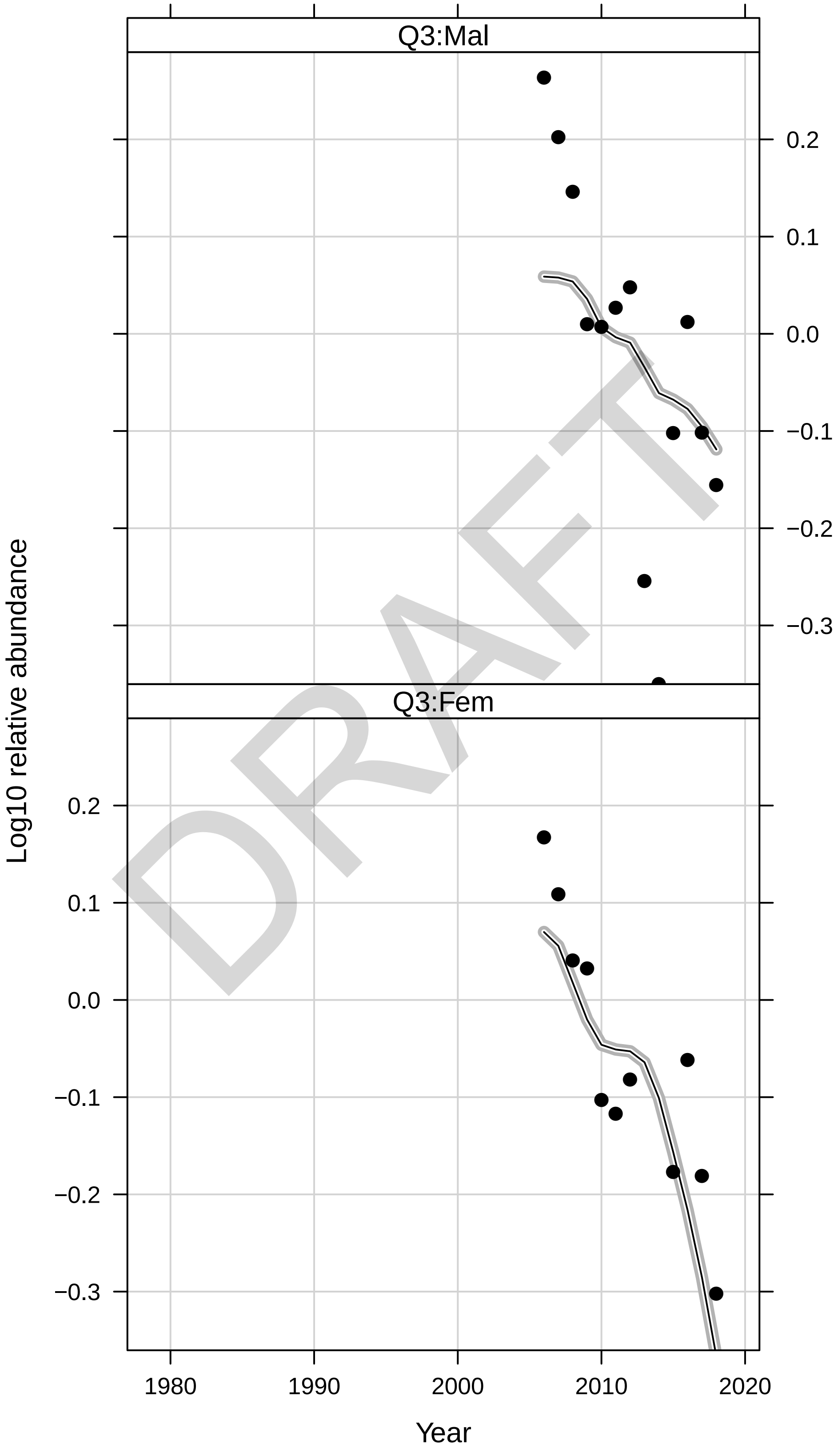
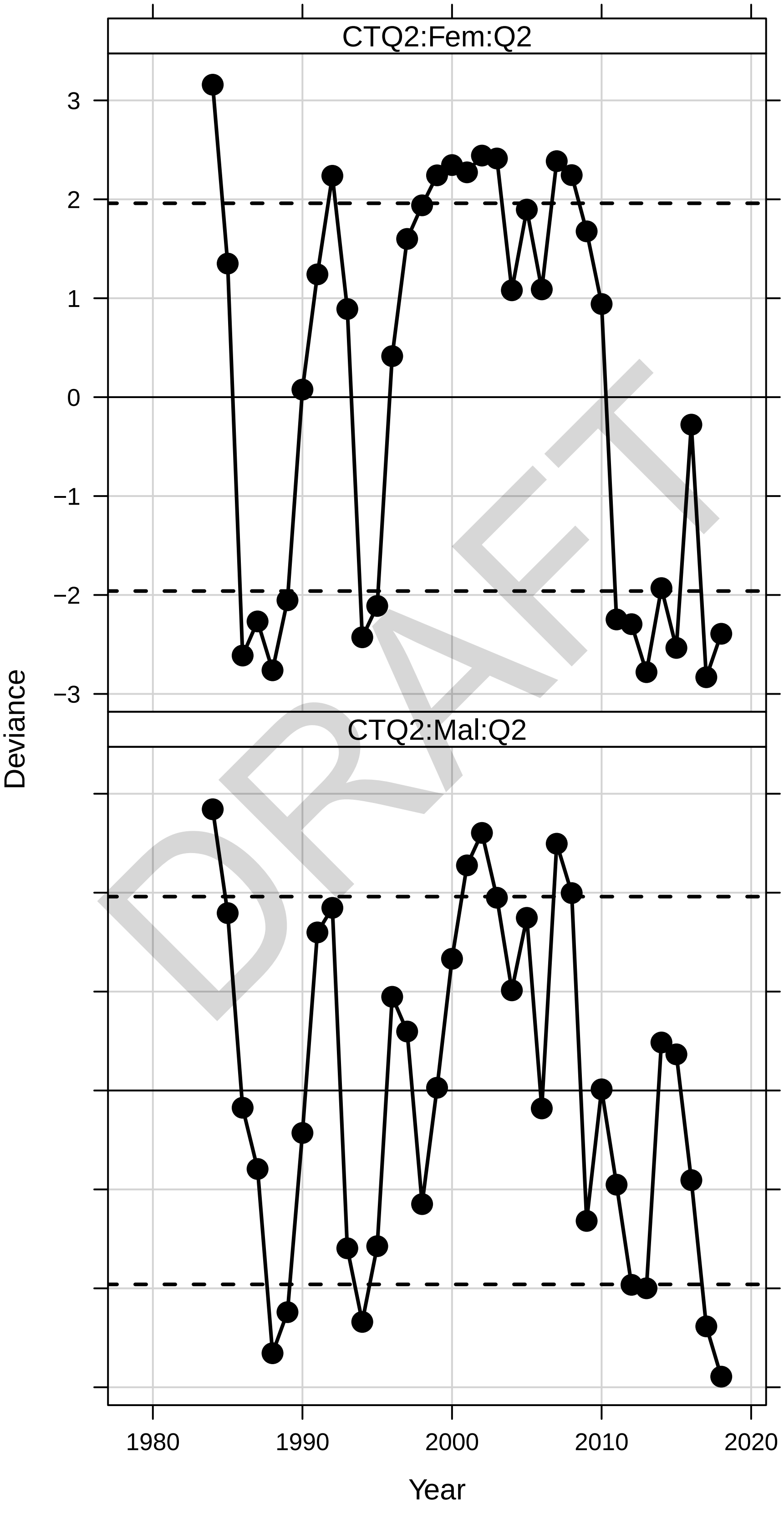
SNE_6F6_2019_orig_select
VTSQ3_model observed and predicted log survey trends



DRAFT

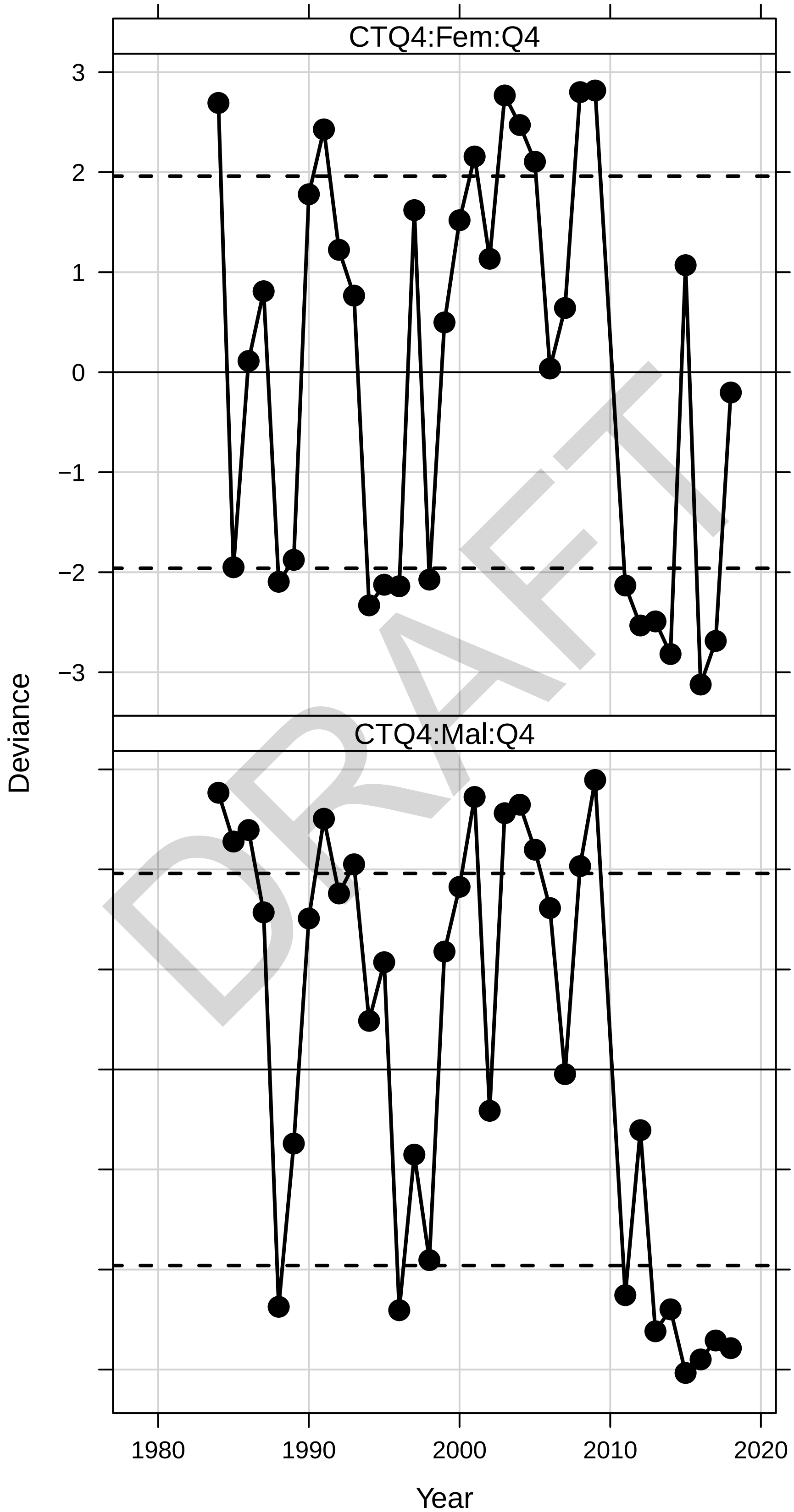
Symbols = observed; Dark line = predicted; Light line = predicted adjust

SNE_6F6_2019_orig_select deviance residuals for trend data CTQ2



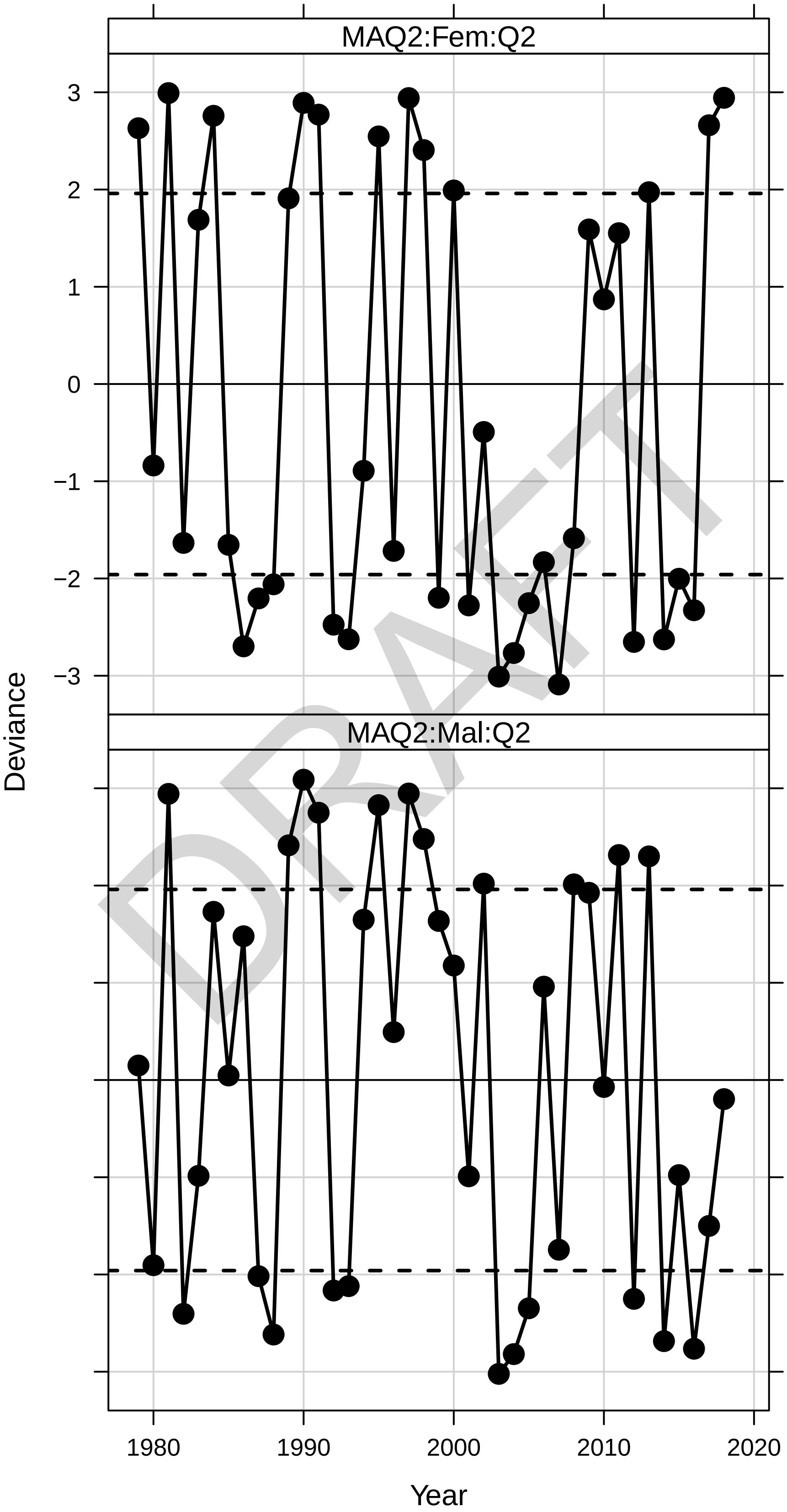
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data CTQ4



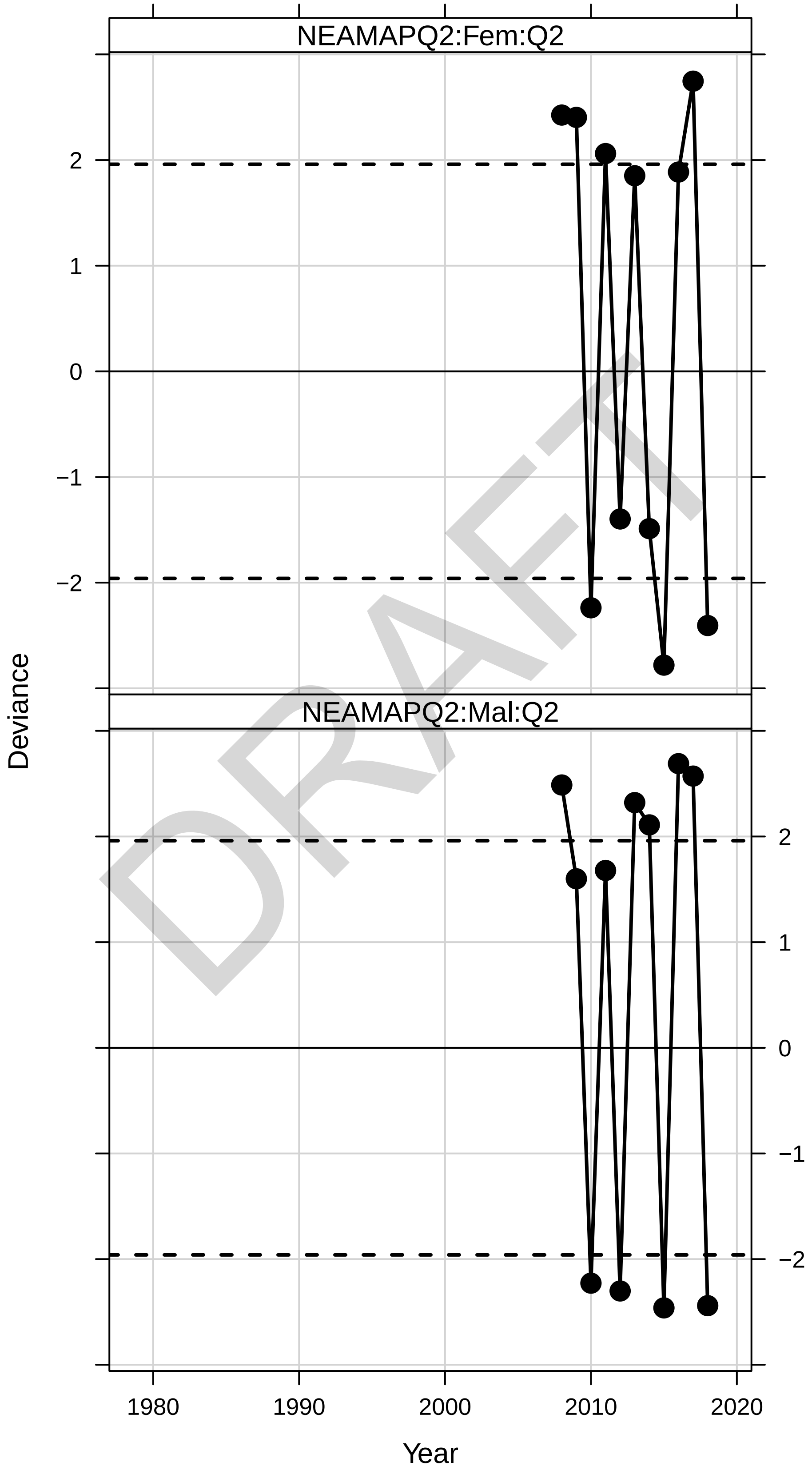
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data MAQ2



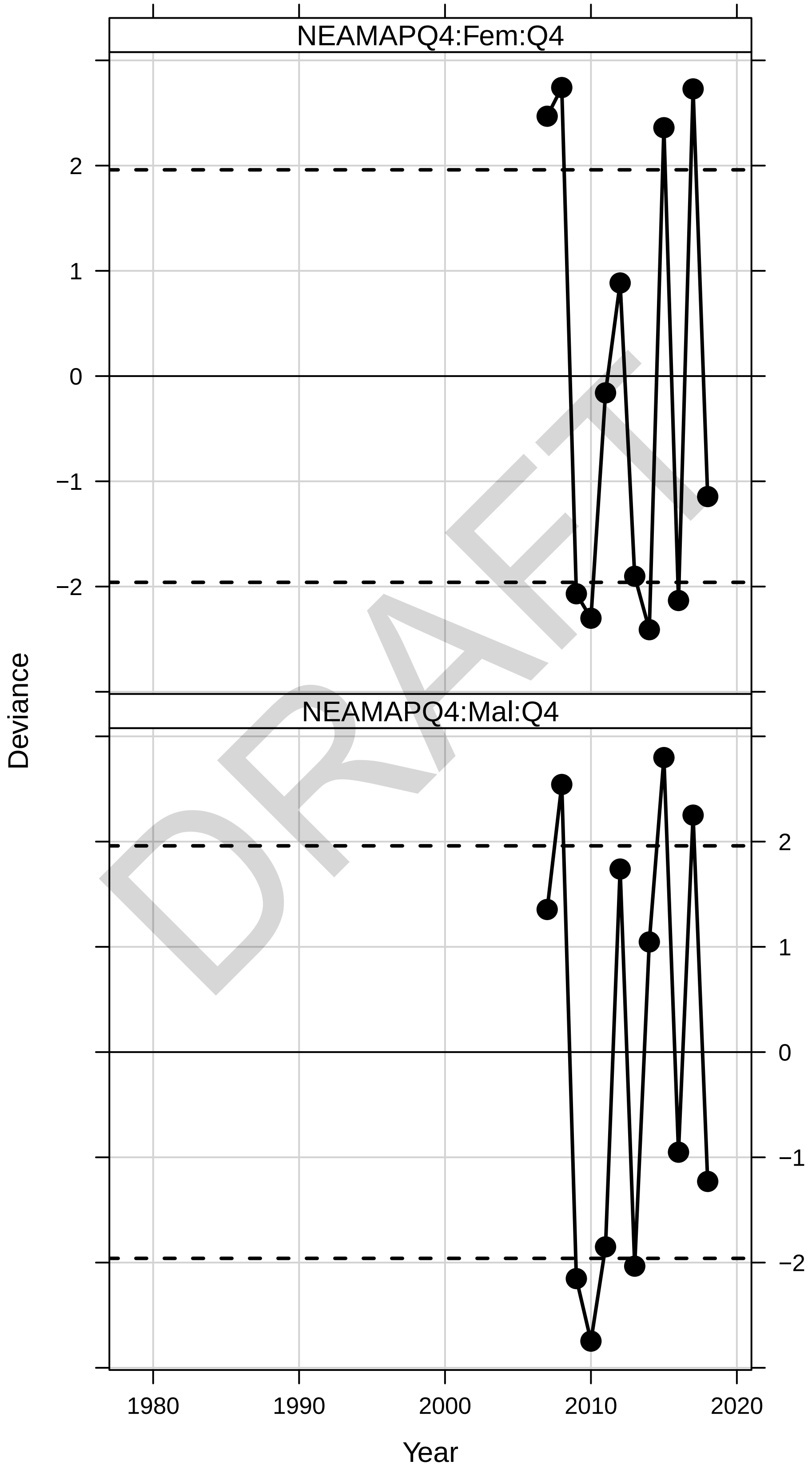
DRAFT

SNE_6F6_2019_orig_select
deviance residuals for trend data NEAMAPQ2



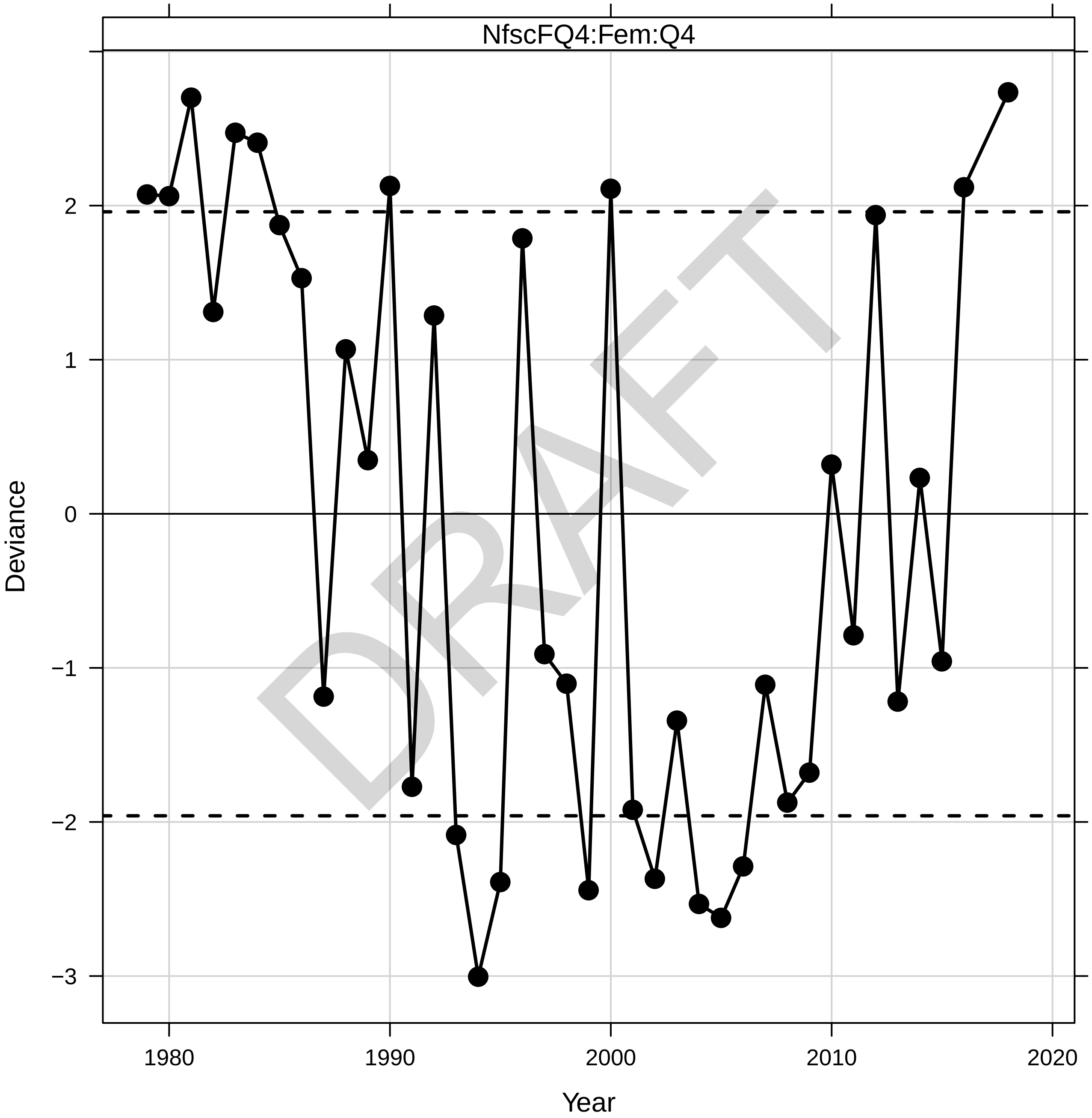
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data NEAMAPQ4



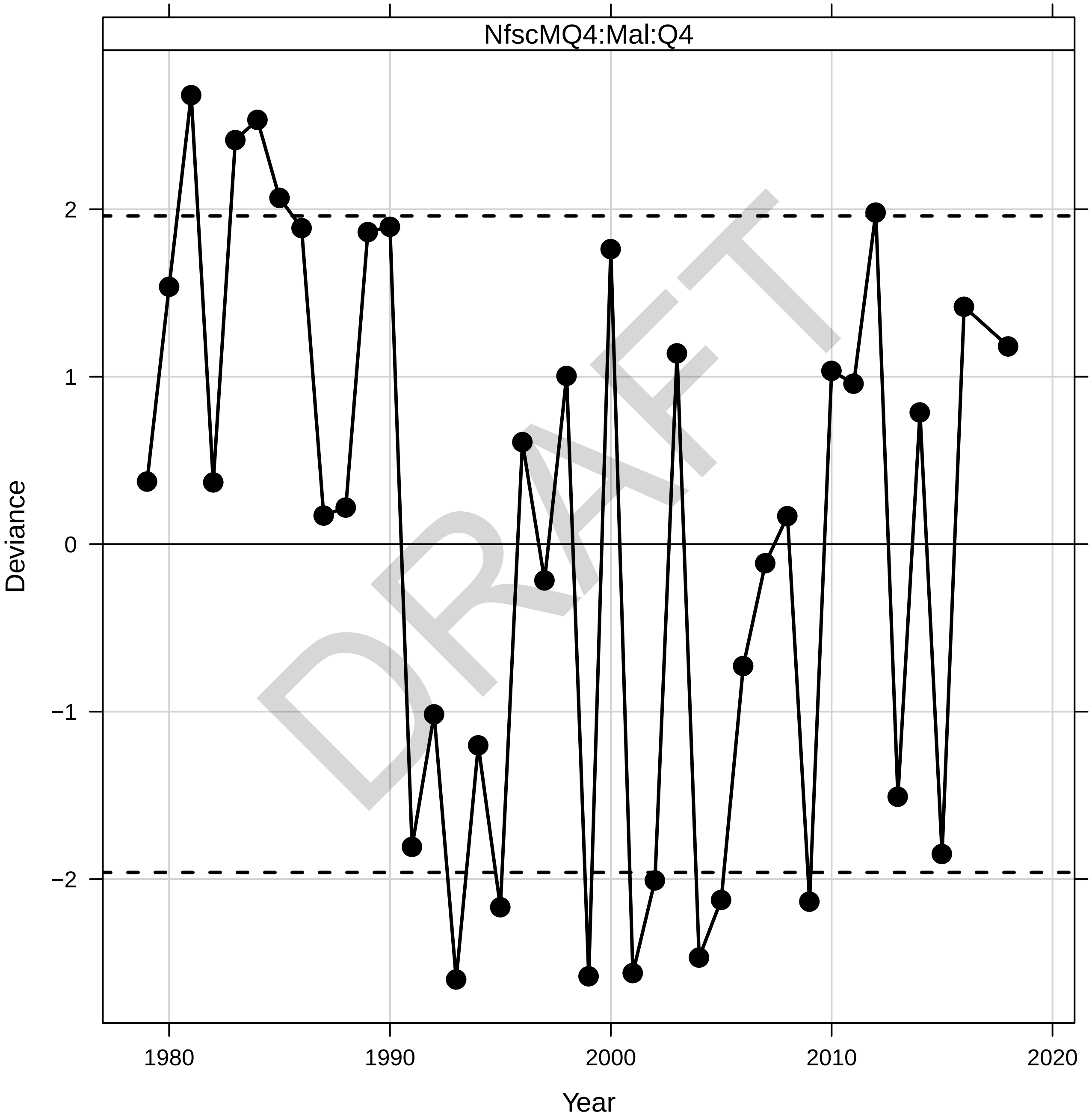
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data NfscFQ4



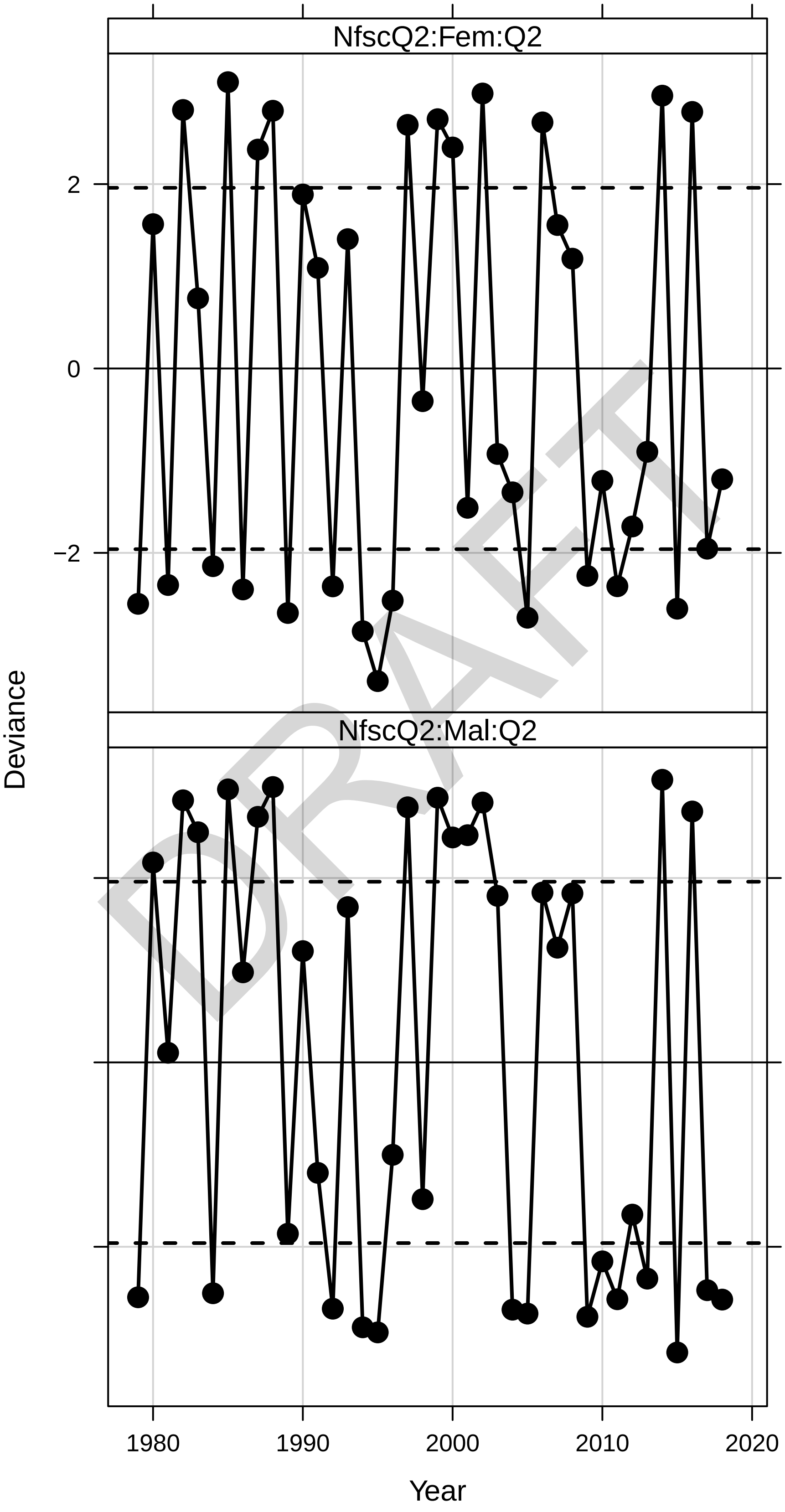
DRAFT

SNE_6F6_2019_orig_select
deviance residuals for trend data NfscMQ4



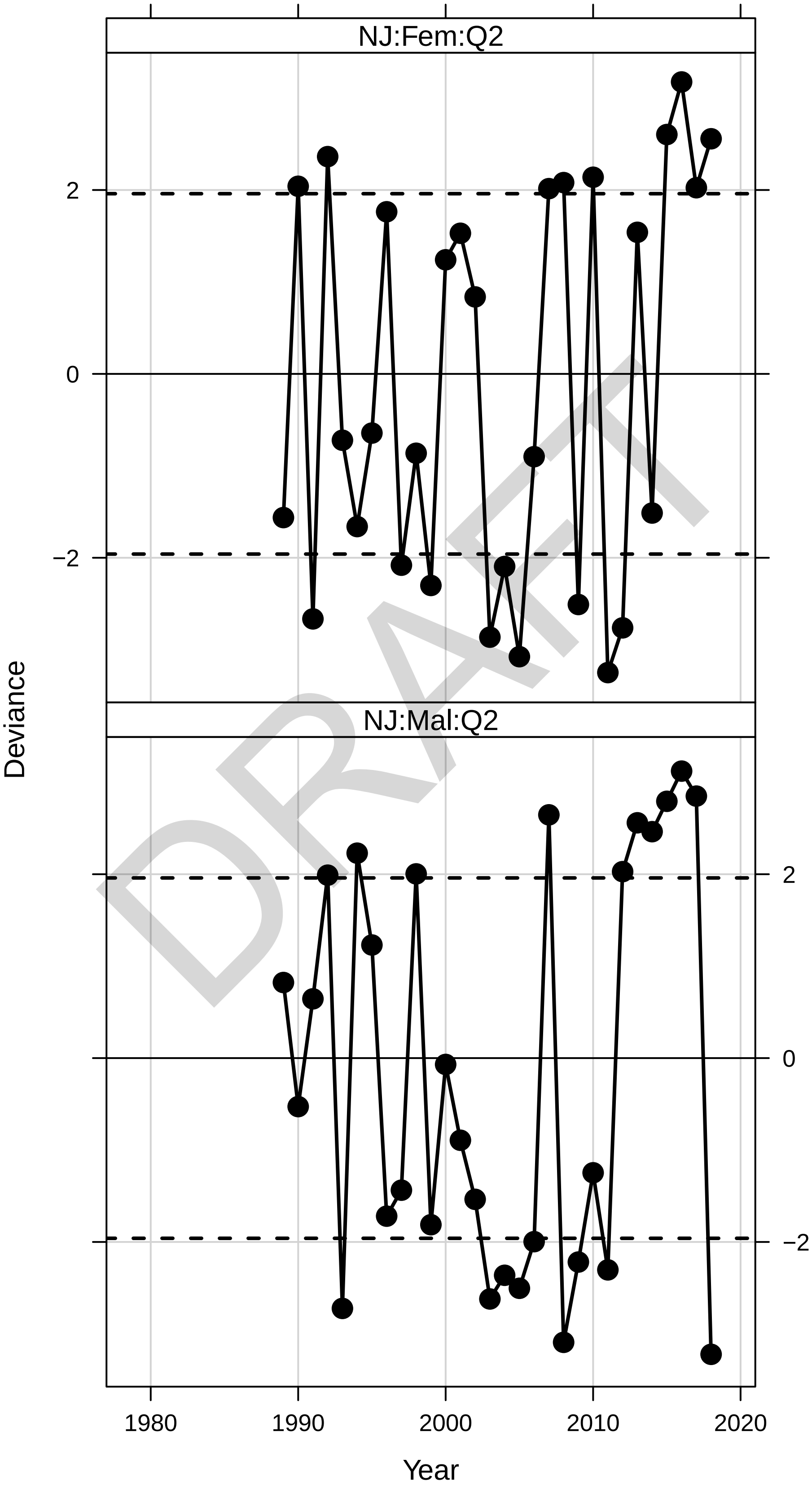
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data NfscQ2



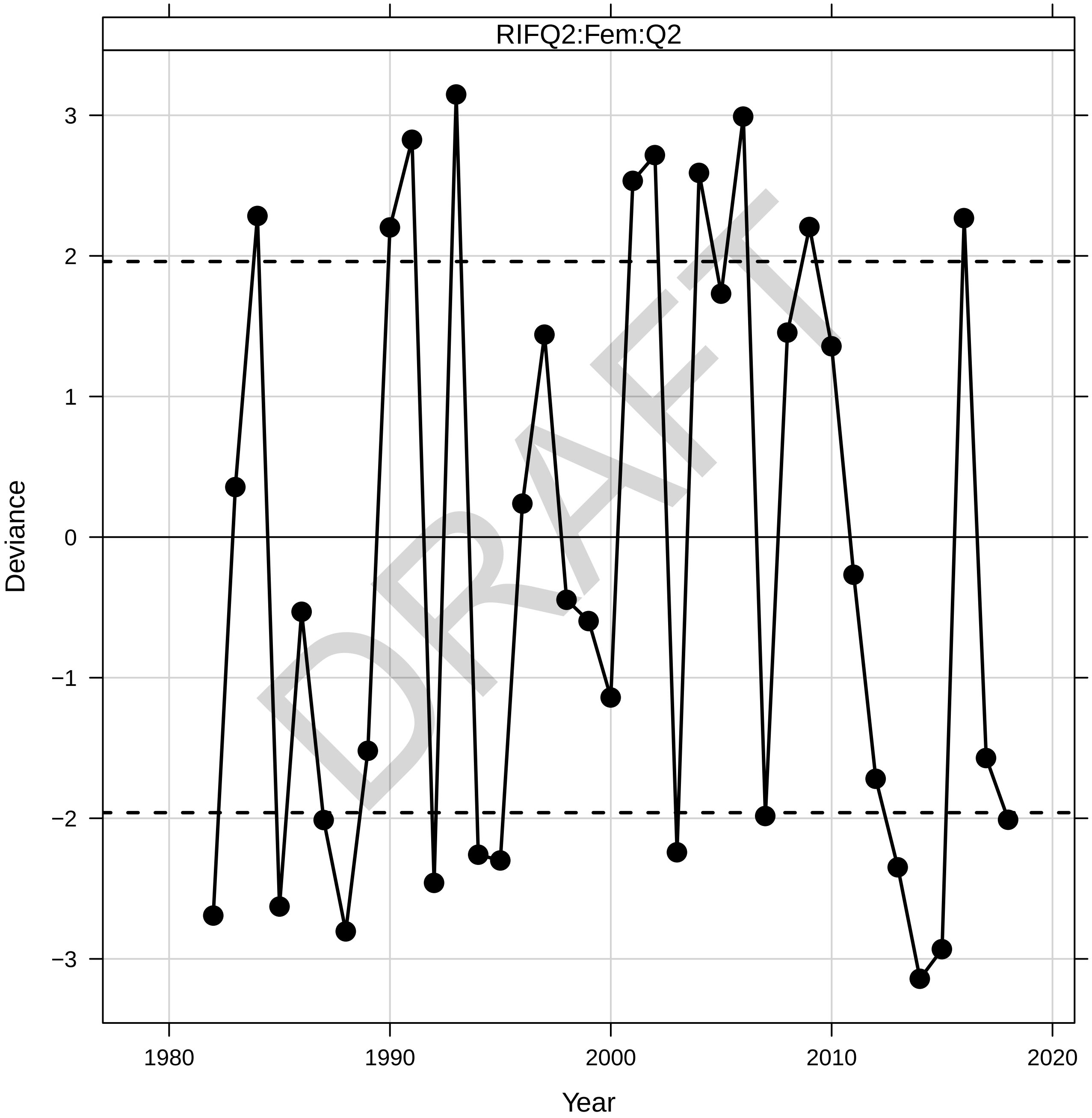
DRAFT

SNE_6F6_2019_orig_select
deviance residuals for trend data NJ



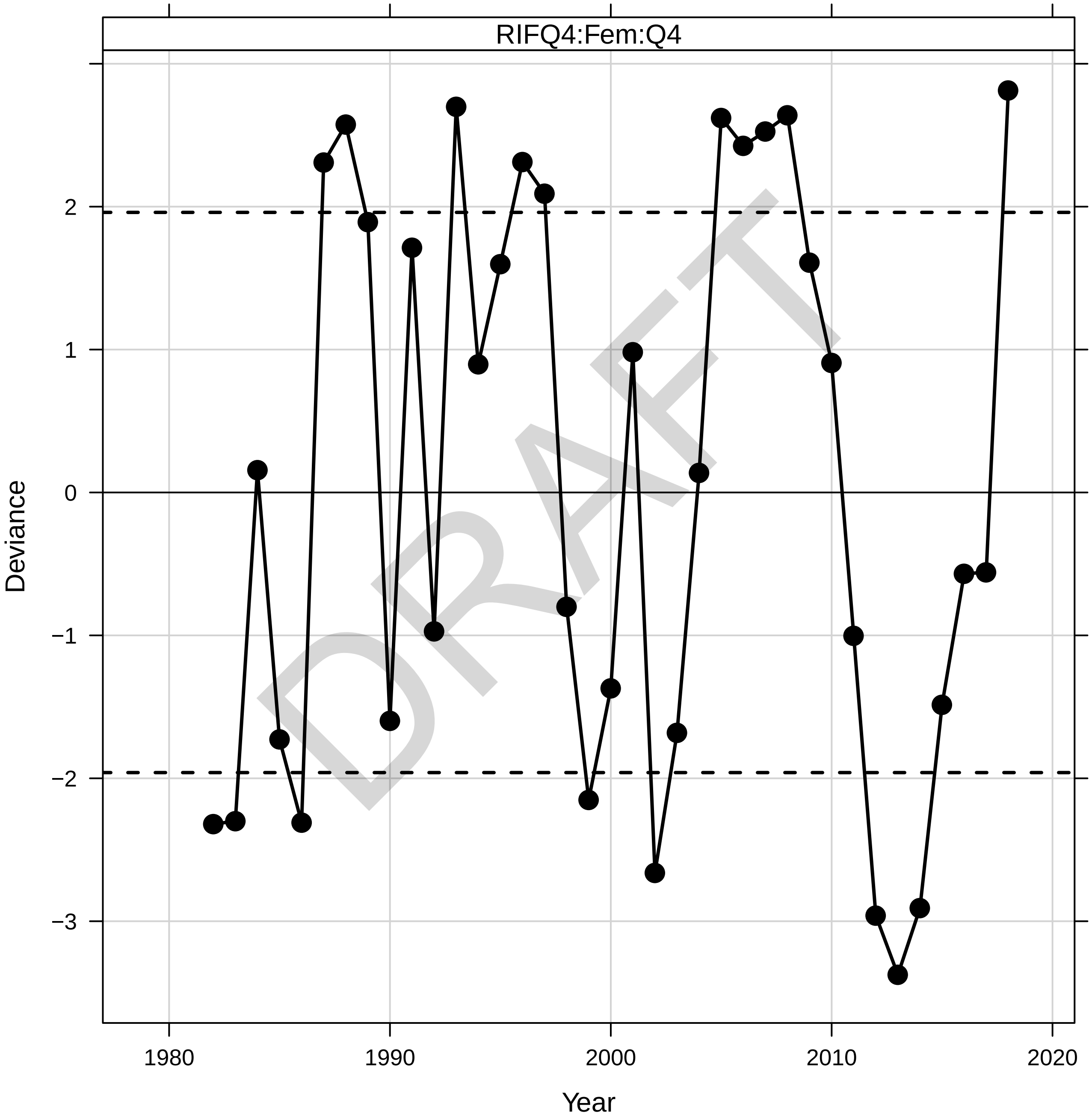
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data RIFQ2



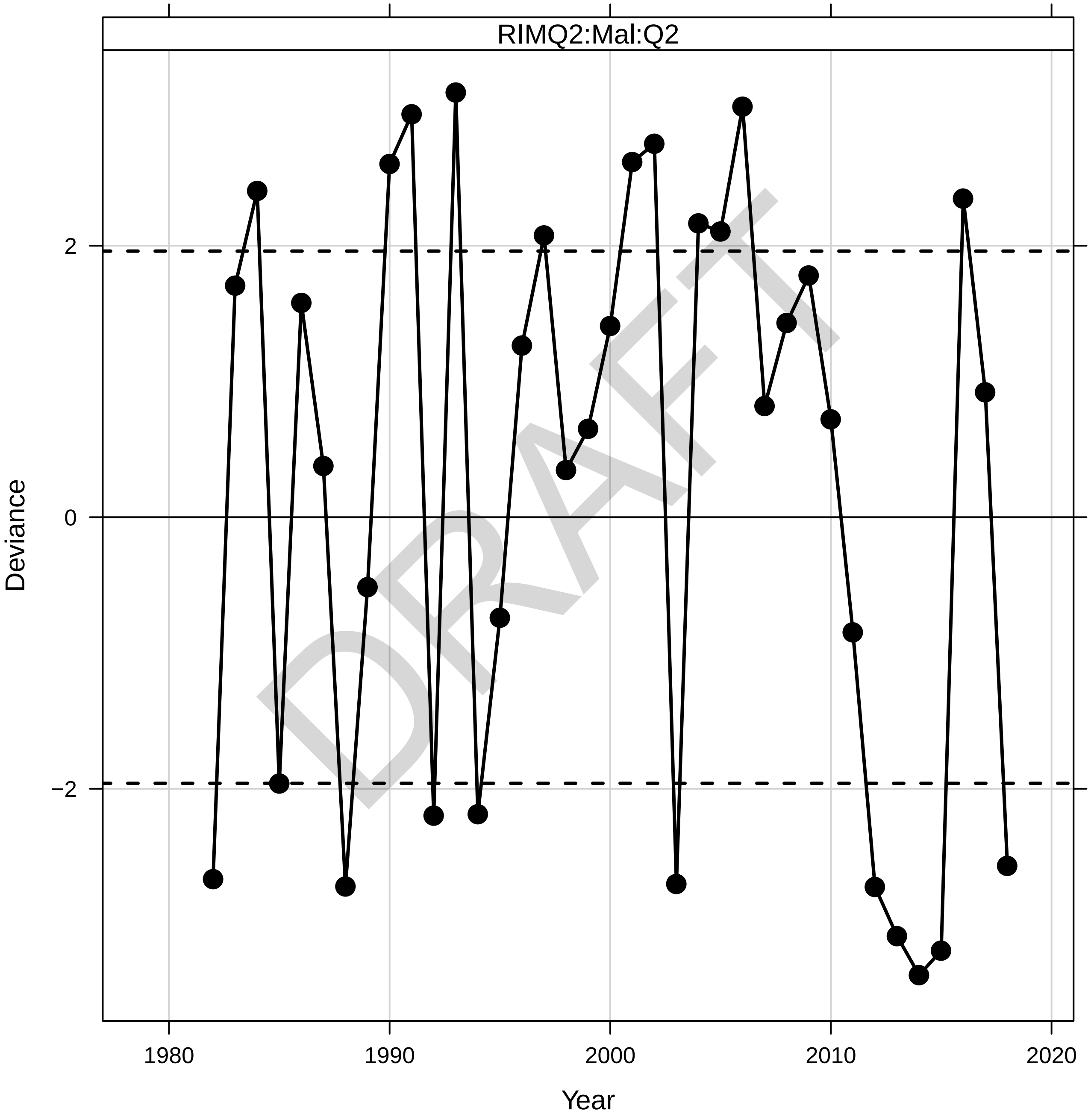
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data RIFQ4



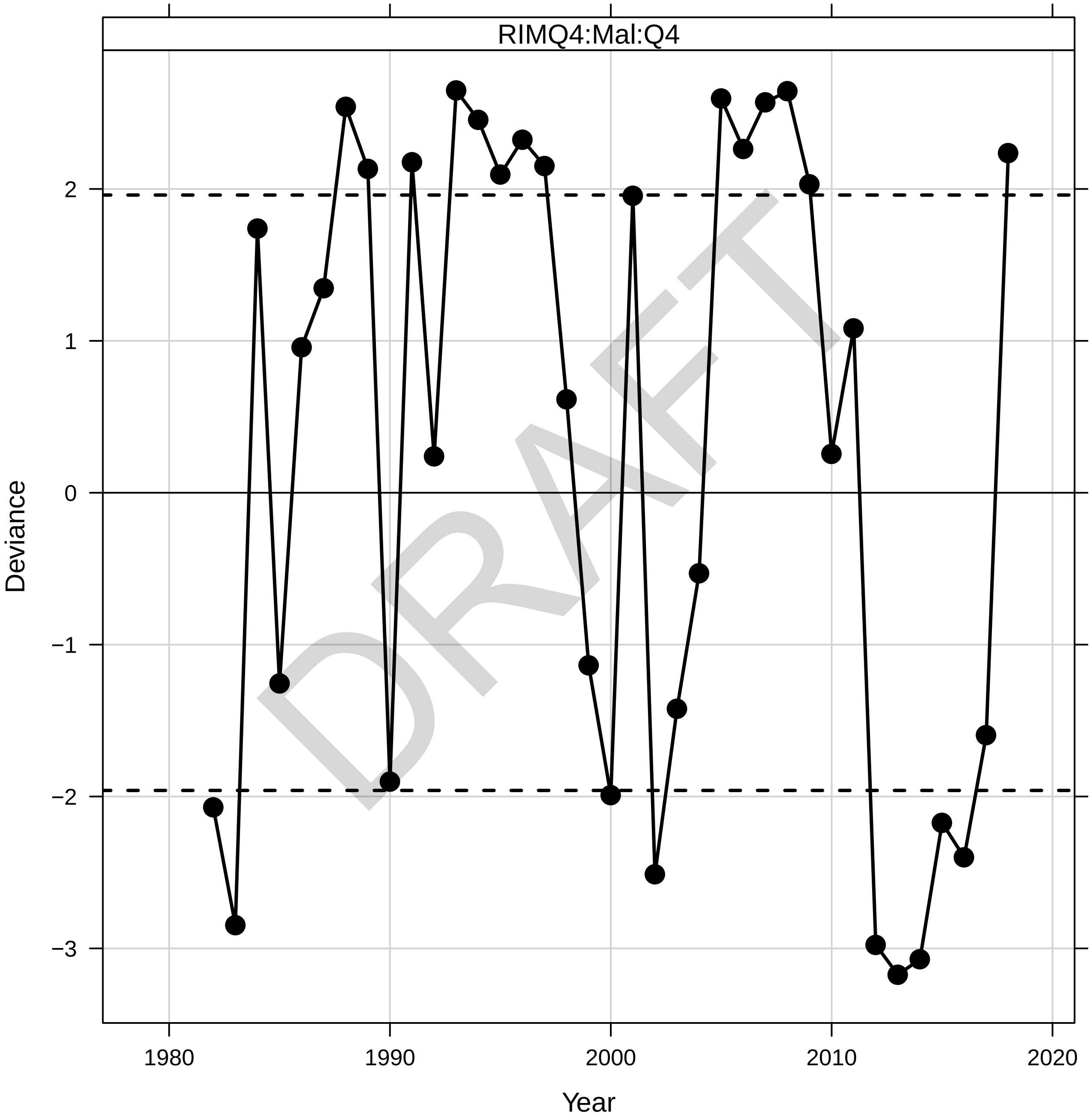
DRAFT

SNE_6F6_2019_orig_select deviance residuals for trend data RIMQ2



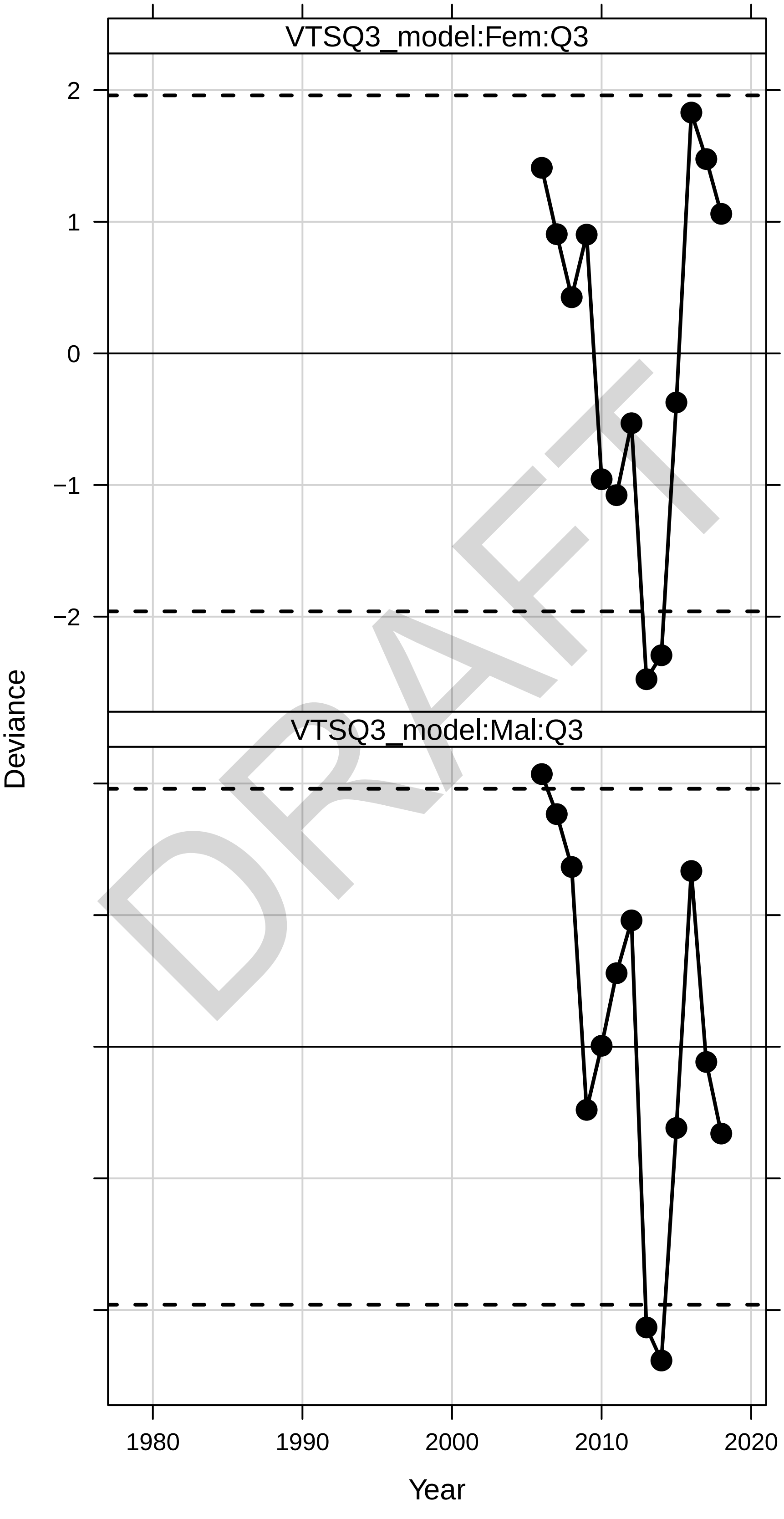
DRAFT

SNE_6F6_2019_orig_select
deviance residuals for trend data RIMQ4



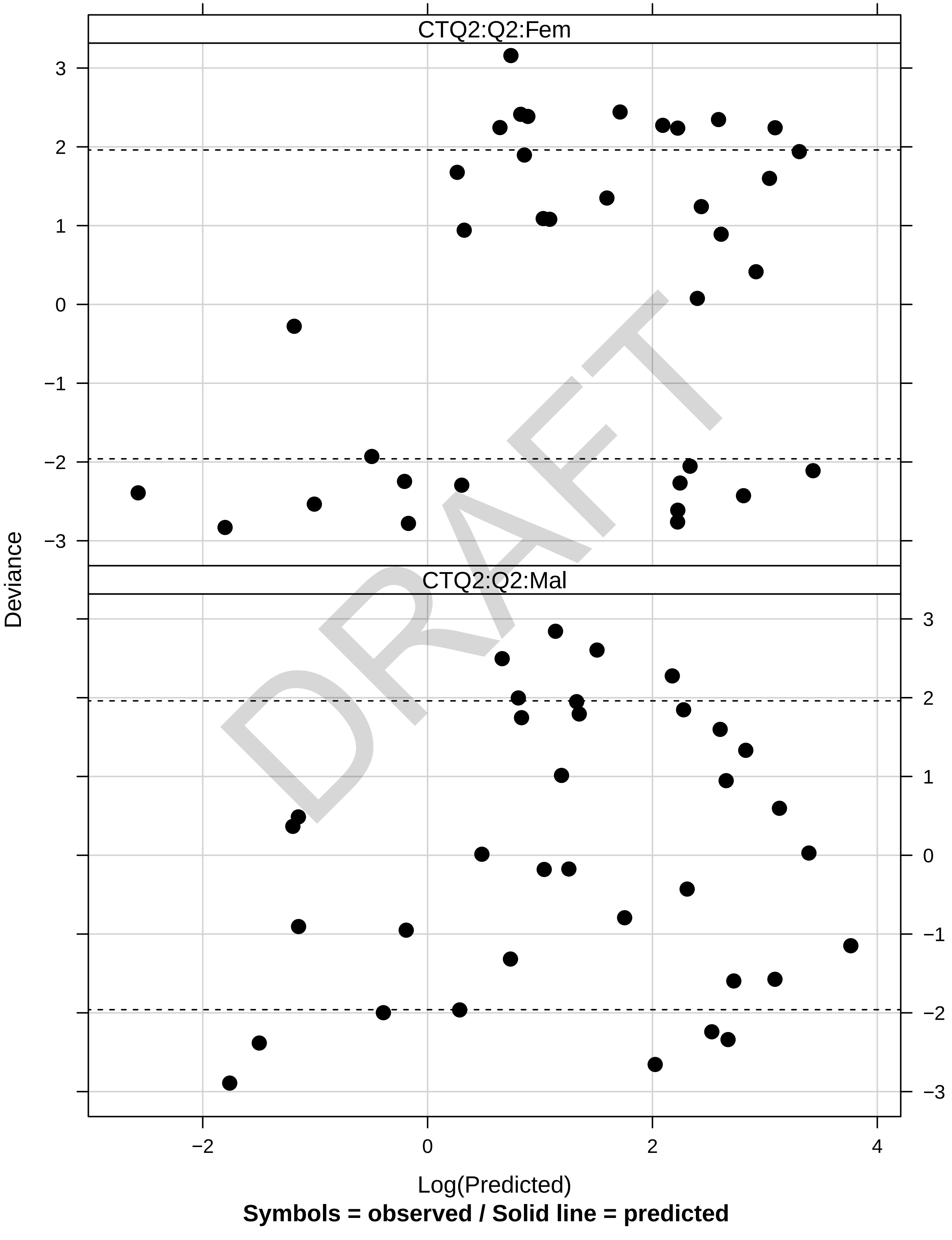
DRAFT

SNE_6F6_2019_orig_select
deviance residuals for trend data VTSQ3_model



DRAFT

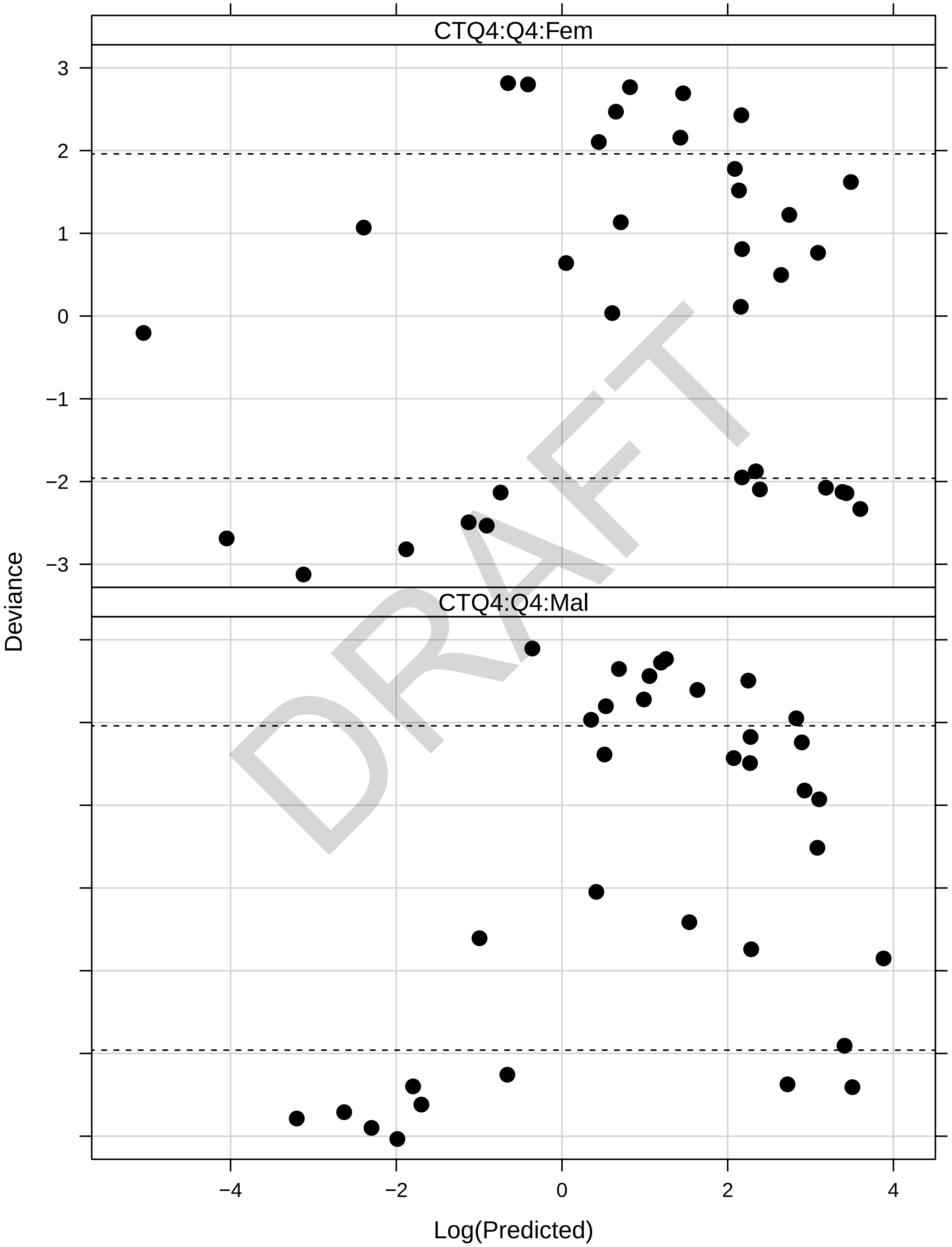
SNE_6F6_2019_orig_select
CTQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

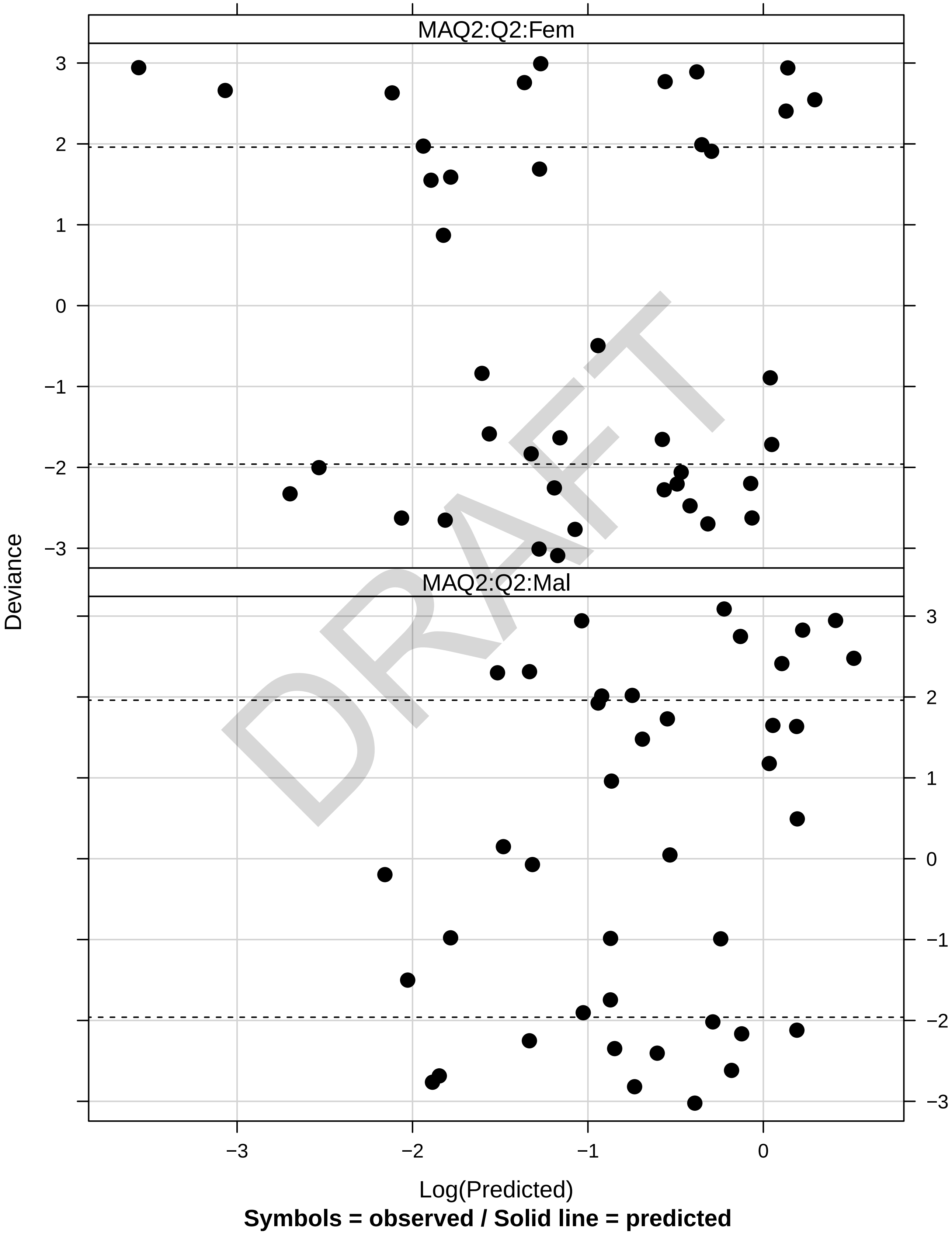
SNE_6F6_2019_orig_select
CTQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

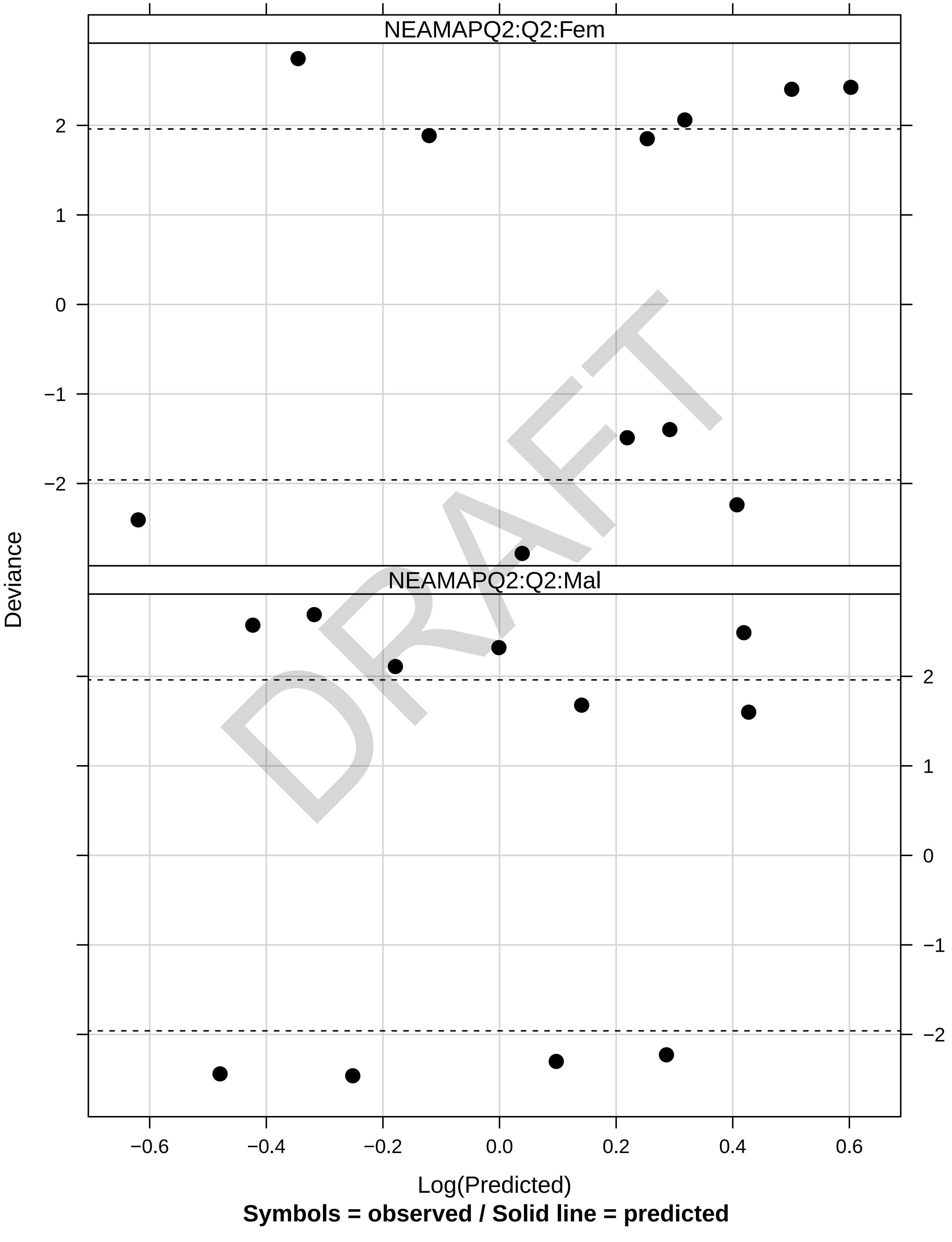
SNE_6F6_2019_orig_select
MAQ2 deviance residuals vs. predicted values



Symbols = observed / Solid line = predicted

DRAFT

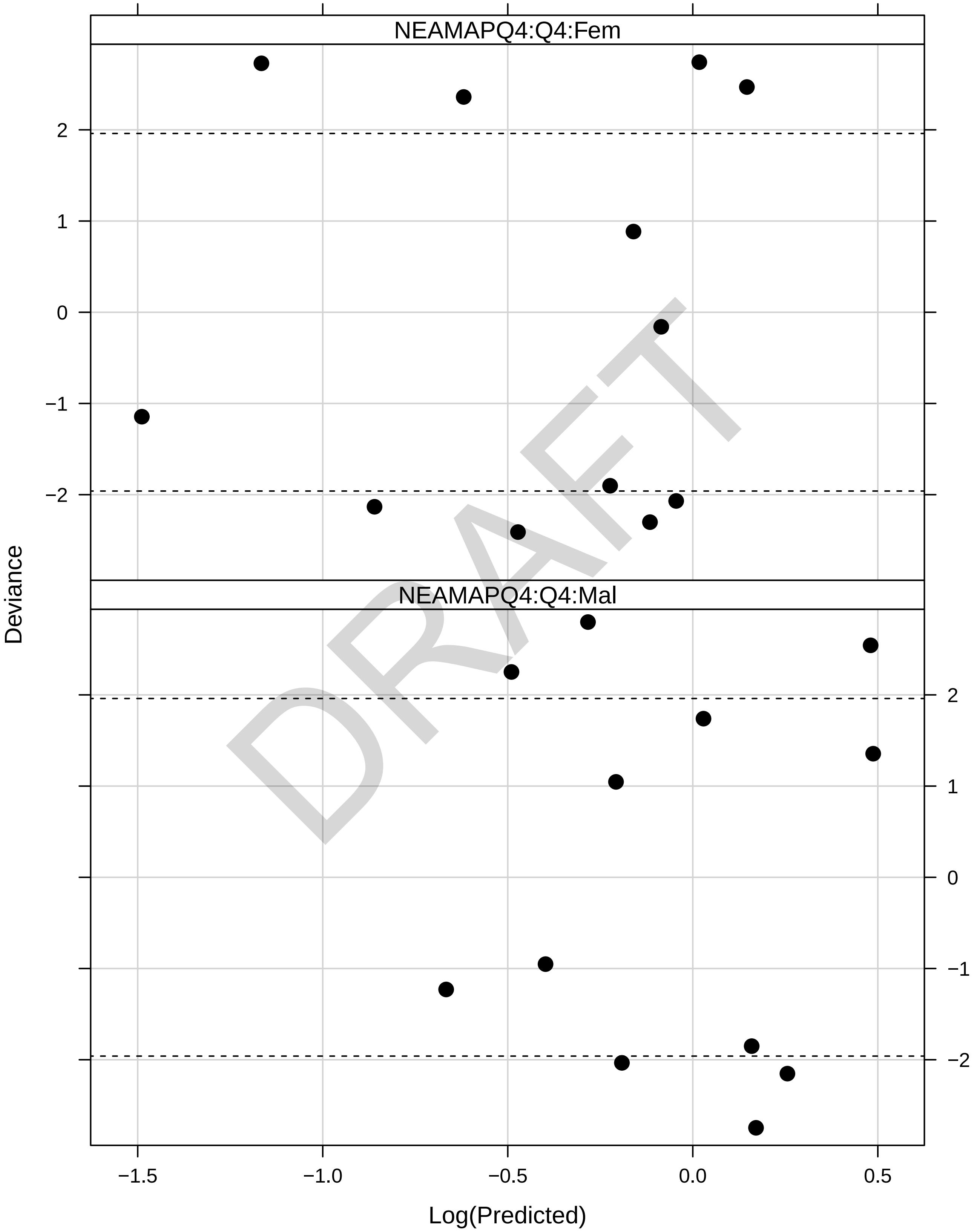
SNE_6F6_2019_orig_select
NEAMAPQ2 deviance residuals vs. predicted values



Symbols = observed / Solid line = predicted

DRAFT

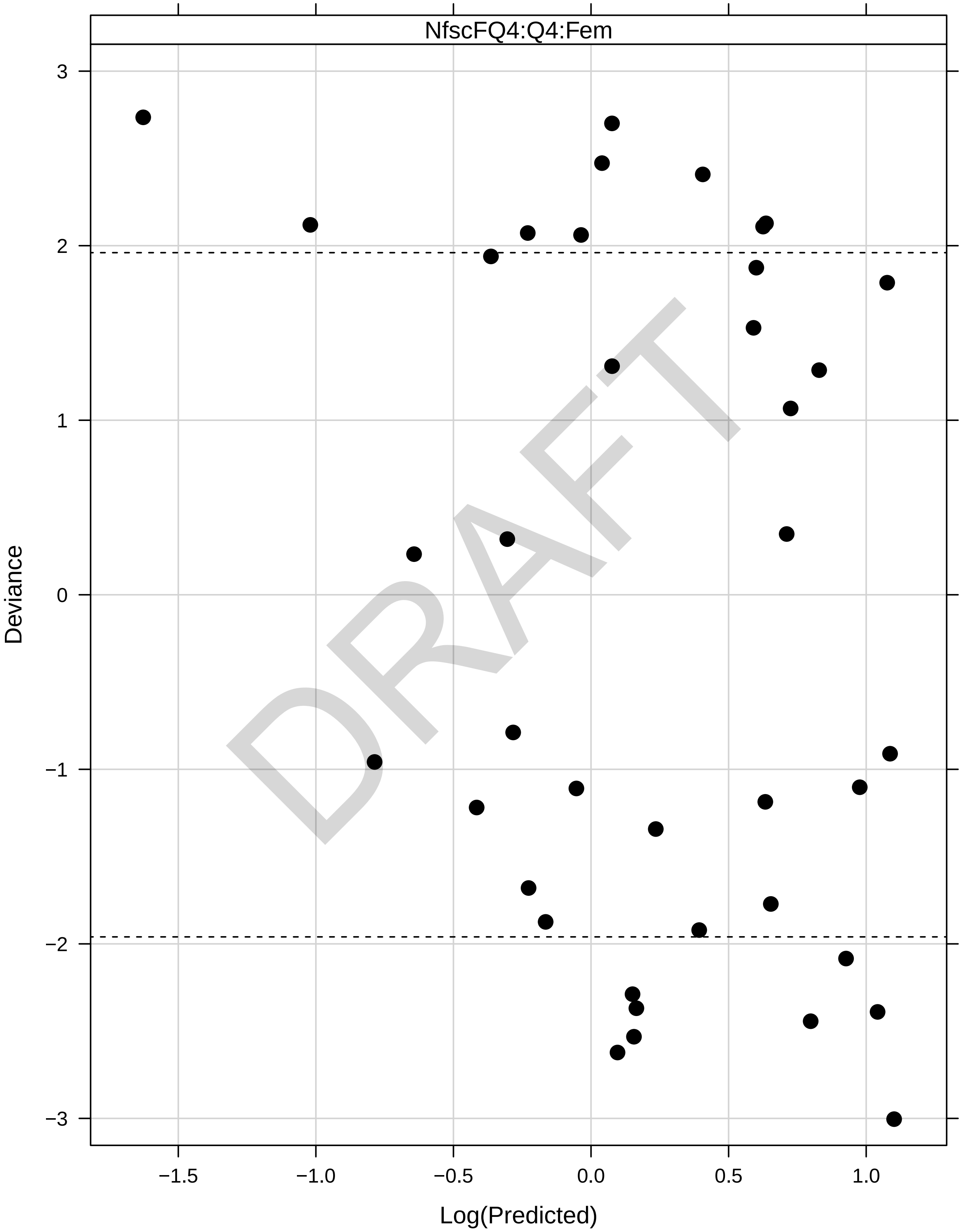
SNE_6F6_2019_orig_select
NEAMAPQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

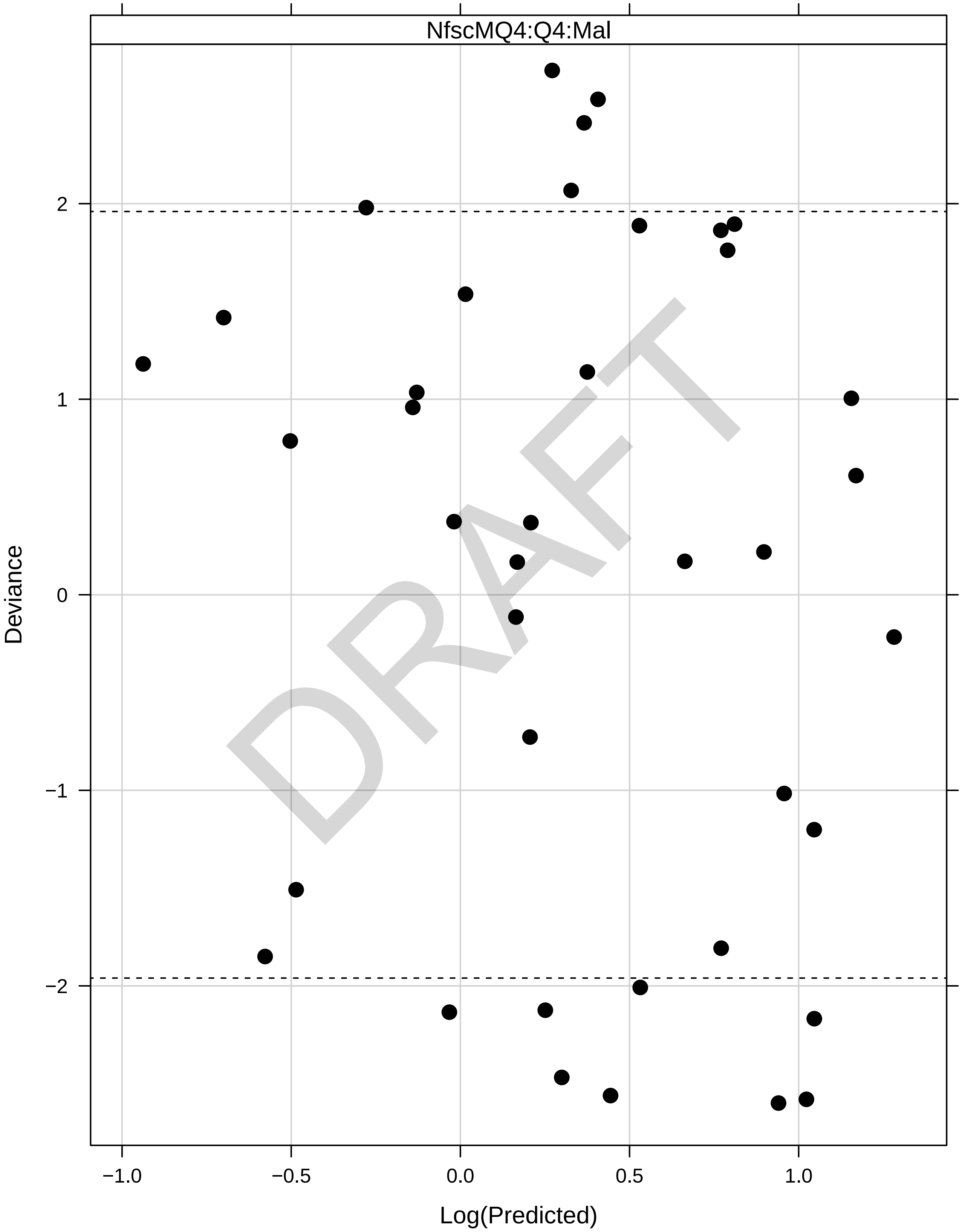
SNE_6F6_2019_orig_select
NfscFQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

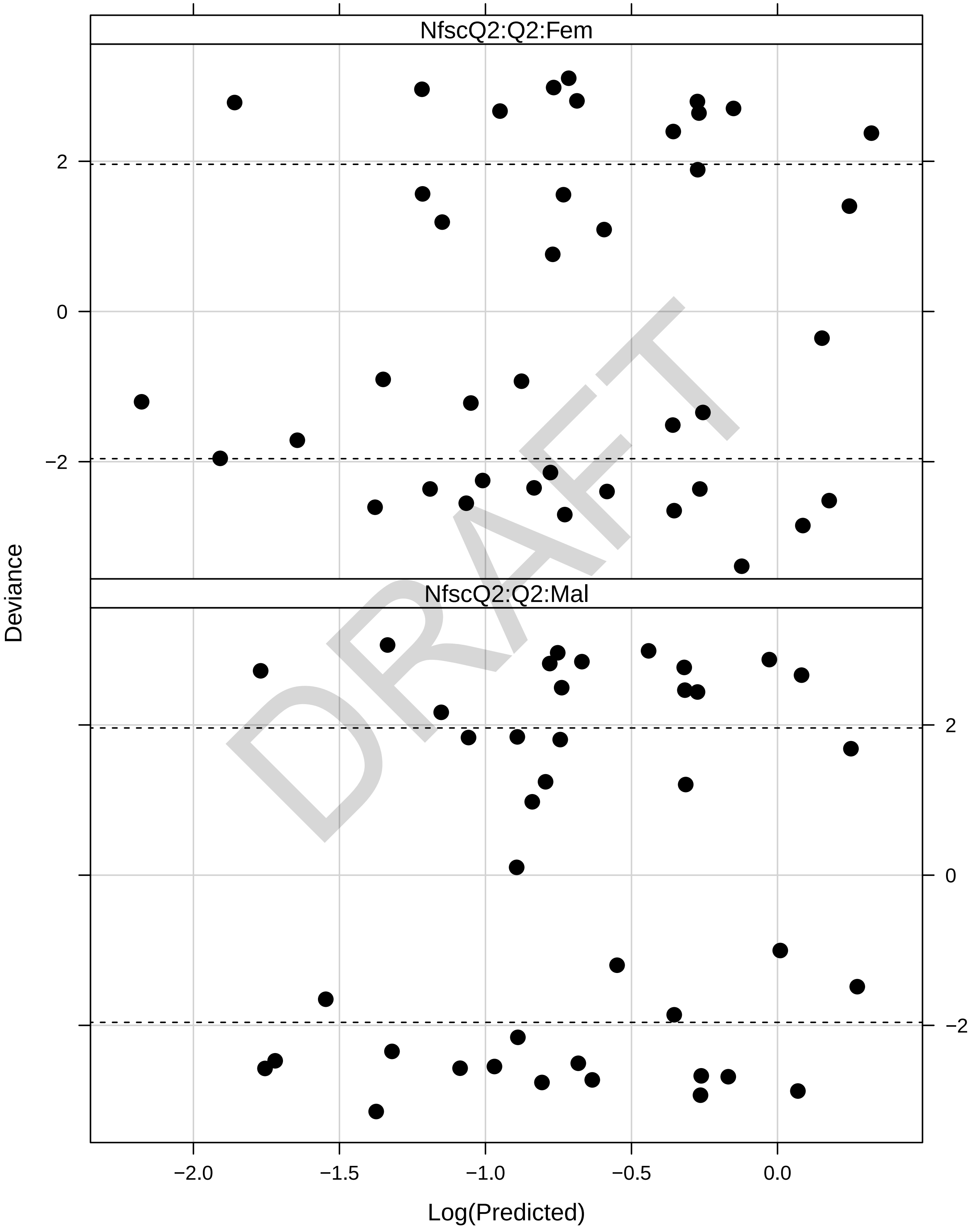
SNE_6F6_2019_orig_select
NfscMQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

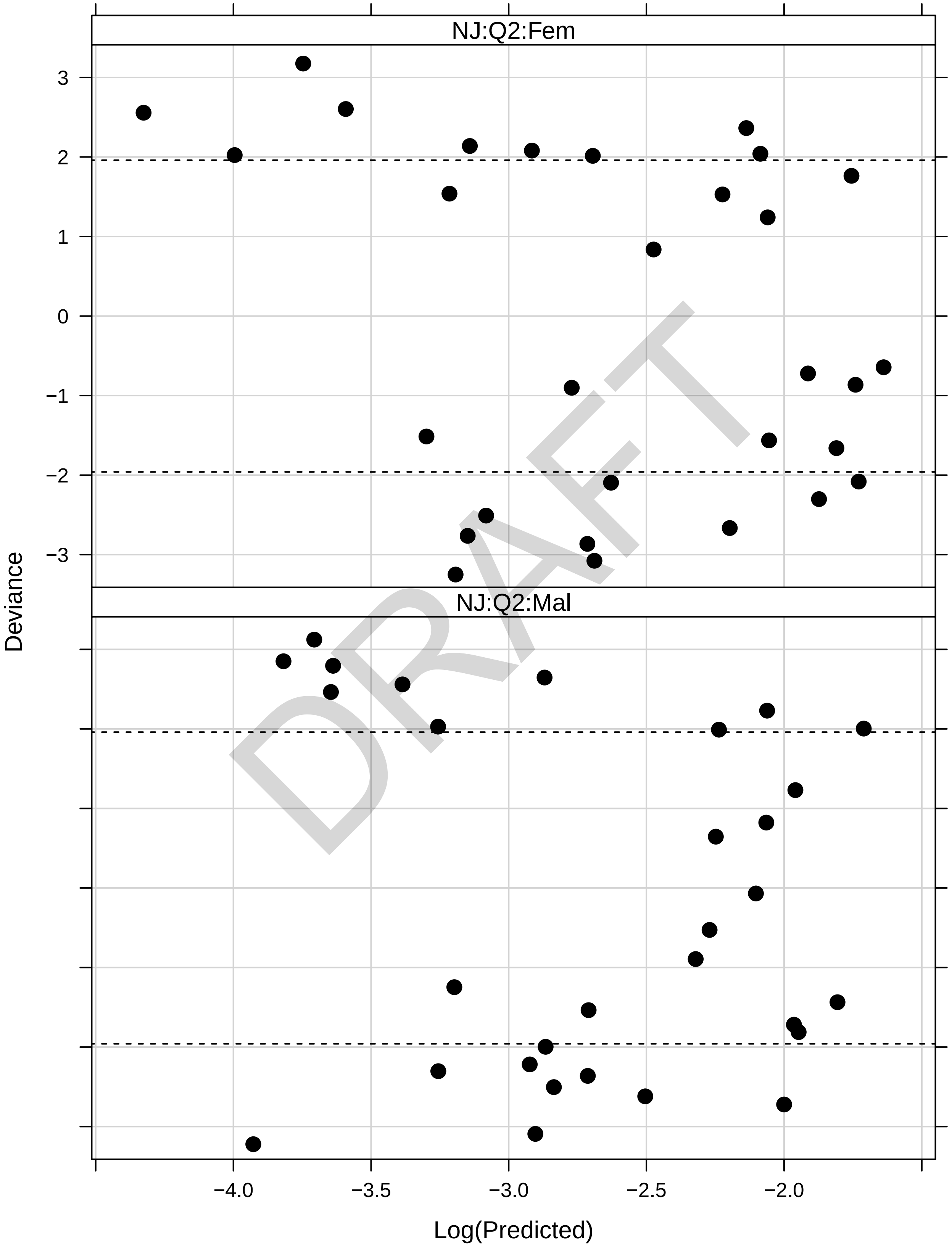
SNE_6F6_2019_orig_select
NfscQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

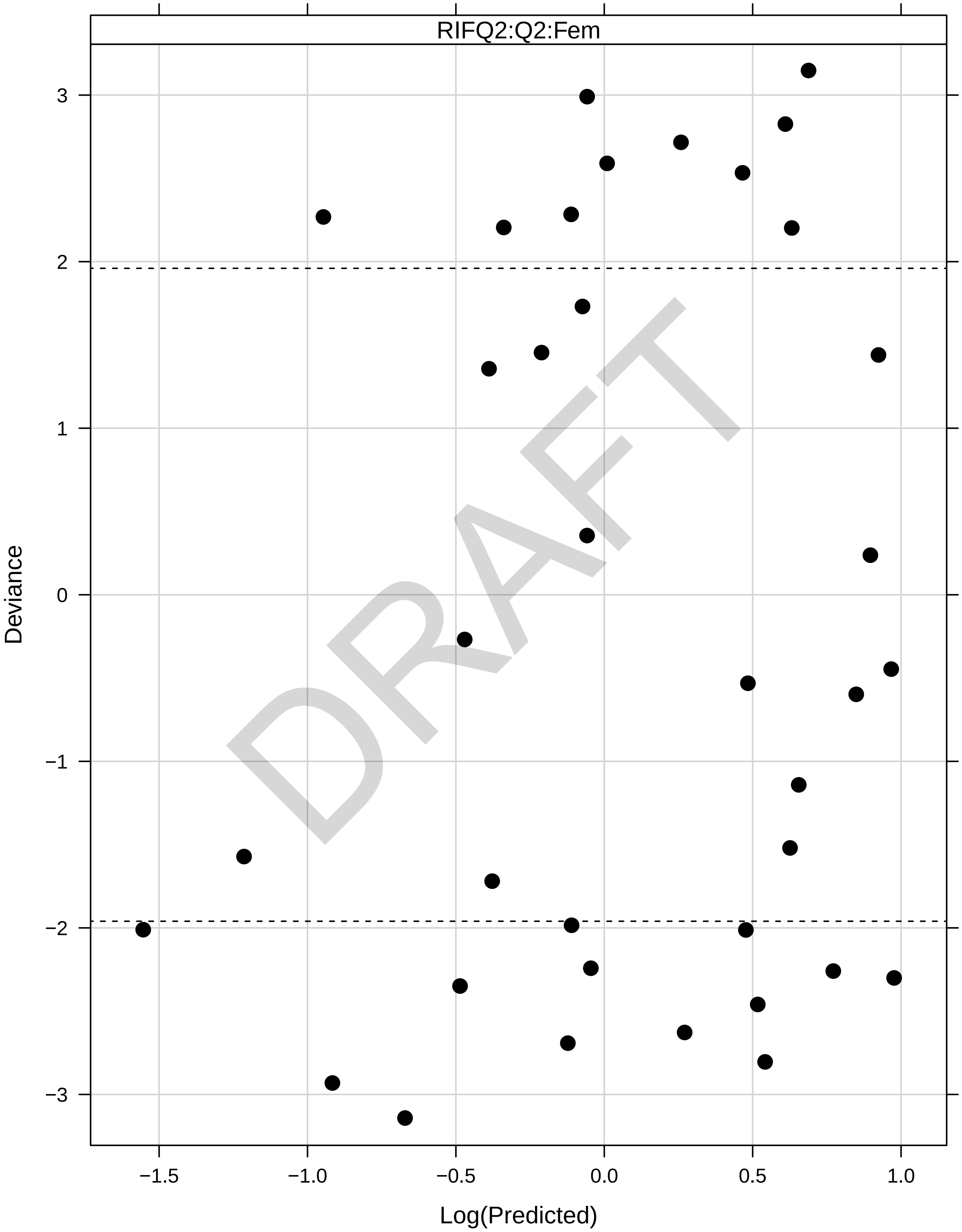
SNE_6F6_2019_orig_select
NJ deviance residuals vs. predicted values



Symbols = observed / Solid line = predicted

DRAFT

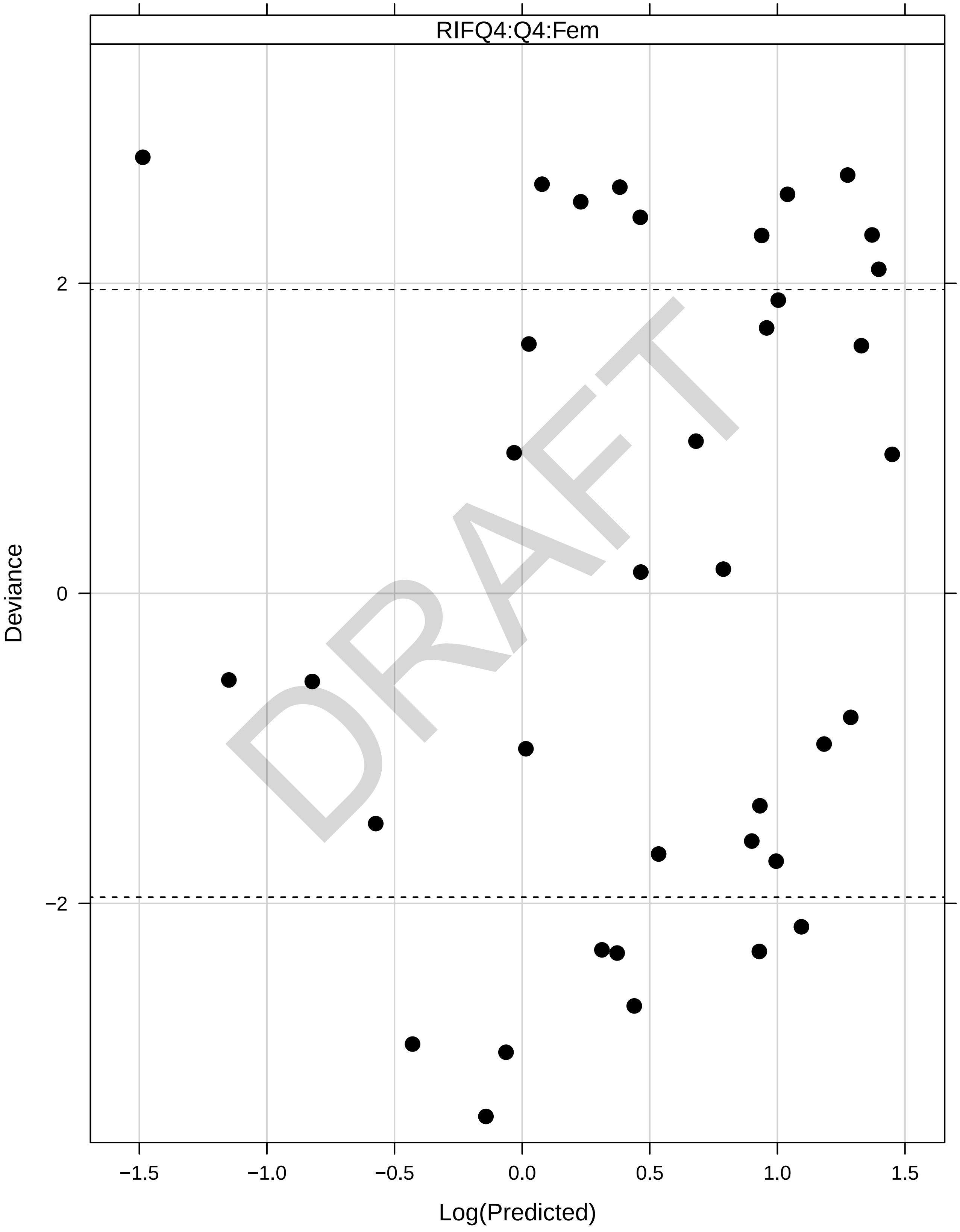
SNE_6F6_2019_orig_select
RIFQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

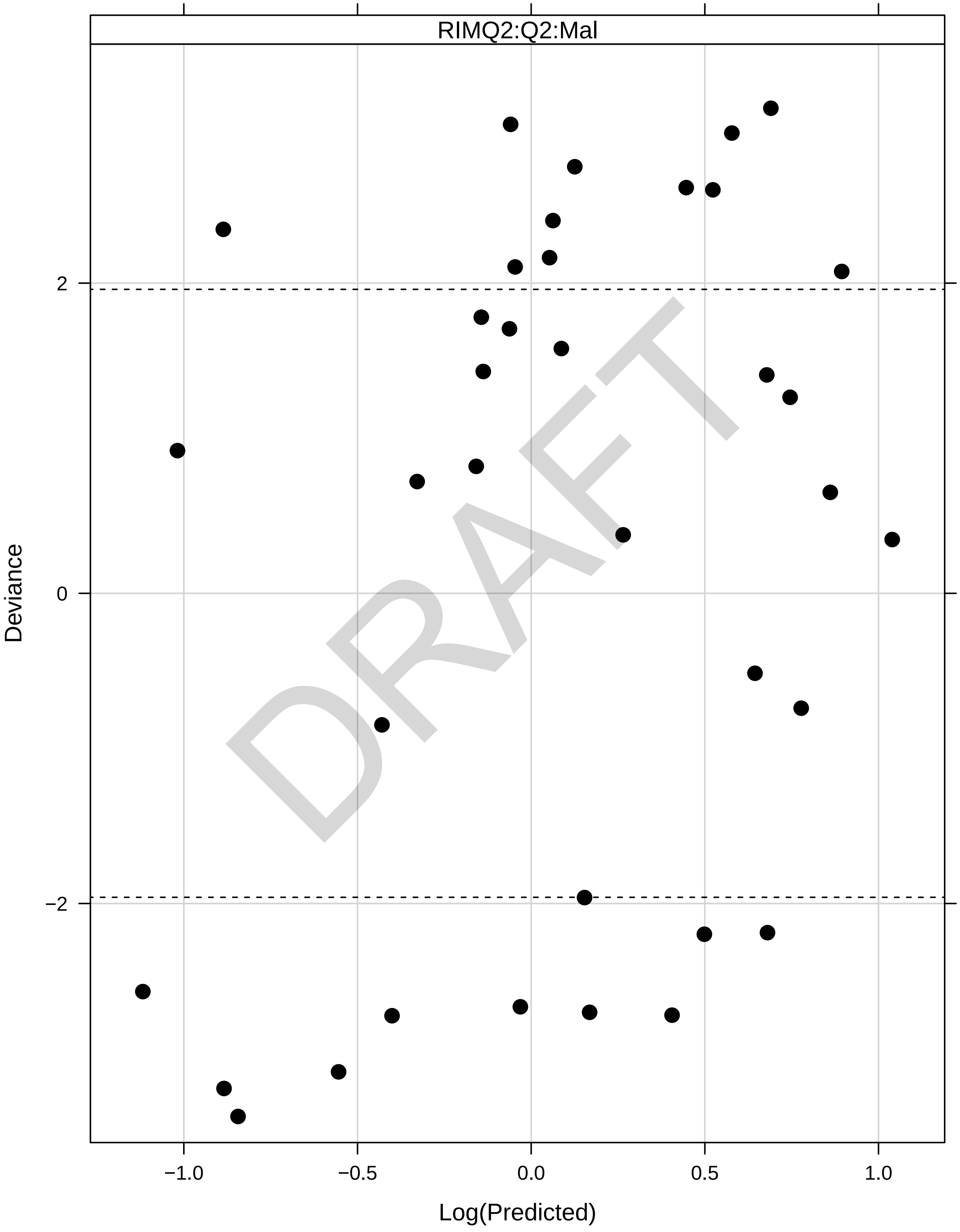
SNE_6F6_2019_orig_select
RIFQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

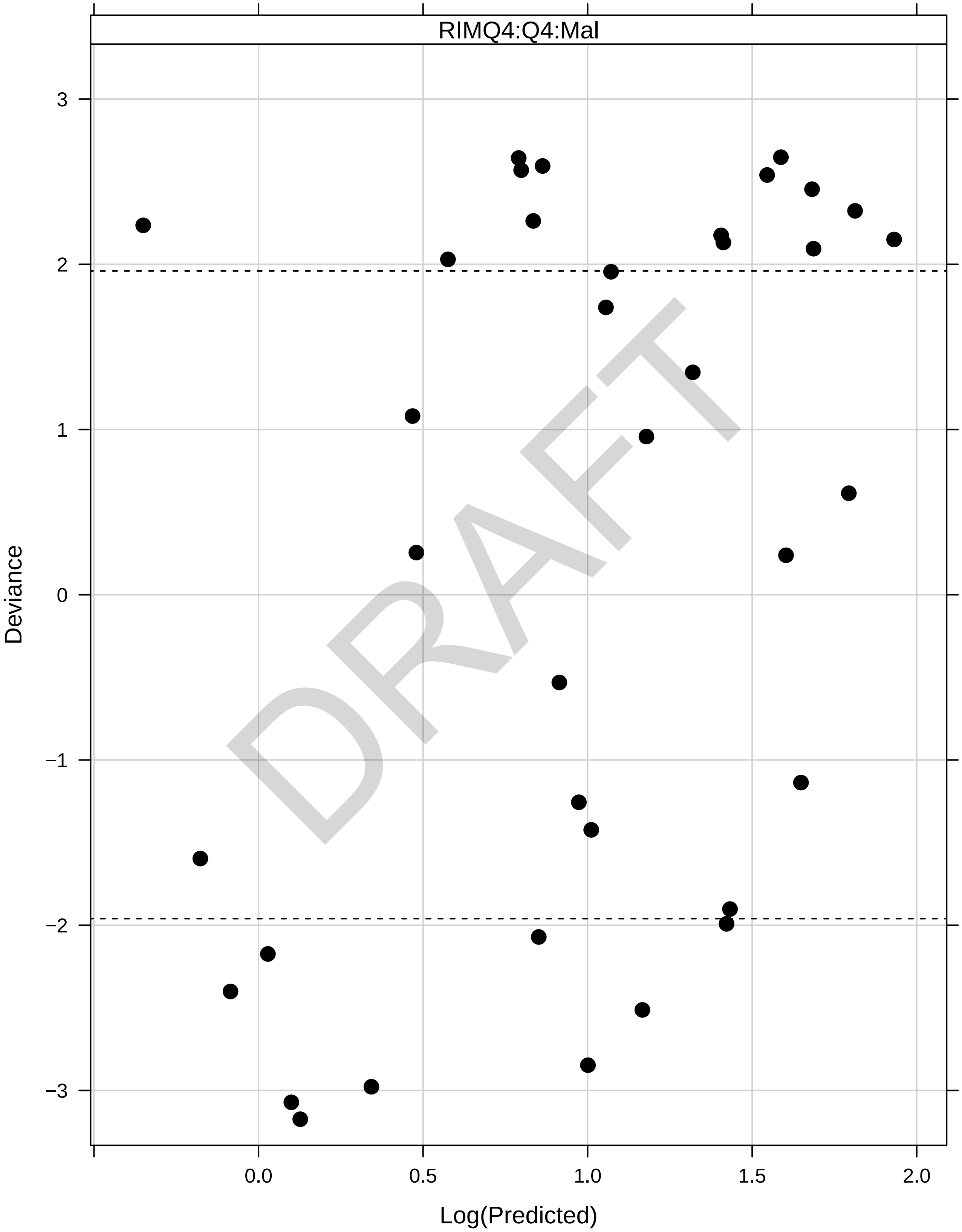
SNE_6F6_2019_orig_select
RIMQ2 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

SNE_6F6_2019_orig_select
RIMQ4 deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

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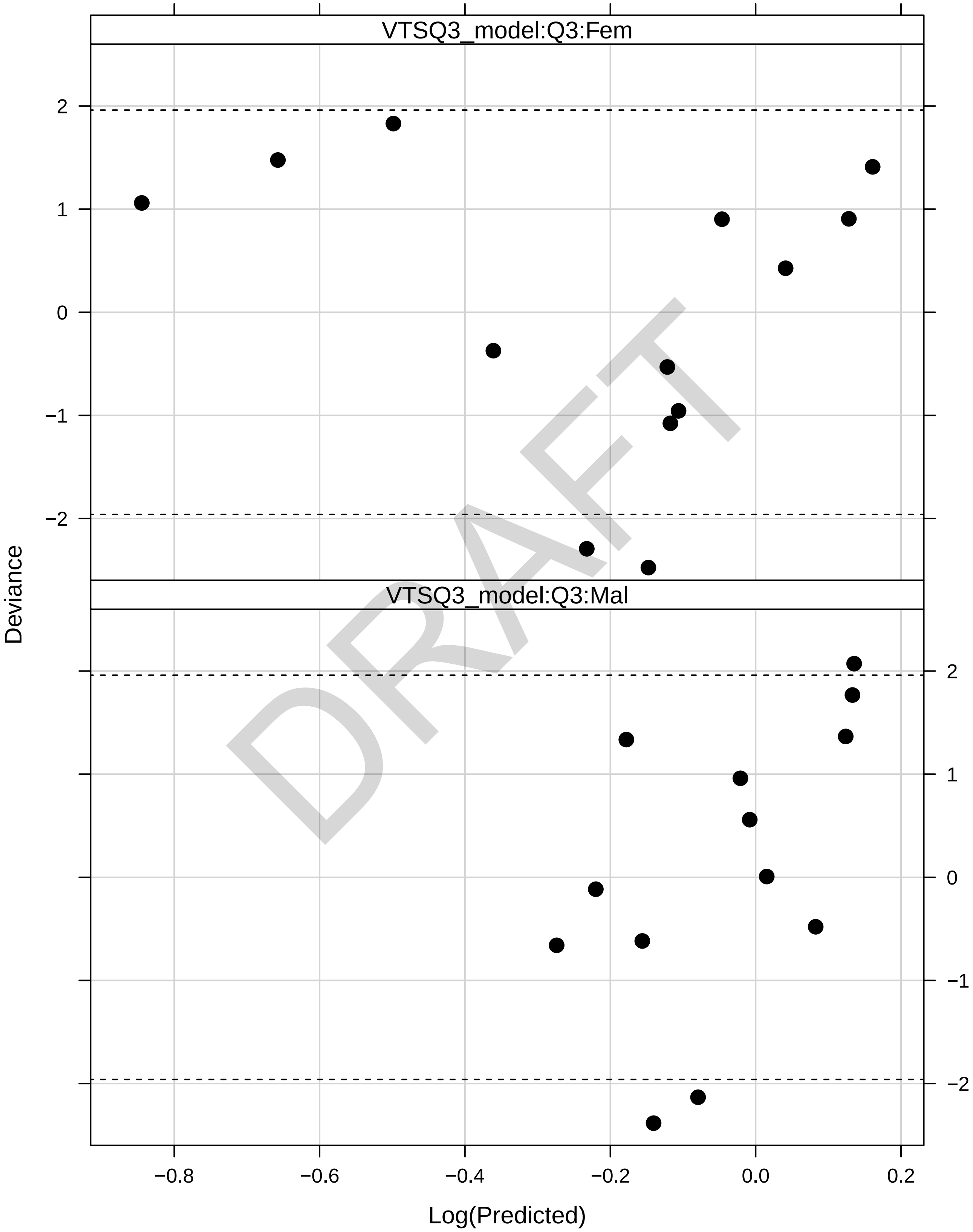
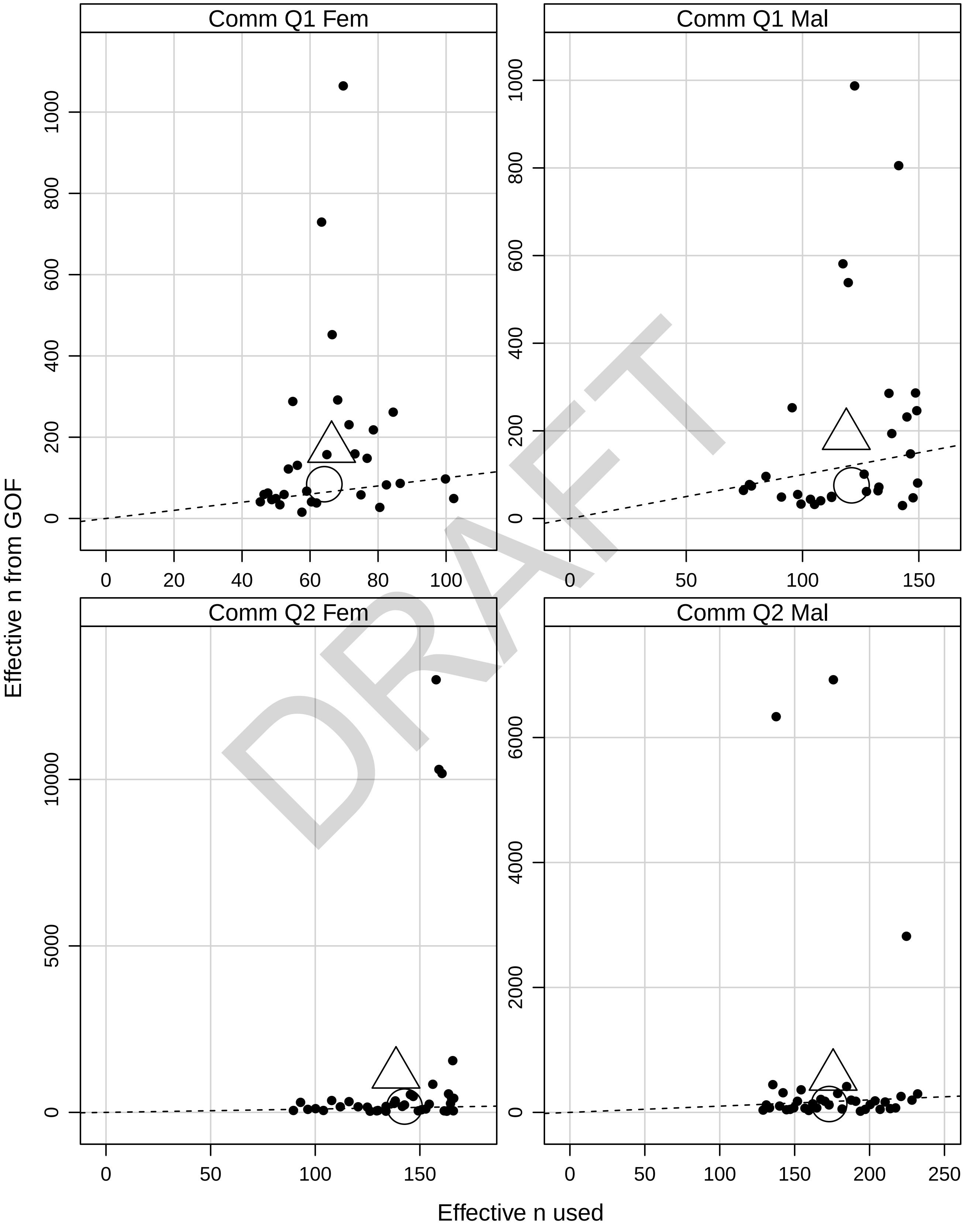
SNE_6F6_2019_orig_select
VTSQ3_model deviance residuals vs. predicted values



DRAFT

Symbols = observed / Solid line = predicted

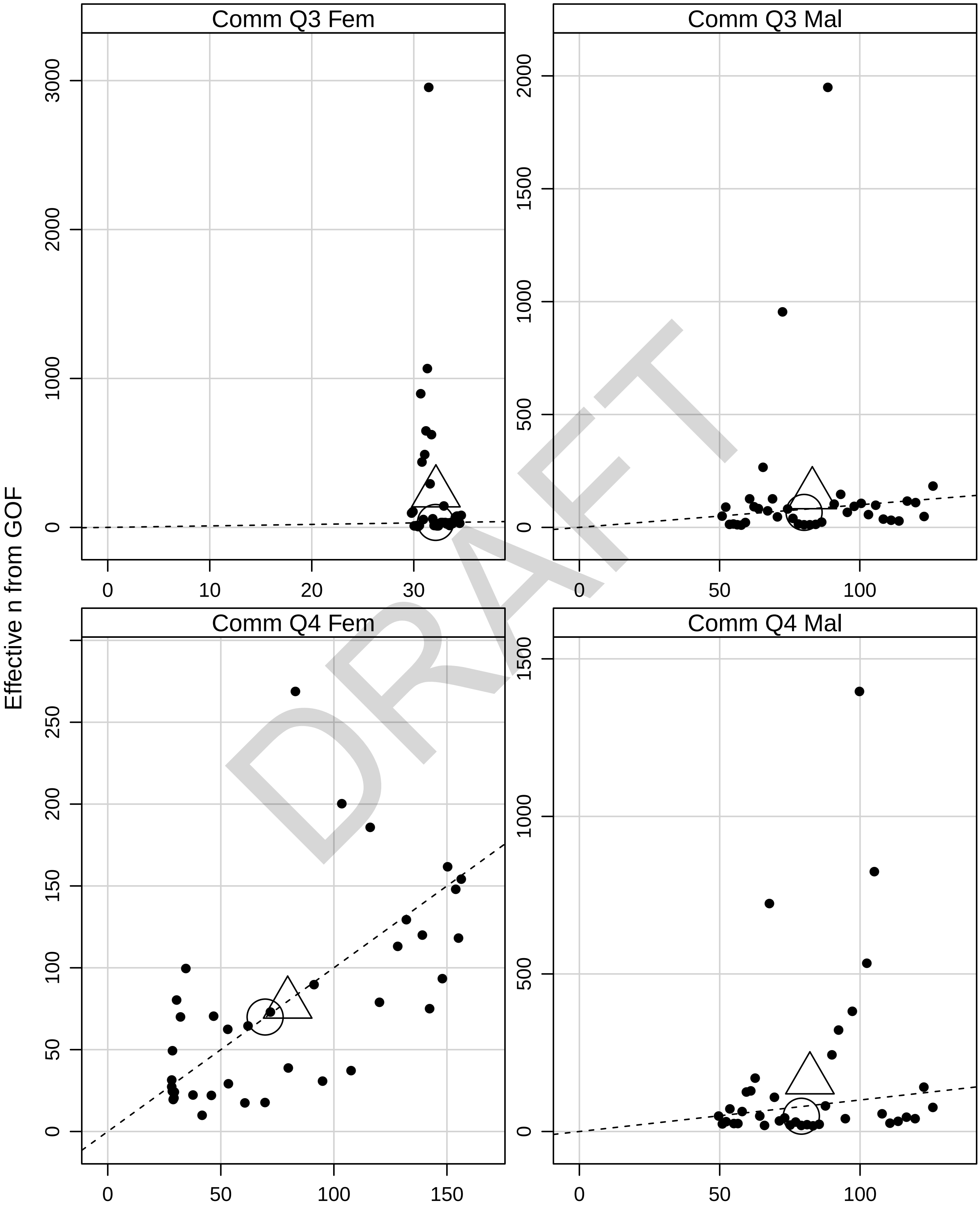
SNE_6F6_2019_orig_select
Effective n for commercial length data



Large circle at bivariate medians, triangles at means

DRAFT

SNE_6F6_2019_orig_select
Effective n for commercial length data



Large circle at bivariate medians, triangles at means

DRAFT

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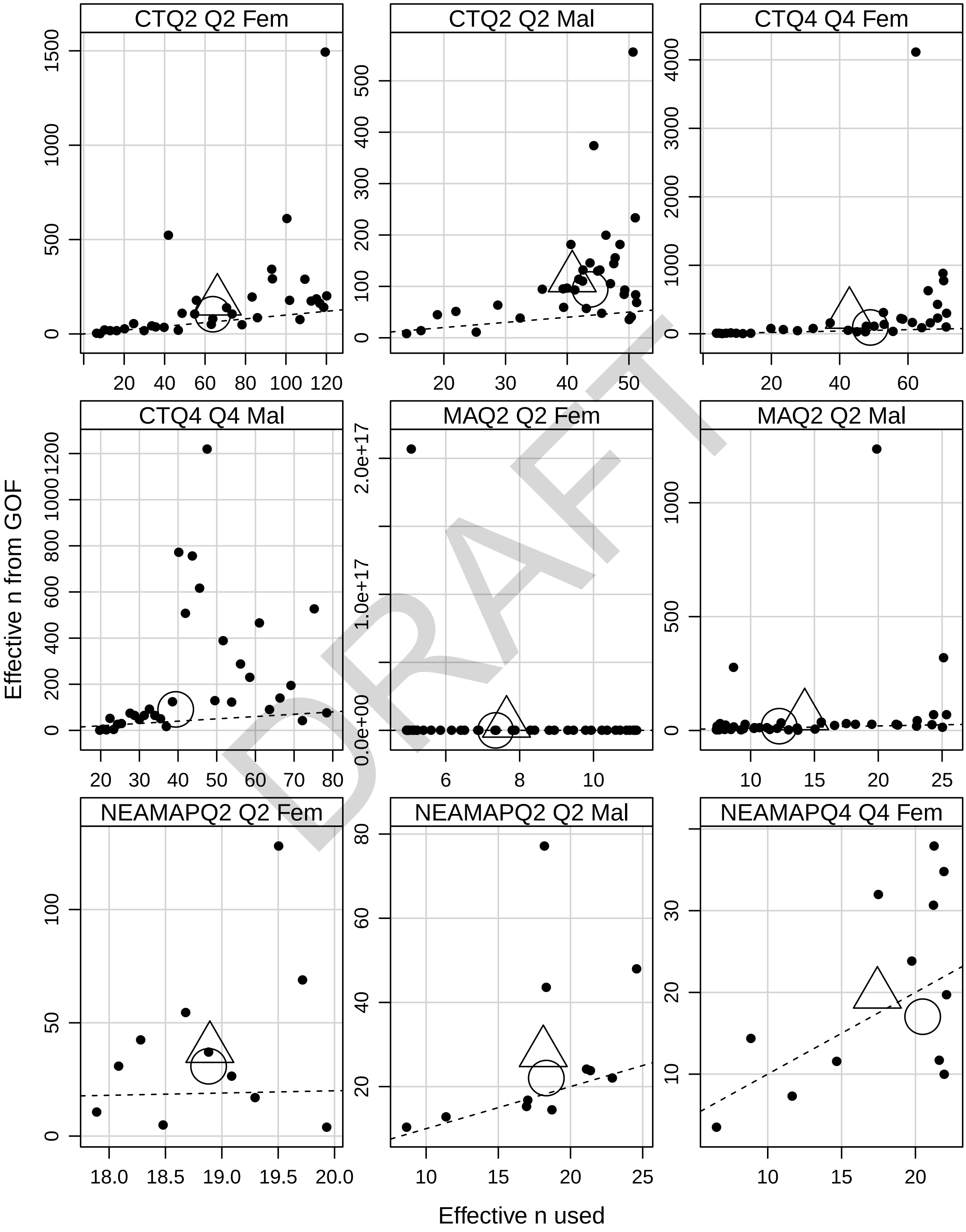
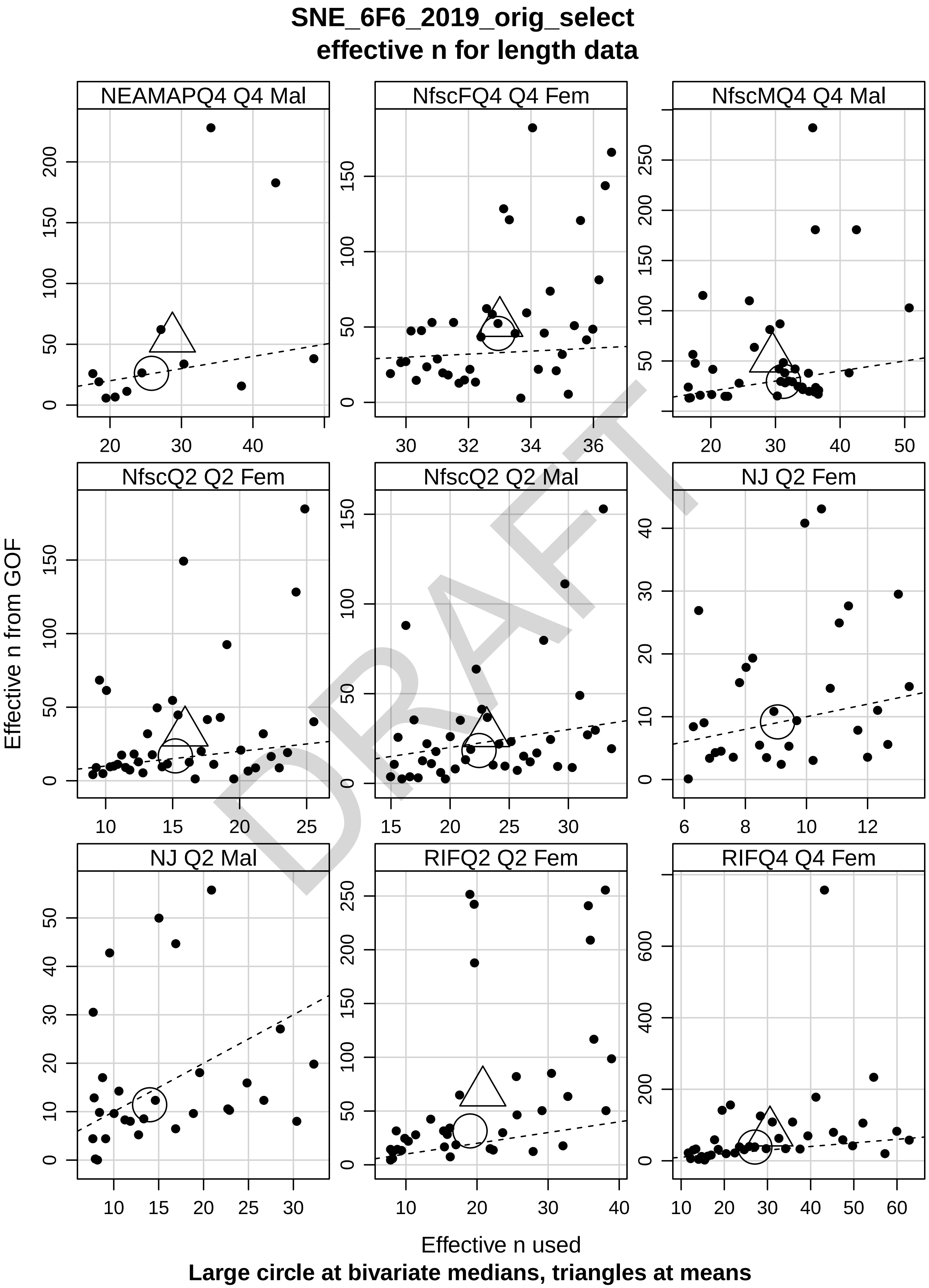
SNE_6F6_2019_orig_select
effective n for length data



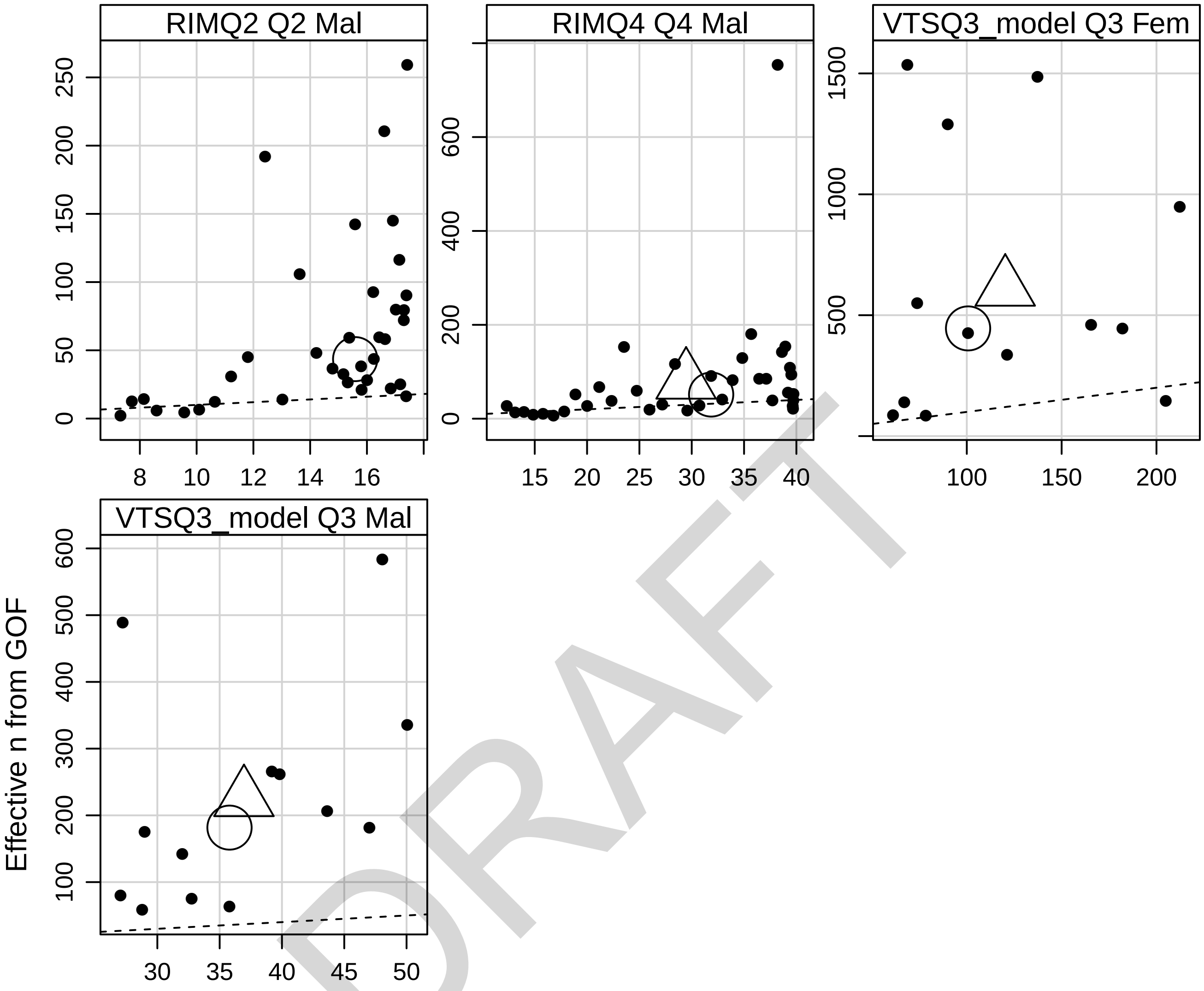
Large circle at bivariate medians, triangles at means

DRAFT


SNE_6F6_2019_orig_select
effective n for length data
NEAMAPQ4 Q4 Mal
NfscFQ4 Q4 Fem
NfscMQ4 Q4 Mal
NfscQ2 Q2 Fem
NfscQ2 Q2 Mal
NJ Q2 Fem
NJ Q2 Mal
RIFQ2 Q2 Fem
RIFQ4 Q4 Fem
Effective n from GOF
Effective n used
Large circle at bivariate medians, triangles at means

DRAFT

SNE_6F6_2019_orig_select effective n for length data

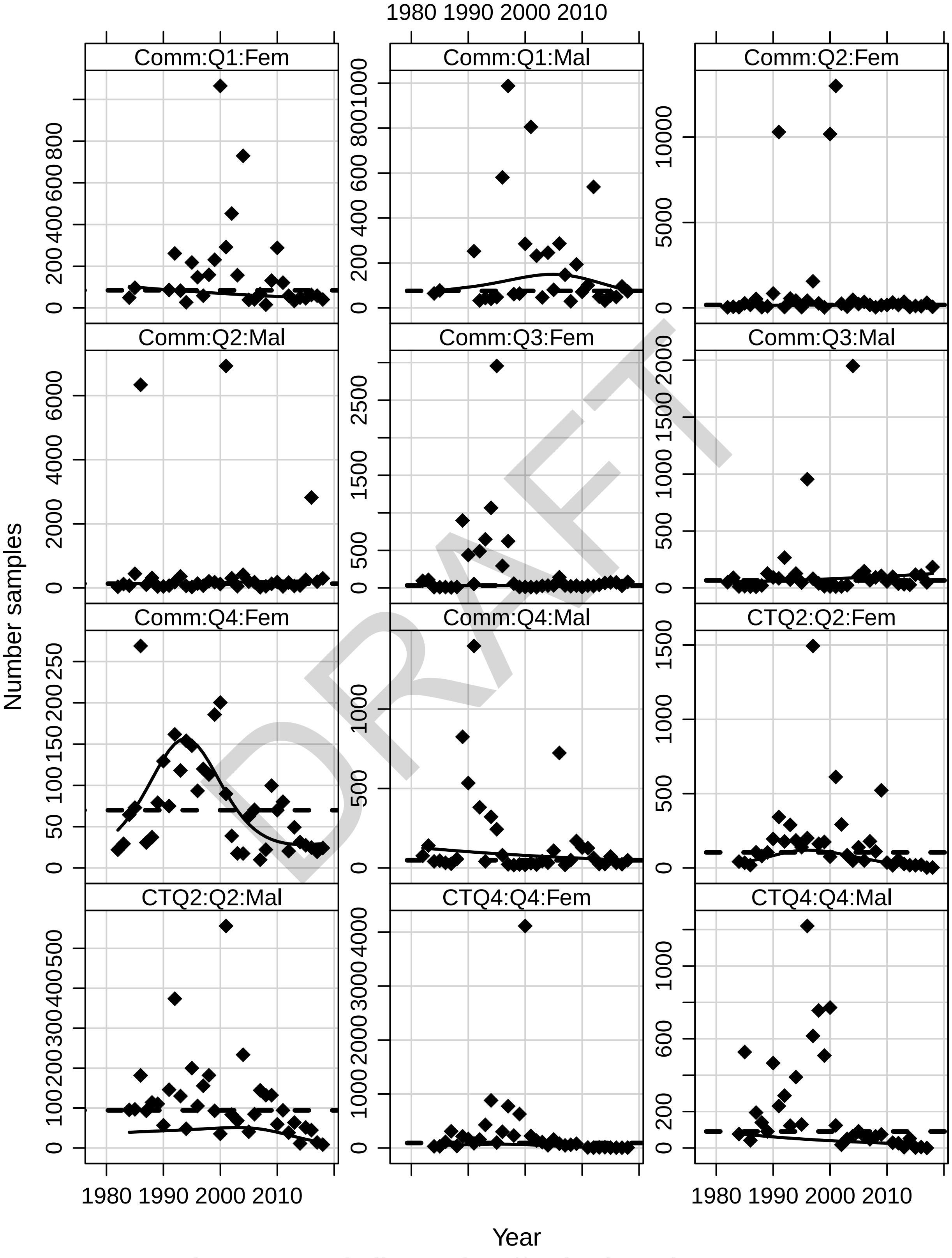


DRAFT

Effective n used

Large circle at bivariate medians, triangles at means

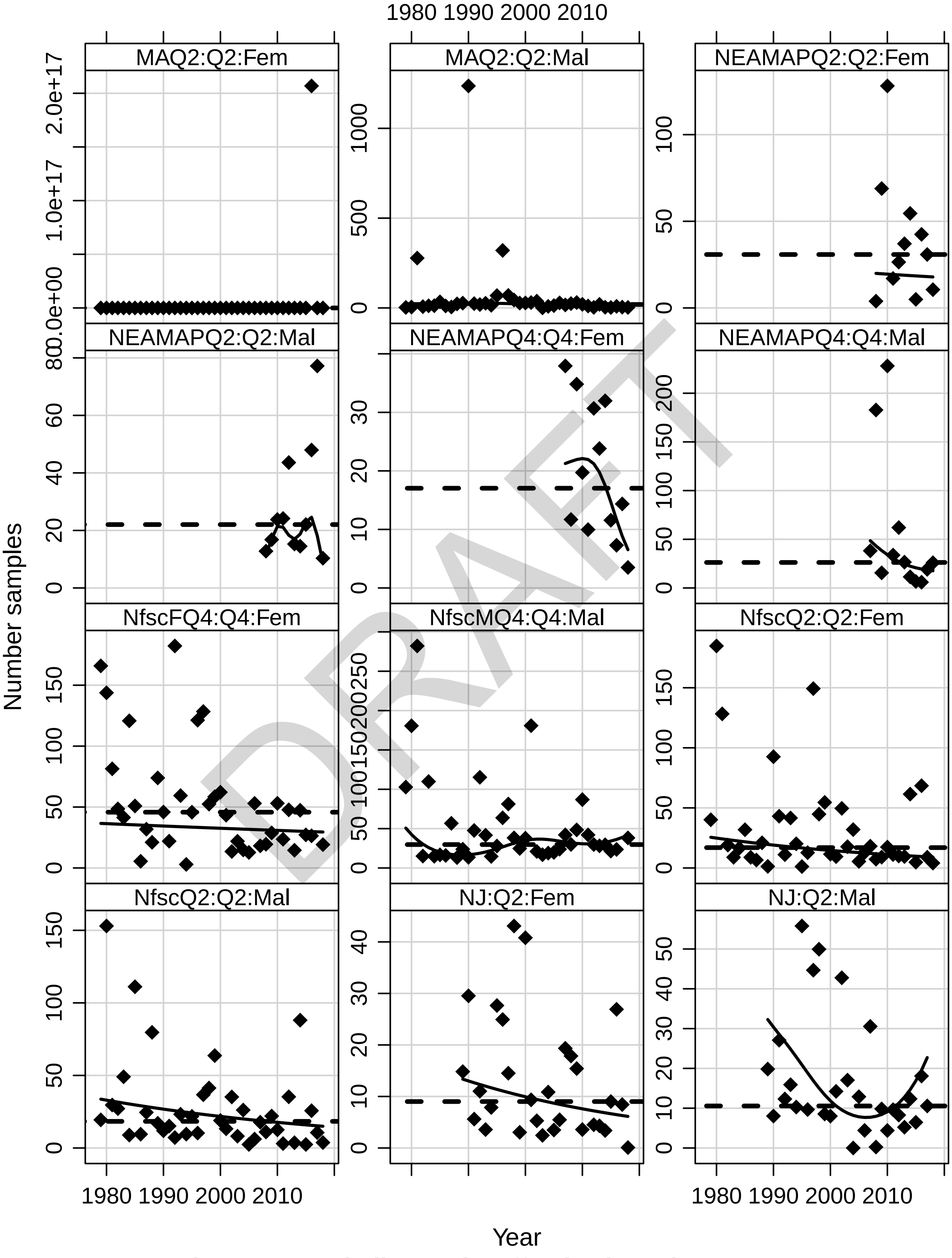
SNE_6F6_2019_orig_select
Effective sample size for length data vs year



DRAFT

**Line=assumed, diamonds=effective based on GOF,
dotted line=median**

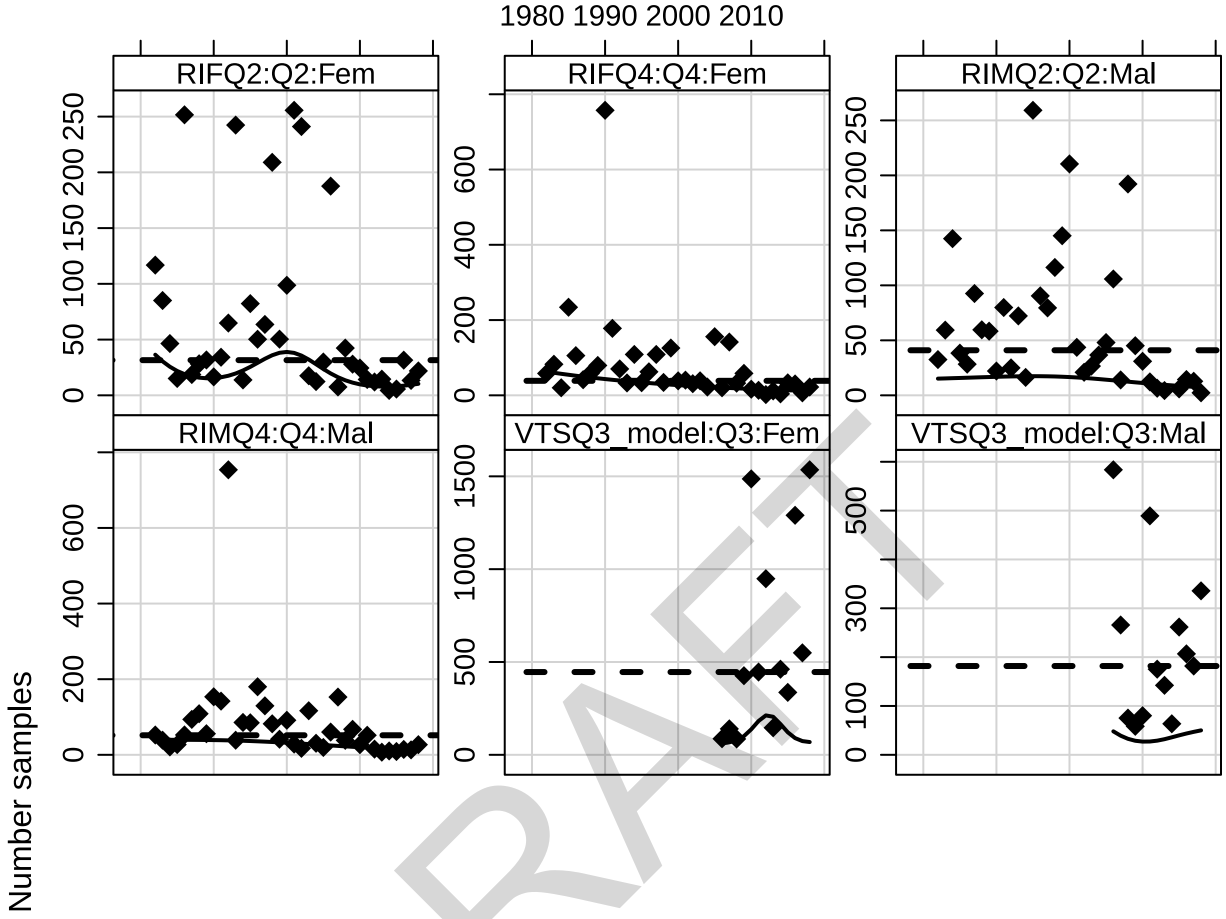
SNE_6F6_2019_orig_select
Effective sample size for length data vs year



Line=assumed, diamonds=effective based on GOF, dotted line=median

DRAFT

SNE_6F6_2019_orig_select
Effective sample size for length data vs year

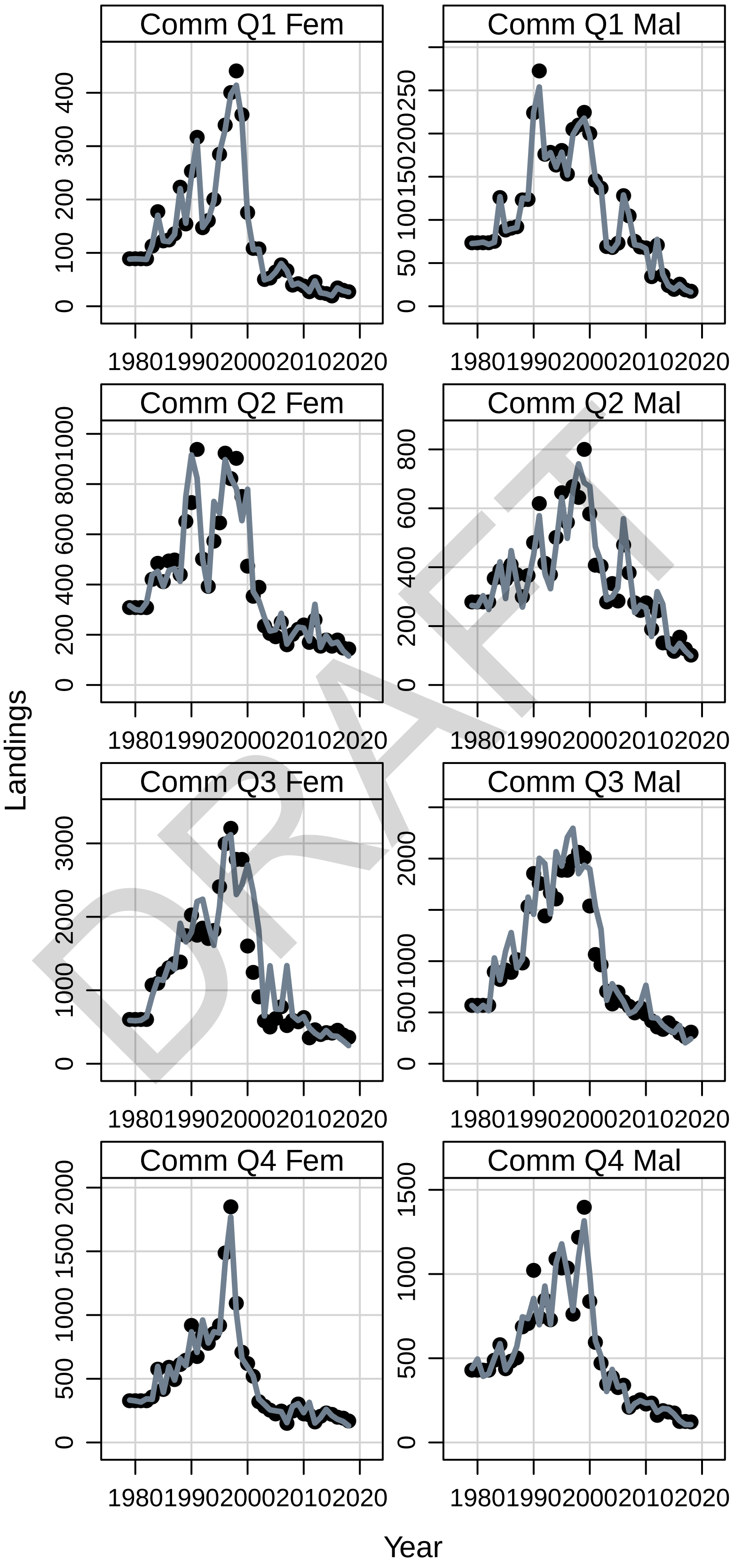


DRAFT

Year

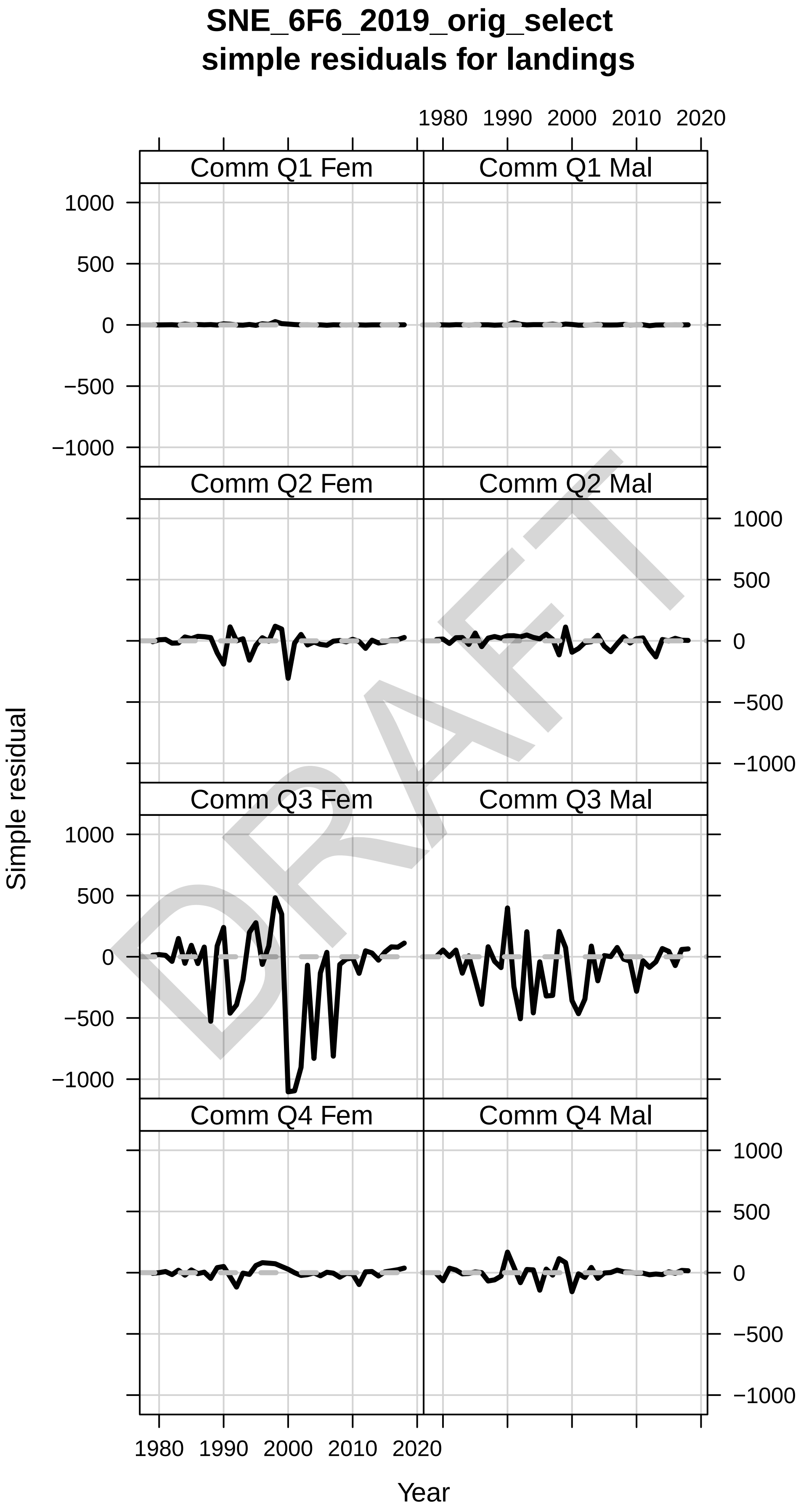
Line=assumed, diamonds=effective based on GOF, dotted line=median

SNE_6F6_2019_orig_select observed and predicted landings

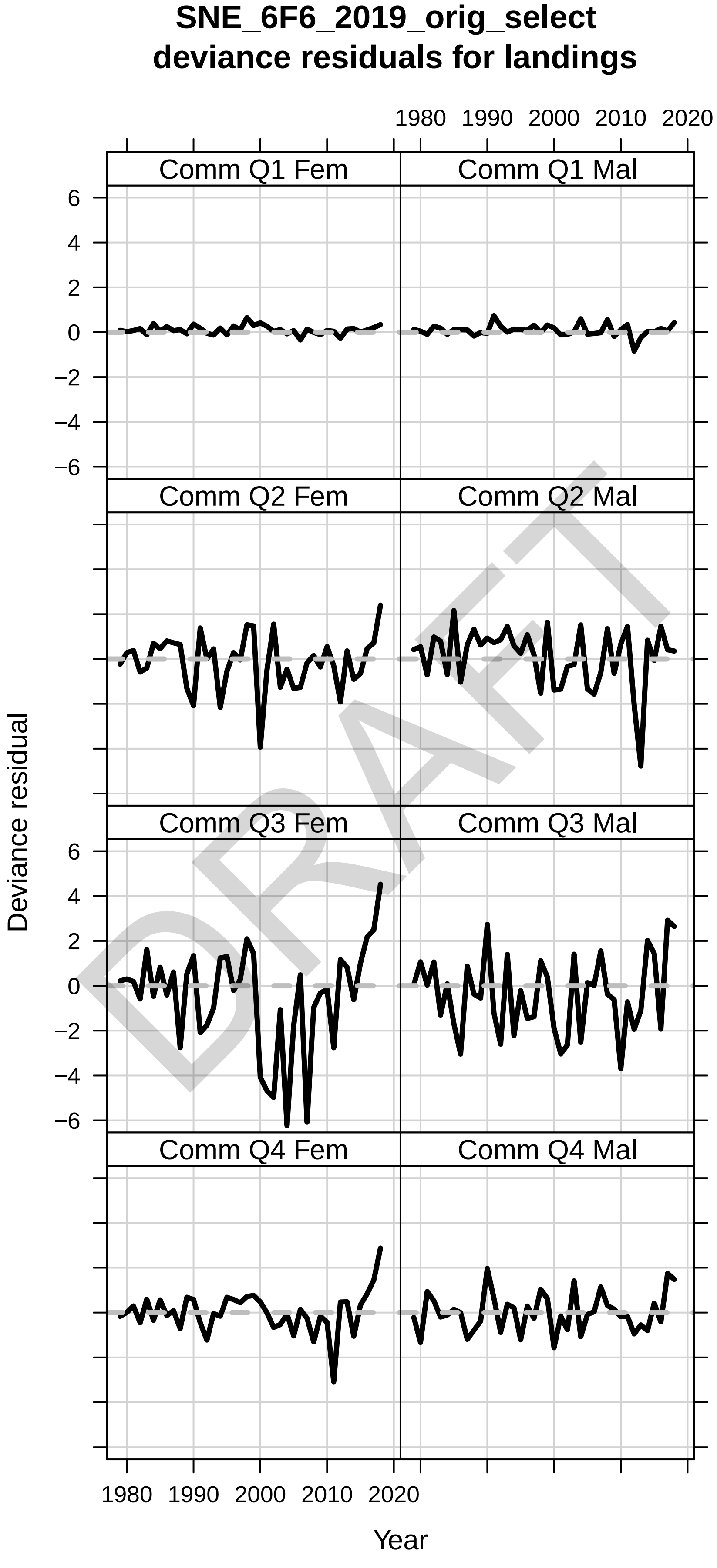


Symbols = observed / Solid line = predicted

DRAFT

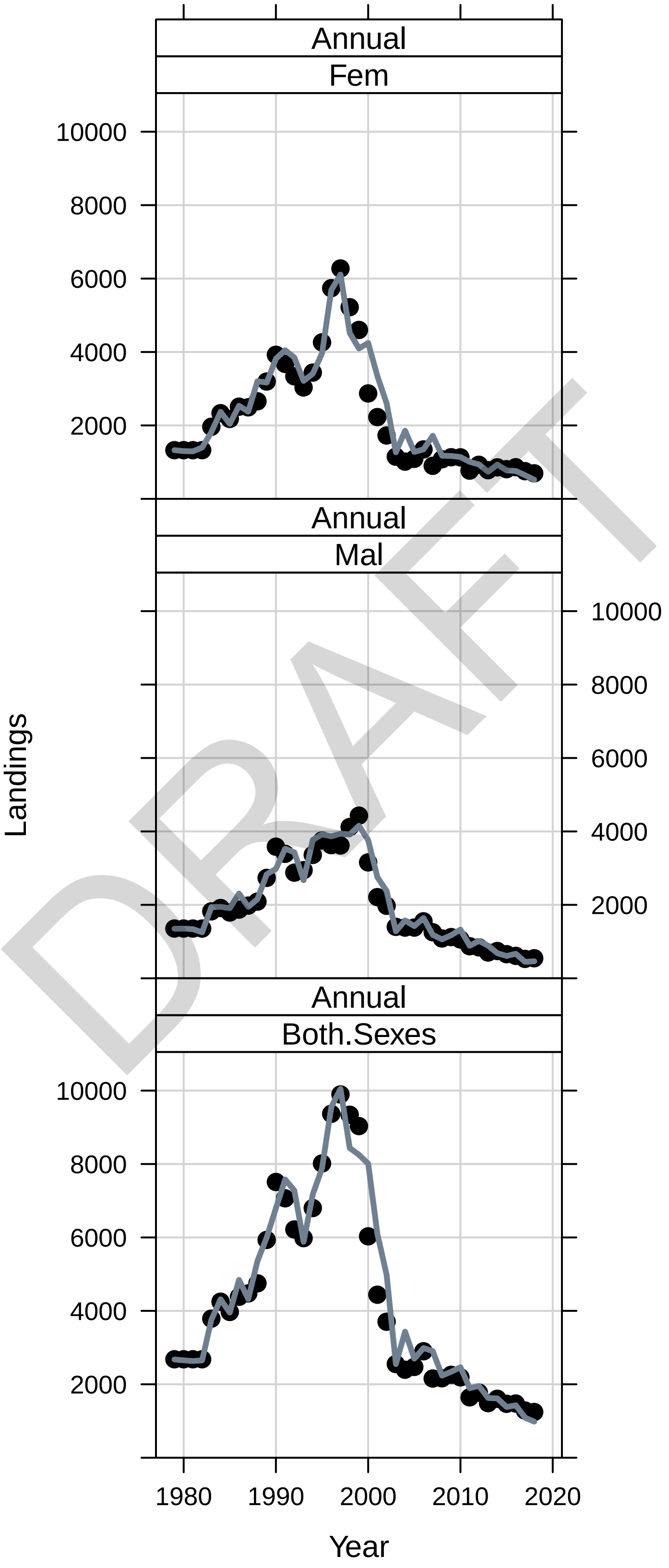

SNE_6F6_2019_orig_select
simple residuals for landings
Comm Q1 Fem
Comm Q1 Mal
Comm Q2 Fem
Comm Q2 Mal
Comm Q3 Fem
Comm Q3 Mal
Comm Q4 Fem
Comm Q4 Mal
1000
500
0
−500
−1000
1980
1990
2000
2010
2020
Simple residual
Year

DRAFT


SNE_6F6_2019_orig_select
deviance residuals for landings
Comm Q1 Fem
Comm Q1 Mal
Comm Q2 Fem
Comm Q2 Mal
Comm Q3 Fem
Comm Q3 Mal
Comm Q4 Fem
Comm Q4 Mal
Deviance residual
Year
1980
1990
2000
2010
2020
6
4
2
0
−2
−4
−6

DRAFT

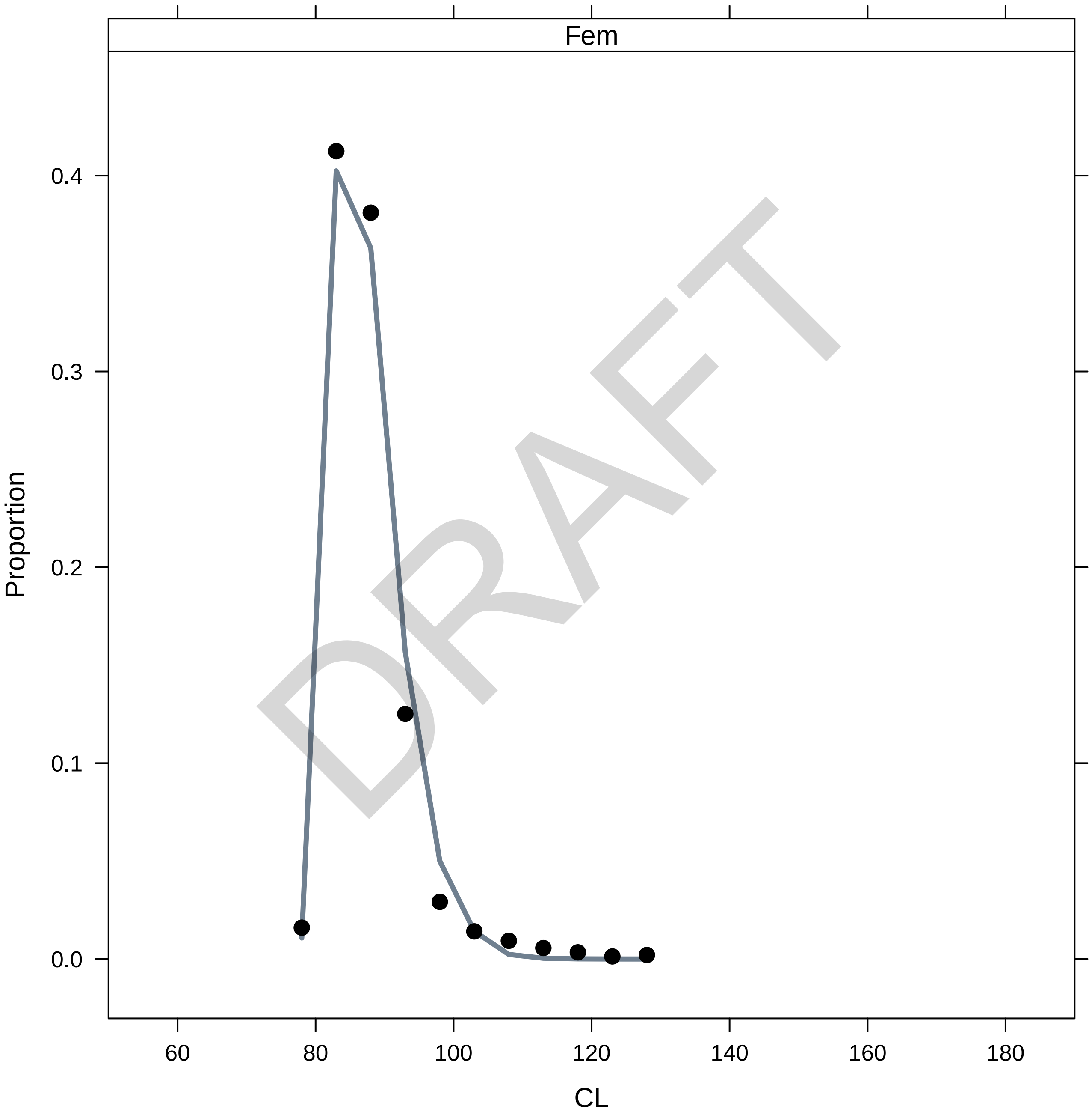
SNE_6F6_2019_orig_select observed and predicted landings



Symbols = observed / Solid line = predicted

DRAFT

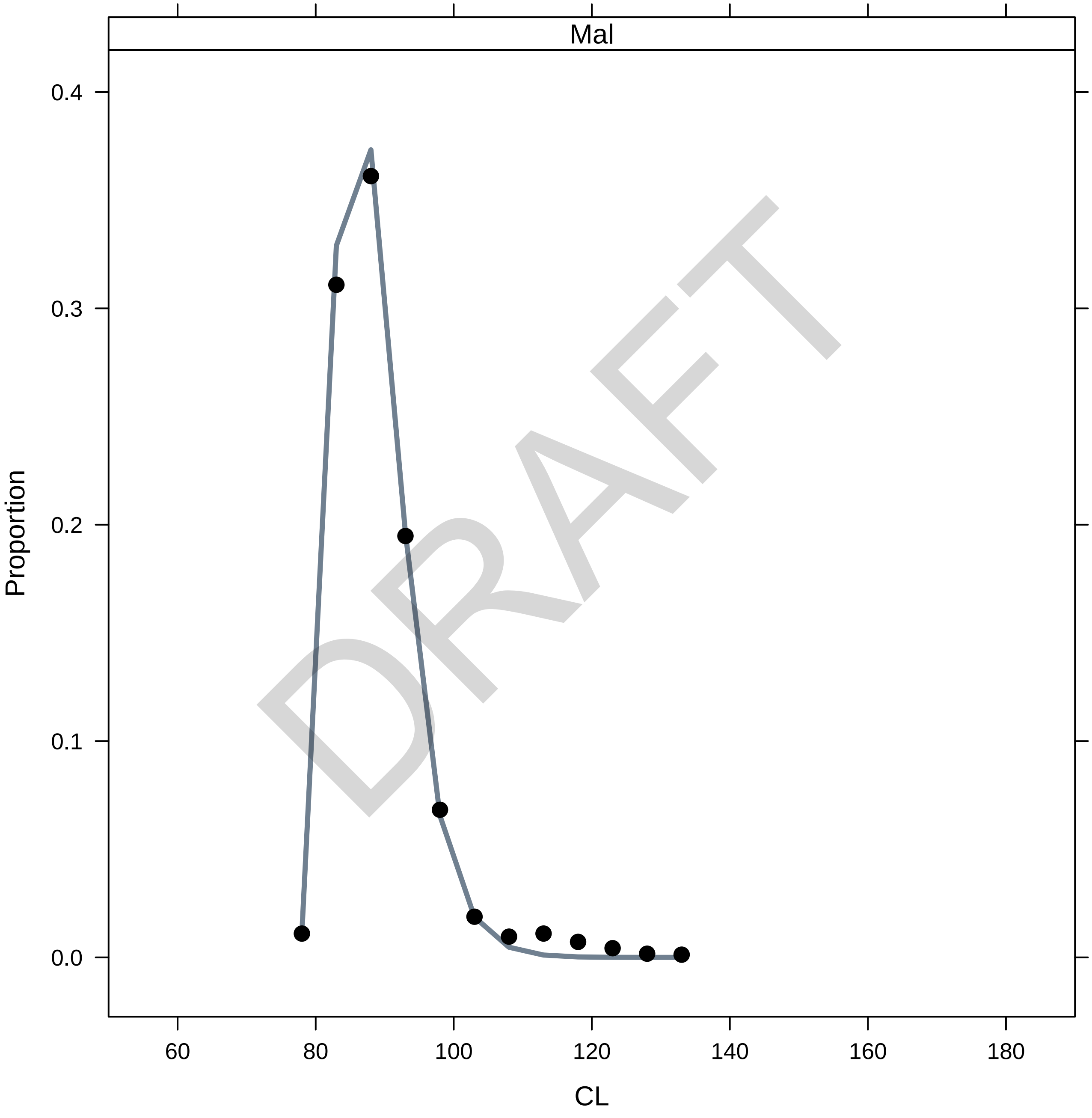
SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q1 Fem



DRAFT

Symbols = observed / Solid line = predicted

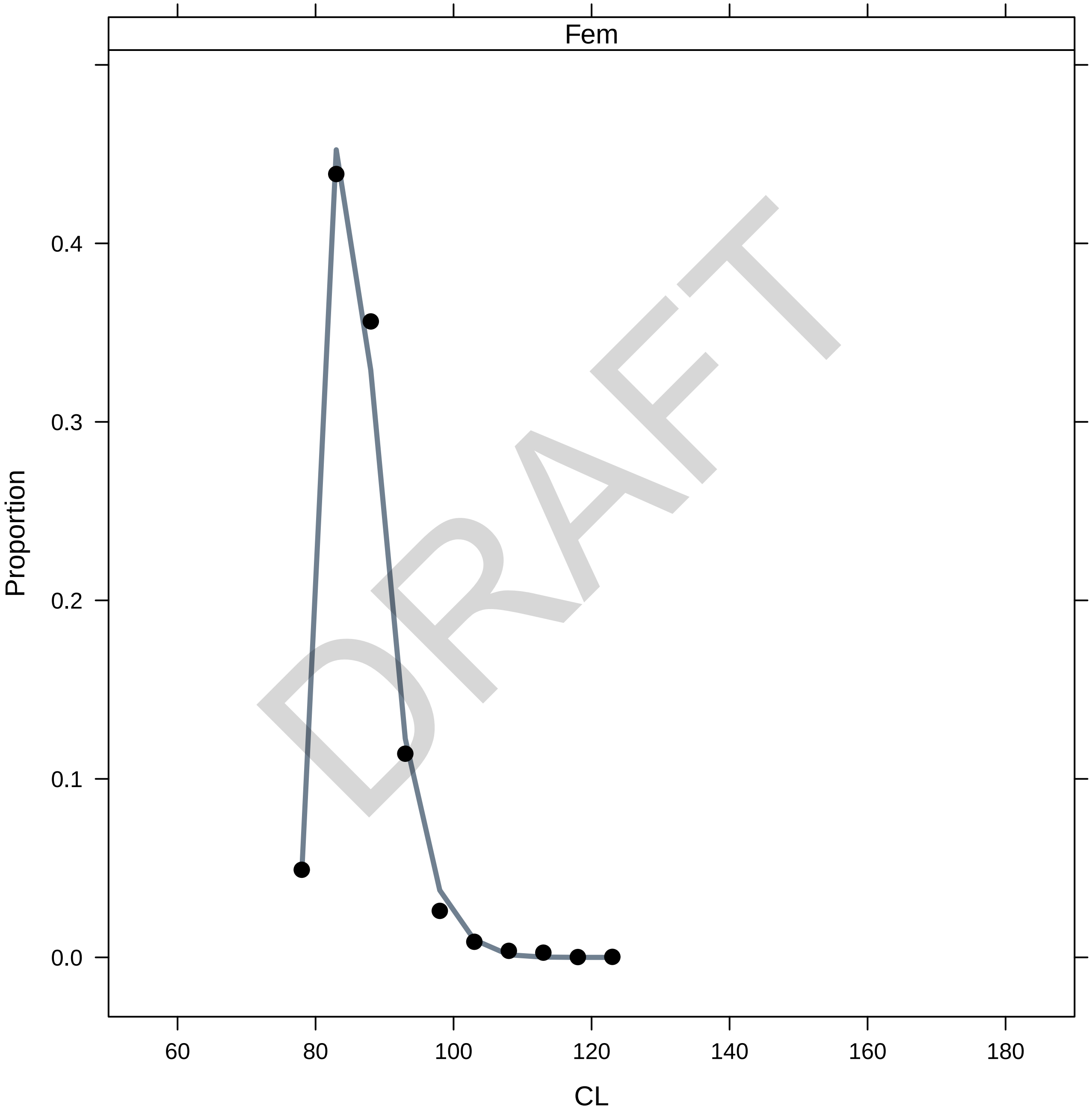
SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q1 Mal



DRAFT

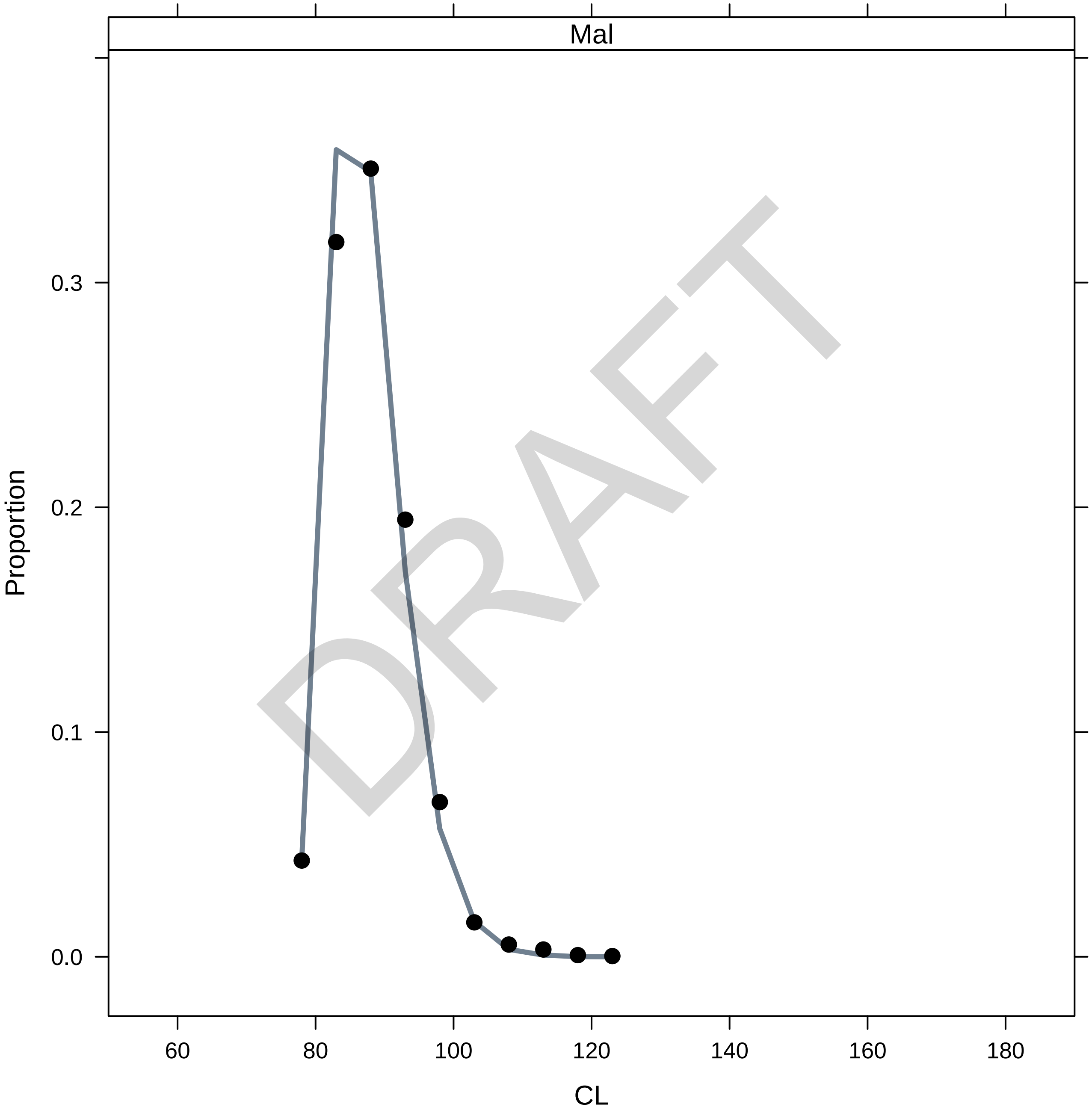
Symbols = observed / Solid line = predicted

SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q2 Fem



Symbols = observed / Solid line = predicted

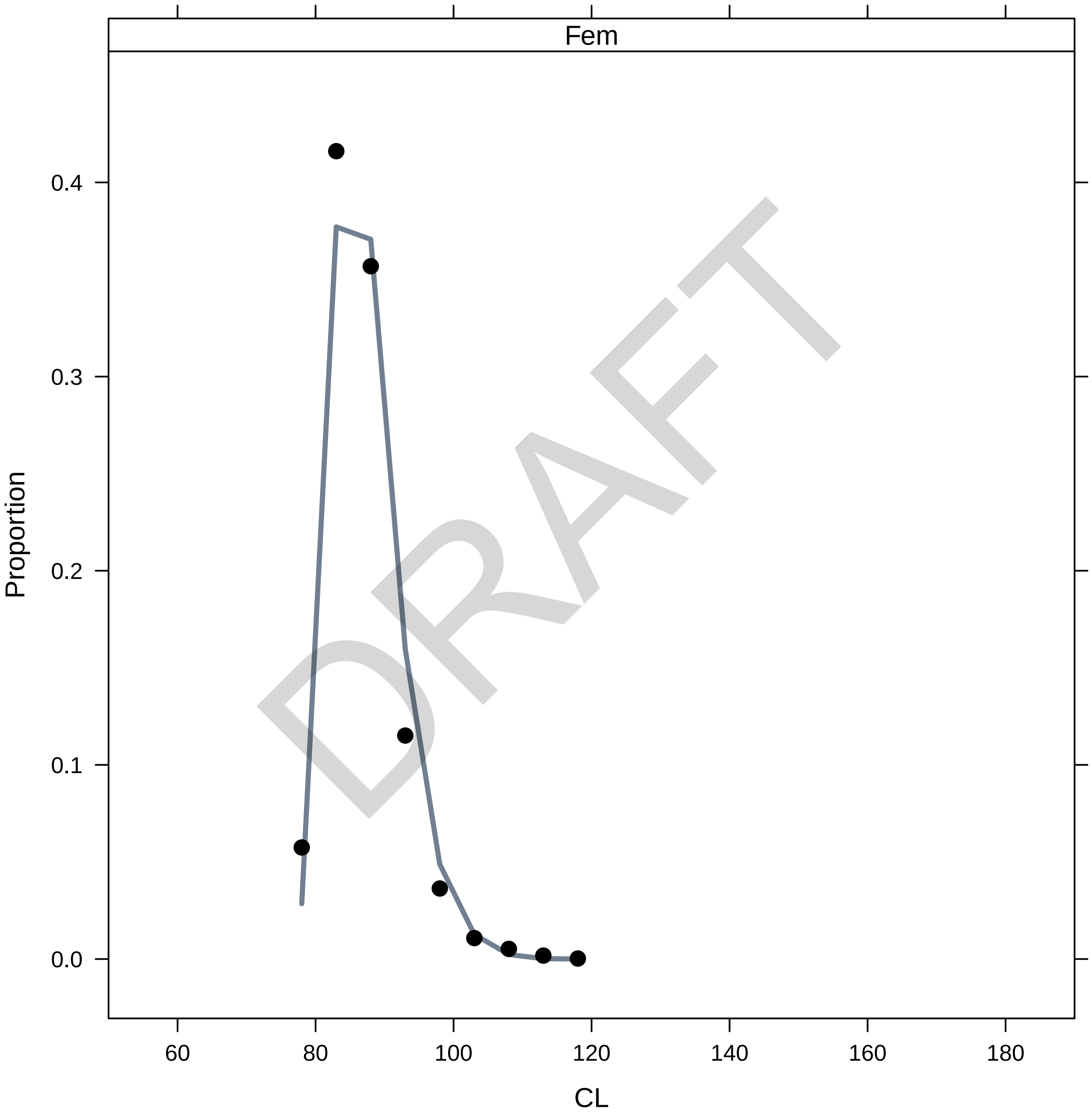
SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q2 Mal



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q3 Fem



Symbols = observed / Solid line = predicted

DRAFT

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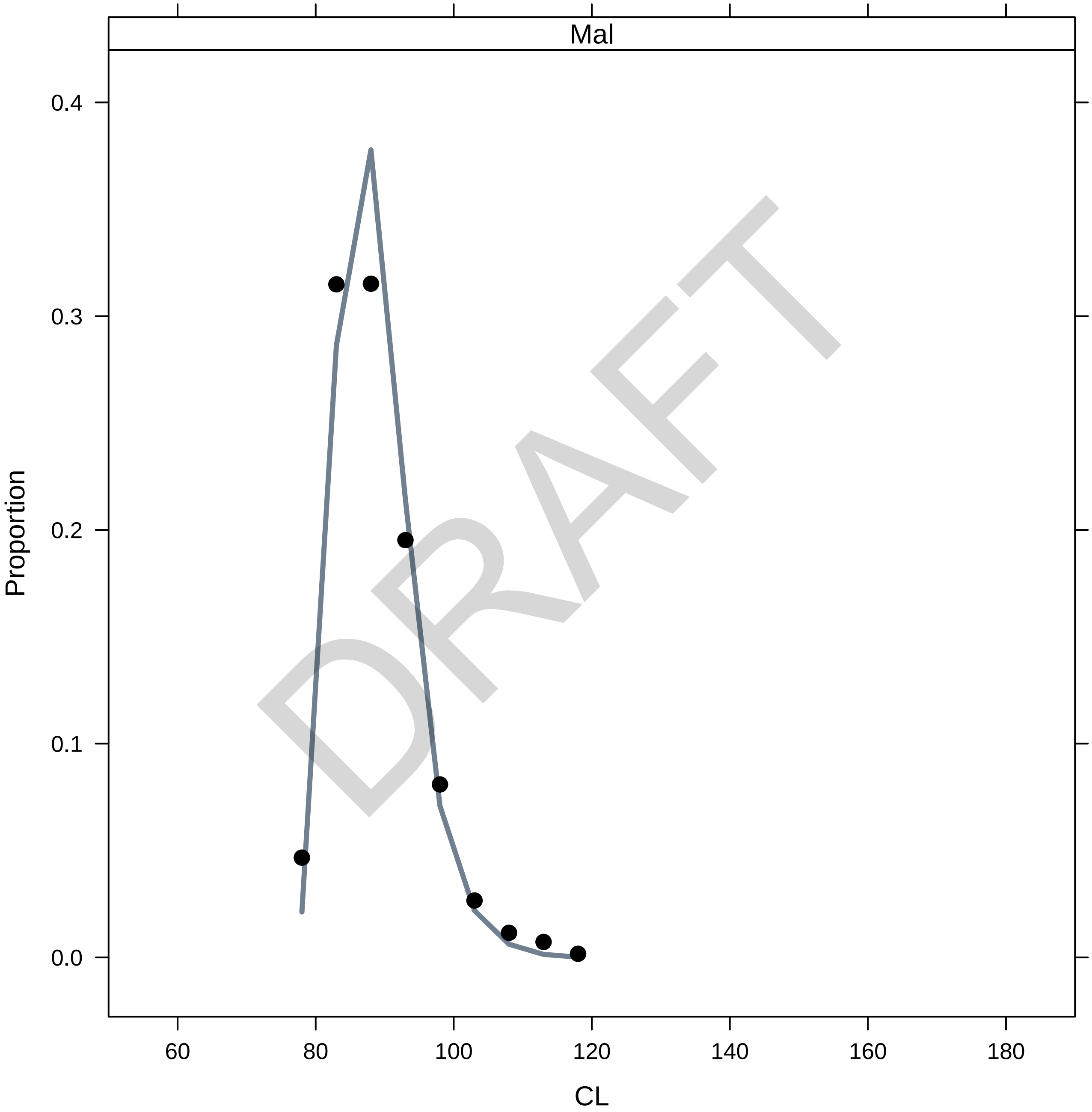
SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q3 Mal



DRAFT

Symbols = observed / Solid line = predicted

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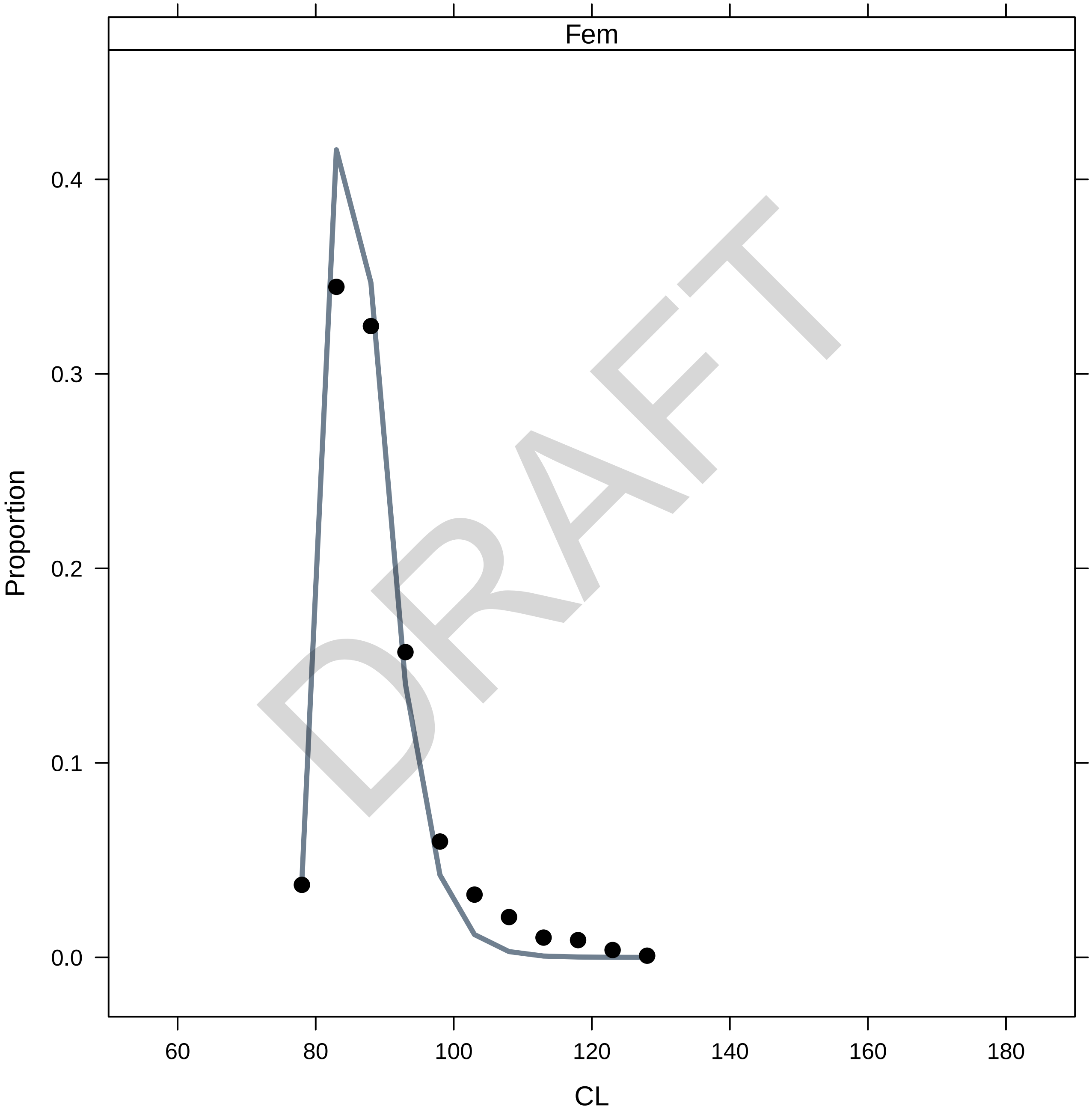
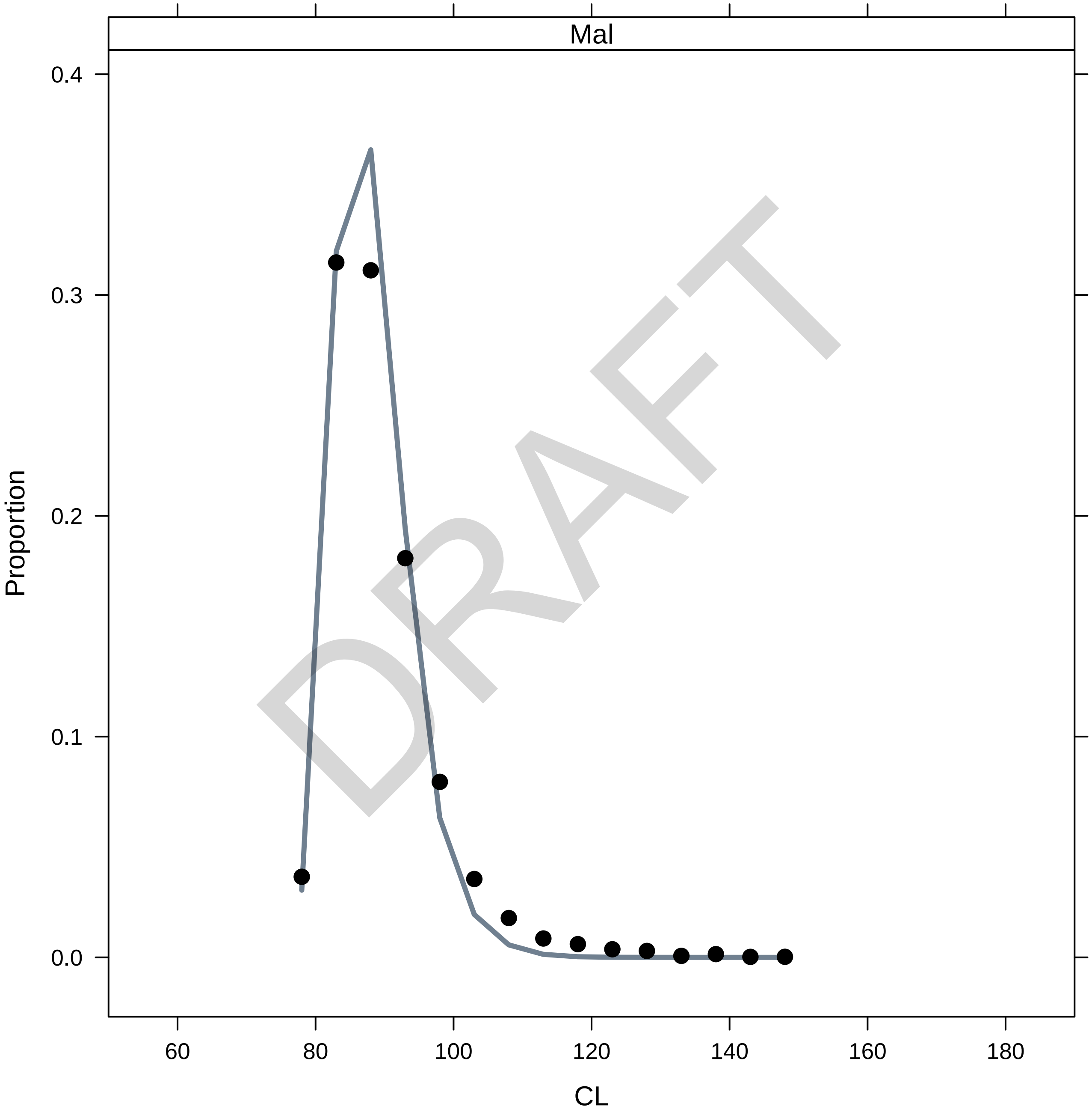
SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q4 Fem



DRAFT

Symbols = observed / Solid line = predicted

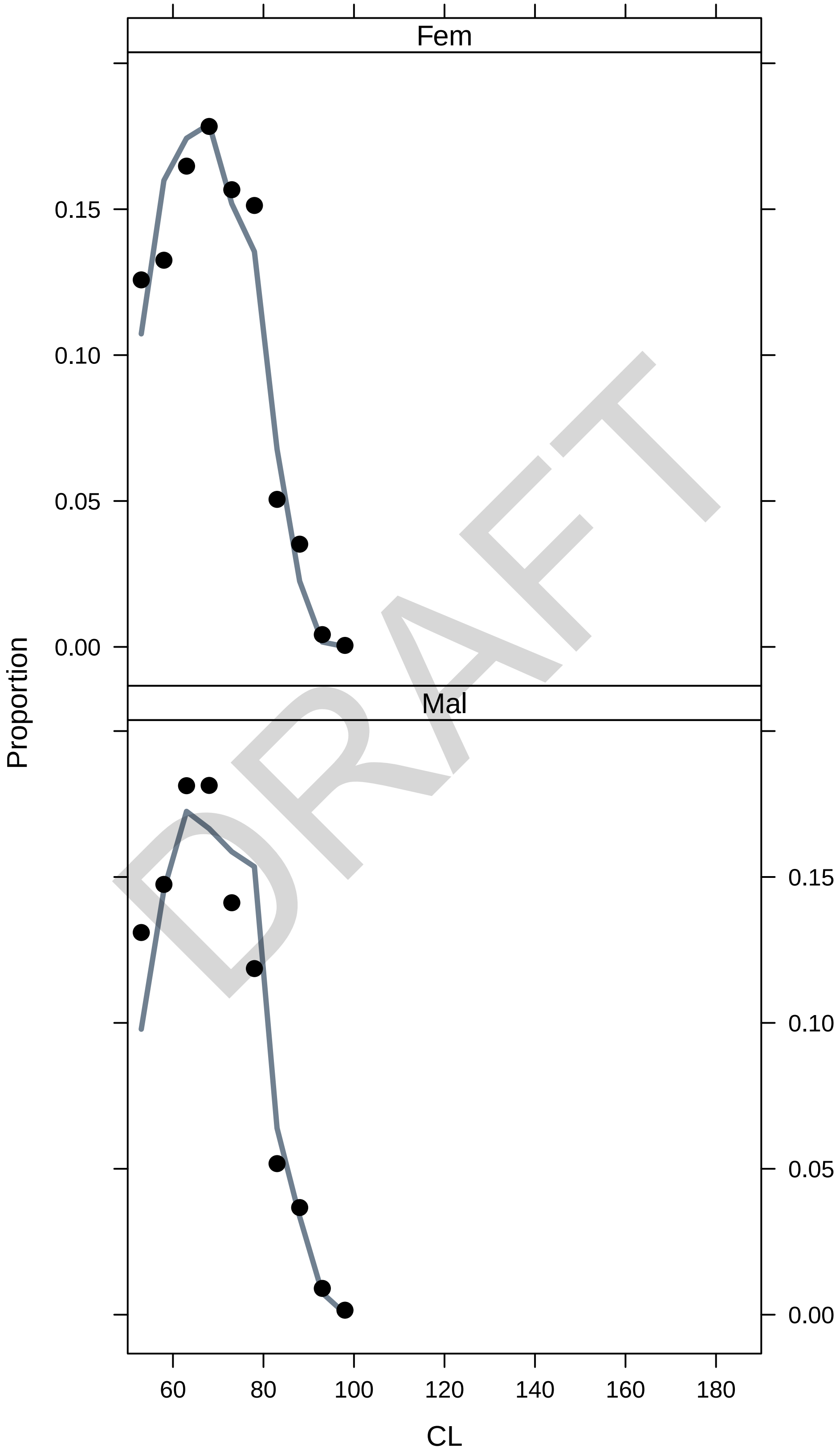
SNE_6F6_2019_orig_select
Average observed and predicted length comps Comm Q4 Mal



DRAFT

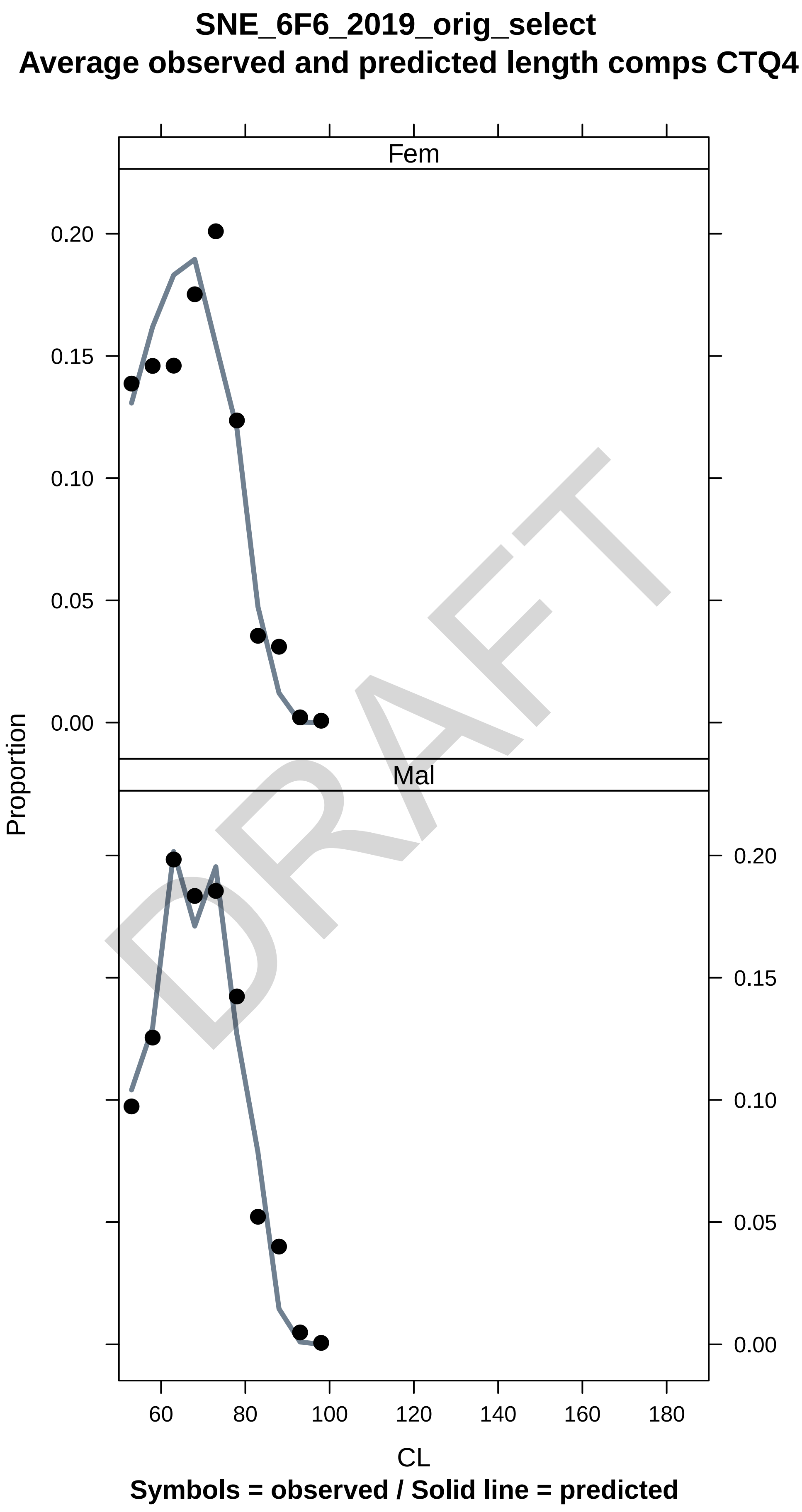
Symbols = observed / Solid line = predicted

SNE_6F6_2019_orig_select
Average observed and predicted length comps CTQ2



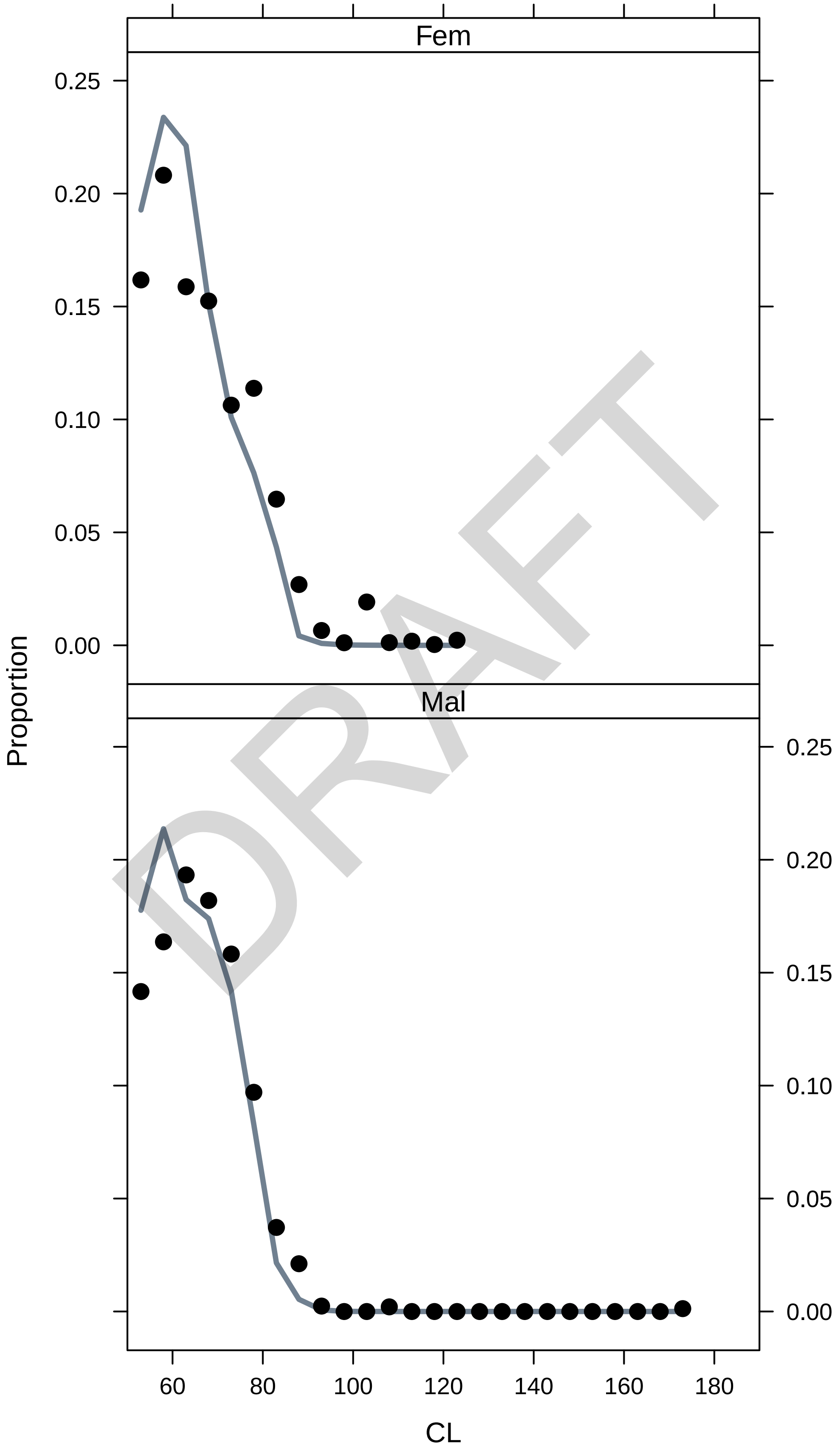
DRAFT

Symbols = observed / Solid line = predicted


SNE_6F6_2019_orig_select
Average observed and predicted length comps CTQ4
Fem
Mal
Proportion
0.00
0.05
0.10
0.15
0.20
CL
60
80
100
120
140
160
180
Symbols = observed / Solid line = predicted

DRAFT

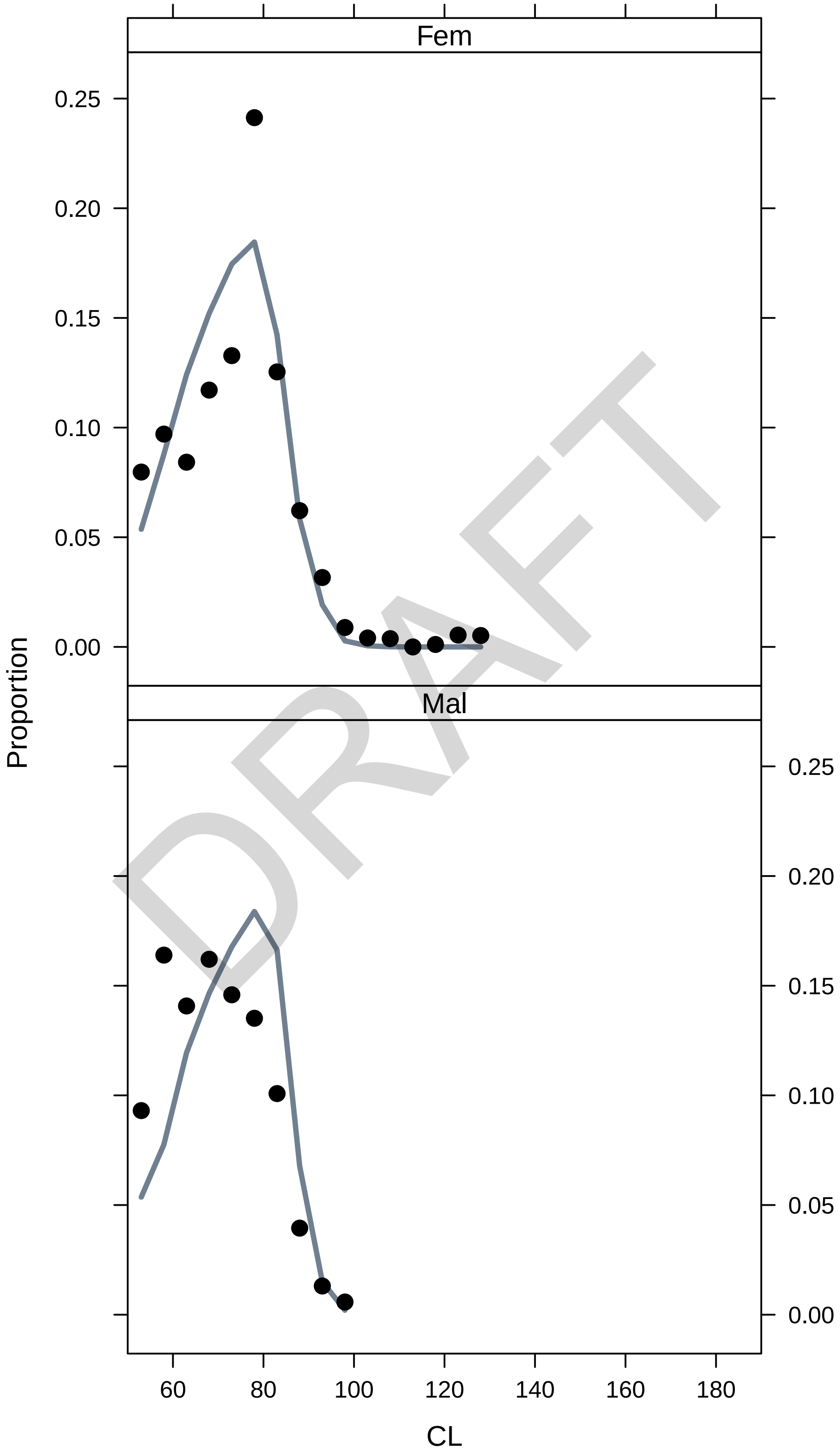
SNE_6F6_2019_orig_select
Average observed and predicted length comps MAQ2



DRAFT

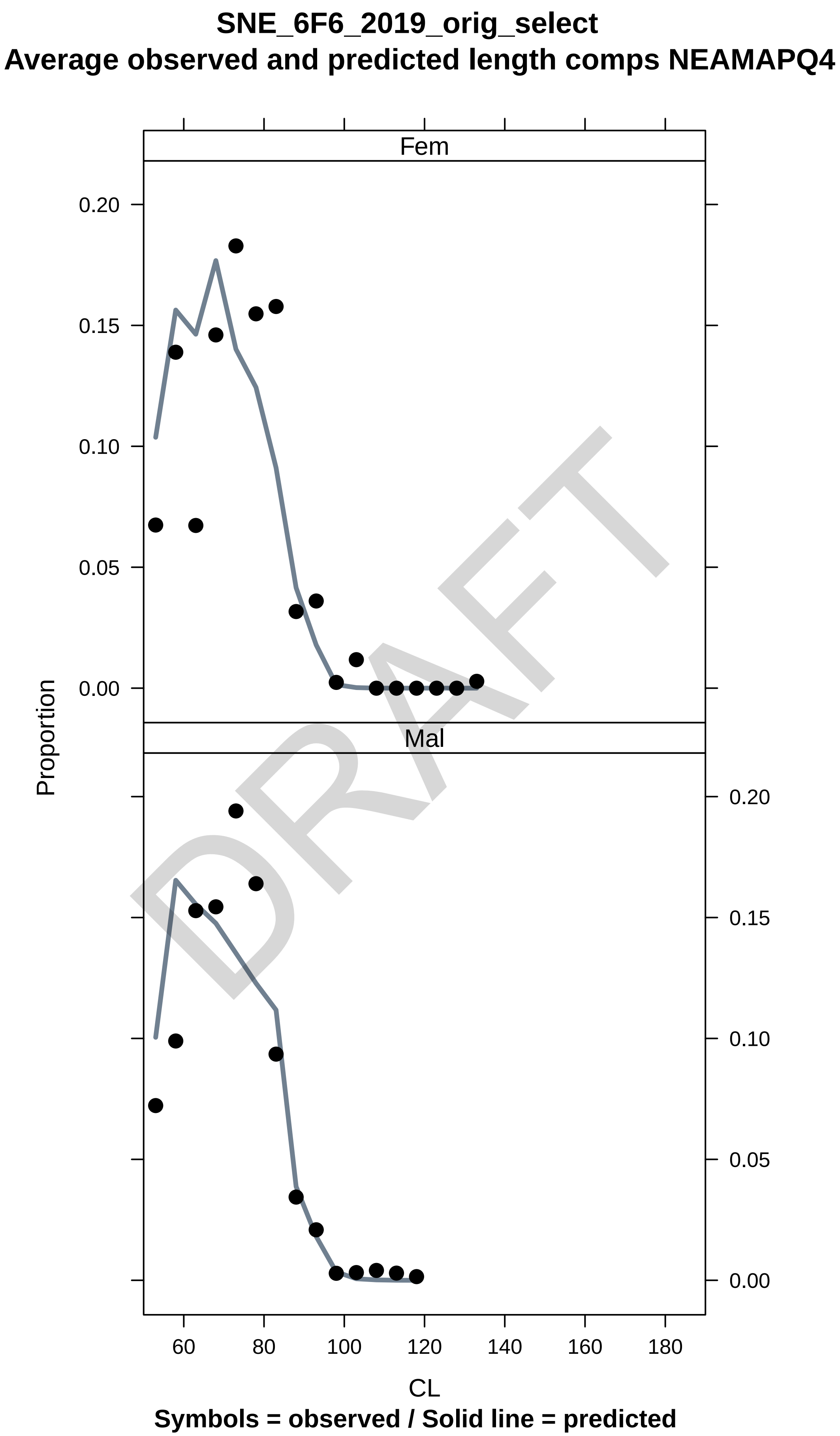
Symbols = observed / Solid line = predicted

SNE_6F6_2019_orig_select
Average observed and predicted length comps NEAMAPQ2



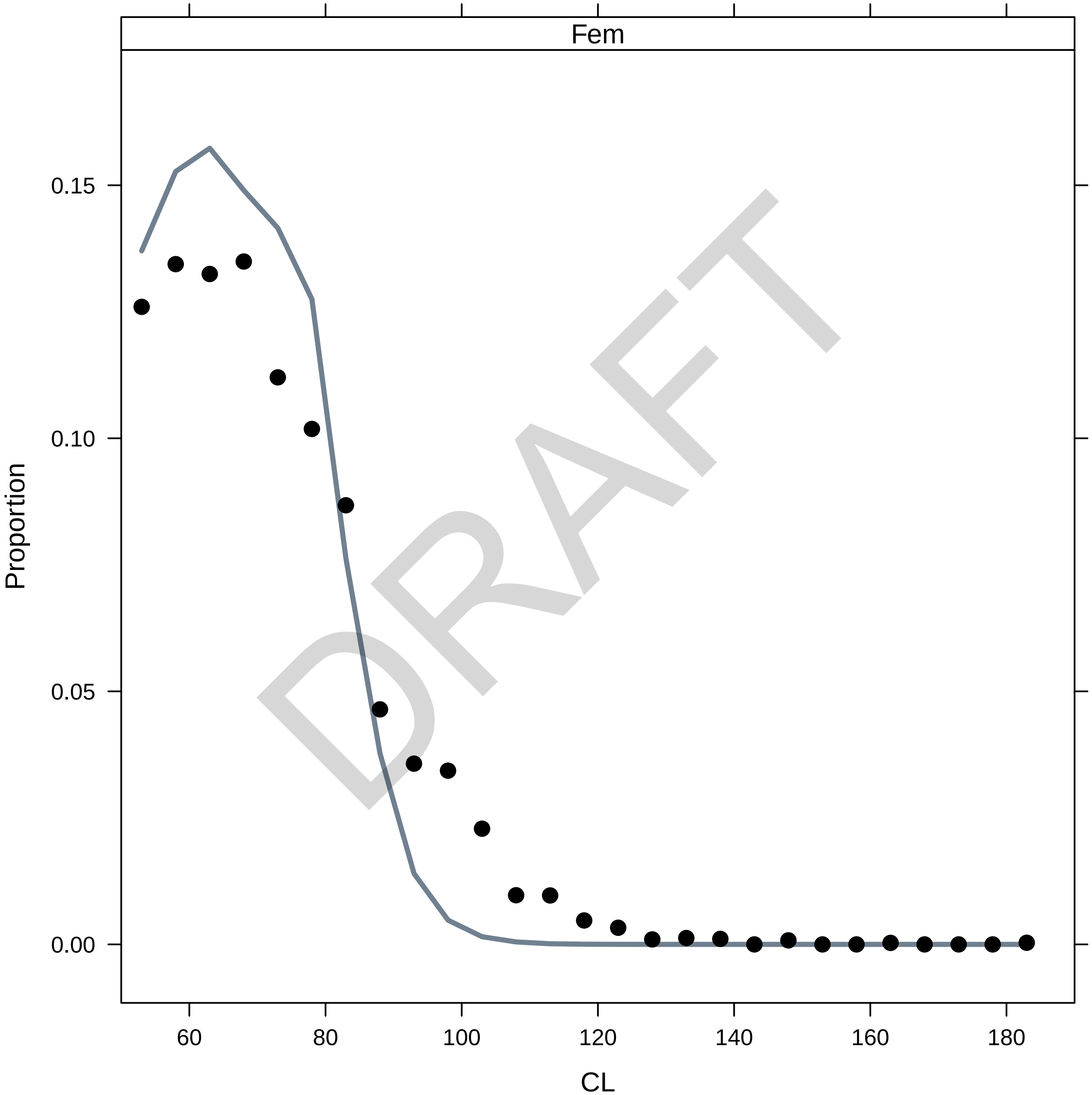
DRAFT

Symbols = observed / Solid line = predicted


SNE_6F6_2019_orig_select
Average observed and predicted length comps NEAMAPQ4
Fem
Mal
Proportion
0.00
0.05
0.10
0.15
0.20
CL
60
80
100
120
140
160
180
Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
Average observed and predicted length comps NfscFQ4



DRAFT

Symbols = observed / Solid line = predicted

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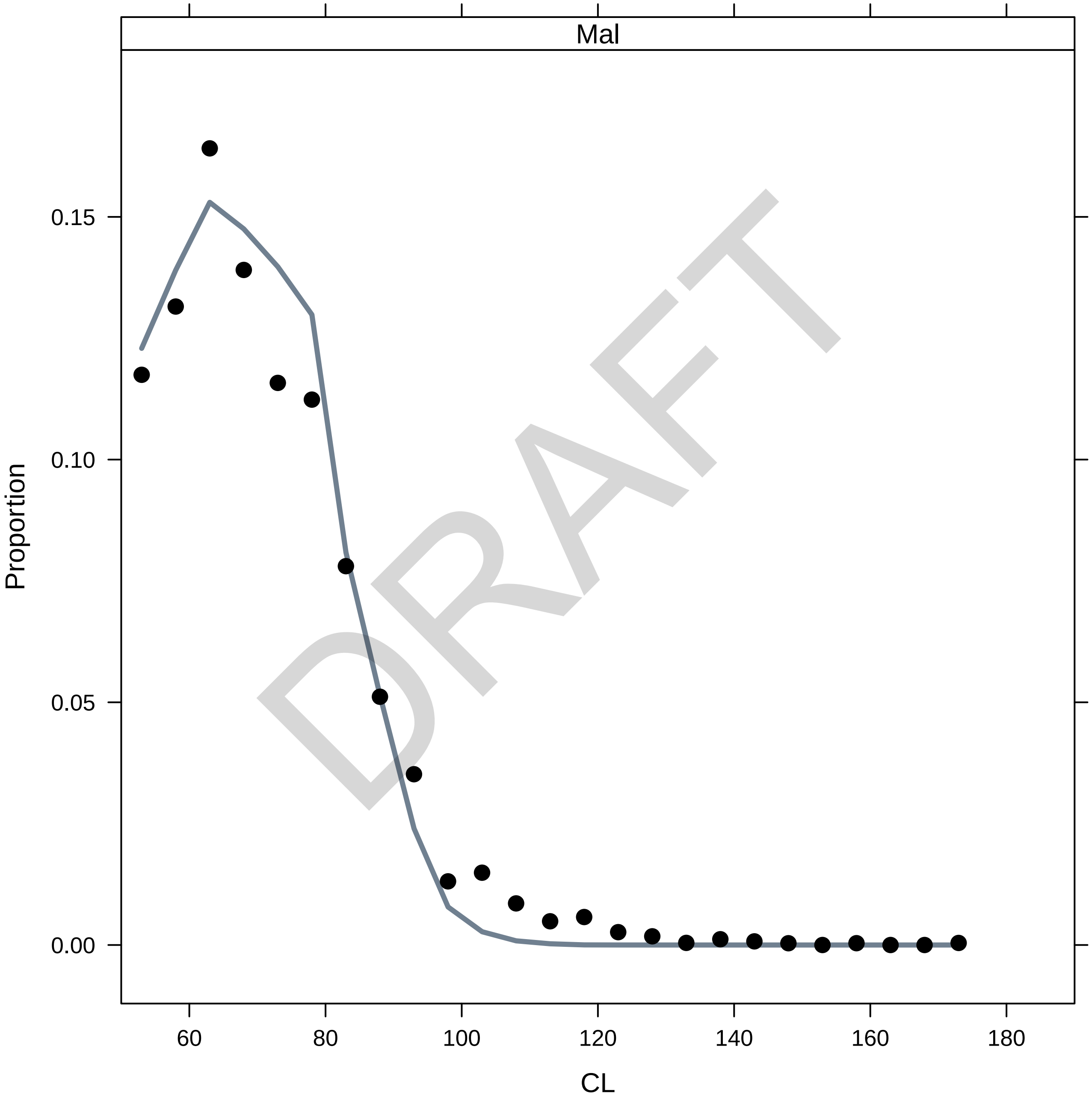
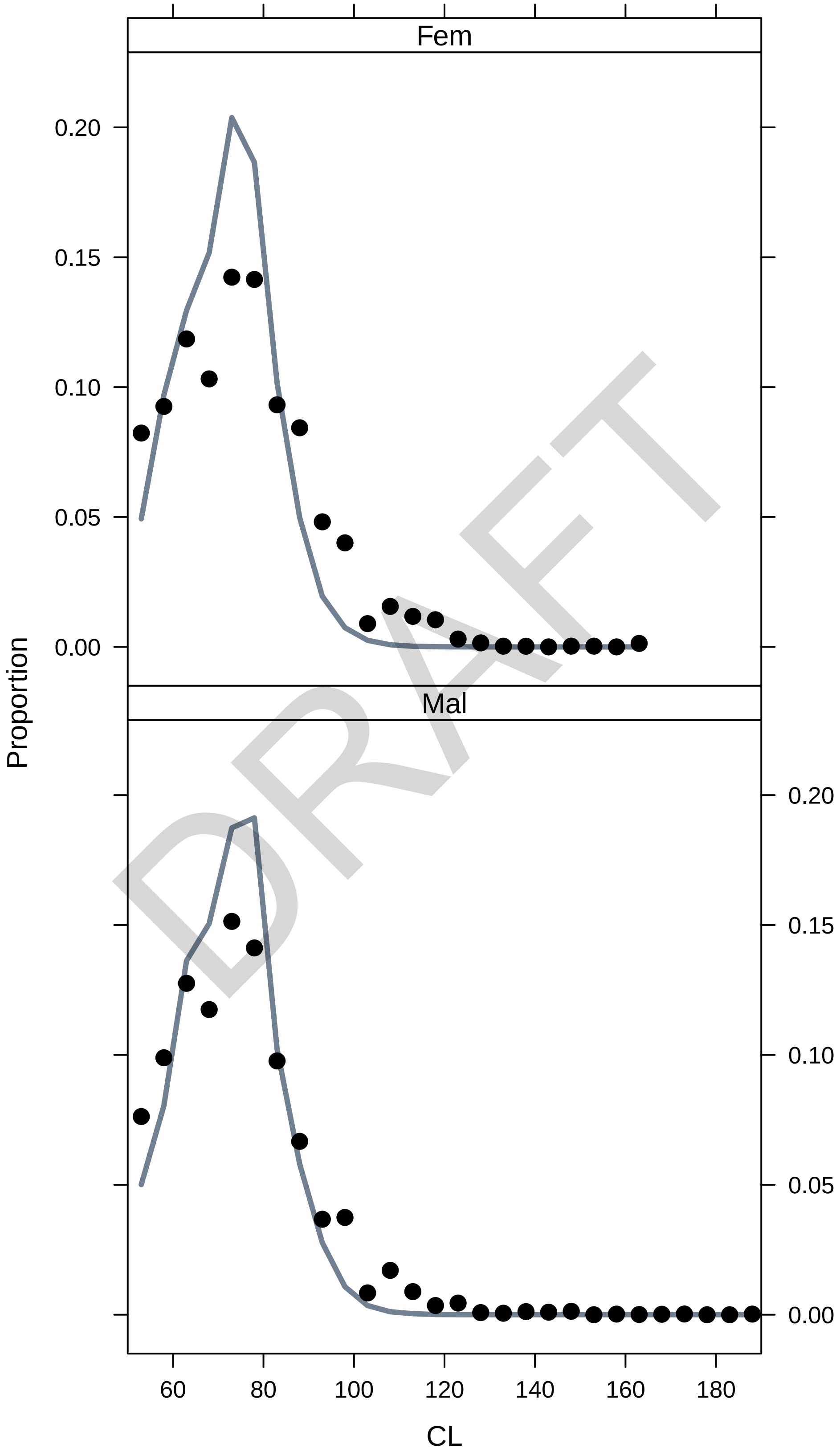
SNE_6F6_2019_orig_select
Average observed and predicted length comps NfscMQ4



DRAFT

Symbols = observed / Solid line = predicted

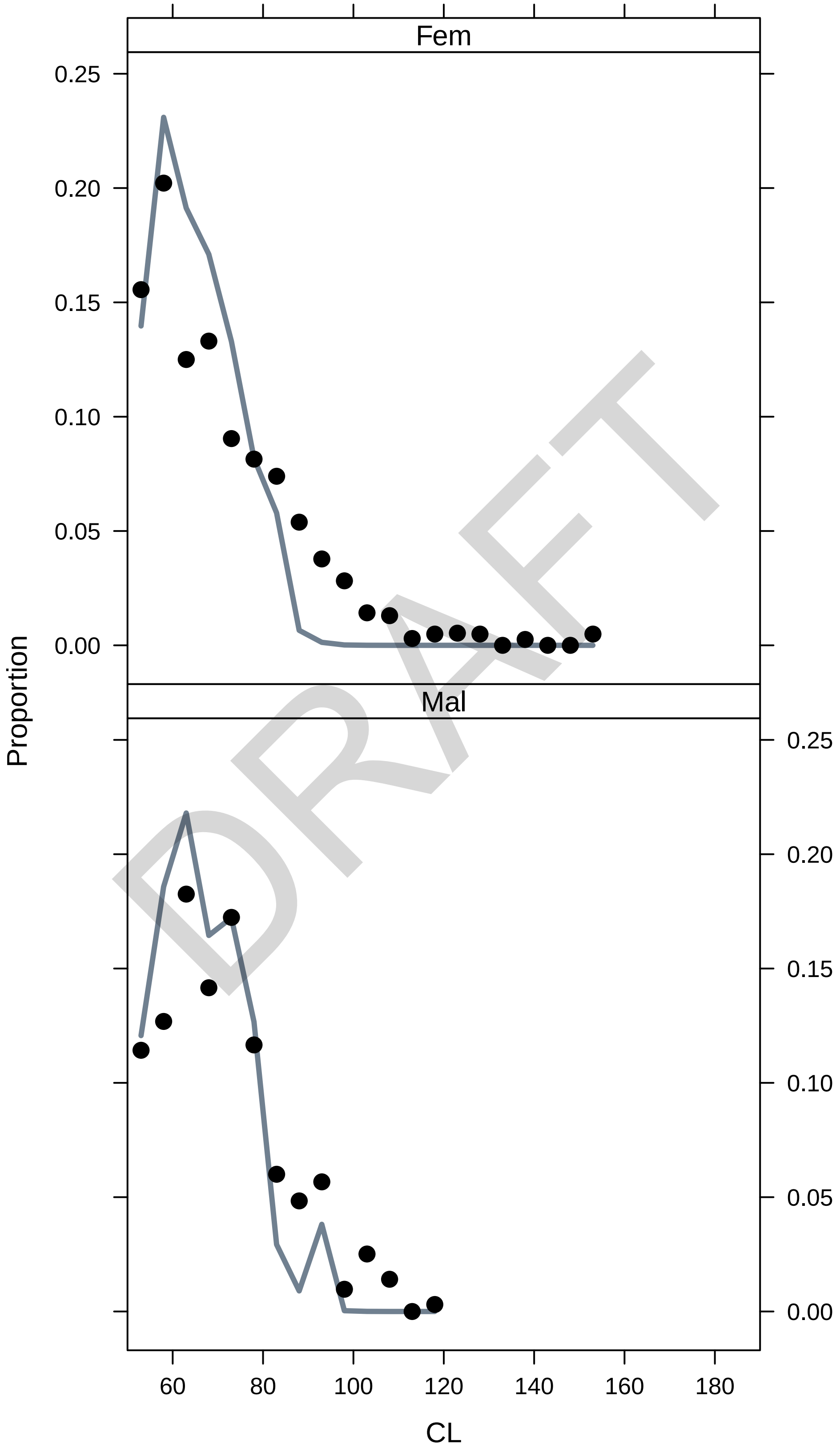
SNE_6F6_2019_orig_select
Average observed and predicted length comps NfscQ2



DRAFT

Symbols = observed / Solid line = predicted

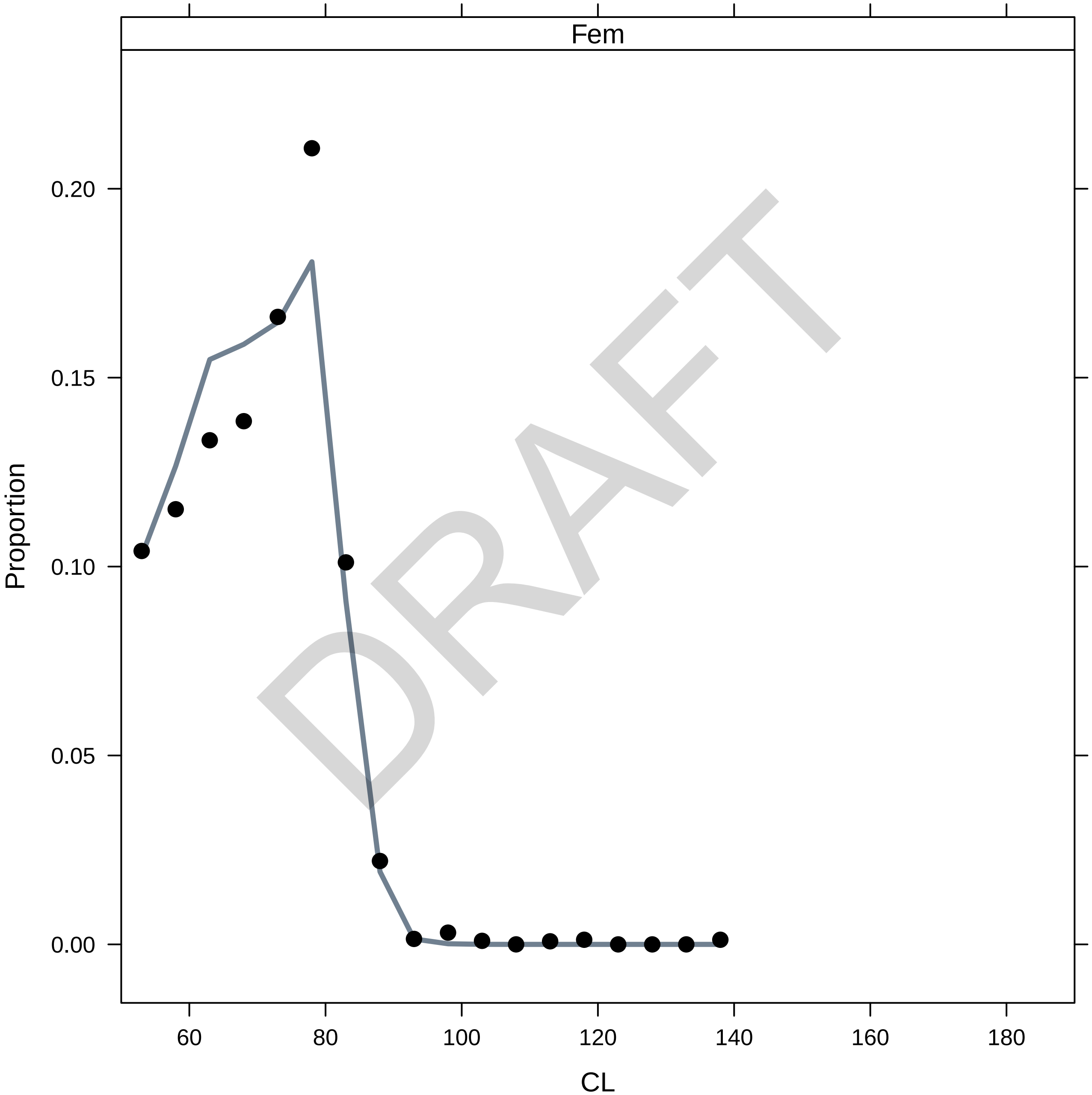
SNE_6F6_2019_orig_select
Average observed and predicted length comps NJ



Symbols = observed / Solid line = predicted

DRAFT

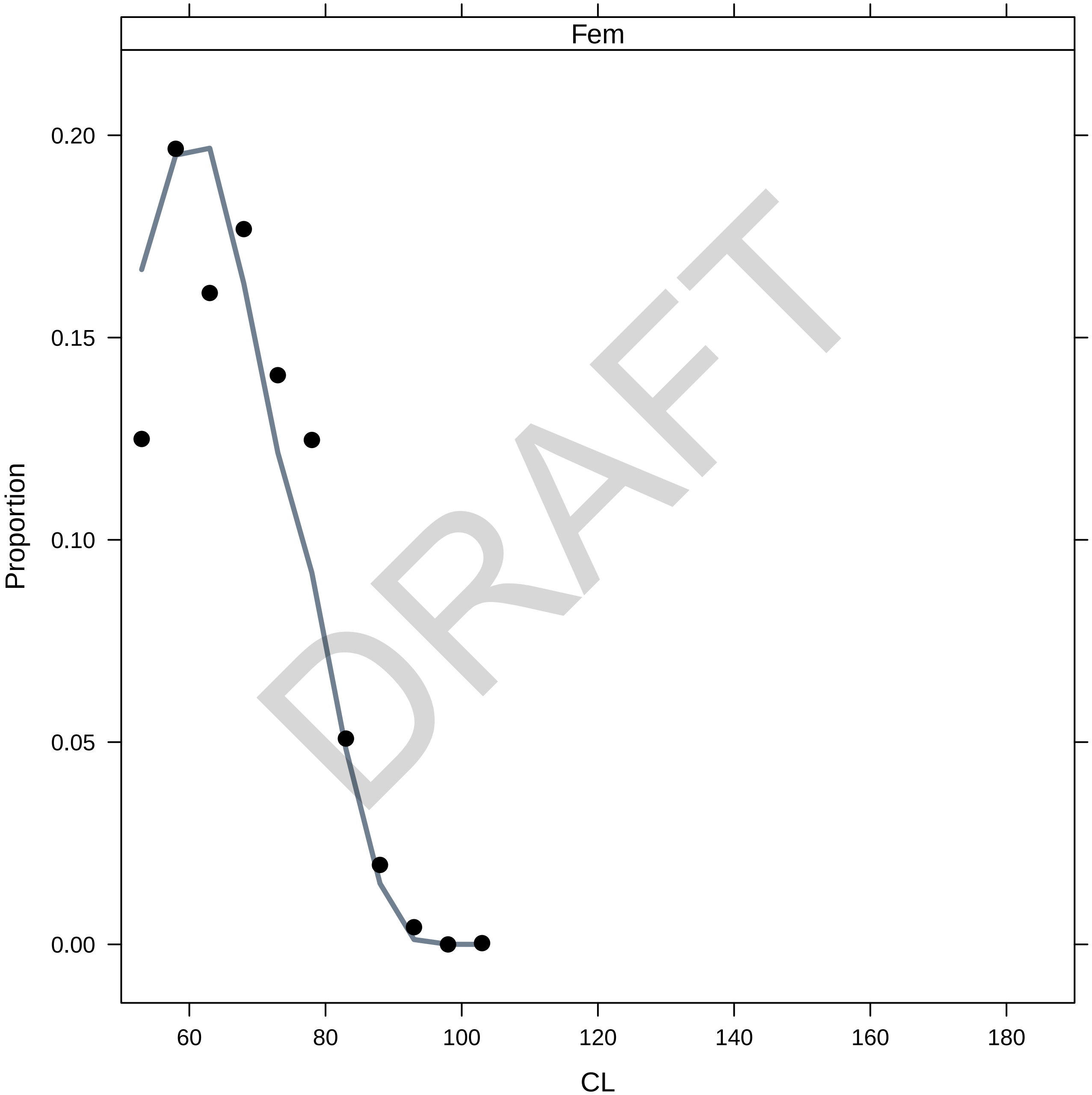
SNE_6F6_2019_orig_select
Average observed and predicted length comps RIFQ2



DRAFT

Symbols = observed / Solid line = predicted

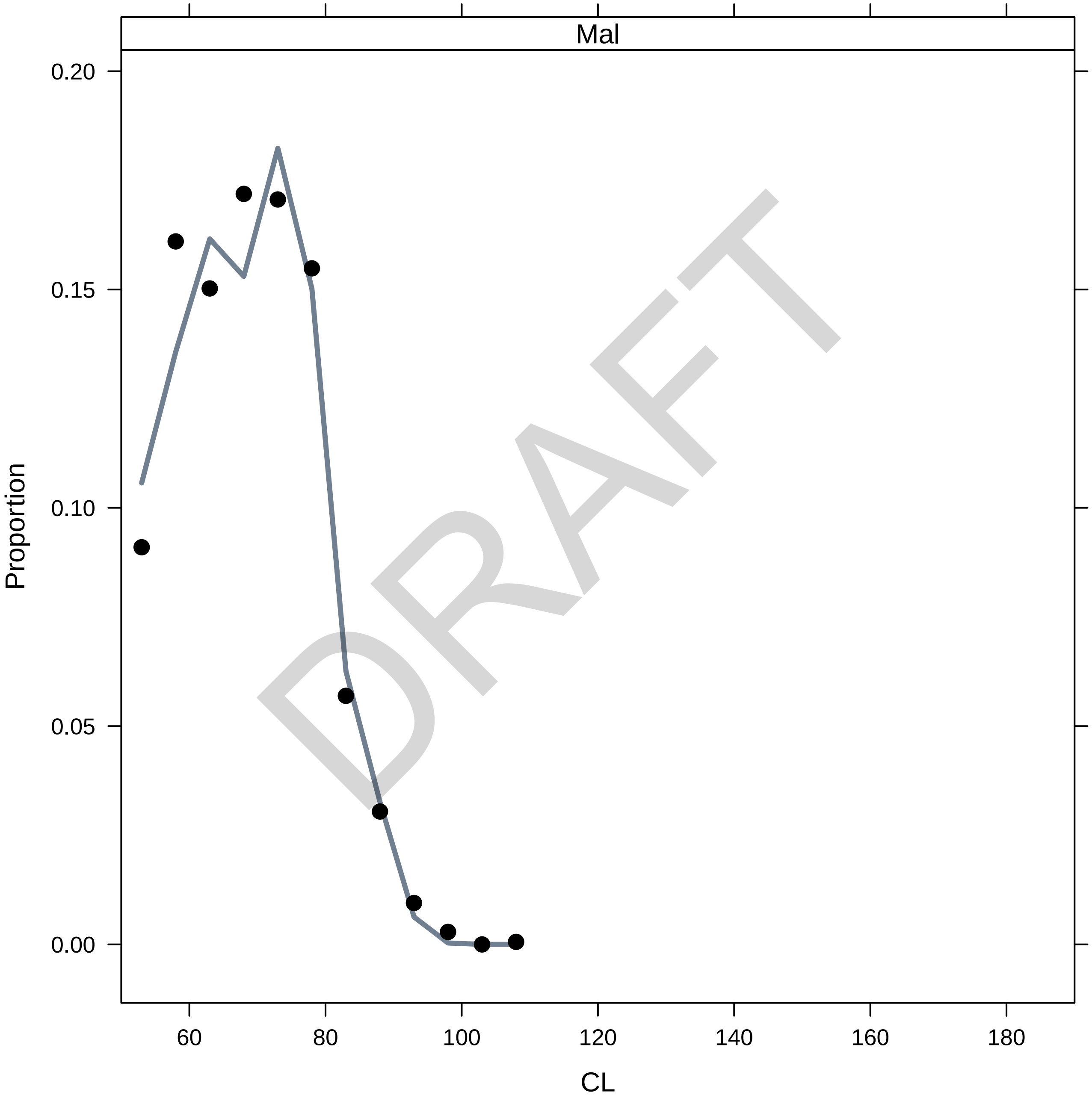
SNE_6F6_2019_orig_select
Average observed and predicted length comps RIFQ4



DRAFT

Symbols = observed / Solid line = predicted

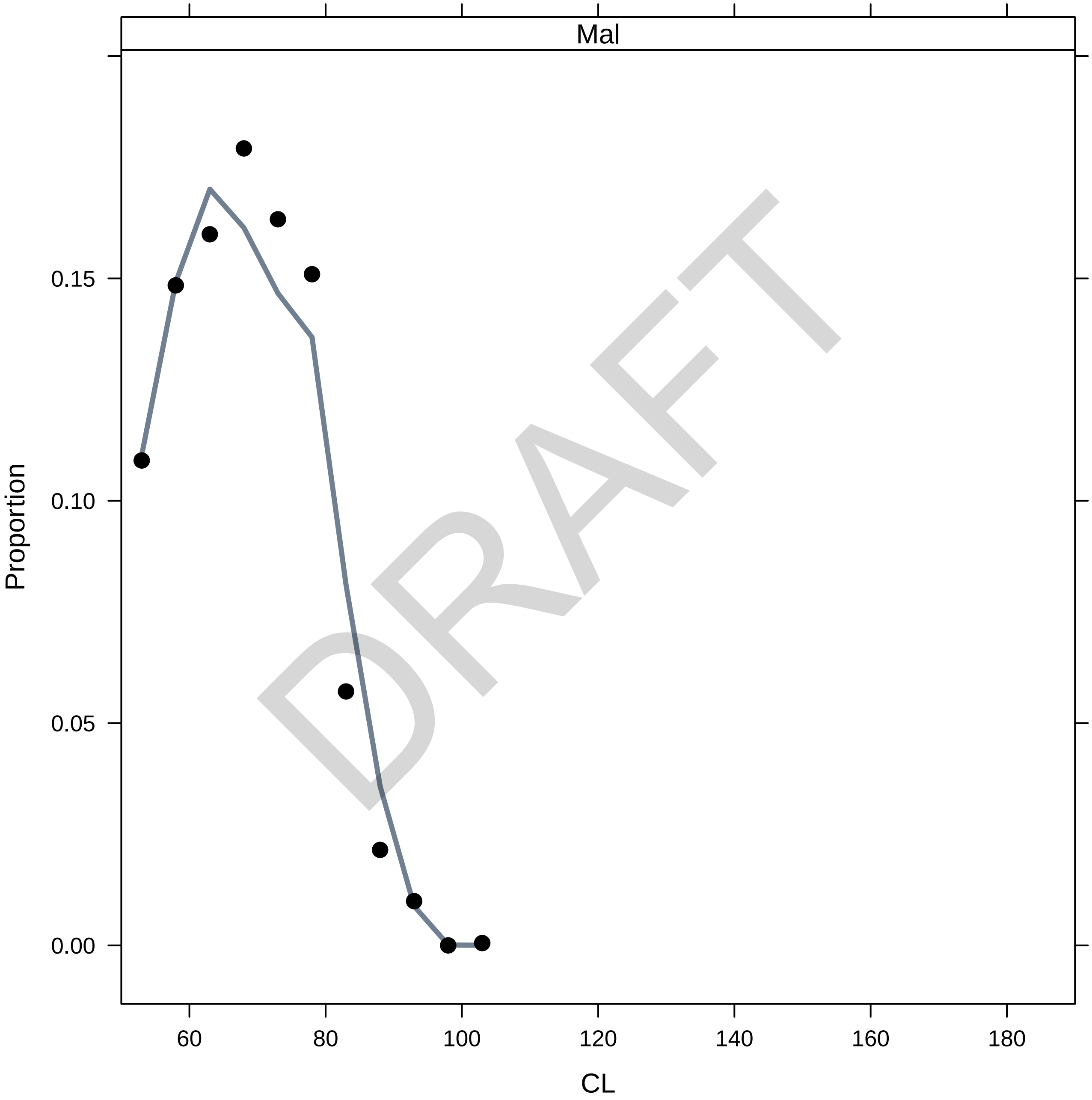
SNE_6F6_2019_orig_select
Average observed and predicted length comps RIMQ2



DRAFT

Symbols = observed / Solid line = predicted

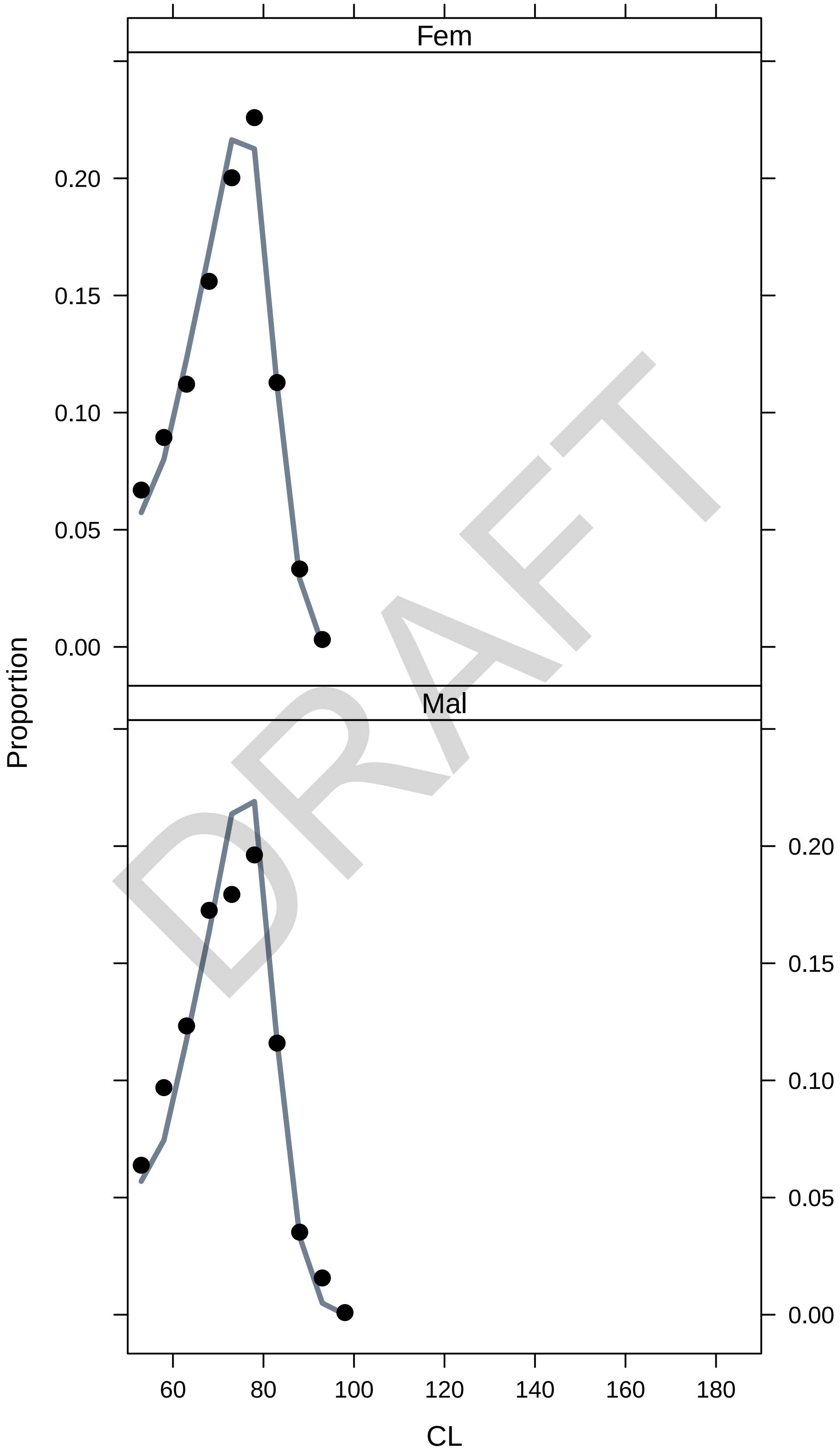
SNE_6F6_2019_orig_select
Average observed and predicted length comps RIMQ4



Symbols = observed / Solid line = predicted

DRAFT

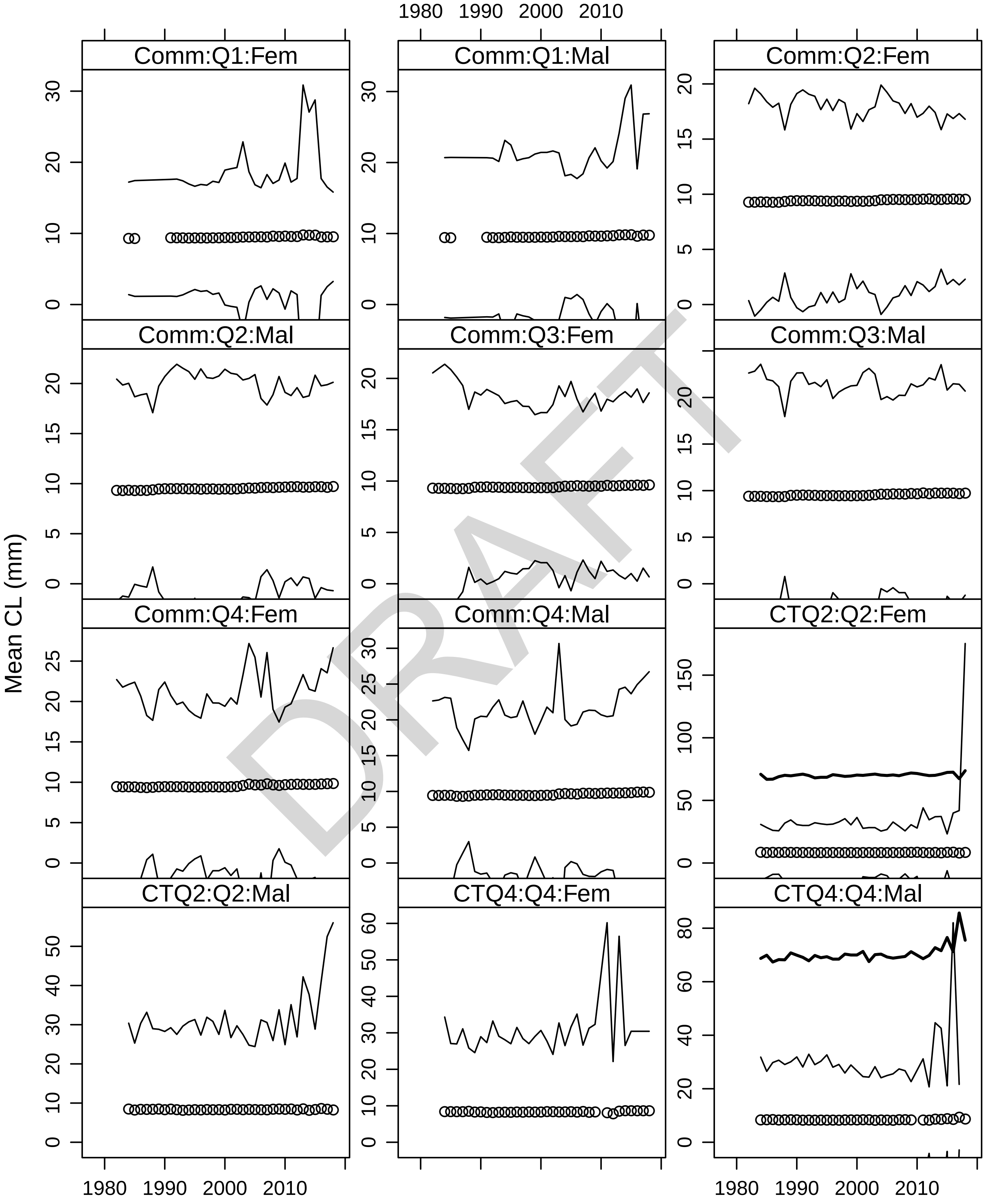
SNE_6F6_2019_orig_select
Average observed and predicted length comps VTSQ3_model



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
Effective N/GOF plots for length data

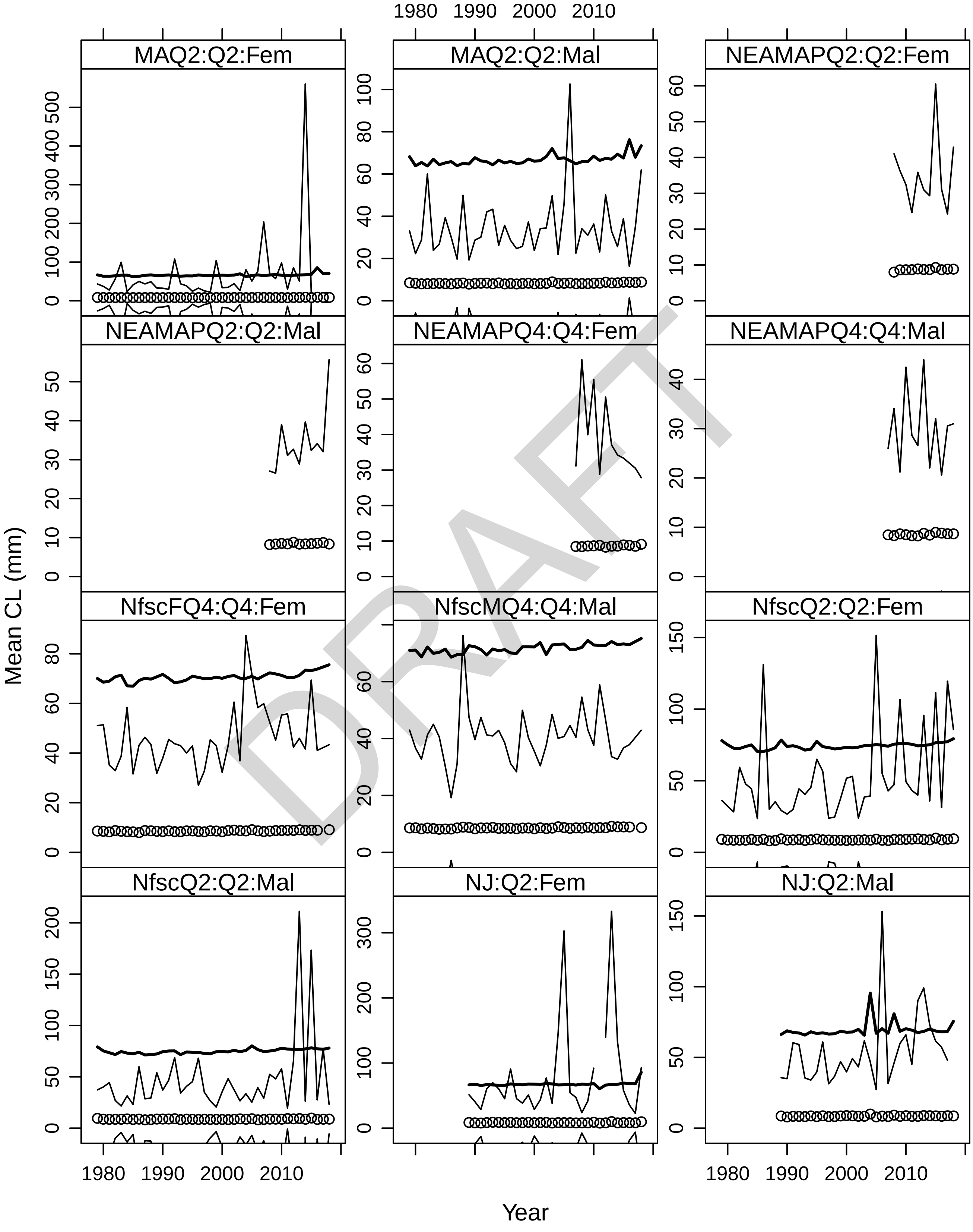


Year

Symbols=observed with 95% CI, heavy line=predicted

DRAFT

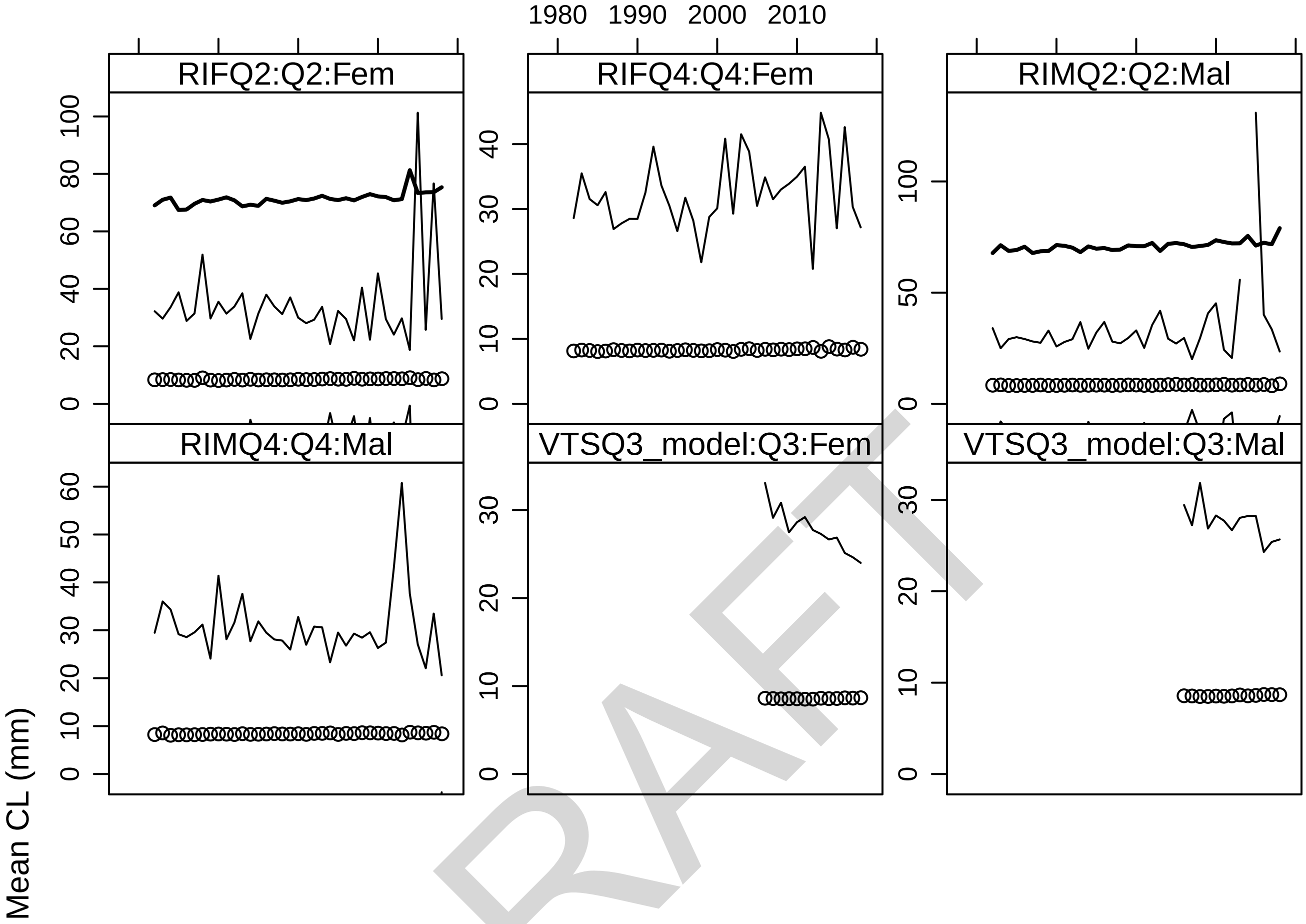
SNE_6F6_2019_orig_select
Effective N/GOF plots for length data



Symbols=observed with 95% CI, heavy line=predicted

DRAFT

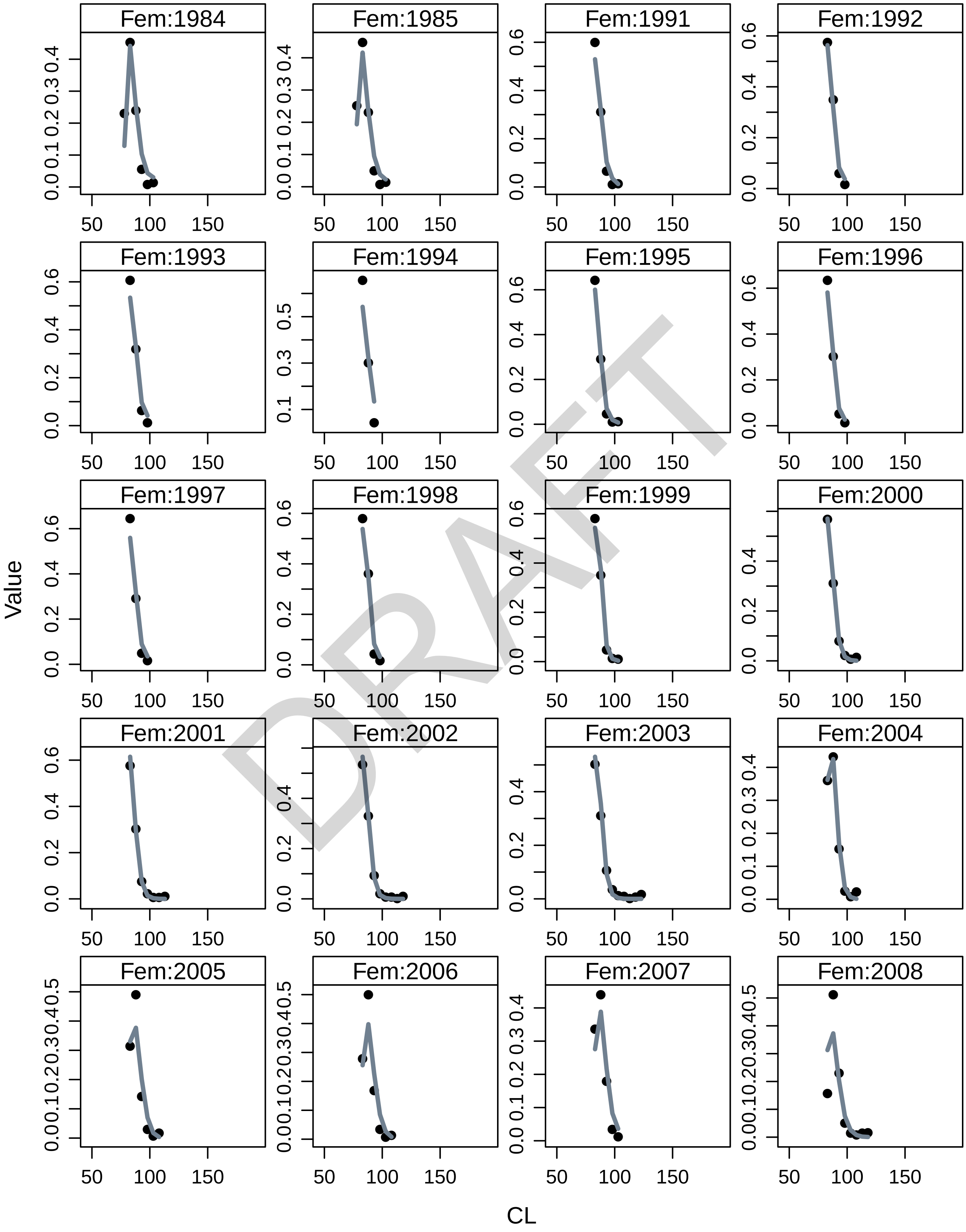
SNE_6F6_2019_orig_select
Effective N/GOF plots for length data



DRAFT

Year
Symbols=observed with 95% CI, heavy line=predicted

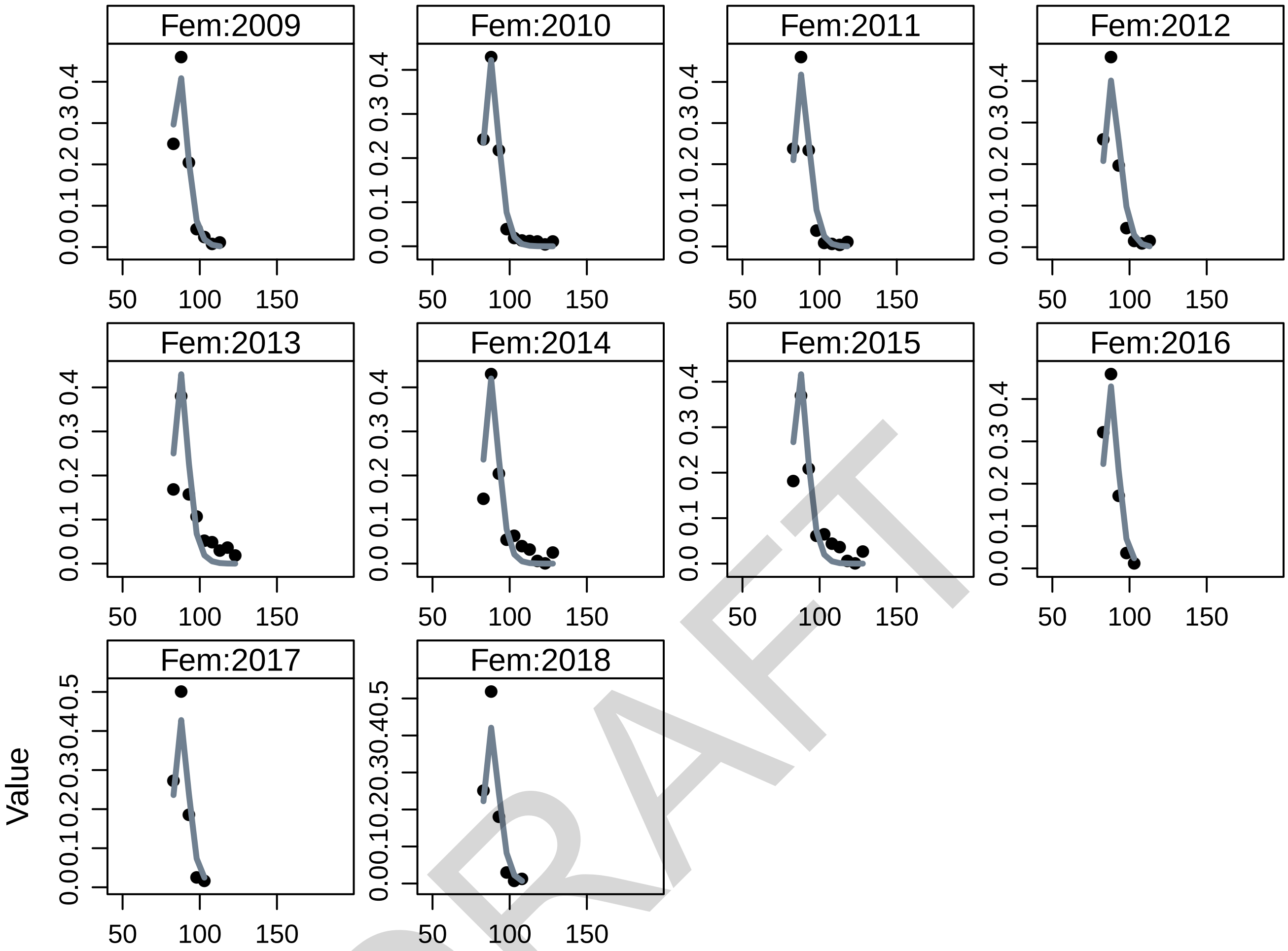
SNE_6F6_2019_orig_select
Comm Q1 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
Comm Q1 Fem observed and predicted length comps

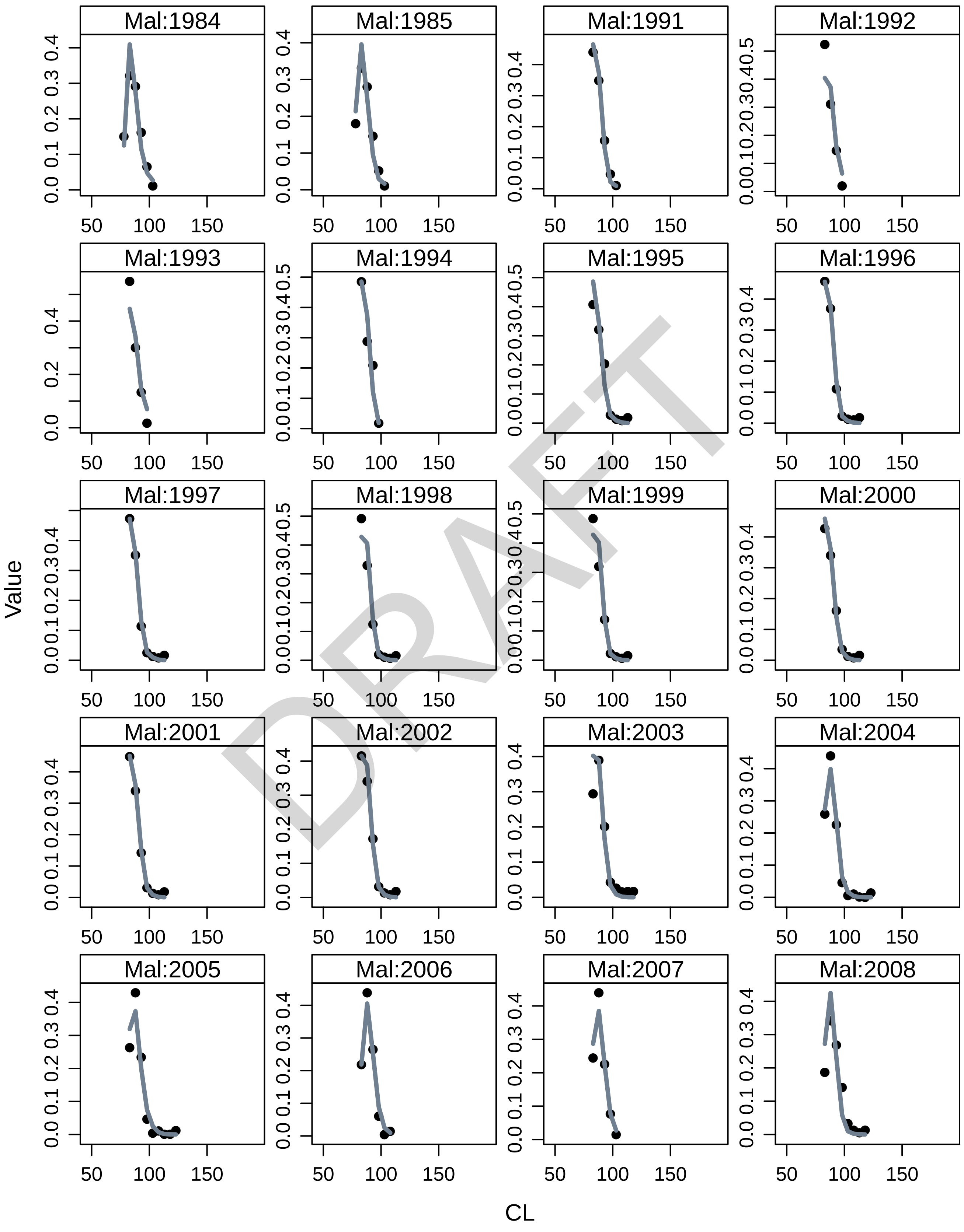


DRAFT

CL

Symbols = observed / Solid line = predicted

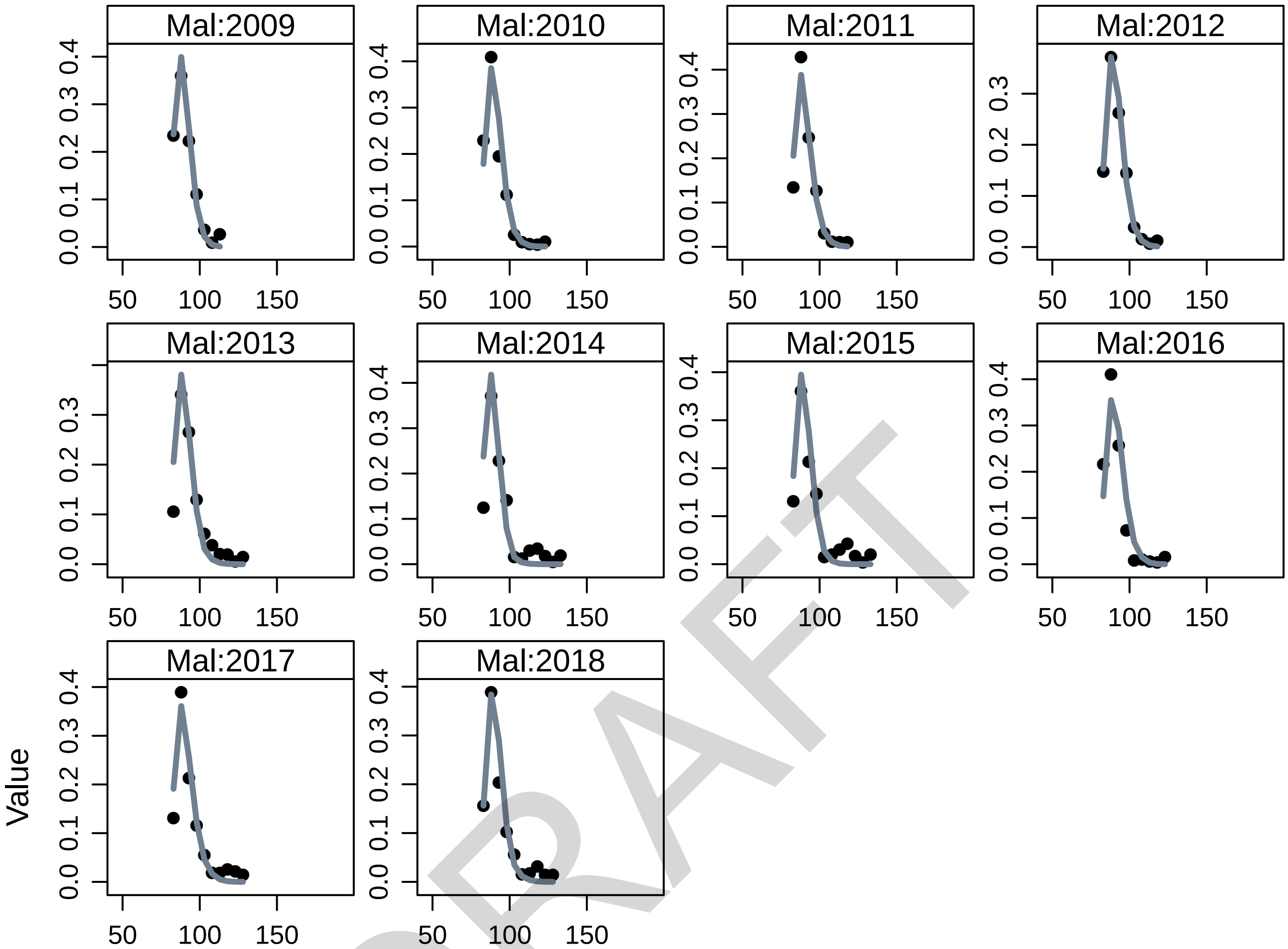
SNE_6F6_2019_orig_select
Comm Q1 Mal observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
Comm Q1 Mal observed and predicted length comps

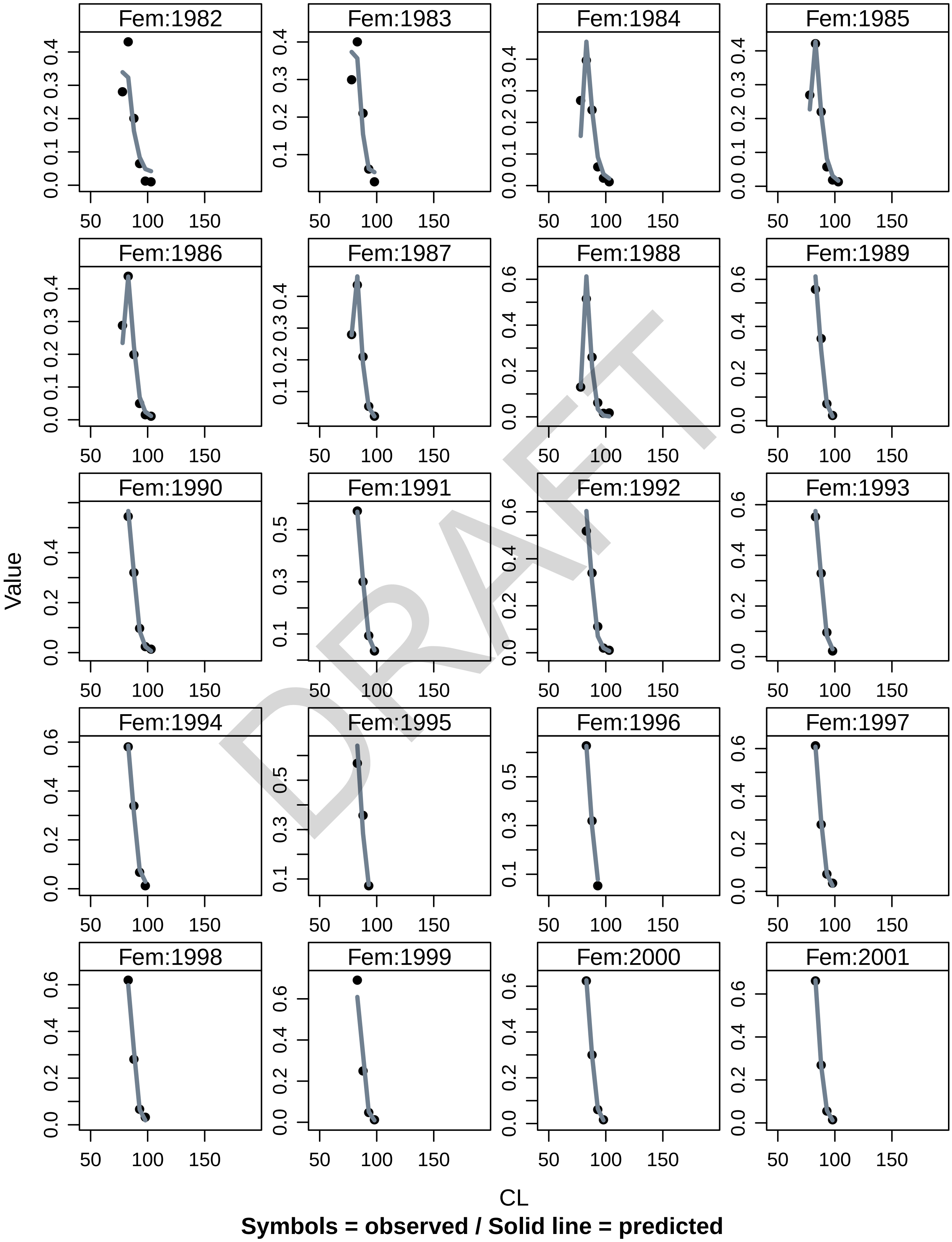


DRAFT

CL

Symbols = observed / Solid line = predicted

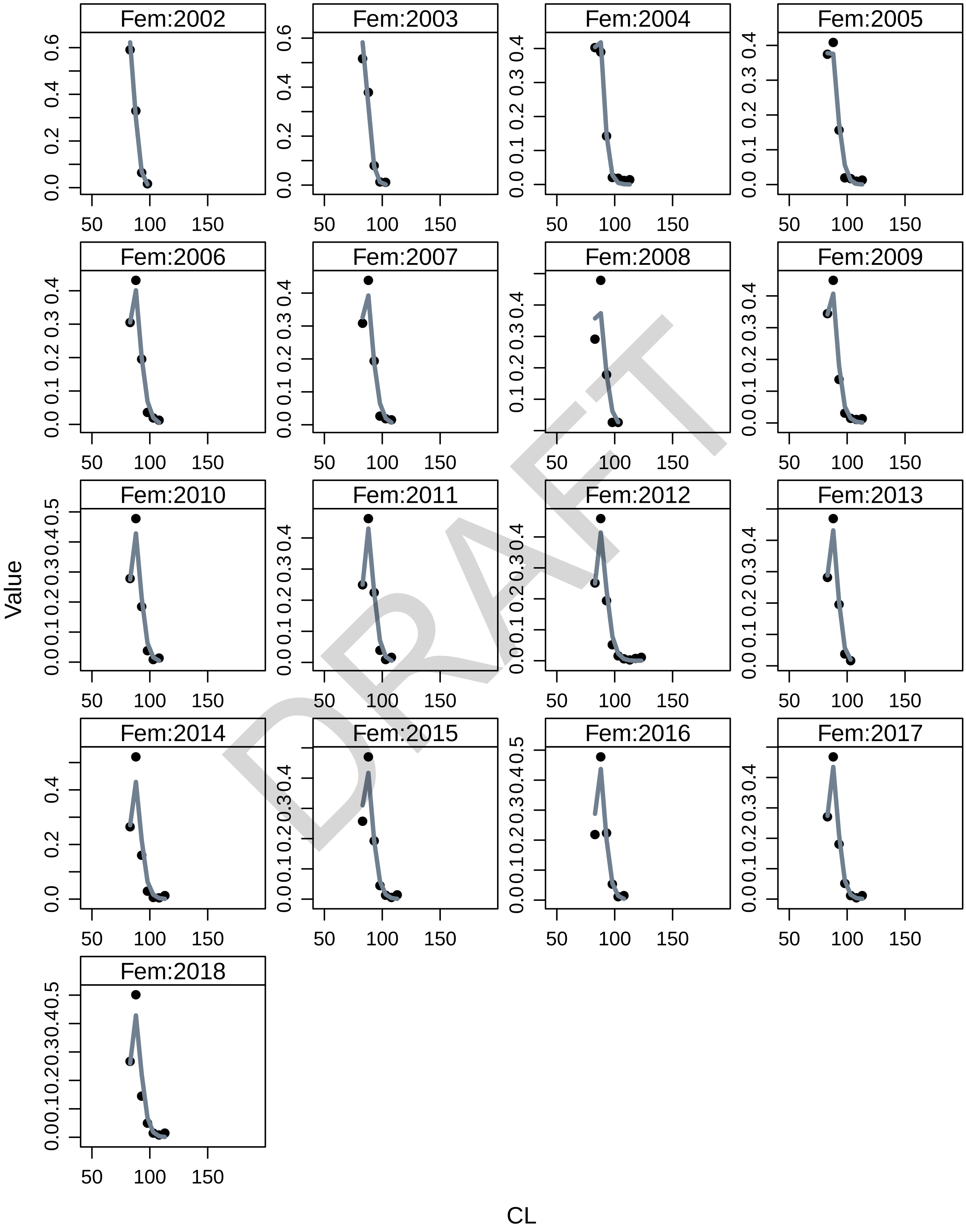
SNE_6F6_2019_orig_select
Comm Q2 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

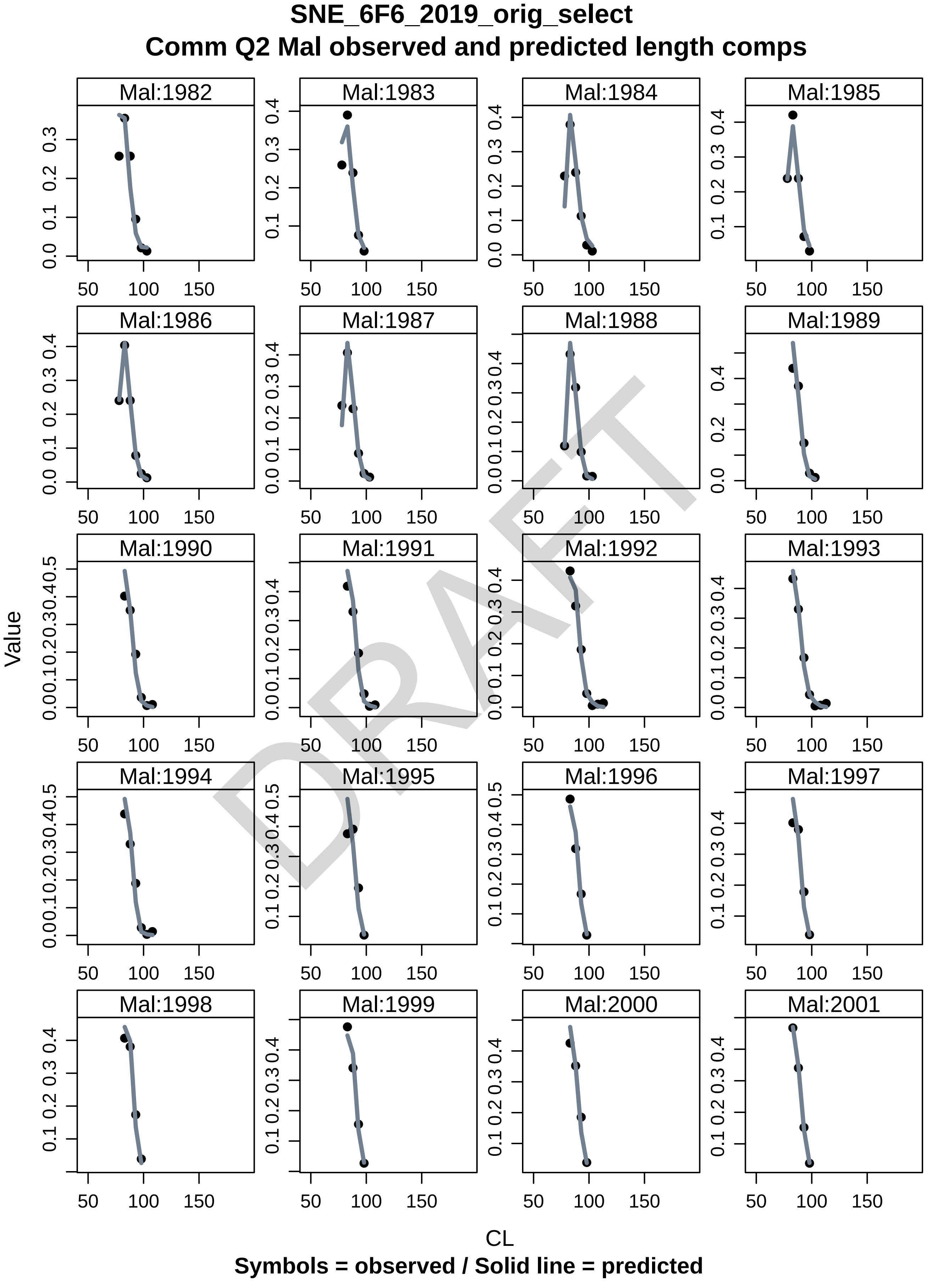
DRAFT

SNE_6F6_2019_orig_select
Comm Q2 Fem observed and predicted length comps



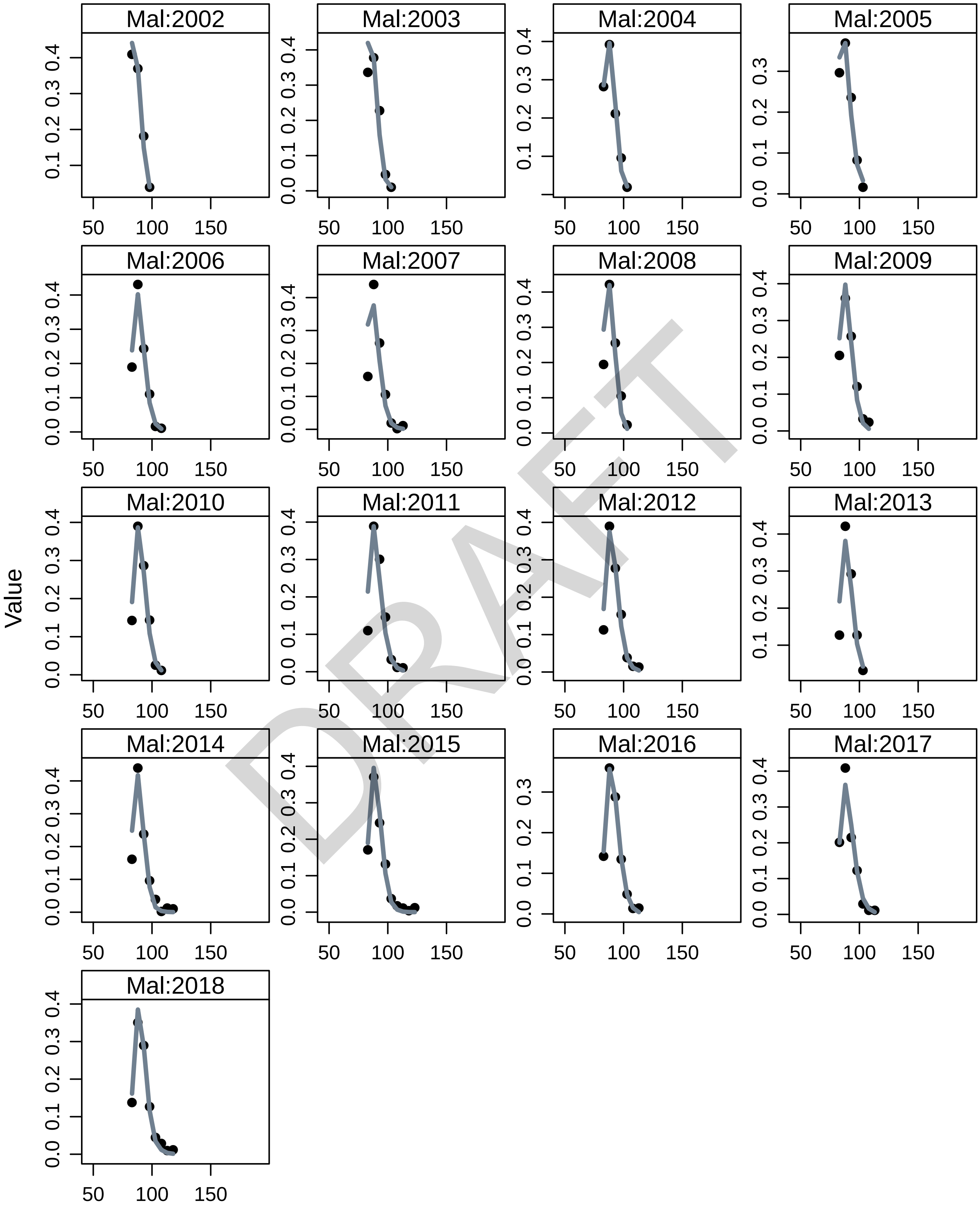
Symbols = observed / Solid line = predicted

DRAFT


SNE_6F6_2019_orig_select
Comm Q2 Mal observed and predicted length comps
Mal:1982
Mal:1983
Mal:1984
Mal:1985
Mal:1986
Mal:1987
Mal:1988
Mal:1989
Mal:1990
Mal:1991
Mal:1992
Mal:1993
Mal:1994
Mal:1995
Mal:1996
Mal:1997
Mal:1998
Mal:1999
Mal:2000
Mal:2001
Value
CL
50
100
150
0.0
0.1
0.2
0.3
0.4
0.5
Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
Comm Q2 Mal observed and predicted length comps

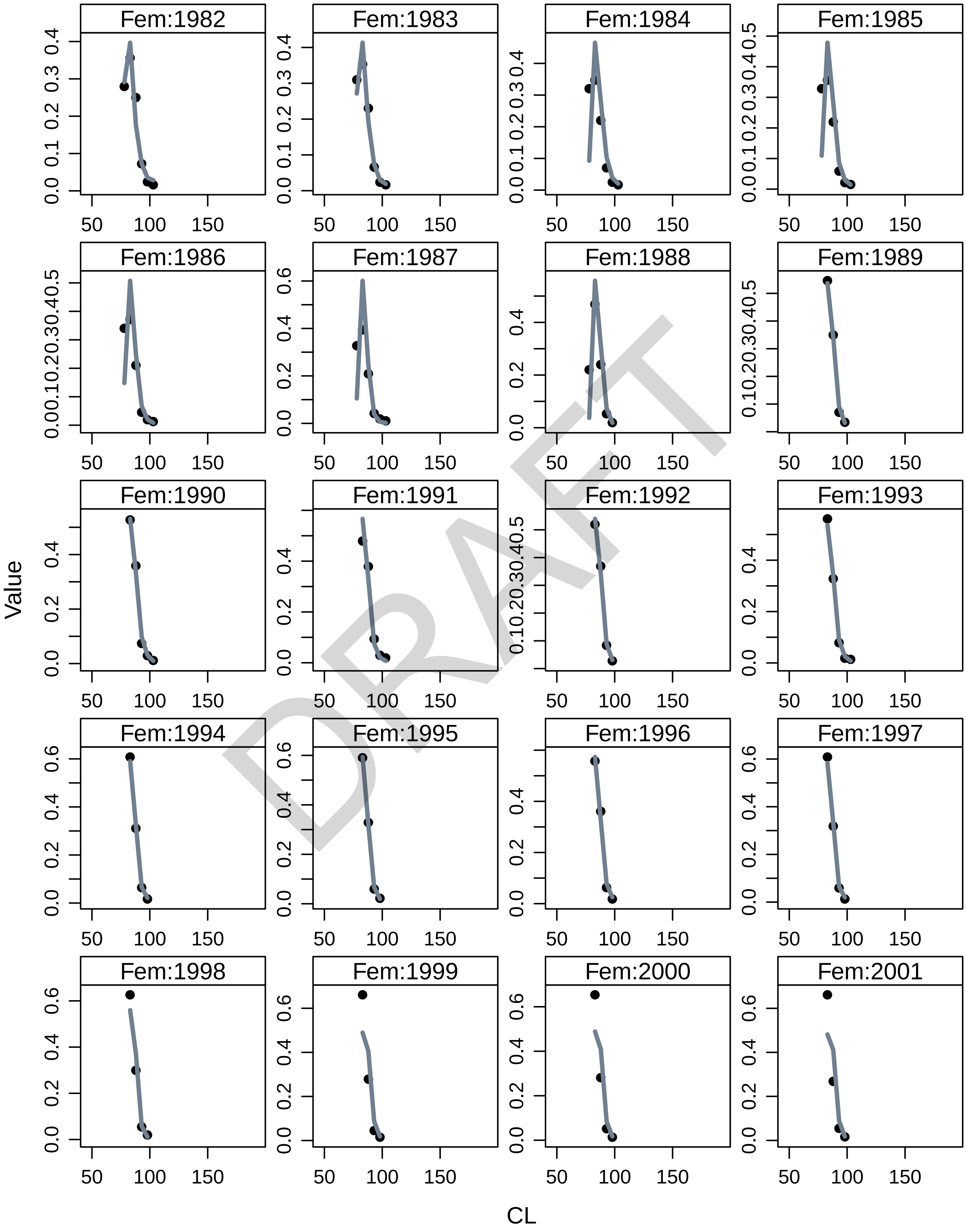


CL

Symbols = observed / Solid line = predicted

DRAFT

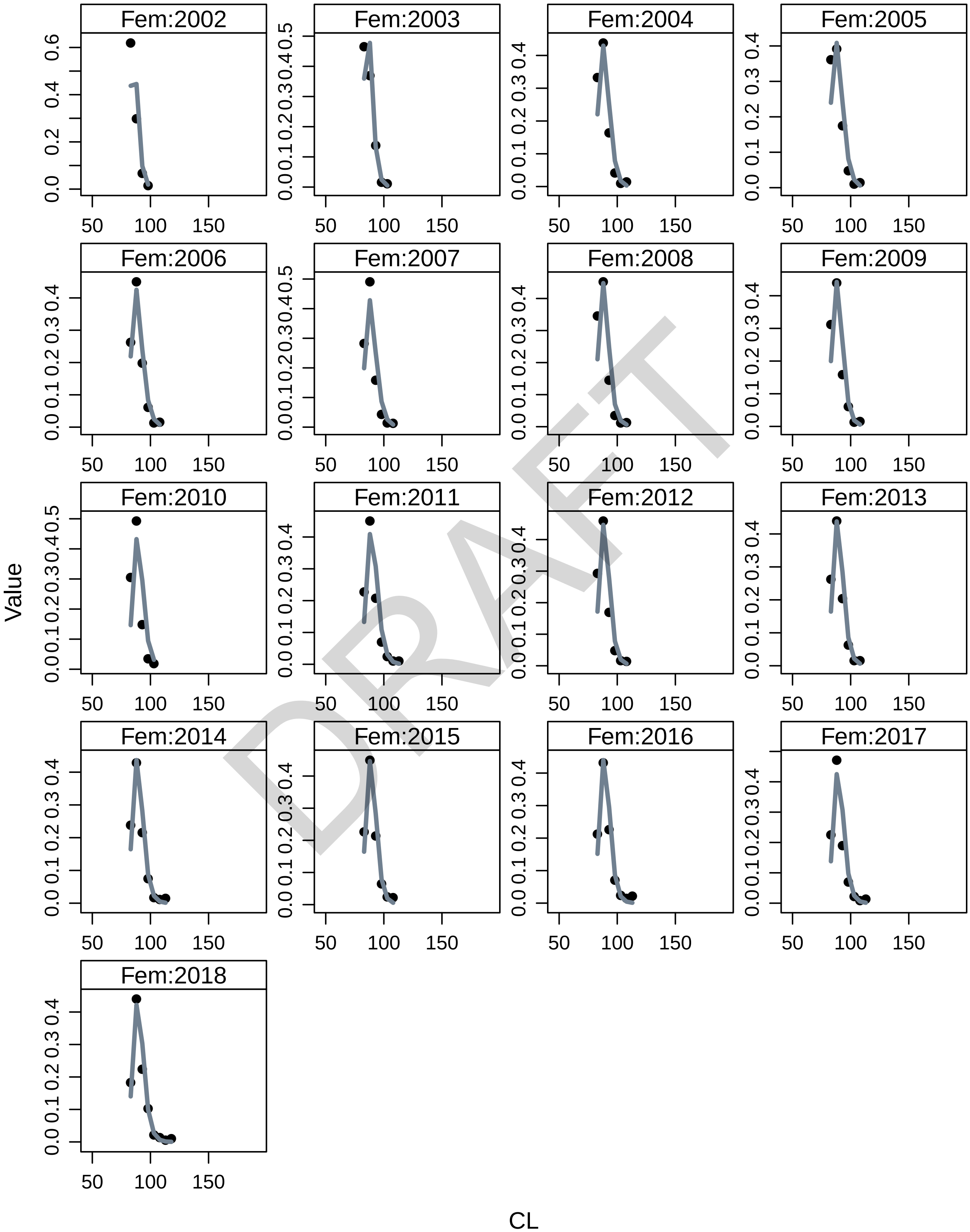
SNE_6F6_2019_orig_select
Comm Q3 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

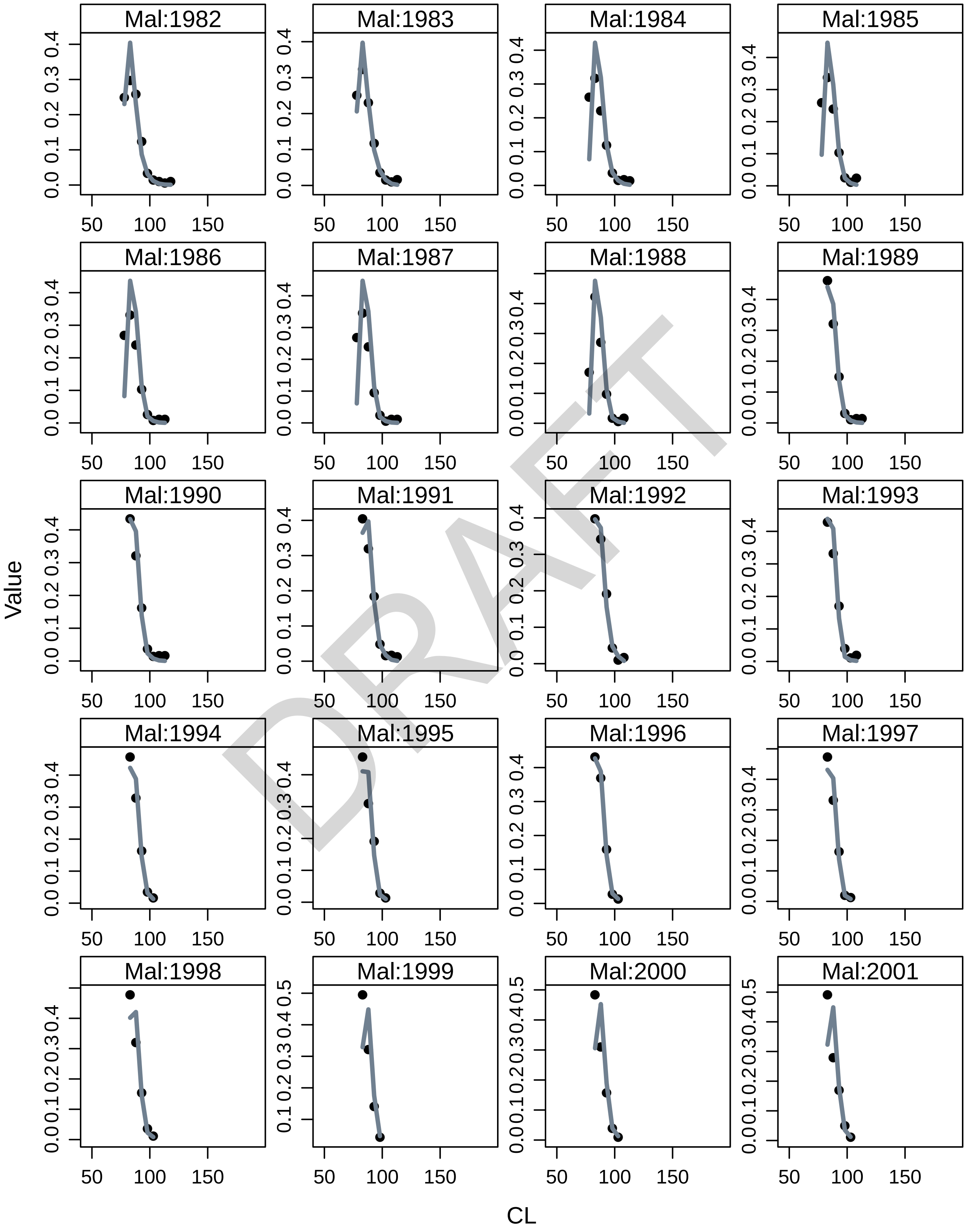
SNE_6F6_2019_orig_select
Comm Q3 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

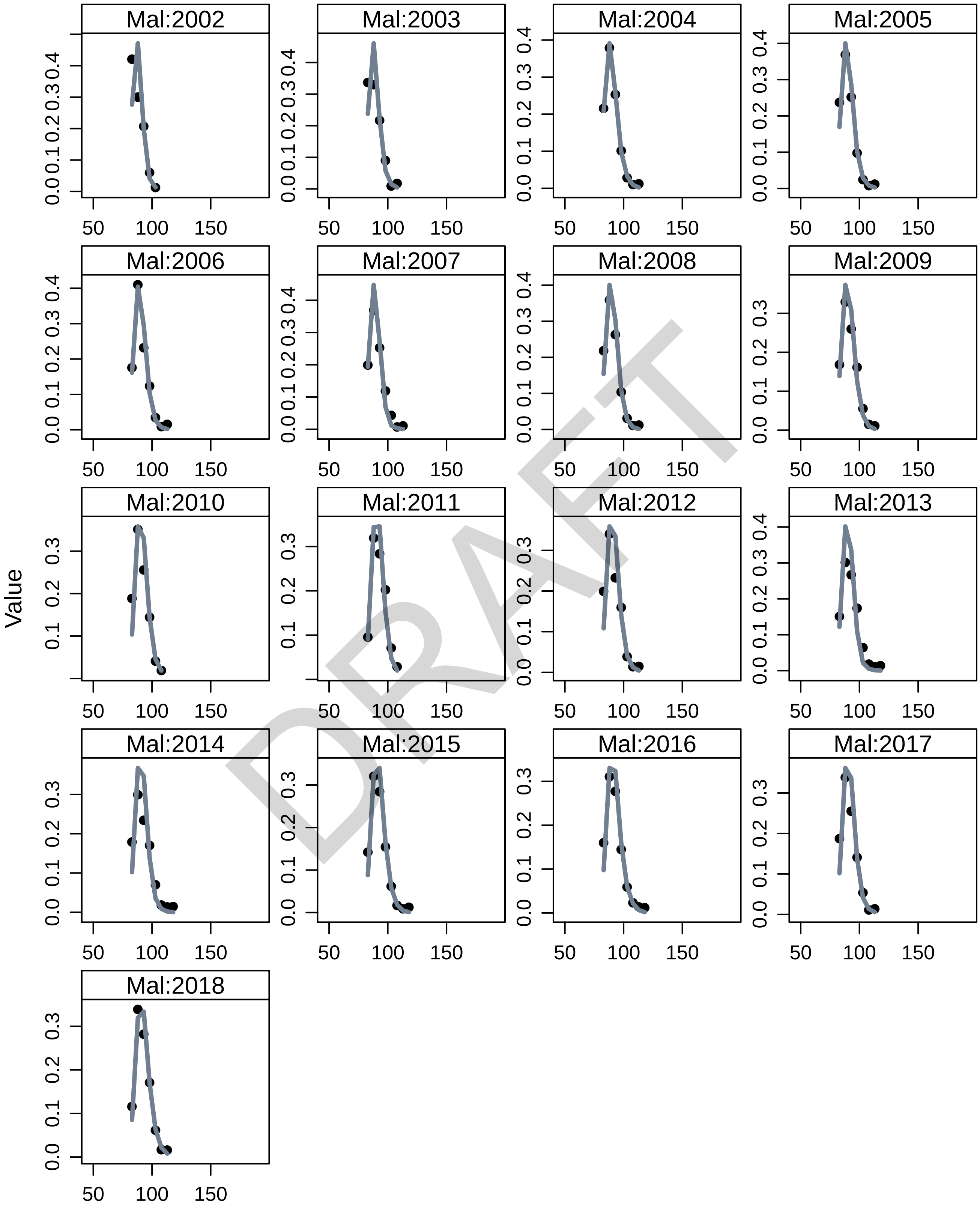
SNE_6F6_2019_orig_select
Comm Q3 Mal observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

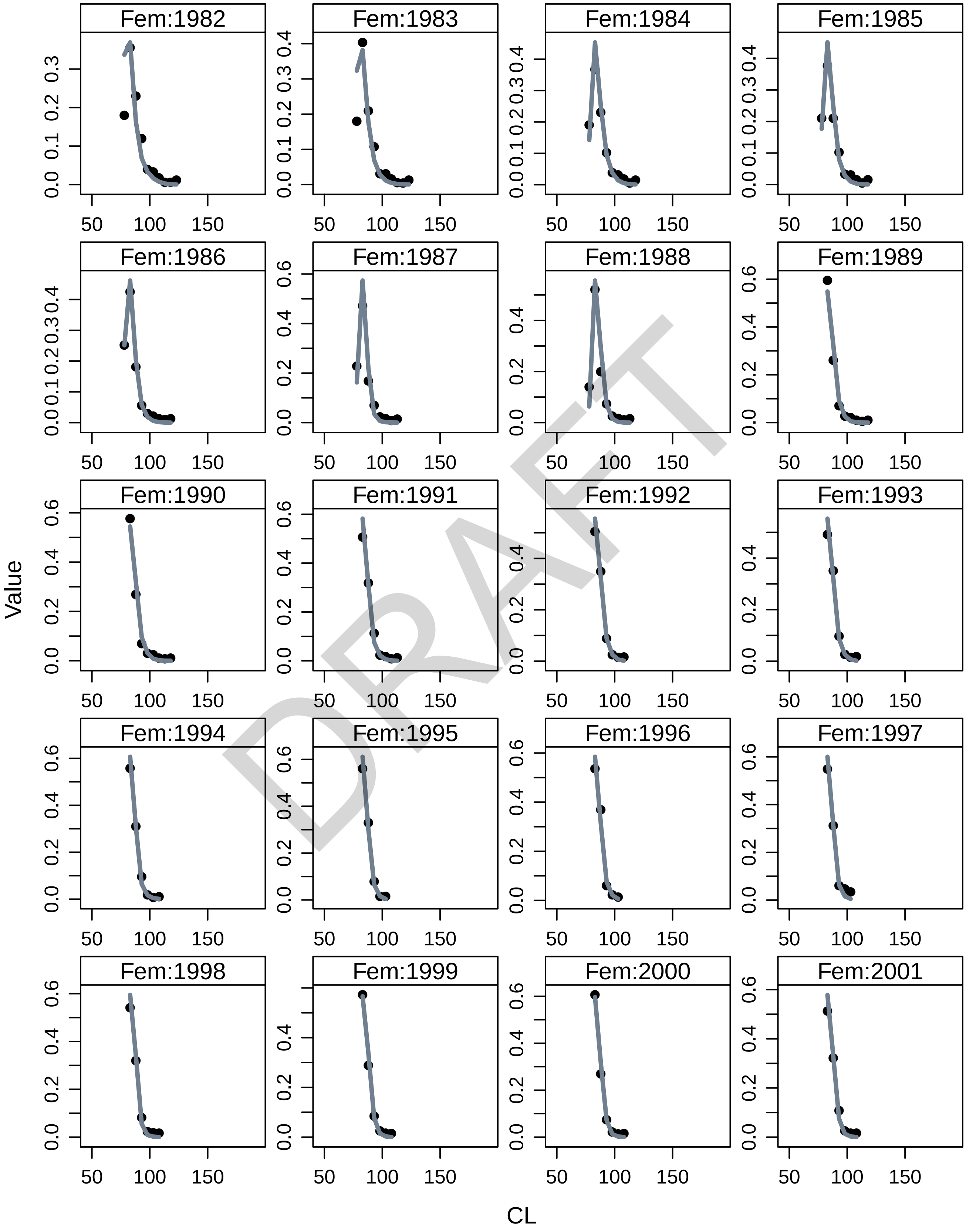
SNE_6F6_2019_orig_select
Comm Q3 Mal observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

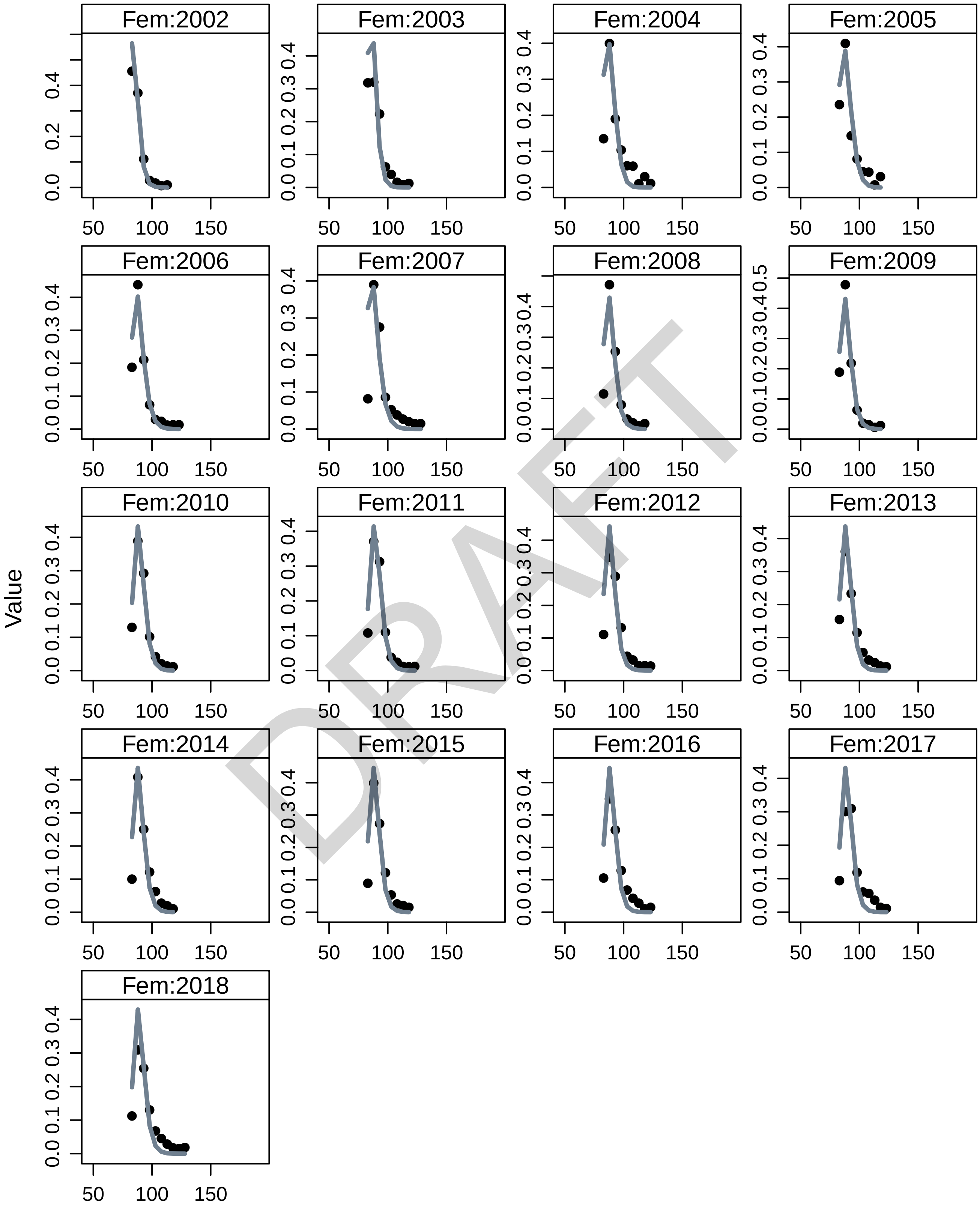
SNE_6F6_2019_orig_select
Comm Q4 Fem observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
Comm Q4 Fem observed and predicted length comps

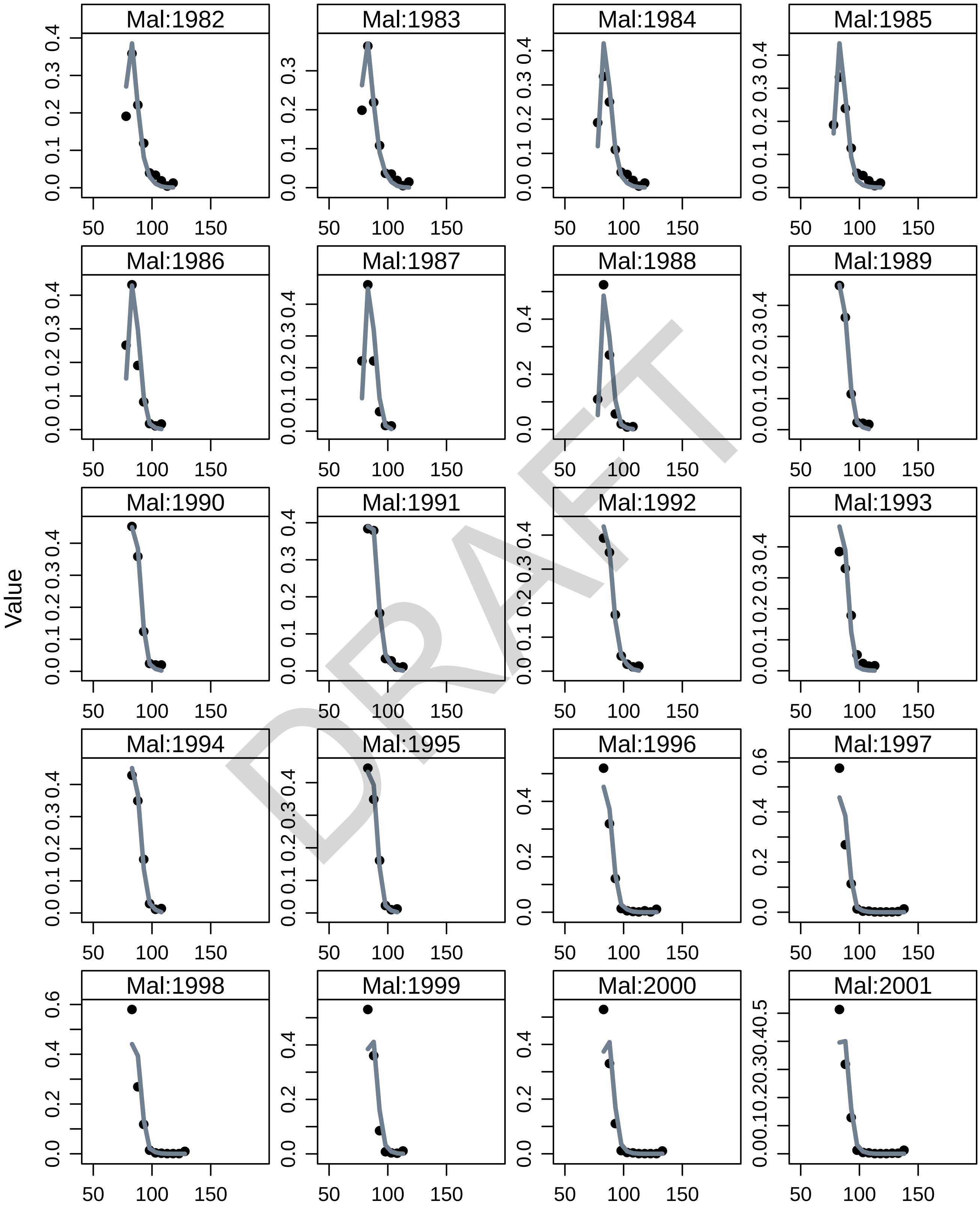


CL

Symbols = observed / Solid line = predicted

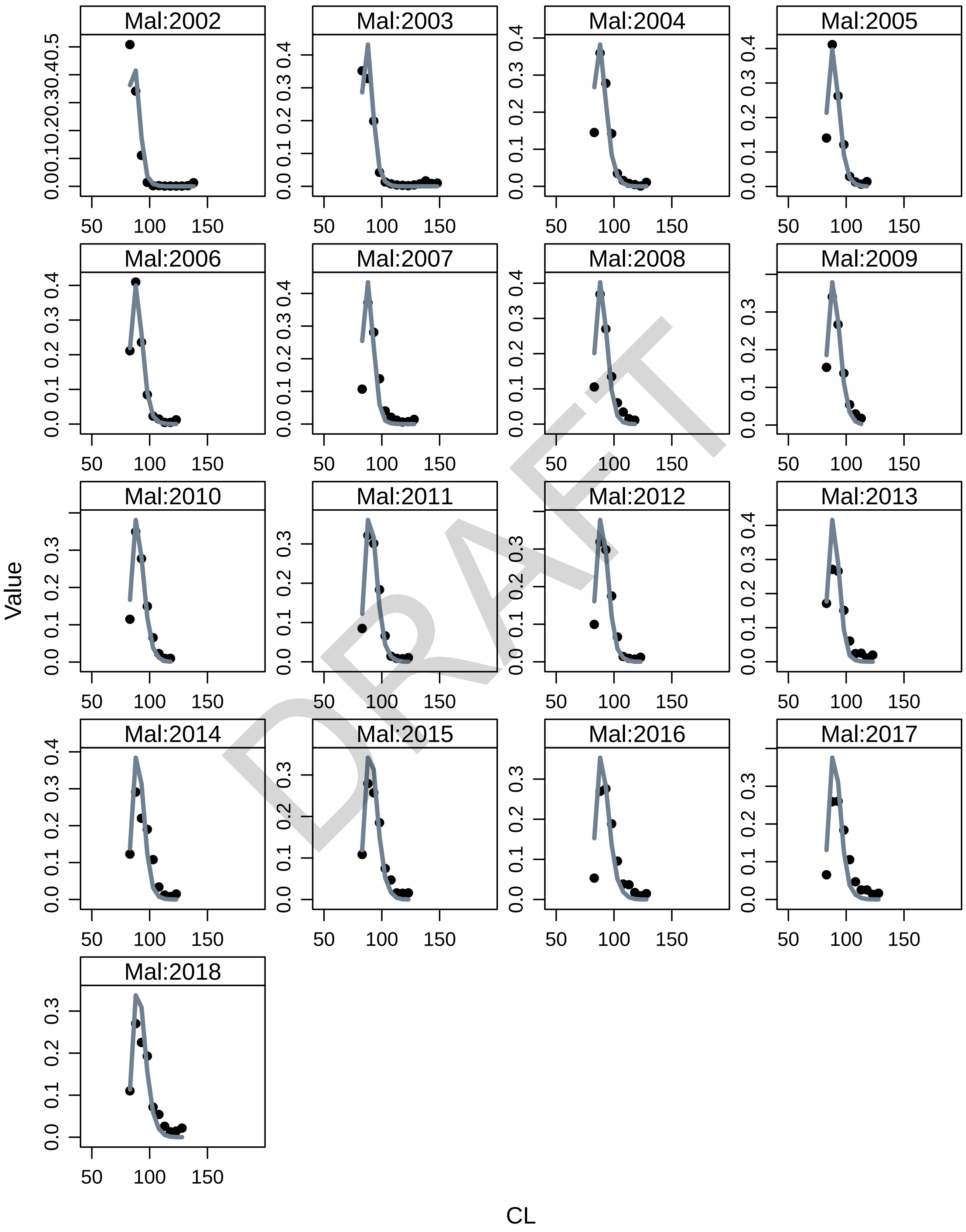
DRAFT

SNE_6F6_2019_orig_select
Comm Q4 Mal observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

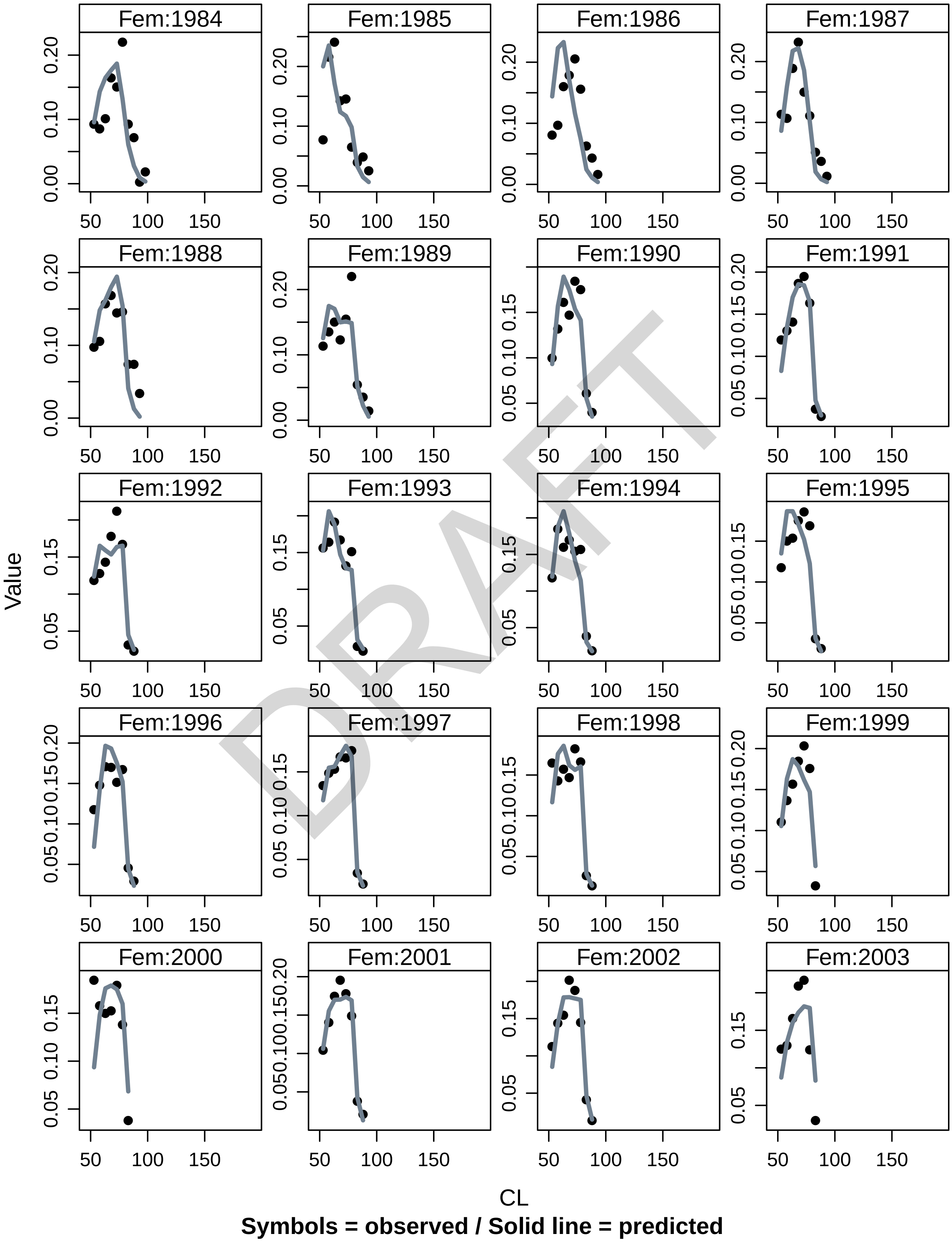


SNE_6F6_2019_orig_select
Comm Q4 Mal observed and predicted length comps

Symbols = observed / Solid line = predicted

DRAFT

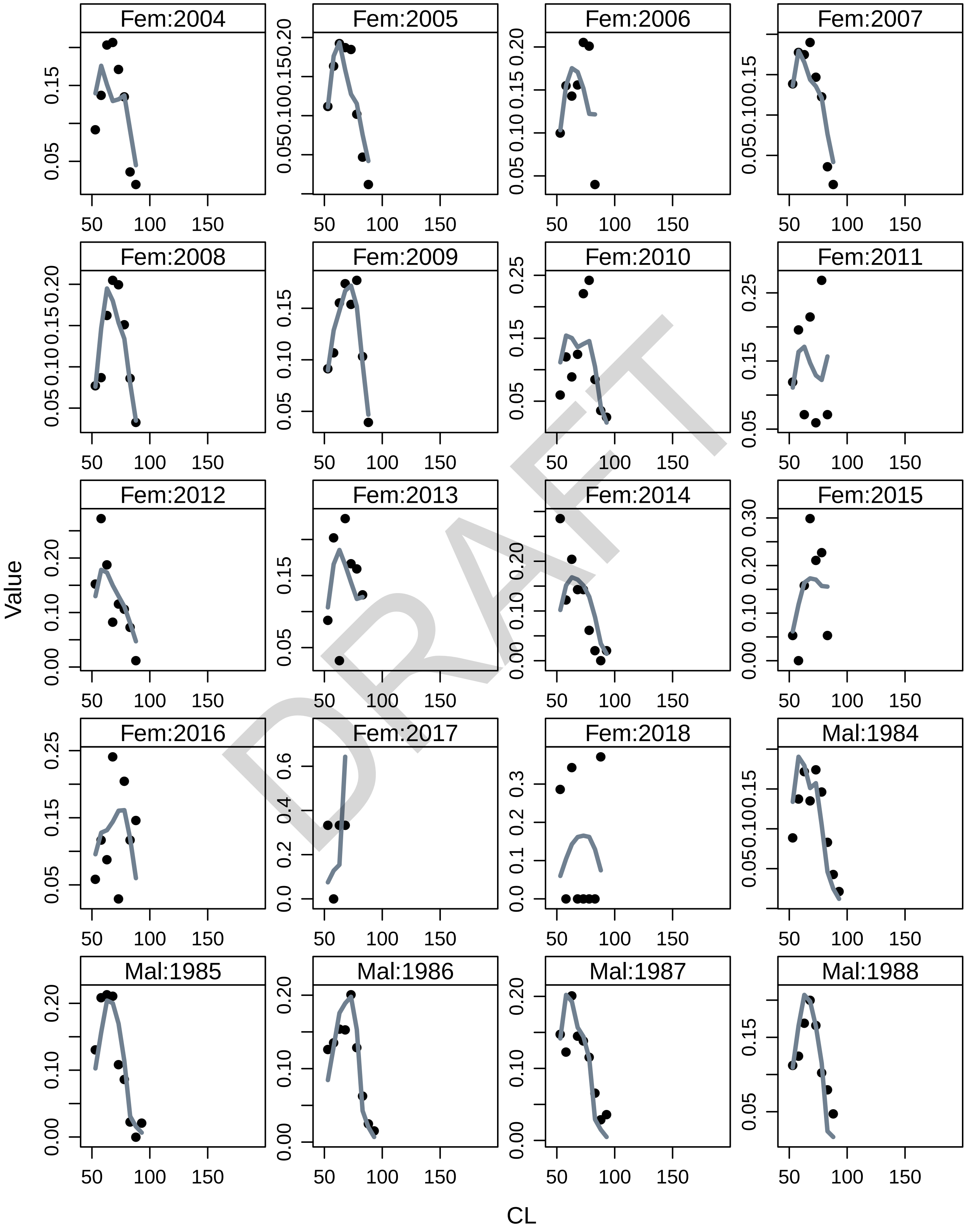
SNE_6F6_2019_orig_select
CTQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

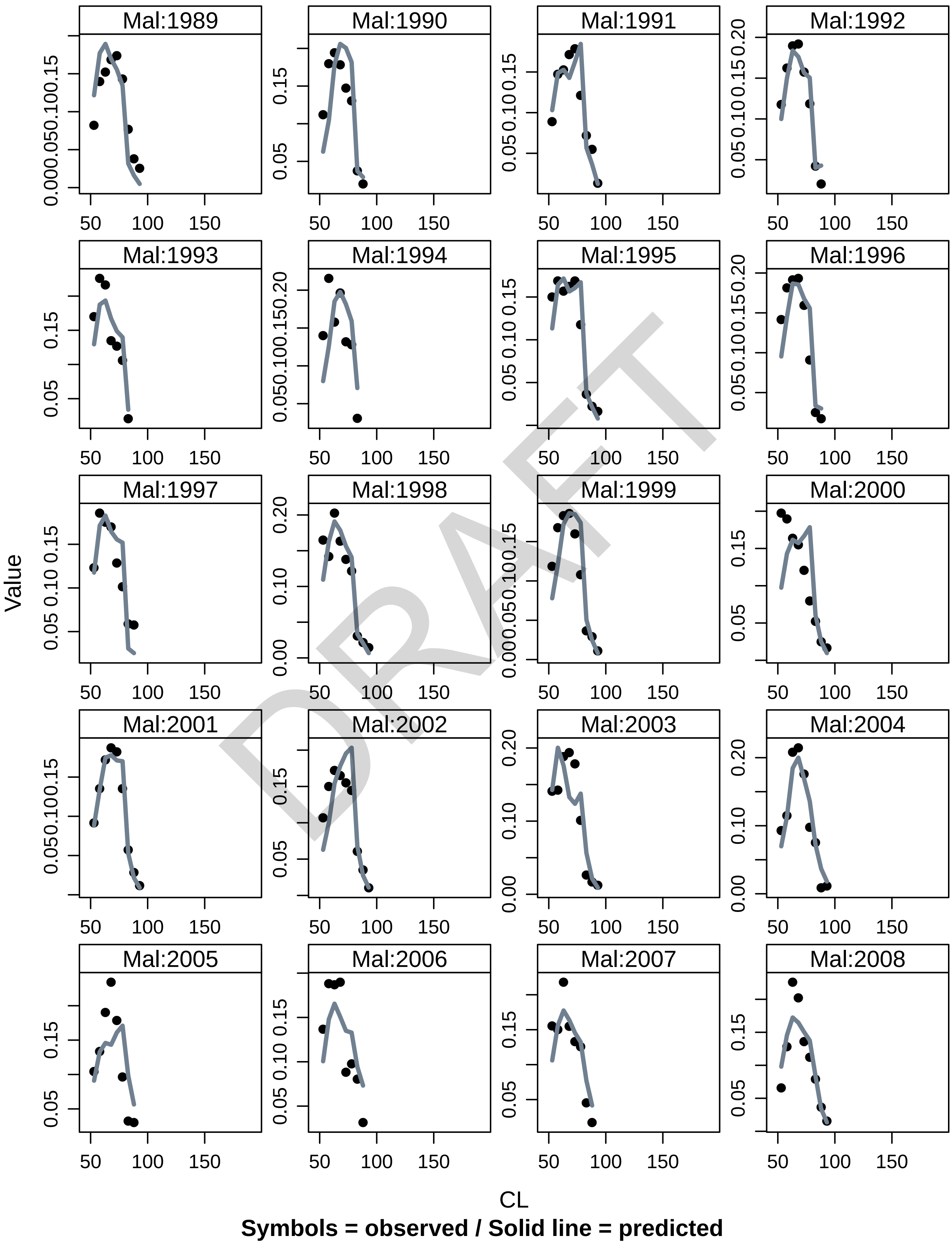
SNE_6F6_2019_orig_select
CTQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

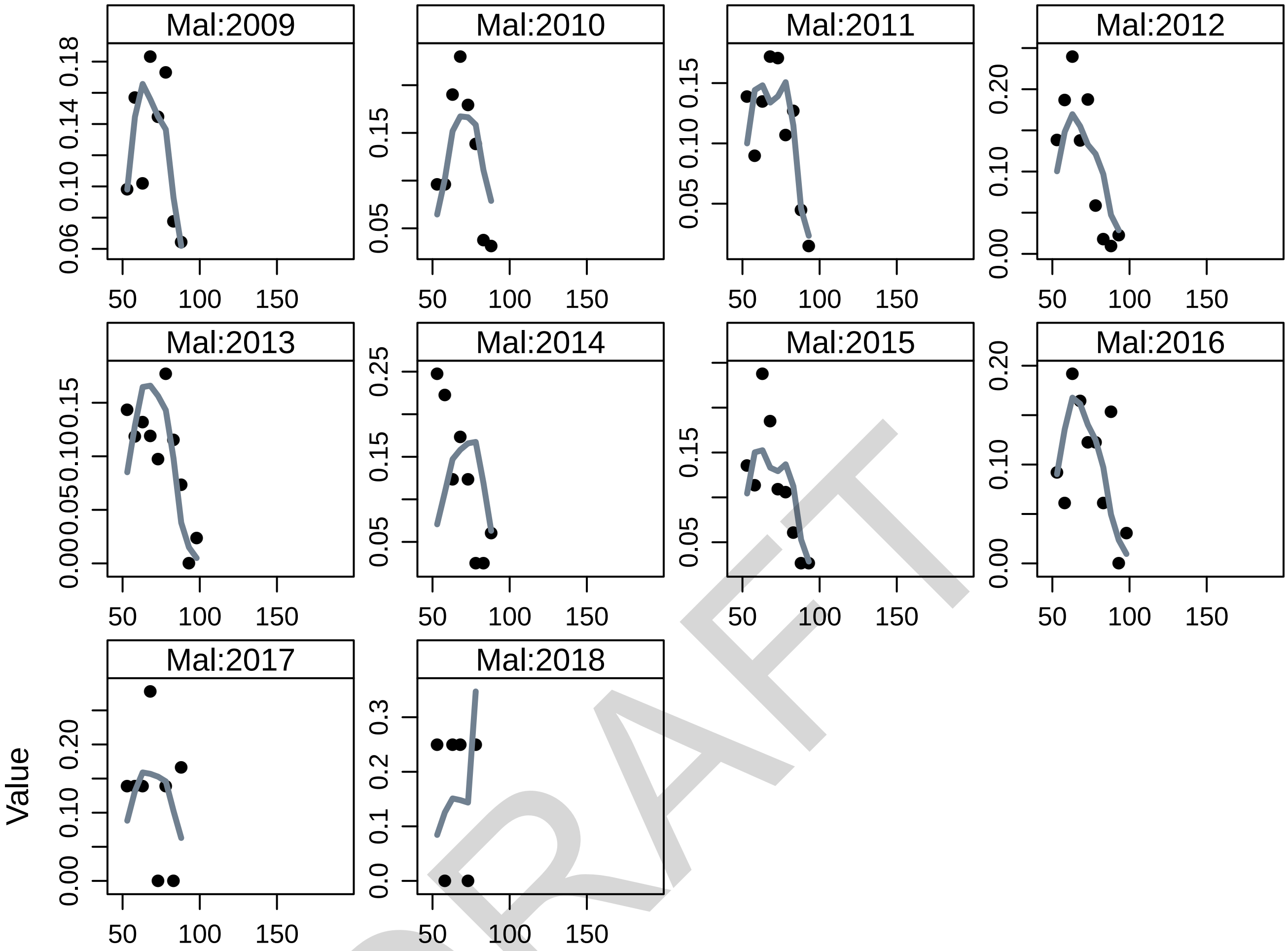
SNE_6F6_2019_orig_select
CTQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
CTQ2 observed and predicted length comps

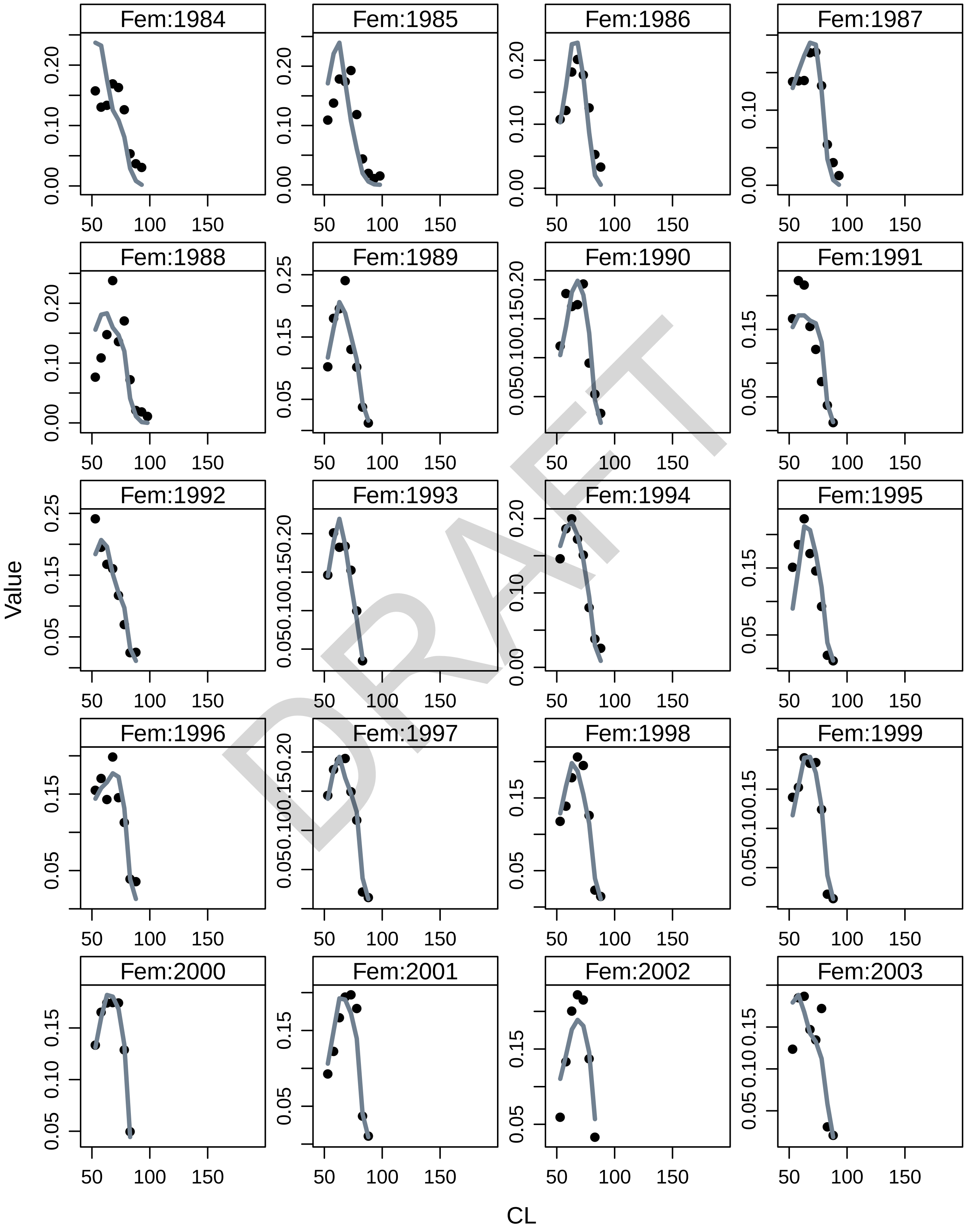


DRAFT

CL

Symbols = observed / Solid line = predicted

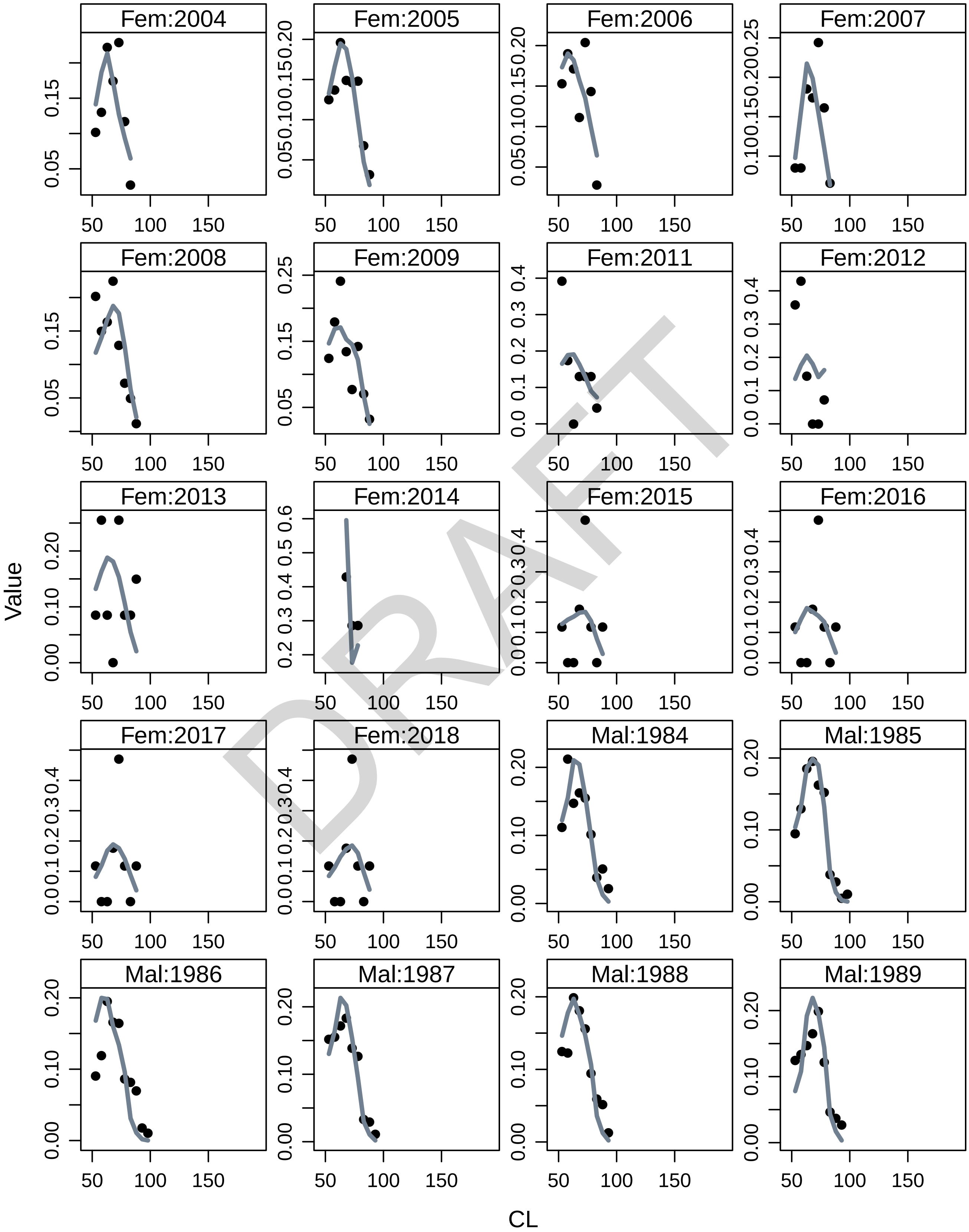
SNE_6F6_2019_orig_select
CTQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

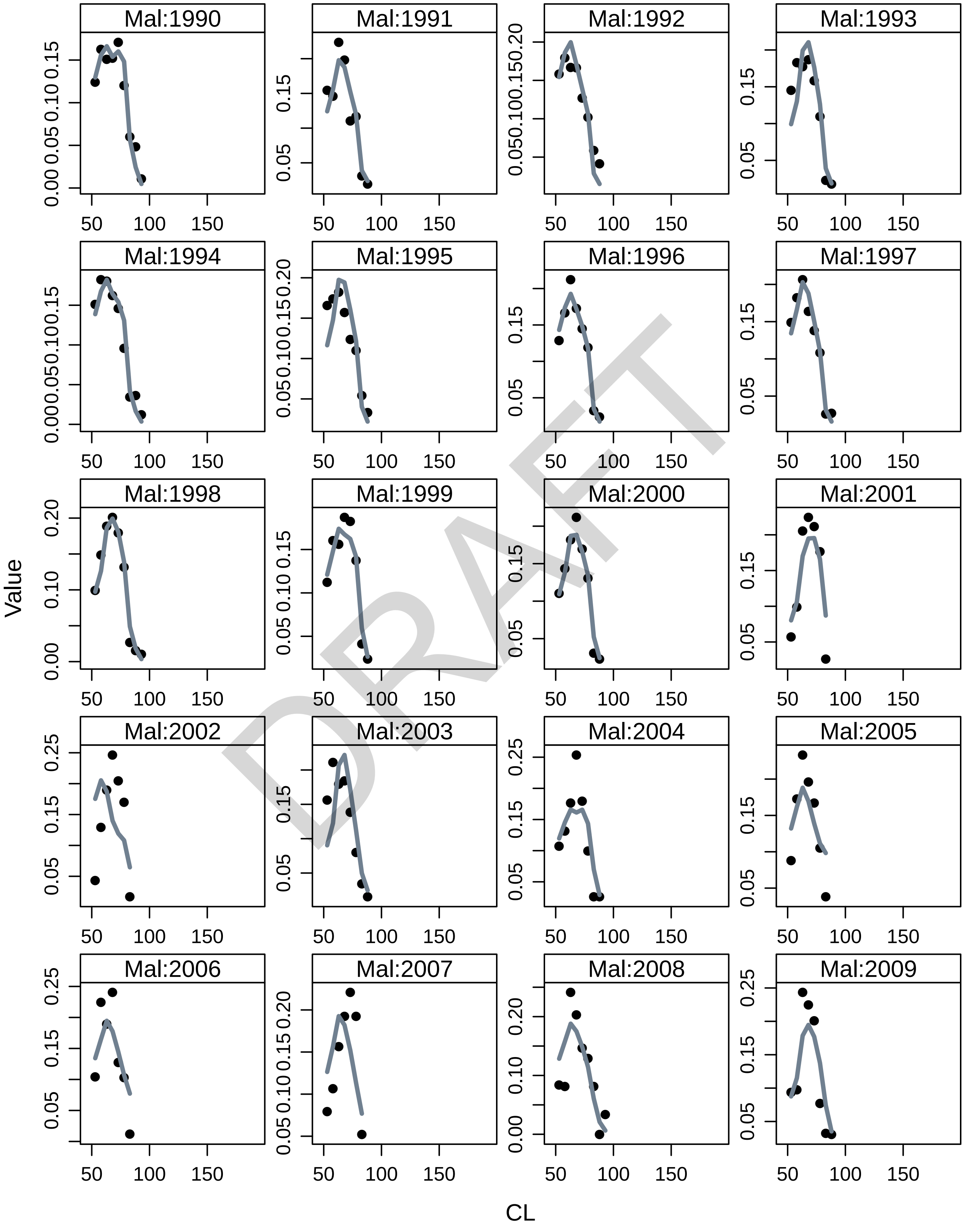
SNE_6F6_2019_orig_select
CTQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

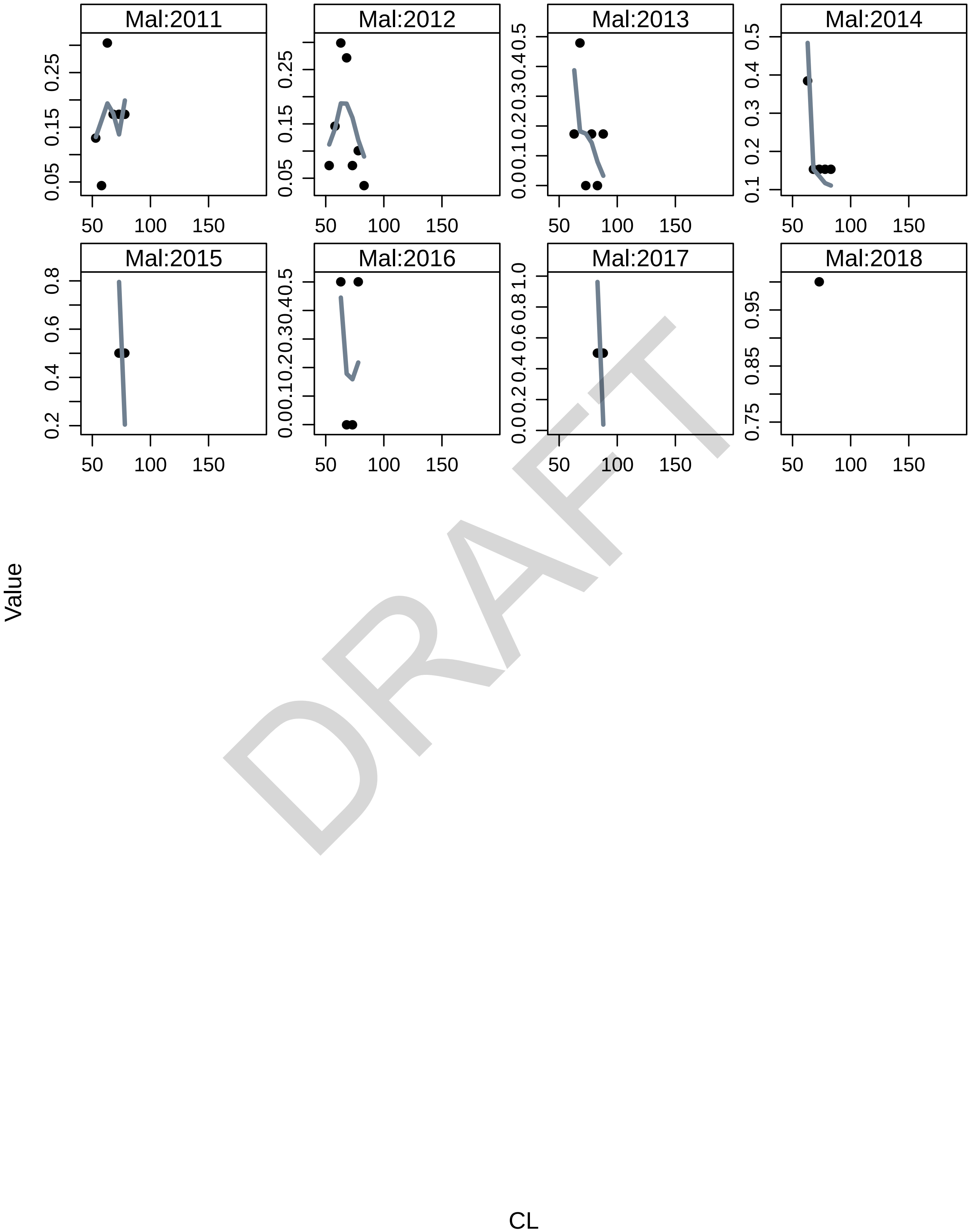
SNE_6F6_2019_orig_select
CTQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

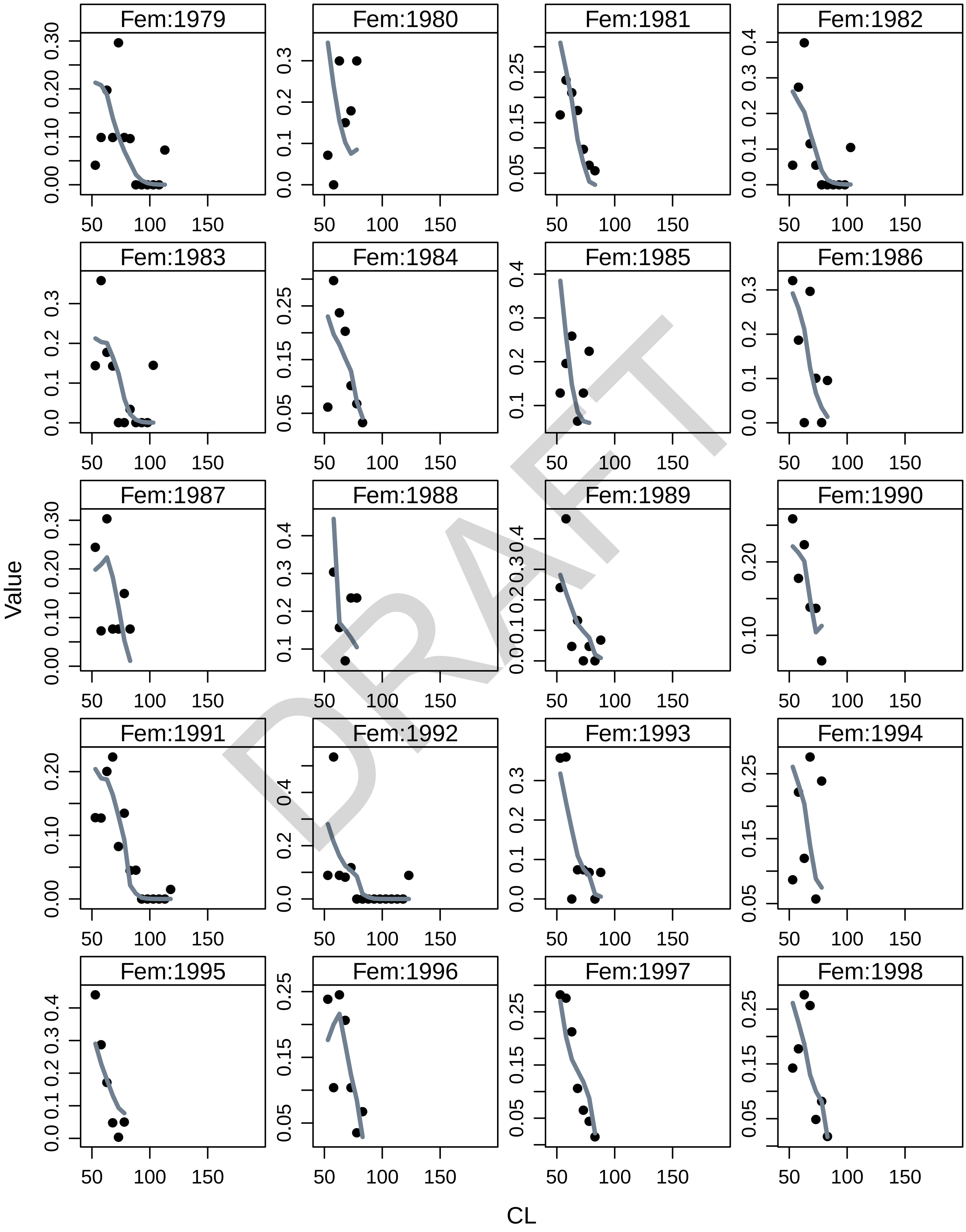
SNE_6F6_2019_orig_select
CTQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

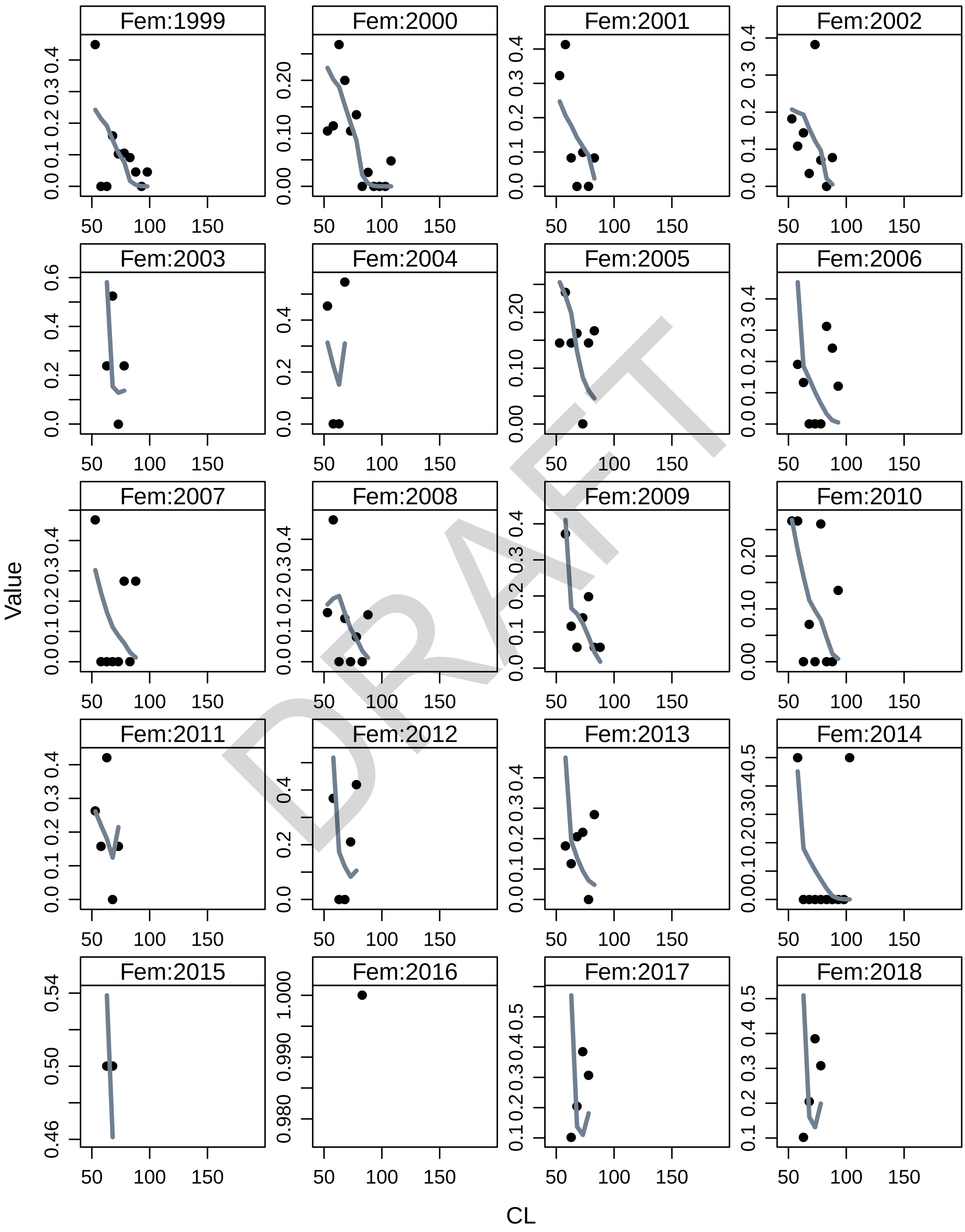
SNE_6F6_2019_orig_select
MAQ2 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

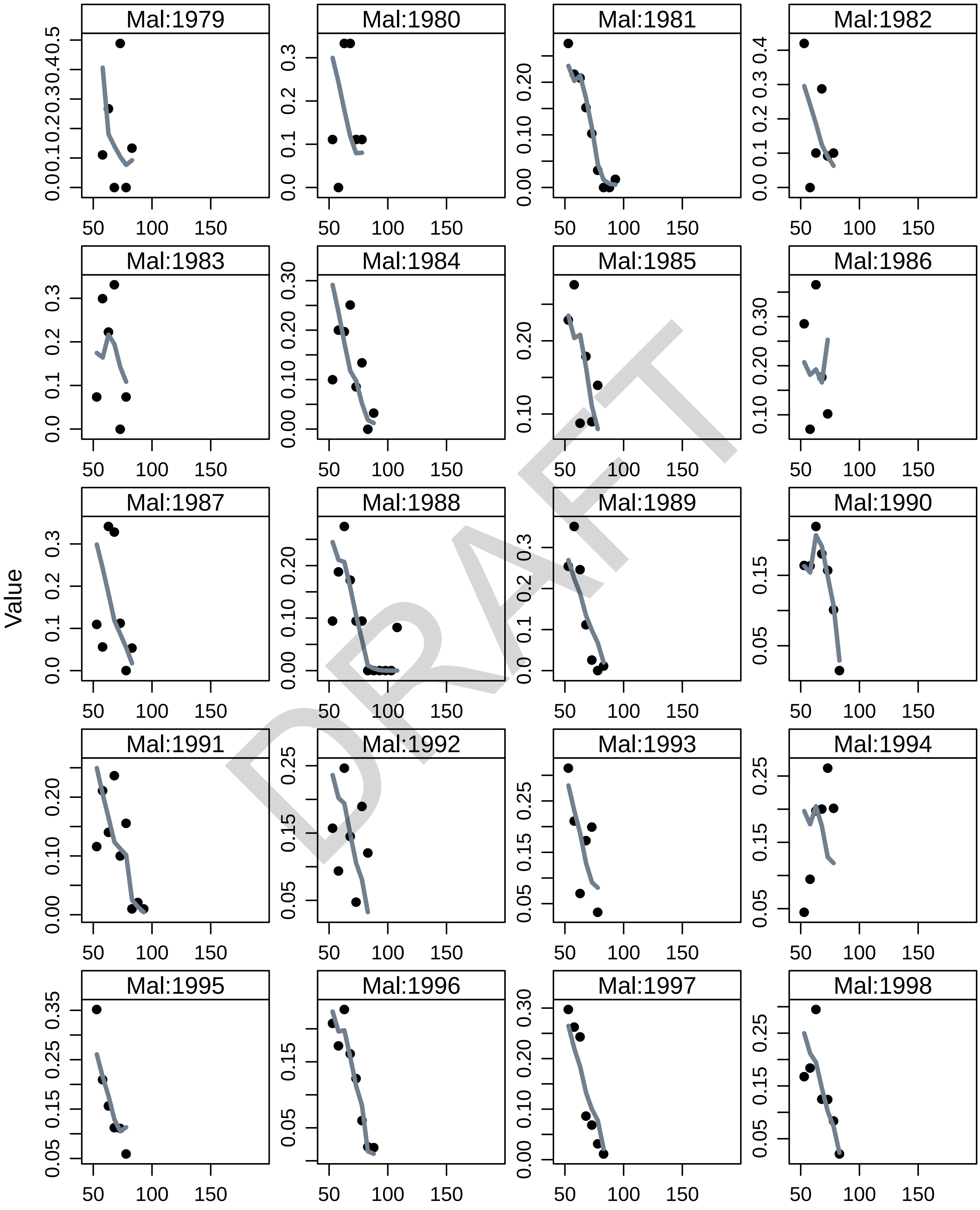
SNE_6F6_2019_orig_select
MAQ2 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

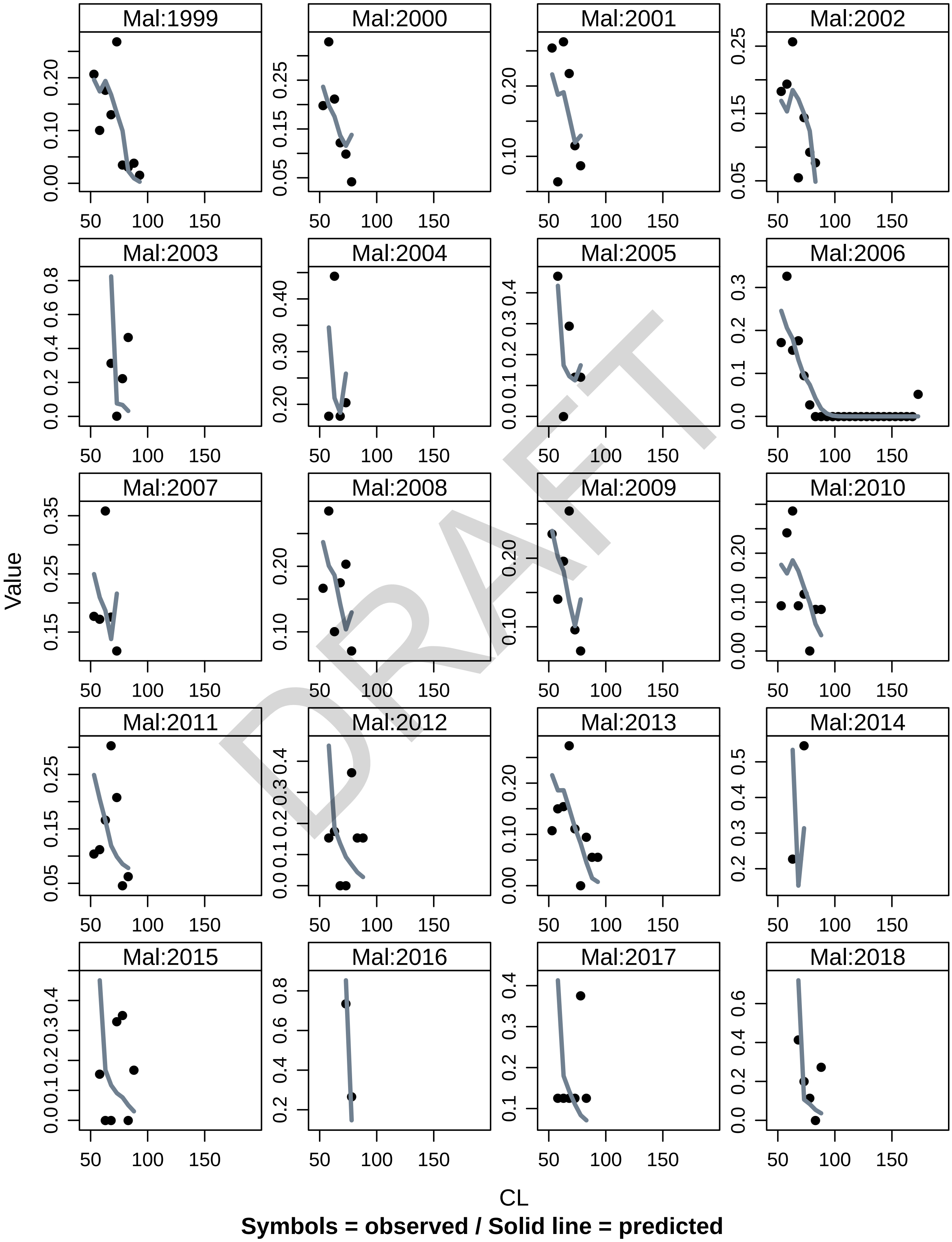
SNE_6F6_2019_orig_select
MAQ2 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

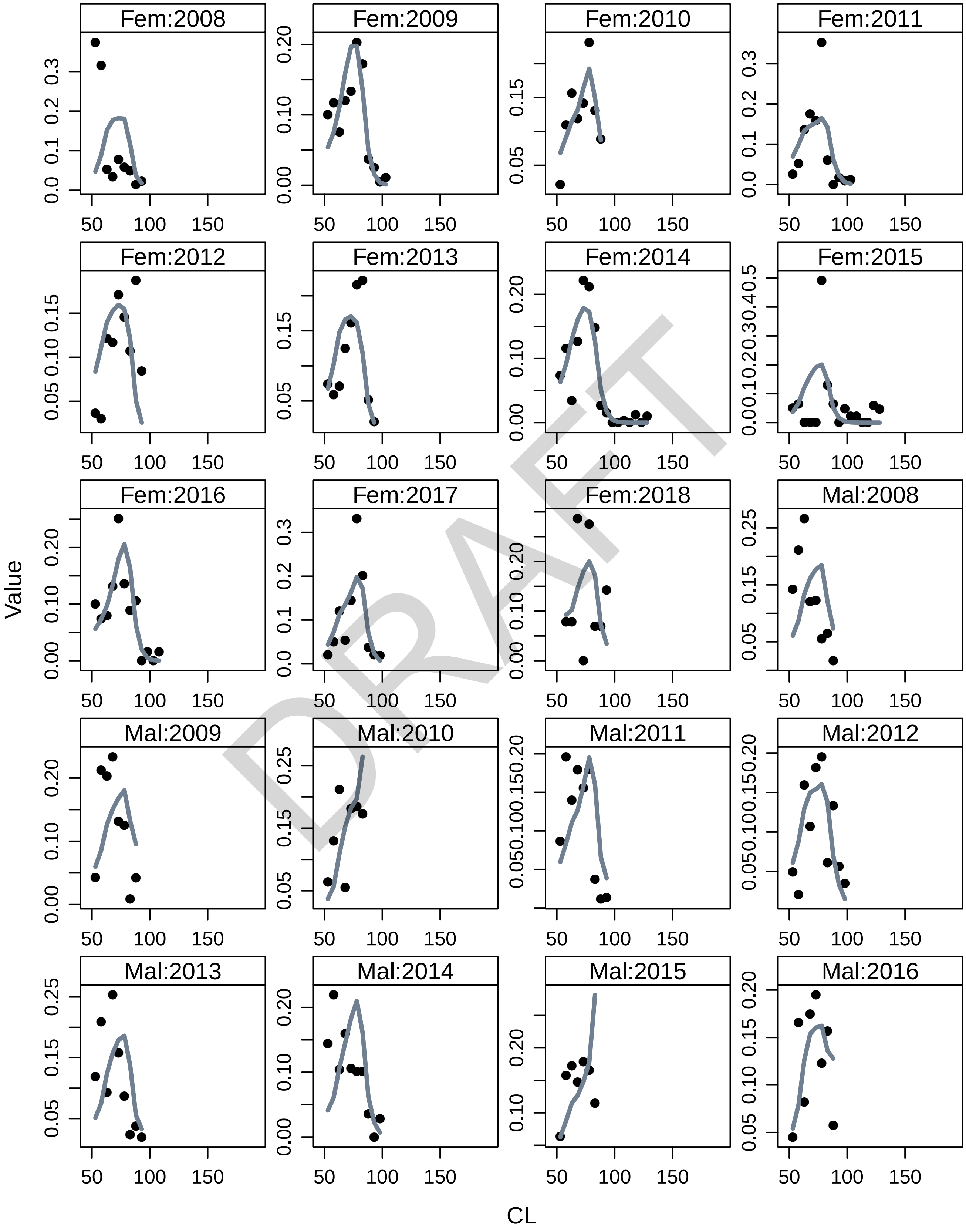
SNE_6F6_2019_orig_select
MAQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

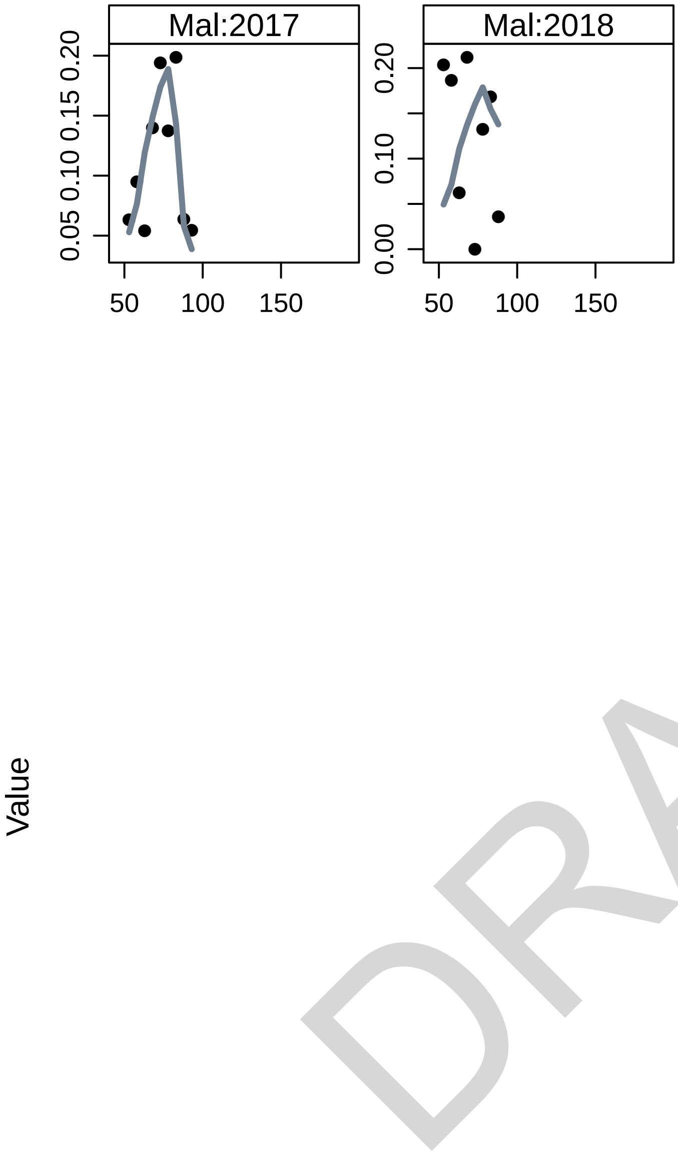
SNE_6F6_2019_orig_select
NEAMAPQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

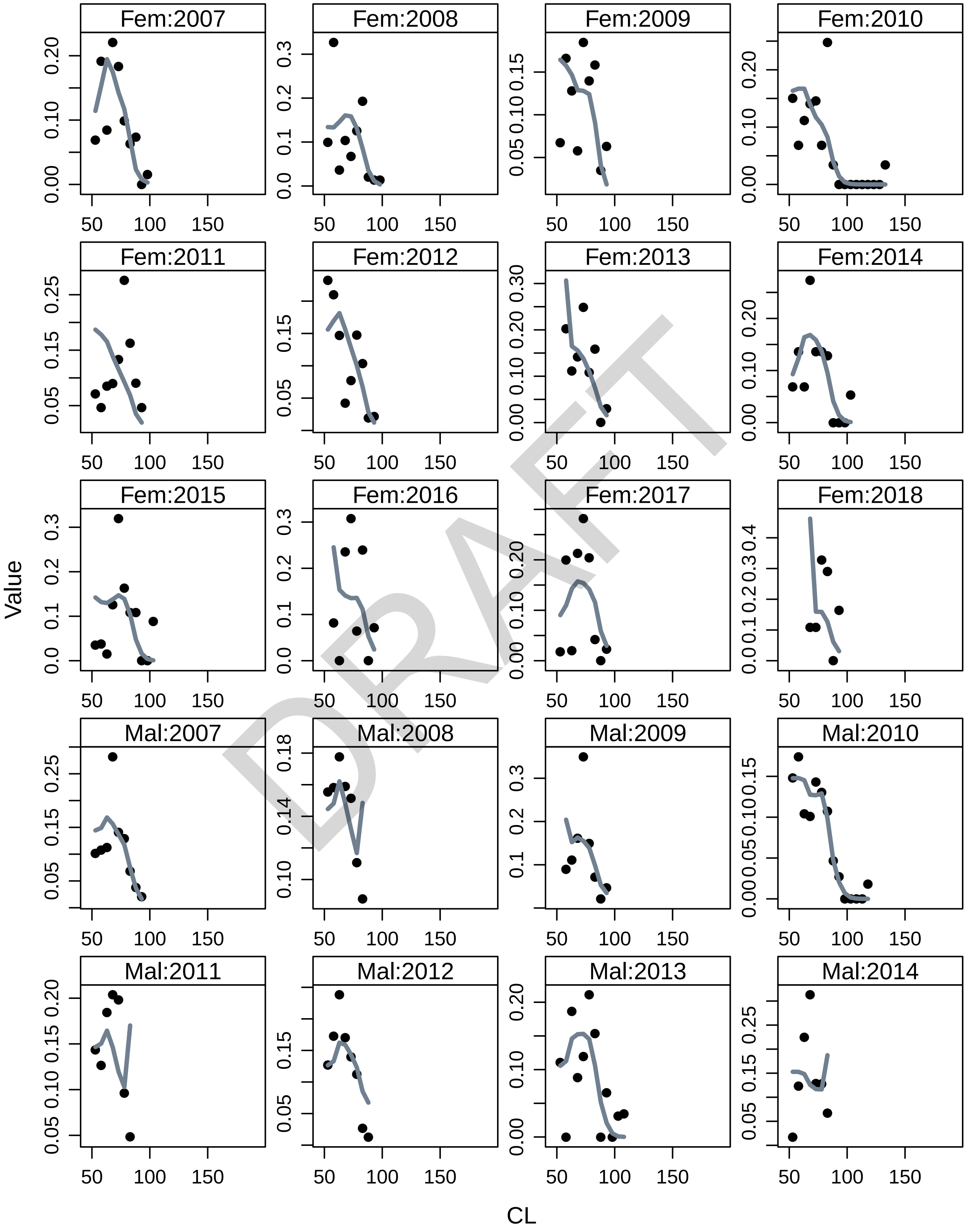
SNE_6F6_2019_orig_select
NEAMAPQ2 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

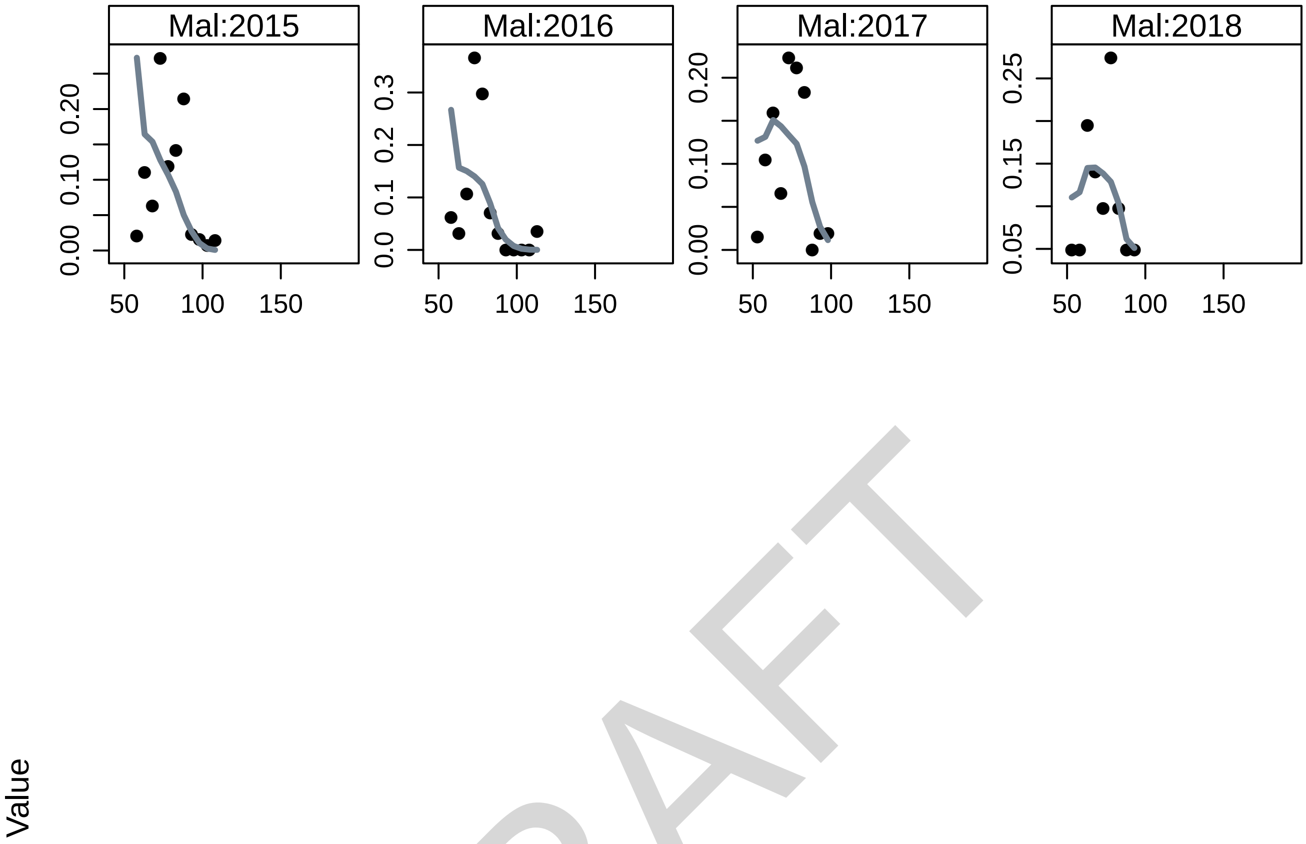
SNE_6F6_2019_orig_select
NEAMAPQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

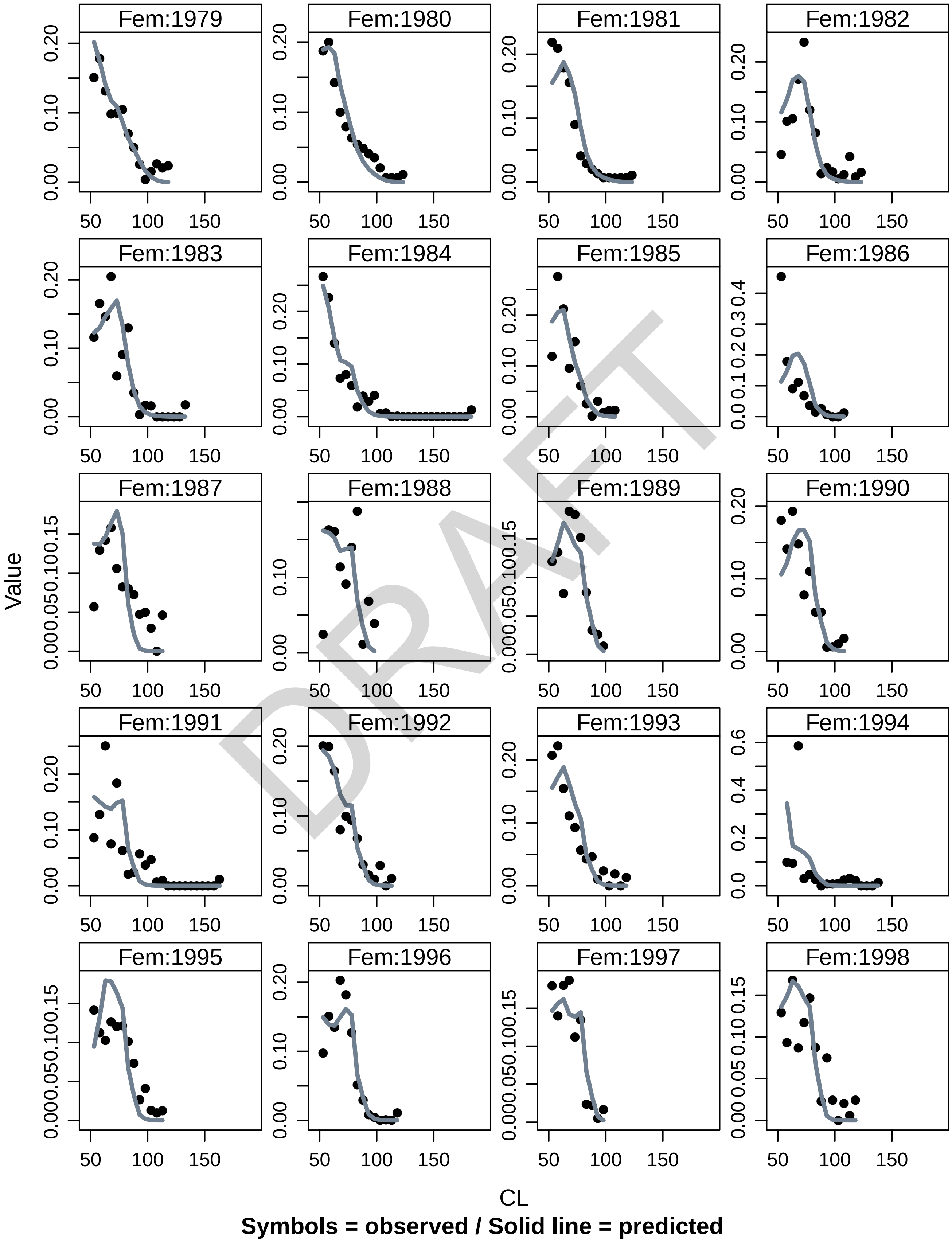
SNE_6F6_2019_orig_select
NEAMAPQ4 observed and predicted length comps



DRAFT

CL
Symbols = observed / Solid line = predicted

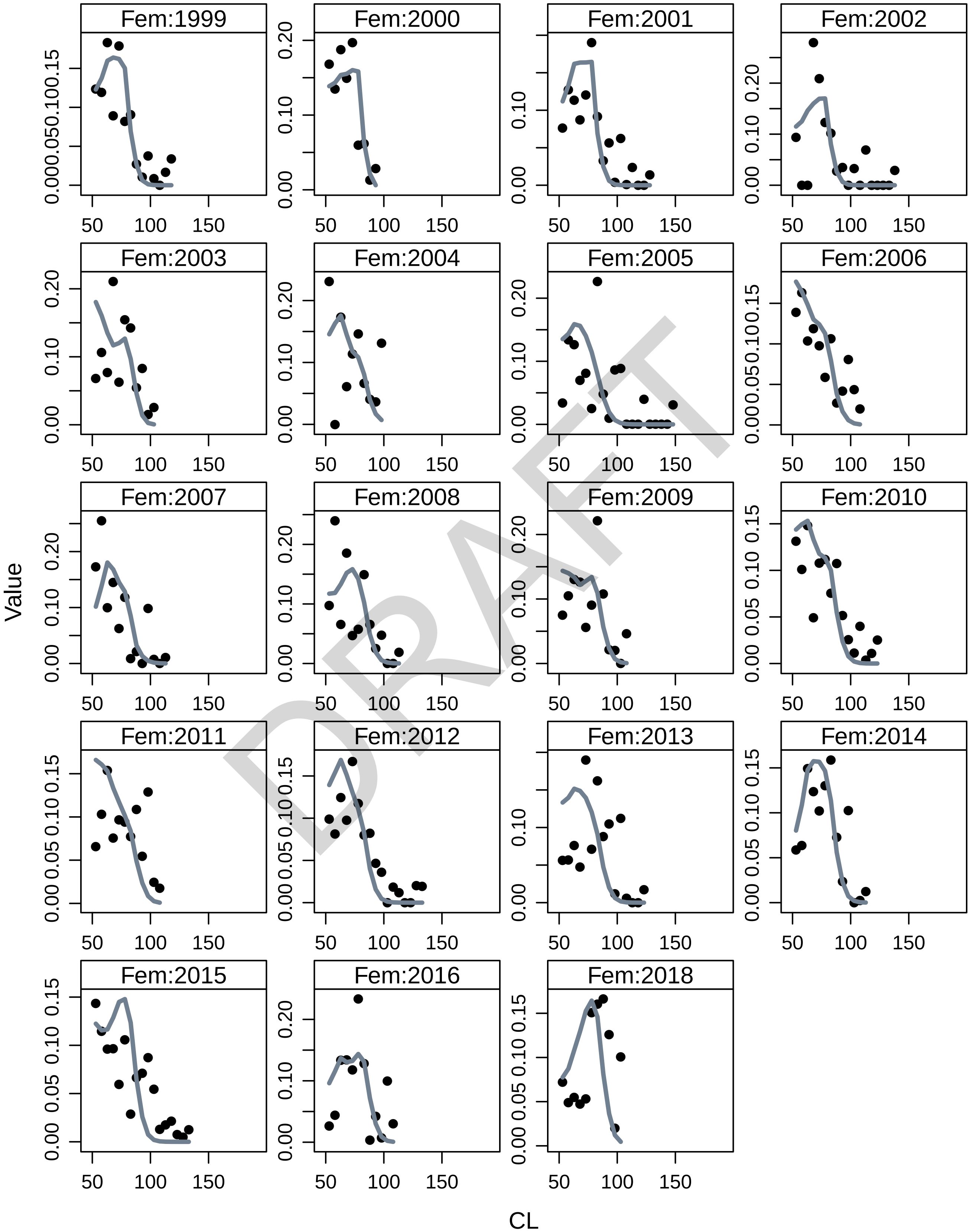
SNE_6F6_2019_orig_select
NfscFQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

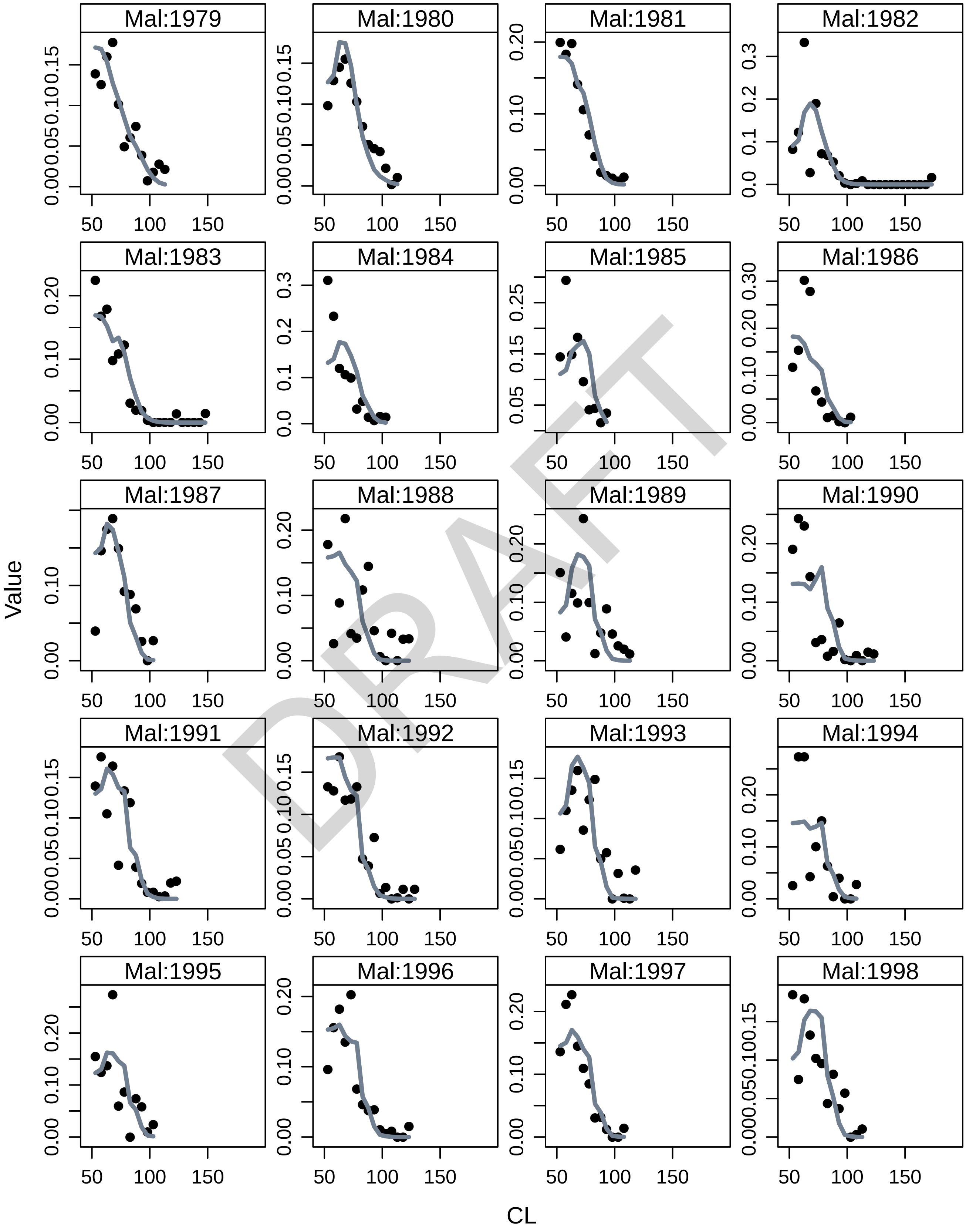
SNE_6F6_2019_orig_select
NfscFQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

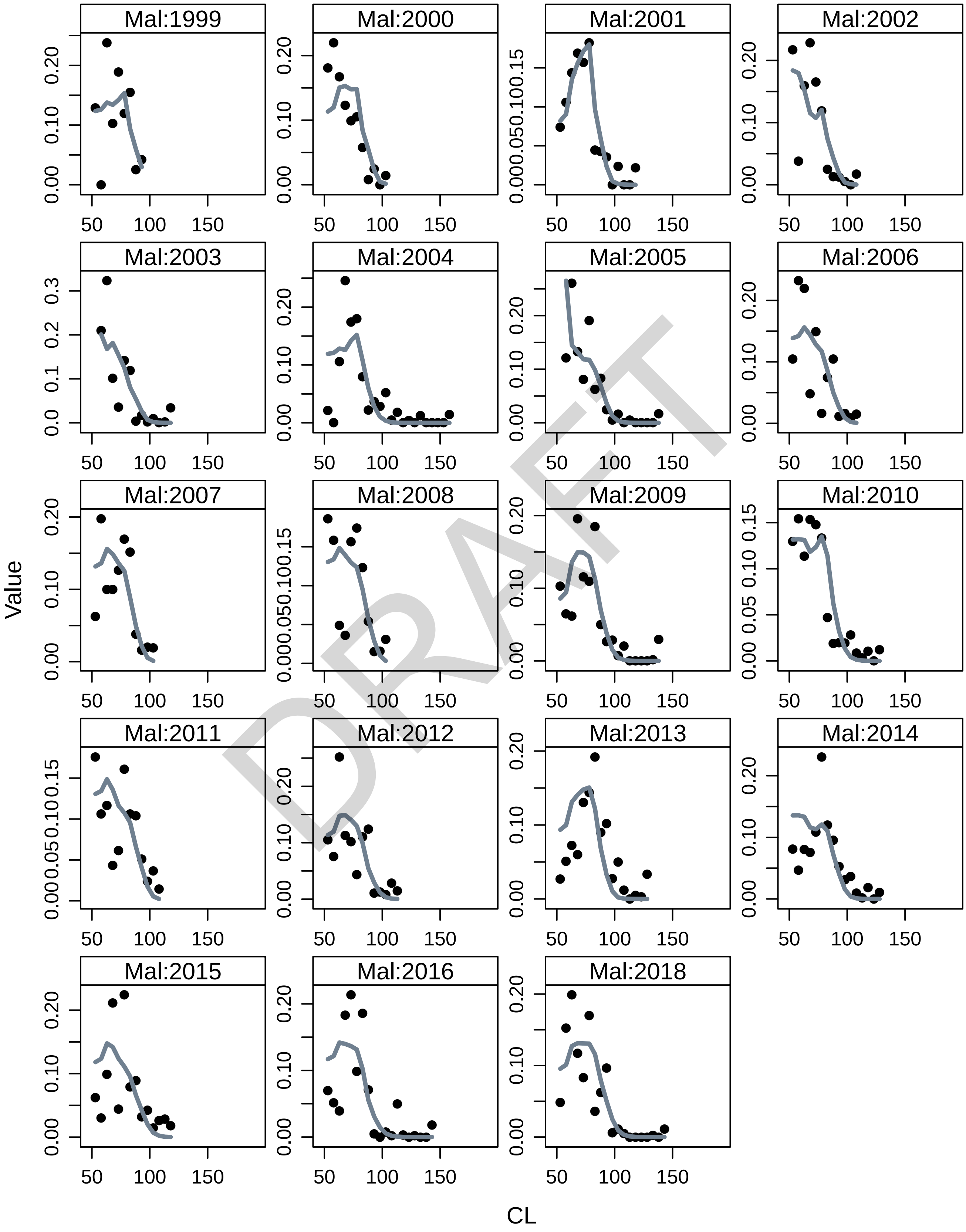
SNE_6F6_2019_orig_select
NfscMQ4 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

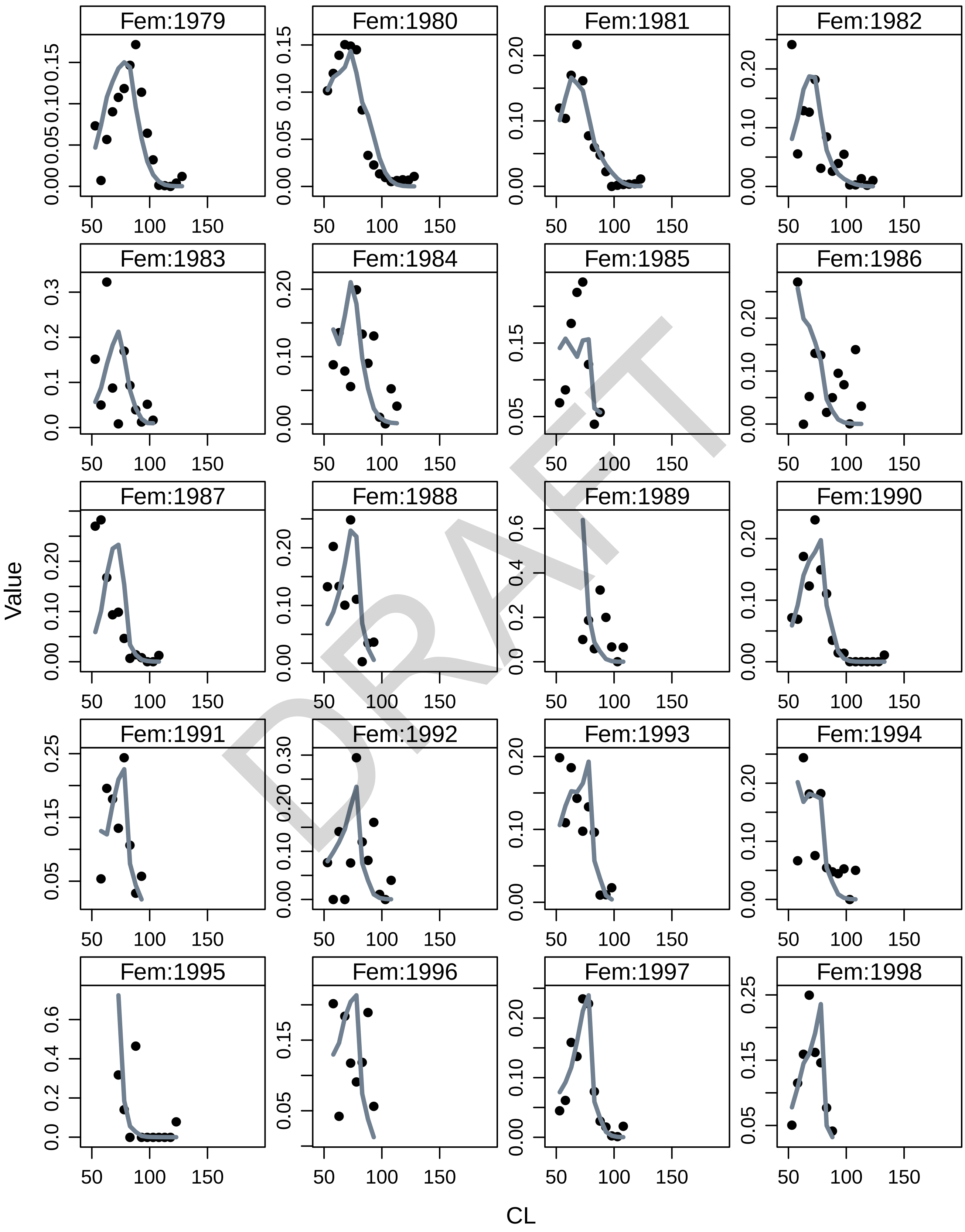
SNE_6F6_2019_orig_select
NfscMQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

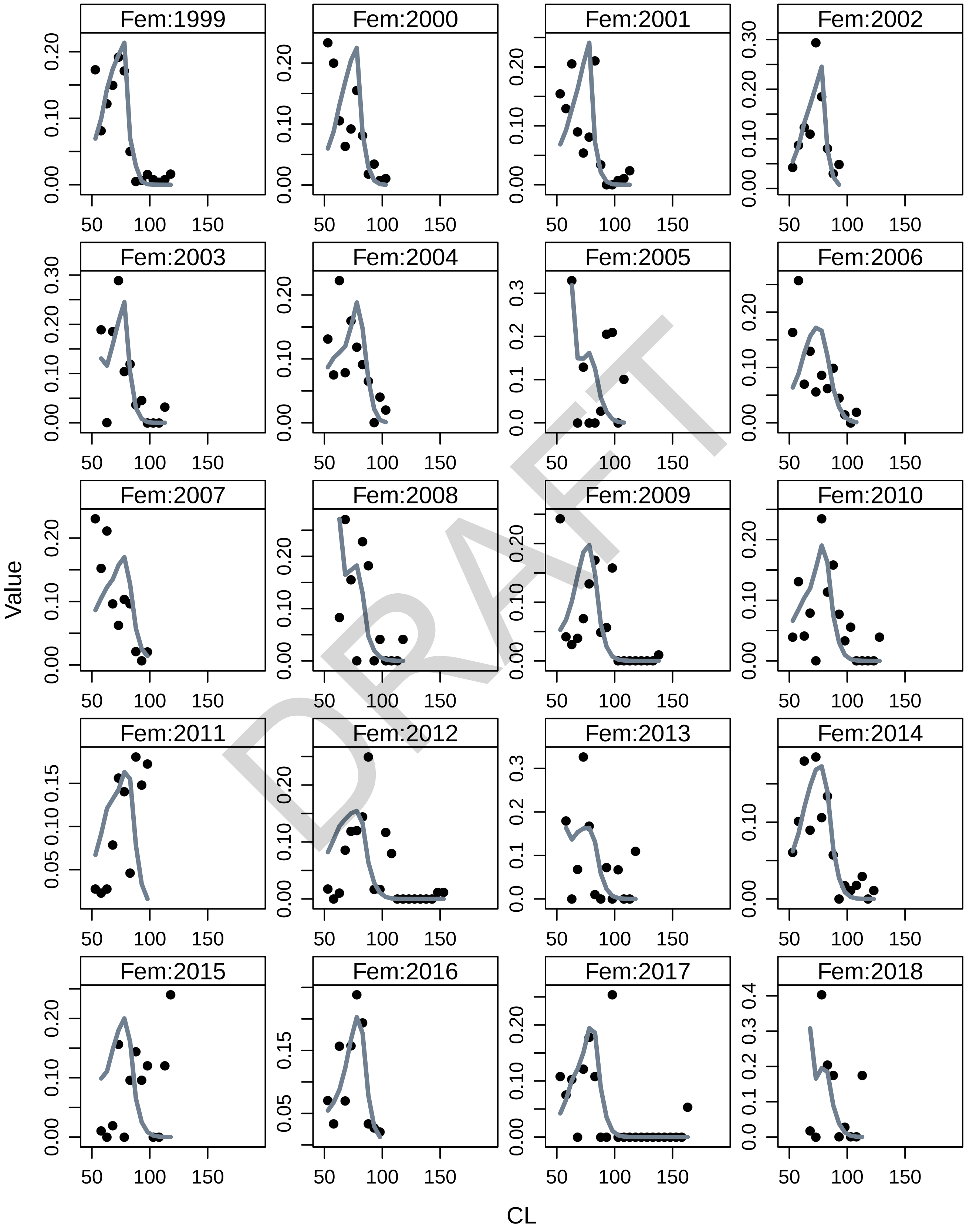
SNE_6F6_2019_orig_select
NfscQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

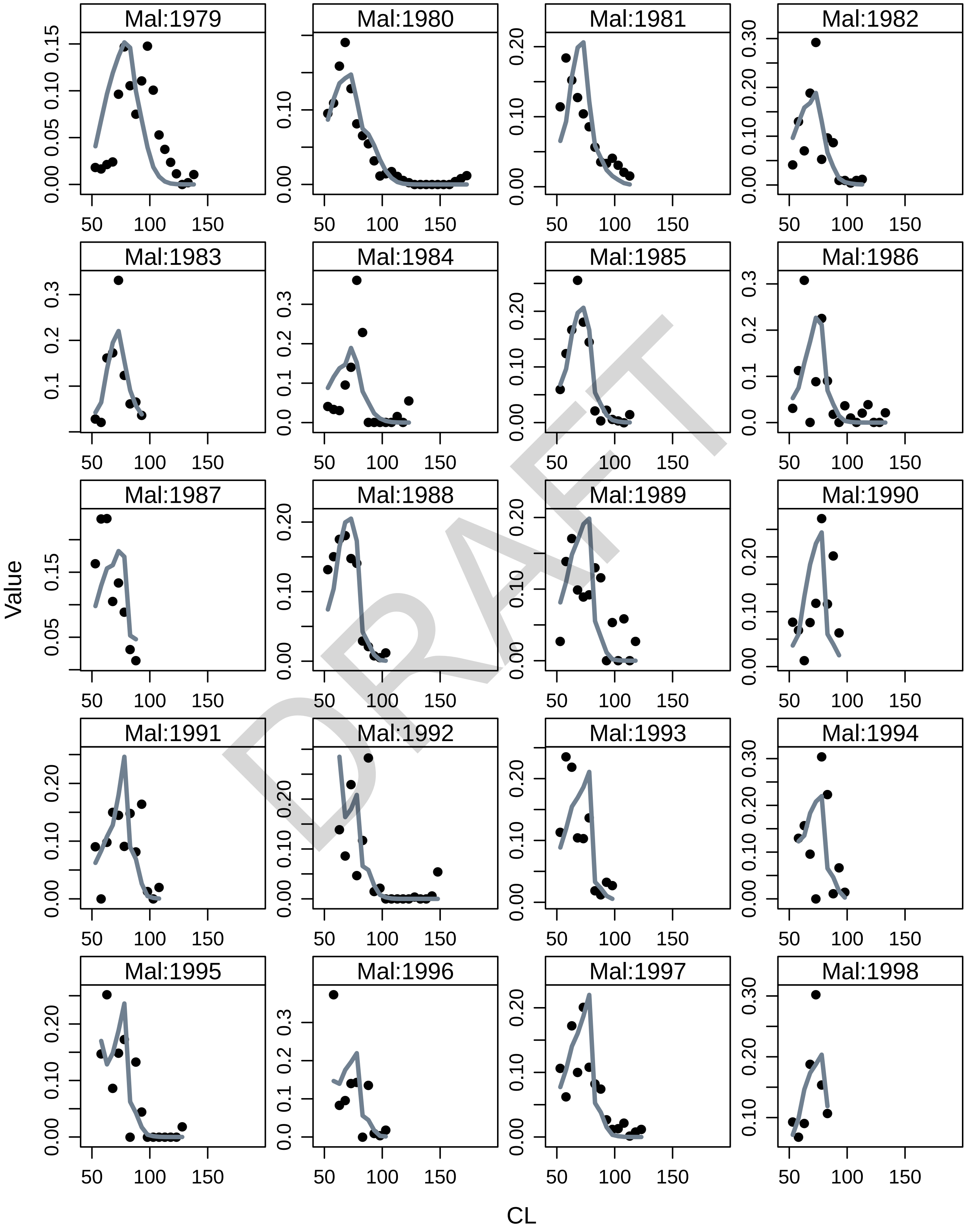
SNE_6F6_2019_orig_select
NfscQ2 observed and predicted length comps



DRAFT

Symbols = observed / Solid line = predicted

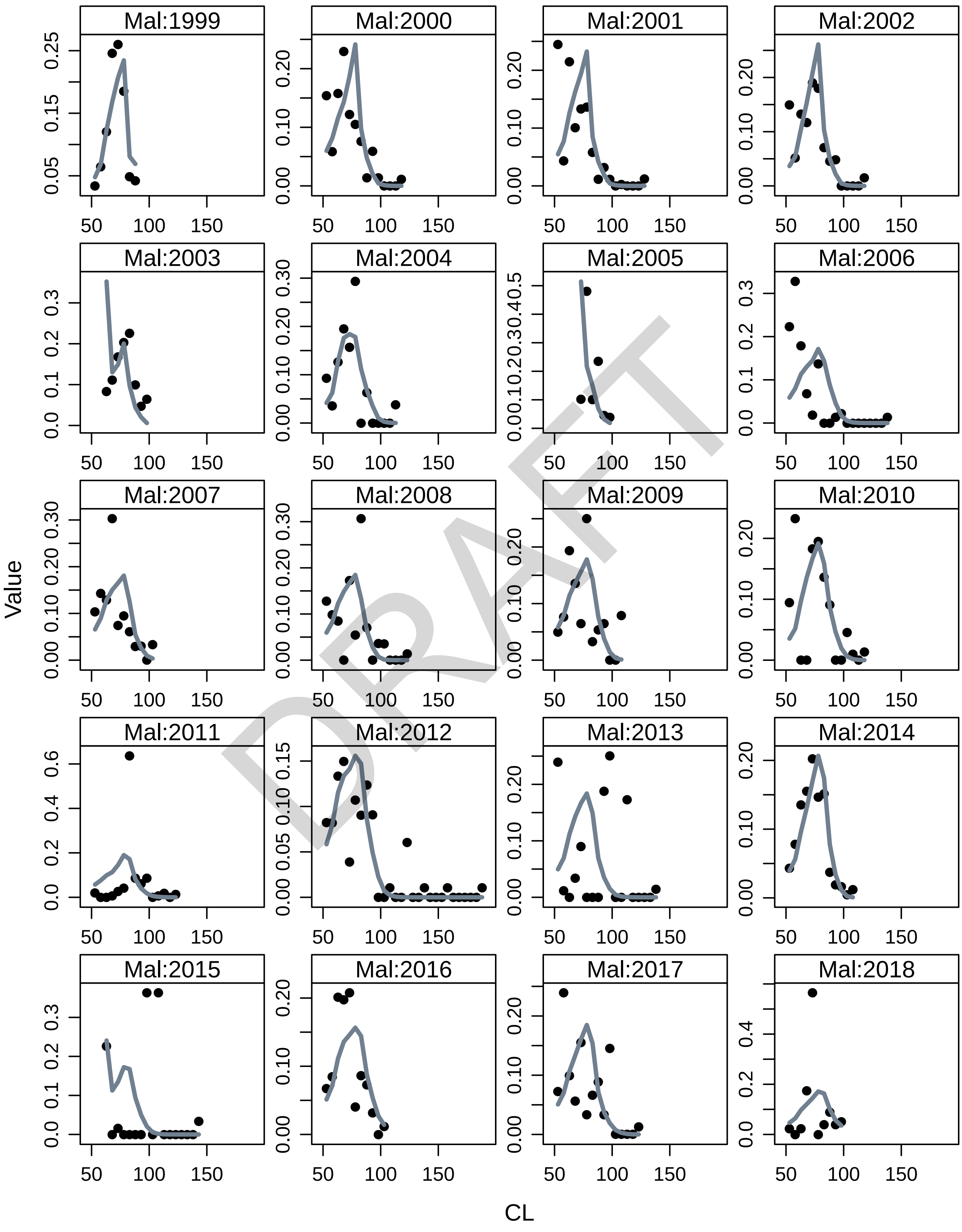
SNE_6F6_2019_orig_select
NfscQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

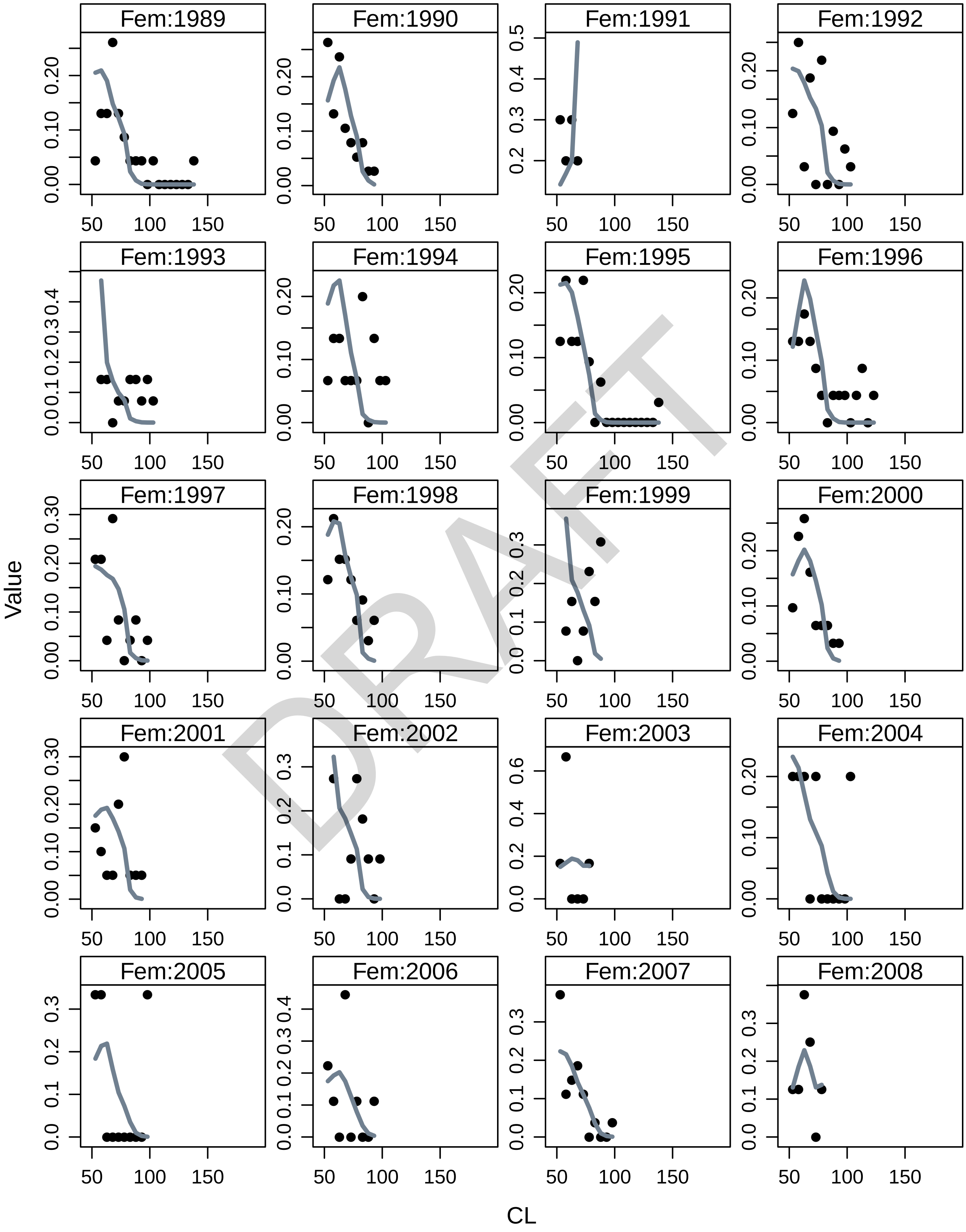
SNE_6F6_2019_orig_select
NfscQ2 observed and predicted length comps



DRAFT

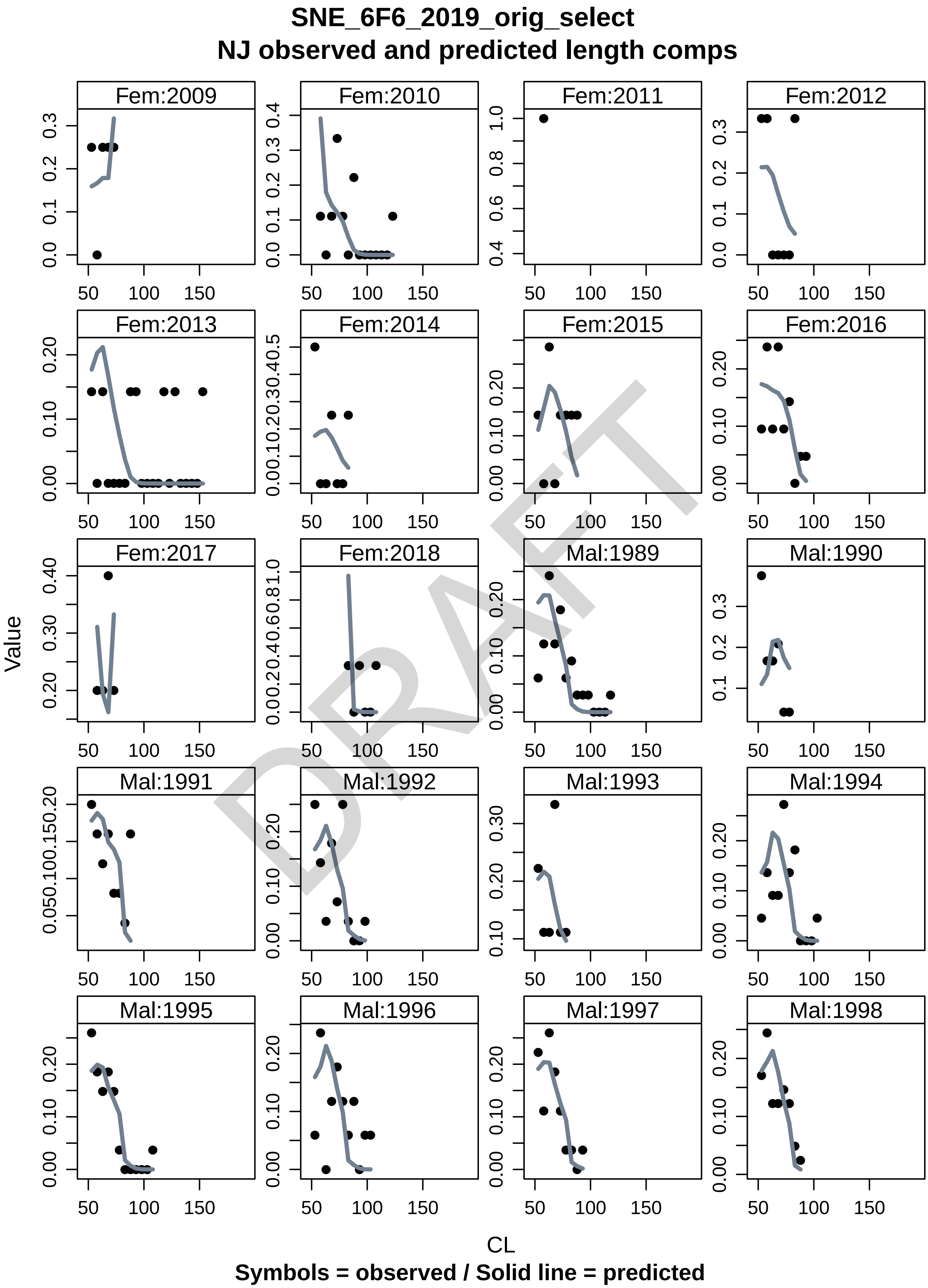
Symbols = observed / Solid line = predicted

SNE_6F6_2019_orig_select
NJ observed and predicted length comps



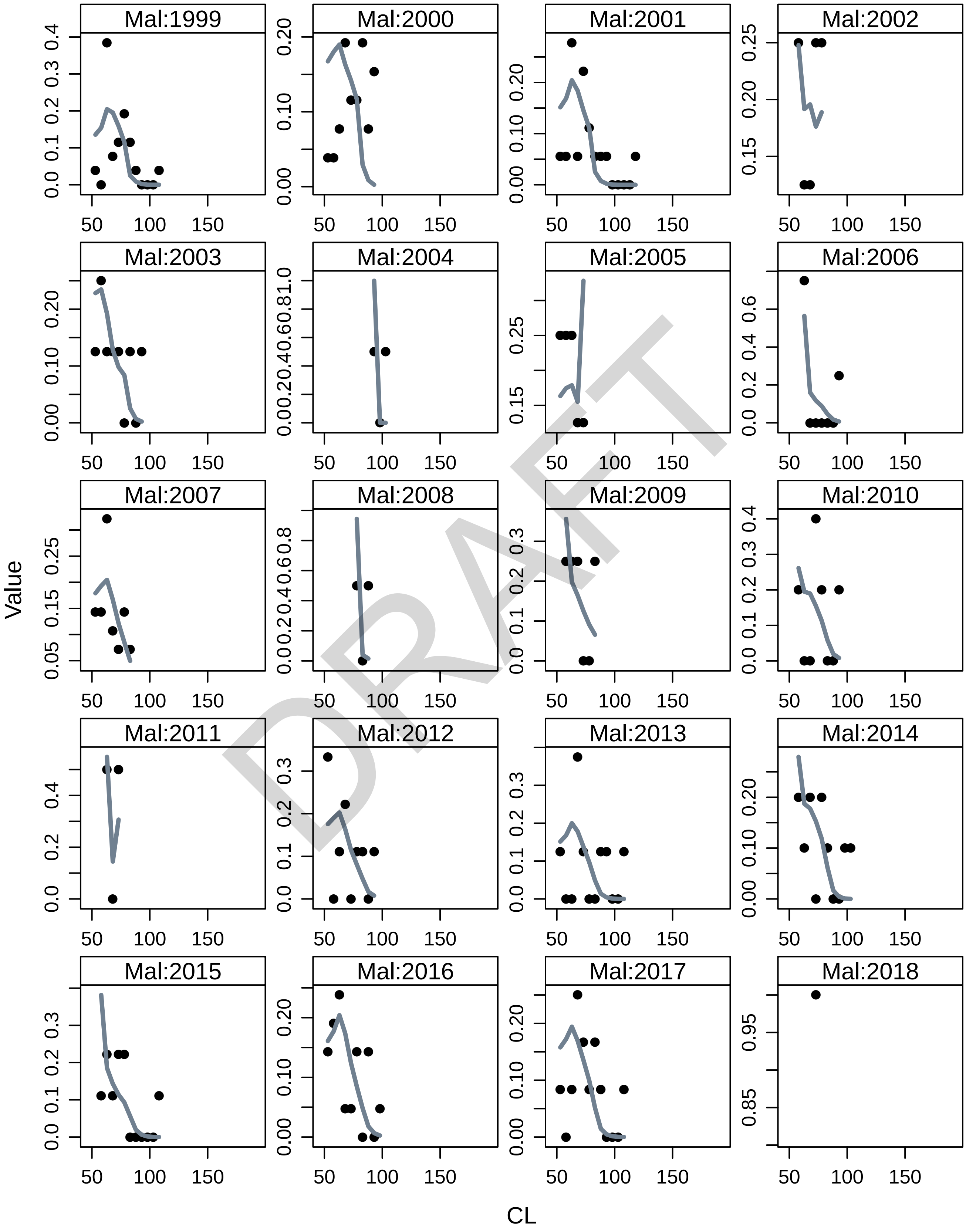
Symbols = observed / Solid line = predicted

DRAFT


SNE_6F6_2019_orig_select
NJ observed and predicted length comps
Fem:2009
Fem:2010
Fem:2011
Fem:2012
Fem:2013
Fem:2014
Fem:2015
Fem:2016
Fem:2017
Fem:2018
Mal:1989
Mal:1990
Mal:1991
Mal:1992
Mal:1993
Mal:1994
Mal:1995
Mal:1996
Mal:1997
Mal:1998
Value
CL
50
100
150
Symbols = observed / Solid line = predicted

DRAFT

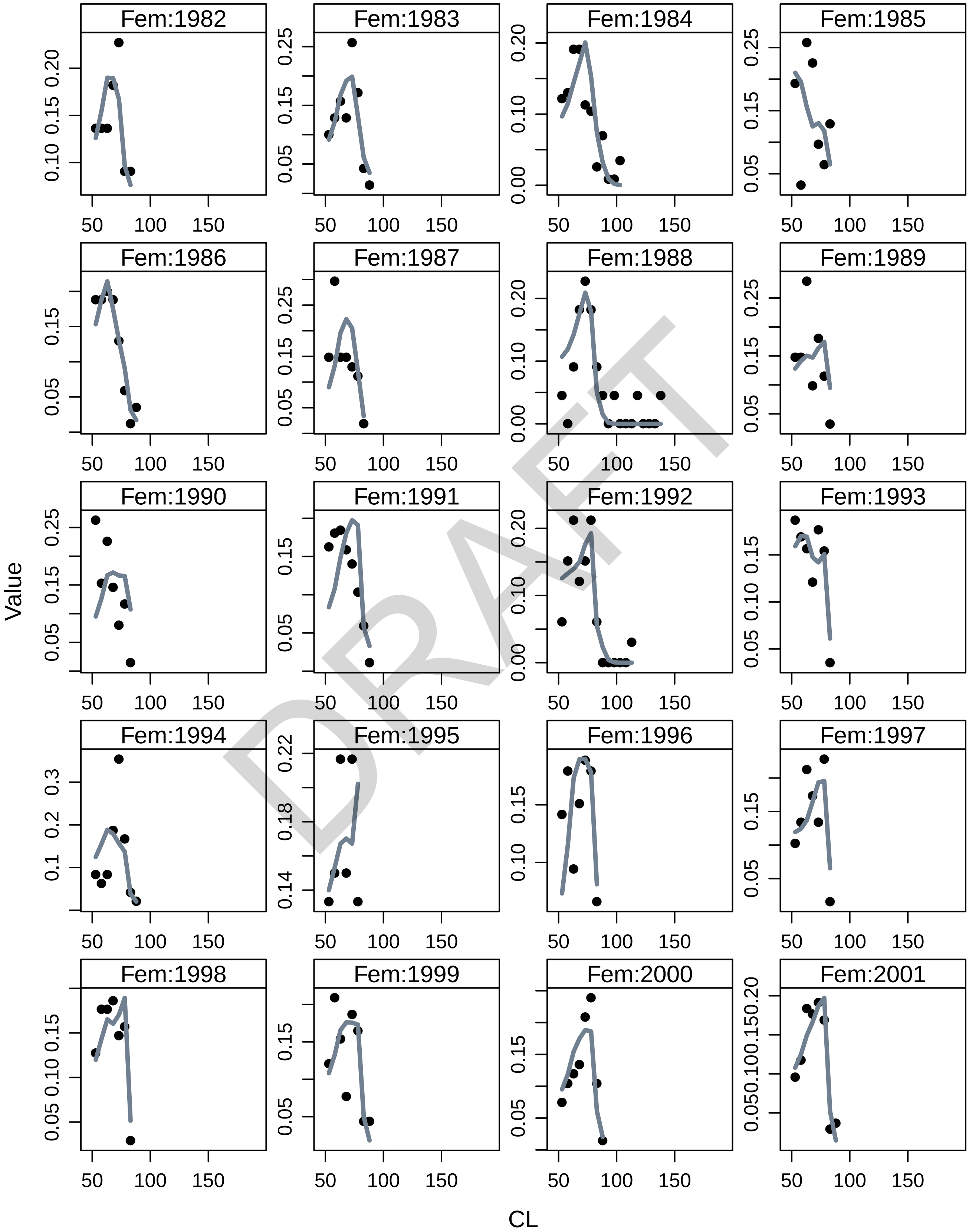
SNE_6F6_2019_orig_select
NJ observed and predicted length comps



Symbols = observed / Solid line = predicted

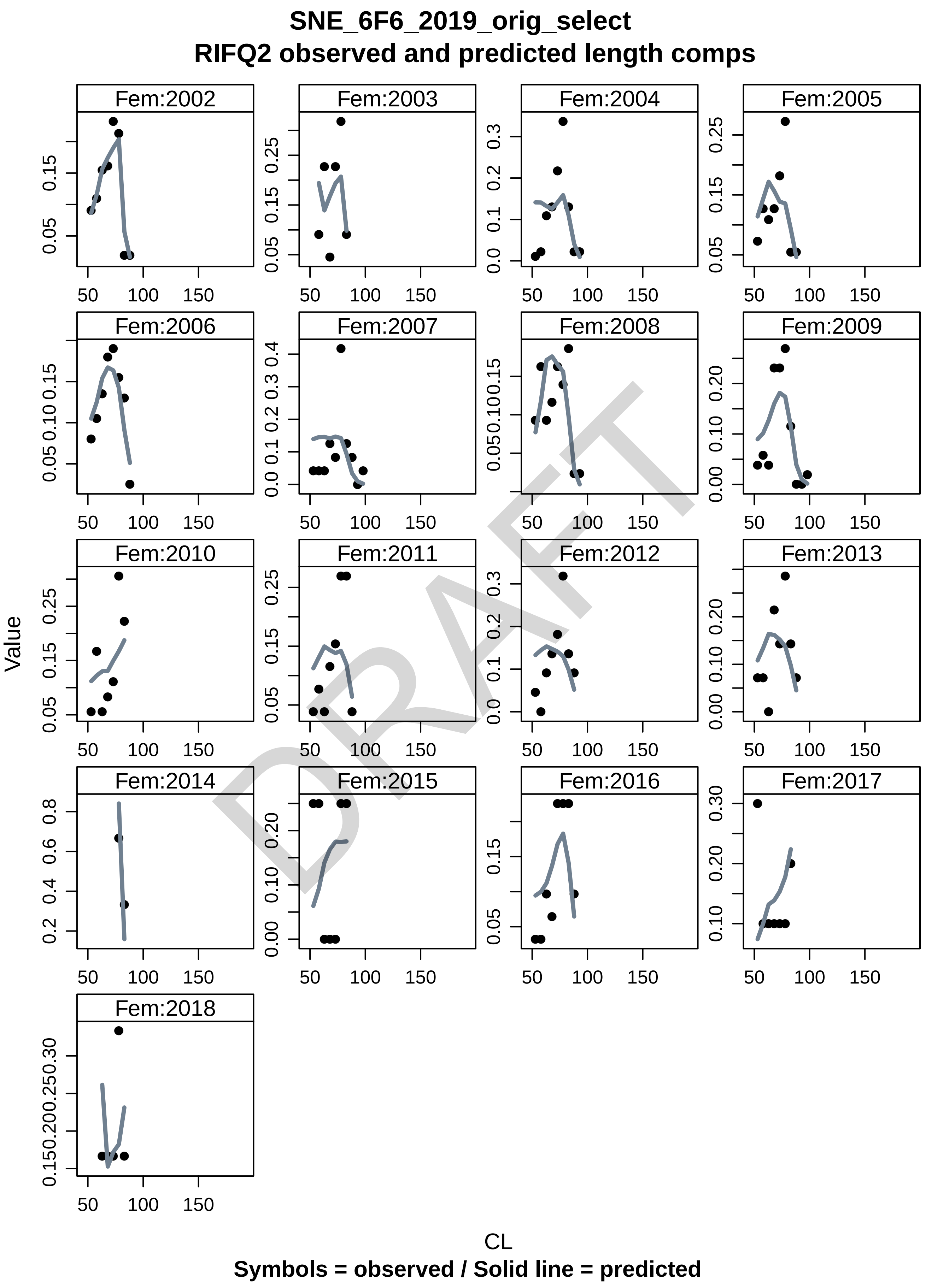
DRAFT

SNE_6F6_2019_orig_select
RIFQ2 observed and predicted length comps



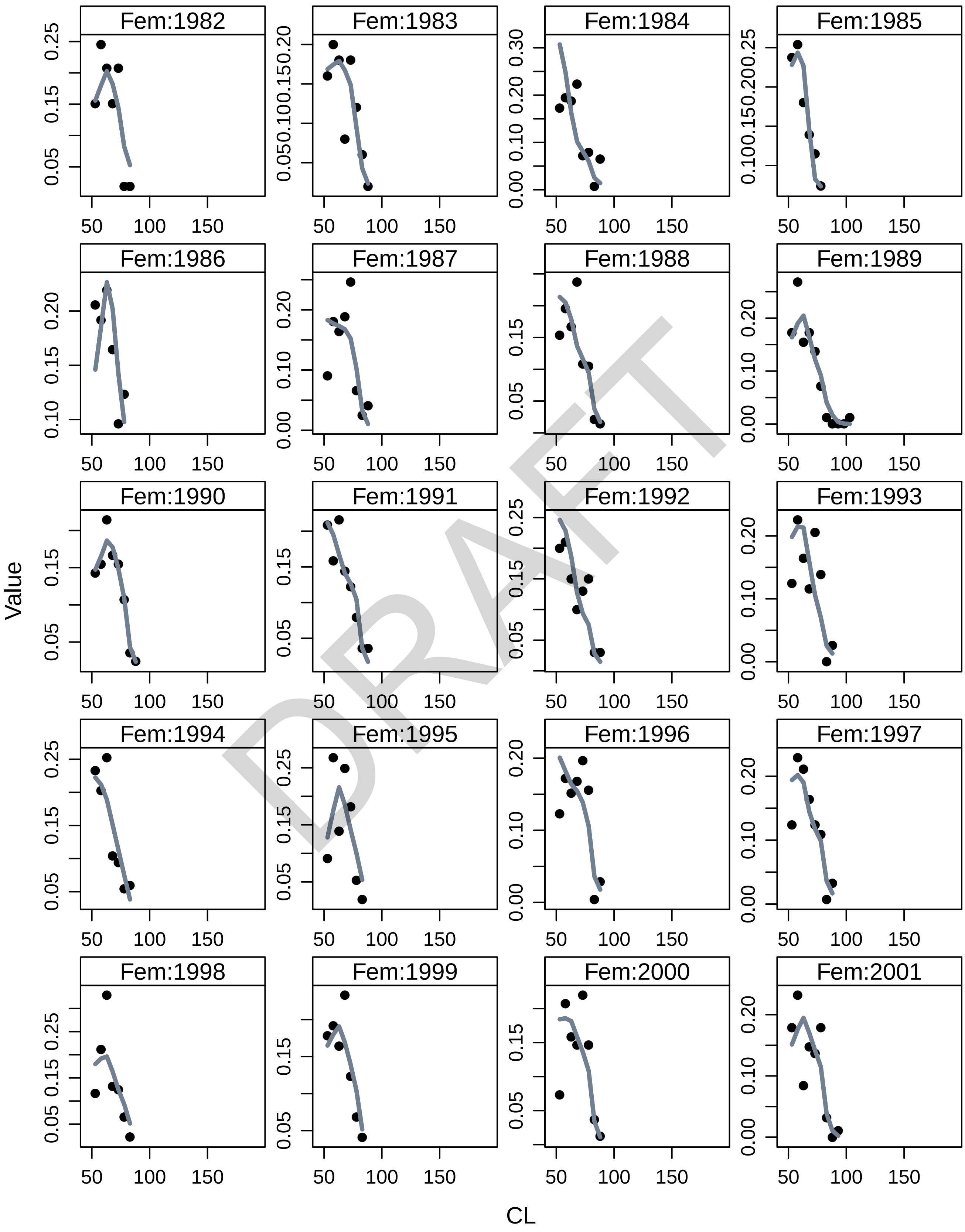
Symbols = observed / Solid line = predicted

DRAFT


SNE_6F6_2019_orig_select
RIFQ2 observed and predicted length comps
Fem:2002
Fem:2003
Fem:2004
Fem:2005
Fem:2006
Fem:2007
Fem:2008
Fem:2009
Fem:2010
Fem:2011
Fem:2012
Fem:2013
Fem:2014
Fem:2015
Fem:2016
Fem:2017
Fem:2018
Value
50
100
150
CL
Symbols = observed / Solid line = predicted

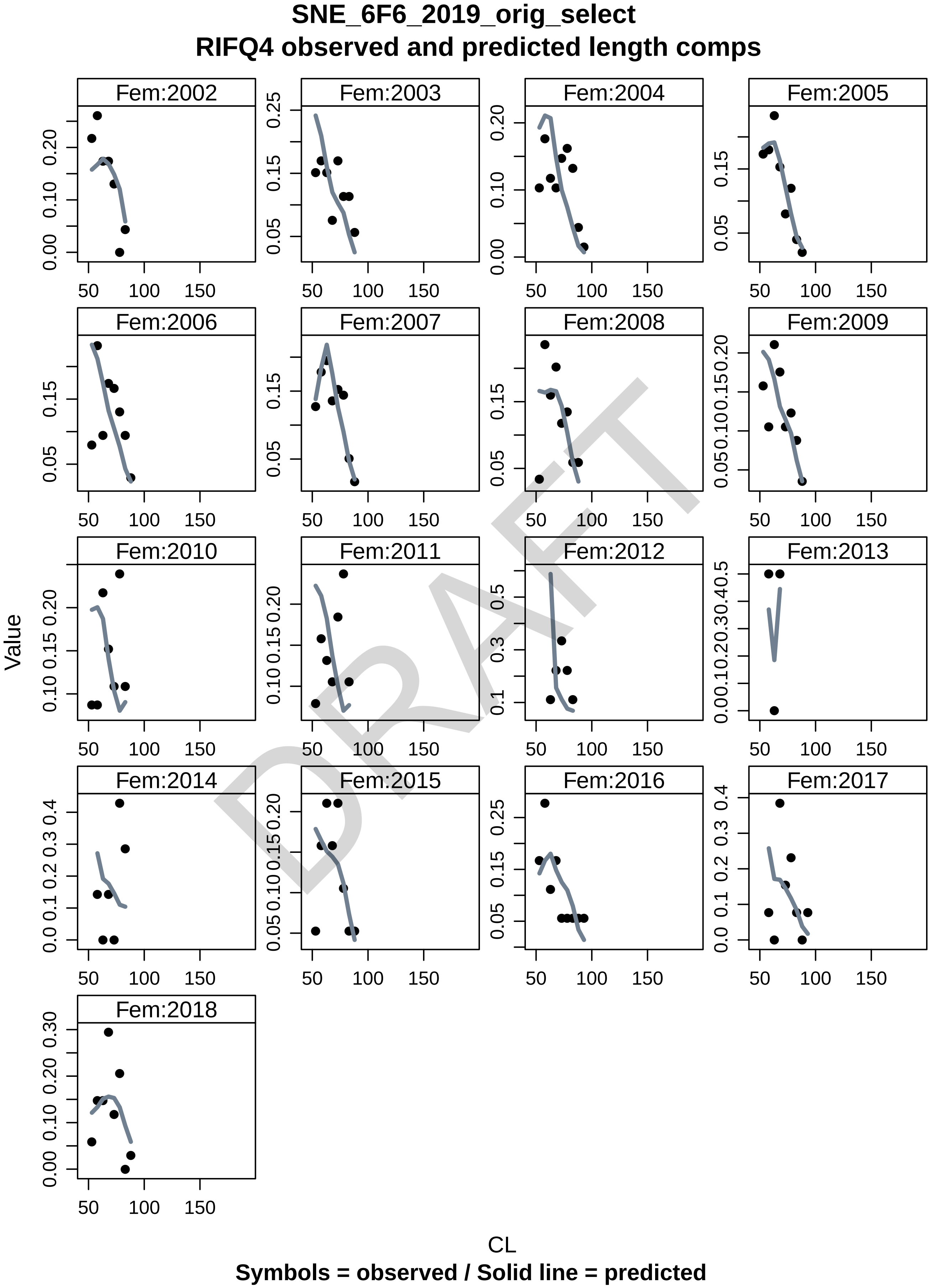
DRAFT

SNE_6F6_2019_orig_select
RIFQ4 observed and predicted length comps



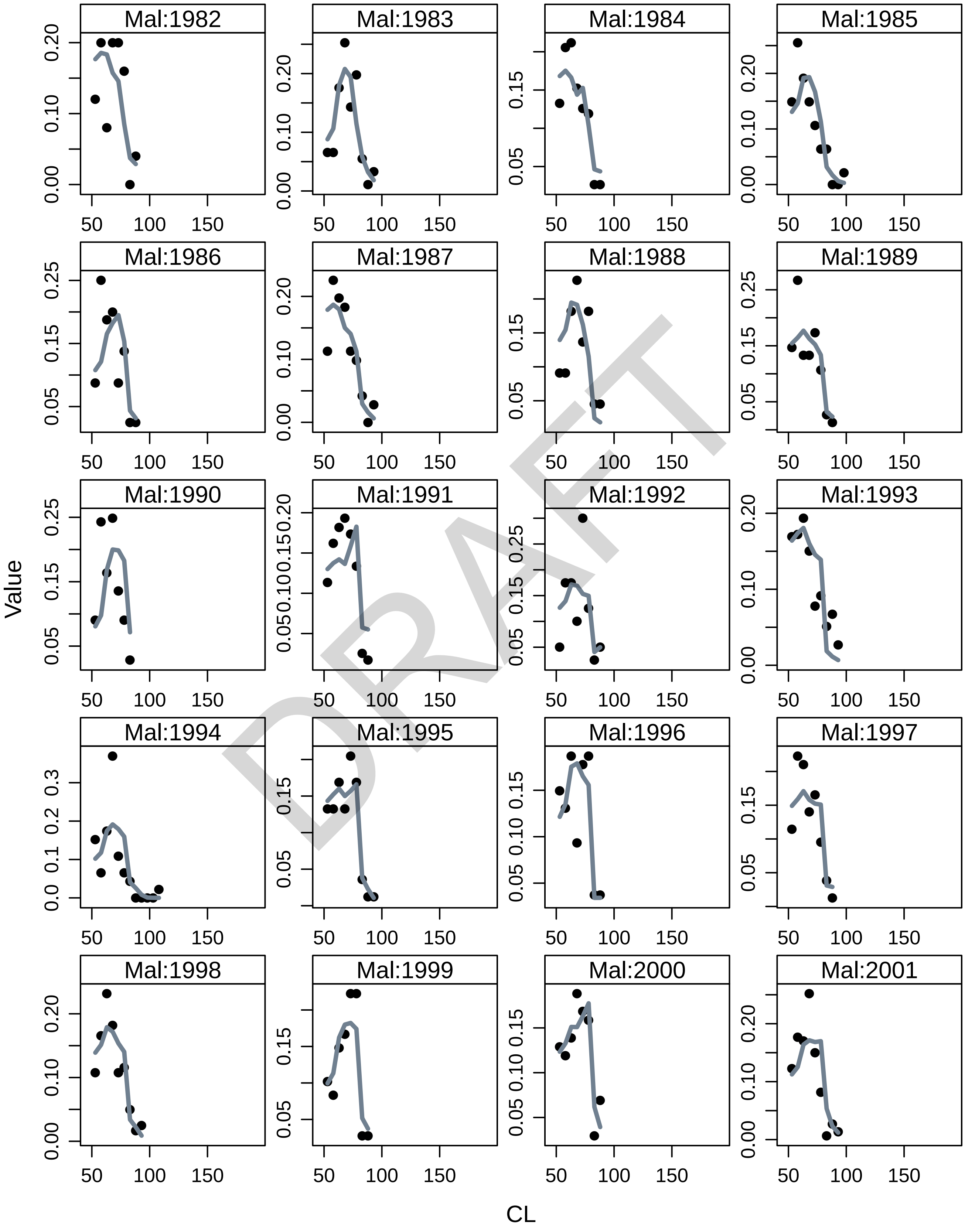
Symbols = observed / Solid line = predicted

DRAFT


SNE_6F6_2019_orig_select
RIFQ4 observed and predicted length comps
Fem:2002
Fem:2003
Fem:2004
Fem:2005
Fem:2006
Fem:2007
Fem:2008
Fem:2009
Fem:2010
Fem:2011
Fem:2012
Fem:2013
Fem:2014
Fem:2015
Fem:2016
Fem:2017
Fem:2018
Value
CL
50
100
150
Symbols = observed / Solid line = predicted

DRAFT

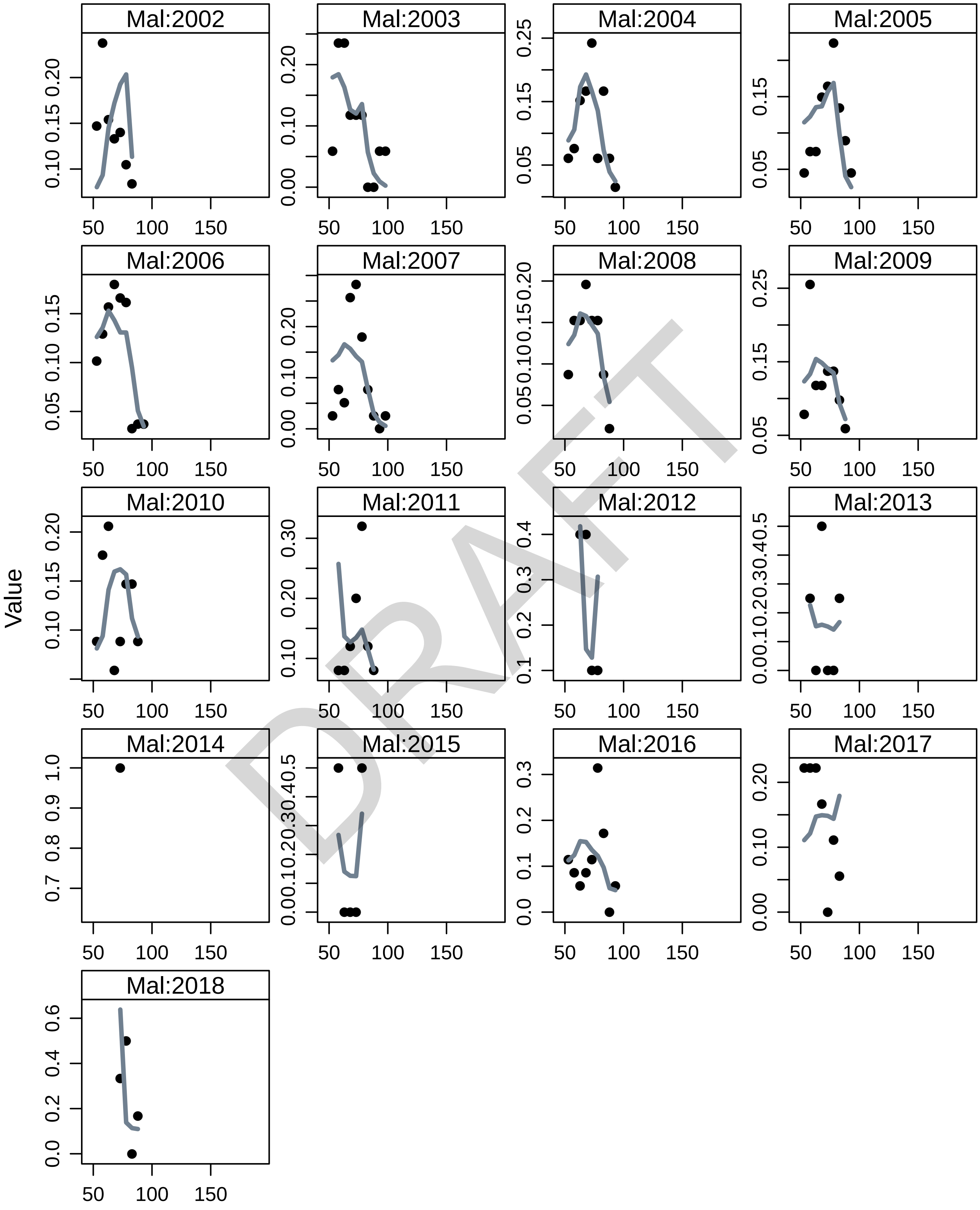
SNE_6F6_2019_orig_select
RIMQ2 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
RIMQ2 observed and predicted length comps

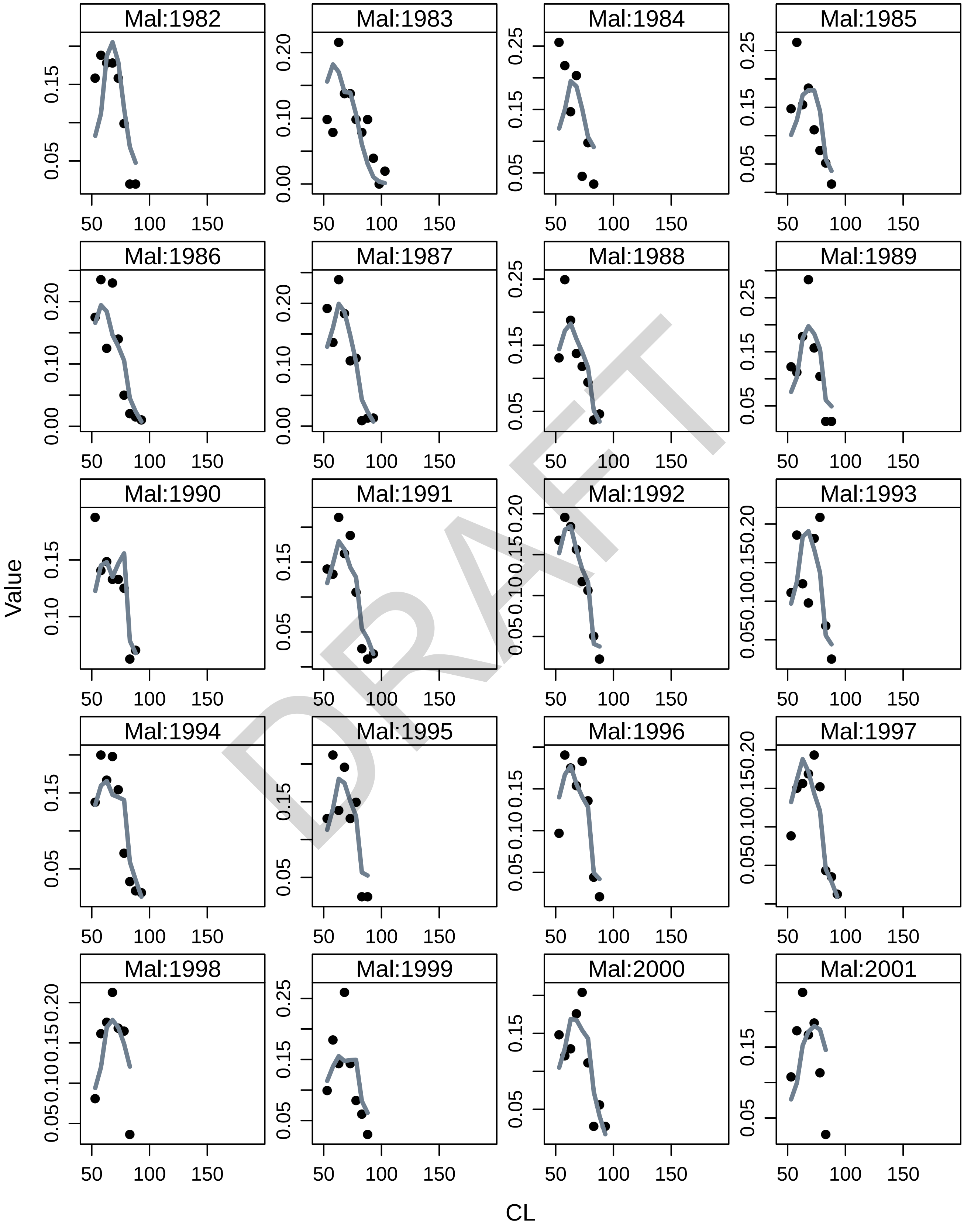


CL

Symbols = observed / Solid line = predicted

DRAFT

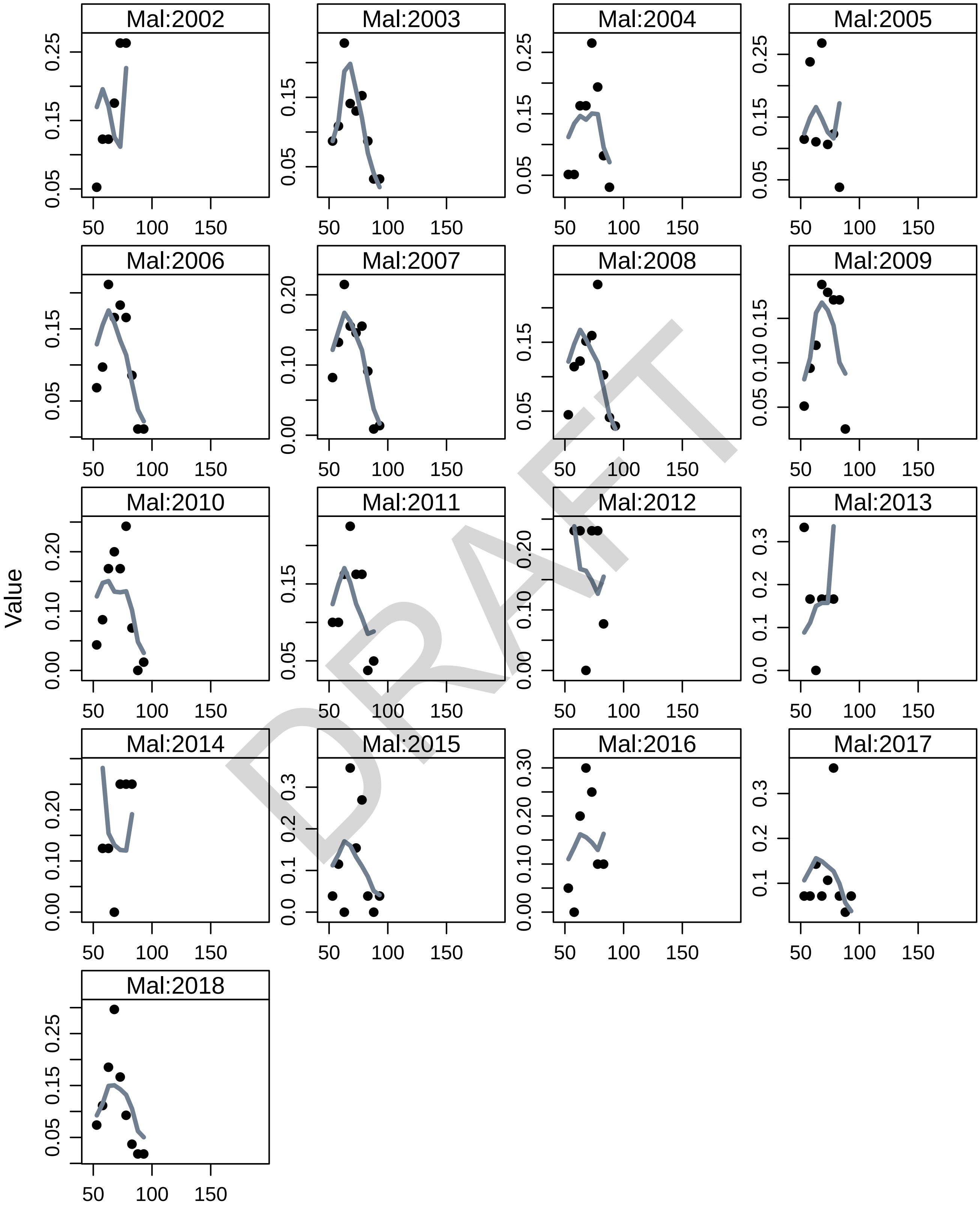
SNE_6F6_2019_orig_select
RIMQ4 observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

SNE_6F6_2019_orig_select
RIMQ4 observed and predicted length comps

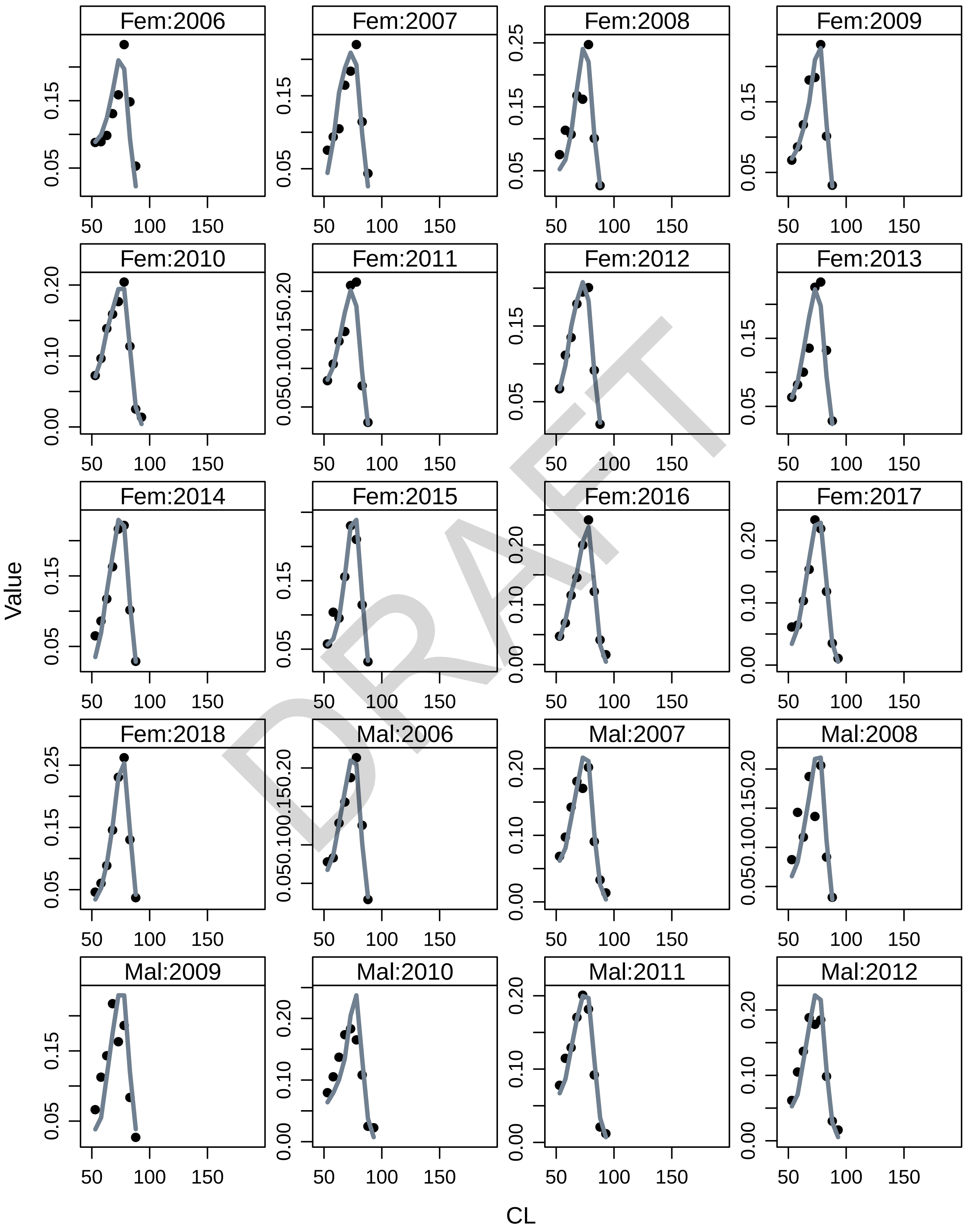


DRAFT

CL

Symbols = observed / Solid line = predicted

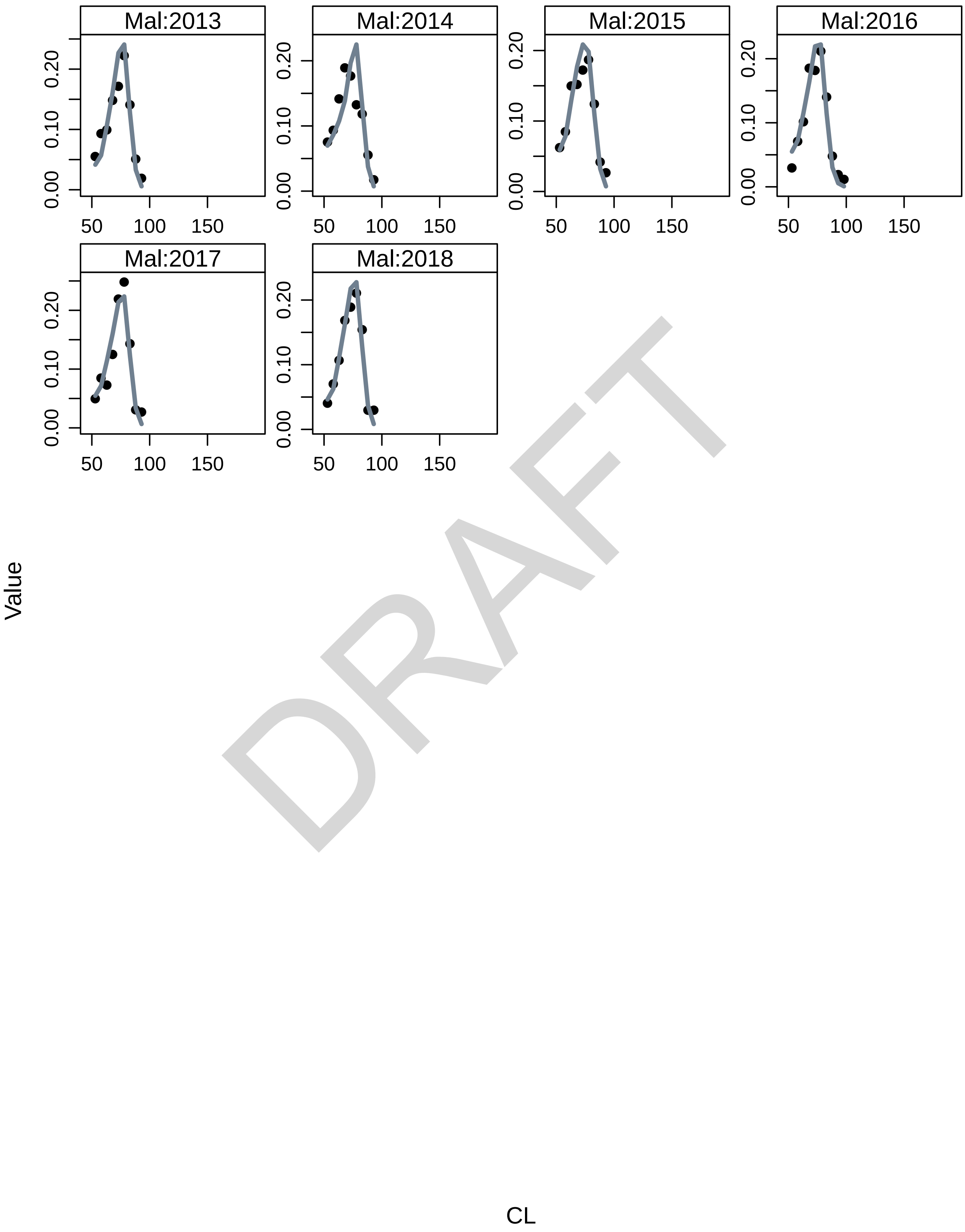
SNE_6F6_2019_orig_select
VTSQ3_model observed and predicted length comps



Symbols = observed / Solid line = predicted

DRAFT

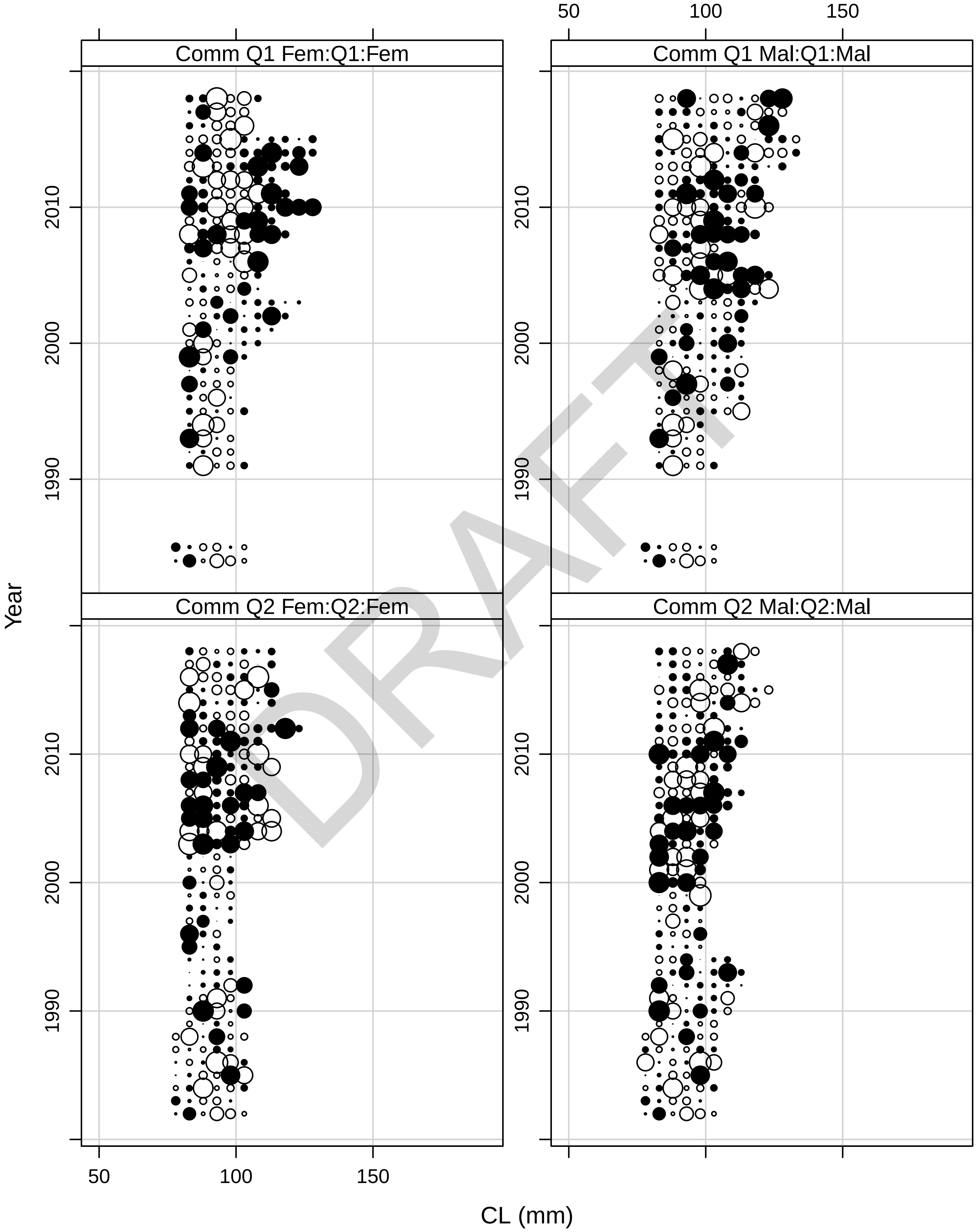
SNE_6F6_2019_orig_select
VTSQ3_model observed and predicted length comps



Symbols = observed / Solid line = predicted

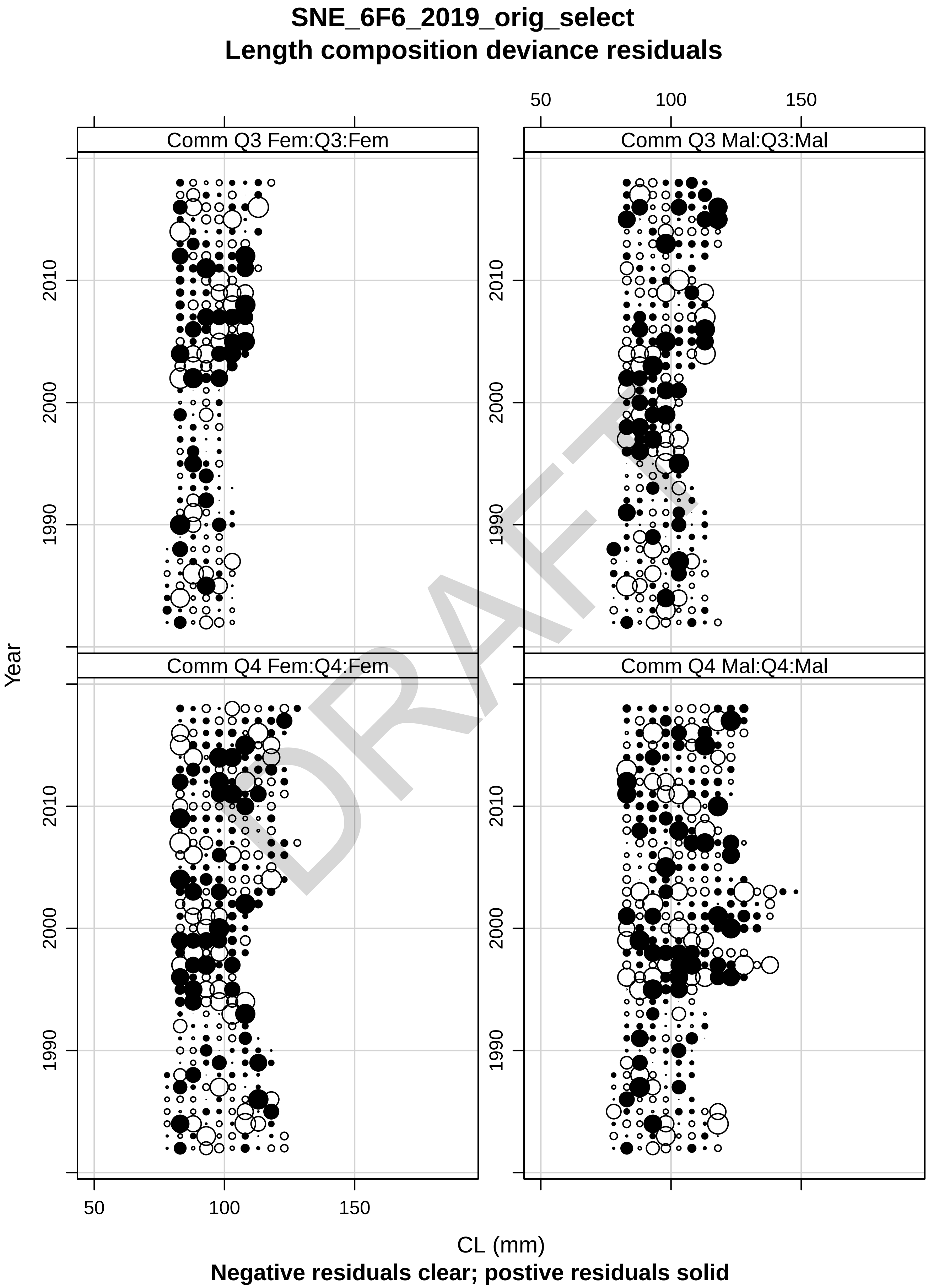
DRAFT

SNE_6F6_2019_orig_select
Length composition deviance residuals

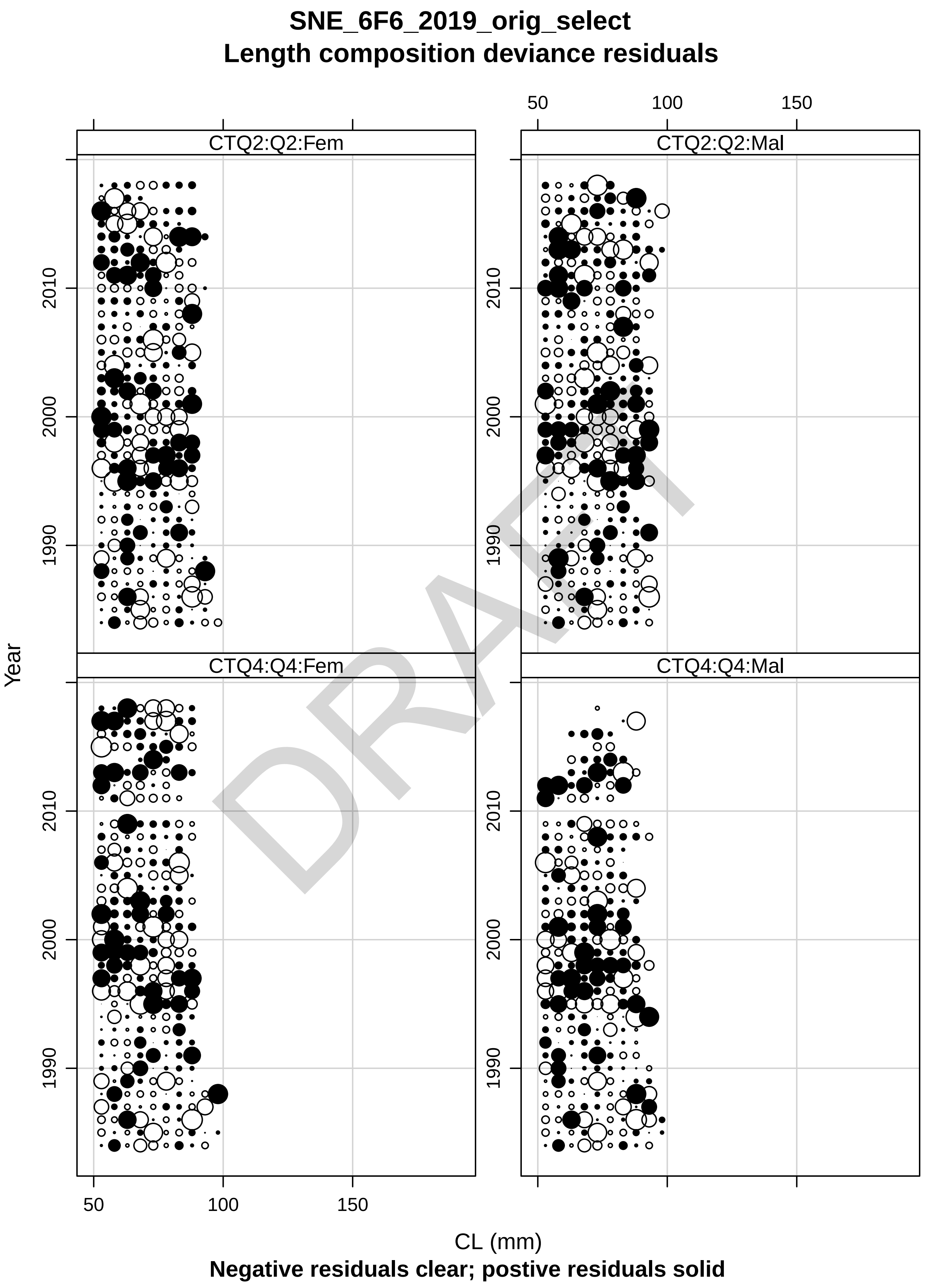


DRAFT

Negative residuals clear; postive residuals solid

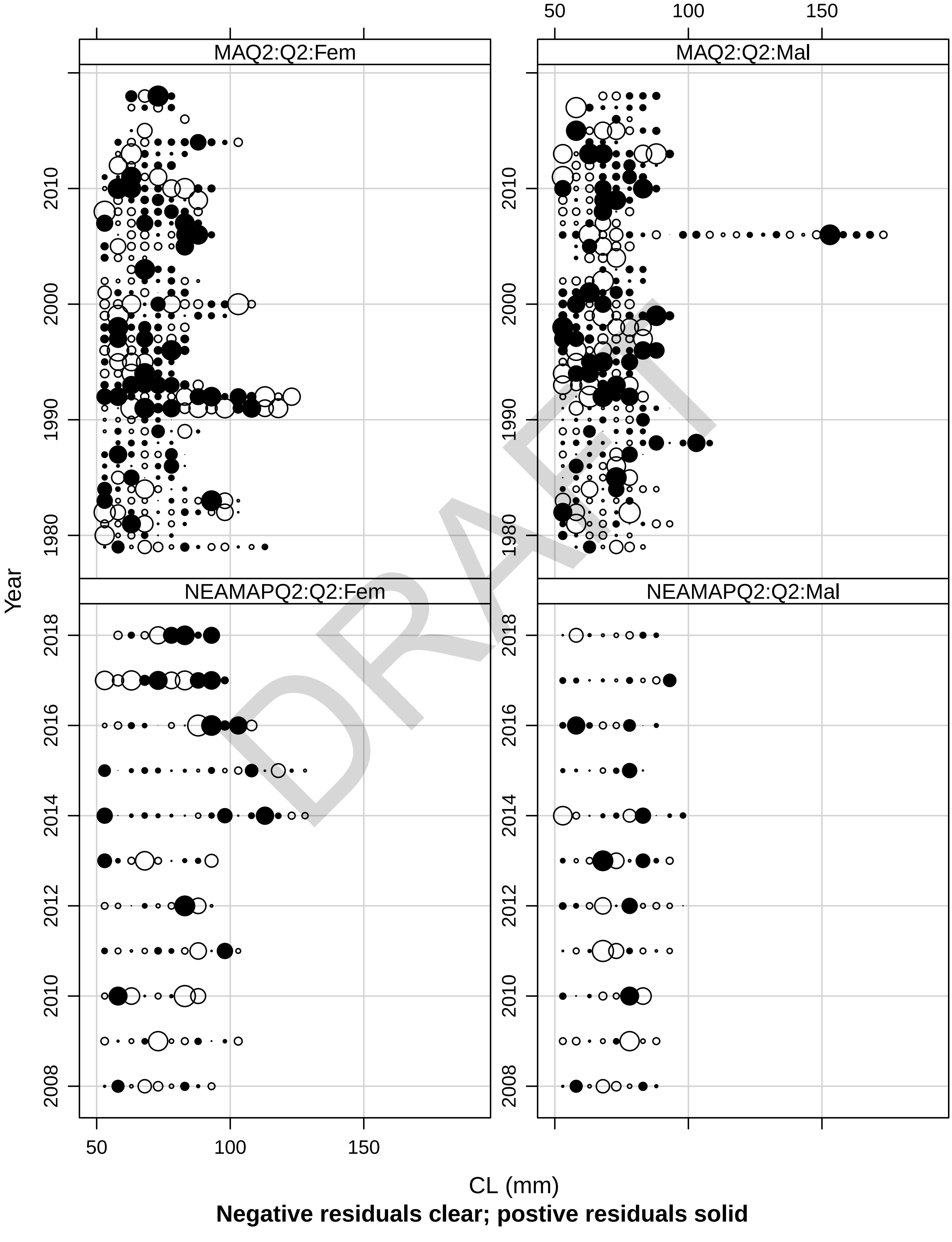

SNE_6F6_2019_orig_select
Length composition deviance residuals
Comm Q3 Fem:Q3:Fem
Comm Q3 Mal:Q3:Mal
Comm Q4 Fem:Q4:Fem
Comm Q4 Mal:Q4:Mal
Year
1990
2000
2010
50
100
150
CL (mm)
Negative residuals clear; postive residuals solid

DRAFT


SNE_6F6_2019_orig_select
Length composition deviance residuals
CTQ2:Q2:Fem
CTQ2:Q2:Mal
CTQ4:Q4:Fem
CTQ4:Q4:Mal
Year
1990
2000
2010
50
100
150
CL (mm)
Negative residuals clear; postive residuals solid

DRAFT

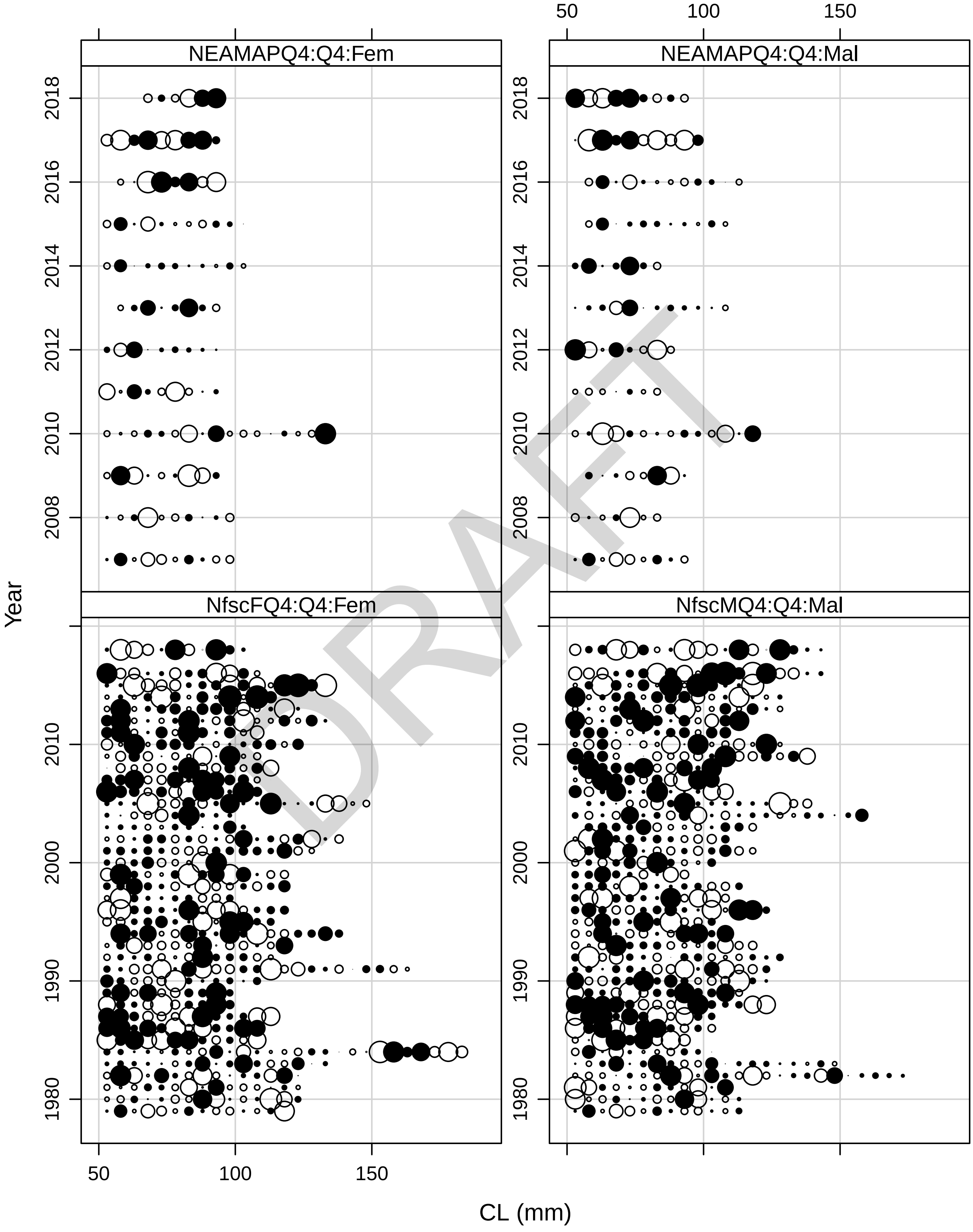
SNE_6F6_2019_orig_select
Length composition deviance residuals



Negative residuals clear; postive residuals solid

DRAFT

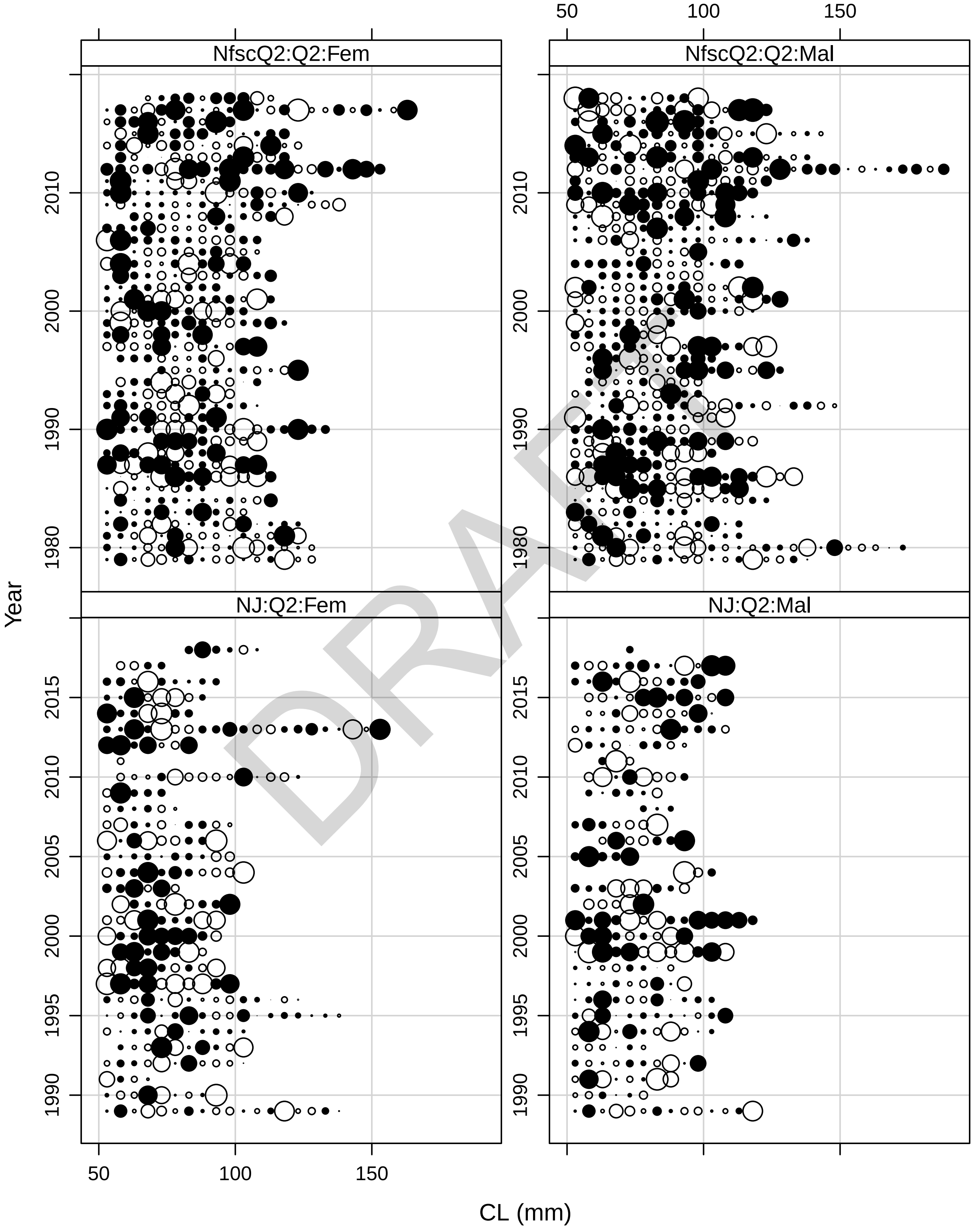
SNE_6F6_2019_orig_select
Length composition deviance residuals



Negative residuals clear; postive residuals solid

DRAFT

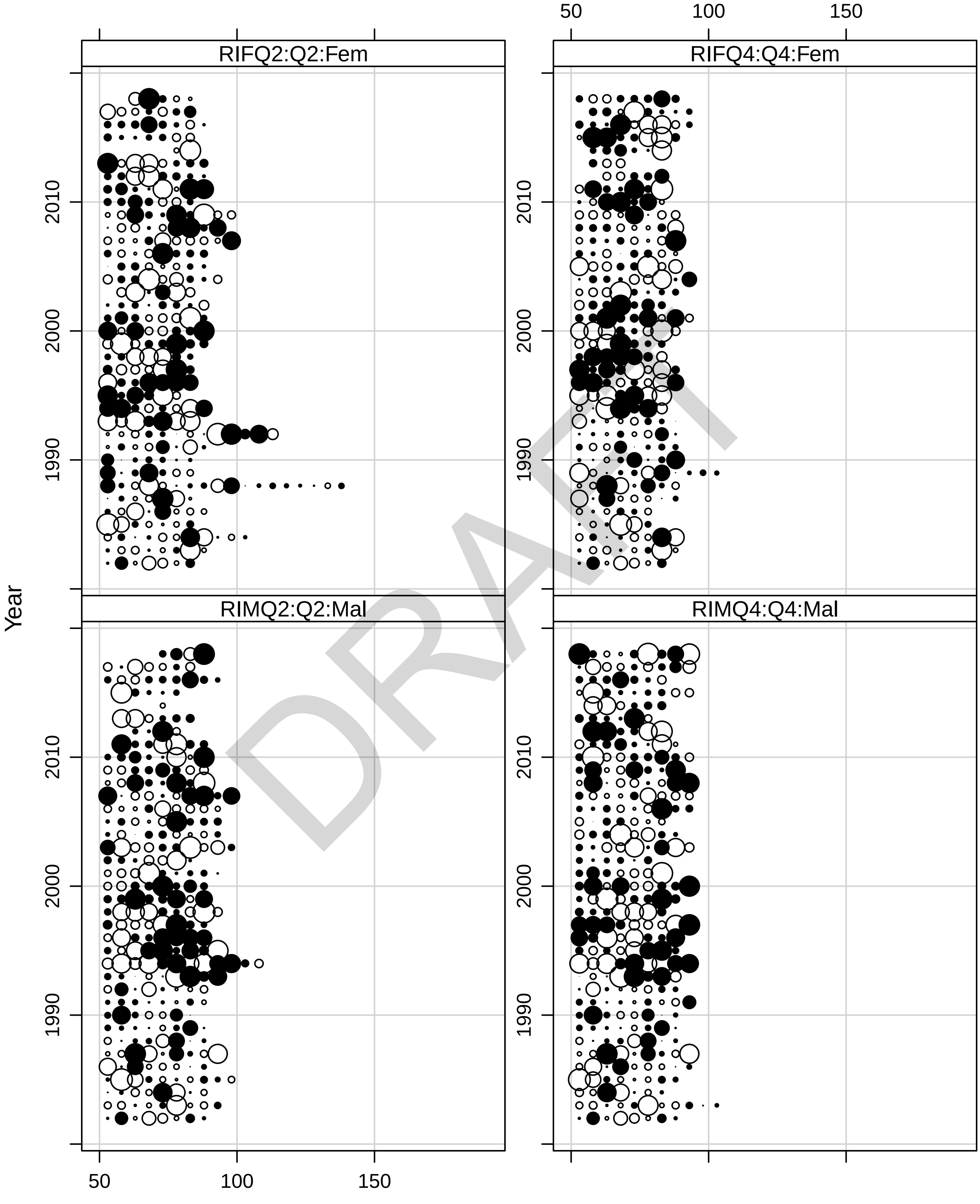
SNE_6F6_2019_orig_select
Length composition deviance residuals



Negative residuals clear; postive residuals solid

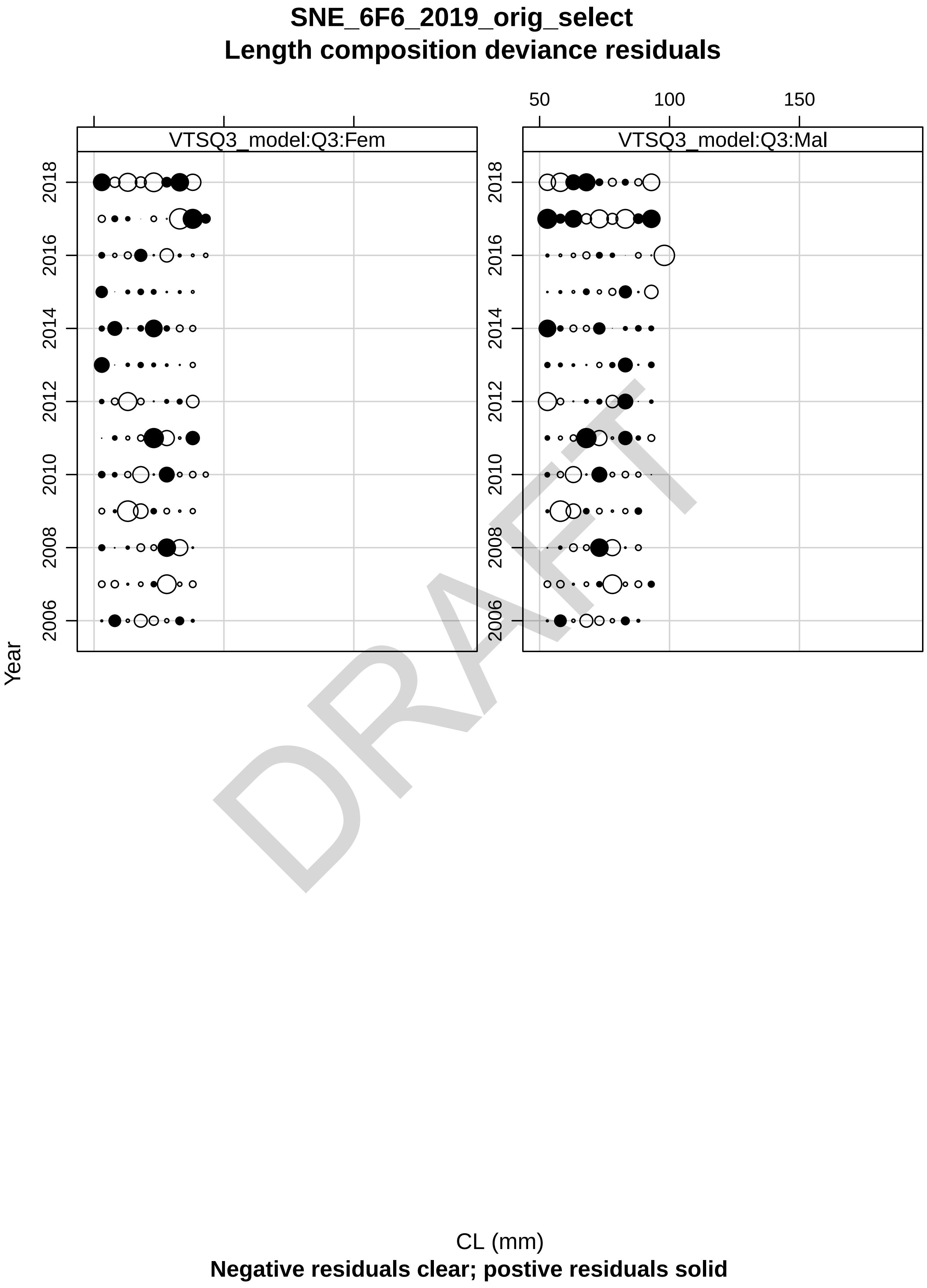
DRAFT

SNE_6F6_2019_orig_select
Length composition deviance residuals

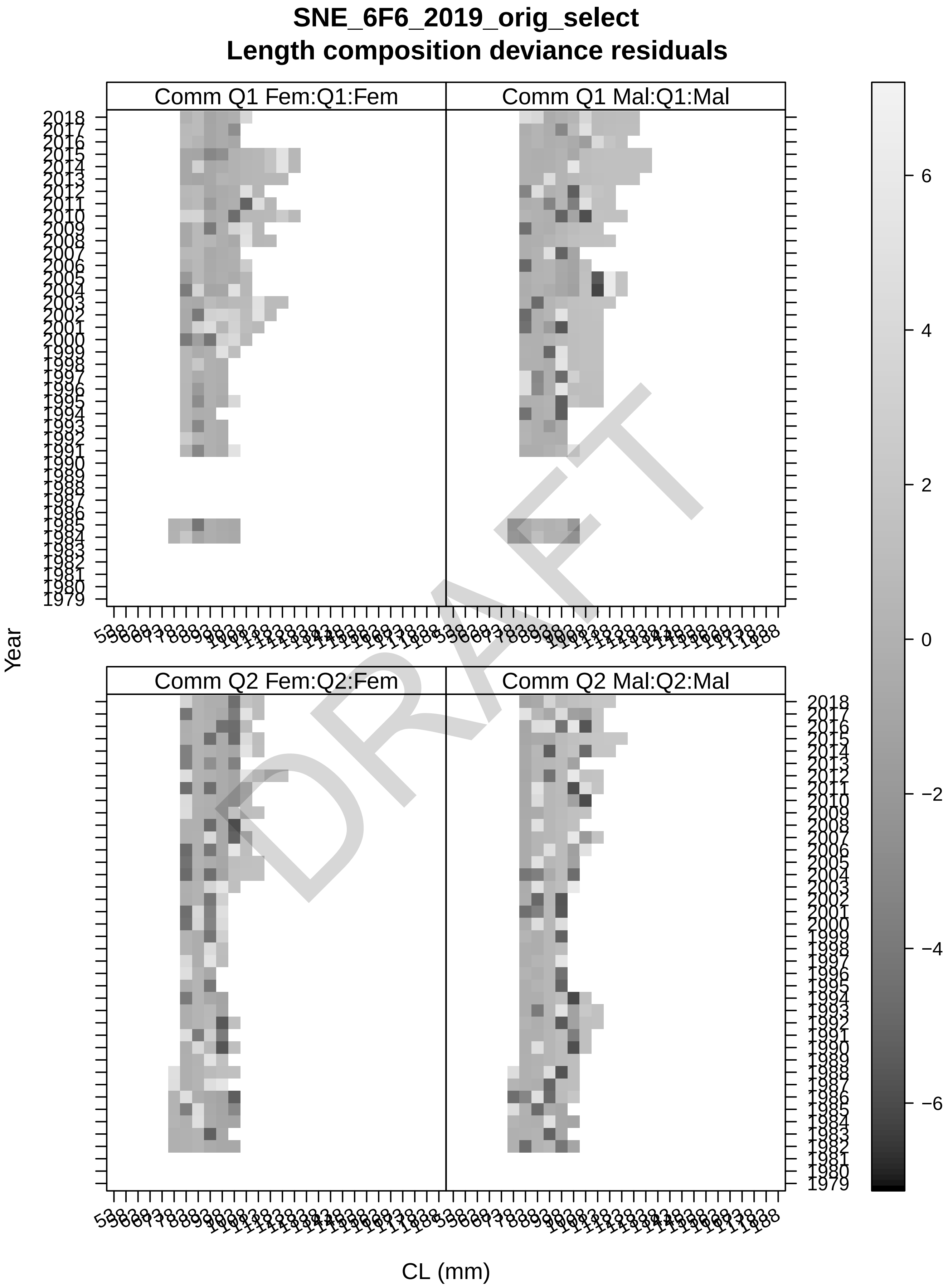


DRAFT

Negative residuals clear; postive residuals solid

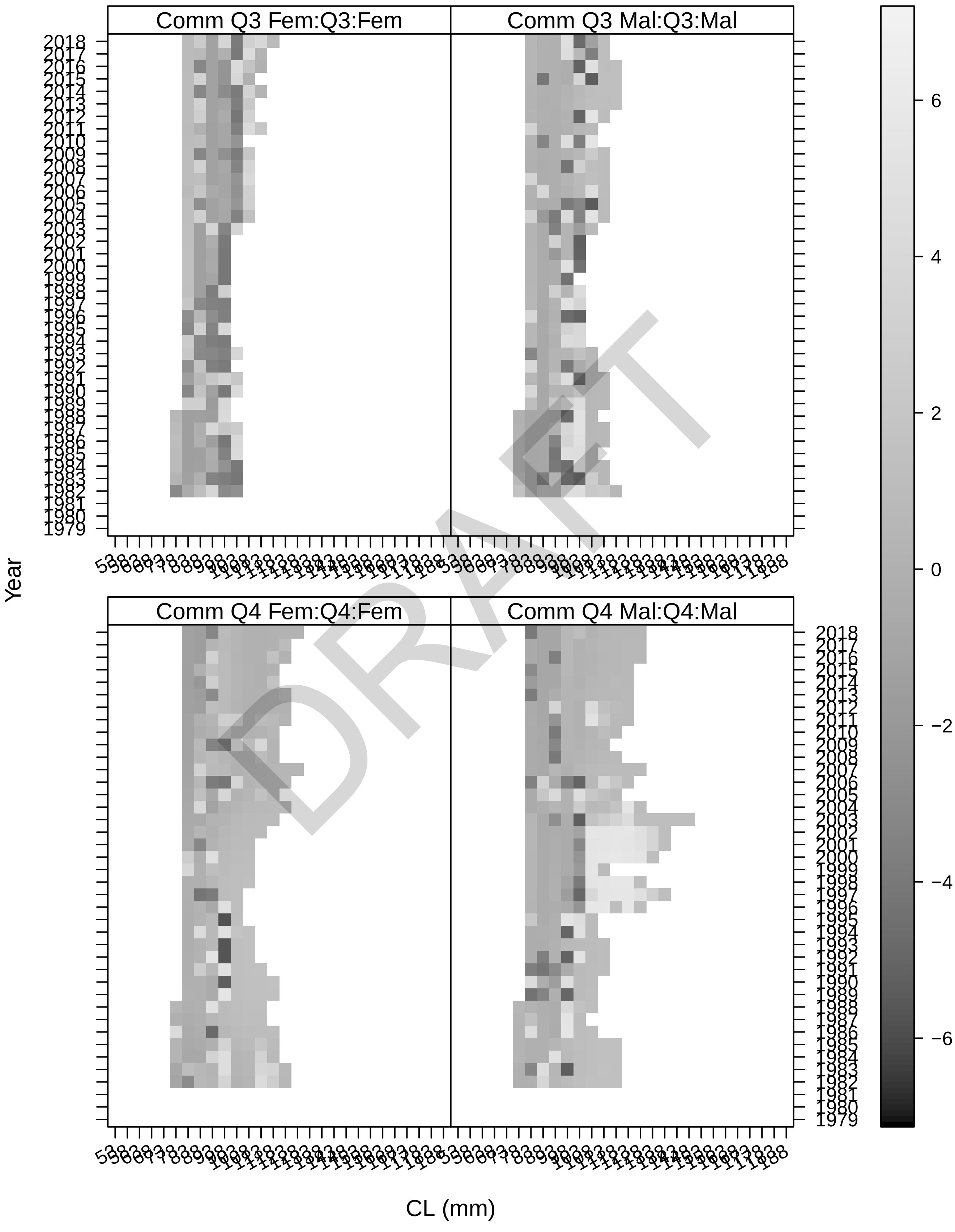

SNE_6F6_2019_orig_select
Length composition deviance residuals
VTSQ3_model:Q3:Fem
VTSQ3_model:Q3:Mal
50
100
150
2018
2016
2014
2012
2010
2008
2006
Year
CL (mm)
Negative residuals clear; postive residuals solid

DRAFT


SNE_6F6_2019_orig_select
Length composition deviance residuals
Comm Q1 Fem:Q1:Fem
Comm Q1 Mal:Q1:Mal
Comm Q2 Fem:Q2:Fem
Comm Q2 Mal:Q2:Mal
Year
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
1993
1992
1991
1990
1989
1988
1987
1986
1985
1984
1983
1982
1981
1980
1979
CL (mm)
6
4
2
0
−2
−4
−6

DRAFT

SNE_6F6_2019_orig_select
Length composition deviance residuals



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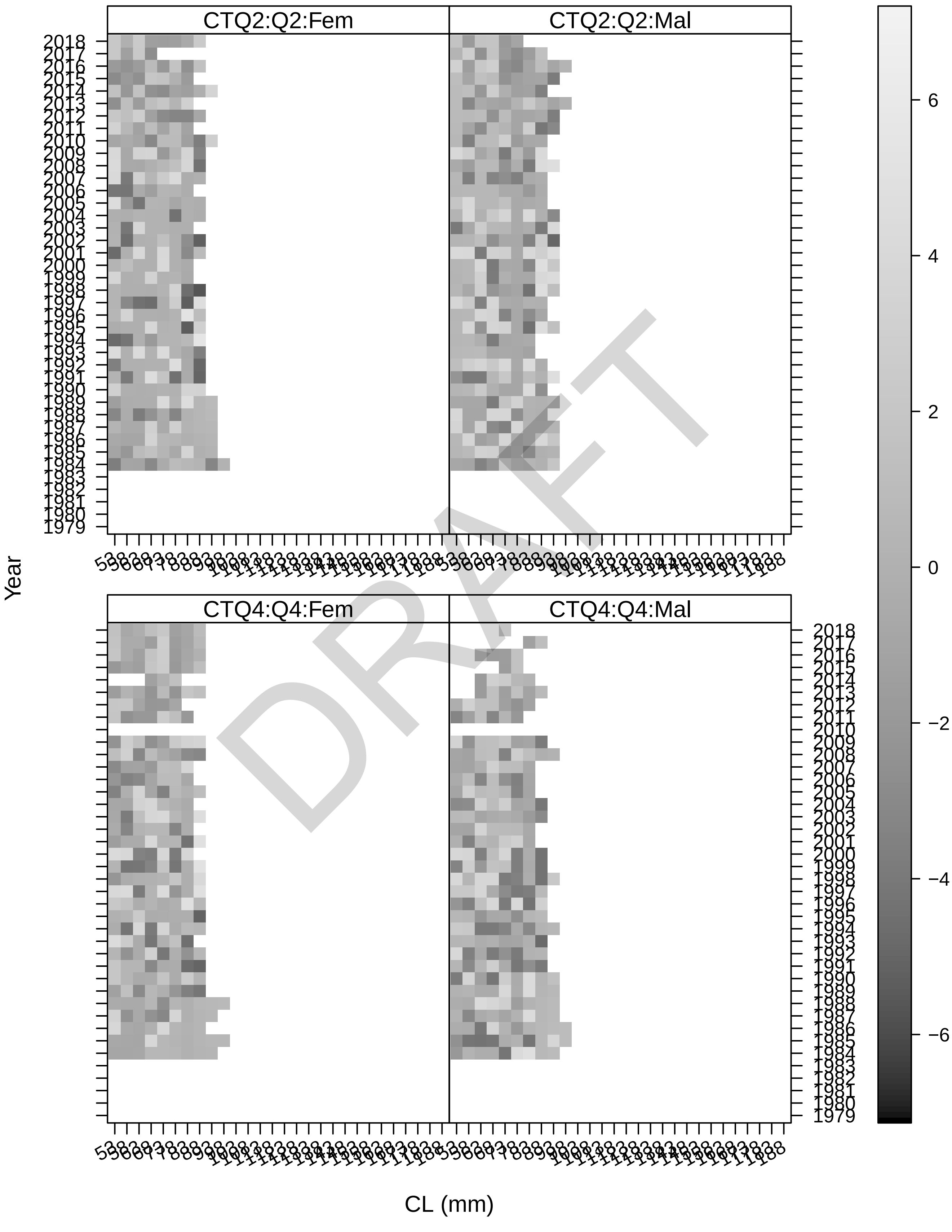
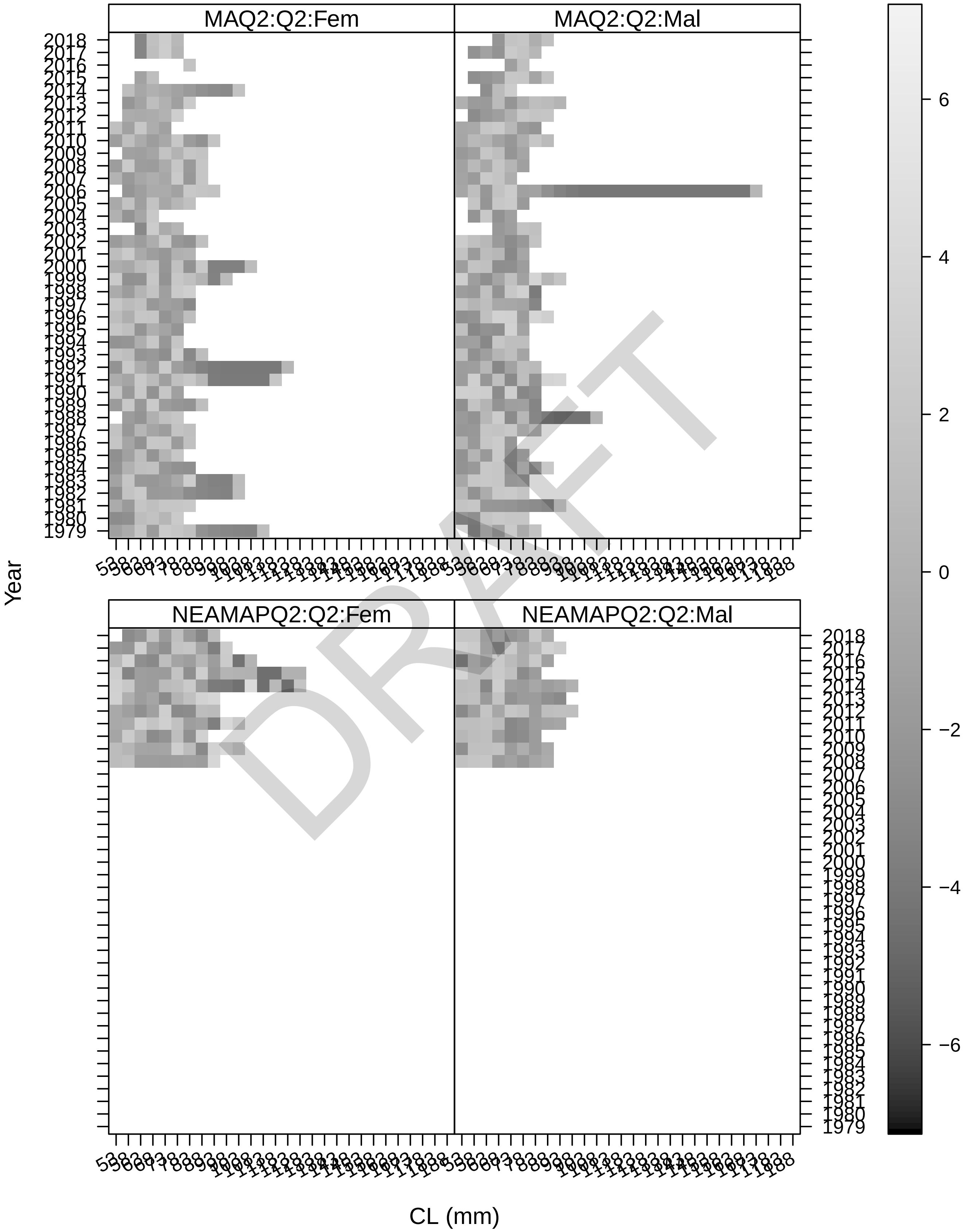
SNE_6F6_2019_orig_select
Length composition deviance residuals

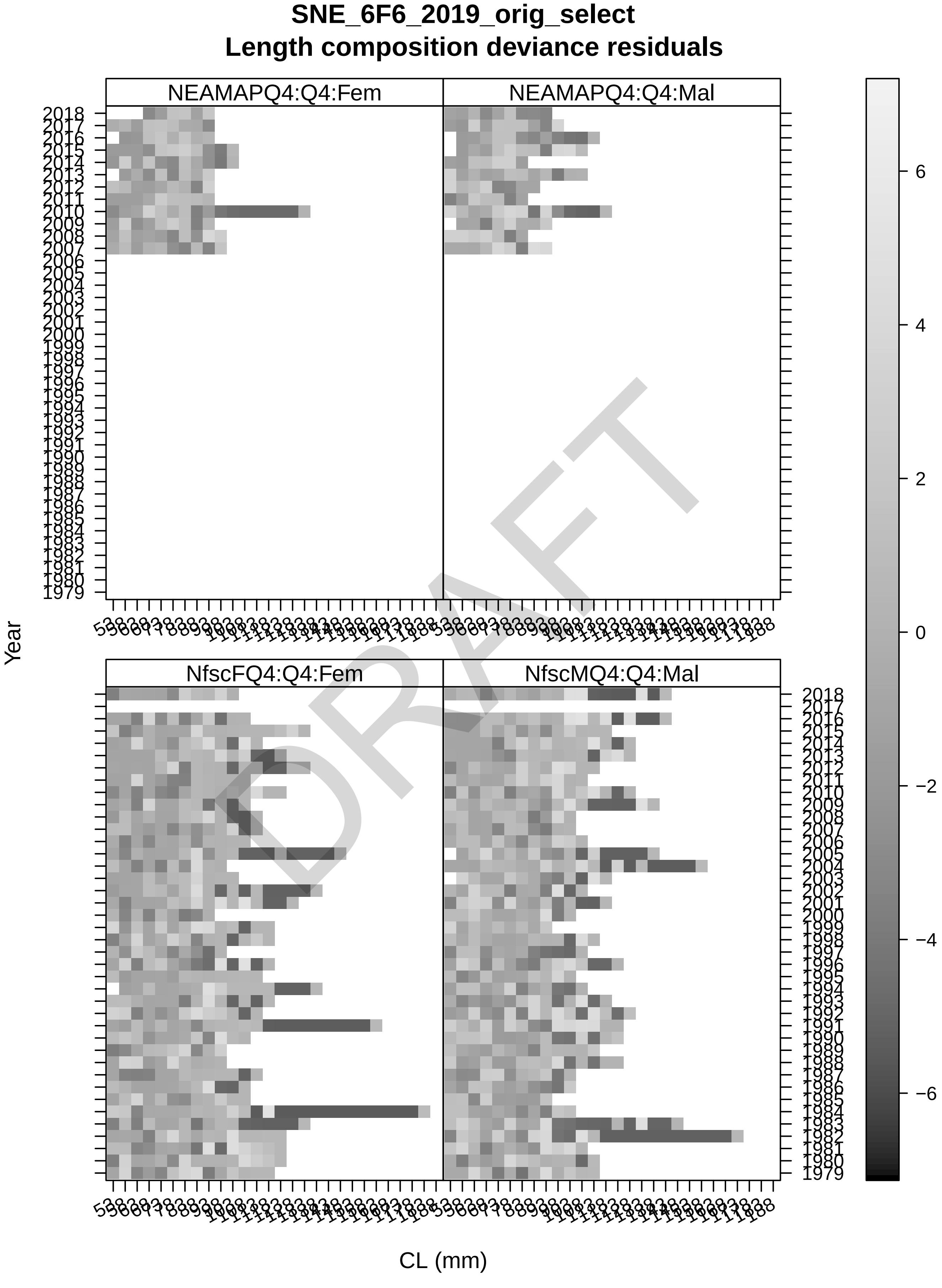


DRAFT

SNE_6F6_2019_orig_select
Length composition deviance residuals



DRAFT


SNE_6F6_2019_orig_select
Length composition deviance residuals
NEAMAPQ4:Q4:Fem
NEAMAPQ4:Q4:Mal
NfscFQ4:Q4:Fem
NfscMQ4:Q4:Mal
Year
CL (mm)
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
1993
1992
1991
1990
1989
1988
1987
1986
1985
1984
1983
1982
1981
1980
1979
6
4
2
0
−2
−4
−6

DRAFT

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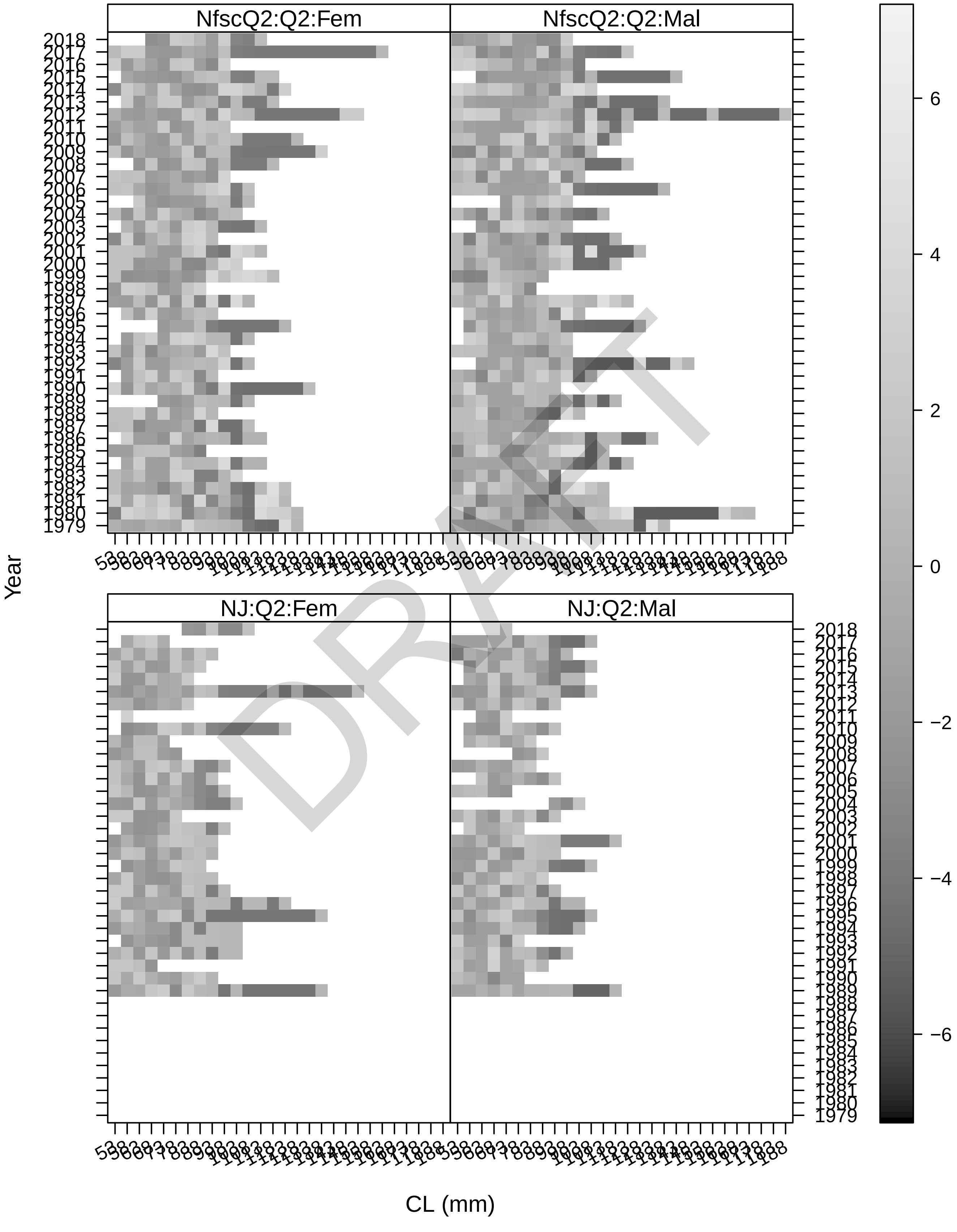
SNE_6F6_2019_orig_select
Length composition deviance residuals



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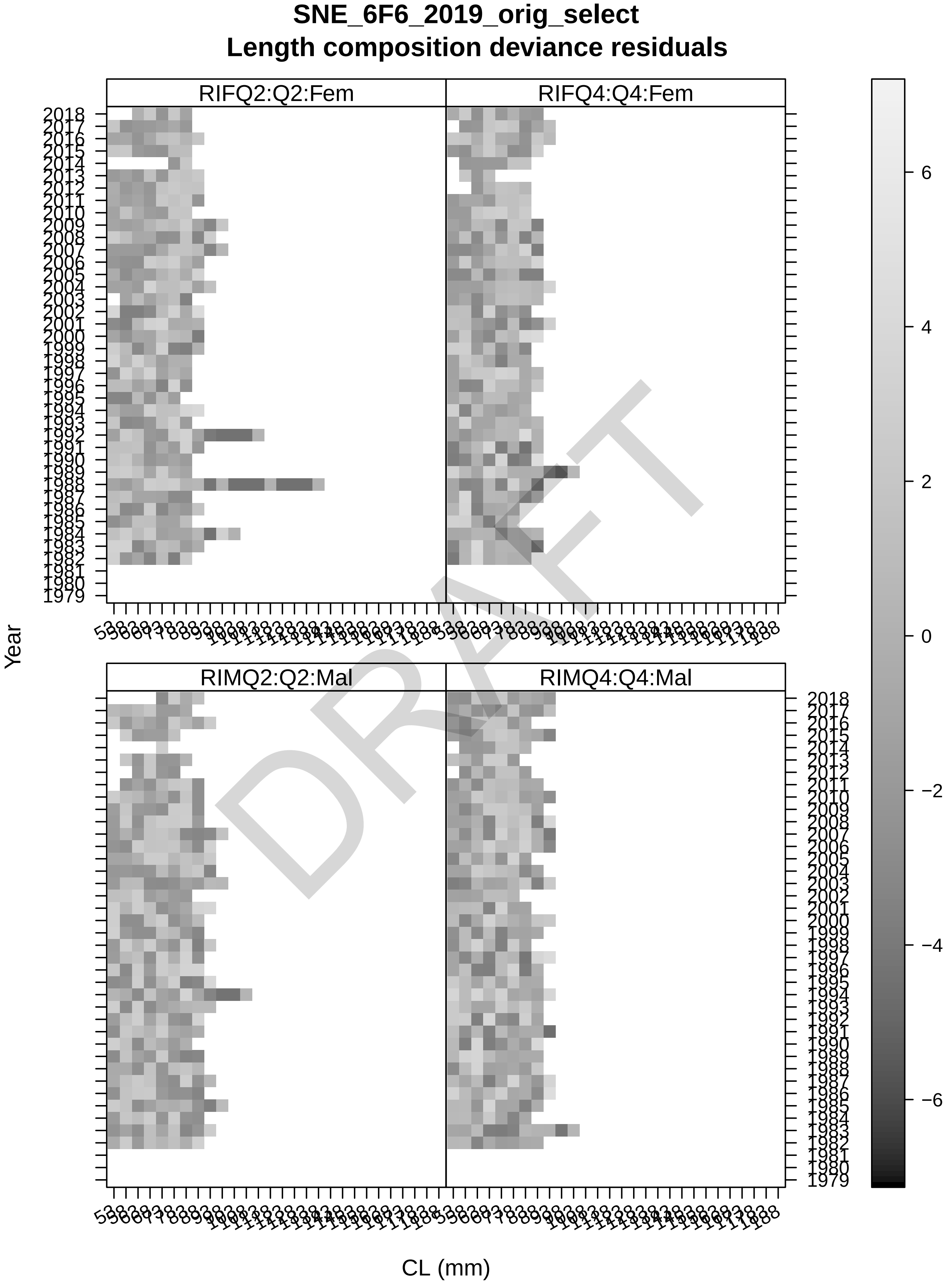
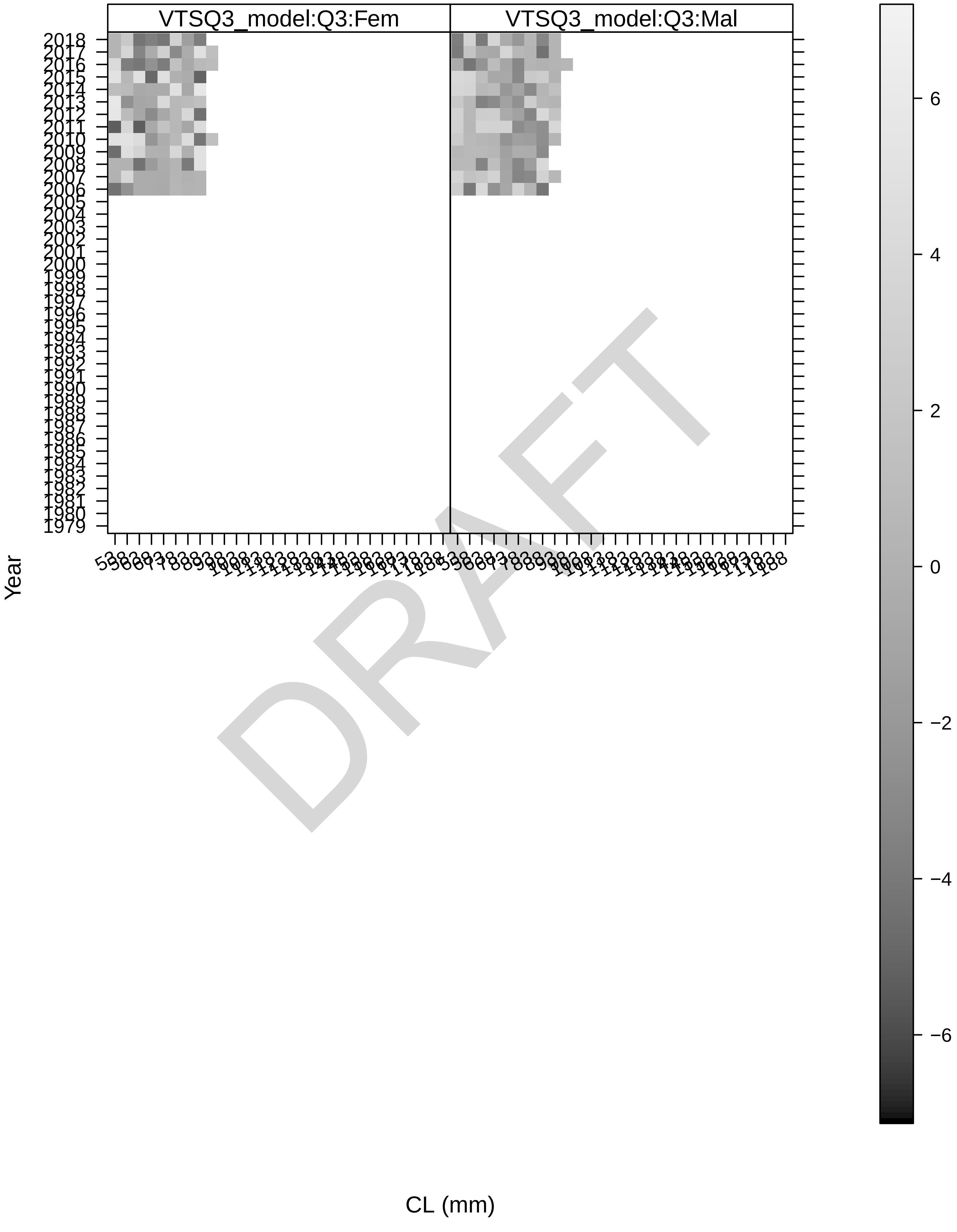
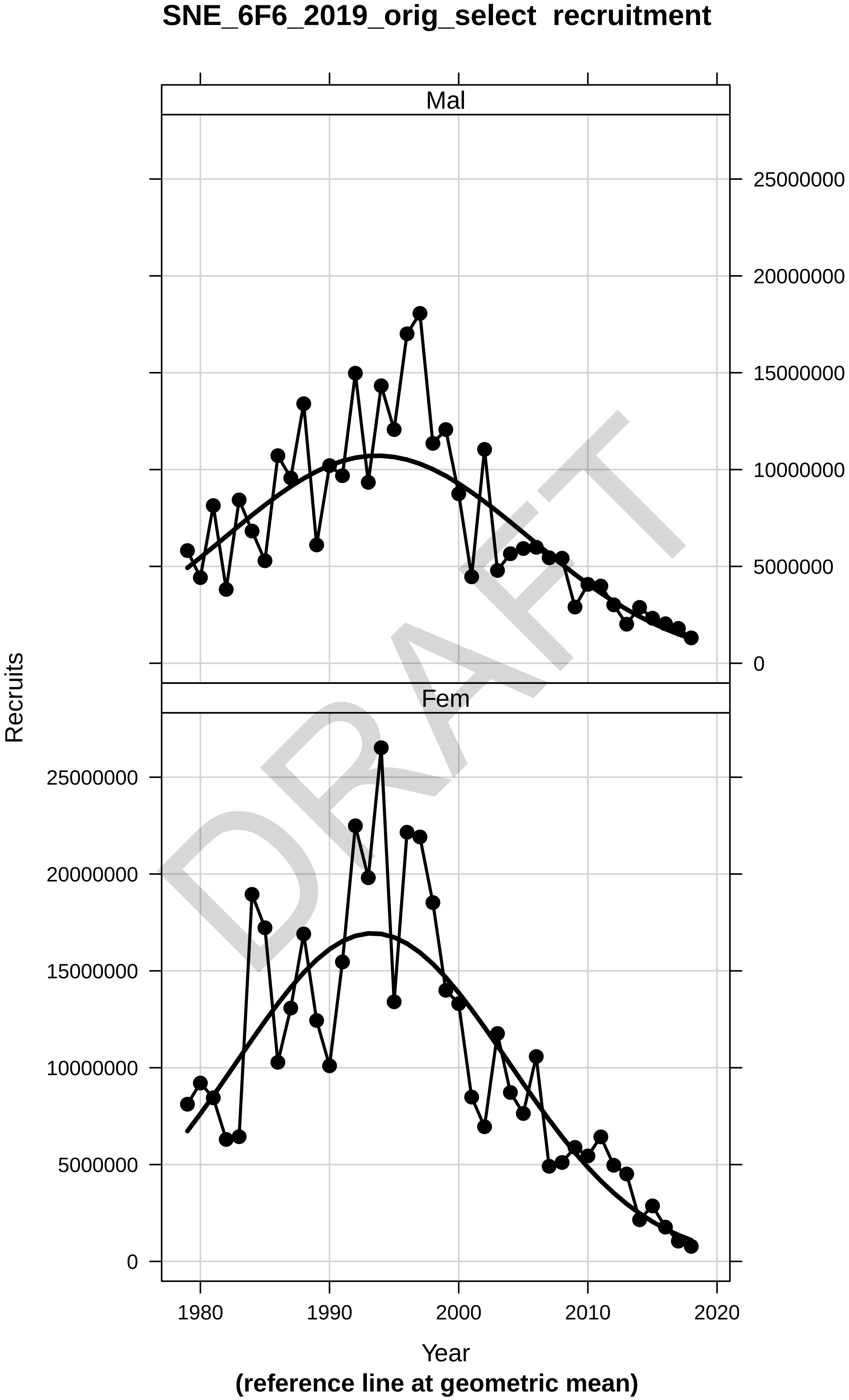

SNE_6F6_2019_orig_select
Length composition deviance residuals
RIFQ2:Q2:Fem
RIFQ4:Q4:Fem
RIMQ2:Q2:Mal
RIMQ4:Q4:Mal
Year
CL (mm)
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
1993
1992
1991
1990
1989
1988
1987
1986
1985
1984
1983
1982
1981
1980
1979
6
4
2
0
−2
−4
−6

DRAFT

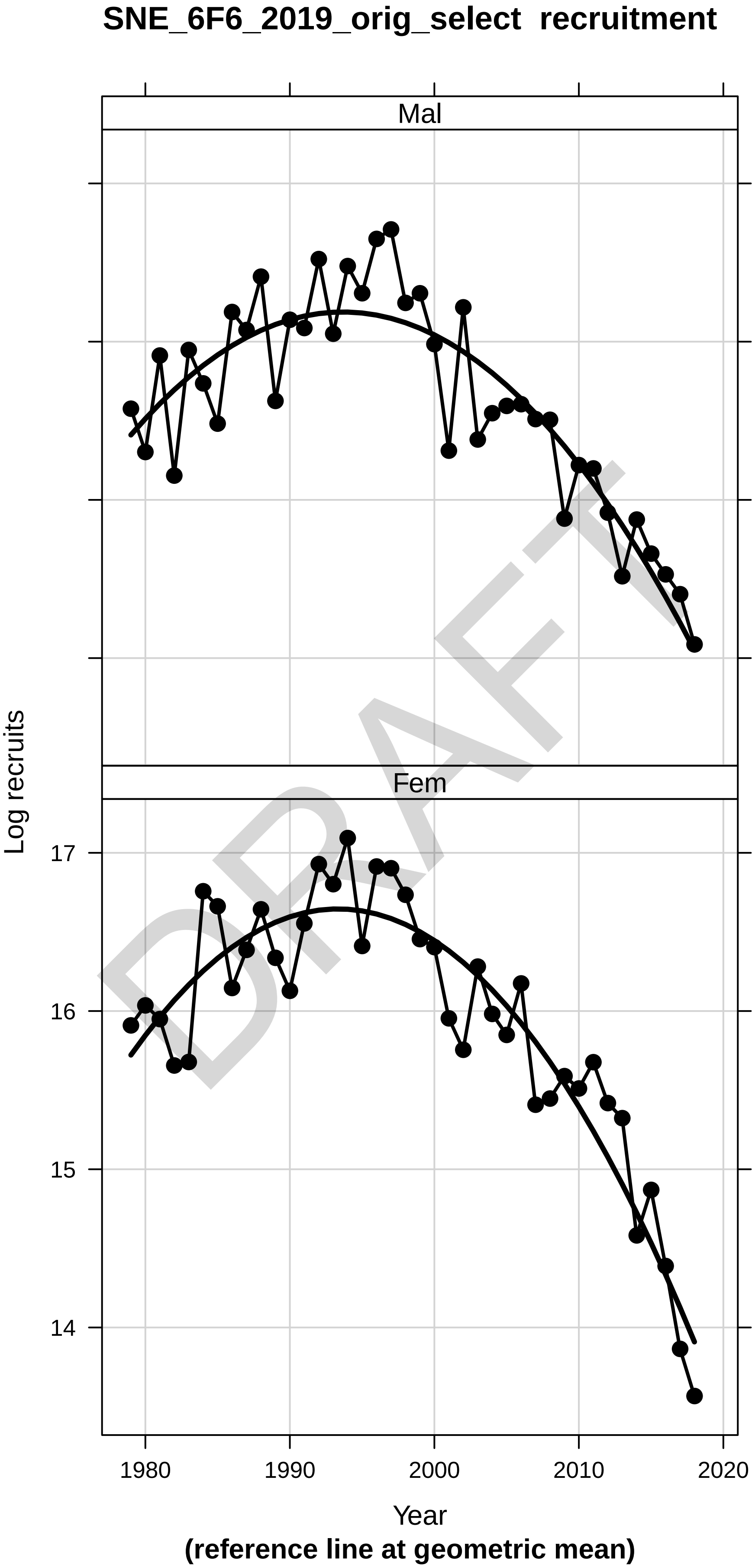
SNE_6F6_2019_orig_select
Length composition deviance residuals



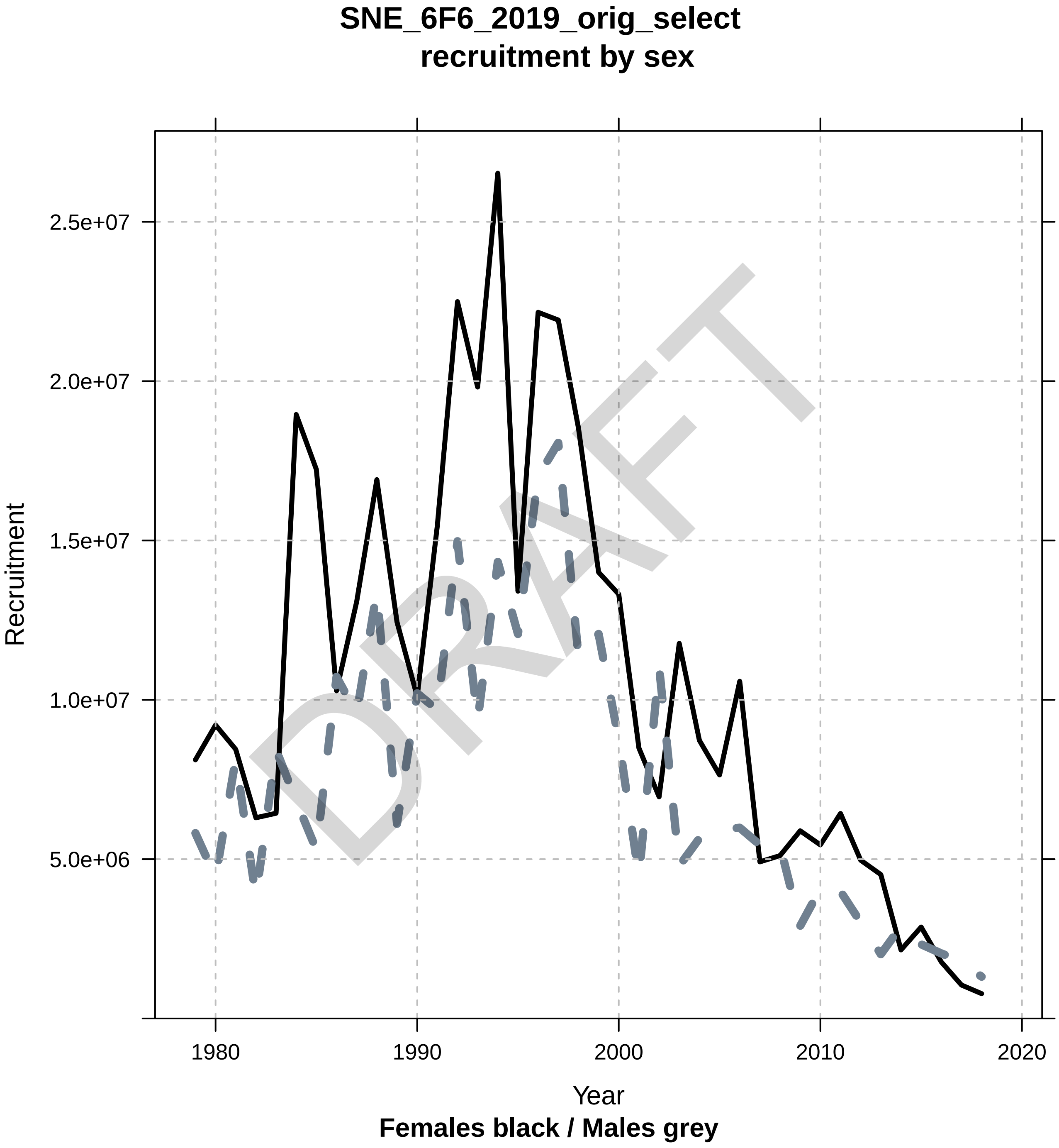
DRAFT

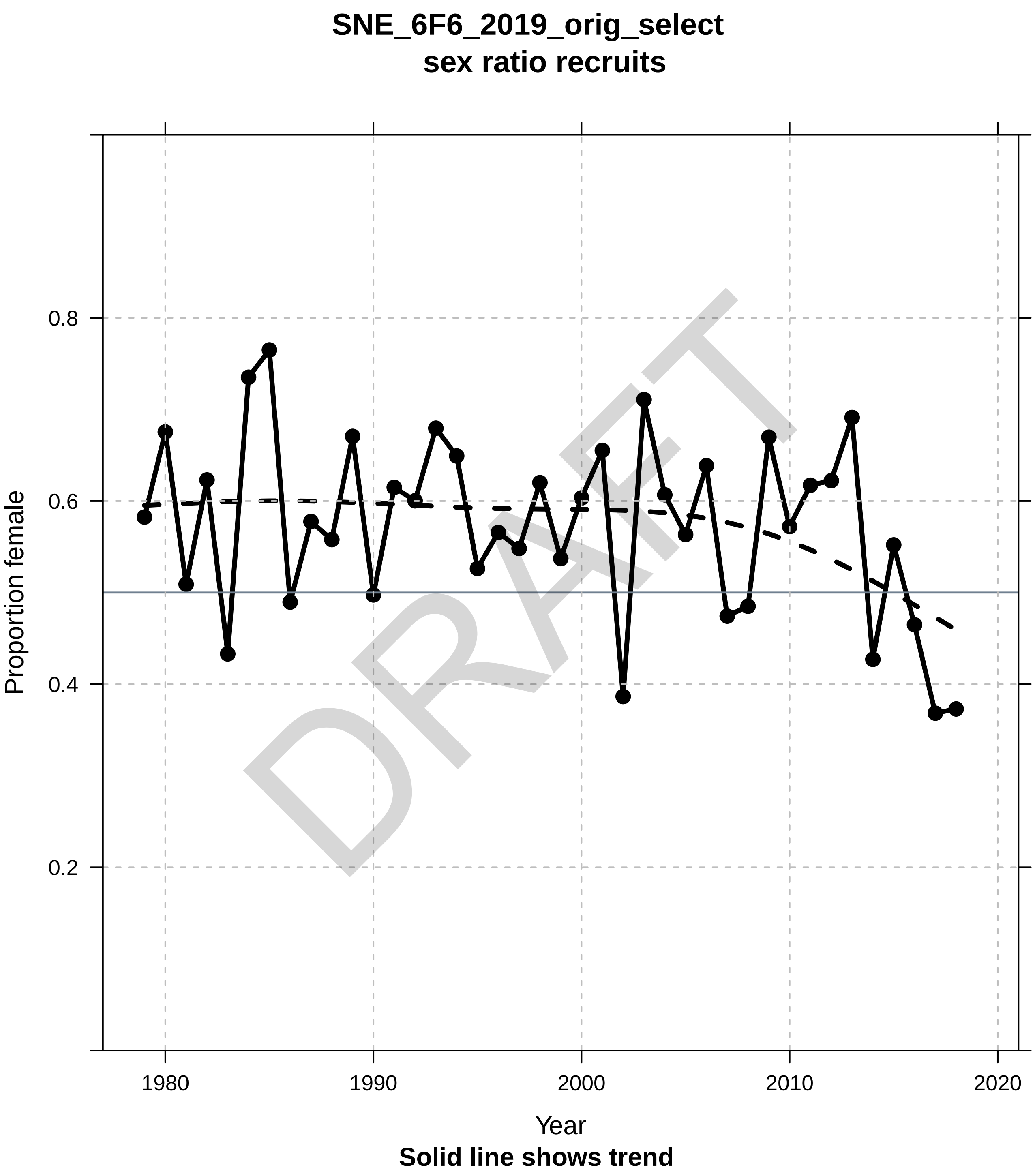

SNE_6F6_2019_orig_select recruitment
Mal
Fem
Recruits
0
5000000
10000000
15000000
20000000
25000000
1980
1990
2000
2010
2020
Year
(reference line at geometric mean)

DRAFT


SNE_6F6_2019_orig_select recruitment
Mal
Fem
Log recruits
14
15
16
17
1980
1990
2000
2010
2020
Year
(reference line at geometric mean)

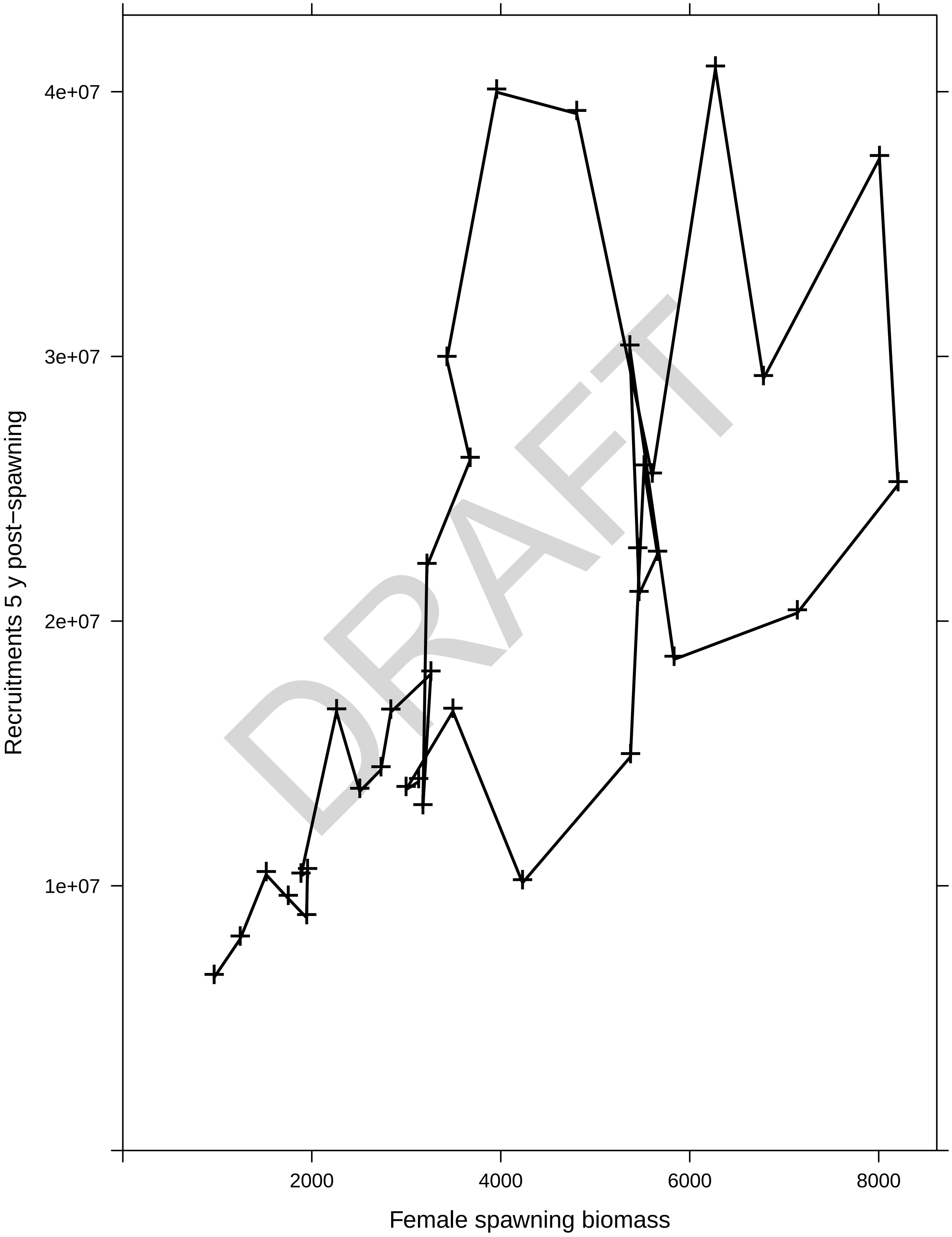
DRAFT


SNE_6F6_2019_orig_select
recruitment by sex
Recruitment
2.5e+07
2.0e+07
1.5e+07
1.0e+07
5.0e+06
1980
1990
2000
2010
2020
Year
Females black / Males grey
DRAFT

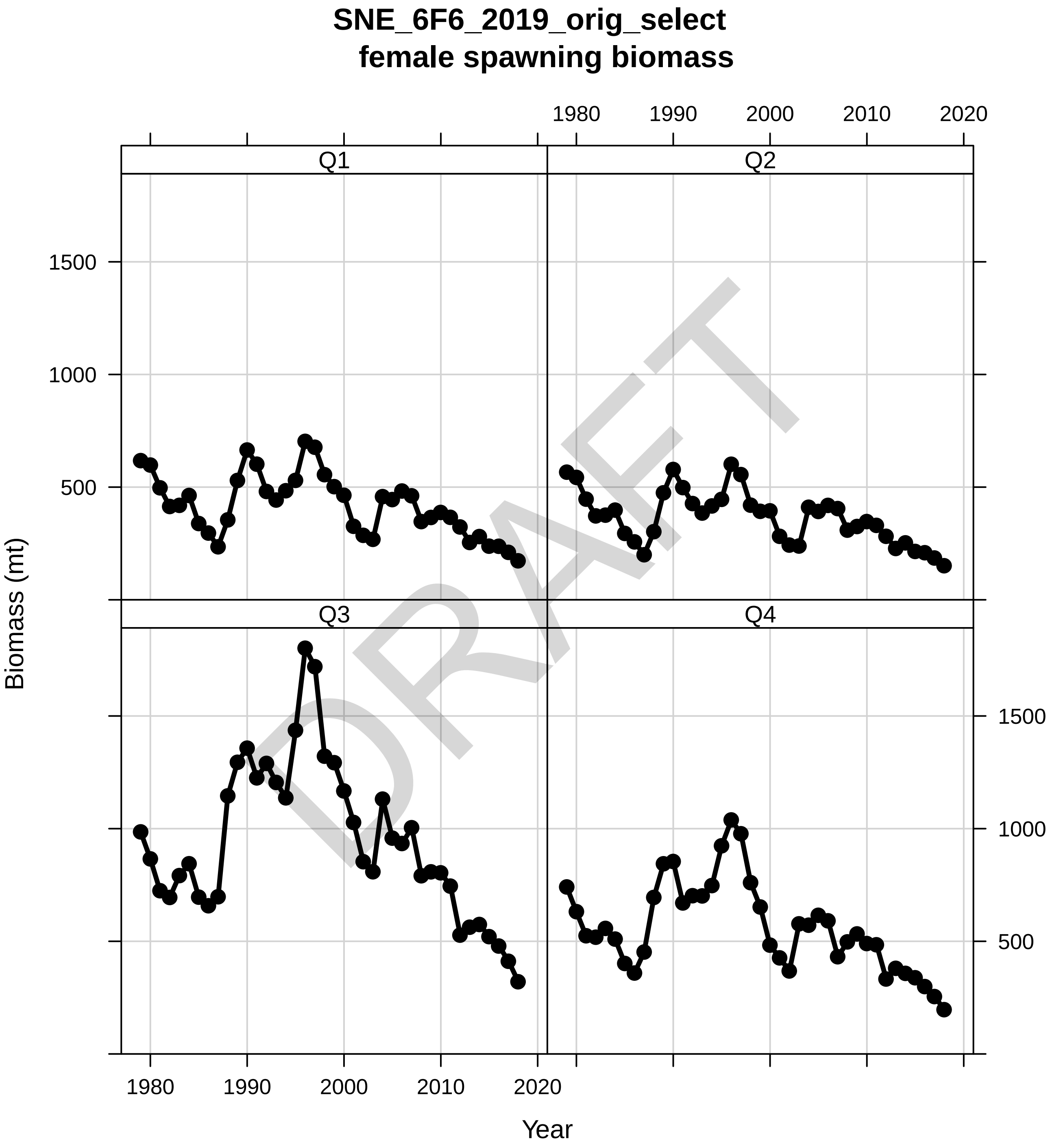

SNE_6F6_2019_orig_select
sex ratio recruits
Proportion female
0.8
0.6
0.4
0.2
1980
1990
2000
2010
2020
Year
Solid line shows trend

DRAFT

SNE_6F6_2019_orig_select spawning biomass−recruitment plot (recruits lag 5 y)

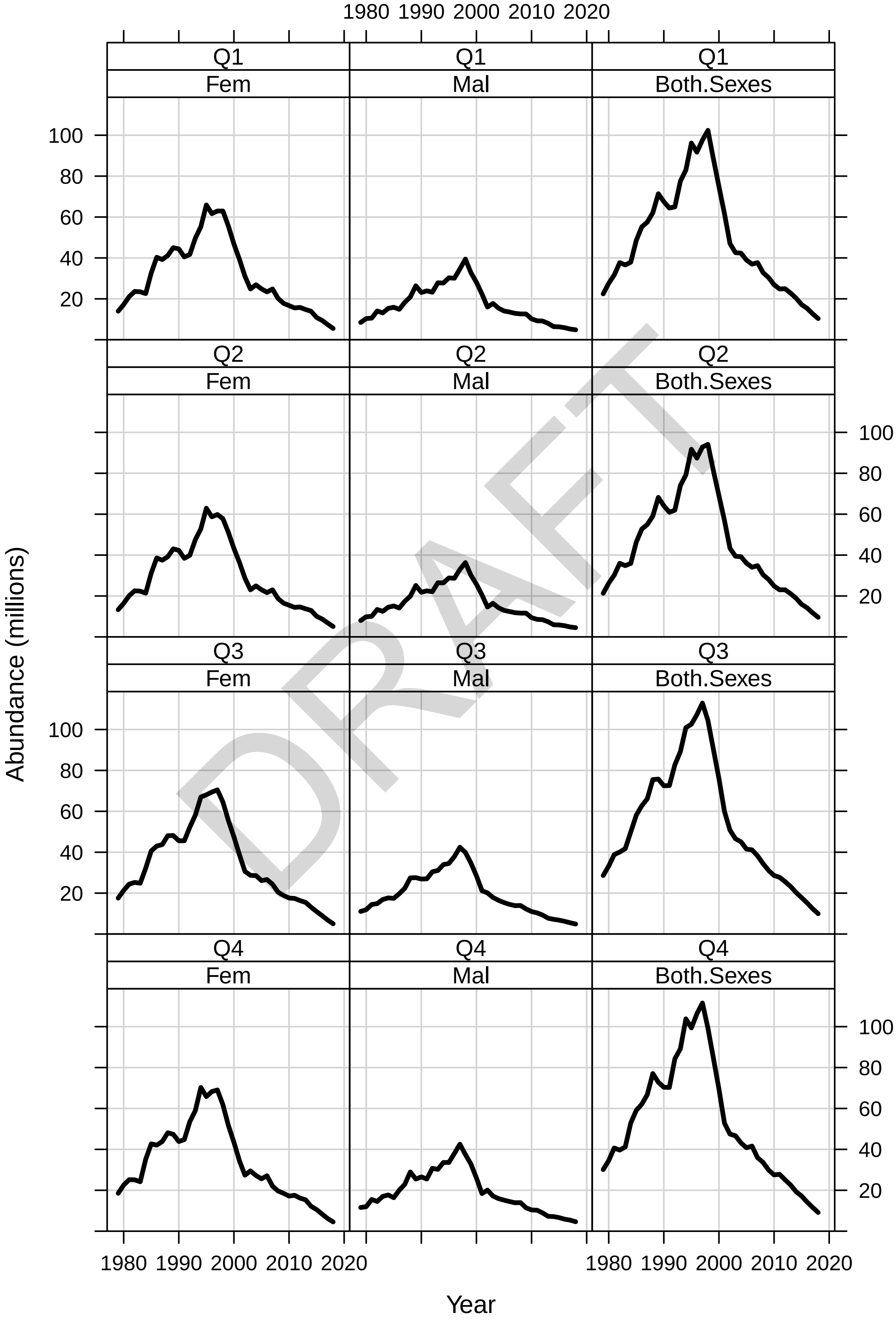


DRAFT


SNE_6F6_2019_orig_select
female spawning biomass
Q1
Q2
Q3
Q4
Biomass (mt)
Year
500
1000
1500
1980
1990
2000
2010
2020

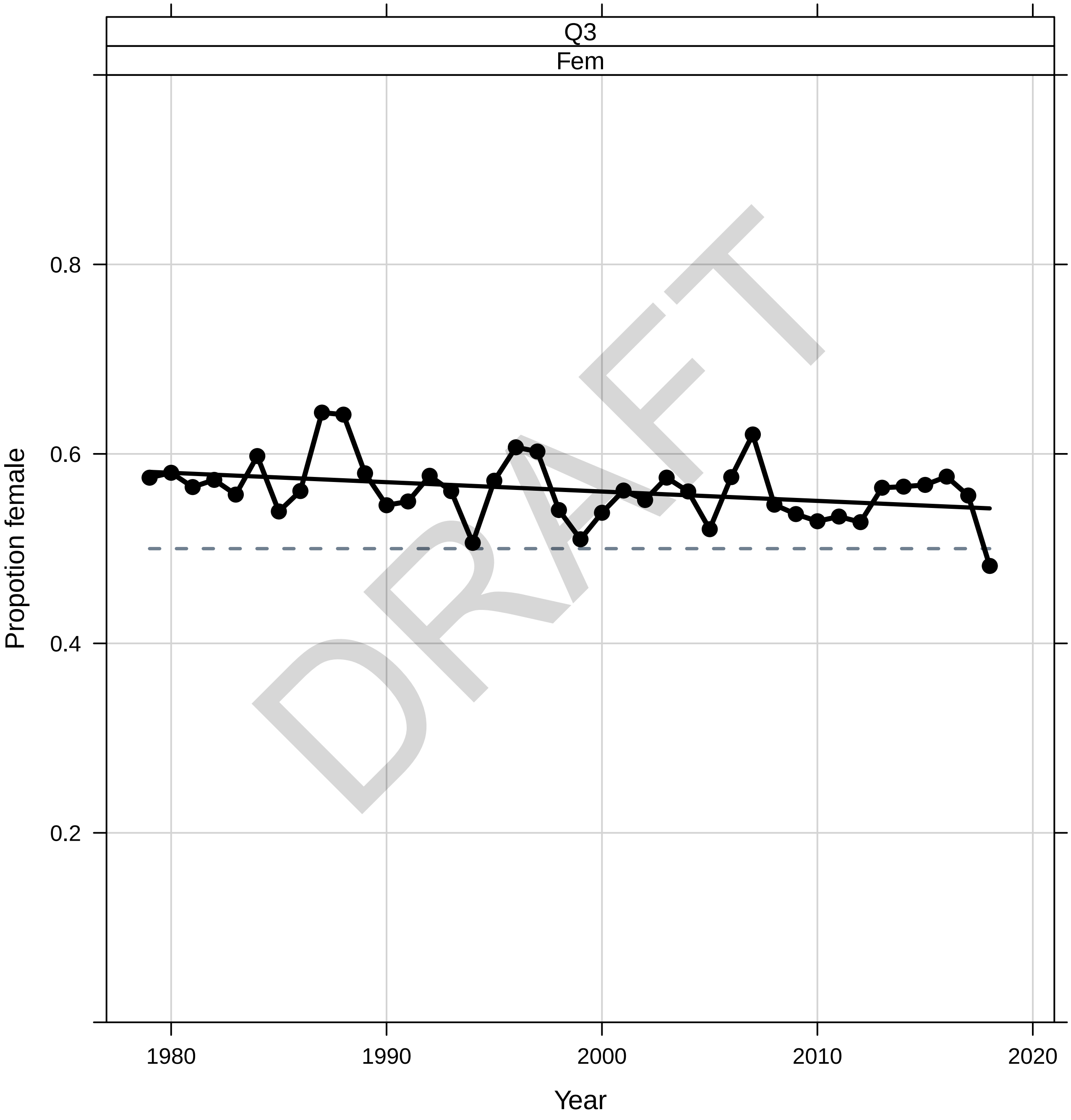
DRAFT

SNE_6F6_2019_orig_select estimated total abundance



DRAFT

SNE_6F6_2019_orig_select
sex ratio legal sizes



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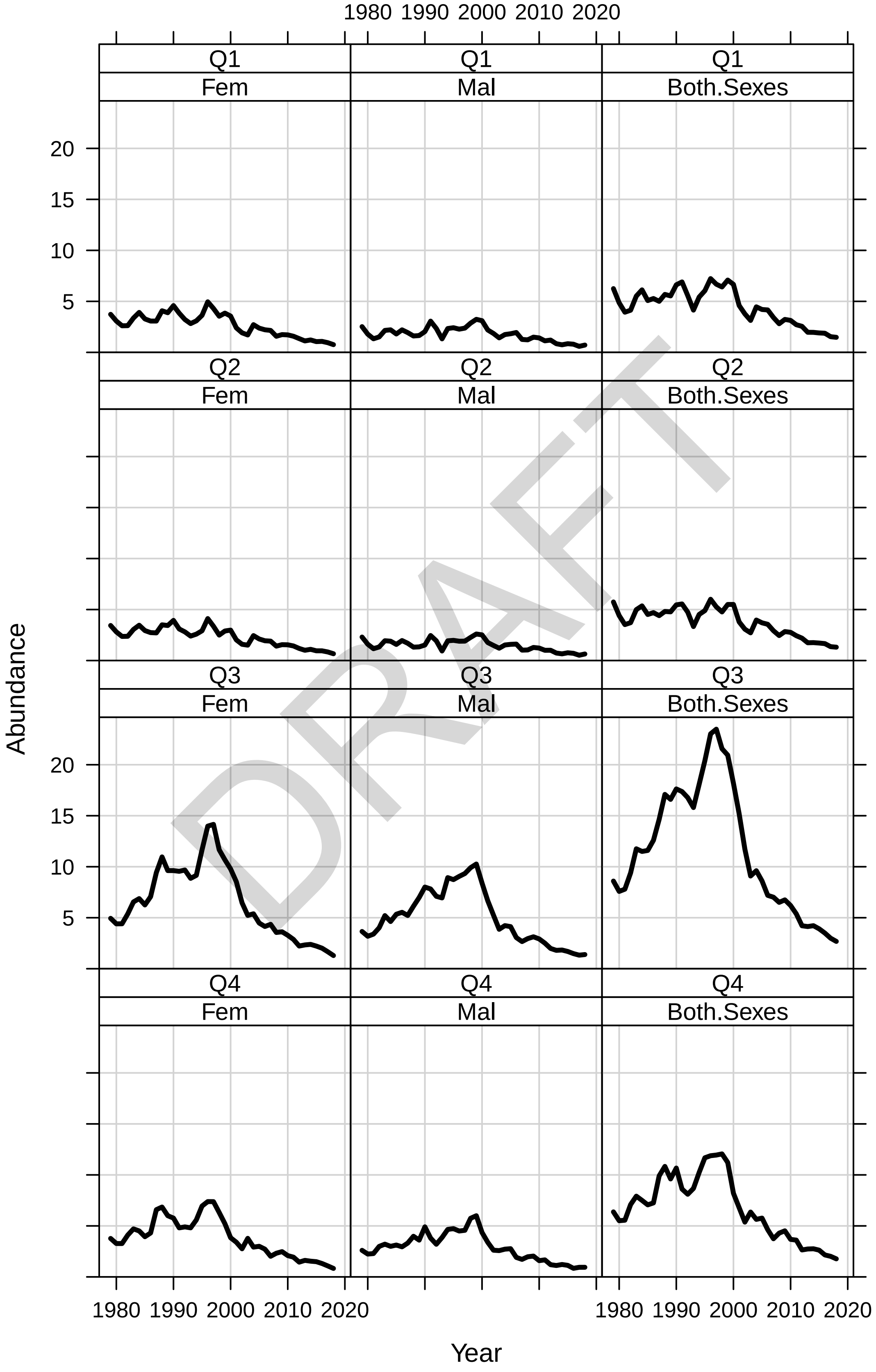
Solid line shows trend

SNE_6F6_2019_orig_select
legal abundance



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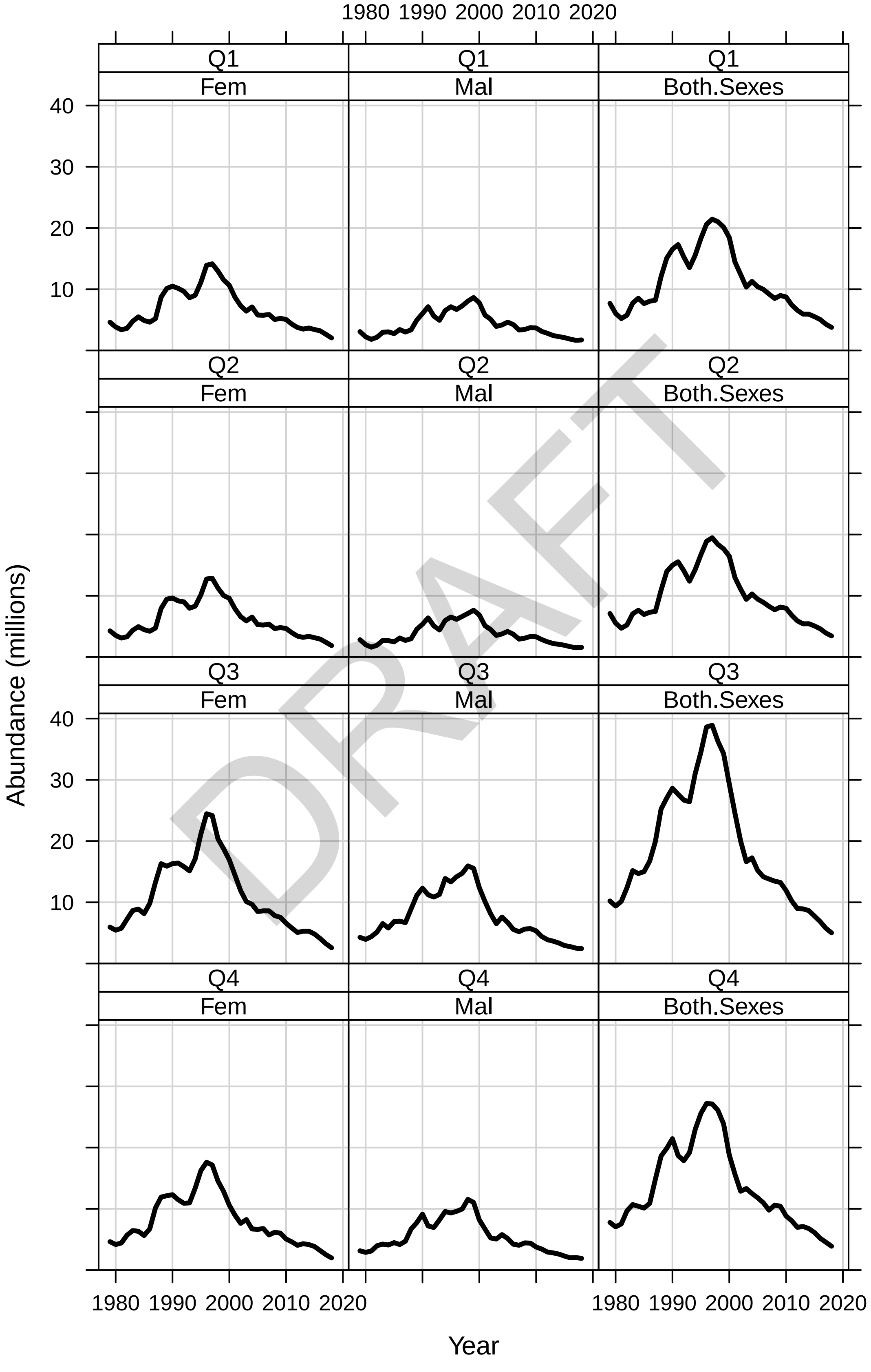
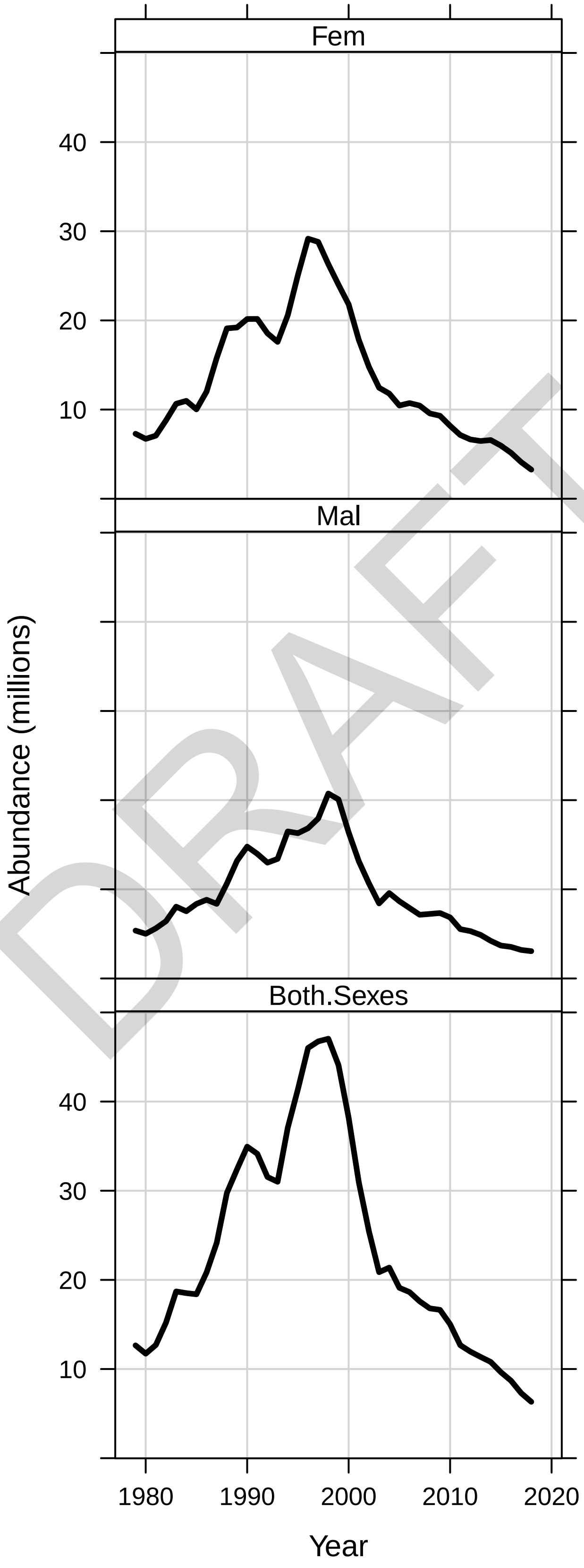
SNE_6F6_2019_orig_select abundance 78 + mm CL



DRAFT

SNE_6F6_2019_orig_select
abundance reference population on Jan. 1



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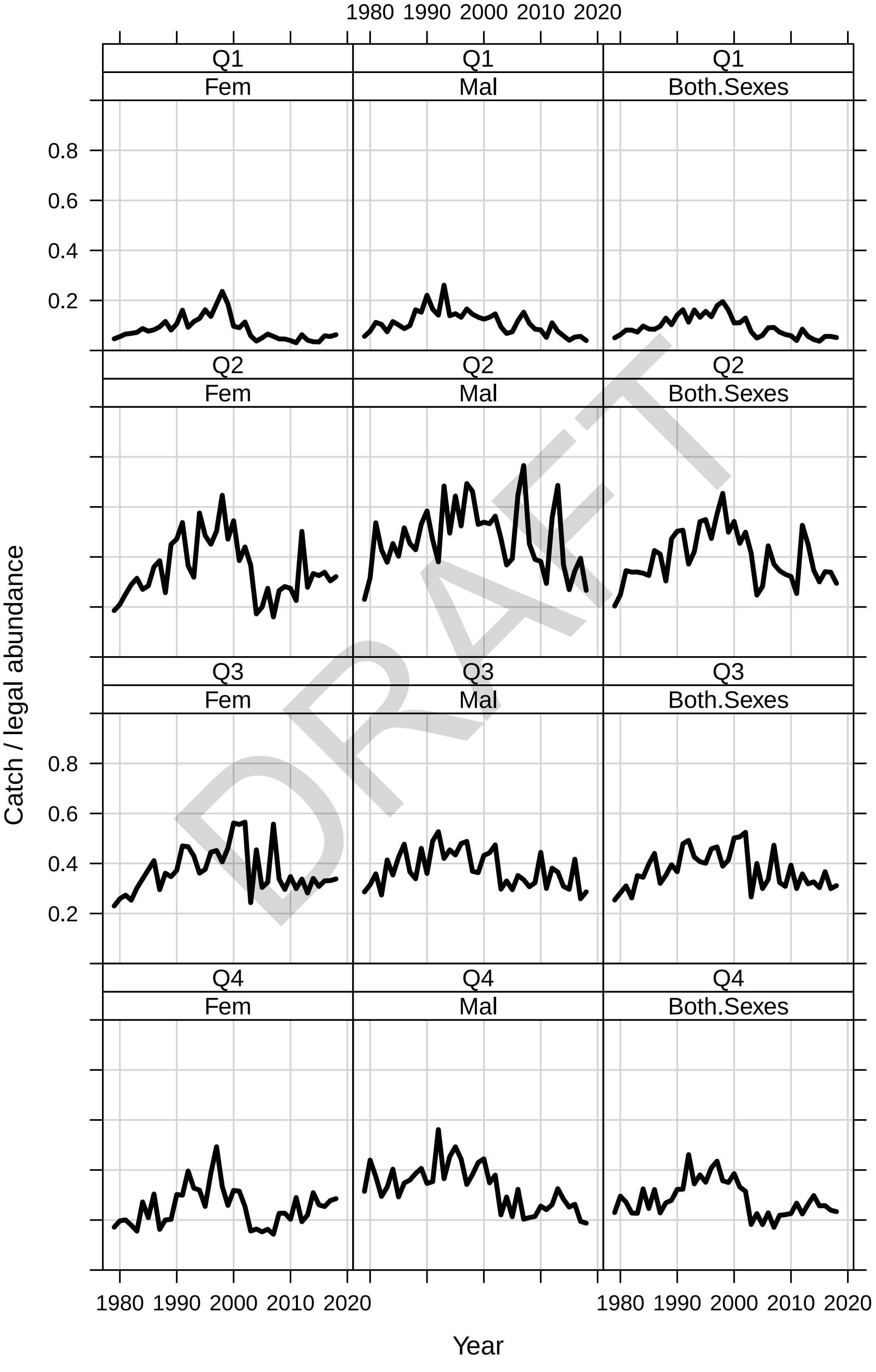
SNE_6F6_2019_orig_select
quarterly exploitation rate (catch/legal abundance)



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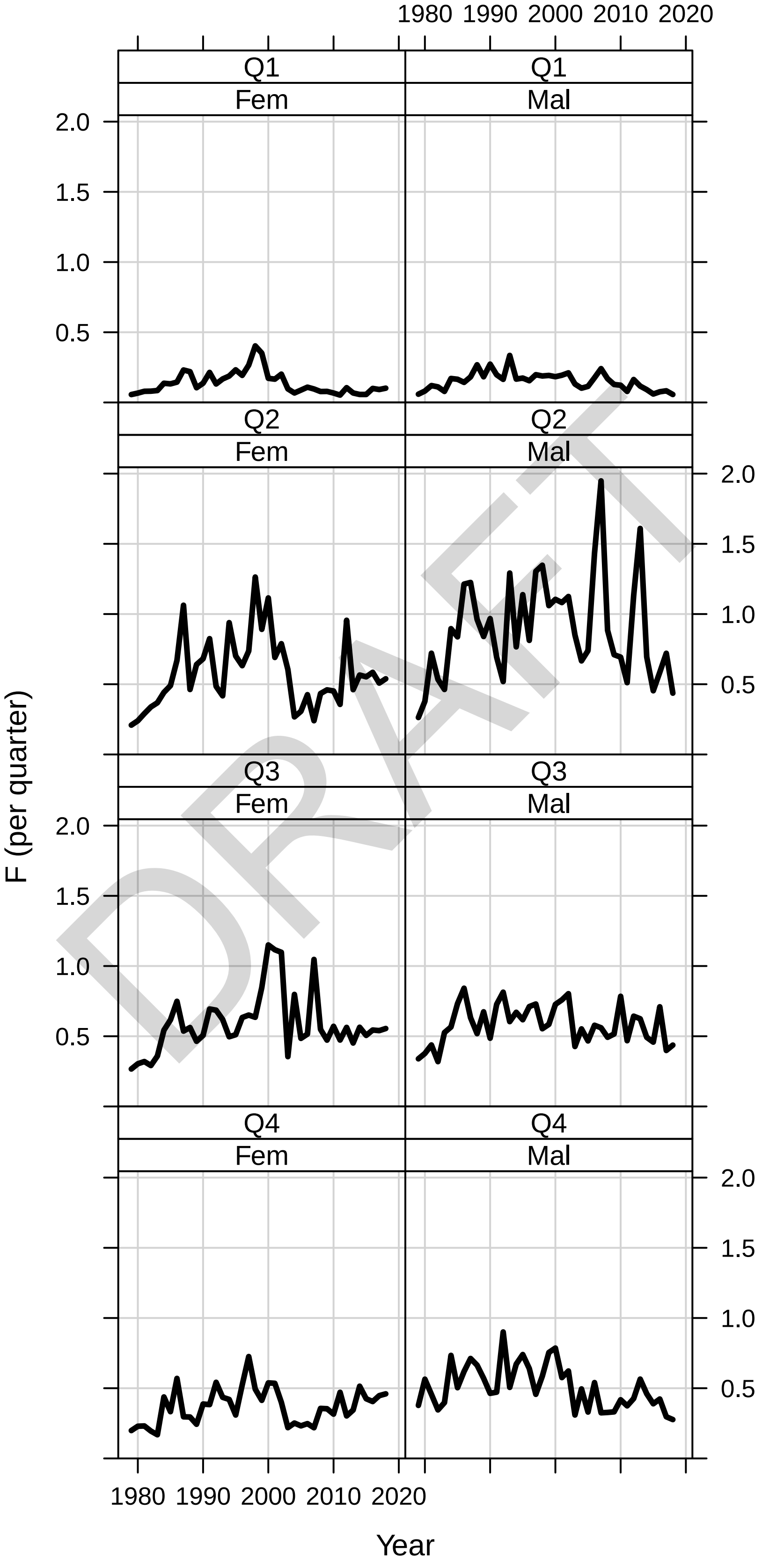
SNE_6F6_2019_orig_select
annual effective exploitation rate

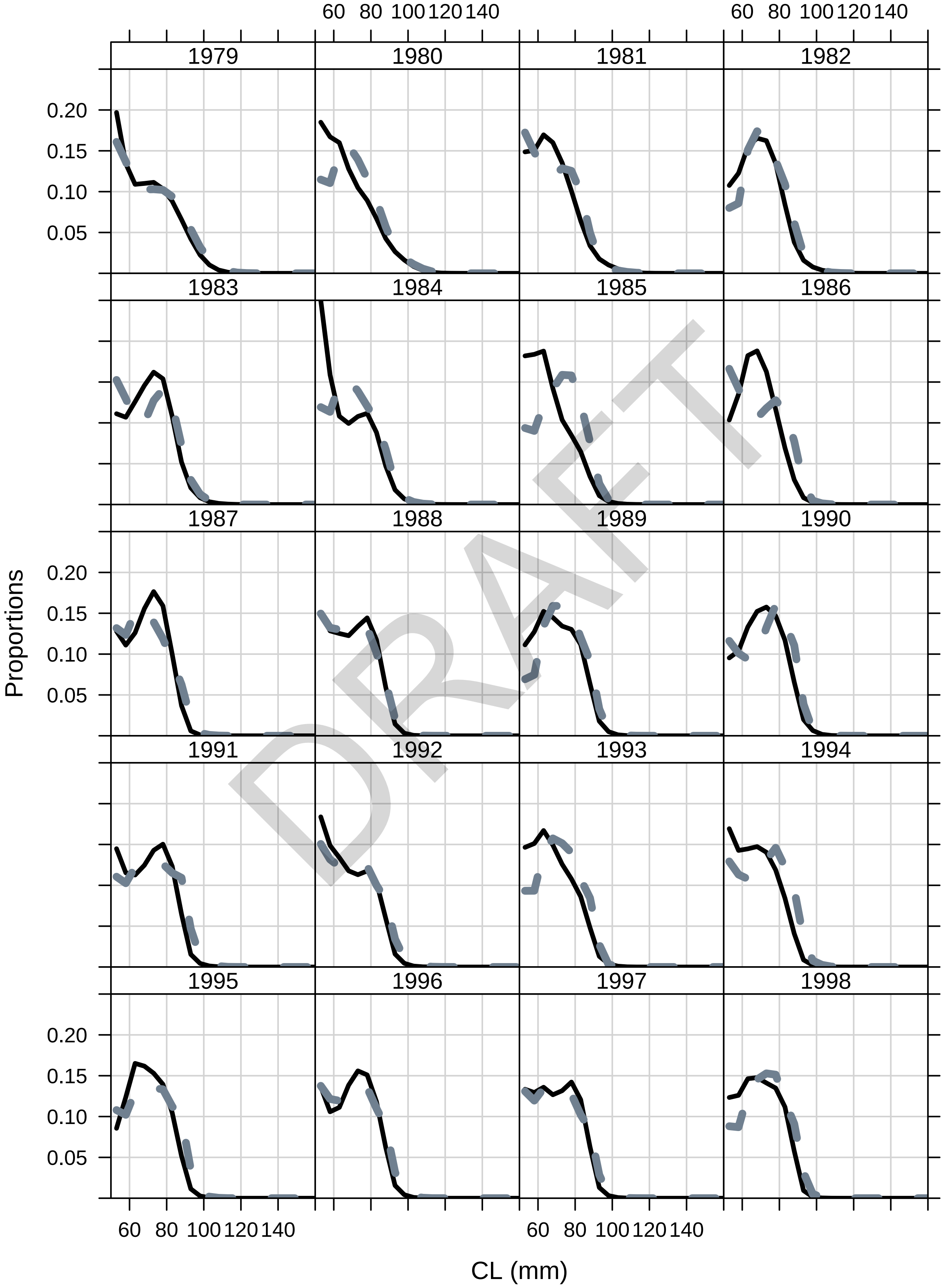
DRAFT

SNE_6F6_2019_orig_select
fully recruited fishing mortality as quarterly rates



DRAFT

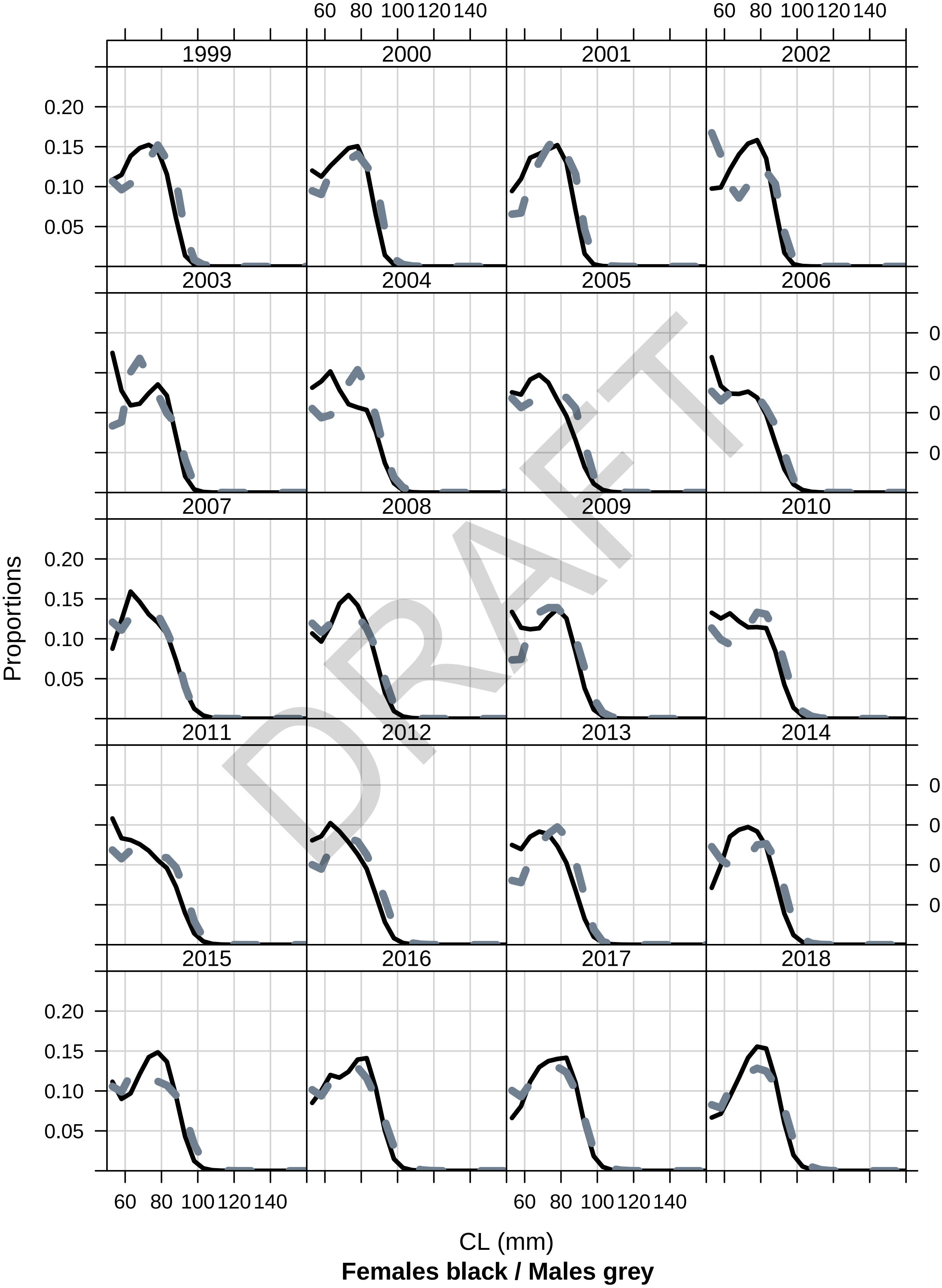
SNE_6F6_2019_orig_select
summer population size composition



DRAFT

Females black / Males grey

SNE_6F6_2019_orig_select
summer population size composition



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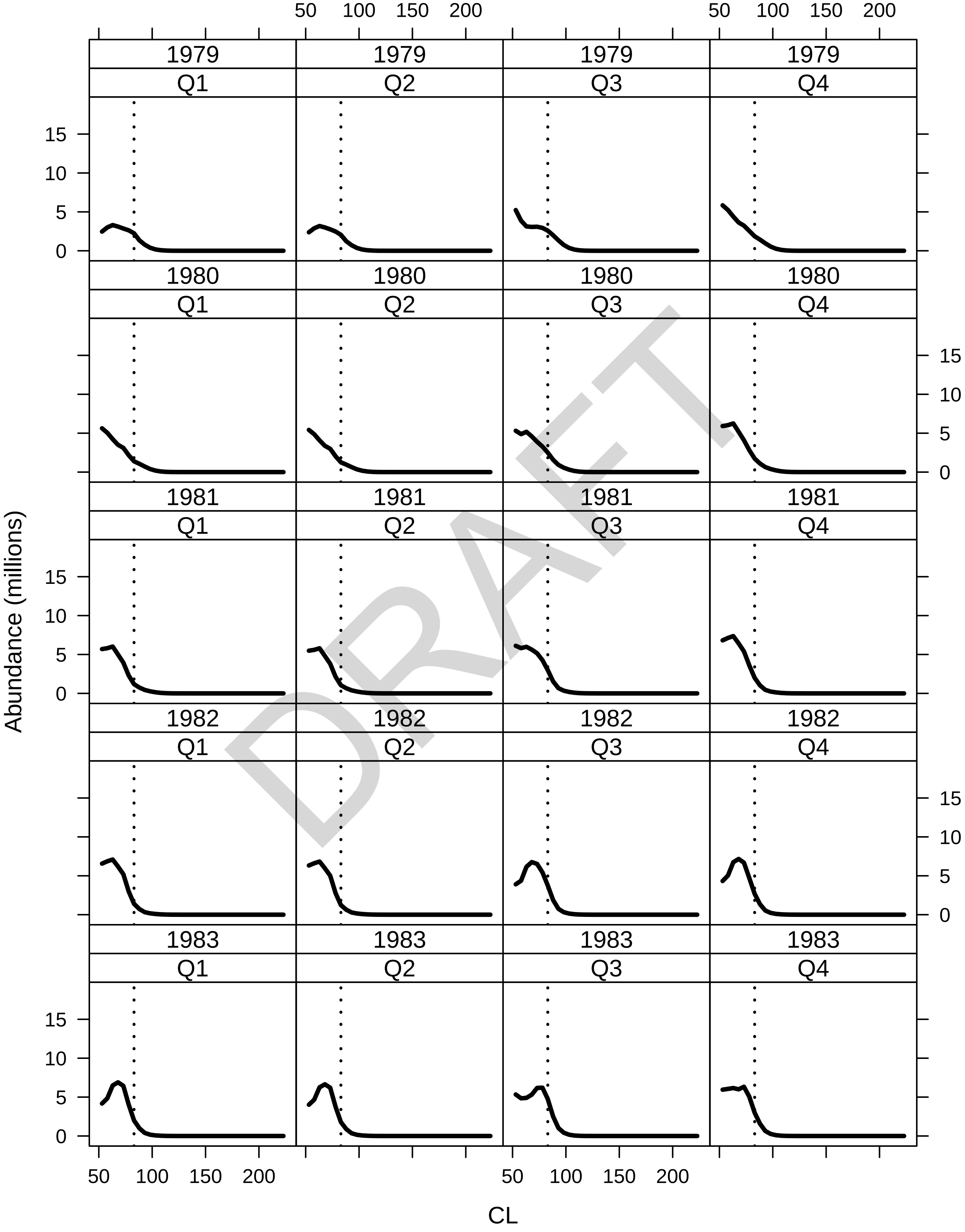
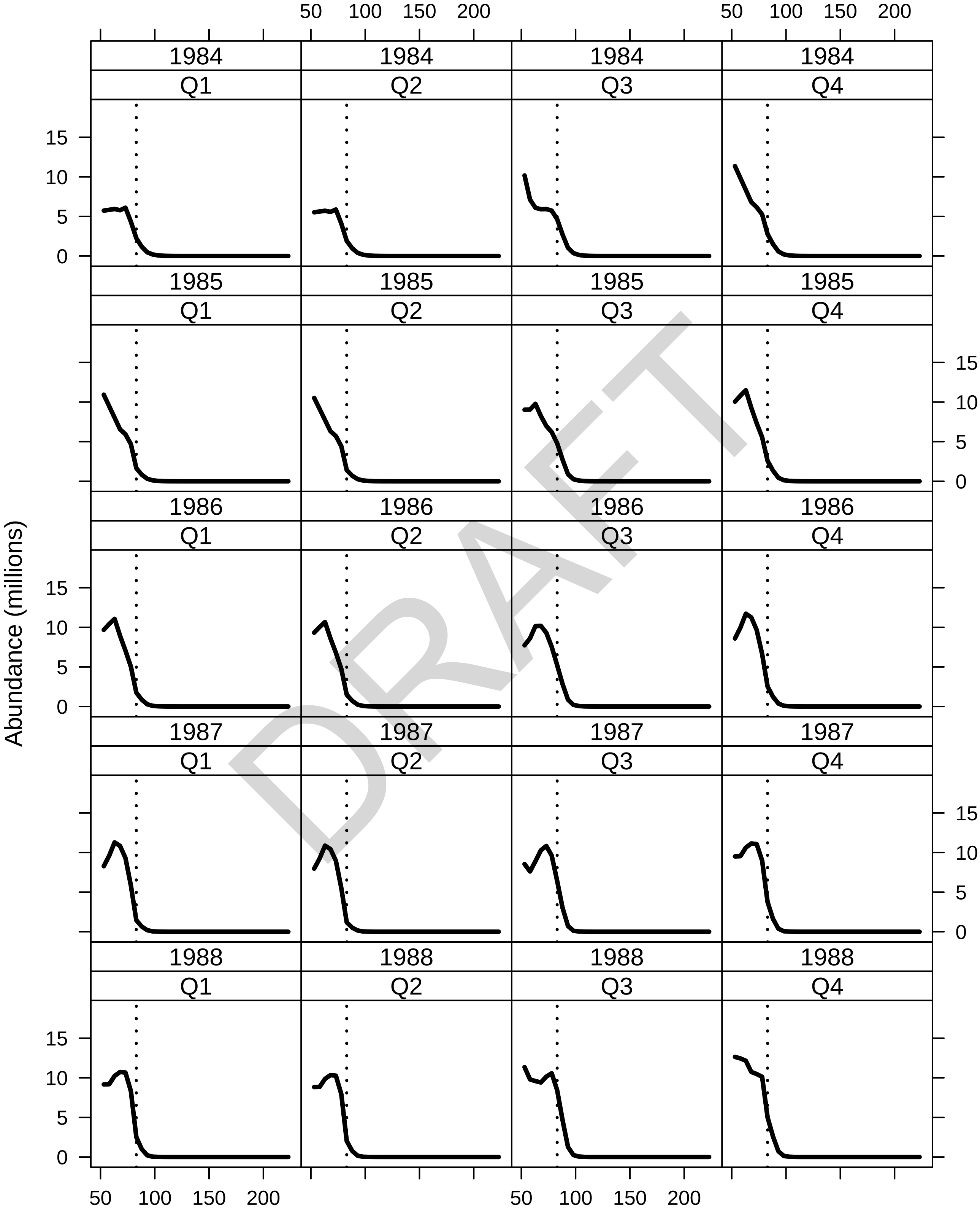
SNE_6F6_2019_orig_select
combined sex abundance at length



DRAFT

Vertical line at 83 mm

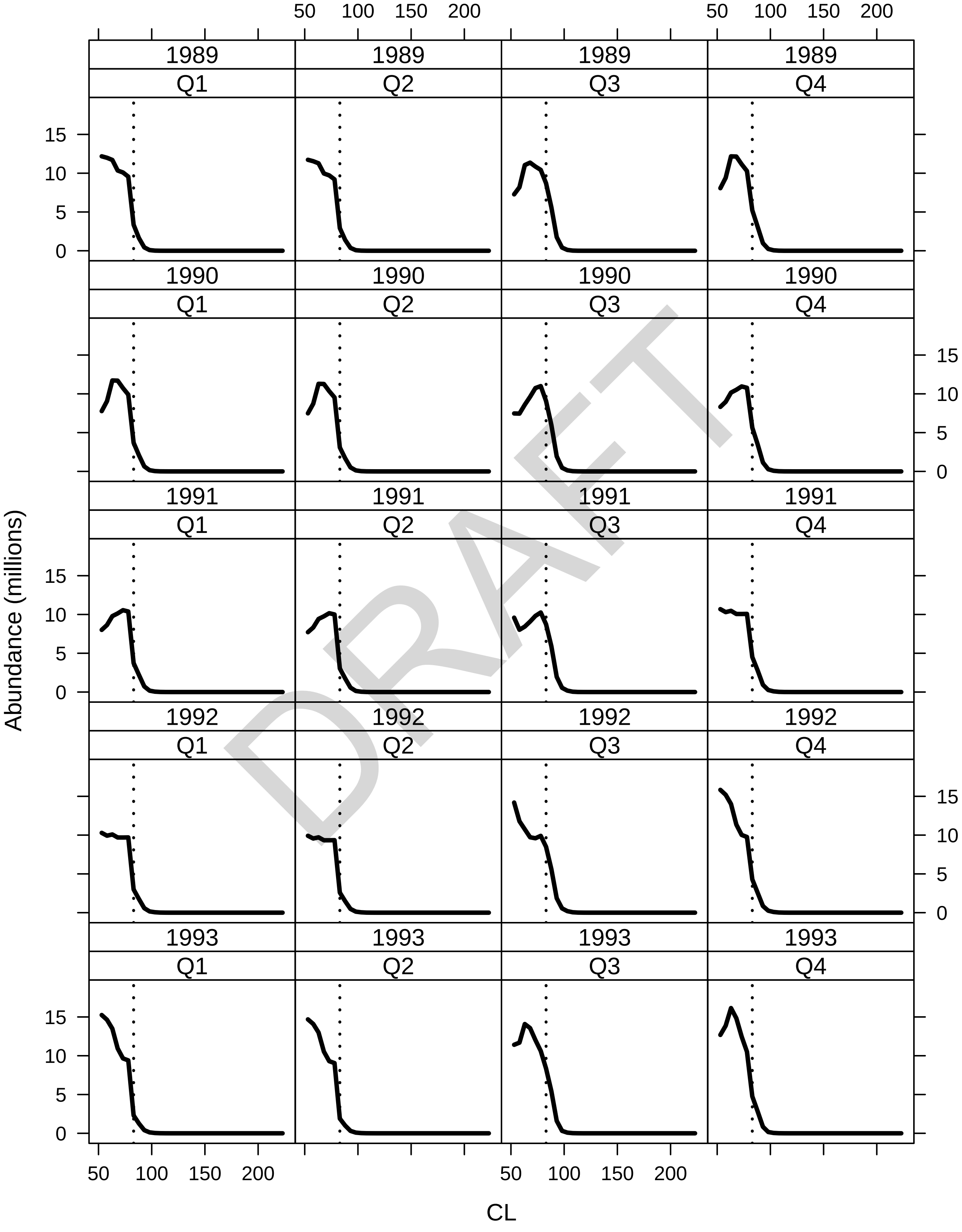
SNE_6F6_2019_orig_select
combined sex abundance at length



Vertical line at 83 mm

DRAFT

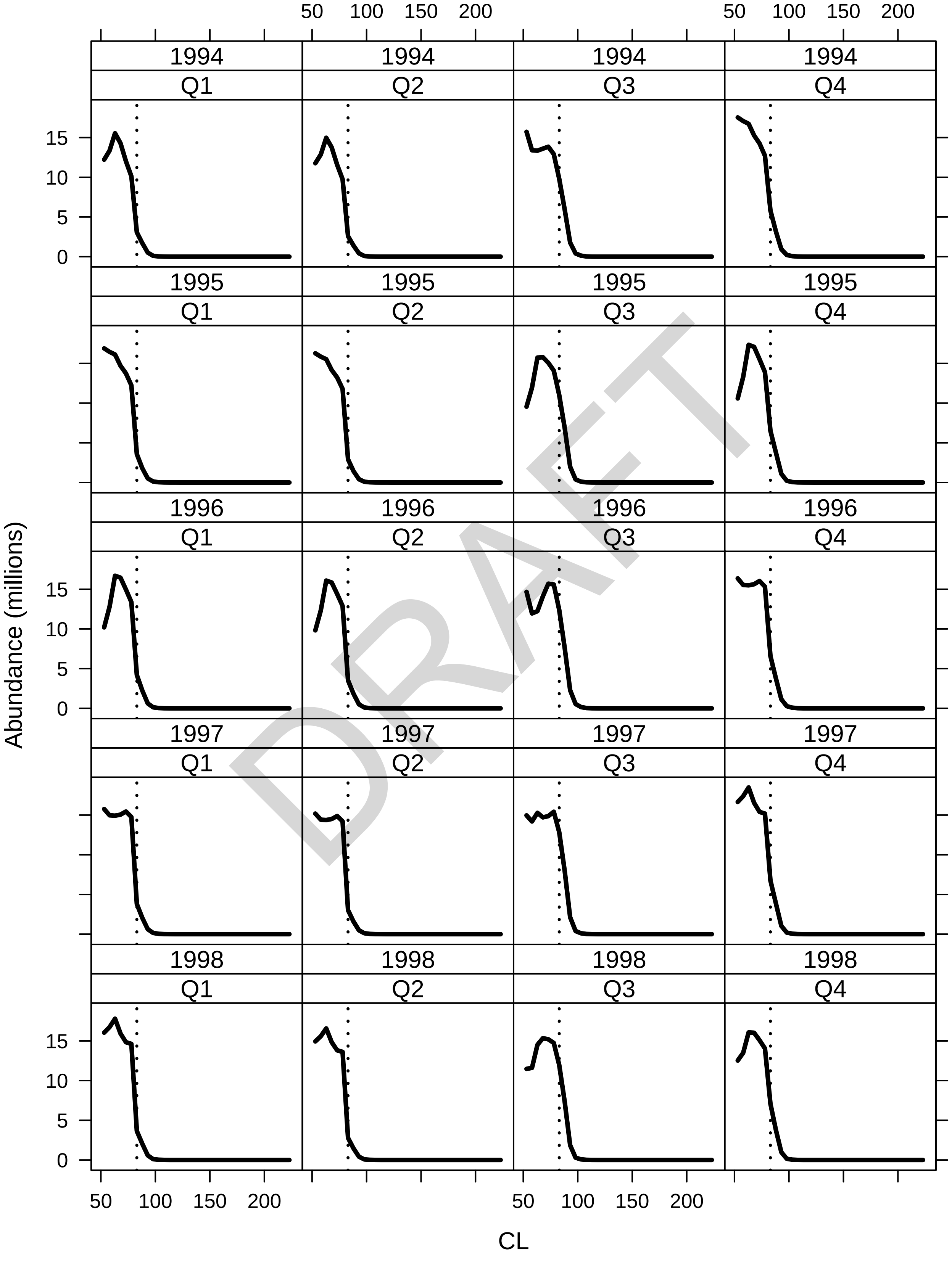
SNE_6F6_2019_orig_select
combined sex abundance at length



Vertical line at 83 mm

DRAFT

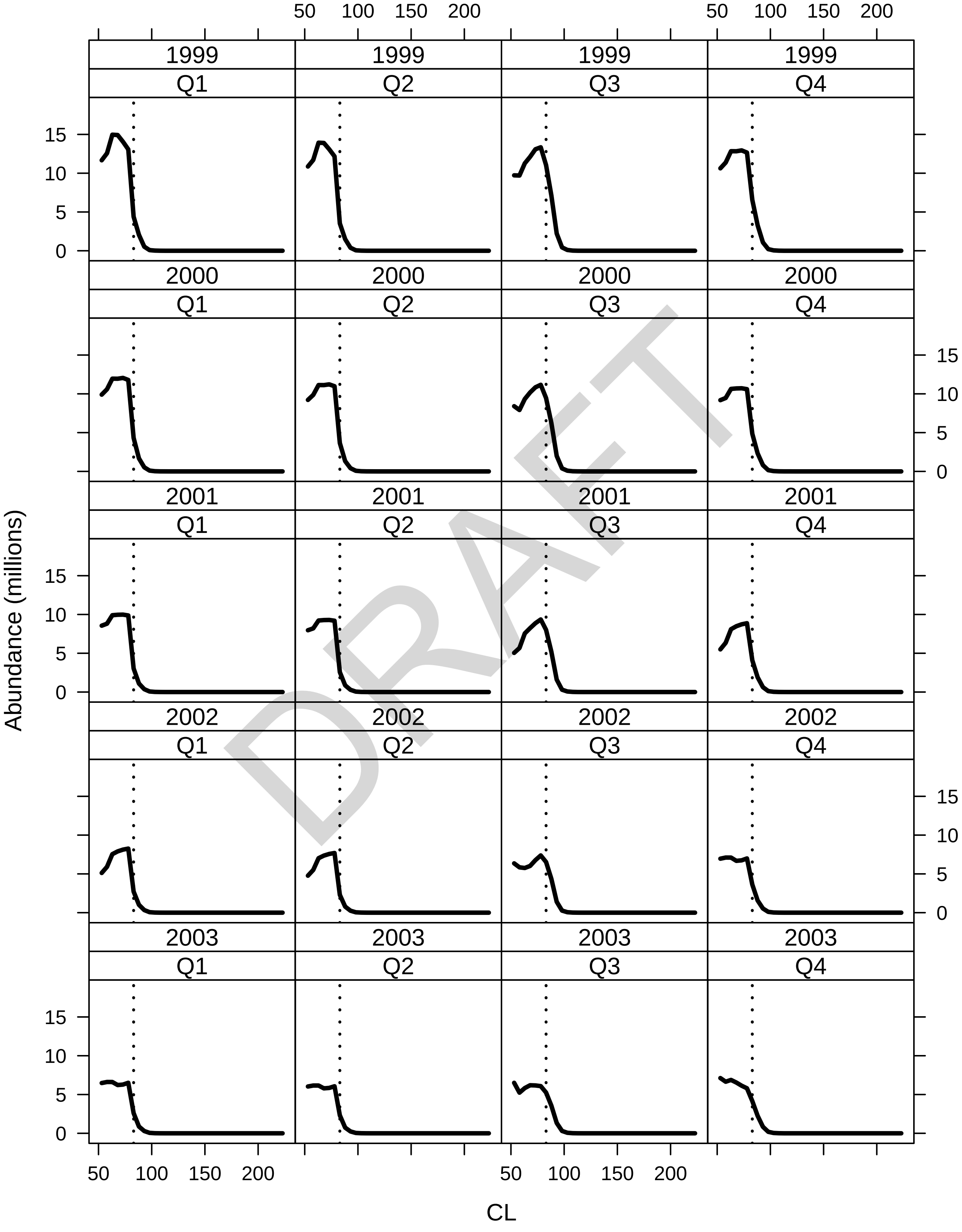
SNE_6F6_2019_orig_select
combined sex abundance at length



DRAFT

Vertical line at 83 mm

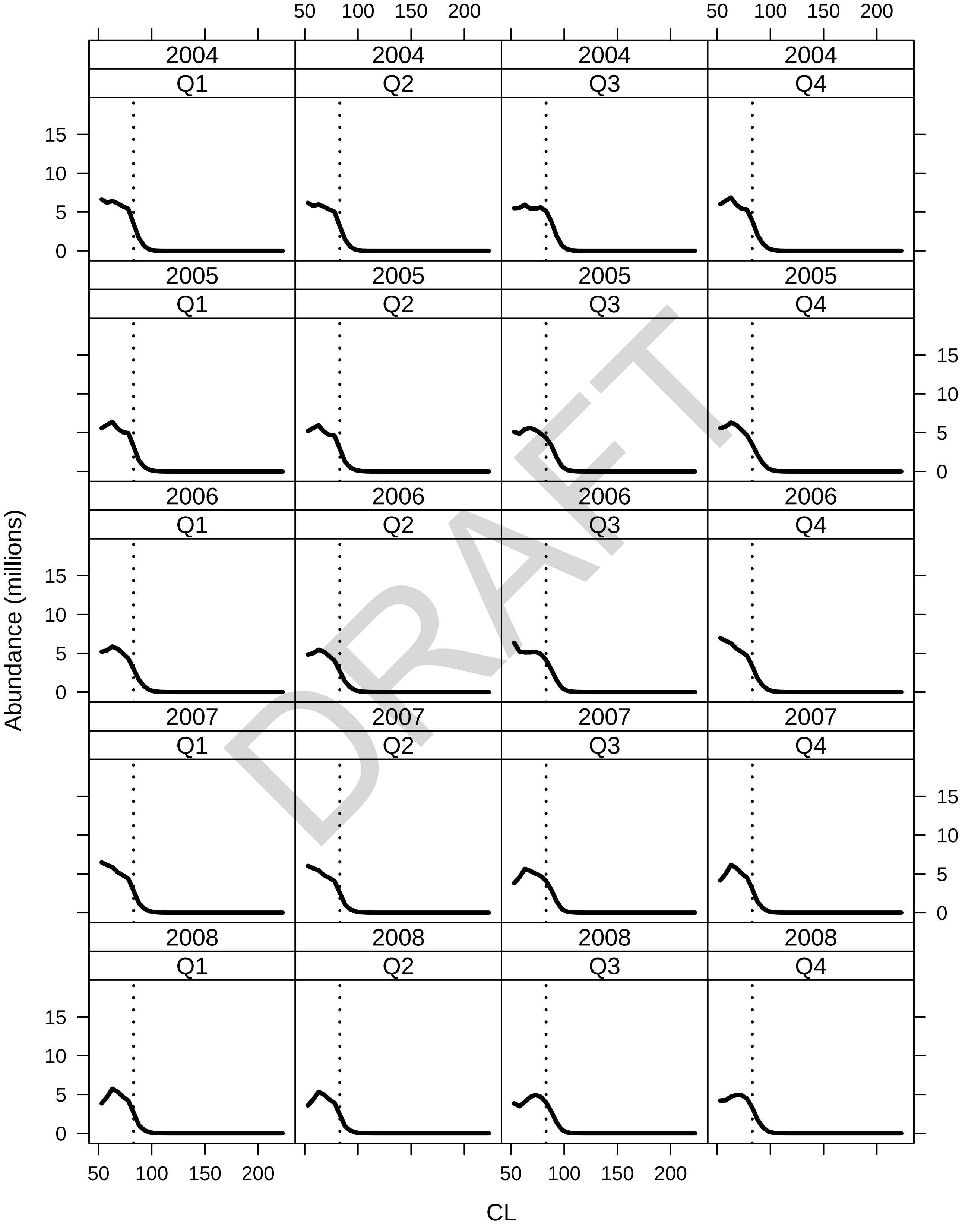
SNE_6F6_2019_orig_select combined sex abundance at length



Vertical line at 83 mm

DRAFT

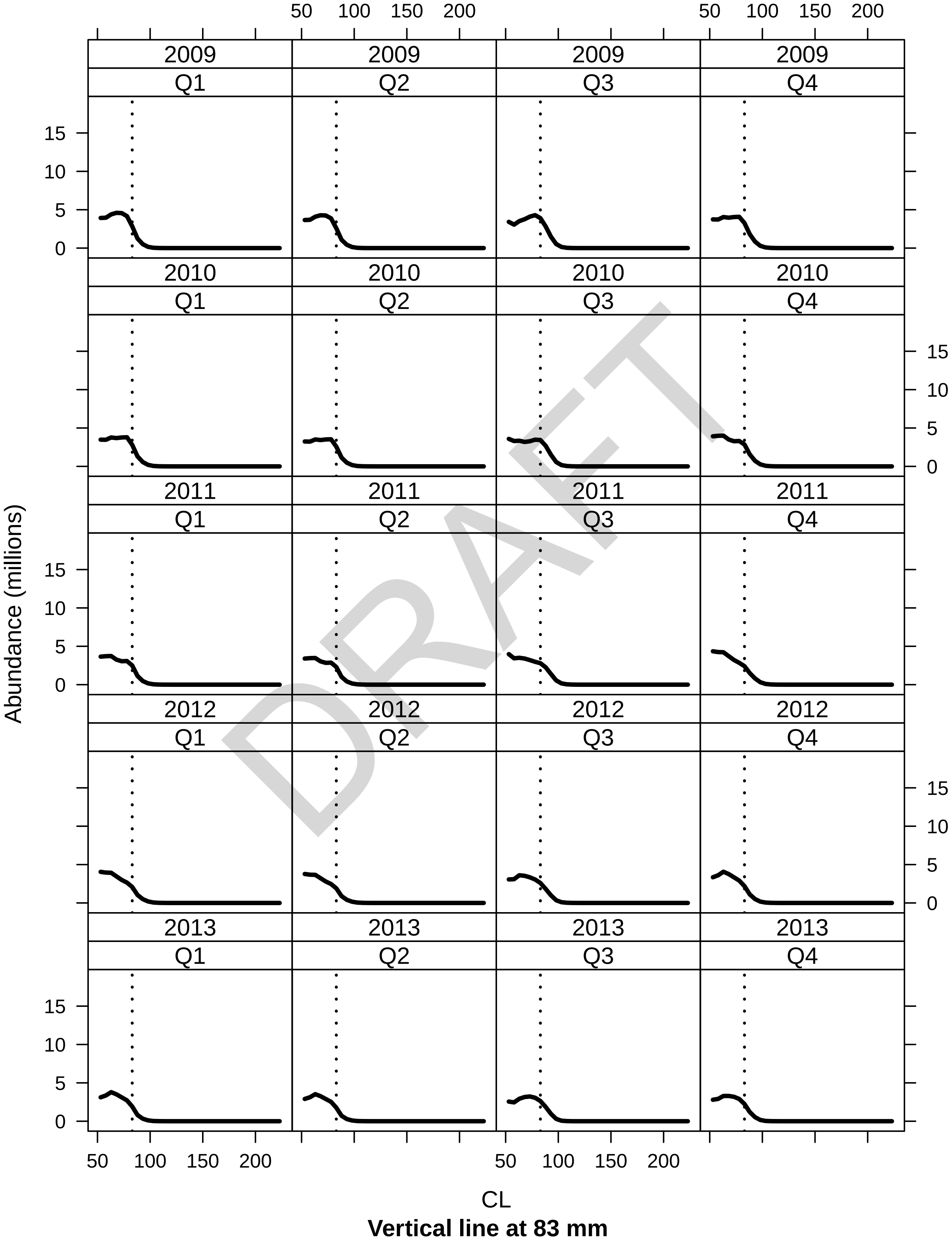
SNE_6F6_2019_orig_select
combined sex abundance at length



DRAFT

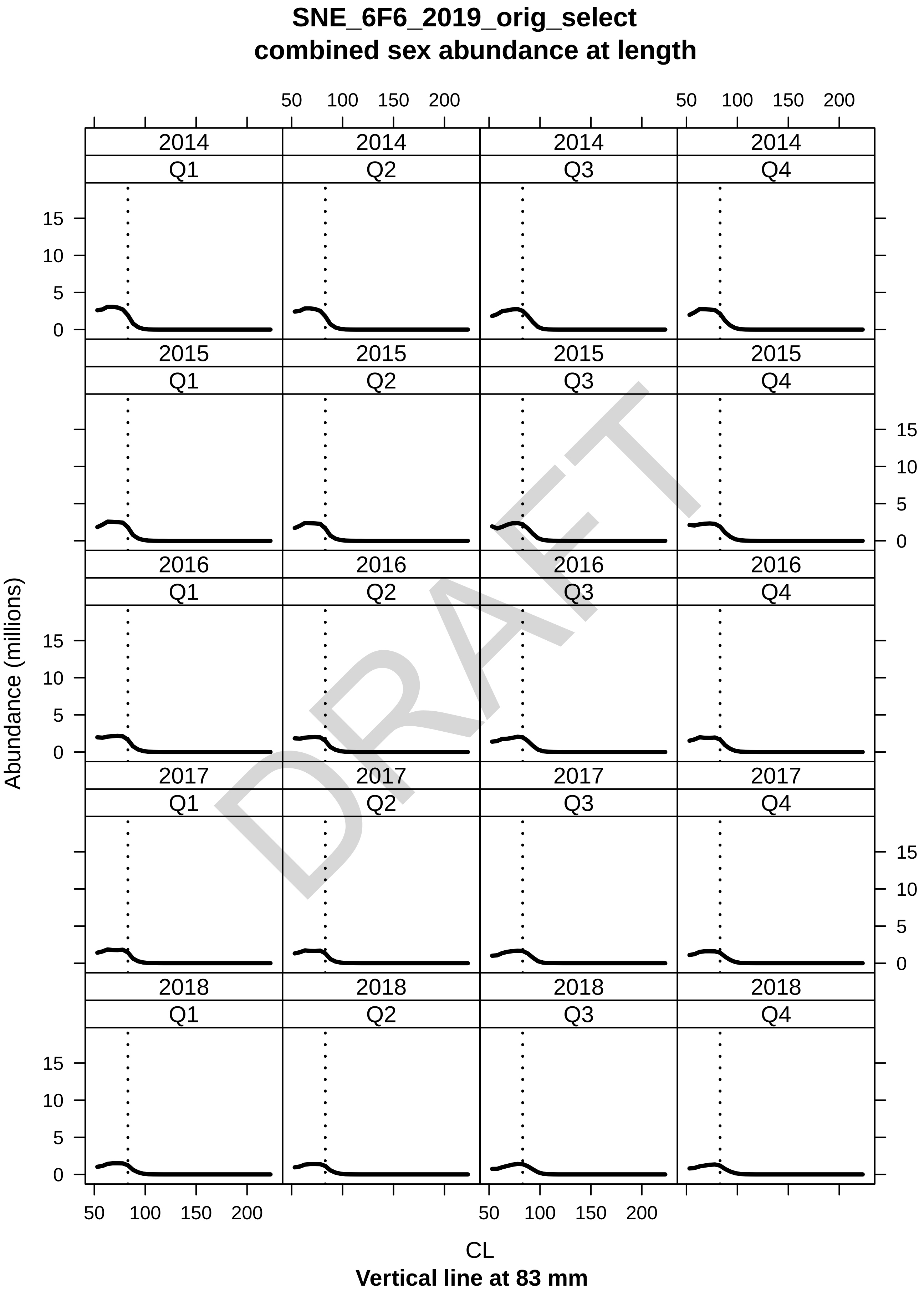
Vertical line at 83 mm

SNE_6F6_2019_orig_select
combined sex abundance at length



Vertical line at 83 mm

DRAFT


SNE_6F6_2019_orig_select
combined sex abundance at length
2014
2015
2016
2017
2018
Q1
Q2
Q3
Q4
Abundance (millions)
0
5
10
15
50
100
150
200
CL
Vertical line at 83 mm

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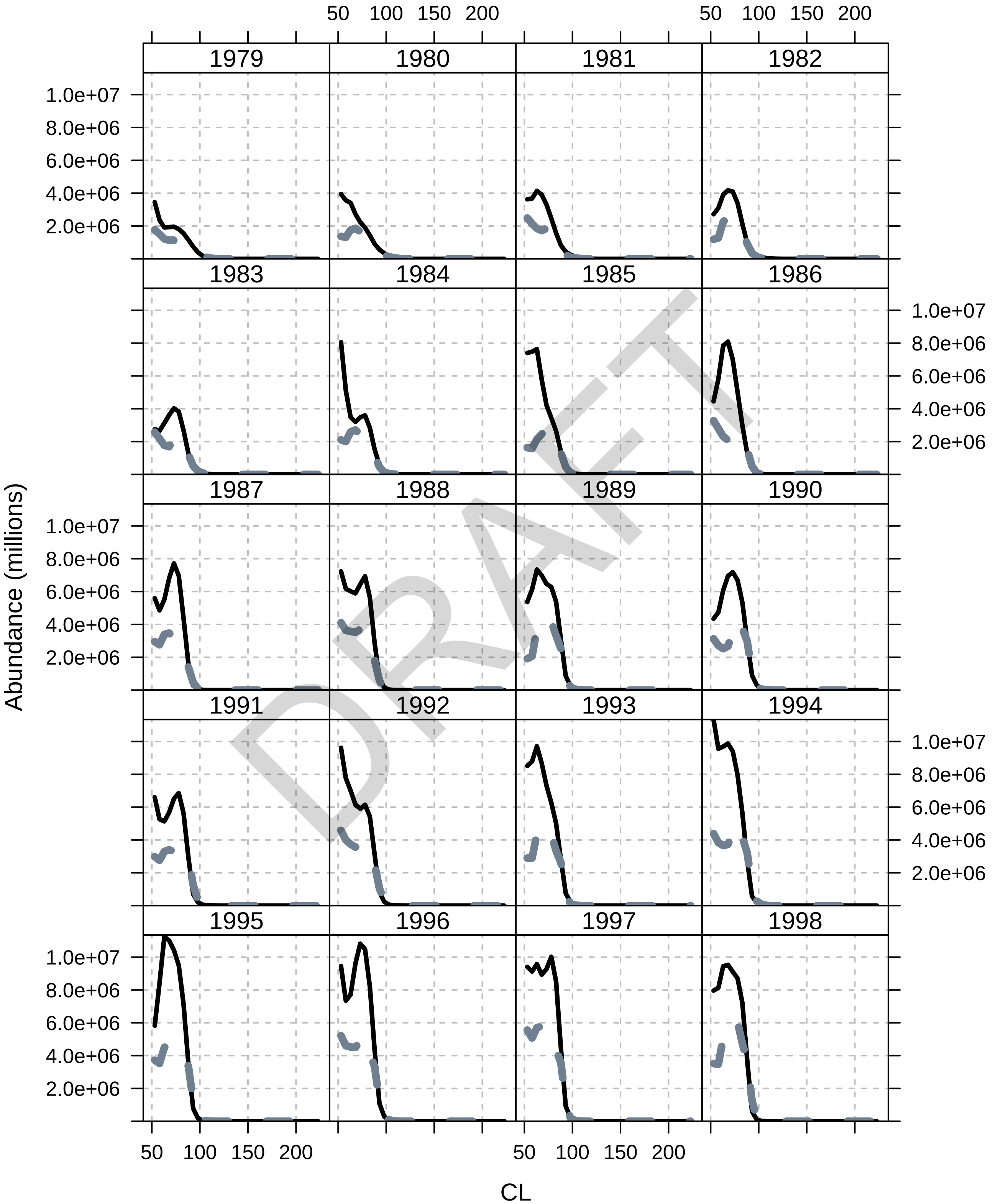
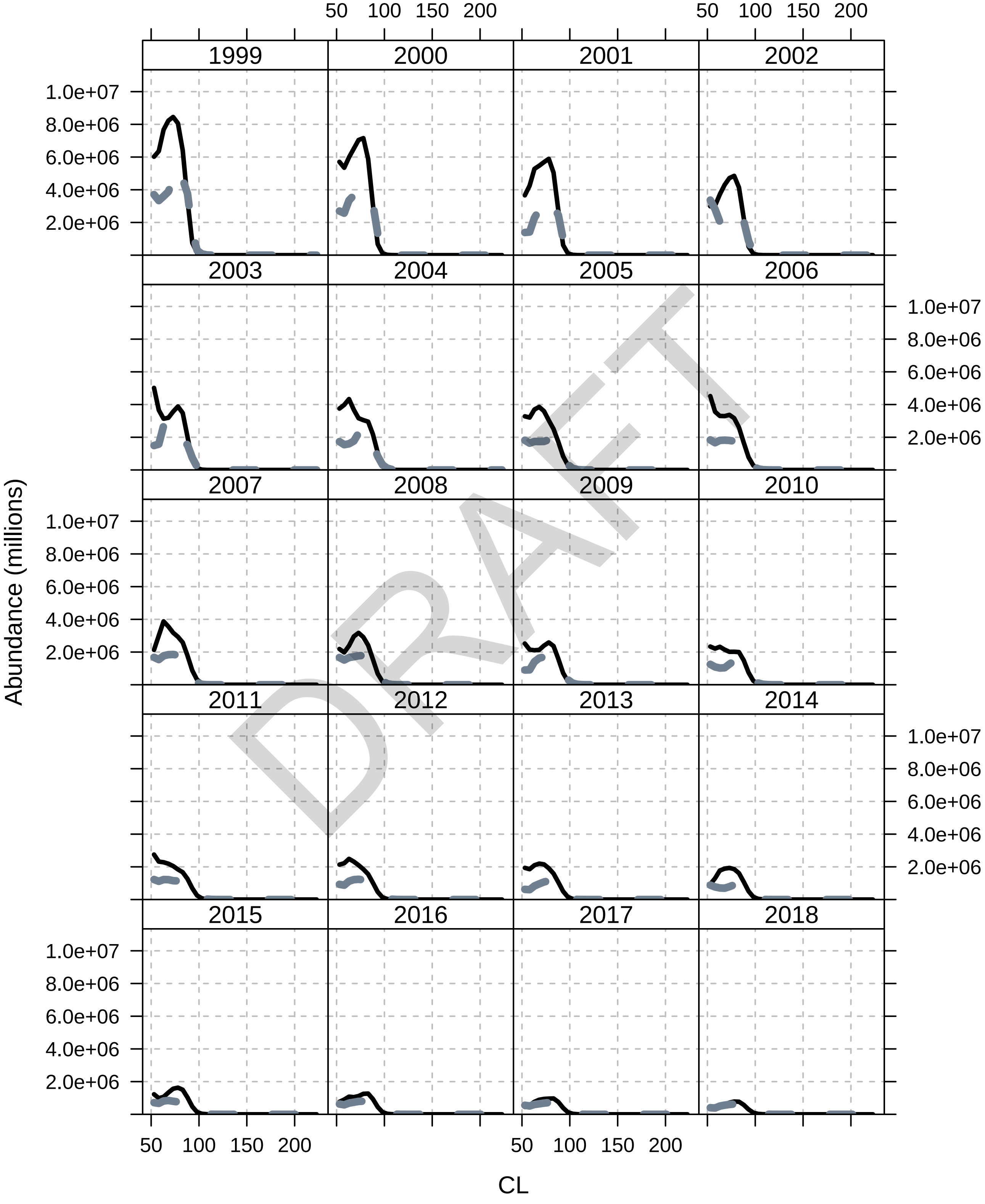
SNE_6F6_2019_orig_select
summer size and sex specific abundance



Females black / Males grey

DRAFT

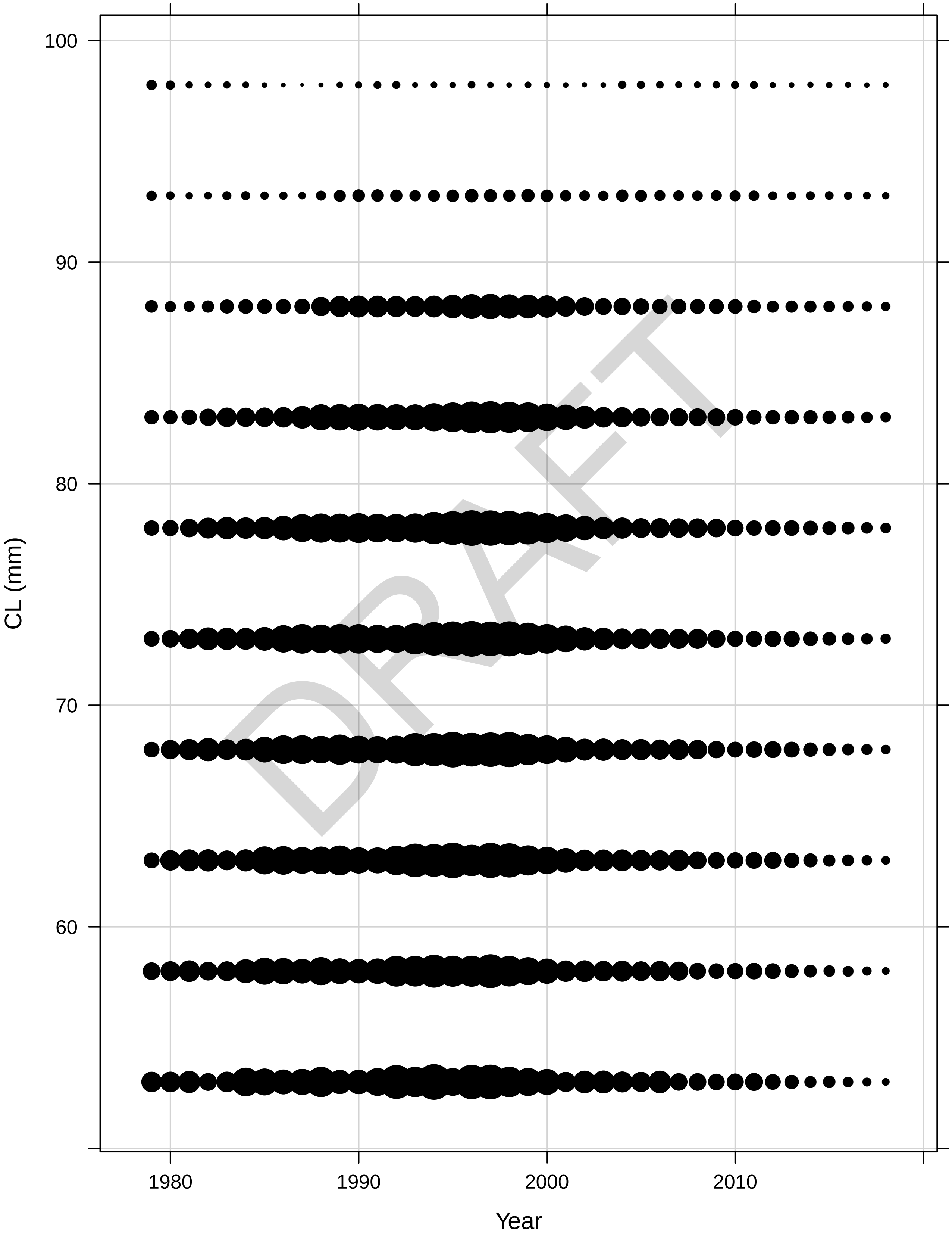
SNE_6F6_2019_orig_select
summer size and sex specific abundance



DRAFT

Females black / Males grey

SNE_6F6_2019_orig_select
June 1 Abundance by year at size



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