Atlantic States Marine Fisheries Commission

Jonah Crab Benchmark Stock Assessment and Peer Review Report

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Sustainable and Cooperative Management of Atlantic Coastal Fisheries

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Prepared by the

ASMFC Jonah Crab Stock Assessment Subcommittee
Joshua Carloni (Chair), New Hampshire Fish and Game
Derek Perry, Massachusetts Division of Marine Fisheries
Kathleen Reardon, Maine Department of Marine Resources
Burton Shank, National Marine Fisheries Service
Corinne Truesdale, Rhode Island Department of Environmental Management, Division of Marine Fisheries
Jeremy Collie, University of Rhode Island
Jeff Kipp, Atlantic States Marine Fisheries Commission

ASMFC Jonah Crab Technical Committee
Derek Perry (Chair), Massachusetts Division of Marine Fisheries
Kathleen Reardon, Maine Department of Marine Resources
Joshua Carloni, New Hampshire Fish and Game
Burton Shank, National Marine Fisheries Service
Allison Murphy, National Marine Fisheries Service
Corinne Truesdale, Rhode Island Department of Environmental Management, Division of Marine Fisheries
Chris Scott, New York State Department of Environmental Conservation, Bureau of Marine Resources
Chad Power, New Jersey Division of Fish and Wildlife
Craig Weedon, Maryland Department of Natural Resources
Somers Smott, Virginia Marine Resources Commission

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PREFACE

The Jonah Crab Benchmark Stock Assessment and Peer Review Report is divided into two sections:

Section A – Jonah Crab Benchmark Stock Assessment Peer Review
PDF pages 4-26

This section provides a summary of the Jonah Crab Benchmark Stock Assessment results supported by the Peer Review Panel. The Terms of Reference Report provides a detailed evaluation of how each Term of Reference was addressed by the Stock Assessment Subcommittee and provides recommendations from the Panel for further improvement of the assessment in the future.

Section B – Jonah Crab Benchmark Stock Assessment
PDF pages 27-240

This section is the Jonah Crab Benchmark Stock Assessment report that describes the background information, data used, and analysis for the assessment submitted to the Peer Review Panel.

Atlantic States Marine Fisheries Commission

Jonah Crab Benchmark Stock Assessment Peer Review Report

Conducted on
August 29-31, 2023
Providence, Rhode Island

Prepared by the
ASMFC Jonah Crab Stock Assessment Review Panel

Rich Wong (Chair), Delaware Division of Fish and Wildlife, Little Creek, Delaware
Dr. Paul Rago, National Marine Fisheries Service (retired), Falmouth, Massachusetts
Dr. Chris Siddon, Alaska Department of Fish and Game, Juneau, Alaska

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

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The Review Panel gratefully recognizes the work conducted by the Jonah Crab Technical Committee in preparing the 2023 Benchmark Assessment and for the professional, open, and constructive spirit of discussion during the review workshop. The Review Panel also thanks the Science staff of the Atlantic States Marine Fisheries Commission for their role in organizing the meeting, and providing materials to the Review Panel in a timely fashion.

Acronyms

CFRF—Cooperative Fisheries Research Foundation
CPUE—Catch per unit effort
CSA—Catch Survey Analysis
CV—Coefficient of Variation
DFO—Department of Fisheries and Oceans, Canada
DRM—Direct Residual Mixture
FD—Fishery Dependent
FI—Fishery-independent
GAMS—Generalized Additive Models
IBM—Index Based Model
IGOM—Inshore Gulf of Maine
ISNE—Inshore Southern New England
LBSPR—Length-Based Spawning Potential Ratio
LOESS—Locally Estimated Scatterplot Smoothing
LPUE—Landings Per Unit Effort
M—Natural Mortality Rate (instantaneous)
MSL—Minimum Size Limit
MSE—Management Strategy Evaluation
OGOM—Offshore Gulf of Maine
OSNE—Offshore Southern New England
SAS—Stock Assessment Subcommittee
SPR—Spawning Potential Ratio
TC—Technical Committee
TOR—Term of Reference
VMS—Vessel Monitoring System
VTS—Vessel Trip/Tracking Survey/System
YOY—Young-of-the-year

EXECUTIVE SUMMARY

The Jonah Crab Stock Assessment is data-limited, preventing estimates of population size, fishing mortality rates, and determinations of overfishing and overfished statuses. The assessment explores other Status Determining Criteria (SDC), relying primarily on fishery-independent (FI) survey and fishery-dependent (FD) indices of abundance.

Despite the limited availability of current data, there is considerable urgency for the assessment due to a very steep, three-year, decline in landings. Commercial landings have declined 51% in three years, after an unprecedented 30-fold rise in landings. Although the recent decline is not well-detected in FI stock indicators, there is some evidence of declining fishery CPUE, creating substantial concern and uncertainty for the status of the stock. Given the mixed signals, the status of the Jonah Crab stock is highly uncertain.

Current conditions closely resemble early stages of the collapse of the Canada Jonah Crab fishery in the early 2000s. In the first three years of the crash, Canada landings dropped 58%. Within five years, landings fell 97%, and stock biomass could no longer support a fishery. FI trawl indicators had not fully captured the signals of a rapidly declining stock. However, declining fishery CPUE was observable preceding and during the landings crash.

Given the high level of uncertainty in the status of the Jonah Crab stock, the Panel strongly recommends close monitoring of annual stock indicators in the next few years. Annual indicators can determine whether sharply declining recent landings are signaling the start of a ‘bust’ phase of a boom-and-bust arc, or are due to fishery and market-related factors uncoupled with Jonah Crab abundance.

In the following report, we evaluate the assessment work by Term of Reference, and provide an Advisory section that may be useful to the Board for making decisions on future management actions, and for setting the direction of research and assessment efforts.

TERMS OF REFERENCE

1. **Evaluate the thoroughness of data collection and the presentation and treatment of fishery-dependent and fishery-independent data in the assessment, including the following but not limited to:**
    a. **Presentation of data source variance (e.g., standard errors).**
    b. **Justification for inclusion or elimination of available data sources,**
    c. **Consideration of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, sample size),**
    d. **Calculation and/or standardization of abundance indices.**

Data collection for the assessment was comprehensive and thoroughly assembled. The Stock Assessment Subcommittee (SAS) presented 53 fishery-independent (FI) survey indices covering four life stages (young-of-the-year, recruit, post-recruit, spawners) and five regions (IGOM, OGOM, ISNE, OSNE, Coastwide). Indices included: five young-of-the-year (YOY) indices (an additional three surveys were evaluated but not included); and 48 post-YOY indices (plus 20 evaluated but not included). Four fishery-dependent (FD), exploitable-size, male crab CPUE indices were presented covering four regions (IGOM, OGOM, ISNE, OSNE).

The SAS presented data source variance where appropriate and necessary. While error estimates were presented in tabular form for the CFRF VTS results and trawl survey estimates, having those estimates on their corresponding figures would be useful.

The inclusion (and exclusion) of all the data sources presented was well justified. In addition to tracking the mean sizes of the largest 5% of exploitable males, it would be informative to see the full-size distributions of crabs (by sex if available) from annual FI and FD collections. Continued monitoring of potential changes in size distributions may be important for detecting overfishing. Importantly, size compositions could yield initial estimates of mortality rates using length-based catch curves and estimates of spawning potential ratio (SPR) as growth parameters are further refined. Further investigation into defining the instantaneous natural mortality rate (M) will be essential for future population models and interpreting mortality rates derived from simple catch curves.

The SAS did a commendable job describing the strengths and weaknesses of the data and how they vary across the four stocks, particularly during the review workshop. The calculations and standardization of all indices were all detailed and appropriate to help interpret complex fishery-dependent data (e.g., the Direct Residual Mixture Model CPUE). Some presentation of raw vs. standardized metrics could be helpful in the future to understand the magnitude of improvements and also what factors were most influential to CPUE metrics and their interpretations. Overall, this was an impressive body of work and the Review Panel is grateful for the breadth of knowledge and attention to detail presented by the SAS.

2. **Evaluate empirical indicators of stock abundance, stock characteristics, and fishery characteristics for their appropriateness to monitor the stock between assessments.**

The Review Panel recommends continued monitoring of all current indicators of stock abundance, and stock and fishery characteristics. However, the SAS's prioritization of importance of indicators was difficult to interpret from the assessment document. Upon discussion with the SAS, opinions varied regarding the most informative indices in providing management advice. Further exploration and the accompanying rationale would be extremely useful in making the management decision process transparent and repeatable.

The utility of any indicator depends on its relationship to the true measure of abundance or underlying rate (e.g., fishing mortality). Fishery-independent data sources for Jonah crab can be difficult to interpret if the efficiency of the sampling gear is unknown or thought to be low. Similarly, fishery-dependent measures of abundance, such as commercial landings per unit effort, often require substantial analyses to isolate the effects of economic factors from measures of abundance. The Review Panel recommends additional work by the SAS to separate the essential from the desirable indicators.

Several proposed indicators of stock status were considered less useful for either measures of overall stock status or future modeling efforts. Measures of YOY settlement, while important region-wide indicators of the ecosystem, can rarely be related to the spawning biomass that produced them or their subsequent recruits to the fishery. Measures of crab biomass and length frequencies for legal and sublegal males, as well as mature females are likely to be critical for future modeling efforts.

Trawl surveys were typically the most valuable data stream since they are likely to be the only synoptic measure of relative density for most stocks. As noted elsewhere, capture efficiency was likely to be low and dependent on unobservable variations in behavior of the crabs. Collaboration with harvesters is encouraged to obtain their perspectives on changes in catchability especially with respect to seasonal factors and spatial distribution. Further development of fishing area maps (composite, not individual harvesters) could be helpful for interpreting fishery-independent surveys.

Details of the trawl survey estimates should be presented for each stock area. Over the past 15 years, the NEFSC allocated about 380 stations per year over 82 strata. Since the crab stock areas bisect some of the strata, there is a possibility that the number of stations in a stock area is very low in some years. ISNE seems to be prone to lower station numbers with consistent patterns of CV>0.70 in many years. Various model-based methods of ‘small area estimation’ may be useful, although not yet applied to NEFSC or other surveys in the crab stock areas.

Efforts should be made to document empirical sex ratios in FI and FD collections. There is also need to monitor for changes in survey-specific ‘operational sex ratios’ as potentially important early warning signals of overfishing, given the predominantly male crab fishery. In this regard, the abrupt decline of Jonah Crab in Canada (DFO 2009) suggests further collaboration with Canadian colleagues and harvesters would be useful to evaluate early warning signs that may be evident in retrospect. The post-mortem analysis should also consider evidence of recovery, or lack thereof.

In view of the potential sensitivity of the stocks to rapid collapse, the use of Kendall’s method for evaluating overall trend may not allow for detection of important short-term trends. More ‘adaptive’ measures of local trends such as LOESS smoothers or Generalized Additive Models (GAMS) should be explored.

Preliminary examination of Jonah crab prices, in conjunction with Landings Per Unite Effort (LPUE) measures, strongly suggest the need to incorporate economic factors when interpreting LPUE trends. Low CPUE when prices are at record highs may be indicative of low availability in traditional fishing areas, or reduced overall abundance. Results of a Rhode Island trip-level LPUE analysis conducted during the review meeting were informative. Continuation of such analyses is strongly encouraged for subsets of data deemed reliable.

For metrics most useful to tracking crab population dynamics, the Review Panel recommends focusing on synoptic trawl surveys with high efficiency gear (e.g., the NEFSC winter survey, 1992-2007); LPUE models informed by economics and harvester inputs; and expansion of the CFRF ventless trap survey to all harvesters, particularly if a design component could be imposed.

3. **Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, including but not limited to:**
    a. **Evaluate the choice and justification of the preferred model(s). Was the most appropriate model (or model averaging approach) chosen given available data and life history of the species?**
    b. **If multiple models were considered, evaluate the analysts' explanation of any differences in results.**
    c. **Evaluate model parameterization and specification (e.g., choice of CVs, effective sample sizes, likelihood weighting schemes, calculation/specification of M, stock-recruitment relationship, choice of time-varying parameters, plus group treatment).**

The SAS evaluated the utility of several data-poor methods based on rates of change in fishery-independent indicators and measures of relative exploitation. Fishery-independent (FI) indicators included one or more trawl surveys in each stock area. In OSNE, the SAS defined relative exploitation as the ratio of landings to the relative abundance from the NEFSC bottom trawl survey. The SAS conducted fishery-independent index-based methods (IBM), called 'Islope' and 'Plan B', and a relative exploitation method called 'Skate'. All of the methods rely on an adjustment of current landings in response to some measure of recent rates of change in fishery abundance index. Islope and Plan B rely on the slope of the indices. The Skate method adjusts catches in response to the ratio of recent exploitation rates to a historical period judged to be a period of stability.

The SAS concluded none of the index-based methods were applicable to Jonah crabs in any stock area. Justifications included the short duration of the time series, the high variability of survey estimates, and the wide range of catch recommendations. Perhaps most importantly, the relationship between total catch (or rates of removal) and population response has not been validated for any index or stock area. An Ensemble method, based on the median of alternative estimates, was also judged inappropriate.

The Review Panel largely agreed with the SAS's conclusions. Longer time series may improve the utility of such methods. However, the general increases in multiple indices over the period in which landings have also increased much more rapidly, suggests fishing mortality is not yet a major factor controlling stock dynamics. However, very recent declines in several fishery-dependent (FD) indicators could be early warning signals of increased exploitation. Without further analyses and the benefits of hindsight and additional data, the Review Panel concluded that further work on Index-Based Methods would not be particularly useful.

The Review Panel suggested that future work on IBMs should be subordinate to the development of other modeling approaches. Further consideration should be given to the application of Catch Survey Analyses (CSA). Such dynamic stage-based models have the advantage of being simple and readily interpretable. Initial attempts to apply these types of models were not successful, often because the size frequency data necessary to identify pre-recruits from recruits was insufficient for the range of years included in the assessment. A related concern is a general lack of knowledge on the molt increment of pre-recruit sized crabs. This is important because CSA requires information on the number of unexploited animals growing into the recruited size range between years. Further examination of existing experimental data and perhaps other experiments may be useful for improving the utility of CSA in at least some areas.

Probably the single most impactful advancement towards generating Jonah Crab population parameters is the development of an unbiased ageing method, based on a thorough examination of marine crustacean ageing research and techniques (e.g., Kilada et al. 2017, Fairfield et al. 2021). At a minimum, simple catch curves of FI and FD age compositions would be feasible, yielding highly informative mortality estimates and providing much insight into Jonah Crab population dynamics. More complex population models and operating models would naturally evolve. The Review Panel does recognize the difficulties in ageing crustaceans. Given the substantial upside of unbiased ageing for practical applications in management, we feel it is worth investigating the method further for Jonah crab.

The Review Panel was impressed with initial results from a Length Based Spawner per Recruit (LBSPR) model parameterized in response to a request from the Panel. Such models often require substantial "borrowing" of growth parameters and natural mortality assumptions from other stock areas and/or related species. Current data are insufficient to support full implementation of the LBSPR approach. However, the Review Panel recommends further development of an LBSPR model in order to guide monitoring efforts and analyze relationships among surveys and landings data. For example, the expected ratio of males to females at length under varying levels of fishing mortality could be derived and monitored routinely to derive static estimates of total mortality by sex. Alternatively, some data suggest that availability of female crabs to the fishery and fishery-independent surveys varies seasonally. If so, an LBSPR model could be useful to interpret such anomalies and distinguish seasonal migrations from changes in mortality rates.

4. **Evaluate the diagnostic analyses performed - e.g., sensitivity analyses to determine model stability and potential consequences of major model assumptions, and retrospective analysis.**

Overall, the SAS presented thorough diagnostics for the analyses they performed while balancing the length and level of detail of the report. Additional diagnostics on model selections (e.g., table of AICs) and their interpretations regarding the magnitude of various factors would have been helpful and interesting, especially in the sections on the CFRF VTS catch rates and the Direct Residual Mixture Model CPUE.

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

In general, the SAS did not formally evaluate the implications of precision of estimates, in part due to the lack of model-based approaches available to limited Jonah crab data. There was however substantial discussion of the relative merits of indices, particularly with respect to their utility for various index-based methods.

6. **Recommend best estimates of stock biomass, abundance, and exploitation from the assessment for use in management, if possible, or specify alternative estimation methods.**

The SAS was unable to develop analytical models of abundance or exploitation. Reasons included concerns about measurement error in abundance indices and insufficient knowledge of basic crab biology, particularly growth. The Review Panel agreed that a credible model could not be developed at this time. A simple catch-survey analysis model may be a useful starting point to explore the feasibility of creating a dynamic model. The Review Panel noted that static models, such as within year depletion models, would be useful for generating biomass and fishing mortality rates. Such models could be useful even when they fail, because results could indicate the relative magnitude of fishing mortality rates. Ultimately, Jonah crab models useful for management will depend on additional years of data, especially from recently initiated data collection programs.

The Review Panel noted that female Jonah crab are uncommon in the fishery, owing largely to the minimum size limit and associated trap vent sizes. In addition, selectivity of smaller sized crabs may be low in fishery-independent surveys, particularly trawls with rockhopper gear. As a result, there are relatively few data streams that would allow application of sex-based methods for mortality estimation. More importantly, there are relatively few empirical measures that could provide early warning signs of overexploitation. The Review Panel encourages further development of monitoring programs that allow for monitoring of size composition of male and female abundances, and evidence of reduced egg production. Ventless traps may be useful, particularly if the current CFRF Ventless Trap Survey could be expanded to the larger fishery. See TOR 8 for more details.

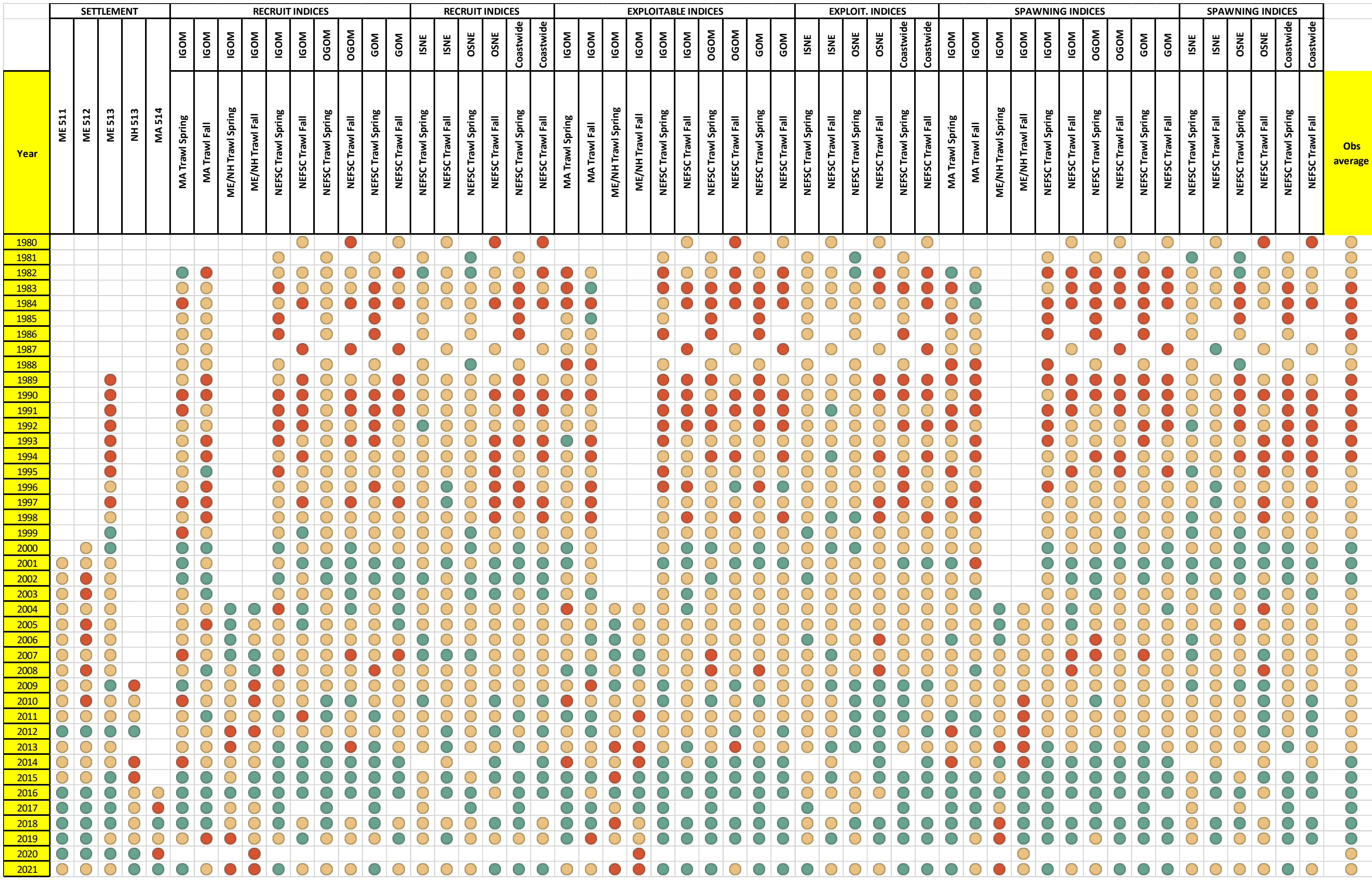
7. **Evaluate the choice of reference points and the methods used to estimate them. Recommend stock status determination from the assessment, or, if appropriate, specify alternative methods/measures.**

While exploitation-based or abundance-based reference points were not yet feasible given essential life history gaps and data constraints, the SAS was able to present numerous indicators and other important fishery and biological background that provided information about stock status. A number of favorable factors exist, such as a cohesive, coastwide, regulatory framework implementing a protective minimum size limit (MSL) that appears to conserve most mature male crabs, particularly in the region where the fishery primarily operates. Furthermore, the fishery selectivity appears to operate at even larger sizes than the MSL, given discussions with the SAS and from a preliminary, post-hoc, Panel-requested, length-based Spawning Potential Ratio (LBSPR) analysis. Importantly, the fishery also does not select female crabs, providing a significant moat to the potential depletion of female spawning biomass. The obvious danger to the stocks' reproductive potential would occur from male depletion and sperm limitation.

An evaluation of stock SPR using the LBSPR approach is a promising status determining criterion for Jonah Crab, given its minimal data requirements. For Jonah Crab, the LBSPR analysis only requires further refinement of growth parameters and natural mortality assumptions, and can be explored for both FD and FI survey size compositions for both sexes.

Fishery-Independent (FI) stock indicators, in bulk, tend to portray a population at higher levels of abundance than at the start of survey time series' (Table 1). However, the positive signals are assessed across a time span up to 42 years, and should be interpreted with caution since there appears to be a regime shift occurring circa 2010.

Table 1. Graphic depiction of ordinal measures of relative abundance indices by stock area and year. Lowest 25% quartile is coded red, interquartile range is coded in yellow, and highest quartile (>75%ile) is coded green. Each index is coded separately. Shorter time series may create bias when compared to longer time series.



Although long-term FI indicators are positive, we see a clear, sharp decline in recent fishery landings and other highly concerning, corroborating, fishery metrics. Jonah Crab landings have declined 51% in the most-recent three-year period (2019-2021) in the OSNE, even while market prices have increased. While we acknowledge other industry and market factors need to be investigated, it is highly concerning to see similar, recent, sharp declines beginning in 2019 in the fishery-dependent (FD) CFRF CPUE, the generally declining FD CPUE in the DRM analysis, and the sharp recent decline in the post-hoc, Panel-requested investigation of directed FD CPUE from RI trip level data (Figure 1). There were also large single-year drops in FI CPUE in the NEFSC OSNE trawl in Fall 2019 and Spring 2020.

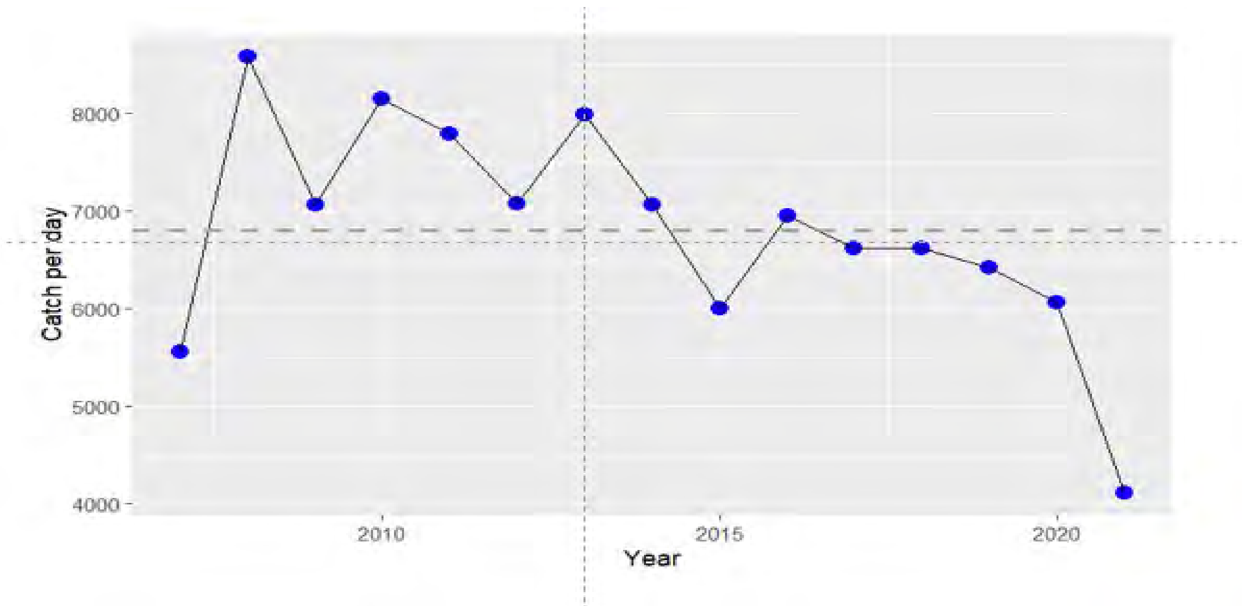


Figure 1. Rhode Island commercial Jonah Crab CPUE (harvest per fishing day) of a harvester group targeting Jonah Crab. (Analysis is preliminary)

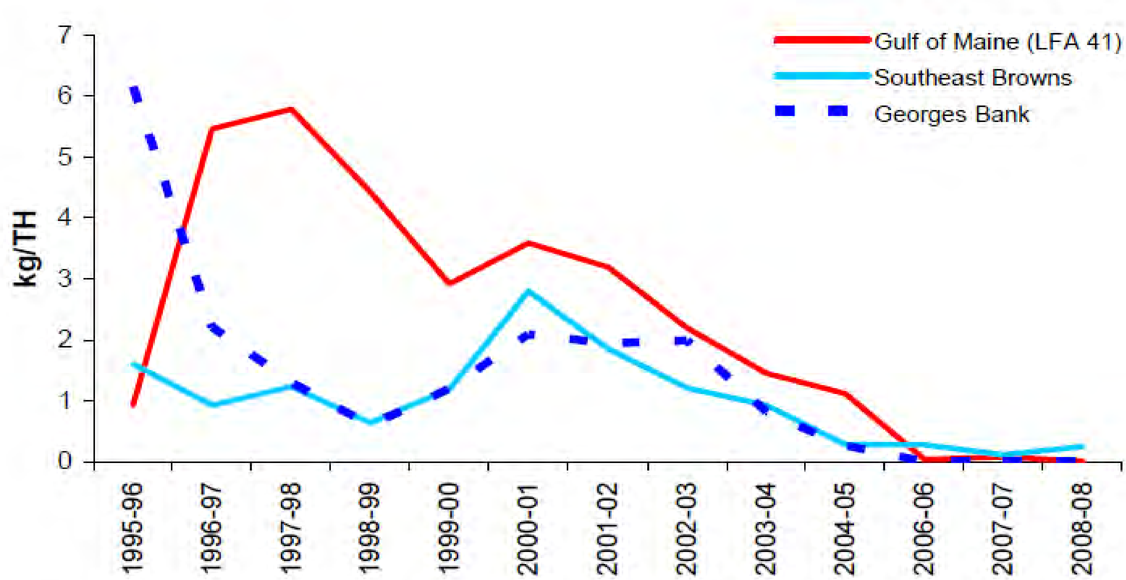


Figure 2. Commercial harvest CPUE (kg/trap) of Jonah Crab during the collapse of the Canada fishery landings that occurred primarily from 2001 to 2004.

It is very worrisome that the extremely rapid collapse of the Canada Jonah crab fishery in the early '00s occurred without noticeable declines in FI indicators (see Canadian Science Advisory Report 2009/034). Canada landings declined by 58% in the first three years of the fishery collapse, comparable to the current, three-year, 51% drop in OSNE landings. Although Canada Fisheries and Oceans (DFO) FI trawl indicators did not capture the deteriorating condition of the stock, declining fishery CPUE was observable preceding and during the landings crash (Figure 2).

8. **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 Technical Committee presented a number of research priorities in their report and, upon the Panel's request, further refined their highest priority research recommendations to improve future Jonah crab stock assessments. The Review Panel thoroughly discussed the High Priority Short-term topics proposed by the TC. The Review Panel recommends the highest priority should be given to determining how to best interpret fishery-dependent data along with potentially new metrics (see pg 47 of Jonah Benchmark Assessment Report). In light of a new indicator brought forward (catch per trip) and the new, higher, resolution fishery dependent data streams (e.g., VMS data) this avenue of research is likely to provide the most-timely improvement in future assessments.

Additional research topics recommended by the Review Panel include: 1) potential expansion of the CFRF ventless trap sampling, 2) examination of the now defunct (ending in 2007) NEFSC Winter Bottom Trawl Survey (Terceiro 2003, NEFSC 2019), 3) more detailed evaluation of female data, and 4) development of interim measures for evaluating 'stock health'.

1) The CFRF ventless trap research provides an intermediate design between fishery-dependent and fishery-independent data collection. Increasing its spatial extent would be valuable, especially in Southern New England (SNE) where current trawl surveys catch very few Jonah crabs. Consideration of expansion and a thoughtful design approach (e.g., stratified random within current fishing grounds) may provide an improved index of abundance through time. A broad-based program might include of one or more ventless traps deployed by <u>all</u> harvesters over the course of the regular fishing operations. While such a survey would not include random selection, ancillary data, such as historical survey, observer data, and new VMS data could be used to generate appropriate weighting factors for relative estimating abundance.

2) Crabs are scarce in the current NEFSC trawl survey in SNE. However, reasonable catches in the previously conducted NEFSC Winter Bottom Trawl Survey, suggest there may be data available to provide historical context to Jonah crab abundance, and may facilitate a small, strategic, and likely cooperative survey utilizing a gear that effectively catches crab (including females) and does not have concerns regarding behavioral interactions with lobster.

3) Similarly, a more exhaustive examination of the currently available female data (including male/female sex ratios, LBSPR) will likely prove to be an informative metric of stock health. Along with the addition of metrics on females, continued research is warranted on repeatable

and transparent methods to better summarize multiple indicators for each of the four stocks. Formalizing the methods will support decision making into the future until more quantitative methods are available.

4) Lastly, the Review Panel would like the TC to consider a more formal approach to incorporate harvesters' Local Knowledge (LK) to provide context to best interpret fishery dependent data. While we recognize fisheries agency staff have good interactions with harvesters, developing a repeatable and consistent metric(s) of local knowledge could lead to improved interpretation and "buy in" from harvesters on assessment outcomes.

9. Recommend timing of the next benchmark assessment and updates, if necessary, relative to the life history and current management of the species.

It is unlikely that sufficient research will be completed to support a stock assessment within the next five years. Up to 10 years may be needed to complete the many tasks identified by the Stock Assessment Subcommittee and Reviewers. New time series of fine-scale spatial data from the fleet should be particularly informative for future assessments. Moreover, potential new surveys, critical laboratory experiments, and more extensive analyses of existing data have been proposed. Sufficient time is needed to summarize and evaluate these projects before conducting a formal assessment.

The proposed interval for the next assessment poses problems for planning. In order to maintain a focus on the assessment, the Review Panel recommends an interim meeting within five years. The purpose of the meeting will be to summarize ongoing work and to set a date for the formal assessment. A meeting coupled with a review of ongoing status derived from indicators, will help fine tune ongoing projects, drop projects unlikely to be useful, and allow for consideration of candidate modeling approaches.

The Review Panel also expressed concerns about the lack of a decision process that will be necessary before the next assessment. Experience with other crustacean stocks suggests that rapid collapses can occur, particularly when the underlying biology of the stock and patterns of fishing mortality are not fully understood. Preliminary analyses reported at the review meeting suggest declines in catch per unit effort from a subset of directed harvesters in the Offshore Southern New England stock. To address these concerns the Review Panel emphasizes the need to:

- Identify and prioritize candidate indicators of relative abundance and fishery performance.
- Conduct a formal annual evaluation of important indicators, and
- Develop a methodology for making decisions based on ordinal data. Analyses by the SAS showed the utility of binning data into 3 bins corresponding to the first quartile, the inter quartile range, and the fourth quartile.

Ideally, the methodology would identify the probability of observing the observed trends in indicators. Simultaneous drops in multiple indicators may be indicative of true declines or coincidence. Randomization tests may be helpful for distinguishing between these alternatives.

Concomitantly the SAS, in collaboration with managers, will need to define appropriate actions in response to indicator patterns. For example, a decision rule might be to reduce catch by 10% if the probability of observing the observed trend is less than 5% due to chance alone, and to reduce catch by 25% if the probability level is less than 1%. The probability thresholds for decisions and the magnitude of management measures should not be ad hoc. Instead, simulation testing or some form of MSE will be necessary and should be considered by ASMFC. This problem is, of course, not unique to Jonah crabs. Therefore, evaluation of national and international research may be helpful.

ADVISORY REPORT

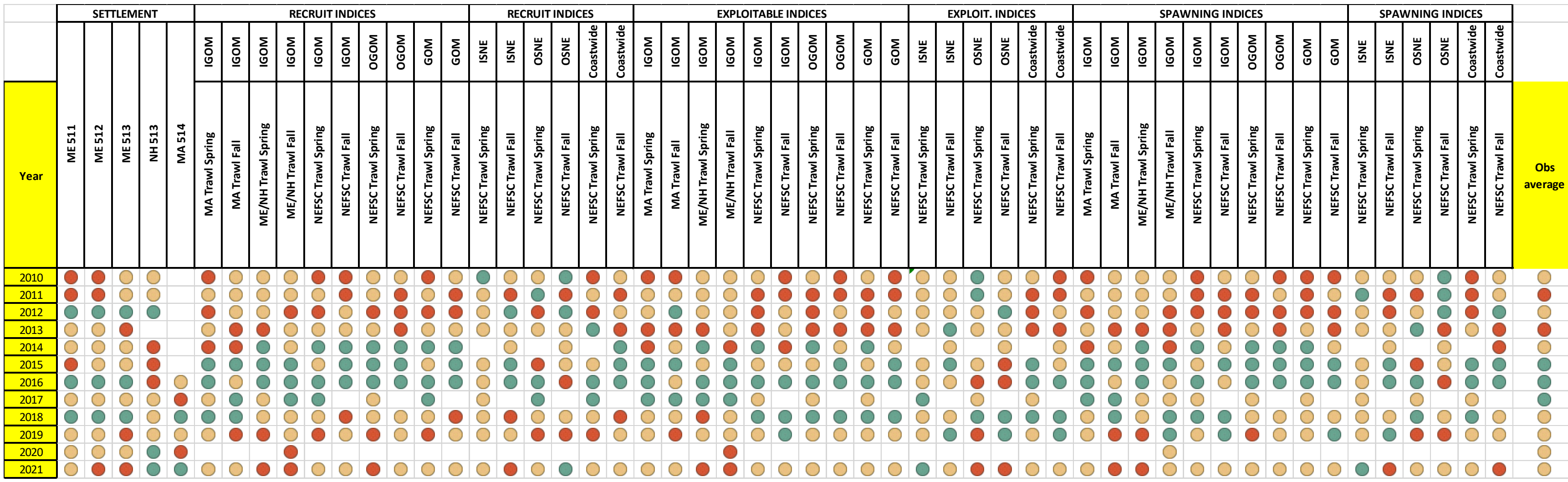
A. Status of the Stock

The Stock Assessment Subcommittee (SAS) brought forward a large assemblage of Jonah crab data in a cohesive and thorough manner. At present, the availability of data was not sufficient to estimate population parameters and biological reference points in order to determine traditional overfishing and overfished statuses. Other status determining criteria (SDC) were explored, including important fishery and biological background and trend analyses of 53 fishery-independent (FI) survey indices and four fishery-dependent (FD) indices. Interpreting stock status was difficult because longer-term trends in stock indicators appear positive, but disturbing, recent indicators signal a potentially, sharply declining stock. The conflicting indicators depicted an uncertain stock status for Jonah crab.

A number of favorable factors exist, such as a cohesive, coastwide, regulatory framework that implements an appropriate minimum size limit (MSL) that reduces harvest of immature crabs. Furthermore, the fishery selects crabs at even larger sizes than the MSL, based on discussions with the SAS and supported by a preliminary Length-Based Spawning Potential Ratio (LBSPR) analysis requested by the Review Panel. Importantly, the fishery also does not select female crabs, which provides a significant moat to the potential depletion of female spawning biomass. Given these fishery dynamics, the larger danger to population reproductive productivity would occur from male depletion/sperm limitation.

Fishery-Independent (FI) stock indicators, in bulk, tend to portray a population at higher levels of abundance than at the start of survey time series (Table 1). However, the positive signals are assessed across a time span up to 42 years, and should be interpreted with caution since there appears to be a potential regime shift occurring circa 2010, when young-of-the-year recruitment indices become conspicuously elevated in the GOM. When examining indicators over a shorter-term, post-regime-shift time span (2010-2021), there are much fewer positive (>75th percentile) index values in the terminal years (2020, 2021) across the range of indices (Table 2).

Table 2. Graphic depiction of ordinal measures of relative abundance indices by stock area and year from 2010-2021. Lowest 25% quartile is coded red, interquartile range is coded in yellow, and highest quartile (>75%ile) is coded green. Each index is coded separately. Shorter time series may create bias when compared to longer time series.



Although long-term FI indicators appear positive, we see a clear, sharp decline in recent fishery landings and other highly concerning, corroborating fishery metrics. Jonah crab landings have declined 51% in the most-recent three-year period in the OSNE, even while market prices have increased. While we acknowledge other industry and market factors should be investigated, it is highly concerning to see similar, recent, sharp declines in the fishery-dependent (FD) CFRF OSNE CPUE beginning in 2017, the generally declining FD CPUE in the inshore RI DRM analysis, and a recent decline in the post-hoc, Panel-requested, investigation of directed FD CPUE from RI trip level data (Figure 1). There were also large single-year drops in FI CPUE in the NEFSC OSNE trawl in Fall 2019 and Spring 2020.

It is particularly worrisome that the extremely rapid collapse of the Canada Jonah crab fishery in the early 2000s occurred without noticeable declines in FI trawl indicators (DFO 2009). In the first three years of the Canada fishery collapse, crab landings declined by 58%, comparable to the current, three-year, 51% drop in OSNE landings. Although Canada Fisheries and Oceans (DFO) FI trawl indicators did not fully capture the deteriorating condition of the stock, declining fishery CPUE was observable preceding and during the landings crash (Figure 2).

Given a data-limited assessment lacking population estimates and biological reference points (BRPs), generally conflicting long- versus short-term indicators, and recent, declining fishery signals, the Panel considers the status of the Jonah crab stock to be highly uncertain and recommends close, annual monitoring of stock indicators to further evaluate recent signals.

B. Data and Assessment

Data collection for the assessment was comprehensive and thoroughly assembled. The SAS presented 53 fishery-independent (FI) survey indices covering four life stages (young-of-the-year, recruit, post-recruit, spawners) and five regions (IGOM, OGOM, ISNE, OSNE, Coastwide). They included: five young-of-the-year (YOY) indices (an additional three surveys were evaluated but not included); and 48 post-YOY indices (plus 20 evaluated but not included). Four fishery-dependent (FD), exploitable-sized, male crab CPUE indices were presented covering four regions (IGOM, OGOM, ISNE, OSNE).

Given life history gaps and tempered confidence in synoptic indices, attempts to construct population models were not detailed in the assessment. Trend analyses of survey and relative exploitation indices were explored, showing mixed results between GOM and SNE regions, and were fairly inconclusive from a coastwide perspective and for the important OSNE region that supports the bulk of the fishery. Index-based methods were also explored and were not recommended for management use, given the apparent disconnect between indices and fishery removals, and concern regarding trawls as an appropriate survey gear for structure-associated Jonah crabs.

Challenges

Age and Growth

Assessing marine invertebrate fishery stocks is notoriously difficult, largely due to the prevailing lack of ageing methods for invertebrates, especially crustaceans. The inability to age individuals and characterize age distributions is particularly troublesome for assessments when the species is long-lived, without highly conspicuous life stages that can be monitored practicably and described using stage-based population models. Significant life history gaps still exist for Jonah crab, particularly with respect to modeling growth and understanding longevity, that could prove highly useful in developing length- or stage-based population models or developing other SDC such as Length-Based Spawning Potential Ratio (LBSPR) modeling. Longevity is particularly important, since maximum age is a powerful, useful predictor of natural mortality rate (M). Growth rate and M are also key elements in constructing basic yield-per-recruit (YPR) and spawner-per-recruit models that can produce fishing mortality-based reference points for Jonah crab and reveal how vulnerable the stock is to overfishing.

Surveys

The SAS did an excellent job producing a long list of FI relative abundance indices, based notably on trawl surveys for all post-young-of-the-year (YOY) FI indices. The potential ineffectiveness of mobile trawl gears for capturing benthic, structure-associated Jonah crabs was a prominent discussion point amongst the Panel and SAS. As an illustration of this potential issue, one out of every five (21.3%) annual trawl index values was zero in the assessment. Trawl ineffectiveness was especially pronounced in certain indices, particularly the Northeast Fisheries Science Center (NEFSC) trawl indices in the ISNE and OSNE (to a lesser degree than the ISNE). Such heavy reliance on trawls is a substantial concern for monitoring Jonah crab indicators.

FD indices based on passive traps and pots offer promise as stock indicators. However, the usual caveats need investigation, such as inter-specific (e.g., lobster) and intra-specific interactions, shifting bait practices, gear saturation, hyperstability in catch rates due to commercial fishing practices, regulation changes, and fluctuations in fleet composition influenced by market factors. Taking these caveats into consideration, during the Review Workshop, at the request of the Panel, the SAS produced a very promising FD catch-per-unit-effort (CPUE) indicator using Rhode Island trip-level data subset to a core group of dedicated Jonah crab harvesters. The CPUE was especially useful because it best incorporated the SAS's practical knowledge of their state fisheries as it relates to the aforementioned caveats. As seen in the Canada DFO Jonah crab assessment, FD CPUE was effective at detecting declining crab abundance during the landings crash in Canada in the early 2000s (DFO 2009).

C. Population Dynamics

The assessment provided for a better understanding of Jonah crab population dynamics that should hopefully aid future assessment efforts to estimate population parameters and biological reference points.

<u>Growth and Reproduction</u>

Jonah crab growth rate was described by Huntsberger (2019) across multiple approaches, including length frequency analysis of field collections, a probabilistic model based on laboratory growth, and ageing of the gastric mill, a calcified structure in the digestive system. Jonah crabs exhibited rather slow growth, taking at least four years, but most likely seven years, to reach the fishery legal size (see Figure 2.7 from Huntsberger (2019)). The slower growth rate does not imply great resiliency to fishing pressure.

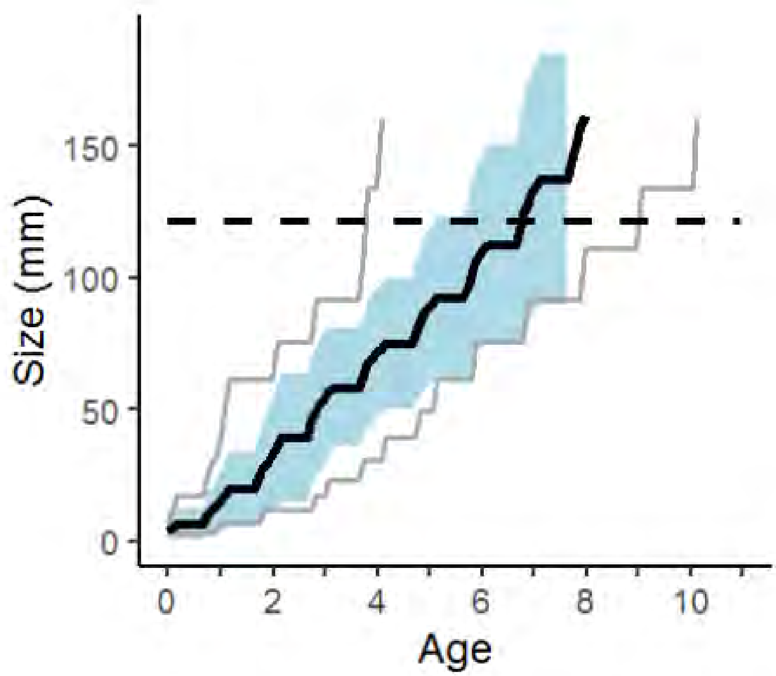


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Figure 2.7 Final output of 1000 runs of the probabilistic growth model for male Jonah crabs. The average size (CW) is the solid black line with the gray lines displaying the minimum and maximum sizes and the blue shaded area as the 95% confidence interval. The dotted line is legal size.

The growth models also have value for potential length-based population modeling, YPR and spawning potential ratio models for generating fishery reference points, and SDC models such as LBSPR. Furthermore, direct ageing of individuals using the gastric mill method would enable the SAS to determine fishing mortality rates from basic catch curves of age distributions, gain insight into Jonah crab longevity, and eventually construct desired age-structured population models.

Size-at-maturity (SM50) estimates documented from a range of sources indicate the fishery minimum size limit is specified at-or-above male SM50s, and far above female size-at-maturity estimates. However, better knowledge of the Jonah crab reproductive biology, particularly maturation rates (e.g., age-at-maturity), terminal molting, spawning frequency, reproductive lifespan, operational sex-ratios, etc. would be useful to gain greater insight into crab population dynamics and vulnerability to overfishing.

Stock-Recruit Relationship

Preliminary stock-recruit (s-r) plots requested by the Panel showed a potential relationship between spawning and YOY indices. However, there are questions about the potential spatial mismatch between GOM (YOY index) and coastwide indices (spawning abundance index) (Figure 3). A s-r relationship seen between indices is encouraging for future population modeling efforts.

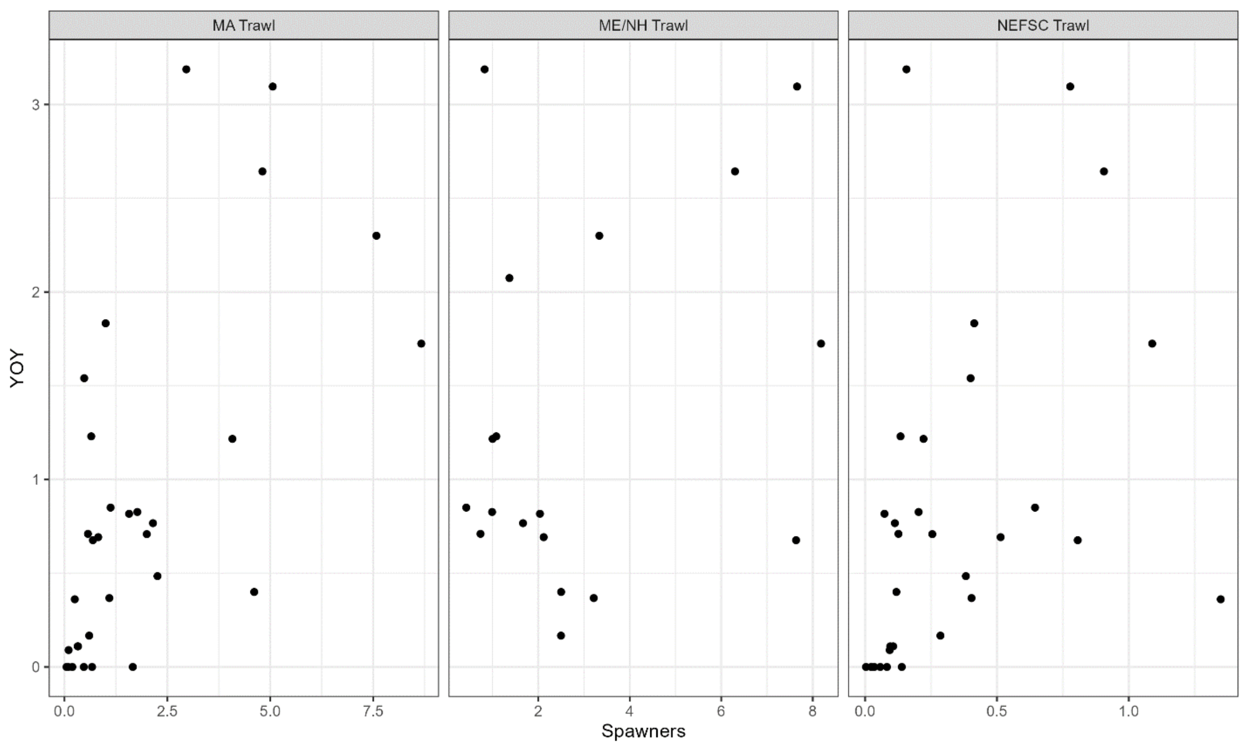


Figure 3. Stock-Recruit plots provided to the Panel during the Review Workshop. Independent axes=Spawner indices, dependent axes=GOM YOY indices (ostensibly lagged, year+1).

D. Fishery

The Jonah crab fishery is dynamic, having recently expanded and shifted towards a more targeted fishery in the past two decades, while also continuing to be strongly tied to the American lobster fishery and its markets. The stock supports a substantial fishery, with recent ex-vessel values peaking at nearly $20 million (Figure 4). Jonah crab harvest is concentrated in one particular region, in the northern area of Offshore Southern New England (OSNE), and is prosecuted mainly by the Massachusetts and Rhode Island fisheries. Considerably smaller state fisheries do operate throughout most of the Jonah crab distribution, from the Gulf of Maine to the Mid-Atlantic.

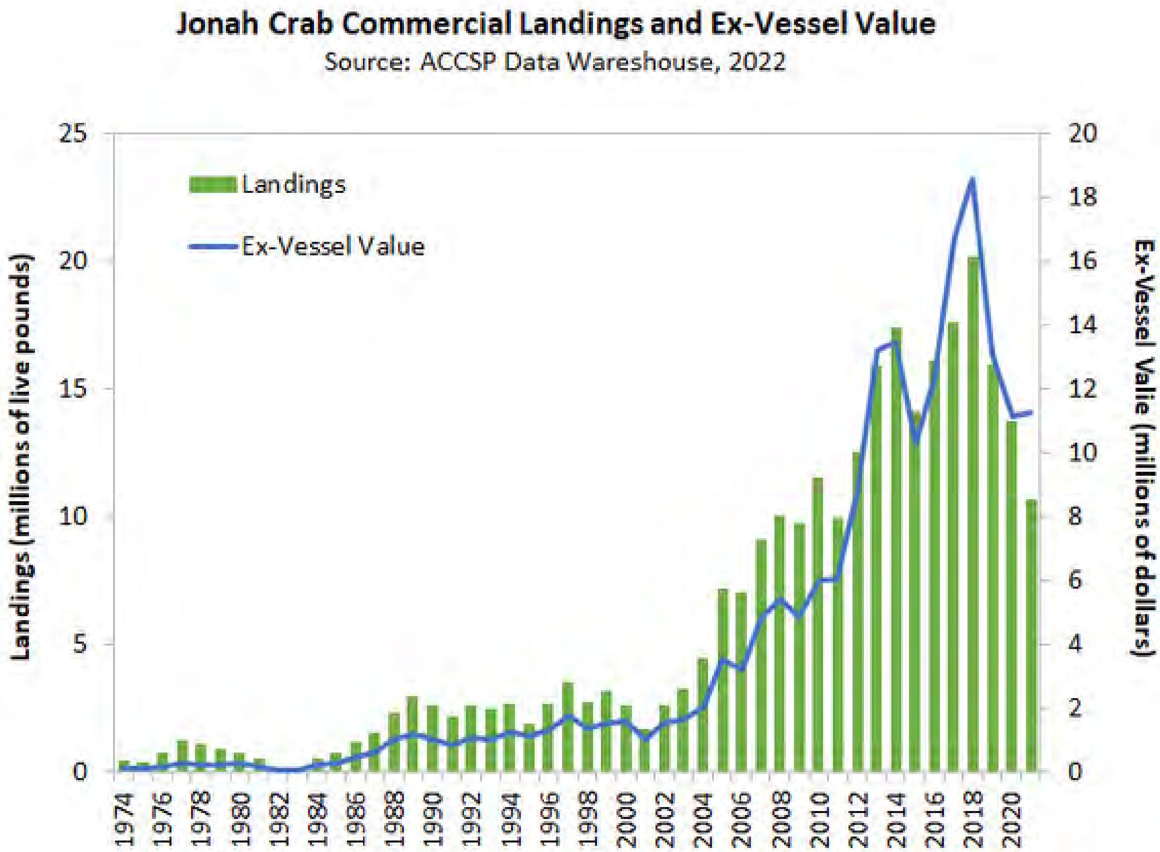


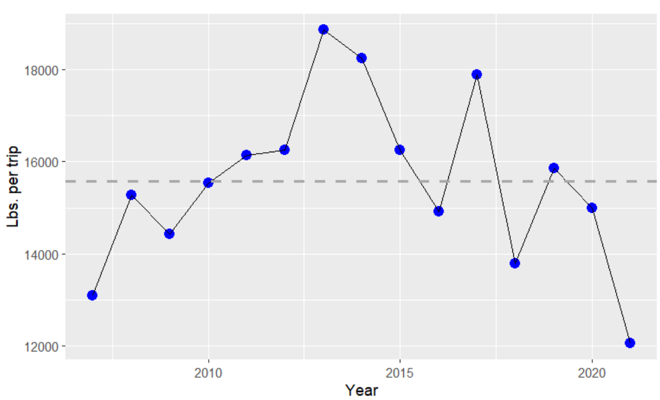
Figure 4. Jonah Crab commercial landings and ex-vessel value.

Jonah crab landings grew substantially (30-fold) in the 2000s and 2010s, and have now declined very sharply (-51%) in the three most-recent years of the assessment. The decline is similar in scope to the beginning stages of the Canada Jonah crab fishery collapse in the early 2000s. In the first three years of the Canada collapse, landings declined 58%. Within five years, landings dropped 97%. In retrospect, Canada DFO concluded that biomass had been severely overfished despite relatively low fishing pressure on a male-only fishery. The ASMFC stock assessment is occurring at a critical time, since it is imperative to determine whether the current steep decline is the start of a 'bust' phase of a boom-and-bust arc, or driven more by market factors.

The SAS brought forward two fishery-dependent (FD) CPUE indicators for the OSNE and ISNE regions in the assessment. CPUE results were mixed, as the ventless trap survey CPUE showed a three-year decline from 2017-2020 in the OSNE, while the Directed Residual Mixture Model (DRM), Rhode Island CPUE showed a declining trend in the ISNE, but no trend in the OSNE. The ventless trap survey possessed a short time-series (2015-2020) and lacked a terminal-year CPUE value for 2021. It is uncertain how well the modeled approach in the DRM performed for identifying targeted trips. After trend analyses, the SAS recommended to not use DRM indicators as measures of exploitable abundance.

Fishery-independent stock indicators, unfortunately, also provided a somewhat unclear perspective on the most-recent three-year period, largely due to the low catchability issues of trawl surveys (see Stock Status, Data and Assessment sections, and TORs for greater detail). As seen in the Canada Jonah Crab Stock Assessment, FI trawl indicators did not detect the rapidly declining stock during the fishery crash in the late 1990s and 2000s (DFO 2009). However, declining fishery-dependent CPUE was evident.

Jonah crab fishery-dependent CPUE analyses are challenging because measuring directed effort is complicated by the mixed Jonah crab and lobster fisheries, and the interplay in fishing effort for both species. Given this uncertainty, the Panel requested a fishery dependent analysis during the Review Workshop that focused on a subset of directed, core Jonah crab harvesters. Based on knowledge of the Rhode Island fishery, the SAS developed basic criteria to subset fishery data to directed Jonah crab trips (>6,000 lb landings) and to participants that were active throughout the time-series. Preliminarily, it does appear that recent fishery CPUE has declined in the OSNE. Further exploration into the directed FD CPUE should continue, with emphasis on investigating caveats typical of FD analyses (i.e., changing market factors and trends in catchability). The Panel also recommended applying the analysis to the Massachusetts fishery data, and to include both as indicators to monitor annually over the next few years, in order to understand the nature and severity of recent falling landings.



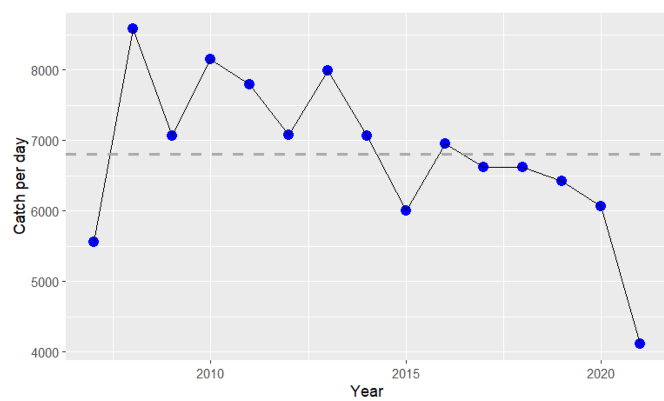


Figure 5. Preliminary analysis of Jonah Crab directed fishery commercial CPUE for select Rhode

E. Future Guidance

The greatest value in this stock assessment may be measured by how well it propels the SAS forward in generating eventual population estimates, reference points, and a clear stock status determination in the ensuing benchmark assessment. Identifying target models and related data needs should logically steer the future research and monitoring efforts of ASFMC partners.

In this assessment, the SAS did a commendable job summarizing available life history information, and constructing and vetting all possible survey and fishery indices. Looking ahead, reasonable target models to pursue would be a Catch-Survey Analysis (CSA) or surplus production model, given their simplicity and minimal data requirements. However, the main barrier to pursuing these and any other population model is the absence of a synoptic Jonah crab abundance index.

Developing a reliable index of abundance is a top priority for the next assessment. If the SAS can further develop the fishery-dependent, directed CPUE in the OSNE, it could fuel first attempts at surplus production modeling. The CPUE is useful because it leverages existing data, and will ostensibly contain a moderately duration time series over a period of substantial contrast in fishery effort and landings. Another direction is to pursue length-based models, possibly using the GMACS (Generalized Model for Assessing Crustacean Stocks) platform. This would likely require much more intensive fishery biosampling to complement the size compositions in existing FI trap and trawl surveys.

Another avenue to explore is the viability of direct ageing of individuals using Huntsberger's (2019) gastric mill method. Direct ageing of specimens would be a game-changer, as it would enable the SAS to generate first estimates of fishing mortality rates from age distributions, gain insight into Jonah crab longevity and natural mortality rate, and enable pursuit of age-structured population models. The time and effort needed to extract and age crab structures will be important factors to consider in understanding its feasibility.

Immediate Steps

The Jonah crab stock is at a pivotal junction. Fishery landings are sharply declining (-51% in the most-recent three years) following a two-decade period of unprecedented growth (30-fold increase). Although FI signals are inconclusive, it appears that fishery CPUE is declining, corroborating the fall in landings. These conditions are highly concerning because they closely resemble the early stages of the Canada Jonah crab fishery collapse in the early 2000s. There is great uncertainty in whether the very large, recent decline in landings is the beginning of a 'bust' stage of a classic boom and bust arc, or merely a short-term drop caused by markets or factors unrelated to Jonah crab abundance.

Given this uncertainty, combined with the lack of population estimates, fishing mortality rates, and reference points, the Panel recommends the SAS/TC closely monitor stock indicators on an annual basis to examine the nature and severity of the recent decline. In addition to any indicators deemed important by the SAS, we highly recommend the ASMFC monitor the directed, fishery-dependent CPUE for Rhode Island and Massachusetts fisheries. This core-fishery CPUE index was preliminarily constructed by the SAS during the Review Workshop at the request of the Panel. Continued development, exploration, and refinement to this fishery analysis are recommended. Additional, potentially-important indicators to consider are 'operational' sex-ratios in FI surveys and FD biosamples. Changes in baseline sex-ratios may signal male depletion and resulting population-level sperm limitation, and could serve as warning signals preceding a population decline.

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Atlantic States Marine Fisheries Commission

Jonah Crab Benchmark Stock Assessment Report

Prepared by the
ASMFC Jonah Crab Stock Assessment Subcommittee

And

Approved by the
ASMFC Jonah Crab Technical Committee
July 18, 2023

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

EXECUTIVE SUMMARY

Stock Structure

Four Jonah crab stocks were defined during the stock assessment based on a combination of biological aspects, management considerations, fishery characteristics, and data availability. These stocks include the Inshore Gulf of Maine stock (IGOM), Offshore Gulf of Maine stock (OGOM), Inshore Southern New England stock (ISNE), and Offshore Southern New England stock (OSNE).

Data

Commercial Landings

Validated commercial landings of Jonah crab are available coastwide back to 1981, but the accuracy of the reporting and the location of where those landings were harvested is uncertain, so this assessment focused on the landings since 2010. However, it is also important to understand the context of the increases in reported landings over time and the changing structure of the fishery. Coastwide landings register a steady increase over most of the time series, but decreased from the record high in 2018 (22.8 million pounds) during the last three years of the stock assessment (2019-2021). These changes are believed to be influenced by relatively variable Jonah crab markets. Historically, Jonah crab has been a bycatch species in the American lobster trap fishery, but in the last two decades, the fishery has shifted with regional differences.

Most U.S. Jonah crab landings come from the OSNE stock which is considered a directed Jonah crab fishery in recent years. From 2010 to 2021, annual landings for this region have accounted for 70 to 85% of the total U.S. Jonah crab landings. The other three Jonah crab stocks are considered to support bycatch fisheries that are primarily targeting American lobster. Landings from the IGOM stock account for 9 to 24% of the coastwide landings from 2010-2021. The OGOM and ISNE stocks have never exceeded 5% of coastwide Jonah crab landings for any year between 2010 and 2021. Although these fisheries currently catch Jonah crab as bycatch, they represent considerable potential growth of Jonah crab fisheries if they become a target species in the future.

Commercial Size Compositions

Commercial biosample data were available from sea sampling and port sampling programs. Data are still too sparse to calculate landings-weighted stockwide statistics, but snapshots of data by stock and statistical area were evaluated for trends. Overall, trends in mean size statistics are stable over the relatively short time series. General lack of trend seen here could be a favorable indication of stock condition (i.e., stable exploitation) or it could indicate that these data are unreliable indicators of stock condition, as appeared to be the case in other crab stock assessments reviewed. These data should be revisited as potential indicators in future stock assessments when longer time series are available and, ideally, there is sufficient coverage to generate landings-weighted stockwide time series, but are not recommended at this time for stock indicators.

Fishery-Independent Indices of Abundance
Five settlement indices of young-of-year (YOY) Jonah crabs were used in the assessment as measures of year class strength. These included ME settlement surveys from three statistical areas in ME waters (statistical area 511, 512, 513), the NH settlement survey (statistical area 513), and the MA settlement survey (statistical area 514). All surveys are in IGOM waters. Indices that extend back into earlier periods in the early to mid-2000s show increasing trends over time. All available indices agree on relatively strong year classes in 2012 and 2018.

Three post-settlement abundance metrics were used as measures of relative abundance including recruit abundance, exploitable abundance, and spawning abundance. Recruit abundance is defined as male Jonah crabs 90-119mm carapace width (CW). Exploitable abundance includes all male Jonah crabs greater than these recruit sizes (120mm+ CW) and is a measure of abundance currently available to the fisheries. Spawning abundance is defined as female Jonah crabs 80mm+ CW. Three survey platforms provided these post-settlement abundance indices including the MA Trawl Survey covering the IGOM stock, the ME/NH Trawl Survey covering the IGOM stock, and the NEFSC Trawl Survey covering all four stocks (although, determined to not be of utility for ISNE stock abundance indices). All three platforms have separate surveys in the spring and fall.

Indices of each post-settlement metric across stocks generally show increasing trends over time series covering historical periods back to the 1980s and 1990s. Indices in GOM stocks show considerable, but brief pulses of abundance around the mid-2010s.

Assessment Methods
Given limitations of available data sets and poor understanding of life history characteristics needed for traditional assessment approaches, data sets were used to develop empirical indicators of stock conditions and fishery performance. These indicators provide a categorical characterization of recent condition (positive, neutral, or negative) relative to historical levels. The stock assessment terminal three years (2019-2021) are averaged to provide a smoothed measure of recent stock condition due to interannual variability reflective, in part, of observation error.

Stock abundance indicators include the YOY settlement, recruit abundance, exploitable abundance, and spawning abundance indices. Fishery performance indicators include landings, the number and proportion of pot/trap trips that landed Jonah crabs, and the number and proportion of active (i.e., reported catch during the year) lobster/crab permits that landed Jonah crab.

Stock Status
According to stock indicators, there have been declines in post-settlement abundance for the IGOM and OGOM stocks from time series highs in the mid-2010s, but conditions in the last three years of the time series are neutral or positive. The one exception is from the ME/NH Trawl survey, but this is due to the shorter time series of this survey not capturing historical lows in earlier years. Indicators for the OSNE stock also indicate neutral or positive post-

settlement abundance conditions in the last three years of the time series. Indicators agree across these stocks that abundance has not been depleted to historical lows. There are no reliable abundance indicators for the ISNE stock and inference cannot be made about condition of this stock's abundance at this time.

YOY indicators generally indicate neutral conditions and do not indicate that recruitment in GOM stocks will decline to historical lows in the near future. Settlement conditions are unknown for SNE stocks.

Landings have steadily declined in the OSNE stock which is the primary stock with targeted/mixed effort for Jonah crab and the stock accounting for the vast majority of coastwide landings. This trend is believed to be influenced by factors other than available abundance but should continue to be monitored closely. There was not sufficient information to make statements about fishing mortality or exploitation with confidence and these population parameters remain major uncertainties.

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TERMS OF REFERENCE

For the 2023 ASMFC Jonah Crab Benchmark Stock Assessment
Board Approved January 2022

Terms of Reference for the Jonah Crab Assessment

1. Characterize precision and accuracy of fishery-dependent and fishery-independent data used in the assessment, including the following but not limited to:
    a. Provide descriptions of each data source (e.g., geographic location, sampling methodology, potential explanation for outlying or anomalous data).
    b. Describe calculation and potential standardization of abundance indices.
    c. Discuss trends and associated estimates of uncertainty (e.g., standard errors).
    d. Justify inclusion or elimination of available data sources.

2. Discuss the effects of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, sample size) on model inputs and outputs.

3. Develop simple, empirical indicators of stock abundance, stock characteristics, and fishery characteristics that can be monitored annually between stock assessments.

4. Develop models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, and analyze model performance.
    a. Describe stability of model (e.g., ability to find a stable solution, invert Hessian).
    b. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    c. Perform sensitivity analyses for starting parameter values, priors, etc. and conduct other model diagnostics as necessary.
    d. Clearly and thoroughly explain model strengths and limitations.
    e. Briefly describe history of model usage, its theory and framework, and document associated peer-reviewed literature. If using a new model, test using simulated data.
    f. If multiple models were considered, justify the choice of preferred model and the explanation of any differences in results among models.

5. State assumptions made for all models and explain the likely effects of assumption violations on synthesis of input data and model outputs. Examples of assumptions may include (but are not limited to):
    a. Choice of stock-recruitment function.
    b. Calculation of M. Choice to use (or estimate) constant or time-varying M and catchability.
    c. Choice of equilibrium reference points or proxies for MSY-based reference points.
    d. Constant ecosystem (abiotic and trophic) conditions.

6. Characterize uncertainty of model estimates and biological or empirical reference points.

7. Recommend stock status as related to reference points (if available). For example:
    a. Is the stock below the biomass threshold?
    b. Is F above the threshold?

8. Other potential scientific issues:
    a. Compare reference points derived in this assessment with what is known about the general life history of the exploited stock. Explain any inconsistencies.
    b. Explore, identify, describe, and, if possible, quantify environmental/climatic drivers.

9. If a minority report has been filed, explain majority reasoning against adopting approach suggested in that report. The minority report should explain reasoning against adopting approach suggested by the majority.

10. 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.

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

Terms of Reference for the Jonah Crab Peer Review

1. Evaluate the thoroughness of data collection and the presentation and treatment of fishery-dependent and fishery-independent data in the assessment, including the following but not limited to:
    a. Presentation of data source variance (e.g., standard errors).
    b. Justification for inclusion or elimination of available data sources,
    c. Consideration of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, sample size),
    d. Calculation and/or standardization of abundance indices.

2. Evaluate empirical indicators of stock abundance, stock characteristics, and fishery characteristics for their appropriateness to monitor the stock between assessments.

3. Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, including but not limited to:

a. Evaluate the choice and justification of the preferred model(s). Was the most appropriate model (or model averaging approach) chosen given available data and life history of the species?
b. If multiple models were considered, evaluate the analysts' explanation of any differences in results.
c. Evaluate model parameterization and specification (e.g., choice of CVs, effective sample sizes, likelihood weighting schemes, calculation/specification of M, stock-recruitment relationship, choice of time-varying parameters, plus group treatment).

4. Evaluate the diagnostic analyses performed (e.g., sensitivity analyses to determine model stability and potential consequences of major model assumptions, retrospective analysis).

5. Evaluate the methods used to characterize uncertainty in estimated parameters. Ensure that the implications of uncertainty in technical conclusions are clearly stated.

6. If a minority report has been filed, review minority opinion and any associated analyses. If possible, make recommendation on current or future use of alternative assessment approach presented in minority report.

7. Recommend best estimates of stock biomass, abundance, and exploitation from the assessment for use in management, if possible, or specify alternative estimation methods.

8. Evaluate the choice of reference points and the methods used to estimate them. Recommend stock status determination from the assessment, or, if appropriate, specify alternative methods/measures.

9. Review the research, data collection, and assessment methodology recommendations provided by the TC 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.

10. Recommend timing of the next benchmark assessment and updates, if necessary, relative to the life history and current management of the species.

11. Prepare a peer review panel terms of reference and advisory report summarizing the panel's evaluation of the stock assessment and addressing each peer review term of reference. Develop a list of tasks to be completed following the workshop. Complete and submit the report within 4 weeks of workshop conclusion.

1 INTRODUCTION

Cooperative interstate management of Jonah crab (*Cancer borealis*) in U.S. waters was first implemented in 2015 with the adoption of the Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fishery Management Plan (FMP; ASMFC 2015). However, there has been no stock assessment of U.S. Jonah crab to date, stock status is unknown, and there has been limited science-based advice available to support management of Jonah crab fisheries.

The Jonah Crab Technical Committee (TC) met in August 2017 to review research projects and discuss data limitations. This review identified limitations on understanding of basic life history processes, but also identified several projects in progress that could help fill some information gaps in coming years. The TC met again in April 2020 and reviewed ongoing research as well as regular agency monitoring efforts. During this meeting, the TC recommended a more in-depth review of available data to better understand limitations and identify stock assessment approaches that could be supported with available data. Subsequently, the ASMFC American Lobster Management Board (Board) tasked the TC in August 2020 with conducting a pre-assessment workshop for Jonah crab and providing a report on available data and recommended assessment approaches. A series of webinars was held November 16-18, 2020, February 11, 2021, June 3, 2021, and June 29, 2021, to review and discuss available Jonah crab data sets, potential assessment approaches, and remaining data limitations.

The TC's evaluation of the data sets, findings on potential approaches for a near-term stock assessment to provide management advice, and research recommendations to advance future stock assessments were provided in a pre-assessment report in July 2021 (ASMFC 2021). In summary, the TC noted limitations in life history information, limitations with available index of abundance information such as lack of overlap with the core fishery area and poorly understood catchability, and limitations with landings data prior to 2006. Despite these limitations, the TC did acknowledge the need for a full benchmark stock assessment to provide information with which to manage the fishery as well as additional information on data needed to improve future stock assessments. The TC presented these finding to the Board and recommended conducting a benchmark assessment to be completed in 2023. The Board accepted this recommendation and initiated an assessment at the ASMFC 2021 Summer Meeting in August.

The TC and Jonah Crab Stock Assessment Subcommittee (SAS) met via webinar for a Data Workshop June 13-15, 2022 to review the available data sets and discuss data development for the assessment. The SAS than met again via webinar October 3-5, 2022 for a Methods Workshop to review updates on data development and discuss potential assessment methods. The SAS met a final time, in-person in New Bedford, MA April 18-20, 2023 to finalize assessment results which the following report covers.

1.1 Brief Overview and History of the Fishery

Until recently, Jonah crab were predominantly a bycatch species in the American lobster fishery—annual commercial Jonah crab landings were generally lower than 6 million pounds through 1996. Since then, as the lobster fishery has declined in southern New England (SNE) and the market for crab has expanded, harvesters have pivoted to target Jonah crab in addition to (or instead of) lobster. A mixed crustacean fishery now exists in which fishers seasonally adjust their fishing strategies to target Jonah crab or lobster. Harvest pressure on Jonah crab has increased substantially over the past two decades, with landings increasing steadily since around 1996 (Figure 1). Between 2010 and 2021, annual landings of Jonah crab averaged about 16 million pounds, ranging between 12.0 million and 22.8 million pounds (2018). Total Jonah crab commercial catch in 2021 was 12.2 million pounds, with a total ex-vessel value of about $12.8 million.

The Jonah crab commercial fishery occurs predominantly in SNE. Most of the U.S. Jonah crab commercial catch is landed in Massachusetts (54%, 2019-2021 average) and Rhode Island (21%), and most harvest occurs offshore in NOAA Fisheries statistical areas (hereafter, statistical area) 537 (50.6%), 526 (12.5%), and 525 (11.4%). Most Jonah crab commercial landings are reported as having been caught in traps and pots.

Coastwide, commercial landings of Jonah crab are highest in the late autumn and winter months (October to February). In an interview study, fishermen indicated that this seasonal shift was driven by the lobster fishery—lobster are less abundant in winter, so harvesters transition to target Jonah crab during these months (Truesdale et al. 2019a). Based on interviews with fifteen Jonah crab fishermen from Rhode Island and Massachusetts, the number of traps set to target Jonah crab over lobster increased by 73% in the winter compared with the summer months. Fishing strategy adjustments made to transition between Jonah crab and lobster include escape vent modifications, bait type, and fishing location changes.

A small Jonah crab claw fishery operates in Delaware, Maryland, and Virginia, wherein the claws of large Jonah crabs are removed and the animal is returned to the ocean alive. Claw harvest comes mostly from lobster vessels fishing in Lobster Conservation Management Area (LCMA) 5 and accounts for less than 1% of the coastwide commercial landings.

There is no regulatory distinction between a lobster trap and a Jonah crab trap, and a vessel's target species can often not be determined from trip reports and dealer data. Inability to identify a target species, and the recency of the development of the Jonah crab fishery makes it challenging to characterize fishing effort, and there is little literature describing the seasonal dynamics, fishing strategies, and socioeconomic aspects of the fishery. Some anecdotal information has been summarized and may provide a starting point for analyzing and characterizing the fishery (Truesdale et al. 2019a). Additionally, some model-based approaches for standardizing catch-per-unit-effort (CPUE) in mixed crustacean fisheries may serve as a path forward for estimating fishery catch rates (Maunder and Punt 2004; Okamura et al. 2018). Quantifying fishing effort for Jonah crab versus lobster remains a data need for future assessments.

1.2 Management Unit Definition

The management unit for Jonah crab includes the U.S. Atlantic states from Maine through Virginia, though the biological range of the species extends from Newfoundland, Canada to Florida.

1.3 Regulatory History

The ASMFC coordinates the interstate management of Jonah crab in state waters (from 0-3 miles offshore). The ASMFC manages Jonah crab through the FMP, which was approved by the Board in August 2015 under the authority of the Atlantic Coastal Fisheries Cooperative Management Act (1993). Management authority in the exclusive economic zone (EEZ), which extends from 3-200 miles offshore, lies with NOAA Fisheries. The FMP was initiated in response to concern about increasing targeted fishing pressure for Jonah crab, which has long been considered a bycatch species in the lobster fishery. The multi-species nature of the fishery created a challenge for managing a Jonah crab fishery completely separate from the lobster fishery without impacting the number of vertical lines and traps in state and federal waters. Furthermore, a lack of universal permitting and reporting requirements made it difficult to characterize catch and effort to the full extent in order to manage the fishery.

The goal of the FMP is to promote conservation, reduce the possibility of recruitment failure, and allow for the full utilization of the resource by the industry. The FMP lays out specific management measures in the commercial fishery to limit effort and protect spawning stock biomass in the absence of a range-wide stock assessment. These include a 4.75 inch (120.65 mm) minimum carapace width (CW) and a prohibition on the retention of egg-bearing females. To prevent the fishery from being open access, the FMP limits participation in the directed Jonah crab trap fishery to lobster permit holders or those who can prove a history of crab-only pot fishing. All others must obtain an incidental permit. In the recreational fishery, the FMP sets a possession limit of 50 whole crabs per person per day and prohibits the retention of egg-bearing females. Due to the lack of data on the Jonah crab fishery, the FMP implements a fishery-dependent data collection program. The FMP also requires harvester and dealer reporting along with port and sea sampling.

Addendum I was approved by the Board in May 2016, and states were required to implement the management measures in Addendum I by January 1, 2017. Addendum I establishes a bycatch limit of 1,000 pounds of crab per trip for non-trap gear (e.g., otter trawls, gillnets) and non-lobster trap gear (e.g., fish and whelk pots). In doing so, the Addendum caps incidental landings of Jonah crab across all non-directed gear types with a uniform bycatch allowance. While the gear types in Addendum I make minimal contributions to total landings in the fishery, the 1,000-pound limit provides a cap to potential increases in effort and trap proliferation.

Addendum II was approved in January 2017, with associated measures required by January 1, 2018. Addendum II establishes a coastwide standard for claw harvest. Specifically, it permits Jonah crab fishermen to detach and harvest claws at sea, with a required minimum claw length (measured along the bottom of the claw, from the joint to the lower tip of the claw) of 2.75” if the volume of claws landed is greater than five gallons. Claw landings less than five gallons do not have to meet the minimum claw length standard. The Addendum also establishes a definition of bycatch in the Jonah crab fishery, whereby the total pounds of Jonah crab caught as bycatch must weigh less than the total amount of the targeted species at all times during a fishing trip. The intent of this definition is to address concerns regarding the expansion of a small-scale fishery under the bycatch limit.

In response to concerns regarding deficits in existing reporting requirements, the Board approved Addendum III in February 2018, which improves the collection of harvester and biological data in the Jonah crab fishery. Specifically, the Addendum improves the spatial resolution of harvester data collection by requiring fishermen to report via 10-minute squares. It also expands the required harvester reporting data elements to collect greater information on gear configurations and effort. In addition, the Addendum established a deadline that within five years, states are required to implement 100% harvester reporting, with the prioritization of electronic harvester reporting development during that time. Finally, the Addendum improves the biological sampling requirements by establishing a baseline of ten sampling trips/year, and encourages states with more than 10% of coastwide landings to conduct additional sampling trips. The provisions of Addendum III went into effect January 1, 2019, however, implementation of the requirement for commercial harvesters to report their fishing location by 10 minute longitudinal/latitudinal square was delayed until January 1, 2021.

Federal regulations complementing the majority of measures included in the FMP and Addenda I and II became effective on December 12, 2019. Commercial measures included requiring a federal lobster permit, a minimum CW, a prohibition on retaining egg-bearing females, incidental catch limits, and federal dealer permitting and reporting requirements. Recreational measures included a daily catch limit and a prohibition on retaining egg-bearing females. The Jonah crab claw-only fishery is not directly regulated in federal waters; harvesters must abide by state requirements.

In March 2022, the Board approved Addendum IV, which expands on the Addendum III reporting improvements by establishing electronic tracking requirements for federally-permitted vessels in the American lobster and Jonah crab fisheries. Specifically, electronic tracking devices will be required for vessels with commercial trap gear area permits for LCMAs 1, 2, 3, 4, 5, and Outer Cape Cod to collect high resolution spatial and temporal effort data. The addendum requirements seek to enhance data for the stock assessment, identify areas where fishing effort might present a risk to endangered North Atlantic right whales, and document the footprint of the fishery to help reduce spatial conflicts with other ocean uses like wind energy development and aquaculture.

1.4 Assessment History

1.4.1 Previous Jonah Crab Assessments

The only stock assessments conducted for Jonah crab to date have been in Canadian waters. The most recent was conducted for Lobster Fishing Area (LFA) 41 where a directed Jonah crab fishery started in 1995. In response to the developing fishery, a total allowable catch (TAC) of 720 metric tons that was not based on scientific advice was implemented for the fishery. This TAC was fully or nearly caught in all seasons from the 1996-1997 fishing season through the 2000-2001 fishing season and was followed by a continuous decline in catch through the 2008 fishing season. Assessments were conducted in 2000 (Robichaud et al. 2000) and 2009 (Pezzack et al. 2009). These assessments provided empirically-based stock indicators developed from existing monitoring programs. Indicators included abundance indicators (fishery-independent indices of abundance, fishery CPUE, and total landings) and fishing pressure indicators (number of traps hauled and median size of Jonah crabs harvested). Indicators were categorized as positive, neutral, or negative and used to provide qualitative characterizations of stock status. In the most recent assessment, all indicators were negative relative to the previous assessment time-period (1995-1999), except for median size. Abundance indicators from surrounding LFAs where directed Jonah crab fisheries had not developed indicated no clear abundance declines over the same time-period. Although the assessment notes some uncertainty in the cause(s) of negative stock conditions, the results suggest the TAC was not sustainable and declines are due to fishing down the biomass from the start of the fishery.

1.4.2 Other Crab Species Assessments

Assessing crab stocks can be challenging, as demonstrated by other assessments reviewed to inform this assessment. Crabs generally lack age estimates, limiting the types of models that can be used. Their growth is incremental, and growth rates can vary by size, age, or maturity status. Some have a terminal molt. Further, selectivity of survey gear can be inconsistent based on substrate type, temperature, interactions with other species, and life-history characteristics. Below are summaries of selected stock assessments used to make management decisions for other crab species.

Brown Crab Stock Assessment, EIFCA, 2019

The Eastern Inshore Fisheries and Conservation Authority's (EIFCA) brown crab (*C. pagurus*) assessment uses an indicator-based model and defines stock boundaries based on pre-existing mixed-species fisheries management areas (EIFCA 2019). The primary fishery landing brown crab is a mixed-crustacean pot fishery, which also targets European lobster (*Homarus gammarus*). Unlike the Jonah crab fishery, female brown crab are regularly landed because they are of similar size to males. The main data sources used in the assessment are commercial trip reports (landings per unit of effort (LPUE)) and port sampling data. The stock is considered stable based on the stability of LPUE data (pot hauls), and recruitment is sufficient to offset harvest, though there was a slight decrease in the most heavily exploited zone. The assessment acknowledges the challenges associated with using effort data in a mixed-crustacean fishery (e.g. uncertainty in primary target species, species interactions impacting catch probability). The EIFCA is looking into the efficacy of using Length Converted Catch Curve fisheries models for future brown crab assessments but is concerned about violating assumptions of the model (e.g., recruitment and natural mortality are consistent) and the application of these models to crustaceans with incremental growth.

Snow Crab Stock Assessment, DFO Canada, 2020

Fisheries and Oceans Canada's (DFO) snow crab (*Chionoecetes opilio*) assessment (DFO 2020) uses a conditional, autoregressive, spatiotemporal model, and a logistic population model, and utilizes fisheries management areas as stock boundaries. The main data sources used in the assessment are commercial landings, commercial sea sampling, and environmental data. Sea sampling data is used to create "age" classes. The fishery is male-only and targets hard shelled-animals. Abundance is modeled using depth, substrate, temperature, and species composition as covariates. The resulting index is used with a logistic population dynamics model to estimate fishable biomass, carrying capacity, and F_{MSY}. Size composition, female recruits, sex ratios, and predator abundance are used as indicators.

Stone Crab Stock Assessment, FWC, 2011

The Florida Fish and Wildlife Conservation Commission's (FWC) 2011 Stone crab (*Menippe spp*.) assessment was conducted using the Gulf Coast of Florida as a management unit (FFWCC 2011). The stone crab fishery targets two species of stone crab, and a hybrid. Specific stone crab species abundance varies along the coast. This is a claw-based fishery where claws from male and female crabs are removed, and the crab is returned to the water. Mortality rates of de-clawed crabs is low if done properly but can be high if both claws are removed improperly. Nearly all Florida stone crab landings (~99%) come from the Gulf Coast. The assessment uses a Surplus Production model and a modified DeLury depletion model to estimate recruitment needed to offset fishing mortality (*F)* and natural mortality (*M)*. The main data sources are commercial landings, port sampling (claw size and stage), maximum age estimates, and octopus catch rates in crab traps (stone crabs avoid traps with octopus). CPUE data (per trip and per trap) are used as indicators. Assessment methods are limited due to a lack of fisheries independent data, claw size not being correlated with crab size or age, and a lack of recreational fishery data (unknown magnitude of landings).

Tanner and King Crab Stock Assessment, NPFMC, 2022

The North Pacific Fishery Management Council conducts assessments for several crab species including multiple species of tanner and king crab (NPFMC 2022). Data used in the assessments included multiple fisheries independent trawl surveys, commercial landings, bycatch from dragger fleet, sea sampling, port sampling, and pot surveys (limited in scale). The 2022 assessment used several models depending on the data available for a given species, including size and sex-based models (mature/immature, new shell/old shell), population dynamics models, random effects models, length-based models (e.g., generalized modeling for Alaskan Crab Stocks (GMACS)), and index-based models. Indicators were used for species with insufficient data to run a model (e.g., mean weight and CW of landed crabs).

Blue Crab, CBSAC, 2022

The Chesapeake Bay Stock Assessment Committee conducts annual status updates of the 2011 benchmark assessment for blue crab in Chesapeake Bay (CBSAC 2022). The main data sources used in the 2022 update were the Maryland Department of Natural Resources (MD DNR)/Virginia Institute of Marine Science (VIMS) winter dredge survey, commercial landings, and recreational landings. The assessment used a sex-specific catch, multiple survey model with four stages, age-0 males, age-0 females, age-1+ males, and age-1+ females. Reproduction was modeled using the abundance of age-1+ females in a Ricker stock-recruit model, and population density was dependent on the number of age-1+ females and males. Estimates of Bay-wide total abundance, recruits, adult female crabs, over-wintering mortality, and reference points were generated.

2 LIFE HISTORY

2.1 Migration

Catch rates of Jonah crab in traps targeting American lobster provide evidence that Jonah crab migrate to deeper water in the winter and return to shallower water in the spring (Jeffries 1966, Krouse 1980, Truesdale et al. 2019b). However, analysis of catch rates from mid-Atlantic trawl surveys indicated that Jonah crab move very little based on the consistency of Jonah crab catch rates in relation to depth and temperature (Haefner 1977).

There have been two Jonah crab tagging studies, one conducted by Rhode Island Department of Environmental Management (RI DEM; Ordzie and Satchwill 1983) and another conducted by Massachusetts Division of Marine Fisheries (MA DMF) with the Atlantic Offshore Lobstermen's Association (AOLA; Perry et al. 2019). Both studies tagged male and female crabs, but females were rarely recaptured in either study. The RI DEM study tagged 1,383 crabs in Rhode Island Sound, Block Island Sound, and mid-shelf (offshore) south of Rhode Island, and had a 1.7% return rate. All recaptures were tagged and recaptured in Rhode Island Sound. The MA DMF/AOLA study tagged 32,294 crabs on Georges Bank (GB), and the inshore and offshore regions of Gulf of Maine (GOM) and SNE, and had a 2.9% return rate. Movements in both studies were generally limited, on the scale of a few kilometers, though a few individuals from the MA DMF/AOLA study traveled between 100 and 416 km. Other *Cancer* crabs (e.g., *C. pagurus*) have been known to move similar distances, though long-distance travel is more common for female *Cancer* crabs, than male (Fahy and Carroll 2008). Movement between offshore SNE and GB was observed in the MA DMF/AOLA study as well as some small-scale seasonal movement patterns. While Jonah crab appear to be capable of moving long distances, most evidence suggests their movements are generally limited, including seasonal movements.

2.2 Growth

Jonah crab growth has been examined in several recent studies, each of which focused on different life stages of Jonah crab in distinct stock regions. A growth study including techniques for age determination was completed by Huntsberger (2019) for Jonah crabs from the GOM. Three independent methods of age determination were compared: (1) length frequency analysis of crabs sampled periodically in wild nursery populations including young-of-year (YOY) crabs, (2) building a probabilistic growth model informed with data from a laboratory growth study, and (3) applying the method of direct gastric mill band counts from crabs collected in two contrasting temperature regimes along Maine's coast. Length frequency analyses provided size-at-age estimates for the first three year classes, clear size ranges for YOY (3.8-6.6 mm CW), and showed correlation between YOY and legal size crabs four to six years later. For the laboratory growth study, 464 Jonah crabs from mid-coast Maine between 3.1 and 143mm CW were monitored in captivity for up to two years. The data collected were used to build a probabilistic molt model estimating the growth of an individual male crab until it reached legal size. Modeled growth of 1,000 crabs highlighted variability in growth, and males reached minimum legal size at an estimated four to nine years of age. Finally, while gastric mill band counts were found to have a one-to-one relationship with Jonah crab age in years, the mechanism by which annuli are formed is not yet understood. Using this method, Huntsberger (2019) estimated that Jonah crabs recruited to the fishery at four to ten years of age.

The molt increment models for males from the GOM study aligned with a laboratory-based growth study conducted at the University of Rhode Island in 2016 and 2017 (Truesdale et al. 2019a), wherein molt increments were collected for 91 male Jonah crabs ranging in pre-molt CW from 97 to 149 mm. This study also measured molt increments for 119 female Jonah crabs ranging in pre-molt CW from 73 to 113 mm, finding that there were diverging trends in the relationship between crab size and molt increment between the sexes: male molt increments increased with size, while female molt increments became smaller with increasing size. This sexual dimorphism in growth-per-molt aligns with historical growth description from Rhode Island (Ordzie and Satchwill, 1983). Considering the Rhode Island study focused on crabs above the size-at-maturity, it was hypothesized that the divergence in molt increment trends relates to somatic investment in reproduction by females (Truesdale et al. 2019a).

The Rhode Island study also examined molting seasonality for mature male Jonah crabs via year-round crab collection and observation, finding that the annual molt period was in June for the inshore Rhode Island fishery. This molting seasonality aligned with the laboratory growth observations from Huntsberger (2019), which saw a peak in molting in late spring and early summer. Additionally, the Rhode Island study found that annual molt probability decreased with increasing CW for male Jonah crabs (Truesdale et al. 2019a). A slowdown in growth with increasing size for mature individuals is evident across studies; in the MA DMF/AOLA tagging study, a few mature crabs had not molted after more than 700 days at large (Perry et al. 2019). The intermolt period for crabs larger than the legal minimum size has not yet been estimated, and the occurrence of a terminal molt for the species is not known.

2.3 Reproduction, Maturity and Fecundity

2.3.1 Reproduction

Cancer crab mating takes place immediately after the female has molted (Elner et al. 1985, Christy 1987, Orensanz et al. 1995, Tallack 2007). The female crab is cradled by the male pre- and post-copulation using his chelae and first two pairs of walking legs (Elner et al. 1985). Males attain larger sizes than females (Carpenter 1978) and use their size advantage to guard females from other potential mates and predators, as seen in other brachyurans (Christy 1987). Sexual maturity in crabs is generally described based on gonadal development, which corresponds to physiological maturity (physiologically capable of producing eggs or sperm), and morphometrically, by using changes in allometric growth patterns in a particular body part. In crustaceans, morphometric maturity is often determined by male chela length or height, and abdominal width for females (Hartnoll 1978, Lizárraga-Cubedo et al. 2008, Öndes et al. 2017). Larger males out-compete smaller males for mating opportunities (Orensanz et al. 1995), similar to other Brachyuran crabs (Sainte-Marie and Lovrich 1994, Sainte-Marie et al. 1997, Comeau et al. 1998). Gonadal maturity may not be enough for Jonah crabs to mate successfully, and morphometric maturity may be an important factor in determining reproductive ability (Conan and Comeau 1986, Comeau and Conan 1992, Stevens et al. 1993).

2.3.2 Size-at-Maturity

Jonah crab size-at-maturity studies have been conducted from the mid-Atlantic Bight through Nova Scotia, Canada (Carpenter 1978, Ordzie and Satchwill 1983, Moriyasu et al. 2002, Perry et al. 2017, Olsen and Stevens 2020, Lawrence et al. 2021, ongoing investigations – see below). Though methods and sample sizes vary over these studies, they generally show that males mature at larger sizes than females, size-at-maturity estimates increase with increasing latitude, and size-at-maturity estimates for inshore regions are generally smaller than estimates for adjacent offshore areas (Table 1 and Table 2). Some of these studies also indicate that males reach gonadal maturity before they reach morphometric maturity, whereas females reach gonadal and morphometric maturity at roughly the same time. All maturity studies conducted in the U.S. estimate Jonah crab to reach sexual maturity below the current U.S. coastwide-Atlantic minimum legal size (120.65 mm CW) except for the GOM region, where male crabs are estimated to reach maturity at 122 mm CW.

Ongoing investigations into geographic variations in size-at-maturity

Morphometric Jonah crab data collected between 2015-2021 by MA DMF, NOAA Northeast Fisheries Science Center (NEFSC), and the University of Maryland Eastern Shore (UMES, Olsen and Stevens 2020) were pooled to estimate the size at which 50% of Jonah crab reached sexual maturity (SM50), by sex and region. Samples sizes by region and data source are shown in Table 3.

We examined the performance of three different statistical models against simulated data, a broken stick model (Olsen and Stevens 2020), a two-line model with a logistic transition (Hall et al. 2006) and the hierarchical clustering method described by Somerton 1980. The Somerton method involves subjectively splitting the data into three subsets based on size (CW): immature, mature, and unknown, where "unknown" individuals are of intermediate size and span the size range where crabs are transitioning between juvenile and adult morphologies. Linear regressions are then fit to both the immature and mature portions of the data set and individuals of intermediate size are categorized as either immature or mature based on nearness to the regression models extrapolated into the intermediate range. The regression modes are then iteratively re-fit and the intermediate-sized individuals re-categorized until the model stabilizes. The simulated data were built from two-line models with logistic transitions, approximately parameterized by exploration of existing data. This model assumes that individuals displaying mature morphology was a probabilistic process around transitional sizes and appropriately recognizes that all individuals will not switch to adult morphologies at the same size due to biological and environmental variations within regions and discontinuous growth processes.

Of the three models tested, the broken-stick model consistently under-estimated SM50. The two-line logistic model, which matched the structure of the simulated data, often estimated unbiased parameters, in aggregate, but was unstable and sometimes failed to converge. The Somerton method can be sensitive to the subjective initial group classifications and produced biased logistic parameters but unbiased derived estimates of SM50. Here, we present only the results from the Somerton method and recognize additional modeling approaches need to be developed to better stabilize these models and improve performance. To derive confidence limits on the SM50 estimates, we bootstrapped the data 1,000 times for each sex and region and refit the models.

A strong geographic gradient in SM50 for female crabs was not detected. SM50 estimates varied from 89.6 to 97.5 across the regions (Table 3 and Figure 2). Bootstrapped medians were within two millimeters of estimates for all regions except SNE Inshore which was 6 mm larger than the estimate (Figure 3). Distributions of bootstrapped SM50 estimates were bi-modal for both GB and SNE Inshore, suggesting that the estimates are unstable and sensitive to anomalous observations. The maturity estimate for the GOM Offshore turned out to be highly sensitive to the assumed range of "unknown" sizes provided to the Somerton method, though this estimate is comparable to adjacent regions.

Males matured at larger sizes in offshore and more northerly regions than in inshore and southerly regions, showing strong geographical size-at-maturity gradients (Table 3 and Figure 4). A pattern of increasing size at maturity is evident for inshore habitats, increasing from 101.7 mm in the Mid Atlantic to 109.7 in inshore GOM. However, size at maturity was less variable offshore, increasing only from 119.4 mm in the offshore SNE to 121.3 mm in offshore GOM.

In general, male size of maturity is near or below minimum legal size across all regions. GOM Inshore is the only region with a history of producing high landings of Jonah crabs where crabs reach maturity at sizes much smaller than legal size. Additionally, the size of crabs generally pursued by the fishing industry is currently larger than the minimum size, suggesting that most crabs are probably reaching maturity before being captured and retained by the fishery. It is informative that the largest geographic variation in maturity occurs between inshore and offshore SNE, a difference of 16mm over about 100km, corresponds to what is probably the largest thermal gradient in bottom temperatures.

2.3.3 Fecundity

Estimated female clutch size for large female Jonah crab (105-135 mm CW) is between 400,000 and 1.8 million eggs (Hines 1991). The number of eggs per clutch increases significantly with increasing CW (Hines 1991). Though data is limited, female Jonah crab are believed to produce a maximum of one clutch of eggs per year (Hines 1991). There are four zoeal and a megalopa stage for Jonah crabs, which are morphologically identical to Atlantic rock crabs *(Cancer* *irroratus*) except for the number of setae on some appendages (Sastry 1977). This study also reported similar larval developmental times for Atlantic rock crabs at 15°C, and Jonah crabs at 20°C, which implies full larval development from hatch to megalopa would take around 25 days at 20°C for Jonah crabs (Johns 1981).

2.4 Natural mortality

Natural mortality rates for Jonah crab have not been estimated, in part due to a lack of empirical and fishery-dependent data needed for commonly applied estimation methods (Maunder et al. 2023). There are various factors known to influence natural mortality for crustaceans, including molt stage (Ryer et al. 1997), size (Canales et al. 2019), life stage (Lorenzen 1996; Vogt 2011), disease (Vogan et al. 2008), and predation (Maunder et al. 2023), which are also expected to affect Jonah crab natural mortality rates.

Epizootic shell disease has been described for the American lobster stock and is known to impact molting and natural mortality for the species (Vogan et al. 2008, Castro et al. 2012). This condition, which has increased in prevalence in lobster since 1996, occurs on a north to south gradient of increasing disease prevalence related to interacting factors of water temperature, size-at-maturity, and intermolt period (ASMFC 2020; Castro et al. 2013; Glenn and Pugh 2006). Larger lobsters and ovigerous females tend to have higher rates of shell disease, likely related to the extended intermolt duration for these groups (Castro and Angell 2000; Glenn and Pugh 2006; Castro et al. 2013; Reardon et al. 2018; DNC 2019). Lobster shell disease prevalence in the population is highest just prior to the time of molting (Tlusty et al. 2014; Groner et al. 2018) and severity has been shown to worsen more rapidly as waters warm (Barris et al. 2018).

A similar condition to lobster epizootic shell disease has been reported for Jonah crab, particularly in SNE (Haefner 1977, Truesdale et al. 2019a), attributed to chitinoclastic bacteria, including Gram-negative bacteria such as Vibrio (Sindermann et al. 1989, Austin and Alderman 1987). Prevalence of disease occurrence is not well described, but shell disease condition data have recently started being collected as part of several state sea sampling and port sampling programs. In inshore Rhode Island waters, it was observed that shell disease prevalence follows a seasonal cycle aligning with the molt season, as with lobster (Truesdale et al. 2019a). Recently, this shell disease has been reported in Jonah crabs as far north as the Bay of Fundy (Carlon et al. 2018). Like lobster shell disease, Jonah crab disease presents as dark spotting on the carapace and claws, in some cases with lesions that erode the shell's structural integrity. This presentation is similar to that of "black spot" caused by bacterial infection in the European brown crab (Stentiford 2008). The extent to which shell disease impacts internal systems and modifies mortality rates in European brown crab is not well described, but injection of bacterial species isolates was shown to lead to systemic infection and increased mortality (Stentiford 2008). Black spotting disease has been noted to be more common among older crabs, likely due to a longer intermolt duration (Ayres and Edwards 1982).

Other pathogens of Jonah crab have not been well described; however, a comprehensive review of diseases impacting the European brown crab characterized several viral, bacterial, and fungal diseases associated with increased mortality rates (Stentiford 2008). Understanding diseases as mortality drivers, including the impacts of fishing practices on disease transmission and severity (e.g., declawing practices, interspecific interactions in traps) has been emphasized as a management consideration (Stentiford 2008).

Predation on Jonah crab has also not been comprehensively described but is expected to comprise an important source of natural mortality for the species based on the available literature and diet data, which indicate that Jonah crab is a major component of the diets of several important predator species on the northeast US continental shelf. In a recent diet study, Cancer crabs were the largest component of the diets of black sea bass (*Centropristis striata*) and Atlantic cod (*Gadus morhua*) in nearshore SNE waters (Santos 2020). Jonah crab have also been found to be important prey species for skates (*Rajidae*), smooth dogfish (*Musteus canis*), spiny dogfish (*Squalus acanthias*), and longhorn sculpin (*Myoxocephalus octodecemspinosus*) in the NEFSC seasonal trawl survey (pers. comm., B. Smith, NOAA NEFSC). Given the importance of Jonah crab as a prey item, it is of interest how the shifting predator field in the region may have influenced Jonah crab mortality rates over time.

2.5 Stock Structure

Four Jonah crab stocks were defined based on a combination of biological aspects, management considerations, fishery characteristics, and data availability. These stocks (Figure 5) include the Inshore Gulf of Maine stock (IGOM), Offshore Gulf of Maine stock (OGOM), Inshore Southern New England stock (ISNE), and Offshore Southern New England stock (OSNE).

Size-at-maturity was the primary biological basis for defining the stock areas, while the available tagging information suggests limited movement of Jonah crab that would be indicative of adult connectivity throughout the population. Larval distribution and supply remain uncertainties for connectivity and stock structure. Individuals generally mature at larger sizes offshore compared to individuals inshore at the same latitudes, and individuals generally mature at smaller sizes moving south within inshore/offshore areas (Table 1 and Table 2). Inshore/offshore boundaries and the inshore GOM/SNE split were matched to existing LCMAs, where possible, recognizing these would be the likely boundaries for any future Jonah crab regulations. Assessing crab stocks at spatial scales defined in part by management and fishery characteristics is a common practice applied in other crab stock assessments (Pezzack et al. 2009, Marcussen 2022). Statistical areas were used for stock boundaries when LCMAs needed to be split because this is the finest level of spatial data available with landings.

The IGOM stock covers LCMA 1 extending from ME through central MA, while offshore stocks primarily cover LCMA 3. LCMA 3 covers offshore waters throughout the entire range of Jonah crab, so there was the need to split this area into GOM/SNE stocks using statistical area boundaries. The GOM/SNE split between offshore stocks was defined as the southern boundaries of statistical areas 521, 522, and 561. Statistical area 521 contains most of the OCC LCMA and most Jonah crab landings within this statistical area are likely to come from offshore areas in LCMA 3, so OCC was grouped with the OGOM stock. Fisheries in OGOM waters, where lobster abundance remains relatively high, target lobsters and tend to catch Jonah crab as bycatch (Section 4). This region has the potential to develop a directed Jonah crab fishery with increased and differential exploitation patterns if lobster abundance declines. These potential patterns could be masked if grouped at a broader scale with statistical areas to the south more associated with mixed crustacean fisheries and fisheries targeting Jonah crab. There is no clear separation of crabs between statistical area 562 and statistical area 525 and no evidence of connectivity between statistical area 562 and statistical area 561 according to MA DMF/AOLA tagging work (Perry et al. 2019), so statistical area 562 is grouped with the OSNE stock. Index of abundance development during the assessment showed different patterns of abundance in these areas further supporting this split (Figure 6). All Mid-Atlantic areas (LCMAs 3, 4, and 5) were grouped with the OSNE stock due to this component of the population being relatively small and located in deep canyons offshore and the expectation they would be more similar to Jonah crab populations offshore of SNE. The available maturity estimates present a more mixed picture for comparison between Mid-Atlantic crabs and those from offshore SNE proper, but the recent studies by Perry et al. 2017 and Olson and Stevens 2020 indicate similar size-at-maturity based on morphometrics for females in these two areas.

The ISNE stock primarily covers LCMA 2. LCMA 5 (Long Island Sound), which opens into LCMA 2 and accounts for minimal Jonah crab harvest, was grouped with the ISNE stock. Statistical area 537 accounts for the majority of Jonah crab harvest and extends into both inshore waters in LCMA 2 and offshore waters in LCMA 3, so there is the need to split this statistical area between SNE stocks. The northern boundary of the LCMA 2/3 overlap, which is in the middle of statistical area 537 and has more similar depths in its western section as the waters just into the LCMA 3 portion of 537 (Figure 7), was set as the boundary between ISNE and OSNE stocks within statistical area 537. The small section of LCMA 2 that extends into statistical area 521 (OGOM stock) and statistical area 526 (OSNE stock) was assumed part of these respective offshore stocks for pragmatic reasons of splitting landings data.

3 HABITAT DESCRIPTION

Jonah crabs can be found from Newfoundland to Florida at depths ranging from the intertidal to 800m but are most abundant in the northern latitudes (Haefner 1977, Stehlik et al. 1991, Pezzack et al. 2011). Limited specific information is available for the distribution as depth, season, habitat, and temperature affect the abundance of Jonah crabs (Stehlik et al. 1991, Carpenter 1978, Haefner 1977, Krouse 1980). The highest abundance of Jonah crab is found in water temperatures of 6-14^{o}C (Stehlik et al. 1991, Haefner 1977, Krouse 1980, Pezzack et al. 2011). Krouse (1980) suggests Jonah crabs have a narrower temperature range tolerance than the similar species, Atlantic rock crab, and may stay further offshore to attain more stable bottom temperatures. Laboratory studies by Lewis and Ayers (2014) found Jonah crabs thermoregulate and will move to a preferred temperature, but previously experienced temperatures significantly impacted temperature preference. At the southern end of their range, Jonah crab prefer greater depths (Jeffries 1966). In the Mid Atlantic Bight, Haefner (1977) provides evidence for an increase in size as depth increases while Carpenter (1978) suggests relative abundances of distinct size groups can be found at different depths depending on the time of year. Carpenter (1978) found female Jonah crabs are more abundant at depths less than 150m while males prefer deeper water.

Historic offshore trawl surveys and recent interviews with SNE fishermen found the highest abundance of Jonah crabs in silty sand and flat muddy habitats (Haefner 1977, Stehlik et al. 1991, Truesdale et al. 2019a), but studies, mostly in the GOM based on inshore SCUBA work, trapping, and video survey, found Jonah crabs associated with more complex cobble, boulder, and sand substrate (Jeffries 1966, Krouse 1980, Richards 1992, Palma et al. 1999, Reardon 2006). YOY and juvenile Jonah crabs are found in relatively high numbers during settlement surveys (Section 6.1) in cobble habitat. Whether offshore areas provide important settlement or nursery habitat is poorly understood. The discrepancy of observed crab habitat could be due to lower catchability of crabs by trawl surveys and commercial pot gear in complex habitat, difference of primary substrate type by life stage, or correlation of substrate with depth.

4 FISHERY CHARACTERIZATION

While landings are available coastwide back to 1981 (Figure 1), the accuracy of the reporting and the location of where those landings were harvested is uncertain, so this assessment has focused on the landings since 2010. However, it is also important to understand the context of the increases in reported landings over time and the changing structure of the fishery. The coastwide landings register a steady increase in Jonah crab landings over time. Historically, Jonah crab has been a bycatch species in the American lobster trap fishery, but in the last two decades, the fishery has shifted with regional differences. The differences in characterization are important to recognize when interpreting catch and participation data. In areas where lobsters are still abundant and available to the commercial fleet, Jonah crab remains primarily a bycatch species, but in areas where lobster abundance has decreased significantly, Jonah crab has become a directed fishery. The numbers of participants vary by states and inshore versus offshore regions. In some areas, the pounds landed per trip are significantly higher, and total landings of Jonah crab are high while the number of active harvesters is low, indicating a more directed fishery. In other areas, the number of active harvesters is significantly higher while the pounds per trip remain low, indicating a bycatch fishery. The inshore fleets tend to be bycatch fisheries while the offshore fleets are directed fisheries. In this section, we provide the characterization of the Jonah crab fishery components by state.

4.1.1.1.1 Spatial Distribution

Most U.S. Jonah crab landings come from the OSNE stock. From 2010 to 2021, annual landings for this region have accounted for 70 to 85% of the total U.S. Jonah crab landings (Figure 8-Figure 19). Landings from the IGOM stock account for 9 to 24% of the coastwide landings over the same period. The OGOM and ISNE regions have never exceeded 5% of coastwide Jonah landings for any year between 2010 and 2021.

Though Jonah crab landings are reported from a wide geographic area, most landings are concentrated in the northern portion of the OSNE stock. In recent years, more than half of the Jonah crab landed in the U.S. are caught in the offshore portion of statistical area 537 (Figure

20-Figure 31), within LCMA 3. Statistical areas 526 and 525 are also important areas. Each area often accounts for more than 10% of the annual U.S. Jonah crab landings.

4.2 State-Specific Fishery Characterizations

Maine

Jonah crab has historically been a bycatch species of the lobster fishery in Maine in LCMA 1. Misreporting is common because the fishing fleet refers to *Cancer borealis* (Jonah crab) as "rock crab" and *Cancer irroratus* (Atlantic rock crab) as numerous local names, but not "rock crab". This misidentification creates challenges in understanding the dynamics of the fishery from landings data. Anecdotally from the fishery, Atlantic rock crab is caught close to shore, predominantly in state waters in bays and rivers, while Jonah crab is predominantly caught in deeper federal waters. Most reported crabs are assumed to be Jonah crab. In the landings data, both species were often reported as "crab unclassified", prior to reporting requirements, and misreporting problems persist. The Jonah crab harvest primarily consist of whole crab, but Maine does allow a personal use exemption for Jonah crab claws. There was a pulse of very high landings of Jonah crab in the early 2000s leading to a peak of almost 10 million pounds landed, but most of that catch was reported as "crab unclassified".

Effort and landings of Jonah crab in Maine are driven by the combination of abundance of lobster, abundance of Jonah crab, and market availability. If the lobster catch is very high or markets for Jonah crab are unavailable, the fleet will actively avoid Jonah crab, even if the crabs are abundant. While poundage has been decreasing in the lobster fishery in recent years, the abundance of lobster is still high and worth much more than Jonah crab, leading to the continued preference for lobster. The bycatch fishery for Jonah crab remains at low levels characterized by low poundage per trip (Figure 32) where a majority of the trips between 2018-2021 are 100lb or less. While the poundage of the trips is low, the scale of the Maine lobster fishery compared to other regions represents high numbers of trips and permits participating in the fishery (Figure 33 and Figure 34). Since 2008, 10% or less of the Maine trap/pot trips reported harvesting Jonah crab, representing between 10,000-30,000 trips annually. Permits actively harvesting Jonah crab represent 14-25% of the active trap/pot permits, totaling 600-1,136 permits annually.

New Hampshire

In New Hampshire, Jonah crabs have historically been harvested as bycatch of the lobster fishery in both LCMA 1 and 3. The LCMA 1 fleet is made up of day boats generally fishing within 25 miles of shore, while the LCMA 3 fleet is characterized by multi-day trips to offshore GOM and GB. Vessels in both LCMAs target lobster and Jonah crab as bycatch with the magnitude of landings for crabs being driven by a number of factors, including but not limited to: 1) abundance of lobster, when lobster catch is high Jonah crabs are more apt to be thrown back, 2) markets for Jonah crab, if dealers are seeking Jonah crabs and make it easy for captains, they will be more likely to harvest crabs, 3) price per pound of Jonah crab, higher price provides more incentive, and 4) desire of captain's helper to retain crabs to sell on their own. Jonah crabs from the inshore fleet have historically been a source of additional income for helpers as they will put them aside and sell once they have enough crabs to go to market. These are the primary factors driving landings and the reason why this bycatch fishery is generally characterized by low catch per trip.

Jonah crab landings in New Hampshire from LCMA 1 averaged 36,061 from 2016-2022, whereas in LCMA 3 they averaged 77,716 pounds. In both LCMAs, Jonah crab landings comprised only 2% of total lobster/Jonah crab landings. During this same time period, 25% of vessels in LCMA 1 and 44% of vessels in LCMA 3 landed Jonah crab. Lobster is the target species for NH vessels fishing in both state and federal waters and Jonah crab makes up a very small percentage of total state landings.

Massachusetts

Jonah crab was traditionally considered a bycatch of the trap-based lobster fishery until the collapse of the SNE lobster stock in the late 1990s. The collapse of the lobster fishery forced many Massachusetts fishers to diversify. State permits that allowed for the harvest of lobster or edible crabs, and simple gear modifications, made it easy for lobster fishers to redirect effort towards Jonah crab. Increasing Jonah crab price per pound due to expanding markets and redirected effort from the lobster fishery led Jonah crab to rapidly become one of the most valuable fisheries in the state based on ex-vessel value. More Jonah crab are landed in Massachusetts than any other state.

Most Jonah crab landed in Massachusetts are caught in federal waters from statistical area 537, 526, or 525 and landed in the ports of New Bedford, Sandwich, or Gloucester. A small number of boats targeting Jonah crab are usually responsible for a large portion of the state landings, but there are numerous fishery participants targeting lobster that land smaller amounts of Jonah crab. Most trips landing Jonah crab catch less than 100 pounds per trip, but trips targeting crab often catch over 10,000 pounds (Figure 35). Some trips have reported over 100,000 pounds. The proportion trips landing Jonah crab in IGOM, OGOM, and ISNE using a Massachusetts lobster/edible crab trap permit is low (Table 4). However, about 75% of OSNE trips by those possessing a Massachusetts lobster/edible crab trap permit, land Jonah crab. The IGOM and ISNE fleet tend to be smaller vessels conducting day trips. The OGOM and OSNE fleet are larger vessels conducting multiday trips.

Crabs are landed whole, and sold to be marketed live, or processed at meat picking facilities. Nearly all the Massachusetts Jonah crab landings come from the lobster/edible crab trap fishery, and nearly all are male due to market preferences for larger crabs. The fishery targets hard-shelled crabs because recently molted crabs have little market value due to low meat yield and lower survival rates.

Rhode Island

The Rhode Island Jonah crab commercial fishery is composed of inshore and offshore fleets, with inshore vessels harvesting Jonah crab in LCMA 2 and offshore vessels harvesting Jonah crab in LCMA 3, corresponding to the inshore and offshore SNE stocks. The inshore fleet generally comprises small vessels conducting day trips, while the offshore fleet is made up of more vessels that conduct multi-day trips. As a result, Jonah crab landings per trip are higher for the offshore fleet (Figure 36). In general, because of the price differential between Jonah crab and lobster and differences in catch rates, Jonah crab harvest per trip is often higher than lobster harvest per trip, even when lobster was the predominant target species, which warrants caution in interpretation of CPUE data. However, there appears to be a decrease in lobster landings for trips landing more than 6,000 lbs. of Jonah crab, suggesting a potential threshold for examination of trips targeting Jonah crab (Figure 37).

Historically, Jonah crab was predominantly a bycatch fishery in Rhode Island, but around 2010, harvesters pivoted to target crab in addition to, or in place of, lobster (Truesdale et al. 2019b). The fishery now comprises vessels that target either species as well as those that switch between target species based on fishing location, season, market factors, and other variables. The offshore fleet includes several vessels that have highly capitalized in the Jonah crab fishery; on average, Jonah crab make a much higher percentage of mixed-crustacean trip landings for the offshore fleet than the inshore fleet (Figure 38). Inshore trips are more frequently mixed-crustacean trips wherein Jonah crabs are retained as bycatch. Only whole Jonah crabs may be retained and sold in Rhode Island.

Overall, Rhode Island's lobster and crab commercial fleets have declined in numbers since 2007, which is attributed in part to the decline of the SNE lobster stock and related management actions over the past decade. The inshore fleet has experienced a decline in number of participants, from nearly 250 permits to just over 100 from 2007 to 2021. However, the number of vessels landing Jonah crab has been largely stable for the inshore fleet at around 35 vessels. The Rhode Island offshore Jonah crab and lobster fleet has decreased from around 30 permits in 2007 to 14 permits in 2021 (Figure 39). However, the offshore fishery accounts for the bulk of Rhode Island's Jonah crab landings; nine offshore vessels brought in more than 65% of the annual landings from 2017 to 2021, on average.

Southern States

The states of Connecticut through Virginia represent a relatively small proportion of the overall Jonah crab fishery. Since 2010, the states of Connecticut through Virginia have contributed under 10% of the coastwide total Jonah crab landings, with New Jersey and New York consistently contributing the large majority of that percentage. According to state compliance reports New York and New Jersey had 19 and 24 Jonah crab fishery participants in 2021, respectively; in Connecticut, Delaware, Maryland, and Virginia there were fewer than five Jonah crab fishery participants in each state.

In New York, the majority of participants fish in offshore SNE, though there are three to five participants that fish in the inshore SNE area, and two or fewer that fish in the GOM (Figure 40). In New Jersey, Delaware, Maryland, and Virginia, all participants fish in the offshore SNE area (Figure 41 and Figure 42).

While the majority of Jonah crab is harvested as whole crabs, fishermen from some states, particularly New York, New Jersey, Delaware, Maryland and Virginia, land Jonah crab claws. Jonah crab claws are relatively large and can be an inexpensive substitute for stone crab claws. As a result, they can provide an important source of income for fishermen. Claws can also be harvested for personal consumption; however, these landings are not well documented. A historic claw fishery takes place along the Delmarva Peninsula. These traditionally small-boat fishermen harvest Jonah crab claws because they do not have a seawater storage tank on board to store whole crabs. As a result, landing claws avoids economic inefficiencies for this small fleet. Jonah crab is also landed as bycatch in non-trap gear, such as bottom otter trawls and gillnets, and non-lobster trap gears, such as whelk pots, crab pots, and fish pots.

In Virginia, the Jonah crab claw fishery was the dominant fishery in the early 2000s and 2010s, where 100% of the catch by weight was claws. In 2015, the claw fishery declined to 1% of the total state catch by weight and whole crab landings became dominant. Since then, claws have represented 0% of the catch by weight in Virginia. In recent years Virginia's fishery in general has decreased significantly, with only one active harvester. This harvester holds a Jonah Crab Incidental Commercial Permit with Virginia, and only harvests Jonah crab as bycatch in other directed fisheries.

4.3 Market Factors

Effort and landings of Jonah crab are driven by the combination of abundance of lobster, abundance of Jonah crab, and market availability. The markets for Jonah crab are volume driven so there may be a lower threshold of volume when markets are not accessible. Markets and price may also be locally driven, or dependent on whole crab versus claw only categories. Southern states are more likely to have claw fisheries so price and pound data should be interpreted with caution.

Price per pound trends by state for states landing whole crabs have generally increased over the time period of 2010-2021 (Table 5). Rhode Island and Massachusetts prices are higher overall and track together. These are also the locations of the highest volume and likely available and consistent markets. The highest prices were experienced in 2021. The price data from Maine should be used with caution because of the misidentification issues discussed in Section 4.2. Jonah crab are typically worth more than Atlantic rock crab. While the average price is lower in Maine, it does track the same trend as Massachusetts and Rhode Island, except in 2014, when it dipped slightly.

Unlike the American lobster, there is not a species recognition for Jonah crab in the seafood consumer markets. Jonah crab is often used as a crab option and can be substituted among multiple species like the Dungeness crab, snow crab, stone crab, or king crab. Markets can be driven by demand but also may depend on the availability and cost of other crab species.

5 FISHERY DEPENDENT DATA SOURCES

5.1 Commercial

5.1.1 Landings Data Collection and Treatment

5.1.1.1 Maine

A Lobster and Crab Fishing License is required to commercially harvest Jonah crab in Maine, and it has historically been a bycatch species of the lobster fishery. A permit endorsement is also available for the drag fishery, which allows a limit of 200 pounds per day and 500 pounds of Jonah crab per trip. Traps are subject to the lobster rules including maximum size, escape vents, and trap tags. There is a recent prohibition of claw harvest, except for a personal use exemption of a 5-gallon bucket maximum. While the market has always dictated a male-only fishery, the FMP provided the guidelines for regulations on size of greater than 4.75 inches.

Misidentification of Jonah crab creates challenges in the landings data because both *Cancer irroratus* (Atlantic rock crab) and *Cancer borealis* (Jonah crab) are harvested as bycatch and have an identical common name of "rock crab". Historically, crab landings were reported on a monthly basis, but were not mandatory until 2004 and were not linked to state harvester identification numbers in the CFDERS database. In 2006, Maine shifted to using the Atlantic Coastal Cooperative Statistics Program's (ACCSP) Standard Atlantic Fisheries Information System (SAFIS) and Maine's MARVIN database for monthly mandatory reporting of landings with associated harvester identification numbers that add accountability. In 2008, the mandatory reporting was required on a trip and species level, yet there are still "crab unclassified" landings in recent years, albeit much reduced as compared to prior to 2008.

Both *Cancer* crab species were considered lower value species compared to lobster and were commonly sold for cash prior to reporting requirements; as such, landings prior to (and potentially after) 2008 should be considered an underestimate. Of the reported landings, ME DMR expects most reported volume and market demand has been for Jonah crab as opposed to Atlantic rock crab, so it is expected that historical and recent landings for Jonah crab should include the "crab unclassified" and "rock crab" landings. It may be possible to identify likely Jonah crab landings based on price (> $0.35/pound), but there is uncertainty on this threshold, especially earlier in the time series.

5.1.1.2 New Hampshire

New Hampshire lobster and crab harvesters have been reporting catch and effort from state waters since 1969 to the NH F&G. Beginning in 2006, all state licensed lobster and crab harvesters were required to report catch and effort. In 2016, with the adoption of the Jonah crab FMP, New Hampshire implemented mandatory Jonah crab harvest reporting on both monthly-summary and trip-level reports. While reporting of Jonah crab catch and effort was not mandatory prior to 2016, harvesters were provided the opportunity to report crab bycatch at the monthly level. Only commercial harvest by state lobster and crab license holders is included.

Historically, the quantity of lobsters and crabs landed in New Hampshire harvested from federal waters was derived from a combination of the NOAA Fisheries weigh out and canvas database and federal VTRs. Currently, NOAA Fisheries has mandatory reporting of harvest data for the majority of federally permitted vessels that land in New Hampshire through VTRs. Those not required to report to NOAA Fisheries are captured under NH F&G harvest reporting.

In cooperation with NOAA Fisheries, 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 or directly through electronic dealer reports (EDR). NOAA Fisheries mandated dealer reporting for lobster landings in 2010. Dealers report all species harvested and both state and federal dealers have been able to report Jonah crab since implementation. Jonah crab landings in New Hampshire have been reported by dealers since 1994.

In order to assign areas to the dealer report records and calculate effort estimates, VTRs and state logbooks are used to identify statistical areas and effort values as dealer reports do not contain area and effort data.

5.1.1.3 Massachusetts

Participation in the Massachusetts Jonah crab fishery has been limited to those that hold a commercial lobster/edible crab permit since 1948. Reporting of landings through Massachusetts trip level reports (MATLR) or NOAA Fisheries VTRs has been mandatory since 2010. On MATLR, fishermen are asked to report location of catch, gear type, amount of gear, soak time, number of trawls, and quantity landed.

Most Jonah crab landed in Massachusetts are caught in federal waters and reported on NOAA Fisheries VTRs. A small number of boats targeting Jonah crab are usually responsible for a large portion of the state Jonah crab landings, but there are numerous fishery participants targeting lobster that land smaller amounts of Jonah crab. Some inshore fishers will crate, or hold their catch, combining landings from multiple trips, until they reach a quantity that is deemed worth selling. Thus, dealer transactions may represent landings from multiple trips. Landings are generally in pounds, but occasionally bushels of crabs are reported. In these cases, a bushel to pounds conversion is made by multiplying the number of bushels by 65. The landing of anything other than whole crabs is prohibited. There is speculation that landings may have been under-reported prior to 2010, as Jonah crab was considered a low value species and some catch may have been sold for cash at the dock.

5.1.1.4 Rhode Island

Commercial landings in Rhode Island before 2003 are derived using NOAA Fisheries' data collection methods. Beginning in 2003, 100% electronic dealer reporting was implemented in Rhode Island through the Rhode Island Fisheries Information System, the predecessor of the SAFIS. It took a period of about three years to develop consistency in reporting among all dealers with the new trip-level system but from 2006 on, electronic dealer reports are believed to account for all Jonah crab landings. For the stock assessment, landings of Jonah crab and Atlantic rock crab were reviewed on a trip-by-trip basis, particularly for years prior to 2011, due to concerns about inconsistency in species identification. Using each vessel's full fishing history, fishing location, harvest weight, and in some cases direct consultation with harvesters, some of the landings reported as Atlantic rock crab were reassigned to Jonah crab. As a result, the time series of Atlantic rock crab landings was adjusted to be more stable over time, consistent with anecdotal reports of the Atlantic rock crab fishery's trajectory.

5.1.1.5 Connecticut

Landings are recorded in the NOAA Fisheries weigh out 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 SAFIS. A quality assurance program has been established to verify the accuracy of reported statistics through law enforcement coverage and electronic crosschecking of harvester catch reports and seafood dealer reports.

5.1.1.6 New York

The commercial harvesting of Jonah crab requires a New York commercial crab permit. The crab permit has been limited entry since 6/29/1999. The limited entry stipulates that no new permits are issued, but a certain percentage of forfeited permits from the previous year are made available the following year. The limited entry permit resulted in an overall decrease in permits over time. Permit holders have until December 30th and may renew anytime during the calendar year.

New York's commercial fishery harvest data has been collected through state and federal VTRs since 2012 for food fish, lobster, and crab commercial permits. State VTR data is entered by staff into the New York Fishery Information on Sales and Harvest (NYFISH) database or entered directly by fishermen into the ACCSP's eTrips online database. New York landings reported through federal VTRs are entered by federal staff and shared with New York on a weekly basis in order to provide timely and accurate landings estimates. Landings data are reported by statistical area.

5.1.1.7 New Jersey

The commercial harvest of Jonah Crab within state waters of New Jersey does not occur, therefore data are not collected. New Jersey reported landings are obtained from NOAA Fisheries VTRs.

5.1.1.8 Delaware

The commercial harvest of Jonah Crab in Delaware requires either a Directed Jonah Crab Landing Permit issued to those who hold a valid Delaware Commercial Lobster Pot License or federal lobster permit, or an Incidental Jonah Crab Landing Permit issued by the Delaware Department of Natural Resources and Environmental Control. Delaware's commercial landings are collected through state logbooks. State logbook data are entered into a state-owned database and uploaded annually to the ACCSP data warehouse. Logbooks report daily catch and are required to be submitted on a monthly basis.

5.1.1.9 Maryland

Maryland is a *de minimis* state and all Jonah crab landings are caught in federal waters and reported on NOAA Fisheries VTRs and through SAFIS. There is no directed fishery of Jonah crab and landings are predominately claws. A small fleet of commercial fishing vessels targeting lobster harvest Jonah crab, predominately in LCMA 5, statistical area 626. In addition to the required federal lobster permit, the Maryland Limited Entry Cancer Crab License is required. The Maryland limited entry Jonah crab claw permit was eliminated by Addendum II (2017).

5.1.1.10 Virginia

Virginia data are collected via required monthly harvester reporting. The majority of landings are from a single harvester and all landings are confidential.

5.1.2 Biological Sampling Methods

5.1.2.1 NOAA Fisheries

Sea Sampling

The Northeast Fisheries Observer Program (NEFOP) has collected data from vessels engaged in the lobster fishery, including the associated Jonah crab fishery, as funding allows since 1991. Because there is no mandate under the Standardized Bycatch Reporting Methodology (SBRM) to monitor the federal lobster and Jonah crab fishery to support the management of these fisheries, the 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 60 sea days in 2015 but coverage has since dropped to about 4 sea days per year. Data collected by NEFOP observers include CW (mm), sex, presence of eggs, 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.

Port Sampling
The NOAA Fisheries Greater Atlantic Regional Fisheries Office initiated a port sampling program for the targeted Jonah crab fishery in 2021. Annual sample requests are stratified by region, stock area, gear type, and calendar quarter and are allocated to focus on the regions where most of the Jonah crab fishery occurs and to be complementary to spatial coverage of port and sea 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. NOAA Fisheries anticipates collecting 74 port samples per year with a standard sample consisting of 40 individuals with CW measurements and gender recorded.

5.1.2.2 Commercial Fisheries Research Foundation

Sea Sampling
The Commercial Fisheries Research Foundation (CFRF) has conducted a fishery-dependent Jonah crab data collection project since 2014. The CFRF project has involved 25 vessels over the time series and offered coverage of inshore and offshore SNE, GB, and offshore GOM. Typically, three sampling sessions are conducted per month from fishermen's regular commercial catch. A sampling session consists of sampling catch from a trawl starting with the first trap hauled until 20 traps have been sampled or 50 crabs have been sampled, whichever comes first. For sampling the regular catch, fishermen decide which day(s) sampling sessions are conducted, but the trawl(s) sampled on those days is selected at random. Data collected include vessel ID, date, time, location, depth (feet), sex, CW (mm), egg-bearing status, shell hardness, and disposition (kept or discarded). Data are collected on Samsung tablets using CFRF's On Deck Data application and periodically uploaded to a database at CFRF where they are QA/QC'd and provided to ACCSP.

5.1.2.3 Maine

Sea Sampling
ME DMR does not have a formal Jonah crab sea sampling program as it has been considered a low value species as compared to lobster and is not a target species for the Maine fishery. ME DMR sampling program samples in both state and federal waters on Maine permitted boats. Some research trips were completed in 2003 and 2004 when the ME DMR was exploring experimental Jonah crab traps that would exclude lobsters yet catch Jonah crab. Those trips included subsampled biological data from both the experimental traps and standard commercial lobster traps. Since 2017, the Lobster Sea Sampling program includes an opportunistic protocol to collect Jonah crab data if they are harvested for commercial sale and the sampler has the capacity to do so. If crabs are sampled, the protocol includes collecting biological data including CW, sex, reproductive status, cull status, and shell hardness. In the future, a standardized subsampling protocol will be developed. ME DMR proposes only using data from trips with more than 20 crabs measured.

5.1.2.4 New Hampshire

Sea Sampling

Jonah crabs have been sampled by NH F&G as bycatch on lobster sea sampling trips since 2015. Samples are collected monthly from May through November at two different locations: the Isles of Shoals, and the coast (Portsmouth harbor to Massachusetts Border). Bycatch is sampled on all observed hauls (50% or more of the total hauls for the day). Data collected on Jonah crabs include sex, CW, shell condition, and cull status. Bycatch data are entered into an Access Database along with the coordinates of the trawl, number of set days, bait type, and water depth.

Port Sampling

NH F&G has conducted Jonah crab port sampling at local dealers on the New Hampshire coast since 2016. Initially, samples were collected from commercial lobster boats harvesting from several different statistical areas throughout the GOM and GB. More recently, due to a lack of fishing effort in some of the statistical areas farther offshore, samples have been obtained from dealers who purchase crabs from vessels fishing in statistical area 513, which includes both state and federal waters. Biological data (CW, sex, molt stage, shell disease, and cull status) are collected on the landed catch, and information is obtained from the dealer to determine total catch and effort where available.

5.1.2.5 Massachusetts

Sea Sampling

MA DMF does not have a formal Jonah crab sea sampling program because roughly 99% of Massachusetts landings come from federal waters, though some samples have been collected opportunistically. Jonah crab sea sampling data were collected during directed lobster trips in Cape Cod Bay (southern statistical area 514) from 2016 to 2018, and during a Jonah crab tagging project in statistical areas 537, 526, 525 from 2016 to 2017. Target species (lobster or Jonah crab) varied during the Jonah crab tagging project trips. Samplers recorded CW (mm), sex, cull status, mortalities, and presence of extruded eggs. The percent cover of shell disease (black spotting) was characterized starting in 2017. Catch was separated by trap. The start of each trawl was recorded using a handheld GPS.

Port Sampling

MA DMF began a Jonah crab port sampling program in the fall of 2013. Sampling intensity was low during 2013 (2 trips) and 2014 (4 trips). A minimum of 10 trips have been conducted annually since 2015. Starting in 2015, vessels and dealers with the most state landings were targeted for sampling. The vast majority of the sampled catch is from statistical areas 537 and 526. Statistical areas 525, 562, and 514 have been sampled with less regularity. A minimum of five crates or the entire catch, whichever is less, is sampled per trip. Data collected include: CW (mm), sex, and cull status. Shell disease and mortalities have been recorded since 2017.

5.1.2.6 Rhode Island

Sea Sampling

Rhode Island does not currently have a sea sampling program for Jonah crab as funds are not available for this purpose. In 2016 and 2017, 12 sea sampling trips did occur as part of a URI research project. These trips occurred in inshore statistical areas 539 and 537. Data collected include number of traps per trawl, soak time, bait, bottom type, depth, trap location (latitude/longitude), and trap configuration. From each sampled trawl, effort was made to sample all captured Jonah crabs—whenever this was not feasible, a systematic random sampling frame was used to census every second or third trap in a trawl. The following data were recorded for each sampled crab: CW, sex, ovigerous condition, shell disease level, molt condition, and number of claws missing.

Port Sampling

The RIDEM DMF initiated Jonah crab port sampling efforts in 2015; four trips were sampled during the initial year, before staffing and funding limitations placed this program on hold until 2019. Since the resumption of the program in late 2019, RIDEM DMF has strived to conduct ten port sampling trips for Jonah crabs per year. Most port samples have come from fishing trips taking place in offshore statistical areas 525 and 526. Port samplers reach out to captains and owners of offshore fishing vessels and coordinate with these parties to intercept a portion of their catch before it is offloaded to seafood transporters and dealers. At the trip level, samplers collect information from vessel captains on fishing area, bait, soak type, bottom type in fishing area, number of traps set, and average depth. Biological data are collected from a minimum of two totes of Jonah crab per port sample (about 200 crabs). Collected biological variables include CW, sex, shell disease level, molt condition, and cull status (number of claws missing).

5.1.2.7 New York

Sea Sampling

New York State Department of Environmental Conservation (NYDEC) sea sampling data are collected on cooperating commercial vessels in Long Island Sound (statistical area 611) and the Atlantic Ocean side of Long Island (statistical areas 612 and 613). However, Jonah crab were not included in the program until 2017, after the ASMFC Jonah crab FMP was adopted, and no Jonah crab have been sampled during the program. Much of the sea sample effort has been in statistical area 611, where few Jonah crab reside.

Port Sampling

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. Sampling protocol adheres to the standards and procedures established in NOAA Fisheries Fishery Statistics Office Biological Sampling Manual. This program was expanded to collect data from LCMA 6 starting in 2013. Limited

Jonah crab sampling was conducted in 2014 and directed sampling was initiated in 2017. Jonah crab have only been sampled during market sampling.

5.1.2.8 Maryland

Sea Sampling

Maryland is a *de minimis* state and does not currently have a sea sampling program for Jonah crab, as funds are not available and there is no requirement to do so. However, state biologists have conducted sea sampling in previous years aboard federally permitted lobster fishing vessels in Ocean City, Maryland. Sampling occurred during calendar years 2015, 2016, 2018 and 2019 with 315 randomly selected Jonah crab caught in lobster pots from LCMA 5 (statistical area 626) sampled for CW and sex. Biologists attempt to randomly measure Jonah crab during lobster sea sampling with the goal of 100 crabs per multiday trip.

5.1.3 Trends

5.1.3.1 Commercial Landings

Coastwide dealer reported Jonah crab landings were queried from the ACCSP Data Warehouse and validated for accuracy with state partners. Additionally, landings reported as rock crabs or unclassified crabs in Maine were included due to the misidentification issues described in Section 5.1.1.1 and expectation that the majority of these landings are Jonah crabs. Stock-specific commercial landings across states were generated through a combination of applying proportions of harvest across statistical areas from harvester reports to dealer reported total landings, direct use of total harvest by statistical area from harvester reports and assigning statistical area to dealer reported landings based on port of landing. For landings from statistical areas other than 537 in RI and MA that overlap multiple stocks, landings were assigned to a stock based on expected areas fished and these assignments are in Table 6. For landings from statistical area 537 in RI and MA where the majority of Jonah crabs are harvested, landings were split between ISNE and OSNE stocks using permit LCMA data from harvester reports. Small proportions of remaining landings without statistical area information could not be assigned to a stock. These landings and proportions of the coastwide totals they make up in each year are in Table 7. Proportions range from 0.0002 to 0.0329 and average 0.0108 across years.

The start year for reliable landings identified in ASMFC 2021 was 2006. However, spatial landings are not available from the primary landing state, MA, until 2010, limiting the start of the time series for stock-specific landings to this year. The vast majority of landings have come from the OSNE stock (Table 7 and Figure 43), averaging just short of 13 million pounds over the time series, followed by the IGOM stock (averaging 2.5 million pounds), the ISNE stock (averaging 460 thousand pounds), and the OGOM stock (averaging 317 thousand pounds). Landings from SNE stocks show similar trends increasing at the beginning of the time series and declining briefly in the mid-2010s, before increasing to time series highs in the later 2010s. Landings then decline sharply in 2019. Landings inshore increase during the following two years at the end of the time series, while landings offshore continue declining to their lowest point of the time series in 2021. The two largest and distinct peaks offshore occur in 2014 and 2018, while two of largest peaks inshore, also relatively distinct, occur a year earlier than seen offshore in 2013 and 2017. Trends in GOM stocks differ both between stocks and from trends in SNE stocks. Landings inshore decline sharply at the beginning of the time series to their lowest levels in the early to mid-2010s. Landings then increase sharply to their time series highs in the later 2010s and are highly variable over the last three years of the time series. Landings offshore are variable around their highest levels in the early 2010s, then decline through the late 2010s before a slight uptick in the last two years of the time series. The peak landings offshore occur during the same year as the first peak in the OSNE stock (2014), while the peak landings inshore occur during the same year as the second peak in the OSNE stock (2018).

Seasonally, landings from the IGOM stock have shifted from being concentrated in quarter two and three to being more evenly distributed across quarters since 2016 (Figure 44). Jonah crabs from the OSNE stock have primarily been landed in quarters one and four with slightly smaller proportions in quarters two and three (Figure 45). Seasonality of landings has been more variable for the two stocks with lower landings (OGOM and ISNE), but have occurred primarily during waves one and two in the OGOM stock (Figure 46) and waves three and four in the ISNE stock (Figure 47) across the time series.

The vast majority of landings (>90%) across stocks come from pot and trap gears.

5.1.3.2 Commercial Biosampling

Commercial biosample data were compiled from all sources. Sea sampling is useful to characterize the biological attributes of the total Jonah crab catch including discarded Jonah crabs. Port or market sampling is useful to characterize the biological attributes of the landed Jonah crab catch. Biosample data through 2019 were summarized in ASMFC 2021 for some background information and are updated through 2021 and split into stock units here. The number of sea and port sampling trips conducted by year, stock, and statistical area are in Table 8 and Table 9, respectively.

Annual summary statistics, including mean size of males in the overall catch and mean size of the largest 5% males in the overall catch, were calculated from sea sampling data as measures of size structure change and potential indicators of mortality changes. Mean size of the largest 5% males was initially compared to 90% of an unpublished von Bertalanffy L_{inf} estimate (Mid-Coast, Maine males gastric mill band count analysis estimate; C. Huntsberger, personal communication, October 11, 2022) as a potential reference point, as was done by Marcussen 2022. However, there are no estimates for SNE Jonah crabs and the estimate used here appears larger than would be expected given maximum sizes of Jonah crabs observed throughout time. Therefore, only trend information was ultimately considered for these data and not the 90% of L_{inf} reference point.

Summary statistics were calculated as weighted averages across trips, weighted by the number of crabs sampled during each trip. Trips with <29 crabs sampled were excluded and strata (Stock+Statistical Area+Year+Quarter) with <2 sampling trips were excluded from the data set.

There were no strata with five years of port sampling data, so these data were not included in the analysis. Data were too sparse to calculate landings-weighted stockwide statistics, even across quarters (Figure 48), so time series by stock and statistical area were evaluated for trends. A Mann-Kendall test, which is nonparametric test for monotonic (i.e., one-way) trends, was applied to data sets to evaluate for trends. Test results with a p-value <0.05 were considered detected trends. For pragmatic reasons, time series with at least five data points were tested and the maximum time series length across data sets was eight years. Tests of these short time series should be considered with caution.

Overall, trends in mean size statistics are stable over the relatively short time series (Table 10-Table 11 and Figure 49-Figure 55). Only one significant trend was detected across data sets, an increasing trend for the ISNE stock in statistical area 539 during quarter four. Note that there were no strata with five data points for the IGOM stock. Mean sizes are typically larger for the offshore stocks. The mean sizes of the 5% largest males are well below the 90% of L_{inf} estimate in all stocks and years, highlighting concerns about the reliability of this estimate as an appropriate reference point.

General lack of trend seen here could be a favorable indication of stock condition or it could indicate that these data are unreliable indicators of stock condition, as appeared to be the case in Pezzack et al. 2009. These data should be revisited as potential indicators in future stock assessments when longer time series are available and, ideally, there is sufficient coverage to generate landings-weighted stockwide time series but are not recommended at this time for stock indicators.

5.1.4 Catch Rates

5.1.4.1 CFRF VTS

In addition to regular commercial trap (i.e., vented) sampling, CFRF provides each vessel with up to three ventless traps to use during the course of the Lobster and Jonah Crab Research Fleet project. To maintain general consistency with most configuration specifications of other ventless trap sampling programs in Rhode Island, Massachusetts, New Hampshire, and Maine, the 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, and a 4” x 6” disabling door. One ventless trap is typically deployed at a fixed temperature monitoring station while the others may be deployed as the lobstermen see fit. Lobstermen also decide to record a session at their discretion and can decide not to record a session after hauling the traps (e.g., poor weather conditions). Ventless trap sampling is not associated with commercial trap sampling, and thus is recorded in a different sampling session. However, harvesters can and do attach the ventless traps to strings of their commercial gear if they choose. CFRF encourages fishing vessels to record at least one ventless Jonah crab sampling session per month at the bottom temperature monitoring site.

This sampling is intended to provide information on presence of sublegal lobsters and crabs and some temperature information. It is not designed to measure size structure of the retained crabs for harvest or abundance. However, given the data limitations faced during the assessment and because this is the only non-trawl sampling of catch rates in the core area of the fishery, CPUE time series were calculated from these data to evaluate as potential measures of abundance.

Data were standardized with negative binomial generalized additive models (GAMs) using catch of male exploitable sized crabs (121+mm CW) per session as the response. Catch is not recorded to the trap level, but rather collectively at the session level. However, only 19 of 658 sessions fished more than one trap and these sessions were excluded so the response was effectively catch per trap. Factors considered in the models for both the ISNE and OSNE stocks included year, month, depth, and soak time. Additionally, statistical area was considered for the ISNE stock, but not the OSNE stock because some less-sampled areas were only sampled in one year leading to multicollinearity between area and year. Both depth and soak time were modeled with smoothers. Model selection was performed with stepwise Akaike's information criterion (AIC) and the model with the lowest AIC was identified as the final model for standardizing CPUE.

Number of sampling sessions and number of crabs sampled are in Table 12. There were only two sampling sessions for the OSNE stock in 2021, so these data were excluded from the data set. For the ISNE stock, the model with year, month, SA, depth, and soak time was identified as the final model. For the OSNE stock, the model with year, month, and depth was identified as the final model. The CPUE trends were similar between stocks, increasing in the first few years of the time series and decreasing in the latter half of the time series (Figure 56). The CPUE inshore increases slightly in 2021 and is not available offshore. Catch rates offshore are about double the catch rates inshore and the rate of change offshore is also greater during the time series.

5.1.4.2 Direct Residual Mixture Model CPUE

5.1.4.3

Fishery-dependent data can be used for deriving indices of abundance for exploited marine species when the catch per unit of effort can be interpreted as an indicator of relative population abundance. However, CPUE is influenced by numerous environmental and temporal variables, which can preclude straightforward interpretation of fishery-dependent data. Standardization techniques for catch and effort data can be used to remove the impact of these other factors on CPUE, allowing fishery-dependent data to be used in deriving an index of abundance (Maunder and Punt 2004). These methods generally comprise model-based approaches, including generalized linear models (GLMs) and GAMs.

Beyond environmental and temporal variables, fishing behavior influences catch rates of exploited species and is therefore impactful to interpretations of CPUE data for abundance indices. In mixed-species fisheries, incorporating fishing behavior into standardization procedures is particularly challenging, as it requires accounting for the fisher's target species, since fishing techniques typically vary among target species and thus impact multispecies catch rates (Stephens and MacCall 2004; Okamura et al. 2018). Several methods have been developed for standardizing catch data in mixed-species fishery to produce indices of abundance. Most commonly, these have involved applying an absolute or proportional landings threshold to identify and subset to trips targeting the species of interest (Biseau 1998; Stephens and MacCall 2004). However, such subsetting methods have been criticized because they lose information and do not allow for comparison of CPUE models before and after subsetting (Okamura et al. 2018). A recently-developed method for CPUE standardization in mixed-species fisheries, called directed residual mixture models (DRMs), allows for use of a full mixed-species fishery dataset without subsetting (Okamura et al. 2018). Here, DRMs were used to standardize Jonah crab CPUE in the Rhode Island mixed species lobster and Jonah crab fishery in inshore and offshore SNE.

The DRM includes variables related to fishing tactics (including targeted species), as well as variables that do not relate to fishing tactics. In model equation form, the DRM can be written:

$$\log\left(CPUE_{s,i}\right) = X_{s,i}^{T}\alpha_s + Z_{s,i}^{T}\beta_s + \varepsilon_{s,i}$$

where in the i^{th} fishing operation for species *s*, $X_{s,I}$ is a vector of variables excluding the variable related to fishing tactics (target species) and its interactions and $Z_{s,I}$ denotes a vector of variables that includes the variable related to fishing tactics and its interactions. The first element of $X_{s,I}$ corresponds to the intercept, and a_s and β_s are the regression parameter vectors for $X_{s,I}$ and $Z_{s,I}$, respectively. The last term, $\varepsilon_{s,I}$ denotes independently and identically distributed random variables. Because the variable related to fishing tactics is not observed, the model that is fitted to the data is:

$$\log\left(CPUE_{s,i}\right) = X_{s,i}^{T}\alpha_s + v_{s,i}$$

where $v_{s,I} \sim N(0, \eta^2)$. The residual $\hat{v}_{s,i}$ = log(CPUE$_{s,i}$) - $X_{s,i}^{T}\hat{\alpha}_s \approx Z_{s,i}^{T}\hat{\beta}_{s,i} + \hat{\varepsilon}_{s,i}$, where $\hat{\alpha}_s$ is the maximum likelihood estimator for a_s and contains information on the variable related to fishing tactics. Essentially, if $\hat{v}_{s,i}$ is large when species *s* is targeted, indicating a high fishing efficiency for species *s* in fishing operation *i,* then the exponentiated $\hat{v}_{s,i}$ divided by the sum of exponentiated residuals for all species, should be large. This transformed residual is written as:

$$\hat{p}_{s,i} = \frac{\exp\left(\hat{v}_{s,i}\right)}{\sum_{u=1}^{S}\exp\left(\hat{v}_{s,i}\right)}$$

It is assumed that the logit transformation of $\hat{p}_{s,i}$ (($\hat{z}_{s,i} = logit(\hat{p}_{s,i}) = \log[\hat{p}_{s,i}/(1-\hat{p}_{s,i})]$) has a normal mixture model of linear regressions with *K* components:

$$f(\hat{z}_{s,i}) = \sum_k \pi_k \Phi(\hat{z}_{s,i}: u_{k,i}, \sigma_k^2)$$

where $\Phi(\hat{z}_{s,i}: u_{k,i}, \sigma_k^2)$ is normally distributed and $\{\pi_k\}$ are the missing proportions, with $\sum_k \pi_k = 1$. The parameter $\mu_{k,i} = M_{k.i}^T \omega_k$ is the expectation given the fishing tactics k, $M_{k,i}$ is a vector of explanatory variables for which the first element is 1 and the rest are related to observed variables, ω_k is the regression coefficient, and σ_k is the standard deviation of the normal distribution for fishing tactics *k.* The parameters are estimated by the expectation-maximization (EM) algorithm, producing a variable that indicates whether the individual trip was targeted or bycatch, based on the posterior probability of belonging in components of the mixture. This variable, called the "target variable" is categorical and assigns the target species for the trip.

Once the target variable has been assigned using the EM algorithm, a GLM can be fitted to the CPUE data of species s (in this case, Jonah crab), with the target variable included as a covariate. Extraction of the year effect from this GLM gives the standardized CPUE index.

Jonah crab DRM model fitting and selection

The Jonah crab DRM was fitted in R using the 'mgcv' package and the EM algorithm code from Okamura et al. (2018). Month, year, and stock region were explored as covariates for derivation of transformed residuals and for the final GLM model. Candidate models were compared using AIC and diagnostic plots (Figure 58).

Trip-level Jonah crab and lobster landings data from Rhode Island for all trips landing Jonah crab from 2007 through 2021 were queried from Rhode Island state harvester logbooks, eTrips data, and federal VTRs. Data were subsetted to the inshore and offshore SNE stock regions and to trips fishing with pot/trap gear. Data were also subsetted to trips landing more than 250 pounds of Jonah crab, as initial data analysis and model exploration indicated that inclusion of trips landing few Jonah crab had an impact on model target species assignment and model estimates. Since trips landing so few Jonah crab could be interpreted not to be targeting Jonah crab, even as a secondary target, and the catch could be highly impacted by factors unrelated to catch rates (e.g., retaining versus discarding low catch due to market factors), these trips were not included in the CPUE standardization process.

The model to derive transformed residuals for the Jonah crab fishery incorporated year and stock covariates as factors predicting log-transformed Jonah crab and lobster landings. Target species as assigned by the EM algorithm was included in the final GLM fitting process. The selected GLM for CPUE was:

```
mod<- glm(log(Jonah)~as.factor(Year)*Stock+TargetSpecies*Stock+as.factor(Month)*Stock)
```

Stock was incorporated as an interactive term with year, target species, and month (Table 14). The interaction with year was included to allow for examination of CPUE trends in the inshore and offshore stock individually. The stock interactions with target species and month align with fishery characteristics since the Jonah crab fishery has distinct inshore and offshore components with different behaviors in terms of fishing seasonality and with regard to targeting behavior (Truesdale et al. 2019).

The stock trajectories for inshore and offshore SNE Jonah crab differ in terms of scale and trend (Table 13 and Figure 57). The offshore stock appears relatively stable over the period of interest without a significant trend. For the inshore stock, there appears to be a period of higher CPUE at the beginning of the time series, with a lower CPUE period beginning around 2014.

5.1.4.4 Reference Fleet CPUE

We used commercial catch-per-trap from LCMA 3 to investigate whether there were any relationships between catch rates from a fishery-dependent "reference fleet" and fishery-independent trawl surveys throughout the GOM/GB. Only vessels landing >199lbs in a statistical area were included in this analysis, and we assessed the years 2004 through 2021 due to limitations in mining data further back than 2004. The reference fleet CPUE correlated with the ME/NH trawl survey catch for both fall males 120mm+ (see Section 6.2 for description of survey and selected size structure, Spearman's r=0.53, P=0.0232) and spring males 120mm+ (Spearman's r=0.49, P=0.0458), note Spearman's was used due to skewed distributions with data. NEFSC trawl survey only showed correlation with a two year lag (Spearman's r=0.5118 and P=0.427) fall trawl 120mm+ males. The correlation in the reference fleet and ME/NH trawl survey suggests some relationship between what was caught in trawl and traps within a year, though the NEFSC trawl takes place within the same region and there was only a correlation with a two year lag. This lag between the trawl survey and commercial catch in this region could be due to the gear selectivity of commercial harvesters and larger size of crabs being landed offshore compared to inshore, although our uncertainty around growth, catchability and incentives for harvesters to retain Jonah crabs is confounding. Nonetheless, we found general agreement between the reference fleet and trawl surveys within the GOM suggesting some spatial and temporal coherence in abundance trends between fishery-dependent and fishery-independent indices.

5.1.5 Commercial Discards/Bycatch

Although the taking of whole crabs is the current harvest practice in most areas of the Jonah crab fishery, claw-only harvesting is also practiced in other areas (e.g,. mid-Atlantic states; Seafood Watch 2014), where harvesters remove both claws from a single Jonah crab (ASMFC, 2015, ASMFC 2019) and then release it at-sea. Although at present, this harvest practice comprises only a small proportion of the overall commercial fishery effort (~ 1 %; ASMFC, 2015), given the potential expansion and growth of this fishery to other areas, it is plausible that a claw-based fishery could become more widespread. Historically, other crab fisheries utilize claw removal prior to releasing animals back to the sea with the assumption that declawed crabs will survive and continue their cycle of molting and regenerating new claws to again be harvested. This practice includes the highly valued stone crab (*Menippe mercenaria;* Duermit et al. 2015; Gandy et al. 2016; Kronstadt et al. 2018; Orrell et al. 2019), northeast Atlantic deep-water red crab (*Chaceon affinis*; Robinson 2008), European brown or edible crab (*Cancer pagurus*; Fahy et al. 2004), and fiddler crab (*Uca tangeri*; Oliveira et al. 2000). Until recently the mortality and sublethal effects of declawing Jonah crabs was unknown but recent work has helped to evaluate the impacts of declawing on harvestable Jonah crabs along with assessing the sublethal effects (e.g., mating, activity, stress, movement) on overall health and function as well (Goldstein and Carloni 2021, Dorrance et al. 2022). Goldstein and Carloni (2021) found markedly higher mortality in Jonah crabs when removing both claws (70%), compared to a single claw (51%), and mortality was significantly correlated with wound size, temperature, and shell condition. Furthermore, they found using a mechanical tool to declaw crabs where crabs would naturally autotomize reduces mortality by over 50%.

In a follow-up study Dorrance et al. (2022) investigated the sublethal effects declawing had on mating, locomotion and feeding ability. First, mating trials revealed that males with both claws removed could successfully mate with recently molted females. Second, through laboratory-based trials, crabs with claws removed were significantly less active compared to control crabs where both claws were intact; this was corroborated by a passive tagging study where declawed crabs moved about half the distance of control crabs. Additionally, declawed crabs were still able to feed, however they were unable to effectively open mussels which may influence their diet in their natural habitat. These data along with Goldstein and Carloni (2021) suggest that those Jonah crabs that do survive the claw removal process might be impaired, but should be able to forage, mate, and potentially help sustain the population.

6 FISHERY INDEPENDENT DATA SOURCES

6.1 Settlement/YOY Surveys

Settlement indices of abundance are provided for Jonah crabs <13mm CW. This size cut-off corresponds closely with size cut-offs identified by Huntsberger 2019 for YOY crabs (10mm CW). Preliminary correlation analyses applied to lagged age-specific settlement indices for ages 0-2 based on cut-offs from Huntsberger 2019 (<10mm CW for age-0, 10-19.9mm CW for age-1, and 20-40mm CW for age-2) failed to detect strong support of cohort tracking within surveys (Figure 59 and Figure 60). These analyses were likely impacted by small sample sizes but may also be indication of growth uncertainty and overlap with age. The YOY indices represent the smallest sizes that may be less affected by overlap in size-at-age and presumably would be the least mobile age class, therefore providing the best measure of year class strength.

Five settlement indices were identified as providing most utility for the assessment. These included ME settlement surveys from three statistical areas in ME waters (statistical area 511, 512, 513), the NH settlement survey (SA 513), and the MA settlement survey (SA 514). All surveys are in IGOM waters.

6.1.1 ME DMR Settlement Surveys

The ME DMR settlement survey primarily was designed to quantify lobster YOY but has also collected Jonah crab data from the sites throughout the time series. The survey was started in 1989 in a smaller regional area close to Boothbay Harbor within statistical area 513E but was expanded to statistical areas 513 W, 512, and 511 in 2000. Therefore, some indices include separate trends for areas in 513 due to the differing time series. The Maine survey currently monitors 40 sites coastwide within 1-10m in depth. The timing of this survey has shifted over time due to dive staff availability to complete the work, but it has generally occurred between September and December annually. Jonah crab information collected includes CW and location. Notations are made if small crabs carry eggs.

6.1.2 NH F&G Settlement Survey

NH F&G has participated in the American Lobster Settlement Index (ALSI) since 2008, and biological information has been collected on Jonah crabs since 2009. New Hampshire follows the standardized coastwide procedures and monitors three sites along the NH Coast.

6.1.3 MA DMF Settlement Survey

Massachusetts has conducted a juvenile lobster settlement survey since 1995. The survey begins in mid to early August, and generally runs through late September. The survey started with nine fixed stations in three regions and by 2018, had grown to include 23 fixed stations in seven different regions. The survey extent contracted in 2019 to 14 sites in five regions. The Vineyard Sound region and two of the Buzzards Bay sites were discontinued because juvenile lobsters are rarely encountered in these areas. The Cape Cod region and some South Shore stations were discontinued due to the increasing presence of white sharks at survey sites during the survey time-period.

The survey is conducted at fixed stations by a team of divers. Divers selectively place 0.5 m^2 quadrats over areas of cobble. Twelve quadrats are sampled per station, which are then immediately sorted on the boat.

Jonah crabs have been consistently identified to species in the survey since 2011. Though the survey has not always identified crabs to species, it has consistently identified *Cancer* crabs to genus over the entire time series. Jonah crabs are counted, measured (CW in mm) and sexed when possible. Crabs less than 5 mm are generally too small to sex or identify to species.

6.1.4 Other Settlement Surveys Considered

Three additional surveys were considered, but not recommended for use at this time (Table 15). These included the RI settlement survey, University of Maine Deepwater Collector survey, and Normandeau Plankton Survey. The RI settlement survey occurs in ISNE waters, but infrequently encounters Jonah crab. The University of Maine Deepwater Collector Survey, which uses collector boxes to sample across a range of depths, was useful for the assessment in that it indicates trends are tracked from shallow to deep waters (Figure 61), improving confidence that accepted settlement surveys, all occurring in shallower waters, are accurately reflecting overall settlement trends. However, settlement indices from this survey do not correlate well with the accepted state surveys which use suction sampling and may provide biased measures of interannual settlement due to the attractive nature of collectors placed in otherwise less ideal habitat. The Normandeau Plankton Survey offers a long time series in IGOM waters but does not record *Cancer* crab species to the species level.

6.2 Post-Settlement Surveys

Three post-settlement abundance metrics were identified based on biology and exploitation of Jonah crab. These metrics are intended to improve interpretation of abundance indices by filtering aggregate indices that encounter intermittent catches of small crabs, behind which the mechanisms of catchability are not well understood (e.g., catch through the trawl mesh as the bag comes into contact with the ground). Because catch rates of larger, older Jonah crabs are also low, these intermittent catches can lead to noise that has considerable impact on the abundance signal and its interpretation. Post-settlement abundance metrics include recruit abundance, exploitable abundance, and spawning abundance. Recruit abundance is defined as male Jonah crabs 90-119 mm CW. Male Jonah crabs 95mm CW are expected to grow to legal size after their next molt, on average, according to the regression equation from Truesdale et al. 2019a (PostMoltCW=1.22*PreMoltCW+5.47; expected PostMoltCW for PreMoltCW of 95mm is 121.37mm). Trawl surveys have historically measured Jonah crabs to the nearest cm, so the recruit size class was structured to include the cm bins capturing 95mm CW crabs up to the largest fully sublegal cm size bin (11cm; current minimum size is 4.75 inches or 120.65mm). Exploitable abundance includes all male Jonah crabs greater than these recruit sizes (120mm+ CW) and is a measure of abundance currently available to the fisheries. Spawning abundance is defined as female Jonah crabs 80mm+ CW. The spawning abundance size structure includes the smallest cm size bin associated with recent SM50 estimates along the coast (Table 1).

Three survey platforms were identified as providing most utility for abundance indices based on broad spatial footprints that overlap with Jonah crab habitat, long time series that cover the period of available stock-specific landings, availability of biological data that allow for filtering to the post-settlement abundance metrics, and similarities in trends measured in the respective stock. These platforms included the MA Trawl Survey covering the IGOM stock, the ME/NH Trawl Survey covering the IGOM stock, and the NEFSC Trawl Survey covering all four stocks (although, later determined to not be of utility for the ISNE stock – see Section 7). All three platforms have separate surveys in the spring and fall.

6.2.1 NEFSC Trawl Survey

The NEFSC bottom trawl survey began collecting Jonah crab data in 1979. The spring survey is generally conducted from March to May and the fall survey is generally conducted in September and October.

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 GOM and GB, is stratified by depth (Figure 7). 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.

Most survey cruises prior to 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 trawler NOAA ship R/V Delaware II. On most spring and fall 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 surveys 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. Paired tow calibration studies were carried out during 2008 to allow for calibration between the R/V Bigelow and R/V Albatross IV and their net types. However, calibrations have not been estimated for Jonah crab. Thus, it is appropriate to treat this survey as separate time series since 2009 until a calibration can be produced.

6.2.2 Maine/New Hampshire Trawl Survey

The ME/NH Inshore Trawl Survey began in 2000 to fill a significant information gap in resource assessment surveys on approximately two-thirds of the inshore portion of the GOM. The survey is conducted in collaboration with NH F&G and its industry partner, Robert Michael, Inc. Conducted biannually, spring and fall, the survey operates on a random stratified sampling design. A goal of 120 survey stations are sampled in 20 strata that are distributed over four depths: 5-20 fathoms, 21-35 fathoms, 36-55 fathoms, and >56 fathoms roughly bounded by the 12-mile limit in five longitudinal regions (Figure 62). The survey samples a portion of 3 statistical areas, 513, 512, and 511. Jonah crab biological data were not fully collected until 2004.

6.2.3 MA DMF Resource Assessment Program Trawl Survey

Since 1978, the MA DMF Resource Assessment Program has conducted an annual spring (May) and fall (September) bottom trawl survey within state territorial waters. The survey obtains fishery-independent data on the distribution, relative abundance and size composition of finfish and select invertebrates, including Jonah crab. A random stratified sampling design is used to select stations from five bio-geographic regions and six depth zones (Figure 63). Stations are selected before each survey and drawn proportional to the area each stratum occupies within the survey area. A minimum of two stations are drawn per stratum. Stations chosen in un-towable locations are redrawn.

The F/V Frances Elizabeth conducted all surveys through fall 1981. All subsequent surveys have been conducted onboard the NOAA ship R/V Gloria Michelle. A 3/4 size North Atlantic type two seam otter trawl (11.9 m headrope/15.5 m footrope) 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, and 147 kg wooden trawl doors have been used for the duration of the survey. A 6.4 mm knotless liner is used in the codend to retain small organisms. Standard tows are 20 minutes but tows of at least 13 minutes are accepted as valid and expanded to the 20 minute standard. Tows are conducted during daylight hours at a tow speed of 2.5 kts. More information on the MA DMF trawl survey can be found by visiting https://www.mass.gov/files/documents/2016/08/tm/tr-38.pdf.

Jonah crabs have been weighed collectively for each tow to the nearest 0.1 kg since 1978, and by sex since 1981. From 1978 through 2009, Jonah crab CW measurements were taken on a wooden measuring board and recorded to the nearest cm on paper logs. Starting during the 2010 spring survey, crabs were measured on electronic length boards and recorded directly in to Fisheries Scientific Computer System (FSCS) data tables. Since the fall 2014 survey, Jonah crab measurements have been recorded with digital calipers to the nearest cm and recorded directly into FSCS. The change to digital calipers was made to improve measurement accuracy, as crab legs sometimes made it difficult to measure crabs on a length board. Female crabs have been inspected for extruded eggs since the fall 2014 survey, but observations of egg bearing crabs are very rare.

Jonah crab are infrequently encountered in SNE (survey regions 1 and 2; Figure 63), so indices of abundance are only calculated for GOM strata (survey region 3-5).

6.2.4 Other Post-Settlement Surveys Considered

Several additional fishery-independent surveys that have encountered Jonah crab were considered during this assessment (Table 16). These surveys were generally more limited in the information provided, reducing their utility for the assessment. Primary limitations of these data sets included poor spatial coverage, short or discontinuous time series, relatively inefficient catchability or low catch rates, and/or lack of biological data. Most of these data sets were identified as having low utility in ASMFC 2021, including several using ventless trap gears. Ventless trap gear catchability issues impacting this gear’s ability to reliably track Jonah crab abundance is further evaluated and described in Section 6.2.5.2.

There was uncertainty in the utility of the NJ Trawl survey in ASMFC 2021 and there was a new survey not considered in ASMFC 2021 but subsequently identified as a survey with relatively high encounters of Jonah crab, the Northern Shrimp Trawl Survey. These surveys were evaluated with preliminary correlation analysis to examine consistency of trends with the other trawl surveys. The NJ Trawl survey has both spring and fall surveys, while the Northern Shrimp Trawl survey has a summer survey only. Both surveys have collected limited biological data, so sex- and size-aggregate abundance indices were used in the correlation analysis. Additionally, it's important to note that there was a gear change for the Northern Shrimp Trawl survey in 2017 and gear change calibration factors are not available, so indices of abundance have not been adjusted for this gear change.

The NJ Trawl index was not correlated with the NEFSC Trawl index which has better spatial overlap with the fishery (Figure 64). This lack of correlation along with the lack of sex data until 2021 limit the utility of this survey and indices were not included in further analyses. The Northern Shrimp Survey was positively correlated with the NEFSC Trawl indices among seasons and spatial domains of indices (IGOM, OGOM and combined GOM areas; Figure 65). These results indicate that trawl surveys are tracking a consistent signal in the GOM. Unfortunately, length data has not been collected during the Northern Shrimp Trawl survey to allow calculation of the Jonah crab abundance metrics and should be prioritized given these correlation results so this survey provides more utility in future stock assessments.

6.2.5 Catchability Analyses

6.2.5.1 Temperature in Trawl Surveys

Given rapidly changing environmental conditions within the Jonah crab range and effects on catchability observed in cohabitating species like lobster (ASMFC 2020), Jonah crab catch rates and temperature time series were evaluated to identify potential temperature-driven catchability effects that may explain noise observed in indices of abundance and provide a better understanding of catchability effects. Because temperature can affect both abundance and survey catchability simultaneously, annual anomalies in catch rate and temperature from underlying trends were evaluated for relationships.

Seasonal catch rates of exploitable Jonah crabs (Figure 6) and temperature time series (Figure 66) from the NEFSC Trawl Survey were generated from adjacent statistical areas associated with high and low commercial landings. There was a period of anomalously low temperatures in the 1980s through 1990 that are not consistent with the underlying trend in other years, so data prior to 1991 were excluded from the analysis. There was a clear linear trend in temperature that was estimated with linear regression and used to calculate residuals as temperature anomalies in the analysis (Figure 67). Identifying the underlying trend in catch rates was more difficult, so two potential trends were included. The first trend was a two-year running average and the second trend was predicted with a LOESS smoother. The span was set at 0.33 to be consistent with the methodology used for the Plan B index-based method applied to Jonah crab index and landings time series (Appendix 14.1). As with the temperature time series, residuals were used as anomalies in catch rates for the analysis (Figure 68 and Figure 69). There was some change in magnitude in residuals, so Spearman's rank correlation was used in the analysis to better handle potential outliers in the relationship.

No significant correlations were detected with a Spearman's rho $\geq \pm 0.5$ in the eight data sets tested (Table 17 and Table 18, Figure 70 and Figure 71). The data for the low catch areas in the spring had a p-value <0.05, but the Spearman's rho indicated only a weak positive association while no other data sets indicated a clear relationship between temperature and catch rate anomalies. These results do not support seasonal temperature being a primary driver of Jonah crab catchability in trawl surveys.

6.2.5.2 Assessing utility of ventless trap surveys for providing Jonah crab abundance indices

The Coastwide Ventless Trap Survey (VTS) was initiated in 2006 from Maine through New York. The impetus for this survey was to track the abundance of juvenile lobster populations, particularly in areas where trawl surveys are not able to tow due to complexity of habitat (ASMFC 2006). Early in the time series, data on bycatch species were not collected on a consistent basis throughout the survey area, and although Jonah crab are now being enumerated for all cooperating organizations, questions remain as to the utility of these surveys for tracking abundance of Jonah crabs. Studies on the interactions between lobsters and Jonah crabs reveal that lobsters are both competitive dominants (Richards et al. 1983, Richards and Cobb 1986, Richards 1992), and common predators of *Cancer* crabs (Ojeda and Dearborn, 1991, Sainte-Marie and Chabot, 2002; Jones and Shulman, 2008). As a result, the presence of lobsters causes crabs to shift their activity decreasing trap entry (Richards et al. 1983). Additionally, there are other covariates that may affect Jonah crab catch rates such as depth, habitat, temperature and/or soak time. With this information in mind, we assessed two historic trap surveys to better understand the effect of soak time and lobster abundance on Jonah crab catch, with the goal of better understanding the ability of these surveys to track Jonah crab abundance over time. The two surveys were: 1) Southern New England Ventless Trap Survey (SNECVTS) conducted off the coasts of Massachusetts and Rhode Island, and 2) Normandeau Associates Inc. Ventless Trap Survey (NAI-VTS) conducted along the coast of New Hampshire.

Southern New England Ventless Trap Survey

We used trap-level data from the SNECVTS in 2018 to test the effect of a number of covariates, including lobster catch, on the catch rate of Jonah crabs. The SNECVTS program sampled 24 stations in the MA/RI wind energy area, twice per month from May to November. At each station, a 10-trap trawl was set with ventless (V) and standard (S) traps in the configuration: V-S-V-S-V-V-S-V-S-V. Target soak time was 5 nights with an acceptable range of 4 to 8 nights (Collie et al. 2019).

Jonah crab catch ranged from 0 to 130, and lobster catch ranged from 0 to 35 per trap. Both distributions were highly skewed with long tails. Jonah crab catch rate was modeled with a GLM with a negative binomial error distribution. The null model included trap type (V or S), latitude*longitude, soak time, and month. Additional candidate models tested the effects of habitat type, lobster and Atlantic rock crabs.

Based on the best-fit model, ventless traps catch more Jonah crabs than standard traps. Jonah crabs are more abundant on sand and soft sediments. Jonah crab catch rate is affected by lobsters but not rock crabs (Figure 72). Catch rate was a dome-shaped function of soak time with a peak at 6 days (Figure 72). In conclusion, Jonah crab and lobster catch rates are inversely related, after accounting for known covariates. The fitted relationship implies that the presence of two lobsters in a trap reduced Jonah crab catch by 11%. These results may account for some of the variability in Jonah crab catch rates in ventless trap surveys. They also suggest that Jonah crab catch rates could be adjusted for lobster abundance in the same traps, as has been done to Figure 72.

Normandeau Associates Ventless Trap Survey

Normandeau Associates conducted a ventless trap survey at two stations along the NH coast since the early 1980s. American lobster, Jonah crab, and Atlantic rock crab were enumerated and measured during trap hauls. Traps were hauled on two-day intervals approximately three times per week from June through November. Trawls consisted of fifteen 1” mesh single parlor traps. Data were aggregated by trawl, as trap-level data were not available. Jonah crab catch peaked during the late 1980s through early 1990s, followed by another peak in the early to mid-2000s and low catch rates from 2009 through 2021 (Figure 73). Lobster catch shows a general upward trend throughout the 40-year time series with highest catch rates being observed over the most recent twelve years (2010-2021). This period of extremely high catch of lobsters coincides with the lowest catch rates of Jonah crabs of the entire time series. Interestingly, the ME/NH trawl survey, picks up the pulse in Jonah crab abundance in the early 2000s, similar to the NAI-VTS, however the pulse picked up by the trawl survey in the mid to late 2010s is not picked up by traps, which coincides with a time period of high lobster catch, suggesting increasing numbers of lobsters within a trap may be deterring Jonah crabs from entering as documented by Richards et al. (1983).

A GAM with a negative binomial error distribution was fit to NAI-VTS data with Jonah crab catches per trawl (15 traps) as the response and year, month, station and lobster catches as covariates. Lobster catches were included as a smooth term. All covariates were retained according to AIC comparisons of reduced models with excluded covariates. Figure 74 shows the estimated effect of lobster catch on Jonah crab catches with a slight increase to catches of ≈80 lobsters per trawl, followed by a steady decrease in Jonah crab catches as lobster catches increase.

Summary

We assessed two trap-based surveys in different geographic areas to evaluate the ability of lobster centric surveys to pick up signals of abundance for Jonah crabs. The analysis of the SNECVTS data shows a positive effect of soft bottom on Jonah crab catch rates, indicating Jonah crabs are more associated with soft bottom that are towable by trawl surveys and not the complex habitat that may be more associated with ventless trap surveys. There were differences in soak times between these surveys, the SNECVTS was designed with a target soak time of 5 days, with a range between 4 and 8 days, whereas the NAI-VTS was designed with a target of 2 days, although longer sets were not uncommon. We found an increasing catch rate of Jonah crab up to six days followed by decreasing catch through eight day sets with SNECVTS. Catch rates increased in the NAI-VTS through 3 days, followed by decreasing catch with increasing soak time (NAI 2016). Although there are some discrepancies in results of catch with soak time between these two surveys, there is still general agreement between both of increasing catch for a number of days followed by decreases likely due to escapes. Similar soak-time dynamics have been observed in American lobster (NAI 2016, Clark et al. 2018). The differences we report here could be due to trap design, bait type/deterioration (Watson et al. 2019), and/or differences in species assemblage and inter and intraspecific competition.

The forty-year time series of the NAI-VTS survey provides a unique opportunity to assess trends of both lobster and crab over a long time series. It becomes even more informative when including an independent measure of crab abundance from the ME/NH trawl survey. Similar to the NAI-VTS, there was a peak in Jonah abundance in the early 2000s, however when the ME/NH trawl peaked again in the mid to late 2010s, this increase was not seen in the NAI-VTS. This time period coincides with unprecedented levels of lobster abundance in the region (ASMFC 2020) and suggests the high catch of lobsters may have deterred Jonah from entering traps, decreasing catchability to a degree that the index is not informative of Jonah crab abundance. Similarly, the models we applied to both surveys showed a decreasing catch of Jonah crabs with increasing lobster catch (Figure 72 and Figure 74), a dynamic which is in agreement with past studies (Richards et al. 1983). Our results, combined with literature on the subject, provide evidence that ventless trap surveys are not ideal for assessing abundance of Jonah crabs, largely due to lobsters being competitively dominant. As demonstrated in Figure 72, there are ways we may be able to adjust crab catch based on number of lobsters in the trap at some levels of lobster catches, though additional work is needed to apply our results to long-term surveys.

7 DATA EVALUATION

7.1 Trend and Correlation Analyses

7.1.1 Methods

After stock structure and abundance metrics were defined, data sets discussed in previous sections were evaluated with correlation analyses to identify consistencies in trends among data sets as an indication of reliability for stock indicators and trend analyses to identify signs of change over time, including:

- YOY settlement indices (<13mm CW; Table 17 and Figure 75)
- Recruit abundance indices (males 90-119mm CW; Table 21-Table 22 and Figure 76)
- Exploitable abundance indices (males 120+mm CW or fishery CPUE; Table 25-Table 27 and Figure 77)
- Spring recruit abundance indices and fall exploitable abundance indices within surveys (Figure 78)
- Exploitable abundance indices and YOY settlement indices lagged from 2-7 years
- Spawning abundance indices (females 80+mm CW; Table 29-Table 31 and Figure 79)
- Jonah crab landings (Table 7 and Figure 43)

Spring recruit abundance indices were evaluated against fall exploitable abundance indices under the assumption that recruits in the spring molt during the summer and recruit to legal-sized abundance in the fall and, therefore, share trend information. For comparisons of exploitable abundance indices and lagged settlement indices, indices from ME settlement surveys and the ME/NH and NEFSC trawl surveys were included because they occur in adjacent areas and cover relatively long time series.

Additional time series were calculated to explore exploitation signals and included:

- Ratios of spring recruit indices and fall exploitable abundance indices (Figure 80)
- Relative exploitation (landings/exploitable abundance index; Figure 81)

Data sets were structured by (1) stock, (2) with the IGOM and OGOM stocks combined due to similarities in trends during preliminary analyses (Section 6.2.4), and (3) coastwide for a perspective on the U.S. population as a whole.

Data sets were evaluated with Spearman's correlation and any results with Spearman's rho (ρ) ≥ ±0.5 and a p-value<0.05 were considered detected correlations. Mann-Kendall trend analysis was applied to test for monotonic trends over time and results with a p-value <0.05 were considered detected trends. Mann-Kendall trend analysis was applied to data sets from 2010-2021 to test for trends since the beginning of the available landings time series which covers the initial ascent of coastwide landings as the fishery developed (Figure 1). However, some data sets started later than 2010 and any with at least five data points were included. Results for these shorter time series should be viewed with caution. Trend analysis was also applied to full time series to provide a historical perspective on trends. It's important to reiterate that vessel change calibration factors for the NEFSC Trawl Survey are not available and indices of abundance have not been adjusted for the vessel change in 2009.

Given limited and noisy data (low encounter rates, high CVs; Table 17-Table 32), emphasis in interpreting results was placed on patterns among all analysis results and less emphasis on individual analysis results between two data sets.

7.1.2 Results

Settlement indices showed correlation among areas in ME waters, but not correlation with indices in waters to the south that had shorter time series (NH and MA; Figure 82). Despite the lack of correlation, all available indices agree on relatively strong year classes in 2012 and 2018. No trends were detected since 2010, but there are increasing trends over the longer time series of all three ME settlement surveys (Table 33).

Recruitment indices showed some consistency between seasons within surveys in GOM and coastwide, but not in SNE stocks (Figure 83 and Figure 84). There were not correlations detected between surveys. No trends were detected in recruitment indices for any areas since 2010, but increasing trends were detected over full time series in eleven surveys covering all areas (Table 34). One decreasing trend over the full time series occurred IGOM in the ME/NH spring survey and is due to the survey beginning later than others during a pulse of abundance in the mid-2000s.

Exploitable abundance also showed consistency between seasons within surveys in GOM and coastwide, as well as some consistency between surveys in GOM (MA and ME/NH; Figure 85 and Figure 86). As with recruit indices, there was no seasonal consistency in SNE and no consistency between fishery-independent indices and fishery-dependent CPUE time series (although there was some correlation in GOM between stocks or with lags, Section 5.1.4.4). Increasing trends since 2010 were detected for the NEFSC fall indices in GOM waters (combined and inshore), while decreasing trends were detected in the ISNE stock with DRM CPUE and the OSNE stock with the NEFSC trawl spring index (Table 35). Over full time series, increasing trends were detected in ten surveys covering all stocks except ISNE. As with recruit indices, the MA/NH spring survey showed a decline from the pulse of abundance at the beginning of its time series. Additionally, the DRM CPUE for the ISNE stock had a declining trend, but this time series was only three years longer than the time series tested since 2010.

Spring recruit indices and fall exploitable abundance indices showed consistency in GOM and coastwide, but not in SNE (Figure 87 and Figure 88). An increasing trend since 2010 was detected in recruit to exploitable abundance ratios with the MA Trawl survey in the IGOM stock, but no other surveys (Table 36). No trends were detected over the full time series.

Given correlations detected among ME settlement surveys, correlation results between the trawl survey exploitable abundance indices and YOY settlement indices were similar across ME settlement indices. Therefore, only results for the central area (statistical area 512) are reported. No positive correlations were detected between the ME/NH indices and lagged settlement indices (Figure 89). However, there were correlations detected between the NEFSC indices and settlement indices lagged from 2-4 years (Figure 90). These correlations decrease as the lag increases and fall apart by a 5-year lag.

Spawning abundance indices showed similar patterns in consistency as male indices, with some seasonal consistency within surveys in GOM and coastwide, but not in SNE (Figure 91 and Figure 92). Additionally, there was some consistency between IGOM surveys. The only trend detected since 2010 was a declining trend for the OSNE stock in the fall (Table 37). During the full time series, increasing trends were detected in twelve indices covering all areas. One declining trend was detected for the ME/NH spring survey.

Landings are not correlated between stocks in GOM and no indices are positively correlated with the landings (Figure 93). In SNE, landings are correlated between stocks and CFRF VTS CPUE is correlated between stocks, while also being correlated with landings ISNE (Figure 94). Coastwide, the indices are not positively correlated with landings (Figure 95). A decreasing trend in relative exploitation was detected using both OGOM seasonal indices, while an increasing trend was detected using the OSNE NEFSC spring index, but not the fall index (Table 38).

7.1.3 Discussion

The only reliable information on settlement comes from IGOM waters. There have been increases in settlement since the 1990s and 2000s, while settlement appears to have become more stable at higher levels in about the last decade. The strong 2012 year class measured across surveys appears to have supported large pulses of abundance that show up in the IGOM and OGOM post-settlement surveys in the mid-2010s. Despite relatively limited correlations detected between surveys in the GOM and some interannual variability in when peak abundances occur, it is clear that brief pulses of increased abundance were detected in GOM waters in the mid-2010s across surveys, as well as during the early 2000s. This cohort signal tracking was measured consistently between the ME settlement surveys and NEFSC trawl survey and the strongest correlations for a two-year lag indicates a slightly shorter lag than detected by Huntsberger 2019 (four year lag between YOY and 110-120mm Jonah crabs). Post-settlement indices also show strong seasonal consistency indicating they are tracking a common signal as opposed to noise alone.

The observed pulses in abundance occur over a very short duration without any clear indication of increased exploitation. Despite the decline of the pulse near the end of the time series, there are no indications of longer-term decreasing abundance or increasing exploitation over approximately the last decade, but rather only indication of increasing abundance and decreasing exploitation.

Settlement trends are unknown in SNE stocks and there was no indication of increased recruitment in the mid-2010s in SNE post-settlement indices. Even indices at a reduced spatial scale in adjacent statistical areas of the OGOM and OSNE stocks that account for low and high magnitudes of overall landings, respectively, show very distinct abundance differences in the mid-2010s (Figure 6). It became clear during these analyses that indices from ISNE are of little utility given low sample sizes (avg. annual tows≈9), infrequency of encounters (multiple zero catch years), and considerable noise (high CVs). These indices were not considered further for information on stock abundance. Additionally, the fishery-dependent CPUE time series for both SNE stocks are not recommended as a measure of exploitable abundance. Despite a trend detected in DRM CPUE, the Mann-Kendall test provides no information on magnitude of changes and the time series shows relatively little change in catch rates despite large changes in landings. Additionally, the CFRF VTS CPUE shows similarities to the landings time series while the fishery-independent indices do not. The methodology of attaching ventless traps to commercial trap strings likely contributes to this and confounds the CPUE's refection of a true abundance trend.

The general consistencies seen in GOM, particularly seasonal consistency, fall apart in the OSNE stock where the bulk of the fishery occurs, making interpretation of these indices more difficult and reducing confidence in their ability to accurately reflect interannual changes in relative abundance. Inconsistencies lead to conflicting pictures of stock condition between seasons, with some signs of increased exploitation and decreased abundance according to spring data that are not apparent with fall data. The spring exploitable abundance index occurs after the primary landings quarters (one and four) and before incoming recruitment and should provide better information on exploitation, but encounter rates are noticeably lower during this season unlike in GOM.

The coastwide data sets present a spatial mismatch with the indices being driven by higher catch rates in GOM areas and landings being driven by the greater magnitude coming from SNE areas. This mismatch could bias true stock-specific exploitation signals.

7.2 Limitations for Assessment Methods

Some analyses of abundance index and landings time series were attempted in order to provide tactical management advice (Appendix 14.1). However, the correlation and trend analyses conducted here highlight two primary limitations for using available data sets in these traditional assessment approaches. First, there does not appear to be a clear relationship between abundance and fishery removals that assessment approaches would depend on and attempt to estimate. The observed abundance “pulse” population dynamics result in short-term, large-scale changes in abundance that appear to be driven by factors other than exploitation given there were no similar changes in landings in the bycatch-driven fisheries of GOM that would explain the rapid decline of these pulses. Another limitation is poor understanding of Jonah crab catchability and low encounter rates for available trawl survey indices. Catch rates have regularly been at or near zero and likely only provide a coarse, qualitative approximation of abundance changes between periods of time as opposed to a reliable quantitative tracking of interannual abundance changes. Therefore, estimates from the index-based methods in Appendix 14.1 are not recommended for management use. Instead, qualitative characterizations of stock status are provided in the next section with empirical stock indicators.

8 STOCK INDICATORS

Given limitations of data sets for traditional assessment approaches, data sets were used to develop empirical indicators of stock conditions and fishery performance. These indicators provide a categorical characterization of recent condition relative to historical levels. The terminal three years (2019-2021) are averaged to provide a smoothed measure of recent stock condition due to interannual variability reflective, in part, of observation error. As is done in American lobster stock assessments (ASMFC 2020), categories are defined as positive, neutral, and negative according to the 25th and 75th percentiles of each indicator’s time series.

8.1 Abundance Indicators

Stock abundance indicators include the YOY settlement, recruit abundance, exploitable abundance, and spawning abundance indices evaluated in the previous section. Indicators are categorized as positive if above their 75th percentile, neutral if between their 75th and 25th percentile, and negative if below their 25th percentile.

8.2 Fishery Performance Indicators

Fishery performance indicators include landings, the number and proportion of pot/trap trips that landed Jonah crabs, and the number and proportion of active (i.e., reported catch during the year) lobster/crab permits that landed Jonah crab. NH harvesters are active in the IGOM and OGOM stocks, but trip and permit data are only available for this state since 2016. Trends and conditions were compared with and without NH data and were very similar, so NH data are excluded from these indicators to maintain the time series back to 2010.

Landings provide indicators of the biomass removed from the stock due to fishing, but, as discussed in Section 4.3, are affected by factors other than available biomass and are not interpreted as an indication of stock biomass. Low landings are not favorable for fishery performance and these indicators are categorized as positive if above their 75th percentile, neutral if between their 75th and 25th percentiles, and negative if below their 25th percentile.

Trip and permit indicators are also affected by factors other than biomass that affect total landings (reduced lobster abundance/target switching, price changes). Due to these confounding factors and that these are presented as fishery performance indicators, these are interpreted similar to landings with lower levels, below their 25th percentile, interpreted as negative conditions due to lower access/participation in the fishery. Moderate levels between their 25th and 75th percentiles are considered neutral and higher levels are interpreted as positive conditions due to greater access/participation in the fishery. The lack of large changes observed in the proportion-based indicators for all stocks result in small interquartile ranges indicative of neutral conditions and conditions will be sensitive to relatively small changes.

A major caveat to the interpretation of these fishery performance indicators is that, at some point, participation in the fishery could result in more fishing pressure (i.e., exploitation) than the stocks can support. The relationship between participation and exploitation is unknown.

8.3 Results

8.3.1 IGOM

YOY settlement indicators in ME all declined in 2021 and were neutral (Table 17 and Figure 96). Indicators to the south of ME (NH and MA) were both positive in 2021. These indicators have the shortest time series but are unavailable during earlier years when low settlement was observed in ME and recent conditions likely are not inflated due to the short time series. Three-year averages are neutral for all surveys except ME 512, which is positive.

Post-settlement indicators generally agree on declines in abundance in recent years from time series highs in the mid-2010s but provide more of a mixed picture in terminal conditions across surveys (Table 21, Table 25, Table 29, and Figure 97-Figure 99). Three-year average conditions are positive across surveys and metrics for the NEFSC trawl survey, vary between positive (exploitable and spawning abundance in spring) and neutral (all metrics in fall and recruit abundance in spring) for the MA trawl survey, and are negative across surveys and metrics for the ME/NH trawl with only one exception (positive fall index of spawning abundance). The negative conditions observed by the ME/NH trawl survey are influenced by the start year of the survey. The survey began during the abundance pulse in the early 2000s and did not capture earlier years when indices observed by both the MA and NEFSC trawl surveys generally were at or near time series lows.

All fishery performance indicators are neutral (Figure 100-Figure 102). Proportional indicators indicate potential for fishery growth in this stock, with observed proportions being very low across the time series. This stock by far accounts for the highest number of trips and permits landing Jonah crabs, being an order of magnitude higher than OSNE indicators despite landings about five times lower than the OSNE stock.

8.3.2 OGOM

All settlement indicators are from IGOM, but, as seen with the data evaluation analyses, have similarities with exploitable abundance trends seen in OGOM and may be reflective of recruitment to this stock.

As with the IGOM stock, post-settlement indicators indicate declines in abundance in recent years from time series highs in the mid-2010s (Table 21, Table 25, Table 29, and Figure 103-Figure 105). Recruit abundance indicators declined to neutral conditions in both seasons, while exploitable abundance indicators remain in positive conditions in both seasons. The spring spawning abundance indicator declined to neutral while the fall indicator remains positive.

The proportion trips landings Jonah crab and both permit indicators are positive due to an upward trend at the end of the time series to the highest levels of the time series in 2021 (Figure 101 and Figure 102). The number of trips indicator is more variable during these years and neutral on average. As with the IGOM stock, proportional indicators are very low and indicate potential for fishery growth in this stock. Unlike the IGOM stock, trips and permits landings Jonah crabs through time have been the lowest observed across stocks. Landings are negative due to general decline during the time series (Table 7 and Figure 100).

8.3.3 ISNE

There are no reliable abundance indicators for the ISNE stock and abundance conditions are unknown.

The landings indicator shows an upward trend during the final three years and is neutral on average (Table 7 and Figure 100). Trip indicators and the number of permits landings Jonah crab indicator are neutral, while the proportion permits landing Jonah crab indicator is positive (Figure 101 and Figure 102). Proportional indicators indicate potential for fishery growth in this stock, but this growth may be constrained by available abundance in these more southerly, inshore waters relative to the GOM stocks.

8.3.4 OSNE

There are no settlement indicators for the OSNE stock and conditions are unknown.

Post-settlement indicators provide a mixed picture on conditions between seasons (Table 23, Table 27, Table 31, and Figure 106-Figure 108). Fall indicators generally show abundance increases to higher abundance from time series lows in the first half of the time series, while spring indicators are more variable without trend. Terminal spring indicators are neutral for all metrics, while fall indicators are positive for recruit and exploitable abundance. The fall spawning abundance indicator shows some decline to neutral conditions. It's important to note that encounter rates are considerably lower for spring indicators and the 25^{th} percentile for the exploitable abundance indicator is actually zero due to several years when no Jonah crabs were encountered.

The landings indicator shows a consistent downward trend since 2018, with the terminal three-year average being neutral and above the terminal year value which is negative (Table 7 and Figure 100). Total count and proportional indicators show opposing trends and conditions in the terminal three years, with counts of trips and permits trending down across the times series and ending in negative (trips) or just neutral (permits) conditions while proportions trend up across the time series ending in positive conditions (Figure 101 and Figure 102). This shows a declining fishery capacity that has increasingly utilized the Jonah crab resource and could indicate shifting targeting towards Jonah crab, increasing Jonah crab abundance, or a combination of both. Greater than half of trips and active permits land Jonah crab in this fishery, contributing to the highest magnitude of landings across stocks.

9 STOCK STATUS

Inference about stock abundance condition is based on the stock abundance indicators. According to these indicators, there have been declines in post-settlement abundance for the IGOM and OGOM stocks from time series highs in the mid-2010s, but conditions in the last three years of the time series are neutral or positive. The one exception is from the ME/NH Trawl survey, but this is due to the shorter time series of this survey not capturing historical lows in earlier years. Indicators for the OSNE stock also indicate neutral or positive post-settlement abundance conditions in the last three years of the time series. Indicators agree across these stocks that abundance has not been depleted to historical lows. There are no reliable abundance indicators for the ISNE stock and inference cannot be made about condition of this stock's abundance at this time.

YOY indicators generally indicate neutral conditions and do not indicate that recruitment in GOM stocks will decline to historical lows in the near future. Settlement conditions are unknown for SNE stocks.

Landings have steadily declined in the OSNE stock which is the primary stock with targeted/mixed effort for Jonah crab and the stock accounting for the vast majority of coastwide landings. This trend is believed to be influenced by factors other than available abundance but should continue to be monitored closely. There was not sufficient information to make statements about fishing mortality or exploitation with confidence and these population parameters remain major uncertainties.

10 RESEARCH RECOMMENDATIONS

The TC recommends updating the stock indicators in five years and evaluating any new information that may allow for advanced methods to provide management advice at that time. In the meantime, the TC provides the following recommendations to improve the information base for Jonah crab. The TC strongly encourages that any prospective researchers considering projects to address these recommendations reach out to the TC to ensure project results would be of most utility for future stock assessments.

High Priority

- Surveys to track abundance in SNE during all life stages (settlement, recruitment to legal size, exploitable abundance, and spawning abundance) are essential for future stock assessments and potential management advice. Current surveys are not adequate for these goals.
- Research should be conducted to provide a more comprehensive understanding of recruitment dynamics, including tracking of spatio-temporal settlement dynamics and the source of recruitment to offshore SNE, to inform development of Jonah crab settlement surveys.
- Appropriate survey methodologies need to be researched to track abundance of Jonah crab. Trawl surveys are available, but encounter rates are very low and detection ability is uncertain. Behavioral interactions with survey gear need to be better understood. Video surveys are recommended to examine these interactions. Video surveys could also be used for snapshot estimates of total stock size (i.e., swept-area biomass) that could be used to gain a better understanding on exploitation levels.
- Female migration pathways/seasonality and distribution needs to be researched. Anecdotal information suggests seasonal aggregations in inshore areas, but research would help to understand these mechanisms and inform connectivity. Ventless trap surveys (state-run and windfarm impact) offer a potential data set to explore interannual variability in distribution
- Information on larval duration in the field, mortality, and dispersal are needed to better understand possible connectivity. Spawning female distribution information would supplement efforts to model these processes. Evaluate larval data sets for species identification and to explore abundance, seasonality, and interannual variability.
- Inter-molt duration of adult crabs is currently unknown and growth increment data for mature crabs is limited. There are no growth data from offshore SNE where the bulk of the fishery occurs and differences in growth between regions are unknown. These data will be necessary for advanced modeling methods.
- Research growth mechanisms for both sexes (e.g., potential for terminal molt, lack of growth associated with molting, high natural mortality for adults) to explain lack of exploitation signal (i.e., lack of size structure change) in available data sets. Dissection of larger crabs with old shells and evaluation of shell formation underneath external shell might help inform this research.
- Increase and improve the consistency of fisheries-dependent monitoring and biosampling. Sampling intensity by statistical area should be based on landings.

- Continue to improve accuracy of commercial reporting to improve quantification of effort in the directed and mixed-crustacean fisheries. Evaluate new spatial data (i.e., vessel tracking data) to better understand spatial dynamics of the fishery.
- Study the effect of temperature on Jonah crab behavior/activity.
- Little is known about ecosystem/environmental drivers of Jonah crab population dynamics. Studies should be done to identify and understand these drivers.
- Determine how to interpret fisheries-dependent data considering interactions between fishery response to abundance, economic drivers, and lobster fishery dynamics.

Moderate Priority

- Explore historical data sets from the scallop dredge survey and video surveys like HabCam to understand habitat use/suitability, abundance, distribution, and to inform potential covariates for catchability effects.
- Food habits data should be analyzed, with an emphasis on offshore areas, to better understand predation of Jonah crab and as a potential measure of abundance and distribution.
- Evaluate evidence for a defined stock-recruit relationship or lack thereof. If lack of evidence, identify recruitment drivers and mechanisms of population abundance change.

Low Priority

- Information should be collected to help delineate stock boundaries and understand possible connectivity, with an emphasis on the GOM/SNE boundary.
- Reproductive studies pertaining to male-female spawning size ratios, the possibility of successful spawning by physiologically mature but morphometrically immature male crabs, and potential for sperm limitations should be conducted.
- If improved abundance data with higher encounter rates becomes available, cohort tracking analyses should be conducted across and within surveys to better understand if surveys are tracking true abundance signals and provide information on growth, mortality, and other demographic factors.
- The development of aging methods or determination of the mechanism responsible for the suspected annuli formation found in the gastric mill should be explored.

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12 TABLES

Table 1. **Estimates of female Jonah crab size-at-maturity (SM50) by study, region, and type of maturity (morphometric and gonadal).**

Study	Year	Region	Morphometric	Gonadal
This Assessment	2023	GOM offshore	98	
Perry et al.	2017	GOM offshore		98
This Assessment	2023	GOM inshore	94	
This Assessment	2023	Georges Bank	97	
Perry et al.	2017	Georges Bank		93
This Assessment	2023	SNE offshore	94	
Perry et al.	2017	SNE offshore		89
This Assessment	2023	SNE inshore	95	
Perry et al.	2017	SNE inshore		86
Ordzie and Satchwill	1983	SNE inshore	40-50	40-50
This Assessment	2023	Mid Atlantic	90	
Carpenter	1978	Mid Atlantic	85	
Olsen and Stevens	2020	Mid Atlantic	88	

Table 2. **Estimates of male Jonah crab size-at-maturity (SM50) by study, region, and type of maturity (morphometric and gonadal).**

Study	Year	Region	Morphometric	Gonadal
Moriyasu et al.	2002	Nova Scotia	128	69
This Assessment	2023	GOM offshore	121	
This Assessment	2023	GOM inshore	110	
This Assessment	2023	Georges Bank	120	
This Assessment	2023	SNE offshore	119	
Lawrence et al.	2021	SNE Inshore	106	
This Assessment	2023	SNE inshore	103	
Ordzie and Satchwill	1983	SNE inshore		50-60
This Assessment	2023	Mid Atlantic	102	
Carpenter	1978	Mid Atlantic	90-100	
Olsen and Stevens	2020	Mid Atlantic	98	

Table 3. **Size-at-maturity (SM50), Boostrapped SM50, Confidence Intervals, and sample sizes by data source. The SM50 estimate for Gulf of Maine Offshore Females (*) was unstable and highly sensitive to the range of "Unknowns" assumed.**

				95% CI		Sample Size and Data Source		
Sex	Region		SM50_Boot	Lower	Upper	MassDMF	NEFSC	UMES
Fem	GOM_OFF	97.5*	97.7	94.6	99.7	161	810	0
Fem	GOM_IN	93.6	94.5	89.5	100.7	170	125	0
Fem	GB	97.3	95.7	88.6	100.2	177	340	0
Fem	SNE_OFF	93.6	93.6	87.4	97.8	250	132	0
Fem	SNE_IN	94.7	100.7	89.2	104.9	237	40	0
Fem	MAB	89.6	91.5	88.0	102.8	0	168	798
Mal	GOM_OFF	121.3	122.6	120.8	124.3	275	1222	0
Mal	GOM_IN	109.7	110.6	104.6	115.3	209	124	0
Mal	GB	120.1	120.0	117.7	122.1	251	382	0
Mal	SNE_OFF	119.4	119.1	117.0	121.3	304	165	0
Mal	SNE_IN	103.2	105.0	101.5	109.3	407	44	0
Mal	MAB	101.7	101.6	99.1	104.3	0	326	564

Table 4. **Proportion of trips landing Jonah crab using a Massachusetts lobster/edible crab trap permit by year and region.**

Year	IGOM	OGOM	ISNE	OSNE
2010	0.02	0.04	0.07	0.72
2011	0.02	0.04	0.06	0.79
2012	0.03	0.03	0.05	0.76
2013	0.04	0.03	0.11	0.82
2014	0.03	0.04	0.15	0.77
2015	0.03	0.06	0.07	0.71
2016	0.04	0.05	0.09	0.79
2017	0.06	0.05	0.11	0.81
2018	0.05	0.03	0.08	0.77
2019	0.05	0.03	0.04	0.73
2020	0.04	0.07	0.03	0.74
2021	0.05	0.07	0.06	0.83

Table 5. **Annual ex-vessel price per pound for whole body Jonah crab landings by state. Asterisks indicate confidential data.**

Year	ME	NH	MA	RI	CT	Mean	MA/RI Mean
2010	$0.34	*	$0.56	$0.52	$0.60	$0.51	$0.54
2011	$0.35	*	$0.68	$0.57	$0.54	$0.54	$0.62
2012	$0.39	*	$0.74	$0.68	$0.65	$0.61	$0.71
2013	$0.49	$0.69	$0.90	$0.72	$0.71	$0.70	$0.81
2014	$0.30	$0.71	$0.78	$0.75	$0.75	$0.66	$0.76
2015	$0.51	*	$0.76	$0.69	$0.84	$0.70	$0.72
2016	$0.51	$0.70	$0.77	$0.77	$0.61	$0.67	$0.77
2017	$0.54	$0.72	$0.98	$0.96	$0.54	$0.75	$0.97
2018	$0.59	$0.66	$0.94	$0.92	$0.81	$0.79	$0.93
2019	$0.55	$0.60	$0.84	$0.80	$0.98	$0.75	$0.82
2020	$0.54	$0.63	$0.82	$0.83	$0.97	$0.76	$0.82
2021	$0.77	$0.76	$1.20	$1.20	$1.00	$0.99	$1.20

Table 6. **Jonah crab stock assignments to statistical area-specific landings for statistical areas that overlap multiple stocks. Blanks indicate no landings in the statistical area and state combination. Proportions are the proportion of landings from the statistical area relative to coastwide landings from all known statistical areas since 2010.**

Statistical Area	ME	NH	MA	RI	CT	NY	NJ	DE-NC	Proportion
510	IGOM								0.0049
511	IGOM								0.0613
512	IGOM			OGOM		OGOM			0.0735
513	IGOM		IGOM	IGOM		IGOM	IGOM		0.0048
515	OGOM		OGOM	OGOM					0.0112
521			OGOM	OGOM			OGOM		0.0019
526			OSNE	OSNE		OSNE			0.1166
537 (for states other than MA and RI)		OSNE			Unknown	OSNE	Unknown	OSNE	0.0129
538	ISNE		ISNE	ISNE					0.0004
539	ISNE		ISNE	ISNE	ISNE	ISNE		ISNE	0.0104
611	ISNE			ISNE	ISNE	ISNE		ISNE	0.0002

Table 7. **Stock-specific Jonah crab landings and landings (total and proportion of coastwide total) that could not be assigned to a stock.**

Year	IGOM	OGOM	ISNE	OSNE	Unknown	Unknown Proportion
2010	3,296,917	495,594	251,663	10,908,252	13,656	0.0009
2011	2,573,190	431,245	292,623	8,784,679	2,336	0.0002
2012	1,805,257	301,728	306,694	11,479,530	8,360	0.0006
2013	1,542,279	431,196	716,553	14,260,261	21,538	0.0013
2014	1,981,181	560,151	400,057	16,648,366	72,590	0.0037
2015	1,890,398	422,987	387,902	13,043,052	70,085	0.0044
2016	2,168,085	393,607	460,474	14,210,751	327,863	0.0187
2017	3,397,455	233,020	912,620	14,619,539	524,715	0.0267
2018	3,673,281	83,833	782,416	17,611,400	615,568	0.0270
2019	3,164,910	55,882	284,094	13,989,900	167,475	0.0095
2020	2,038,465	187,250	299,548	11,642,200	481,767	0.0329
2021	2,944,330	205,669	428,611	8,626,968	41,035	0.0034
2019-2021 average	2,715,902	149,600	337,418	11,419,689	230,092	0.0152
25th Percentile	1,958,485	201,065	297,817	11,336,711	19,568	0.0012
75th Percentile	3,197,912	431,208	524,494	14,350,081	366,339	0.0207

Table 8. **Number of Jonah crab sea sampling trips. Colors are scaled to the minimum and maximum number of trips, with green indicating the greatest sampling intensity and red indicating the lowest sampling intensity.**

Year	IGOM				OGOM								ISNE		OSNE										
	511	512	513	514	464	465	511	512	515	521	522	561	537	539	525	526	537	562	613	615	616	622	623	626	627
2003	1	9																							
2004		2	1																						
2005				1												1									
......																									
2014													17	60	18	2	7	7	1		3				
2015					1	2		2				4	17	80	20	20	21	9	3		1			1	
2016				4	9	2		4	3			13	18	113	22	5	15	7	1					1	
2017	1	2	3	6	1	1		4	2			15	16	113	17	7	5	3	21			5			
2018	6	1	6	13	10	5		7	1			8	10	97	8	25	23	8			13	4		2	
2019	1	7	8		6	12		6	9			23	9	98	3	22	40	2			11	3	1	3	1
2020	1	1	9		9	7	1	6	1		3	16	13	90	21	30	25	2		1	16	1		1	
2021			4	6	12	3	3	5	1	1		15	9	83	15	12	8	2			2				

Table 9. **Number of Jonah crab port sampling trips. Colors are scaled to the minimum and maximum number of trips, with green indicating the greatest sampling intensity and red indicating the lowest sampling intensity.**

Year	IGOM		OGOM		ISNE		OSNE						
	513	514	521	561	537	611	525	526	537	562	612	613	616
2013					2								
2014					2					2			
2015		3						4	6				
2016							1	8	8	1	1		
2017	2		1	2			2	5	10			5	
2018	6		1		1		3	3	7	1			
2019	4					1	4	5	2	1			
2020	4	5					8	4	1				1
2021	5			1				4		1			

Table 10. **Mann-Kendall test results for mean size of males in the overall catch from sea sampling data.**

Stock	Statistical Area	Quarter	n years	tau	p-value
OGOM	561	2	5	-0.40	0.462
OGOM	561	4	6	-0.47	0.260
OGOM	464	1	5	-0.60	0.221
OGOM	464	3	5	0.20	0.806
ISNE	537	2	5	-0.20	0.806
ISNE	537	3	7	-0.62	0.072
ISNE	537	4	6	-0.33	0.452
ISNE	539	1	8	0.21	0.536
ISNE	539	2	8	0.07	0.902
ISNE	539	3	8	-0.29	0.386
ISNE	539	4	8	-0.29	0.386
OSNE	525	1	5	0.00	1.000
OSNE	525	2	7	-0.62	0.072
OSNE	525	3	7	-0.24	0.548
OSNE	525	4	5	-0.40	0.462
OSNE	526	2	8	-0.29	0.386
OSNE	526	3	7	0.62	0.072
OSNE	526	4	5	0.20	0.806
OSNE	537	1	6	0.20	0.707
OSNE	537	3	8	-0.21	0.536

Table 11. **Mann-Kendall test results for mean size of the largest 5% males in the overall catch from sea sampling data. Bold and italicized font indicates a significant trend.**

Stock	Statistical Area	Quarter	n years	tau	p-value
OGOM	561	2	5	0.00	1.000
OGOM	561	4	6	-0.20	0.707
ISNE	537	3	7	-0.52	0.133
ISNE	537	4	5	-0.20	0.806
ISNE	539	1	8	0.57	0.063
ISNE	539	2	8	0.29	0.386
ISNE	539	3	8	-0.29	0.386
ISNE	539	4	8	***0.64***	***0.035***
OSNE	525	2	6	-0.07	1.000
OSNE	525	3	6	-0.07	1.000
OSNE	525	4	5	-0.20	0.806
OSNE	526	2	7	0.14	0.764
OSNE	526	3	6	0.60	0.133
OSNE	526	4	5	0.60	0.221
OSNE	537	1	5	0.20	0.806
OSNE	537	3	6	0.20	0.707

Table 12. **CFRF VTS summary for exploitable-sized (>121mm CW) male crabs.**

Year	Inshore SNE					Offshore SNE				
	n Sessions	Proportion Positive	n Crabs	Mean CPUE	CPUE CV	n Sessions	Proportion Positive	n Crabs	Mean CPUE	CPUE CV
2015	42	0.95	268	7.08	0.40	57	0.89	527	9.97	0.29
2016	49	0.84	338	7.52	0.36	45	0.93	512	12.16	0.24
2017	29	1.00	251	8.82	0.30	72	0.99	1,724	17.81	0.17
2018	30	0.97	214	9.49	0.27	97	0.98	1,882	16.63	0.19
2019	39	0.97	264	7.63	0.34	34	1.00	549	15.45	0.21
2020	25	0.84	175	6.33	0.41	35	0.97	589	12.14	0.29
2021	31	0.84	190	6.71	0.39	NA	NA	NA	NA	NA

Table 13. **Directed Residual Model CPUE (catch per trip) predictions for Rhode Island Jonah crab harvest in inshore and offshore SNE in February. Predictions are in log space.**

	Inshore SNE			Offshore SNE		
Year	Number Trips	Predicted CPUE	Prediction S.E.	Number Trips	Predicted CPUE	Prediction S.E.
2007	51	8.17	0.13	525	9.65	0.06
2008	70	7.85	0.11	591	9.72	0.05
2009	89	8.10	0.10	572	9.61	0.05
2010	81	8.03	0.11	493	9.54	0.06
2011	67	7.75	0.12	414	9.52	0.06
2012	103	8.08	0.10	419	9.65	0.06
2013	328	8.02	0.07	373	9.76	0.06
2014	219	7.70	0.08	420	9.78	0.06
2015	208	7.54	0.08	386	9.80	0.06
2016	153	7.50	0.09	369	9.78	0.06
2017	212	7.71	0.08	372	9.69	0.06
2018	213	7.82	0.08	411	9.66	0.06
2019	96	7.62	0.10	375	9.84	0.06
2020	70	7.73	0.11	301	9.75	0.06
2021	101	7.32	0.10	266	9.55	0.07

Table 14. **Model summary table for DRM fitted to Rhode Island trip-level landings data.**

```
Call:
glm(formula = lCRJ ~ Year * Stock + Stock * P1 + Month * P1,
    data = alldat)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.2666  -0.5437   0.0224   0.5689   2.7492

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)      6.65350    0.14977  44.425  < 2e-16 ***
Year2008        -0.32670    0.15920  -2.052 0.040187 *
Year2009        -0.07114    0.15188  -0.468 0.639523
Year2010        -0.14206    0.15456  -0.919 0.358074
Year2011        -0.42222    0.16075  -2.627 0.008642 **
Year2012        -0.09723    0.14832  -0.656 0.512148
Year2013        -0.15305    0.13020  -1.176 0.239822
Year2014        -0.47852    0.13460  -3.555 0.000380 ***
Year2015        -0.62914    0.13519  -4.654 3.31e-06 ***
Year2016        -0.66976    0.13977  -4.792 1.68e-06 ***
Year2017        -0.46667    0.13475  -3.463 0.000536 ***
Year2018        -0.35018    0.13472  -2.599 0.009357 **
Year2019        -0.55310    0.14988  -3.690 0.000225 ***
Year2020        -0.44303    0.15910  -2.785 0.005372 **
Year2021        -0.85532    0.14915  -5.735 1.01e-08 ***
Stock1           0.90913    0.12805   7.100 1.35e-12 ***
P1               1.46652    0.10128  14.480  < 2e-16 ***
Month10          0.18152    0.09364   1.938 0.052597 .
Month11          0.36240    0.09556   3.793 0.000150 ***
Month12          0.26642    0.10667   2.498 0.012521 *
Month2          -0.01692    0.17157  -0.099 0.921419
Month3           0.16735    0.14770   1.133 0.257217
Month4           0.14593    0.11497   1.269 0.204392
Month5           0.10440    0.09930   1.051 0.293086
Month6           0.09948    0.09486   1.049 0.294355
Month7          -0.07951    0.09397  -0.846 0.397537
Month8          -0.09166    0.09301  -0.985 0.324443
Month9           0.07784    0.09280   0.839 0.401599
Year2008:Stock1  0.39636    0.16739   2.368 0.017910 *
Year2009:Stock1  0.02806    0.16056   0.175 0.861294
Year2010:Stock1  0.03693    0.16379   0.225 0.821606
Year2011:Stock1  0.29547    0.17042   1.734 0.083001 .
Year2012:Stock1  0.09707    0.15877   0.611 0.540948
Year2013:Stock1  0.26762    0.14272   1.875 0.060805 .
Year2014:Stock1  0.61212    0.14599   4.193 2.78e-05 ***
Year2015:Stock1  0.78430    0.14708   5.332 9.95e-08 ***
Year2016:Stock1  0.80358    0.15168   5.298 1.20e-07 ***
Year2017:Stock1  0.50773    0.14703   3.453 0.000556 ***
Year2018:Stock1  0.36928    0.14644   2.522 0.011694 *
Year2019:Stock1  0.74128    0.16102   4.604 4.21e-06 ***
Year2020:Stock1  0.54627    0.17096   3.195 0.001402 **
Year2021:Stock1  0.75229    0.16279   4.621 3.87e-06 ***
Stock1:P1        0.56470    0.04667  12.101  < 2e-16 ***
P1:Month10      -0.84037    0.11452  -7.338 2.36e-13 ***
P1:Month11      -0.92095    0.11344  -8.118 5.40e-16 ***
P1:Month12      -0.61971    0.11926  -5.196 2.08e-07 ***
P1:Month2        0.07140    0.17994   0.397 0.691548
P1:Month3       -0.35201    0.15764  -2.233 0.025574 *
P1:Month4       -0.60371    0.12992  -4.647 3.42e-06 ***
P1:Month5       -0.70646    0.11474  -6.157 7.77e-10 ***
P1:Month6       -0.90512    0.11392  -7.945 2.20e-15 ***
P1:Month7       -0.86350    0.11732  -7.360 2.01e-13 ***
P1:Month8       -0.98593    0.11666  -8.451  < 2e-16 ***
P1:Month9       -0.90097    0.11323  -7.957 2.00e-15 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.74397)

    Null deviance: 16147.0  on 8347  degrees of freedom
Residual deviance:  6170.5  on 8294  degrees of freedom
AIC: 21277

Number of Fisher Scoring iterations: 2
```

Table 15. **Surveys encountering settling Jonah crabs considered for the stock assessment, but lacking utility for tracking abundance metrics of interest. Reasons identified for limitations of utility were lack of Cancer crab species identification (SID) and inadequate catch rates/inefficient catchability (CR).**

Survey	*Time Series*	*CWs*	*Limitations*	*Notes*
Normandeau Plankton Survey	1982-present	N	SID	
RIDEM DMF Settlement Survey	1990-present	Y	CR	
UMaine Deepwater Collectors	2007-present	Y	CR	Sampling discontinued from 2009-2015

Table 16. **Surveys encountering post-settlement Jonah crabs considered for the stock assessment, but lacking utility for tracking abundance metrics of interest. Data fields collected after the start year when Jonah crab counts were added to survey protocols are included in parentheses. Reasons identified for limitations of utility were lack of spatial overlap between the survey domain and Jonah crab population and/or small spatial domain (SS), short and/or discontinuous time series (TS), inadequate catch rates/inefficient catchability (CR), and lack of biological data (BD).**

Survey	*Time Series*	*CWs*	*Sex*	*Limitations*	*Notes*
ME Urchin Survey	2004-present	Y	Y	SS	
ME VTS	2016*-present	Y (2016)	Y (2016)	SS, CR	Counts collected prior to 2016, but ID issues render counts unreliable
NH VTS	2009-present	Y (2015)	Y (2015)	SS, CR	
Normandeau VTS	1982-present	Y	Y	SS, CR	
MA VTS	2007-present	Y	Y (2015)	SS, CR	
SMAST VTS	2019	Y	Y	SS, TS, CR	
CFRF SNE Cooperative VTS	2014-2018	Y	Y	SS, TS, CR	
RI VTS	2006-present	Y	Y	SS, CR	
NY VTS	2006-2010	N	N	SS, TS, CR, BD	
NJ Fixed Gear Survey	2016-present	Y	Y	SS, CR	
DE Structure Oriented Survey	2018-present	Y	Y (2020)	SS, TS, CR, BD	
CFRF-South Fork Wind Farm Cox's Ledge/RI Sound Trawl	2020-present	Y	Y	SS, TS	

Coonamessett Farm Foundation Scallop Dredge	2010-present	N	N	TS, BD	Data collection ceased from 2016-August 2021 and only resumed at limited stations
RI Trawl Survey	2015-present	Y	Y	CR	
URI GSO Trawl Survey	2016-present	Y	Y	CR	
CT Trawl Survey	1979-present	Y	Y	SS, CR	
NY Trawl Survey	2017-present	Y	Y	SS, TS	
NJ DFW Ocean Trawl Survey	1989-present	Y	Y (2021)	SS, BD	
NEAMAP Trawl Survey	2007-present	Y	Y	CR	
Northern Shrimp Trawl Survey	1984-present	N	Y	BD	

Table 17. **Spearman correlation results for seasonal catch rate and temperature anomalies using a two-year running average as the underlying trend in catch rates to calculate anomalies.**

Season and Areas	Spearman's Rho	p-value
Spring 521, 522, 561	0.302	0.11
Fall 521, 522, 561	0.089	0.64
Spring 537, 526, 525, 562	-0.091	0.64
Fall 537, 526, 525, 562	-0.047	0.81

Table 18. **Spearman correlation results for seasonal catch rate and temperature anomalies using a LOESS smoother fit as the underlying trend in catch rates to calculate anomalies.**

Season and Areas	Spearman's Rho	p-value
Spring 521, 522, 561	0.407	0.03
Fall 521, 522, 561	-0.119	0.53
Spring 537, 526, 525, 562	-0.044	0.82
Fall 537, 526, 525, 562	-0.034	0.86

Table 19. **Jonah crab settlement indices in GOM areas.**

Year	ME 511	ME 512	ME 513	NH 513	MA 514
1989			0.000		
1990			0.000		
1991			0.000		
1992			0.000		
1993			0.000		
1994			0.090		
1995			0.000		
1996			0.110		
1997			0.000		
1998			0.110		
1999			1.540		
2000		0.039	1.833		
2001	0.040	0.223	0.361		
2002	0.000	0.000	0.709		
2003	0.000	0.000	0.485		
2004	0.000	0.057	0.368		
2005	0.000	0.000	0.167		
2006	0.000	0.000	0.767		
2007	0.000	0.031	0.817		
2008	0.030	0.016	0.400		
2009	0.000	0.021	1.230	0.222	
2010	0.030	0.011	0.827	0.722	
2011	0.000	0.131	1.217	0.667	
2012	1.500	1.571	3.188	4.333	
2013	0.350	0.180	0.710		
2014	0.350	0.303	0.850	0.222	
2015	0.040	0.334	1.725	0.056	
2016	0.600	1.526	2.643	0.444	1.817
2017	0.470	0.450	2.300	2.389	1.033
2018	1.140	1.154	3.096	4.111	8.967
2019	0.380	0.368	0.676	2.167	1.617
2020	0.380	0.615	2.074	4.667	1.583
2021	0.057	0.119	0.692	4.222	2.417
2019-2021 average	***0.272***	***0.367***	***1.147***	***3.685***	***1.872***
25th Percentile	***0.000***	***0.017***	***0.110***	***0.389***	***1.592***
75th Percentile	***0.380***	***0.359***	***1.230***	***4.139***	***2.267***

Table 20. **Coefficient of variation for Jonah crab settlement indices in GOM areas.**

Year	ME 511	ME 512	ME 513	NH 513	MA 514
1989			0.000		
1990			0.000		
1991			0.000		
1992			0.000		
1993			0.000		
1994			0.556		
1995			0.000		
1996			1.000		
1997			0.000		
1998			0.455		
1999			0.377		
2000		1.341	0.244		
2001	1.000	0.563	0.530		
2002	0.000	0.000	0.233		
2003	0.000	0.000	0.396		
2004	0.000	1.276	0.484		
2005	0.000	0.000	1.270		
2006	0.000	0.000	0.244		
2007	0.000	2.089	0.234		
2008	1.000	2.880	0.851		
2009	0.000	1.929	0.242	NA	
2010	1.000	2.824	0.323	NA	
2011	0.000	0.663	0.210	NA	
2012	0.200	0.120	0.144	NA	
2013	0.371	0.472	0.245		
2014	0.743	0.515	0.164	NA	
2015	1.000	0.533	0.163	NA	
2016	0.450	0.138	0.089	NA	0.148
2017	0.277	0.222	0.178	NA	0.171
2018	0.494	0.221	0.211	NA	0.082
2019	0.500	0.164	0.203	NA	0.117
2020	0.368	0.316	0.146	NA	0.195
2021	1.000	0.469	0.246	NA	0.116

Table 21. **Jonah crab recruit abundance indices in GOM areas.**

Year	IGOM	IGOM	IGOM	IGOM	IGOM	IGOM	OGOM	OGOM	GOM	GOM
	MA Trawl Spring	MA Trawl Fall	ME/NH Trawl Spring	ME/NH Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall
1980						0.149		0.000		0.050
1981					0.065		0.029		0.041	
1982	0.410	0.060			0.033	0.032	0.075	0.025	0.050	0.026
1983	0.030	0.440			0.000	0.045	0.000	0.032	0.000	0.037
1984	0.010	0.150			0.034	0.000	0.000	0.006	0.013	0.004
1985	0.020	0.410			0.000		0.000		0.000	
1986	0.020	0.080			0.000		0.000		0.000	
1987	0.070	0.290				0.000		0.000		0.000
1988	0.020	0.220			0.183		0.000		0.054	
1989	0.090	0.000			0.017	0.000	0.000	0.032	0.016	0.020
1990	0.000	0.040			0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.100			0.000	0.000	0.013	0.005	0.008	0.003
1992	0.020	0.120			0.000	0.024	0.000	0.072	0.000	0.062
1993	0.080	0.030			0.000	0.100	0.009	0.000	0.006	0.029
1994	0.040	0.040			0.189	0.026	0.000	0.041	0.058	0.035
1995	0.020	0.920			0.000	0.076	0.127	0.072	0.091	0.077
1996	0.060	0.050			0.016	0.044	0.000	0.135	0.006	0.114
1997	0.000	0.030			0.045	0.026	0.036	0.000	0.042	0.009
1998	0.060	0.000			0.158	0.060	0.047	0.035	0.082	0.045
1999	0.000	0.440			0.078	0.382	0.080	0.086	0.077	0.178
2000	0.140	0.760			0.490	0.160	0.033	0.203	0.202	0.189
2001	0.270	0.260			0.216	1.593	0.186	0.458	0.206	0.859
2002	0.120	0.690			0.454	0.264	0.232	0.319	0.315	0.297
2003	0.020	0.770			0.123	0.256	0.104	0.310	0.116	0.291
2004	0.070	0.490	1.588	1.810	0.009	0.307	0.055	0.204	0.040	0.245
2005	0.100	0.070	2.580	0.782	0.053	0.616	0.061	0.029	0.057	0.198
2006	0.040	0.360	2.610	0.981	0.011	0.127	0.040	0.009	0.029	0.051
2007	0.010	0.260	0.805	1.562	0.032	0.064	0.062	0.004	0.047	0.025
2008	0.030	0.850	0.779	1.325	0.009	0.164	0.000	0.033	0.003	0.074
2009	0.120	0.230	0.574	0.286	0.210	0.152	0.079	0.053	0.128	0.079
2010	0.000	0.560	0.305	0.308	0.178	0.038	0.142	0.230	0.155	0.160
2011	0.060	0.790	0.449	0.417	0.451	0.022	0.187	0.041	0.241	0.029
2012	0.020	0.430	0.268	0.290	0.207	0.116	0.056	0.045	0.113	0.070
2013	0.040	0.160	0.203	0.417	0.376	0.283	0.532	0.000	0.481	0.098
2014	0.000	0.350	0.578	0.341	2.266	0.795	1.894	0.385	2.123	0.516
2015	0.400	2.710	0.566	5.429	0.356	0.683	0.538	0.784	0.483	0.724
2016	0.850	0.770	2.437	3.017	1.290	0.443	1.790	0.395	1.548	0.392
2017	0.150	1.210	0.491	0.616	0.825		0.484		0.596	
2018	0.160	0.910	0.304	0.482	0.592	0.064	0.146	0.050	0.270	0.051
2019	0.040	0.040	0.237	0.343	0.187	0.377	0.056	0.081	0.115	0.216
2020				0.177						
2021	0.110	0.680	0.165	0.147	0.619	0.173	0.069	0.070	0.217	0.109
2019-2021 average	***0.075***	***0.360***	***0.201***	***0.222***	***0.403***	***0.275***	***0.062***	***0.075***	***0.166***	***0.162***
25th Percentile	***0.020***	***0.075***	***0.304***	***0.316***	***0.010***	***0.030***	***0.000***	***0.008***	***0.014***	***0.029***
75th Percentile	***0.105***	***0.685***	***0.805***	***1.239***	***0.286***	***0.269***	***0.134***	***0.152***	***0.204***	***0.191***

Table 22. **Coefficient of variation for Jonah crab recruit abundance indices in GOM areas.**

Year	IGOM MA Trawl Spring	IGOM MA Trawl Fall	IGOM ME/NH Trawl Spring	IGOM ME/NH Trawl Fall	IGOM NEFSC Trawl Spring	IGOM NEFSC Trawl Fall	OGOM NEFSC Trawl Spring	OGOM NEFSC Trawl Fall	GOM NEFSC Trawl Spring	GOM NEFSC Trawl Fall
1980						0.658		Inf		0.658
1981					0.604		0.464		0.372	
1982	0.670	0.760			1.000	0.777	1.000	0.707	0.799	0.534
1983	1.000	0.260			Inf	0.604		1.000	Inf	0.597
1984	1.000	0.610			0.938	Inf	Inf	1.000	1.005	1.000
1985	1.000	0.470			Inf		Inf		Inf	
1986	1.000	0.500			Inf		Inf		Inf	
1987	0.710	0.460				Inf		Inf		Inf
1988	1.000	0.250			0.893		Inf		0.883	
1989	0.750				1.000	Inf	Inf	1.000	1.000	1.000
1990		0.750			Inf	Inf	Inf	Inf	Inf	Inf
1991		0.600			Inf	Inf	1.000	1.000	1.000	1.000
1992	1.000	1.000			Inf	1.211	Inf	1.000	Inf	0.905
1993	0.590	0.710			Inf	1.000	1.000	Inf	1.000	1.000
1994	0.720	0.710			1.000	1.000	Inf	0.741	1.000	0.610
1995	1.000	0.390			Inf	0.769	0.412	0.713	0.420	0.553
1996	0.520	0.730			1.211	0.779	Inf	0.605	1.382	0.550
1997		1.000			0.612	1.000	1.000	Inf	0.699	1.000
1998	0.580				0.382	0.672	0.583	1.000	0.346	0.602
1999		0.380			0.791	0.581	0.618	0.889	0.487	0.474
2000	0.550	0.330			0.623	0.431	0.811	0.440	0.571	0.328
2001	0.400	0.290			0.417	0.194	0.426	0.357	0.318	0.178
2002	0.330	0.510			0.291	0.420	0.443	0.342	0.258	0.270
2003	1.000	0.240			1.000	0.473	0.436	0.346	0.481	0.275
2004	0.610	0.420	0.479	0.265	1.000	0.972	0.725	0.545	0.665	0.530
2005	0.480	0.570	0.294	0.354	1.000	0.757	0.719	0.892	0.584	0.717
2006	0.710	0.400	0.471	0.666	1.211	0.546	1.467	1.000	1.223	0.517
2007	1.000	0.360	0.385	0.291	1.000	0.541	0.658	1.000	0.570	0.497
2008	0.580	0.330	0.325	0.270	1.000	0.523	Inf	0.601	1.000	0.428
2009	0.470	0.460	0.411	0.569	0.359	0.528	0.467	0.711	0.286	0.424
2010		0.190	0.527	0.554	0.507	0.670	0.865	0.628	0.540	0.582
2011	0.580	0.310	0.533	0.539	0.562	0.584	0.621	0.801	0.385	0.599
2012	1.000	0.250	0.569	0.437	0.329	0.571	0.584	0.708	0.295	0.444
2013	1.000	0.420	0.604	0.620	0.541	0.345	0.464	Inf	0.406	0.355
2014		0.340	0.684	0.539	0.290	0.218	0.209	0.299	0.174	0.198
2015	0.290	0.430	0.487	0.545	0.495	0.251	0.266	0.371	0.219	0.235
2016	0.210	0.270	0.340	0.340	0.253	0.348	0.347	0.425	0.242	0.307
2017	0.400	0.260	0.443	0.392	0.318		0.248		0.204	
2018	0.400	0.320	0.662	0.516	0.611	0.614	0.562	0.707	0.413	0.487
2019	0.500	1.000	0.879	0.498	0.641	0.300	0.722	0.554	0.465	0.279
2020				0.721						
2021	0.720	0.710	0.672	0.794	0.565	0.488	0.784	0.528	0.333	0.361

Table 23. **Jonah crab recruit abundance indices in SNE areas and coastwide.**

Year	ISNE	ISNE	OSNE	OSNE	Coastwide	Coastwide
	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall
1980		0.000		0.005		0.019
1981	0.000		0.064		0.050	
1982	0.125	0.000	0.091	0.026	0.061	0.021
1983	0.000	0.000	0.000	0.059	0.000	0.044
1984	0.000	0.000	0.000	0.007	0.004	0.005
1985	0.000		0.006		0.007	
1986	0.000		0.010		0.005	
1987		0.100		0.043		0.026
1988	0.000		0.047		0.043	
1989	0.000	0.000	0.000	0.060	0.007	0.038
1990	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.000	0.000	0.048	0.002	0.025
1992	0.449	0.000	0.000	0.058	0.023	0.043
1993	0.000	0.000	0.000	0.007	0.002	0.013
1994	0.000	0.000	0.000	0.002	0.018	0.012
1995	0.000	0.000	0.002	0.000	0.032	0.029
1996	0.000	0.501	0.001	0.000	0.004	0.052
1997	0.000	0.288	0.001	0.000	0.012	0.008
1998	0.000	0.073	0.009	0.008	0.041	0.020
1999	0.000	0.000	0.066	0.010	0.060	0.065
2000	0.000	0.090	0.040	0.055	0.093	0.106
2001	0.000	0.294	0.019	0.103	0.076	0.350
2002	0.147	0.090	0.086	0.134	0.149	0.183
2003	0.000	0.090	0.033	0.154	0.058	0.180
2004	0.000	0.058	0.000	0.027	0.021	0.097
2005	0.000	0.000	0.010	0.012	0.023	0.073
2006	0.159	0.000	0.010	0.051	0.016	0.044
2007	0.042	0.137	0.041	0.087	0.038	0.068
2008	0.000	0.000	0.019	0.027	0.015	0.042
2009	0.000	0.088	0.014	0.057	0.048	0.062
2010	0.021	0.058	0.009	0.163	0.063	0.142
2011	0.000	0.000	0.023	0.052	0.089	0.047
2012	0.000	0.154	0.004	0.144	0.041	0.111
2013	0.000	0.111	0.009	0.075	0.168	0.071
2014		0.064		0.117		0.224
2015	0.000	0.469	0.002	0.111	0.147	0.298
2016	0.000	0.171	0.032	0.040	0.513	0.176
2017	0.000		0.028		0.294	
2018	0.000	0.000	0.018	0.100	0.126	0.073
2019	0.000	0.128	0.000	0.021	0.038	0.087
2020						
2021	0.000	0.012	0.020	0.177	0.102	0.127
2019-2021 average	***0.000***	***0.070***	***0.010***	***0.099***	***0.070***	***0.107***
25th Percentile	***0.000***	***0.000***	***0.000***	***0.009***	***0.013***	***0.026***
75th Percentile	***0.000***	***0.103***	***0.027***	***0.090***	***0.073***	***0.107***

Table 24. **Coefficient of variation for Jonah crab recruit abundance indices in SNE areas and coastwide.**

Year	ISNE NEFSC Trawl Spring	ISNE NEFSC Trawl Fall	OSNE NEFSC Trawl Spring	OSNE NEFSC Trawl Fall	Coastwide NEFSC Trawl Spring	Coastwide NEFSC Trawl Fall
1980		Inf		0.756		0.568
1981	Inf		0.361		0.256	
1982	1.000	Inf	0.304	0.597	0.276	0.429
1983	Inf	Inf	Inf	0.461	Inf	0.372
1984	Inf	Inf	Inf	0.764	1.076	0.609
1985	Inf		1.515		0.909	
1986	Inf		1.000		1.000	
1987		1.400		0.410		0.333
1988			0.492		0.459	
1989	Inf	Inf	Inf	0.468	0.781	0.418
1990	Inf	Inf	Inf	Inf	Inf	Inf
1991	Inf	Inf	Inf	0.532	1.000	0.514
1992	1.000	Inf	Inf	0.473	1.000	0.444
1993	Inf	Inf	Inf	1.000	1.000	0.770
1994	Inf	Inf	Inf	1.000	1.000	0.557
1995		Inf	1.519	Inf	0.406	0.477
1996	Inf	0.803	1.000	Inf	0.862	0.440
1997	Inf	0.783	1.000	Inf	0.632	0.625
1998	Inf	1.000	1.000	1.000	0.358	0.493
1999	Inf	Inf	0.633	1.000	0.422	0.424
2000	Inf	1.000	0.917	0.435	0.448	0.253
2001	Inf	1.000	0.956	0.285	0.302	0.149
2002	1.000	1.400	0.490	0.351	0.232	0.212
2003	Inf	1.400	0.673	0.294	0.370	0.192
2004	Inf	1.000	Inf	0.556	0.498	0.427
2005	Inf	Inf	1.000	1.000	0.507	0.608
2006	0.783	Inf	1.000	0.418	0.514	0.320
2007	1.000	1.000	0.947	0.266	0.585	0.220
2008	Inf	Inf	0.710	0.537	0.546	0.320
2009	Inf	0.638	0.708	0.334	0.267	0.247
2010	1.000	1.000	1.000	0.380	0.434	0.309
2011	Inf	Inf	0.580	0.342	0.338	0.295
2012	Inf	1.093	1.000	0.451	0.277	0.322
2013		0.661	1.000	0.479	0.345	0.296
2014		0.949		0.332		0.159
2015		1.000	1.000	0.356	0.217	0.192
2016	Inf	1.000	0.430	0.396	0.227	0.247
2017	Inf		0.560		0.282	
2018	Inf	Inf	0.828	0.262	0.302	0.231
2019	Inf	1.000	Inf	0.556	0.435	0.230
2020						
2021	Inf	0.000	0.729	0.306	0.273	0.243

Table 25. **Jonah crab exploitable abundance indices in GOM areas.**

Year	IGOM	IGOM	IGOM	IGOM	IGOM	IGOM	OGOM	OGOM	GOM	GOM
	MA Trawl Spring	**MA Trawl Fall**	**ME/NH Trawl Spring**	**ME/NH Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**
10						0.087		0.025		0.045
1981					0.062		0.204		0.160	
1982	0.020	0.150			0.000	0.056	0.075	0.012	0.038	0.026
1983	0.000	0.630			0.022	0.000	0.000	0.009	0.007	0.006
1984	0.010	0.080			0.095	0.000	0.000	0.000	0.037	0.000
1985	0.120	0.680			0.088		0.000		0.023	
1986	0.040	0.310			0.000		0.000		0.000	
1987	0.090	0.430				0.000		0.033		0.021
1988	0.000	0.090			0.081		0.025		0.039	
1989	0.030	0.140			0.000	0.000	0.006	0.064	0.004	0.036
1990	0.010	0.030			0.000	0.000	0.041	0.007	0.015	0.005
1991	0.040	0.230			0.000	0.000	0.013	0.005	0.008	0.003
1992	0.100	0.210			0.000	0.000	0.012	0.036	0.008	0.028
1993	0.130	0.080			0.000	0.200	0.092	0.150	0.072	0.169
1994	0.040	0.000			0.126	0.062	0.008	0.000	0.044	0.023
1995	0.100	0.320			0.000	0.031	0.063	0.076	0.048	0.068
1996	0.100	0.040			0.000	0.000	0.026	0.321	0.019	0.261
1997	0.070	0.020			0.071	0.075	0.031	0.087	0.042	0.080
1998	0.080	0.060			0.261	0.000	0.072	0.007	0.139	0.004
1999	0.030	0.220			0.075	0.267	0.165	0.052	0.125	0.124
2000	0.130	0.440			0.269	0.295	0.314	0.186	0.314	0.224
2001	0.170	0.240			0.586	0.482	0.275	0.414	0.413	0.437
2002	0.050	0.400			0.262	0.098	0.338	0.072	0.295	0.083
2003	0.070	0.860			0.215	0.288	0.034	0.212	0.117	0.236
2004	0.020	0.350	1.173	0.864	0.083	0.349	0.203	0.069	0.160	0.187
2005	0.060	0.170	1.825	0.709	0.106	0.280	0.036	0.034	0.057	0.102
2006	0.120	0.450	1.351	0.845	0.099	0.061	0.021	0.041	0.047	0.049
2007	0.080	0.430	2.208	1.435	0.124	0.045	0.000	0.087	0.043	0.072
2008	0.210	0.680	1.305	2.195	0.036	0.050	0.000	0.071	0.025	0.072
2009	0.050	0.030	1.457	0.427	0.477	0.128	0.194	0.280	0.295	0.214
2010	0.020	0.280	0.649	0.674	0.542	0.085	0.286	0.083	0.399	0.091
2011	0.130	0.560	0.675	0.291	0.405	0.181	0.233	0.261	0.299	0.233
2012	0.080	0.620	0.704	0.316	0.318	0.224	0.139	0.282	0.208	0.259
2013	0.030	0.150	0.332	0.234	0.240	0.286	0.257	0.018	0.259	0.113
2014	0.000	0.300	0.944	0.142	2.354	0.172	1.936	0.435	2.154	0.357
2015	0.290	1.470	0.636	1.812	1.144	0.335	0.933	0.783	1.042	0.625
2016	0.710	0.380	2.310	1.535	1.459	0.449	1.466	1.166	1.446	0.907
2017	0.250	2.140	0.796	1.436	0.851		0.846		0.862	
2018	0.180	0.500	0.616	0.735	1.485	0.420	1.095	0.834	1.215	0.674
2019	0.180	0.080	0.686	0.523	0.408	0.561	0.652	0.508	0.547	0.560
2020				0.065						
2021	0.080	0.300	0.299	0.146	1.250	0.393	0.640	0.265	0.914	0.314
2019-2021 average	***0.130***	***0.190***	***0.492***	***0.245***	***0.829***	***0.477***	***0.646***	***0.387***	***0.730***	***0.437***
25th Percentile	***0.030***	***0.115***	***0.649***	***0.298***	***0.029***	***0.024***	***0.017***	***0.031***	***0.038***	***0.034***
75th Percentile	***0.125***	***0.445***	***1.351***	***1.292***	***0.407***	***0.286***	***0.280***	***0.269***	***0.307***	***0.242***

Table 26. **Coefficient of variation for Jonah crab exploitable abundance indices in GOM areas.**

Year	IGOM	IGOM	IGOM	IGOM	IGOM	IGOM	OGOM	OGOM	GOM	GOM
	MA Trawl Spring	**MA Trawl Fall**	**ME/NH Trawl Spring**	**ME/NH Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**
1980						0.655		1.000		0.550
1981					0.599		0.280		0.251	
1982	1.000	0.490			Inf	0.606	1.000	1.000	1.000	0.532
1983		0.310			1.000	Inf		1.000	1.000	1.000
1984	1.000	0.520			0.819	Inf	Inf	Inf	0.732	Inf
1985	0.610	0.190			1.000		Inf		1.000	
1986	1.000	0.390			Inf		Inf		Inf	
1987	0.540	0.310				Inf		1.000		1.000
1988		0.720			1.000		1.000		0.722	
1989	0.710	0.330			Inf	Inf	1.000	0.707	1.000	0.713
1990	1.000	1.000			Inf	Inf	1.000	1.000	1.000	1.000
1991	0.710	0.430			Inf	Inf	1.000	1.000	1.000	1.000
1992	0.660	0.640			Inf	Inf	1.000	1.000	1.000	1.000
1993	0.630	0.730			Inf	1.000	0.808	0.443	0.814	0.394
1994	0.720				1.000	1.000	1.000	Inf	0.888	1.000
1995	0.470	0.290			Inf	0.758	0.718	0.467	0.719	0.423
1996	0.670	0.810			Inf	Inf	1.000	0.576	1.000	0.555
1997	0.500	1.000			0.532	0.638	1.000	0.486	0.551	0.396
1998	0.640	0.780			0.438	Inf	0.614	1.000	0.352	1.000
1999	1.000	0.270			0.821	0.372	0.648	0.663	0.559	0.304
2000	0.430	0.280			0.399	0.494	0.459	0.441	0.364	0.341
2001	0.470	0.380			0.441	0.242	0.253	0.278	0.262	0.190
2002	0.590	0.570			0.291	0.786	0.311	0.569	0.233	0.478
2003	0.500	0.220			0.474	0.470	0.728	0.444	0.387	0.325
2004	1.000	0.320	0.454	0.304	0.900	0.525	1.000	0.573	0.819	0.363
2005	0.760	0.520	0.451	0.279	0.000	0.517	1.000	0.734	0.392	0.439
2006	0.390	0.300	0.282	0.319	0.627	1.000	1.000	0.710	0.541	0.603
2007	0.440	0.310	0.363	0.335	0.698	0.713	Inf	0.500	0.720	0.420
2008	0.330	0.330	0.289	0.237	0.798	0.654	Inf	0.581	0.887	0.455
2009	0.580	1.000	0.295	0.326	0.389	0.636	0.311	0.415	0.264	0.344
2010	1.000	0.300	0.419	0.603	0.363	0.691	0.372	0.539	0.260	0.407
2011	0.560	0.320	0.415	0.502	0.346	0.511	0.543	0.785	0.281	0.685
2012	0.450	0.350	0.354	0.433	0.278	0.500	0.483	0.440	0.246	0.335
2013	0.720	0.580	0.438	0.556	0.468	0.305	0.296	1.000	0.246	0.298
2014		0.450	0.454	0.645	0.254	0.401	0.275	0.423	0.189	0.377
2015	0.500	0.250	0.432	0.424	0.314	0.251	0.278	0.283	0.194	0.226
2016	0.190	0.220	0.392	0.321	0.480	0.272	0.194	0.271	0.228	0.224
2017	0.360	0.550	0.405	0.316	0.202		0.312		0.204	
2018	0.420	0.340	0.377	0.502	0.144	0.446	0.340	0.279	0.161	0.245
2019	0.380	0.510	0.748	0.332	0.429	0.319	0.358	0.332	0.285	0.215
2020				0.905						
2021	0.510	0.450	0.590	0.708	0.226	0.334	0.464	0.272	0.273	0.225

Table 27. **Jonah crab exploitable abundance indices in SNE areas and coastwide.**

Year	ISNE	ISNE	OSNE	OSNE	Coastwide	Coastwide
	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall
1980		0.000		0.014		0.021
1981	0.000		0.059		0.093	
1982	0.000	0.000	0.123	0.006	0.073	0.011
1983	0.000	0.000	0.007	0.009	0.006	0.007
1984	0.000	0.000	0.024	0.023	0.024	0.013
1985	0.000		0.027		0.022	
1986	0.000		0.003		0.001	
1987		0.000		0.010		0.012
1988	0.000		0.000		0.017	
1989	0.000	0.000	0.000	0.009	0.006	0.018
1990	0.000	0.000	0.007	0.000	0.009	0.001
1991	0.000	0.392	0.022	0.027	0.014	0.022
1992	0.000	0.000	0.000	0.019	0.002	0.019
1993	0.000	0.055	0.000	0.010	0.016	0.061
1994	0.000	0.259	0.000	0.000	0.014	0.018
1995	0.000	0.000	0.000	0.013	0.013	0.031
1996	0.000	0.000	0.000	0.025	0.006	0.087
1997	0.000	0.000	0.000	0.000	0.013	0.027
1998	0.000	0.110	0.089	0.001	0.095	0.005
1999	0.062	0.000	0.016	0.021	0.051	0.051
2000	0.000	0.180	0.054	0.023	0.125	0.100
2001	0.000	0.052	0.024	0.019	0.153	0.156
2002	0.147	0.000	0.022	0.037	0.113	0.047
2003	0.000	0.000	0.036	0.067	0.062	0.106
2004	0.000	0.000	0.000	0.016	0.054	0.073
2005	0.000	0.000	0.010	0.014	0.023	0.041
2006	0.042	0.000	0.000	0.009	0.019	0.024
2007	0.000	0.128	0.037	0.038	0.039	0.047
2008	0.000	0.000	0.017	0.009	0.019	0.034
2009	0.000	0.167	0.091	0.147	0.151	0.148
2010	0.000	0.031	0.054	0.118	0.156	0.109
2011	0.000	0.000	0.059	0.080	0.138	0.120
2012	0.000	0.073	0.047	0.199	0.110	0.198
2013	0.000	0.184	0.047	0.125	0.112	0.118
2014		0.000		0.138		0.178
2015	0.000	0.469	0.039	0.077	0.346	0.273
2016	0.000	0.000	0.020	0.039	0.486	0.322
2017	0.042		0.030		0.303	
2018	0.000	0.000	0.108	0.163	0.489	0.313
2019	0.000	0.196	0.000	0.181	0.170	0.304
2020						
2021	0.058	0.076	0.012	0.067	0.270	0.147
2019-2021 average	***0.029***	***0.136***	***0.006***	***0.124***	***0.220***	***0.226***
25th Percentile	***0.000***	***0.000***	***0.000***	***0.010***	***0.014***	***0.021***
75th Percentile	***0.000***	***0.084***	***0.045***	***0.070***	***0.135***	***0.127***

Table 28. **Coefficient of variation for Jonah crab exploitable abundance indices in SNE areas and coastwide.**

Year	ISNE	ISNE	OSNE	OSNE	Coastwide	Coastwide
	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall	NEFSC Trawl Spring	NEFSC Trawl Fall
1980		Inf		0.586		0.412
1981	Inf		0.295		0.201	
1982	Inf	Inf	0.302	1.000	0.285	0.480
1983	Inf	Inf	1.000	1.000	0.727	0.790
1984	Inf	Inf	0.655	0.689	0.485	0.597
1985	Inf		0.514		0.478	
1986	Inf		1.000		1.000	
1987		Inf		1.000		0.726
1988			Inf		0.594	
1989	Inf	Inf	Inf	0.874	0.795	0.550
1990	Inf	Inf	1.613	Inf	0.868	1.000
1991	Inf	0.741	1.609	0.667	1.315	0.463
1992	Inf	Inf	Inf	0.710	1.000	0.598
1993	Inf	1.000	Inf	0.852	0.659	0.350
1994	Inf	1.000	Inf	Inf	0.884	0.609
1995		Inf	Inf	1.000	0.711	0.412
1996	Inf	Inf	Inf	0.579	1.000	0.477
1997	Inf		Inf	Inf	0.551	0.413
1998	Inf	1.000	0.546	1.000	0.322	0.622
1999	1.000	Inf	0.886	0.744	0.467	0.293
2000	Inf	0.500	0.689	0.661	0.278	0.286
2001	Inf	1.000	0.537	0.654	0.238	0.189
2002	1.000	Inf	0.649	0.783	0.216	0.403
2003	Inf	Inf	0.800	0.409	0.361	0.260
2004	Inf	Inf	Inf	0.723	0.832	0.304
2005	Inf	Inf	1.000	1.141	0.384	0.411
2006	1.000	Inf	Inf	0.874	0.490	0.495
2007	Inf	1.000	0.621	0.552	0.415	0.300
2008	Inf	Inf	1.000	1.000	0.620	0.390
2009	Inf	0.837	0.288	0.292	0.194	0.218
2010	Inf	1.000	0.529	0.284	0.230	0.212
2011	Inf	Inf	0.516	0.357	0.238	0.251
2012	Inf	0.500	0.516	0.326	0.206	0.223
2013		0.862	0.624	0.343	0.228	0.223
2014		Inf		0.311		0.199
2015		1.000	0.520	0.538	0.181	0.189
2016	Inf	Inf	0.647	0.431	0.214	0.222
2017	1.000		0.530		0.183	
2018	Inf	Inf	0.460	0.255	0.161	0.189
2019	Inf	0.756	Inf	0.227	0.278	0.155
2020						
2021	1.000	0.923	0.848	0.314	0.193	0.170

Table 29. **Jonah crab spawning abundance indices in GOM areas.**

Year	IGOM	IGOM	IGOM	IGOM	IGOM	IGOM	OGOM	OGOM	GOM	GOM
	MA Trawl Spring	**MA Trawl Fall**	**ME/NH Trawl Spring**	**ME/NH Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**
1980						0.199		0.057		0.103
1981					0.345		0.045		0.134	
1982	0.970	0.610			0.000	0.073	0.000	0.020	0.000	0.032
1983	0.000	2.950			0.064	0.091	0.000	0.013	0.023	0.040
1984	0.120	2.750			0.000	0.000	0.000	0.000	0.000	0.000
1985	0.040	1.670			0.000		0.000		0.000	
1986	0.130	1.040			0.000		0.000		0.000	
1987	0.230	1.420				0.103		0.000		0.035
1988	0.000	0.430			0.000		0.111		0.070	
1989	0.040	0.050			0.000	0.041	0.000	0.032	0.000	0.035
1990	0.090	0.080			0.017	0.026	0.000	0.021	0.004	0.023
1991	0.000	0.470			0.000	0.000	0.098	0.005	0.075	0.003
1992	0.030	0.670			0.000	0.094	0.019	0.038	0.013	0.057
1993	0.150	0.190			0.000	0.133	0.031	0.073	0.020	0.083
1994	0.130	0.100			0.126	0.219	0.008	0.027	0.044	0.093
1995	0.020	1.660			0.096	0.022	0.063	0.028	0.067	0.025
1996	0.140	0.320			0.000	0.119	0.057	0.073	0.034	0.095
1997	0.030	0.090			0.197	0.221	0.049	0.083	0.094	0.139
1998	0.200	0.330			0.498	0.120	0.152	0.097	0.284	0.106
1999	0.110	0.480			0.019	0.283	0.109	0.441	0.082	0.400
2000	0.220	1.000			0.815	0.242	0.205	0.500	0.437	0.414
2001	0.650	0.250			1.486	1.375	0.647	1.191	0.978	1.349
2002	0.110	2.000			0.429	0.492	0.709	0.112	0.605	0.255
2003	0.080	2.260			0.144	0.454	0.361	0.308	0.304	0.382
2004	0.220	1.090	2.596	3.214	0.044	0.713	0.092	0.230	0.077	0.403
2005	0.240	0.600	4.553	2.498	0.159	0.694	0.242	0.110	0.204	0.285
2006	0.430	2.150	3.458	1.668	0.226	0.105	0.000	0.107	0.085	0.113
2007	0.090	1.570	1.913	2.038	0.009	0.073	0.000	0.074	0.003	0.073
2008	0.230	4.610	1.578	2.501	0.101	0.074	0.014	0.144	0.051	0.118
2009	0.130	0.650	1.315	1.083	0.331	0.259	0.216	0.055	0.261	0.134
2010	0.050	1.770	1.150	0.992	0.551	0.252	0.525	0.153	0.543	0.203
2011	0.460	4.080	1.005	1.003	0.500	0.114	0.166	0.269	0.279	0.221
2012	0.000	2.960	0.808	0.829	0.515	0.116	0.173	0.169	0.289	0.157
2013	0.060	0.570	0.529	0.739	0.681	0.154	0.485	0.096	0.546	0.126
2014	0.020	1.120	1.992	0.428	3.569	0.783	3.124	0.583	3.410	0.644
2015	0.880	8.670	1.718	8.181	1.293	0.858	1.551	1.373	1.532	1.089
2016	3.650	4.810	5.933	6.301	1.803	0.848	1.830	0.907	1.776	0.906
2017	0.880	7.580	1.291	3.335	1.211		0.598		0.815	
2018	0.540	5.060	0.751	7.657	1.307	1.303	0.358	0.480	0.691	0.778
2019	0.420	0.690	0.528	7.635	0.915	1.331	0.221	0.353	0.599	0.806
2020				1.371						
2021	0.350	0.820	0.433	2.120	1.291	0.360	0.275	0.484	0.619	0.514
2019-2021 average	***0.385***	***0.755***	***0.481***	***3.709***	***1.103***	***0.846***	***0.248***	***0.419***	***0.609***	***0.660***
25th Percentile	***0.045***	***0.475***	***0.808***	***1.023***	***0.005***	***0.093***	***0.011***	***0.036***	***0.029***	***0.069***
75th Percentile	***0.295***	***2.205***	***1.992***	***3.305***	***0.616***	***0.464***	***0.317***	***0.319***	***0.545***	***0.401***

Table 30. **Coefficient of variation for Jonah crab spawning abundance indices in GOM areas.**

Year	IGOM	IGOM	IGOM	IGOM	IGOM	IGOM	OGOM	OGOM	GOM	GOM
	MA Trawl Spring	**MA Trawl Fall**	**ME/NH Trawl Spring**	**ME/NH Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**	**NEFSC Trawl Spring**	**NEFSC Trawl Fall**
1980						0.520		0.814		0.442
1981					0.407		0.369		0.328	
1982	0.740	0.520			Inf	0.664	Inf	1.142	Inf	0.639
1983		0.430			1.000	0.437		1.000	1.000	0.402
1984	0.560	0.640			Inf	Inf	Inf	Inf	Inf	Inf
1985	0.500	0.370			Inf		Inf		Inf	
1986	0.600	0.160			Inf		Inf		Inf	
1987	0.890	0.440				0.577		Inf		0.577
1988		0.180			Inf		0.430		0.475	
1989	1.000	1.000			Inf	0.757	Inf	1.000	Inf	0.673
1990	0.610	0.510			1.069	1.000	Inf	1.000	1.000	0.718
1991		0.450			Inf	Inf	0.500	1.000	0.500	1.000
1992	0.720	0.290			Inf	1.000	0.733	0.709	0.733	0.585
1993	0.790	0.420			Inf	0.792	1.000	0.740	1.000	0.523
1994	0.500	0.720			0.612	0.439	1.000	1.000	0.569	0.409
1995	1.000	0.300			1.069	1.000	0.718	1.000	0.551	0.773
1996	0.450	0.430			Inf	0.469	0.711	0.556	0.712	0.369
1997	0.720	0.580			0.515	0.435	0.733	0.671	0.412	0.340
1998	0.660	0.740			0.390	0.539	0.359	0.765	0.285	0.465
1999	0.530	0.360			0.737	0.380	0.507	0.409	0.439	0.304
2000	0.570	0.190			0.408	0.534	0.351	0.359	0.305	0.294
2001	0.420	0.300			0.251	0.311	0.258	0.275	0.185	0.218
2002	0.520	0.510			0.338	0.492	0.251	0.457	0.204	0.400
2003	0.810	0.140			0.514	0.348	0.376	0.292	0.306	0.216
2004	0.600	0.300	0.581	0.584	0.661	0.641	0.558	0.340	0.456	0.422
2005	0.750	0.420	0.348	0.457	0.538	0.737	0.522	0.443	0.410	0.554
2006	0.510	0.280	0.684	0.451	0.411	0.507	Inf	0.456	0.426	0.342
2007	0.470	0.190	0.422	0.360	1.000	0.489	Inf	0.529	1.000	0.382
2008	0.420	0.240	0.283	0.326	0.715	0.571	1.000	0.527	0.612	0.431
2009	0.330	0.470	0.310	0.422	0.410	0.644	0.333	0.660	0.259	0.434
2010	0.580	0.260	0.625	0.346	0.409	0.658	0.622	0.507	0.410	0.403
2011	0.570	0.250	0.438	0.417	0.309	0.454	0.447	0.740	0.254	0.661
2012		0.260	0.358	0.350	0.320	0.514	0.556	0.461	0.256	0.363
2013	0.820	0.240	0.556	0.324	0.397	0.399	0.339	0.511	0.255	0.346
2014	1.000	0.420	0.443	0.482	0.214	0.211	0.175	0.239	0.139	0.162
2015	0.420	0.220	0.426	0.593	0.247	0.243	0.159	0.424	0.155	0.286
2016	0.210	0.200	0.537	0.333	0.178	0.509	0.225	0.435	0.153	0.319
2017	0.240	0.290	0.340	0.293	0.335		0.348		0.251	
2018	0.400	0.220	0.368	0.416	0.502	0.568	0.364	0.414	0.286	0.389
2019	0.390	0.460	0.475	0.215	0.258	0.230	0.515	0.404	0.304	0.221
2020				0.678						
2021	0.780	0.620	0.488	0.402	0.210	0.403	0.454	0.326	0.196	0.271

Table 31. **Jonah crab spawning abundance indices in SNE areas and coastwide.**

Year	ISNE NEFSC Trawl Spring	ISNE NEFSC Trawl Fall	OSNE NEFSC Trawl Spring	OSNE NEFSC Trawl Fall	Coastwide NEFSC Trawl Spring	Coastwide NEFSC Trawl Fall
1980		0.000		0.042		0.057
1981	0.064		0.134		0.123	
1982	0.000	0.000	0.149	0.110	0.079	0.072
1983	0.000	0.000	0.005	0.165	0.010	0.104
1984	0.000	0.157	0.000	0.078	0.000	0.049
1985	0.000		0.005		0.003	
1986	0.000		0.057		0.031	
1987		0.890		0.215		0.157
1988	0.000		0.121		0.087	
1989	0.000	0.000	0.005	0.149	0.003	0.094
1990	0.000	0.000	0.002	0.053	0.002	0.040
1991	0.000	0.135	0.000	0.063	0.015	0.043
1992	0.180	0.042	0.000	0.062	0.012	0.050
1993	0.000	0.000	0.016	0.010	0.018	0.034
1994	0.000	0.000	0.002	0.022	0.015	0.042
1995	0.064	0.000	0.036	0.035	0.061	0.038
1996	0.005	0.501	0.023	0.106	0.039	0.103
1997	0.000	0.425	0.010	0.000	0.036	0.055
1998	0.125	0.302	0.071	0.030	0.137	0.060
1999	0.062	0.058	0.084	0.216	0.081	0.236
2000	0.000	0.205	0.092	0.295	0.193	0.296
2001	0.092	0.617	0.076	0.263	0.381	0.636
2002	0.796	0.263	0.149	0.224	0.311	0.214
2003	0.010	5.155	0.027	0.605	0.147	0.561
2004	0.000	0.173	0.009	0.060	0.034	0.169
2005	0.000	0.000	0.008	0.126	0.070	0.158
2006	0.449	0.000	0.031	0.135	0.057	0.114
2007	0.042	0.000	0.055	0.314	0.030	0.200
2008	0.000	0.000	0.018	0.054	0.035	0.077
2009	0.104	0.029	0.082	0.270	0.138	0.203
2010	0.000	0.318	0.034	0.592	0.187	0.394
2011	0.010	0.000	0.026	0.377	0.110	0.319
2012	0.000	0.061	0.038	0.914	0.128	0.572
2013	0.000	0.211	0.050	0.129	0.225	0.119
2014		0.220		0.134		0.318
2015	0.000	0.979	0.020	0.230	0.491	0.475
2016	0.000	0.542	0.078	0.120	0.616	0.403
2017	0.000		0.030		0.277	
2018	0.000	0.394	0.126	0.199	0.336	0.374
2019	0.000	0.574	0.021	0.132	0.205	0.362
2020						
2021	0.030	0.012	0.045	0.173	0.247	0.273
2019-2021 average	***0.015***	***0.293***	***0.033***	***0.152***	***0.226***	***0.317***
25th Percentile	***0.000***	***0.000***	***0.009***	***0.061***	***0.030***	***0.059***
75th Percentile	***0.039***	***0.337***	***0.074***	***0.225***	***0.192***	***0.319***

Table 32. **Coefficient of variation for Jonah crab spawning abundance indices in SNE areas and coastwide.**

Year	ISNE NEFSC Trawl Spring	ISNE NEFSC Trawl Fall	OSNE NEFSC Trawl Spring	OSNE NEFSC Trawl Fall	Coastwide NEFSC Trawl Spring	Coastwide NEFSC Trawl Fall
1980		Inf		0.506		0.334
1981	1.000		0.266		0.196	
1982	Inf	Inf	0.425	0.465	0.424	0.391
1983	Inf	Inf	1.000	0.290	0.788	0.256
1984	Inf	1.000	Inf	0.370	Inf	0.331
1985	Inf		1.000		1.000	
1986	Inf		0.555		0.554	
1987		0.644		0.260		0.222
1988			0.467		0.365	
1989	Inf	Inf	1.424	0.284	1.362	0.254
1990	Inf	Inf	1.000	0.377	0.707	0.318
1991	Inf	1.000	Inf	0.341	0.655	0.298
1992	1.000	1.000	Inf	0.685	0.767	0.471
1993	Inf	Inf	0.719	0.632	0.517	0.429
1994	Inf	Inf	1.000	0.596	0.540	0.328
1995	1.000	Inf	0.501	0.592	0.284	0.400
1996	1.000	0.345	1.000	0.314	0.545	0.209
1997	Inf	0.577	1.000	Inf	0.370	0.299
1998	1.399	0.707	0.461	0.589	0.233	0.314
1999	1.000	1.000	0.395	0.215	0.279	0.177
2000	Inf	0.900	0.517	0.346	0.253	0.220
2001	1.000	1.395	0.608	0.320	0.175	0.165
2002	0.637	1.049	0.378	0.216	0.169	0.198
2003	1.399	0.797	0.581	0.172	0.274	0.183
2004	Inf	1.000	1.000	0.383	0.386	0.327
2005	Inf	Inf	1.000	0.292	0.393	0.337
2006	0.784	Inf	0.544	0.407	0.305	0.281
2007	1.000	Inf	0.611	0.197	0.580	0.173
2008	Inf	Inf	0.708	0.457	0.406	0.283
2009	1.000	1.000	0.373	0.310	0.209	0.248
2010	Inf	0.837	0.483	0.201	0.371	0.177
2011	1.000	Inf	0.489	0.272	0.224	0.257
2012	Inf	0.721	0.536	0.677	0.207	0.575
2013		0.783	0.573	0.247	0.227	0.194
2014		0.800		0.252		0.156
2015		0.481	0.915	0.316	0.155	0.217
2016	Inf	0.948	0.542	0.266	0.144	0.262
2017	Inf		0.542		0.233	
2018	Inf	0.663	0.641	0.225	0.265	0.272
2019	Inf	0.900	0.964	0.303	0.274	0.181
2020						
2021	1.000	1.000	0.710	0.244	0.193	0.181

Table 33. **Mann-Kendall results for young-of-year settlement indices.**

Stock	Survey	SA	Since 2010			Full Time Series		
			n	tau	p-value	n	tau	p-value
IGOM	ME Settlement	511	12	0.18	0.45	21	0.53	0.00
IGOM	ME Settlement	512	12	0.24	0.30	22	0.50	0.00
IGOM	ME Settlement	513	12	0.00	1.00	33	0.62	0.00
IGOM	NH Settlement	513	11	0.35	0.16	12	0.41	0.07
IGOM	MA Settlement	514	6	0.07	1.00	6	0.07	1.00

Table 34. **Mann-Kendall results for recruit abundance indices.**

Stock	Survey	Season	Since 2010			Full Time Series		
			n	tau	p-value	n	tau	p-value
IGOM	MA Trawl	Spring	11	0.31	0.21	39	0.19	0.10
IGOM	MA Trawl	Fall	11	0.02	1.00	39	0.32	0.00
IGOM	ME/NH Trawl	Spring	11	-0.20	0.44	17	-0.56	0.00
IGOM	ME/NH Trawl	Fall	12	-0.15	0.54	18	-0.31	0.08
IGOM	NEFSC Trawl	Spring	11	0.20	0.44	39	0.49	0.00
IGOM	NEFSC Trawl	Fall	10	0.24	0.37	36	0.42	0.00
OGOM	NEFSC Trawl	Spring	11	-0.13	0.64	39	0.53	0.00
OGOM	NEFSC Trawl	Fall	10	0.16	0.59	36	0.35	0.00
GOM	NEFSC Trawl	Spring	11	0.05	0.88	39	0.54	0.00
GOM	NEFSC Trawl	Fall	10	0.16	0.59	36	0.41	0.00
ISNE	NEFSC Trawl	Spring	10	-0.45	0.16	38	-0.03	0.81
ISNE	NEFSC Trawl	Fall	10	0.04	0.93	36	0.29	0.02
OSNE	NEFSC Trawl	Spring	10	0.02	1.00	38	0.15	0.19
OSNE	NEFSC Trawl	Fall	10	-0.20	0.47	36	0.37	0.00
Coastwide	NEFSC Trawl	Spring	10	0.07	0.86	38	0.47	0.00
Coastwide	NEFSC Trawl	Fall	10	0.11	0.72	36	0.50	0.00

Table 35. **Mann-Kendall results for exploitable abundance indices.**

Stock	Survey	Season	Since 2010			Full Time Series		
			n	tau	p-value	n	tau	p-value
IGOM	MA Trawl	Spring	11	0.20	0.43	39	0.32	0.00
IGOM	MA Trawl	Fall	11	0.00	1.00	39	0.22	0.05
IGOM	ME/NH Trawl	Spring	11	-0.09	0.76	17	-0.41	0.02
IGOM	ME/NH Trawl	Fall	12	-0.18	0.45	18	-0.29	0.10
IGOM	NEFSC Trawl	Spring	11	0.24	0.35	39	0.59	0.00
IGOM	NEFSC Trawl	Fall	10	0.69	0.01	36	0.53	0.00
OGOM	NEFSC Trawl	Spring	11	0.20	0.44	39	0.51	0.00
OGOM	NEFSC Trawl	Fall	10	0.42	0.11	36	0.52	0.00
OGOM	Reference Fleet CPUE	All	12	-0.15	0.54	18	-0.32	0.07
GOM	NEFSC Trawl	Spring	11	0.24	0.35	39	0.58	0.00
GOM	NEFSC Trawl	Fall	10	0.51	0.05	36	0.58	0.00
ISNE	NEFSC Trawl	Spring	10	0.47	0.12	38	0.22	0.10
ISNE	NEFSC Trawl	Fall	10	0.17	0.58	36	0.24	0.07
ISNE	DRM CPUE	All	12	-0.55	0.02	15	-0.58	0.00
ISNE	CFRF VTS	NA	7	-0.14	0.76	7	-0.14	0.76
OSNE	NEFSC Trawl	Spring	10	-0.56	0.03	38	0.16	0.18
OSNE	NEFSC Trawl	Fall	10	-0.07	0.86	36	0.51	0.00
OSNE	DRM CPUE	All	12	0.03	0.95	15	0.03	0.92
OSNE	CFRF VTS	NA	6	0.07	1.00	6	0.07	1.00
Coastwide	NEFSC Trawl	Spring	10	0.33	0.21	38	0.52	0.00
Coastwide	NEFSC Trawl	Fall	10	0.47	0.07	36	0.66	0.00

Table 36. **Mann-Kendall results for spring recruit and fall exploitable abundance index ratios.**

Stock	Survey	n	tau	p-value
IGOM	MA Trawl	11	0.55	0.02
IGOM	ME/NH Trawl	11	-0.02	1.00
IGOM	NEFSC Trawl	10	-0.11	0.72
OGOM	NEFSC Trawl	10	-0.42	0.11
GOM	NEFSC Trawl	10	-0.33	0.21
ISNE	NEFSC Trawl	6	-0.58	0.24
OSNE	NEFSC Trawl	9	0.00	1.00
Coastwide	NEFSC Trawl	9	-0.11	0.75

Table 37. **Mann-Kendall results for spawning abundance indices.**

Stock	Survey	Season	Since 2010			Full Time Series		
			n	tau	p-value	n	tau	p-value
IGOM	MA Trawl	Spring	11	0.22	0.39	39	0.29	0.01
IGOM	MA Trawl	Fall	11	0.02	1.00	39	0.30	0.01
IGOM	ME/NH Trawl	Spring	11	-0.31	0.21	17	-0.53	0.00
IGOM	ME/NH Trawl	Fall	12	0.24	0.30	18	0.03	0.88
IGOM	NEFSC Trawl	Spring	11	0.35	0.16	39	0.61	0.00
IGOM	NEFSC Trawl	Fall	10	0.60	0.02	36	0.47	0.00
OGOM	NEFSC Trawl	Spring	11	-0.02	1.00	39	0.55	0.00
OGOM	NEFSC Trawl	Fall	10	0.33	0.21	36	0.60	0.00
GOM	NEFSC Trawl	Spring	11	0.24	0.35	39	0.61	0.00
GOM	NEFSC Trawl	Fall	10	0.33	0.21	36	0.57	0.00
ISNE	NEFSC Trawl	Spring	10	0.11	0.80	38	0.02	0.87
ISNE	NEFSC Trawl	Fall	10	0.29	0.28	36	0.25	0.04
OSNE	NEFSC Trawl	Spring	10	0.16	0.59	38	0.17	0.14
OSNE	NEFSC Trawl	Fall	10	-0.38	0.15	36	0.28	0.02
Coastwide	NEFSC Trawl	Spring	10	0.33	0.21	38	0.52	0.00
Coastwide	NEFSC Trawl	Fall	10	-0.20	0.47	36	0.48	0.00

Table 38. **Mann-Kendall results for relative exploitation time series.**

Stock	Survey	Season	n	tau	p-value
IGOM	MA Trawl	Spring	10	-0.16	0.59
IGOM	MA Trawl	Fall	11	0.09	0.76
IGOM	ME/NH Trawl	Spring	11	0.20	0.44
IGOM	ME/NH Trawl	Fall	12	0.24	0.30
IGOM	NEFSC Trawl	Spring	11	-0.13	0.64
IGOM	NEFSC Trawl	Fall	10	-0.42	0.11
OGOM	NEFSC Trawl	Spring	11	-0.60	0.01
OGOM	NEFSC Trawl	Fall	10	-0.60	0.02
OGOM	Reference Fleet CPUE	All	12	-0.33	0.15
GOM	NEFSC Trawl	Spring	11	-0.27	0.28
GOM	NEFSC Trawl	Fall	10	-0.42	0.11
ISNE	NEFSC Trawl	Fall	6	-0.33	0.45
ISNE	DRM CPUE	All	12	0.36	0.11
ISNE	CFRF VTS	NA	7	-0.05	1.00
OSNE	NEFSC Trawl	Spring	9	0.56	0.05
OSNE	NEFSC Trawl	Fall	10	0.29	0.28
OSNE	DRM CPUE	All	12	0.15	0.54
OSNE	CFRF VTS	NA	6	-0.47	0.26
Coastwide	NEFSC Trawl	Spring	10	-0.29	0.28
Coastwide	NEFSC Trawl	Fall	10	-0.33	0.21

13 FIGURES

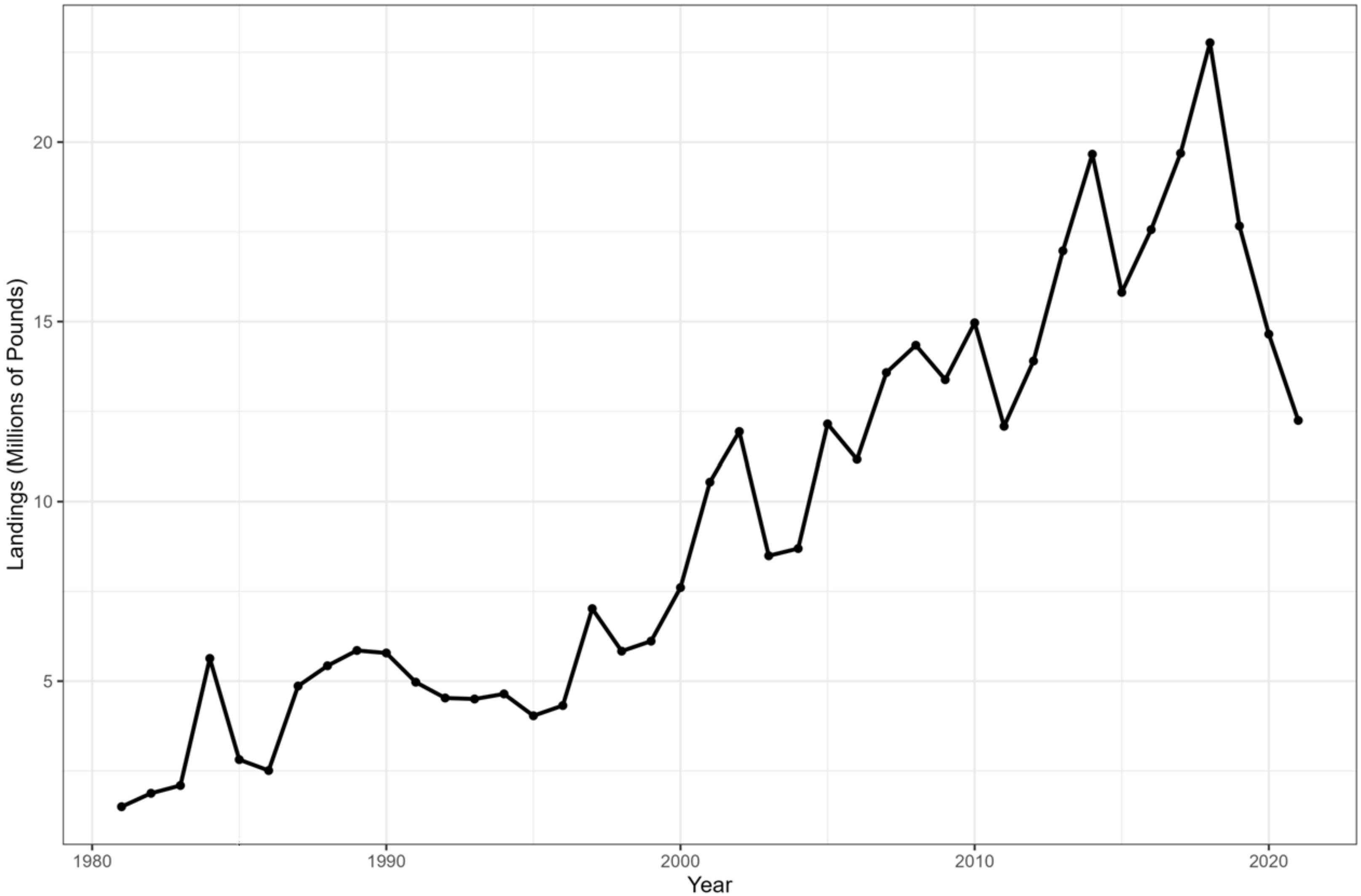

Figure 1. Coastwide landings of Jonah crab 1981-2021.

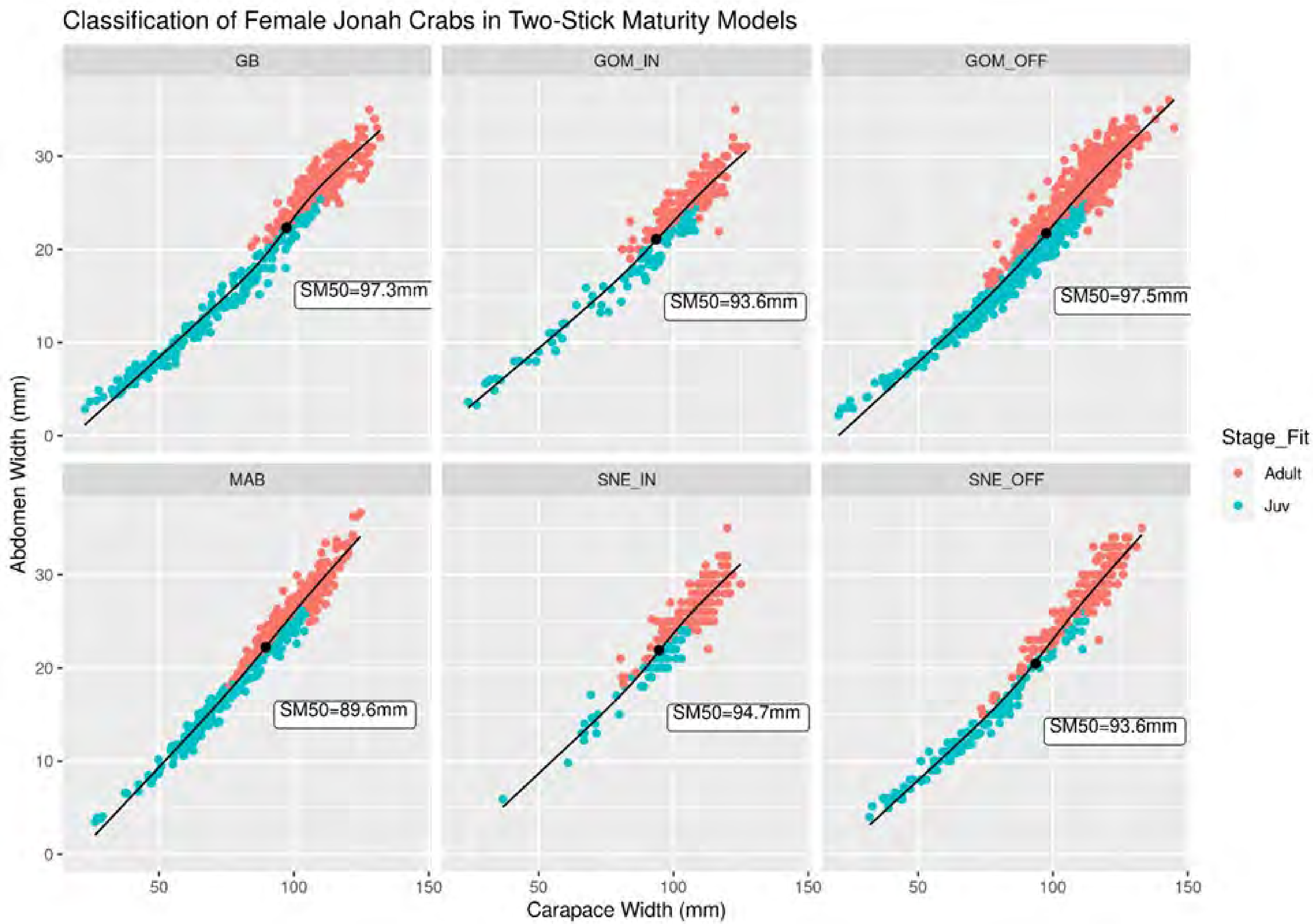

Figure 2. Relationship between abdomen width and carapace width (CW) for female Jonah crabs with fitted mean prediction at CW and estimated size-at-maturity (SM50). Color indicates predicted maturity based on Somerton method.

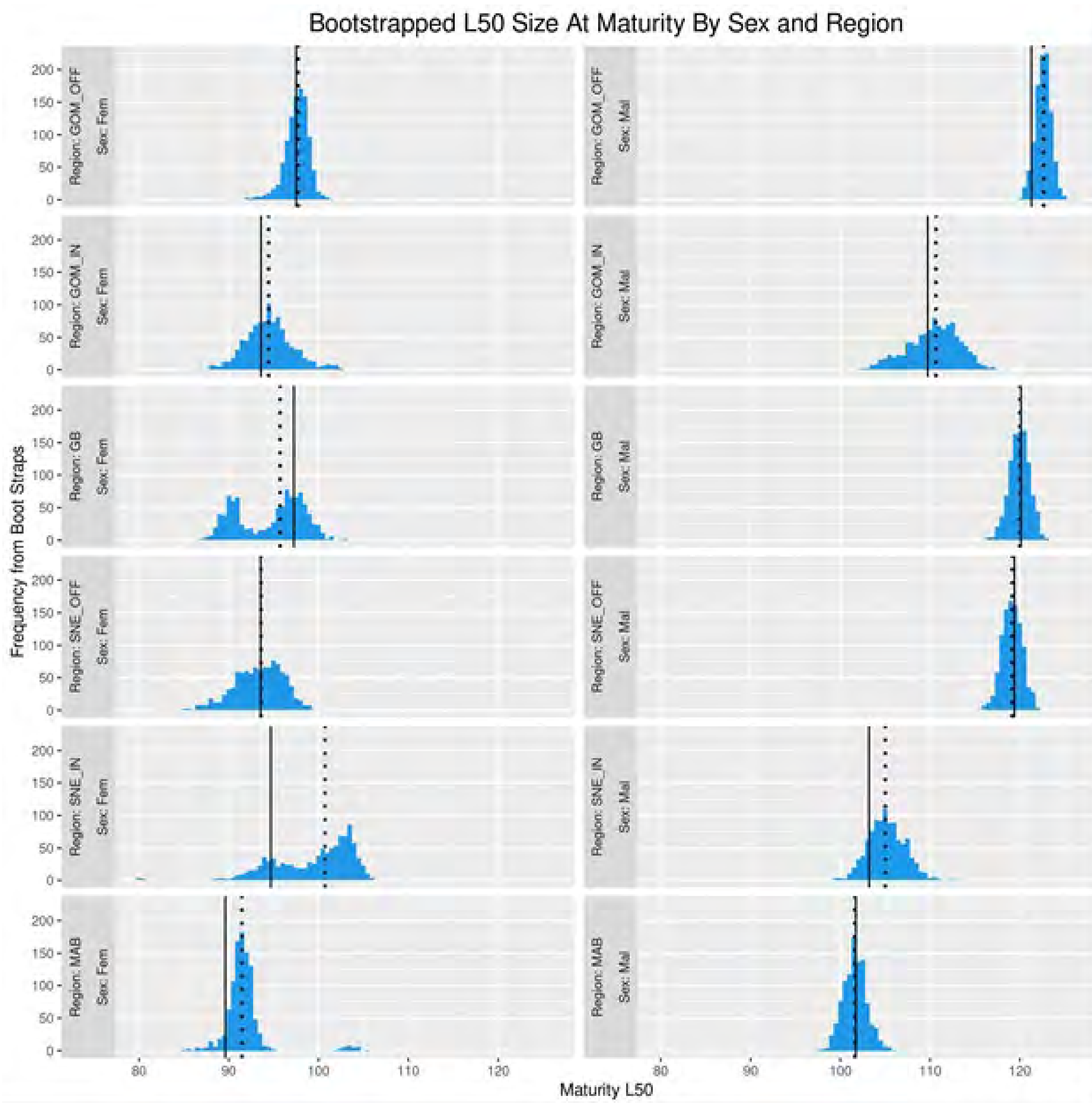

Figure 3. Bootstrapped distribution of size-at-maturity (SM50) by region and sex. Solid black line represents estimated SM50 while dotted line represents median of bootstrap.

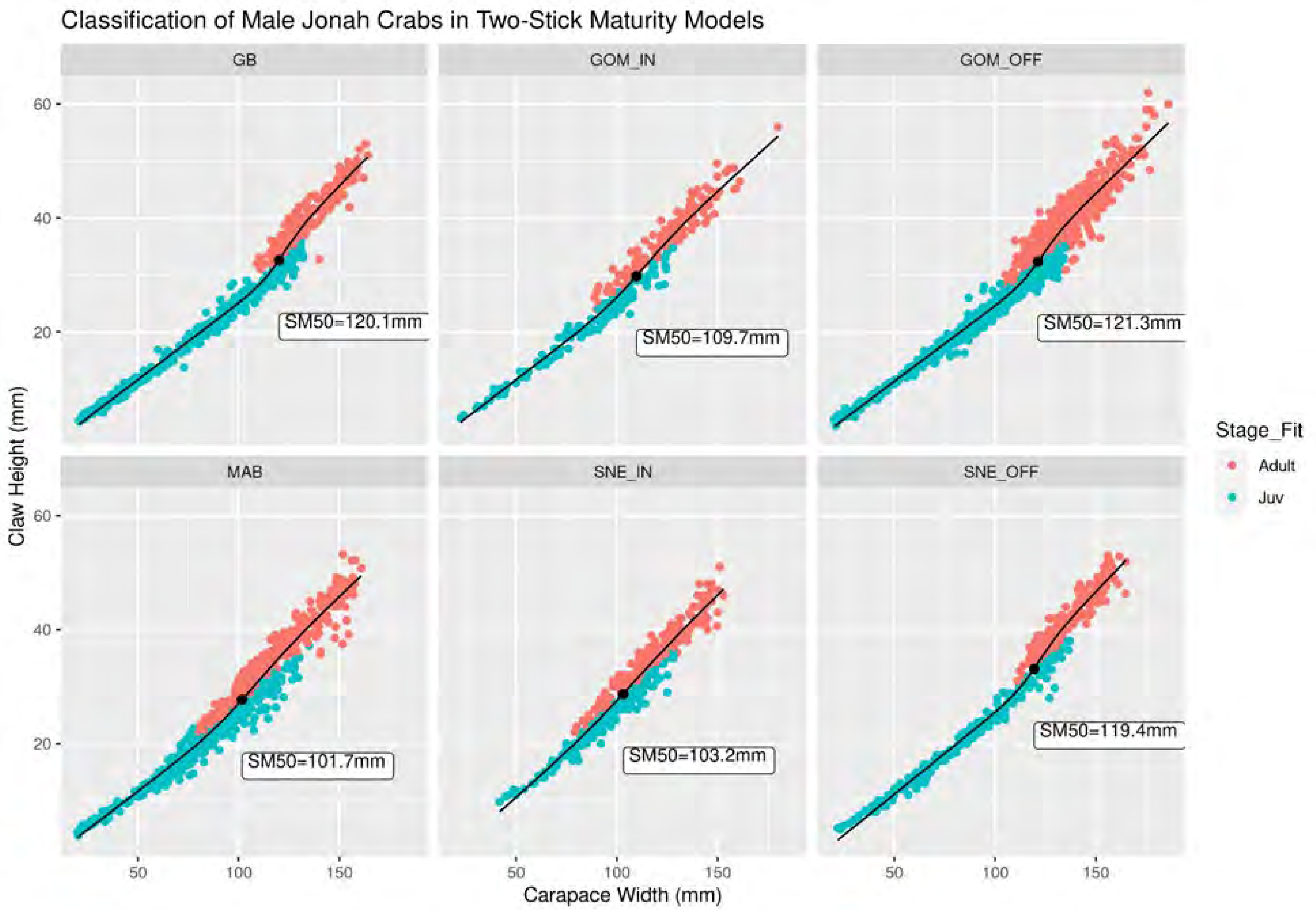

Figure 4. Relationship between claw height and carapace width (CW) for male Jonah crabs with fitted mean prediction at CW and estimated size-at-maturity (SM50). Color indicates predicted maturity based on Somerton method.

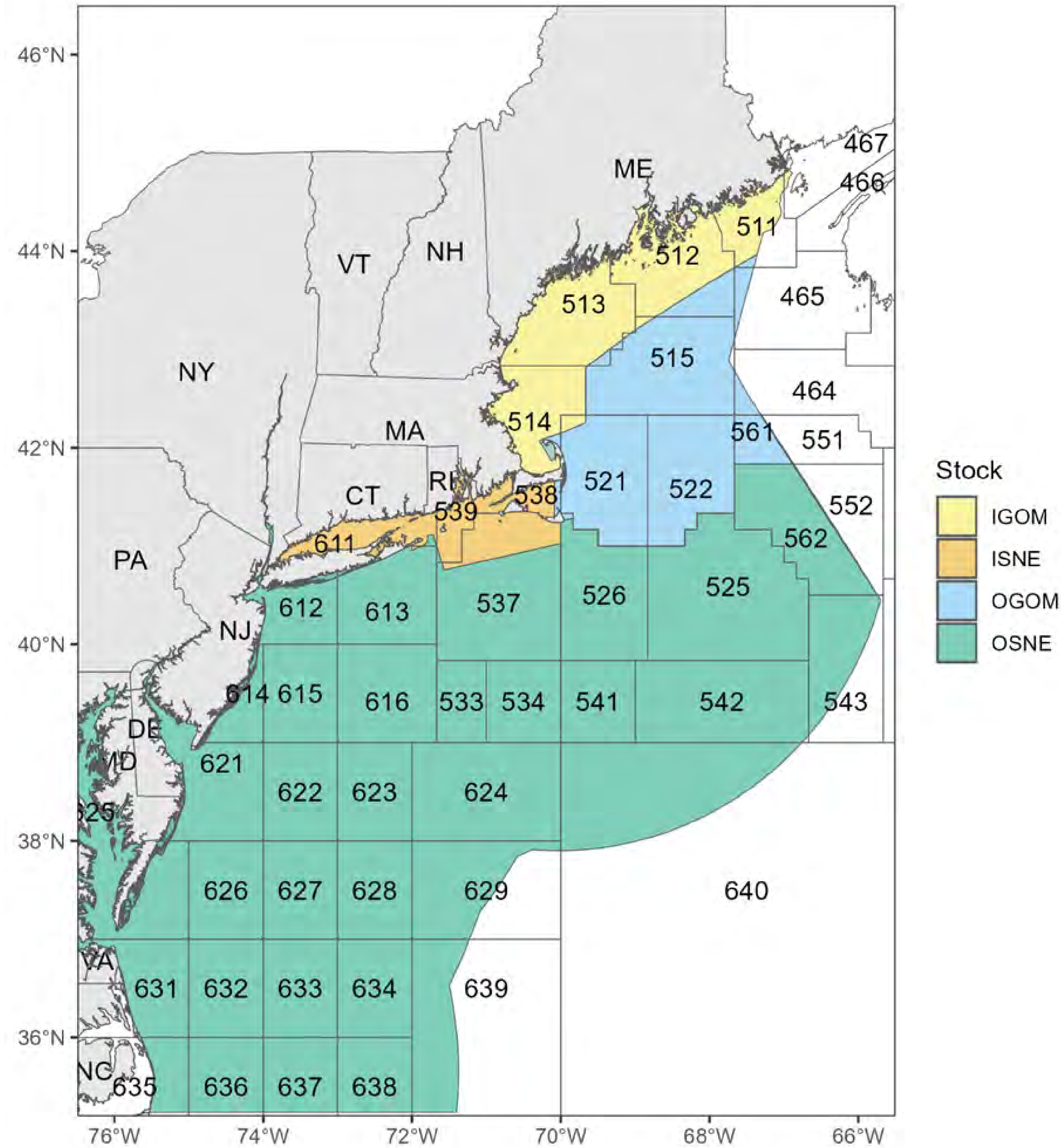

Figure 5. US Jonah crab stocks.

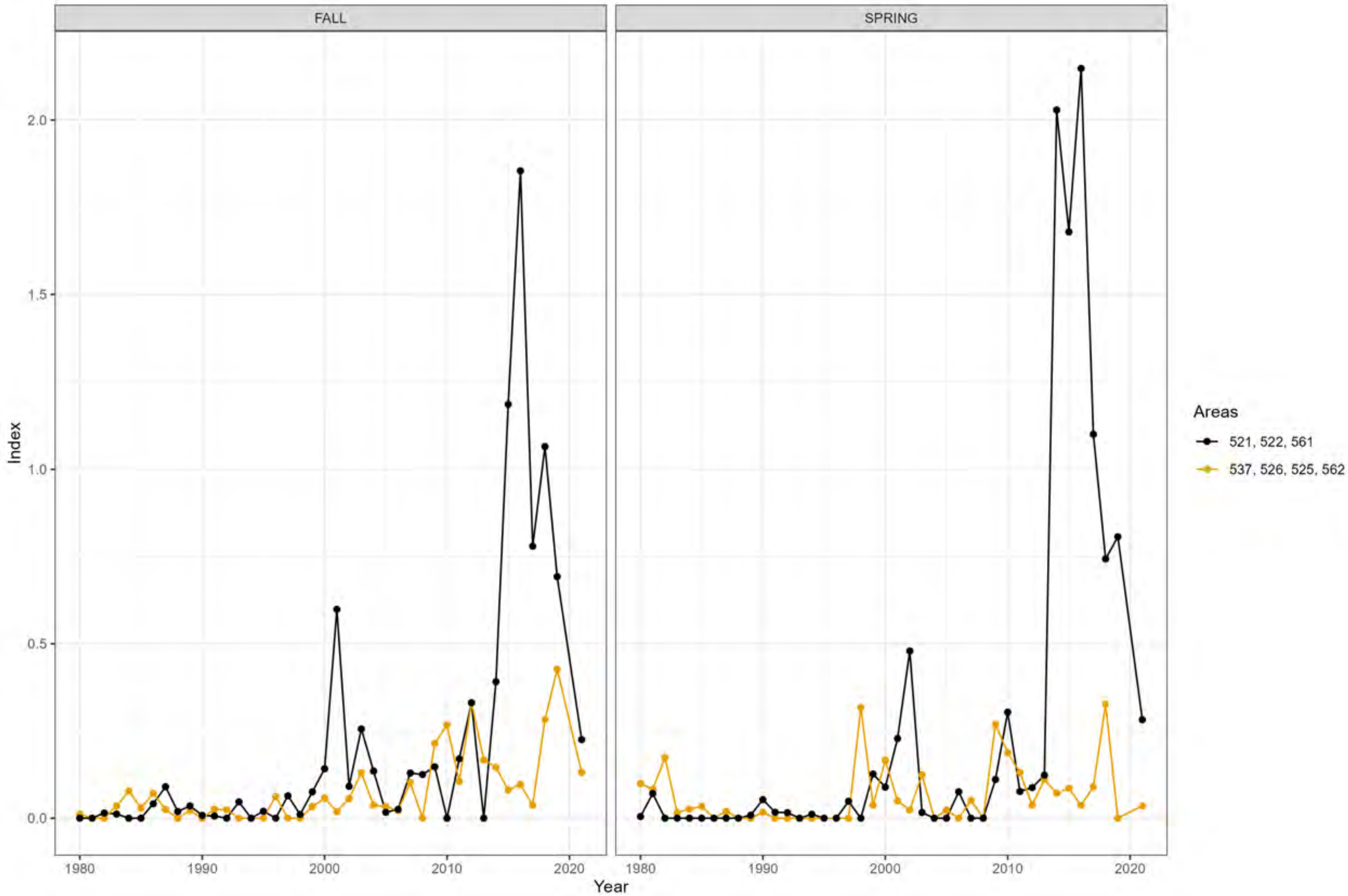

Figure 6. NEFSC Trawl Survey exploitable abundance indices (males 120mm+ CW) for adjacent NOAA statistical areas associated with high landings of Jonah crabs (Areas 537, 526, 525, 562) and low landings of Jonah crabs (Areas 521, 522, 561).

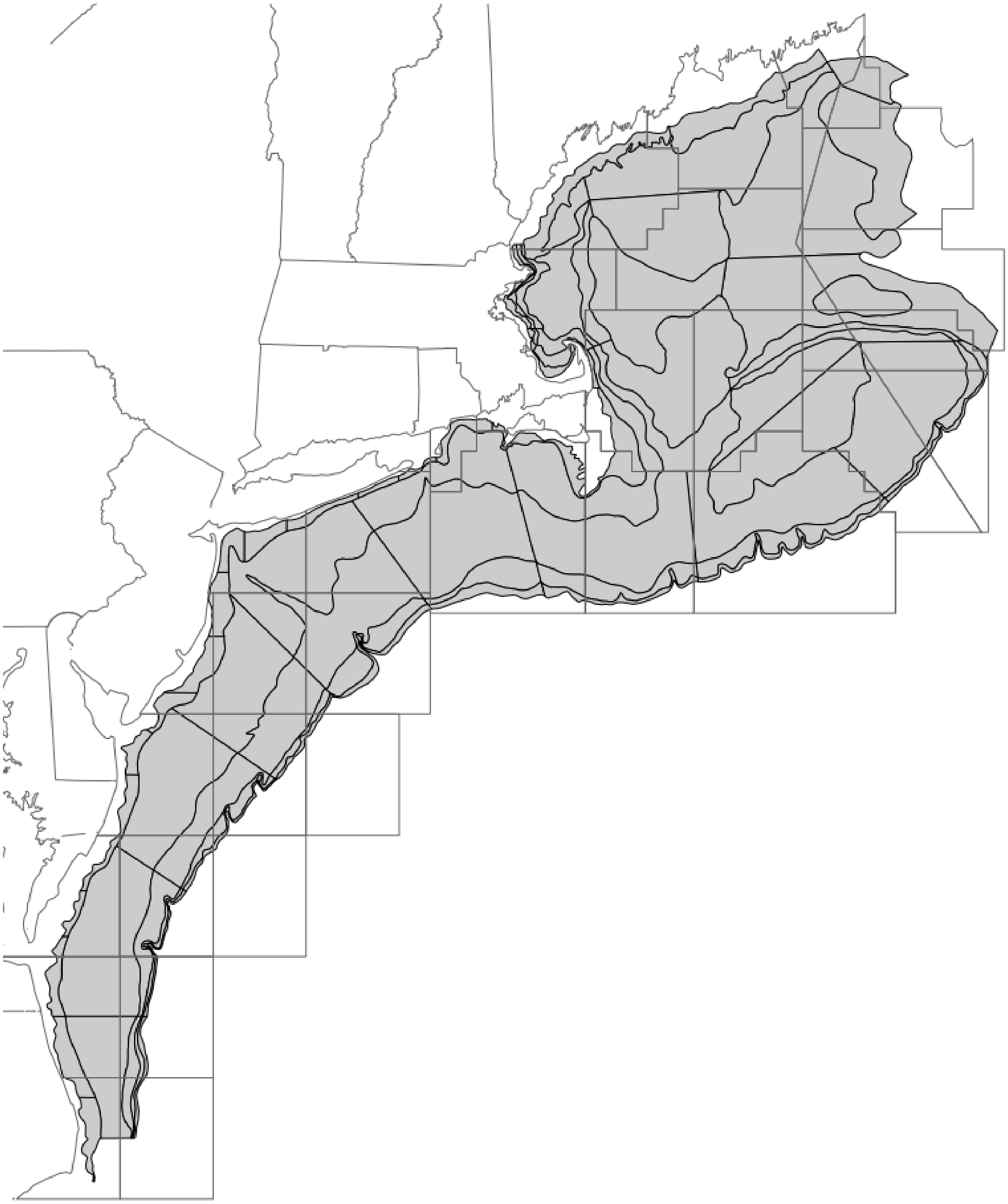

Figure 7. Survey footprint for the NEFSC Trawl Survey overlayed with NOAA statistical areas and depth contours.

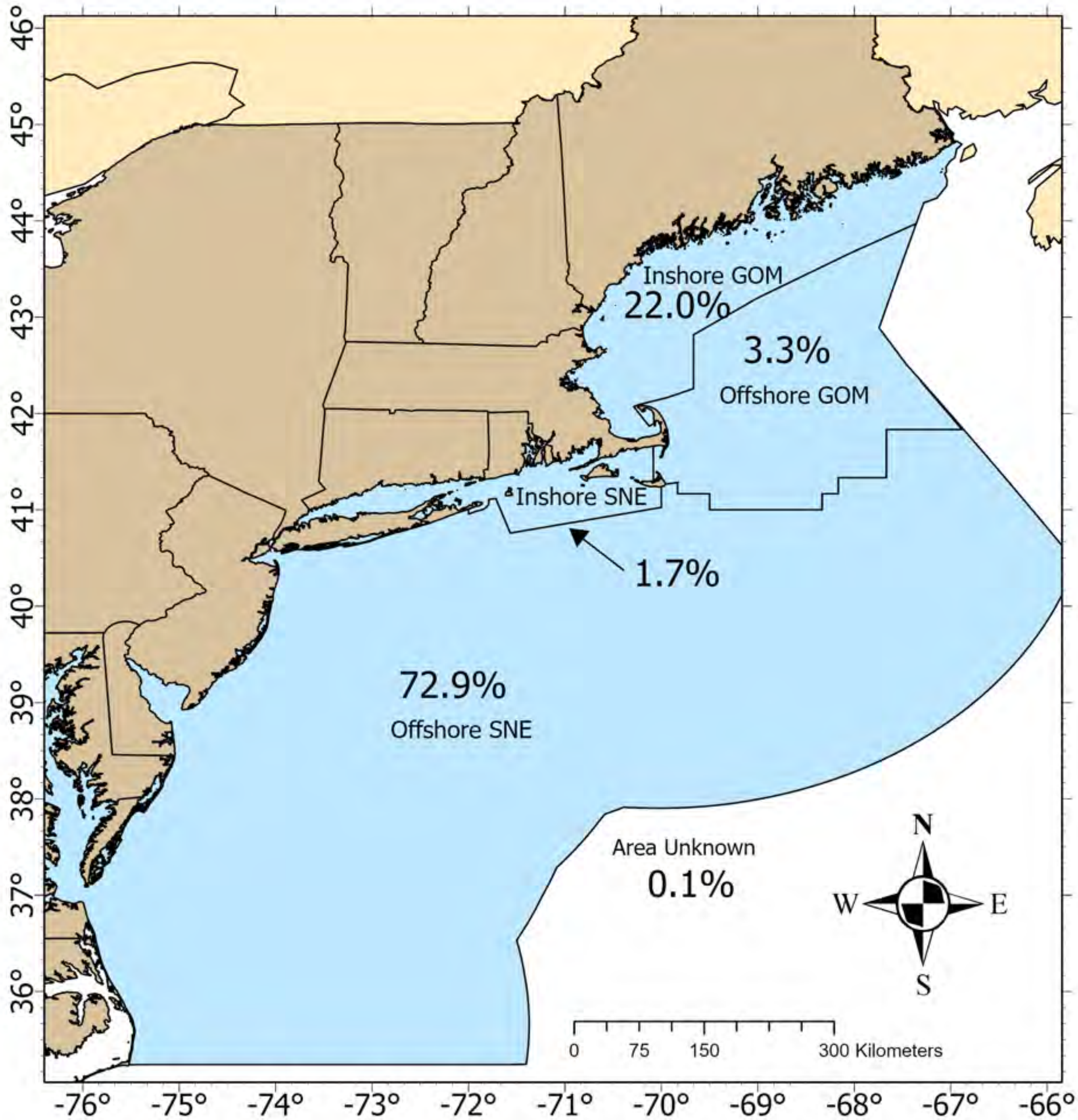

Figure 8. Percent of 2010 U.S. Jonah crab landings by stock area.

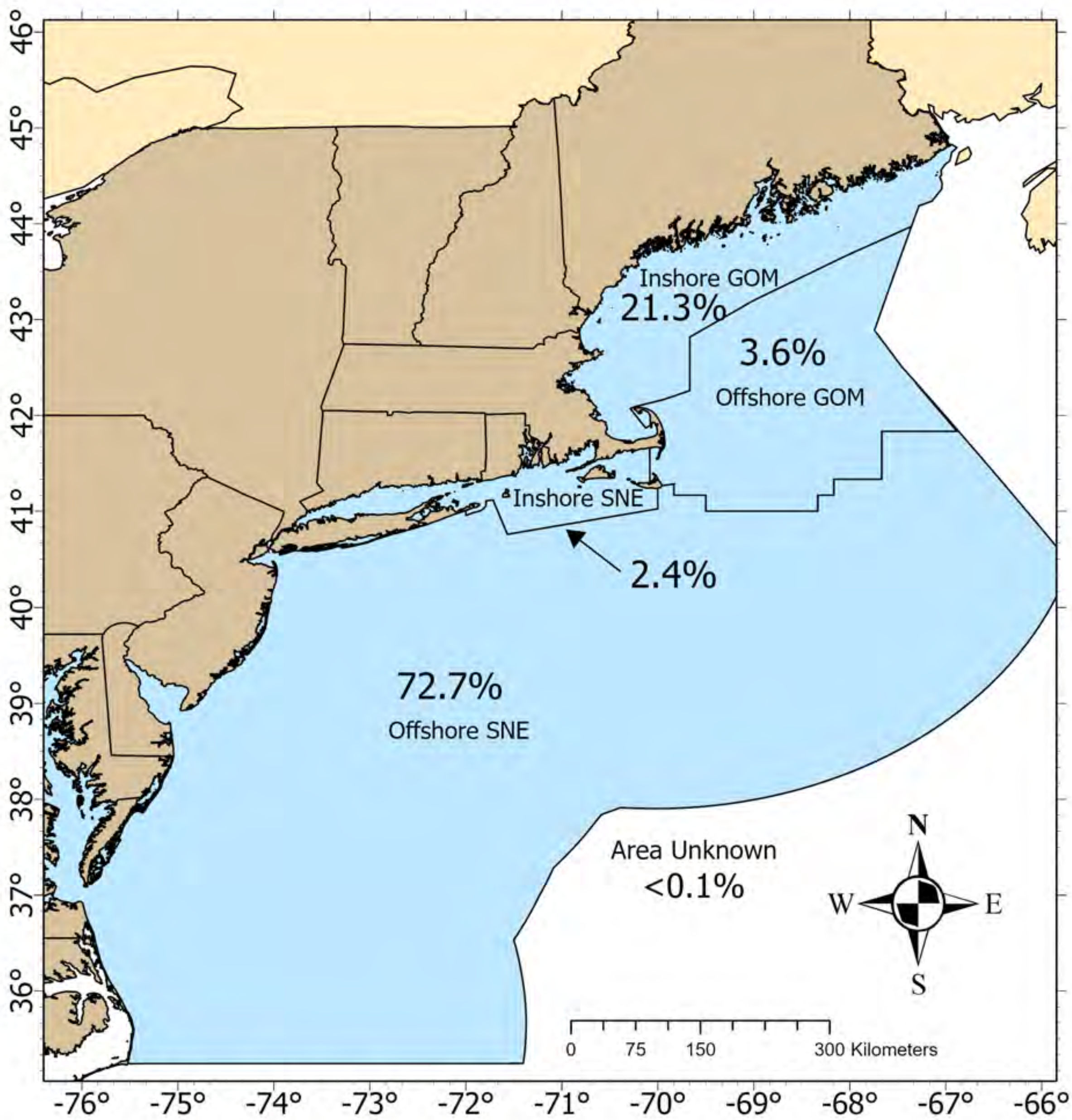

Figure 9. Percent of 2011 U.S. Jonah crab landings by stock area.

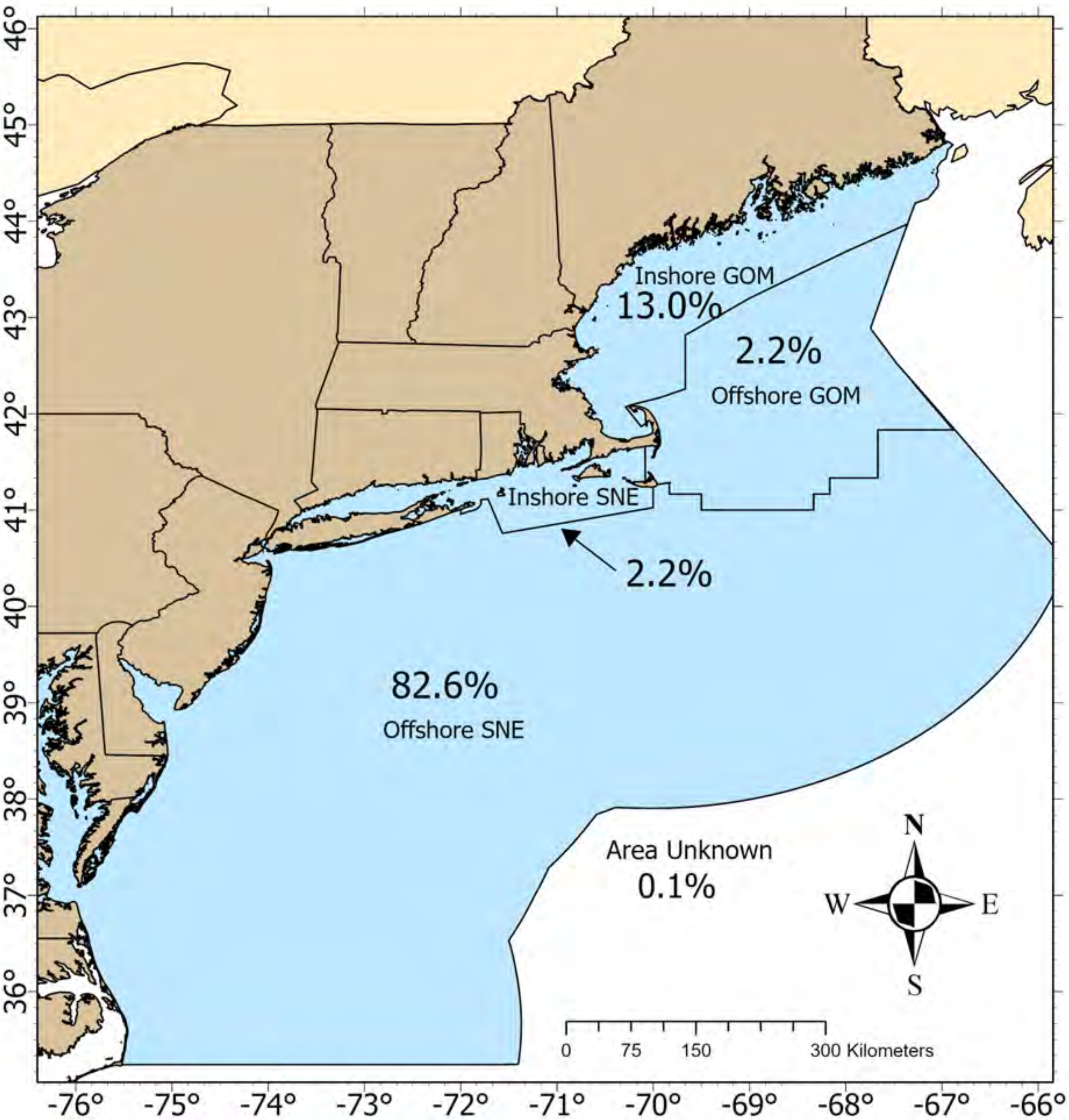

Figure 10. Percent of 2012 U.S. Jonah crab landings by stock area.

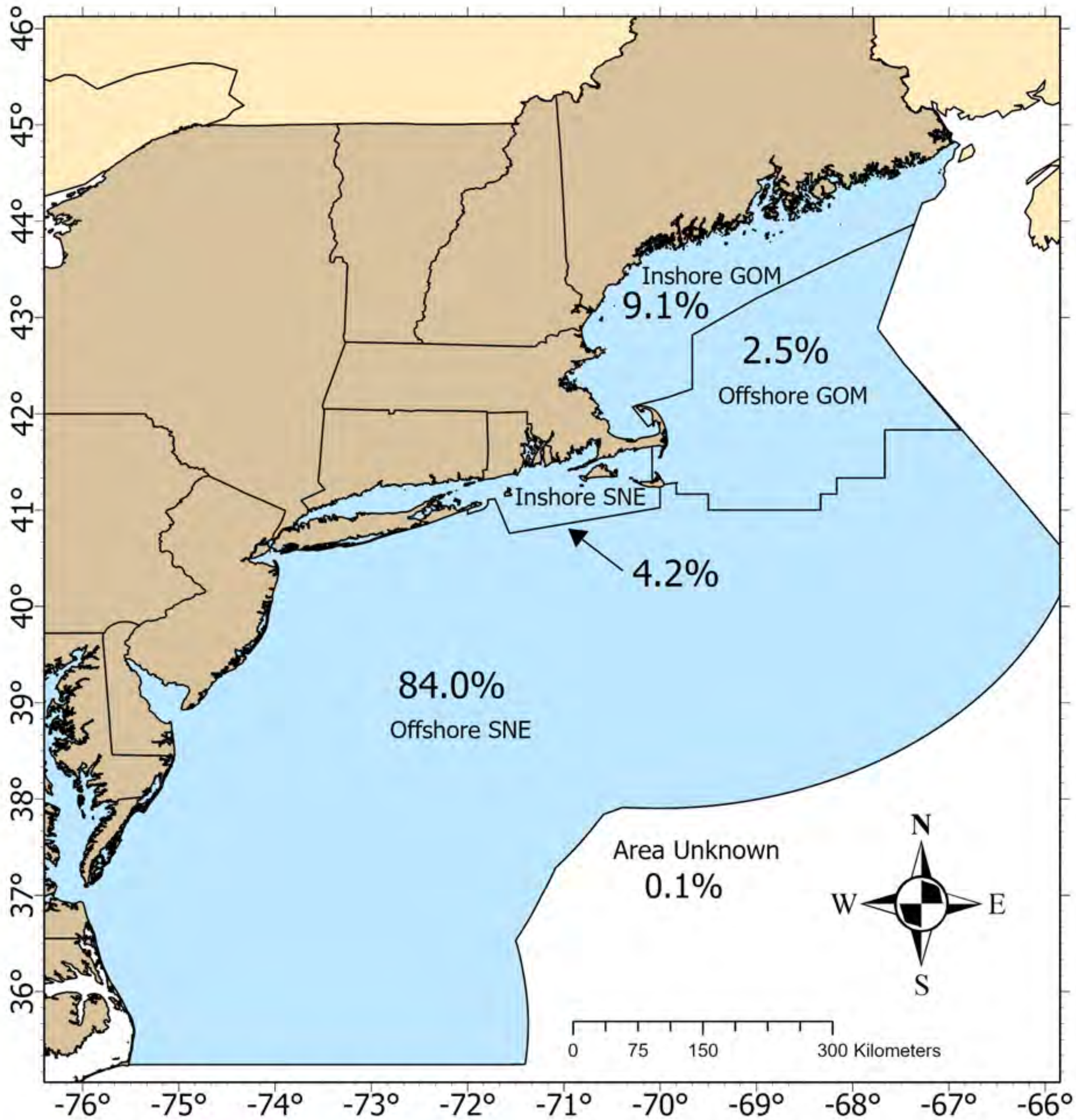

Figure 11. Percent of 2013 U.S. Jonah crab landings by stock area.

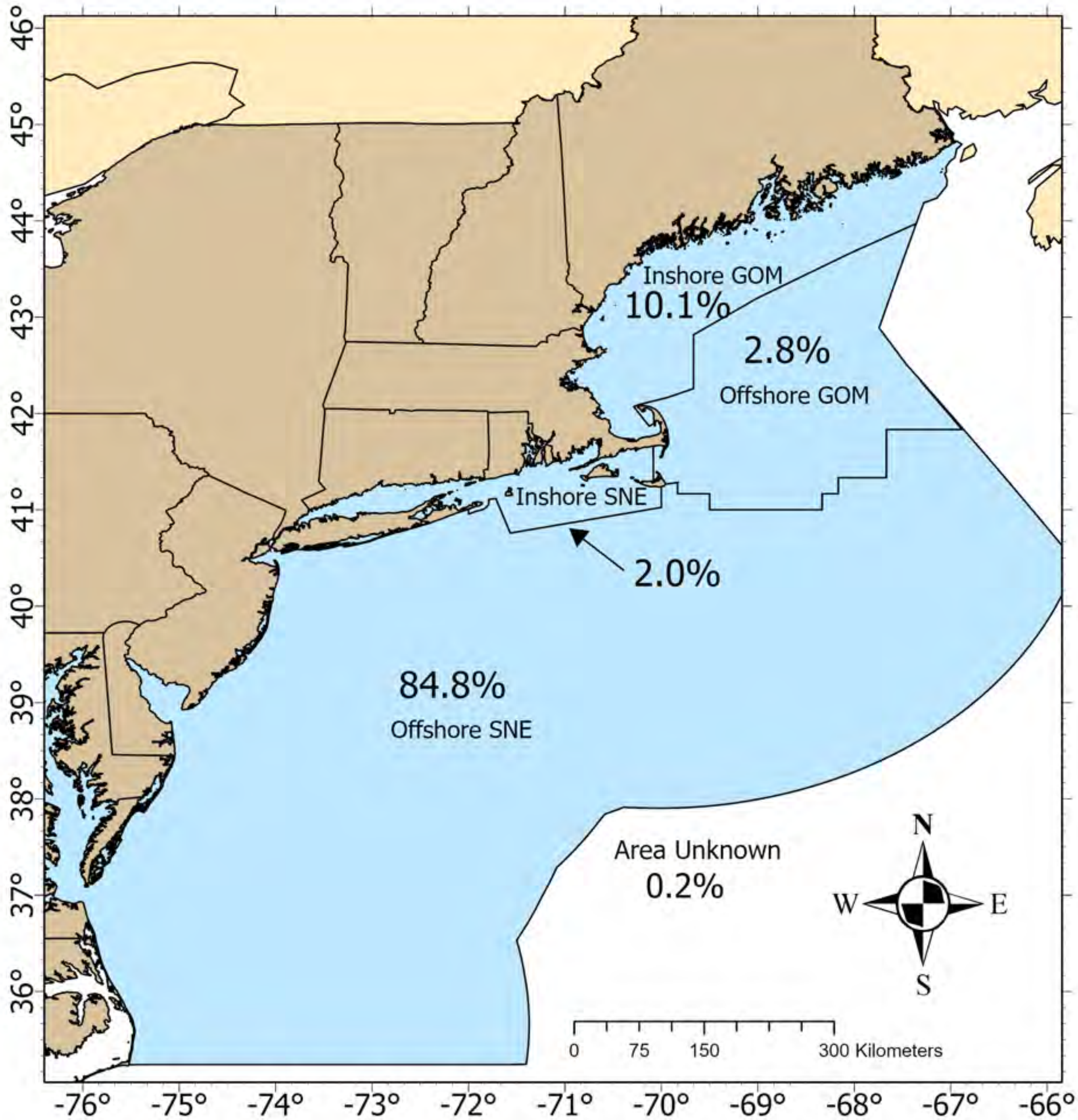

Figure 12. Percent of 2014 U.S. Jonah crab landings by stock area.

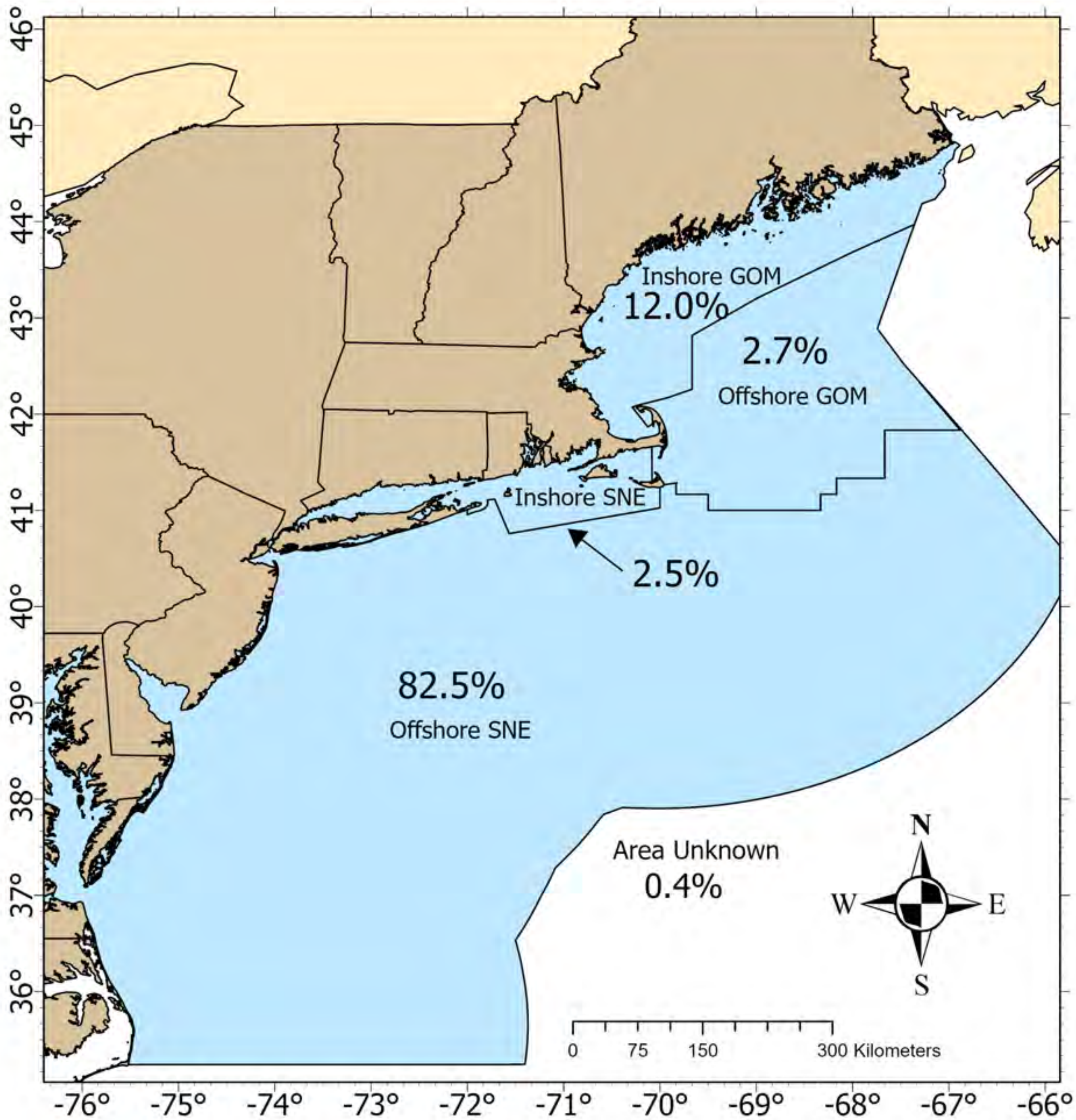

Figure 13. Percent of 2015 U.S. Jonah crab landings by stock area.

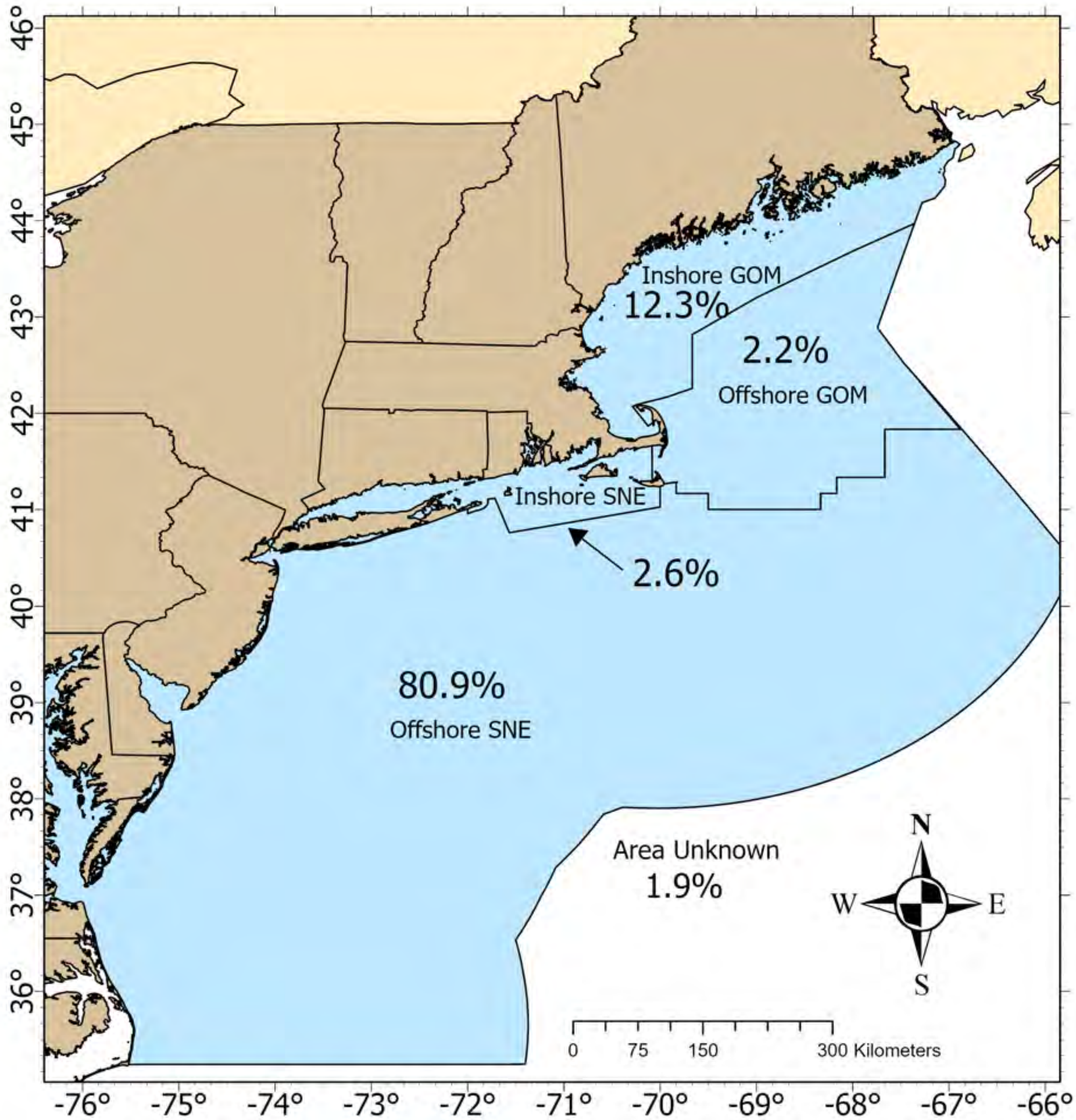

Figure 14. Percent of 2016 U.S. Jonah crab landings by stock area.

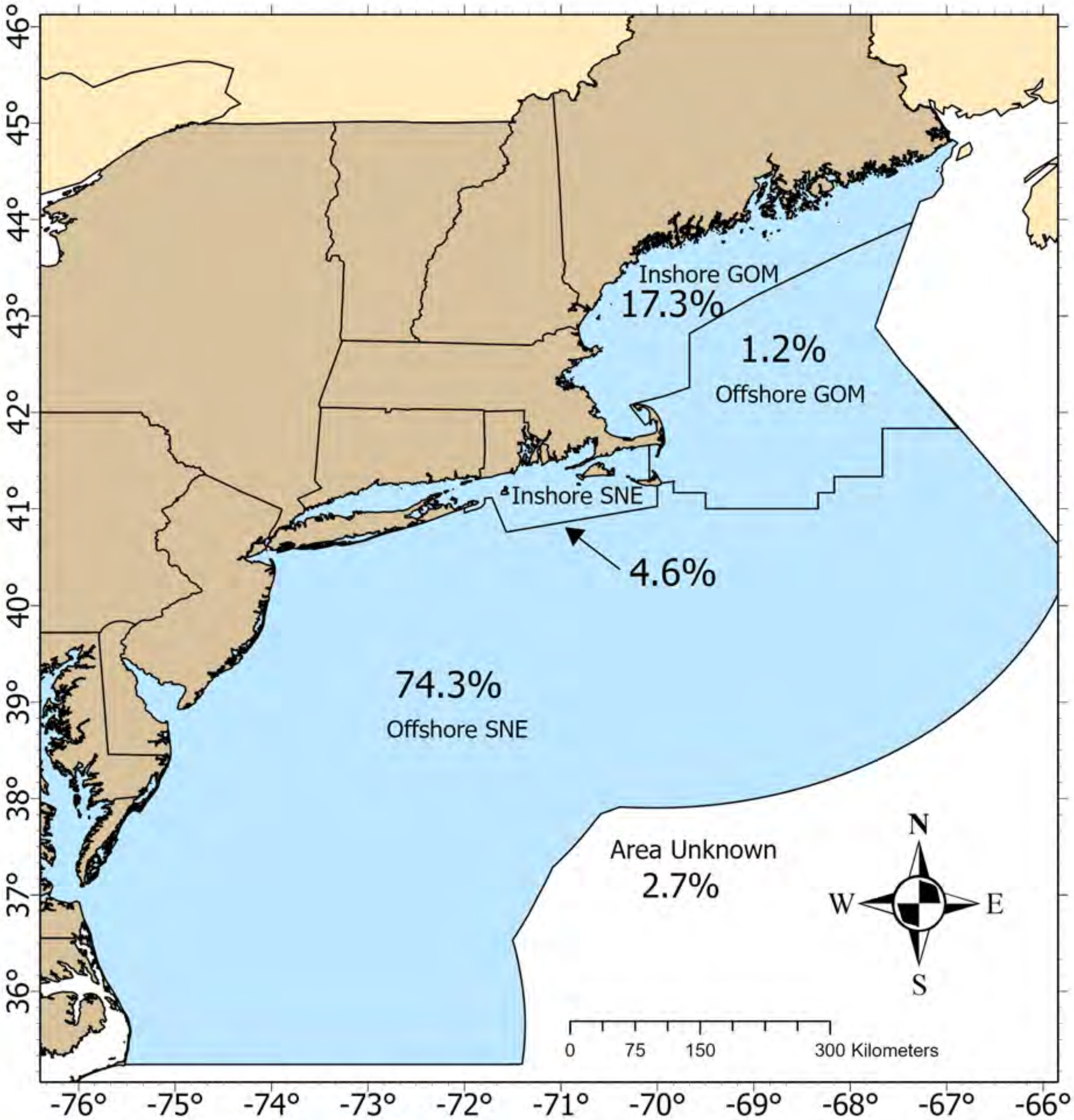

Figure 15. Percent of 2017 U.S. Jonah crab landings by stock area.

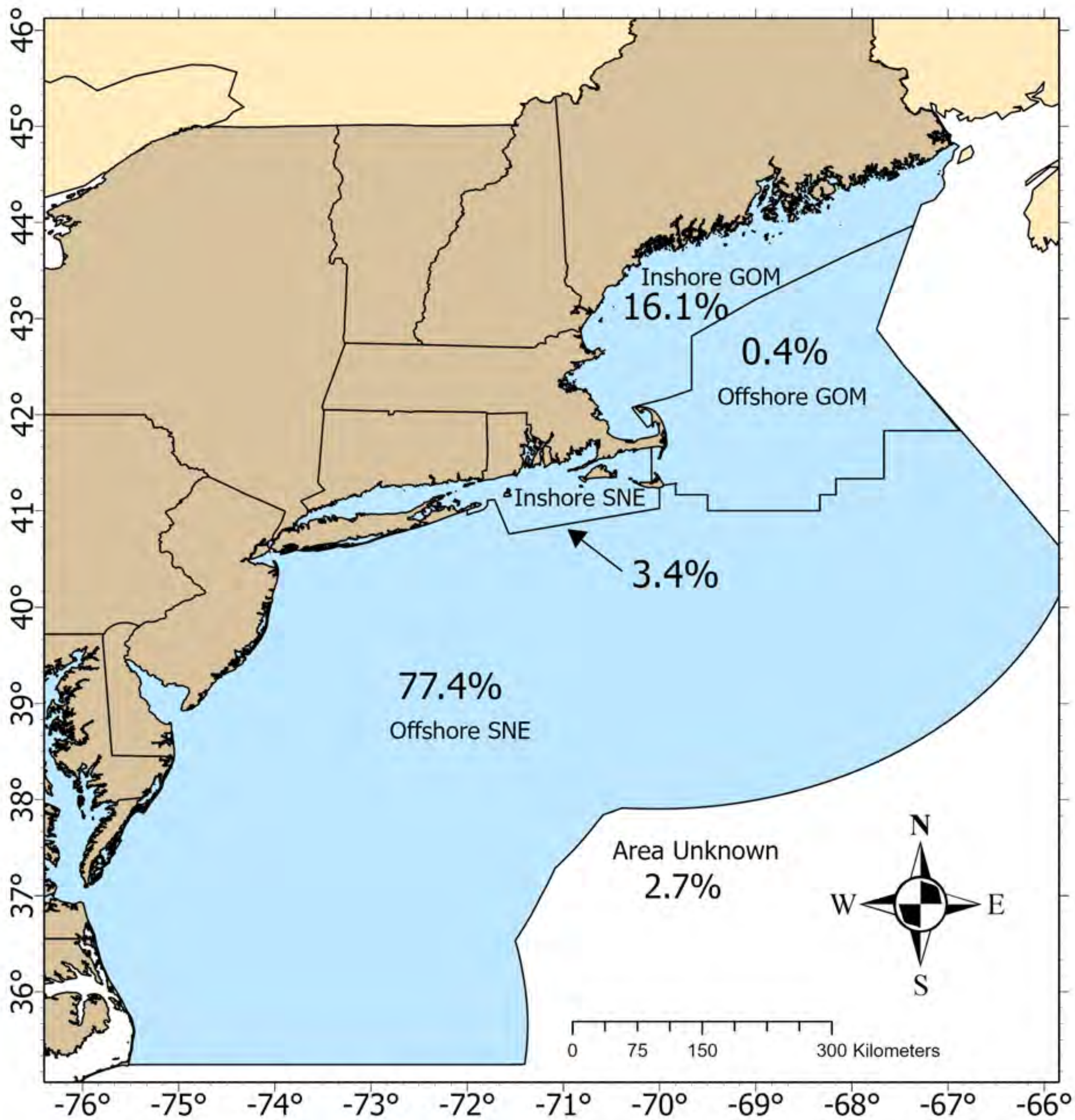

Figure 16. Percent of 2018 U.S. Jonah crab landings by stock area.

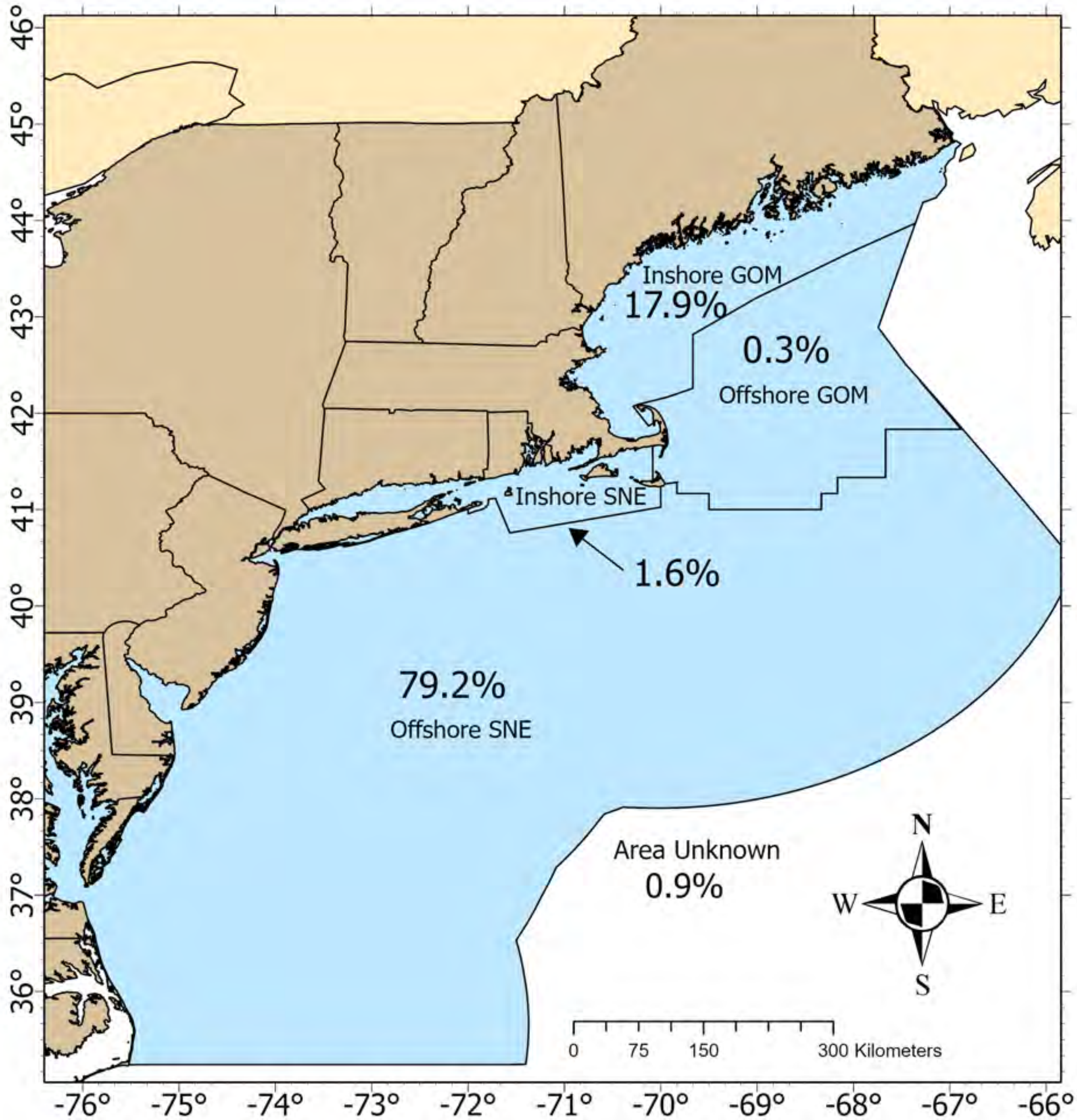

Figure 17. Percent of 2019 U.S. Jonah crab landings by stock area.

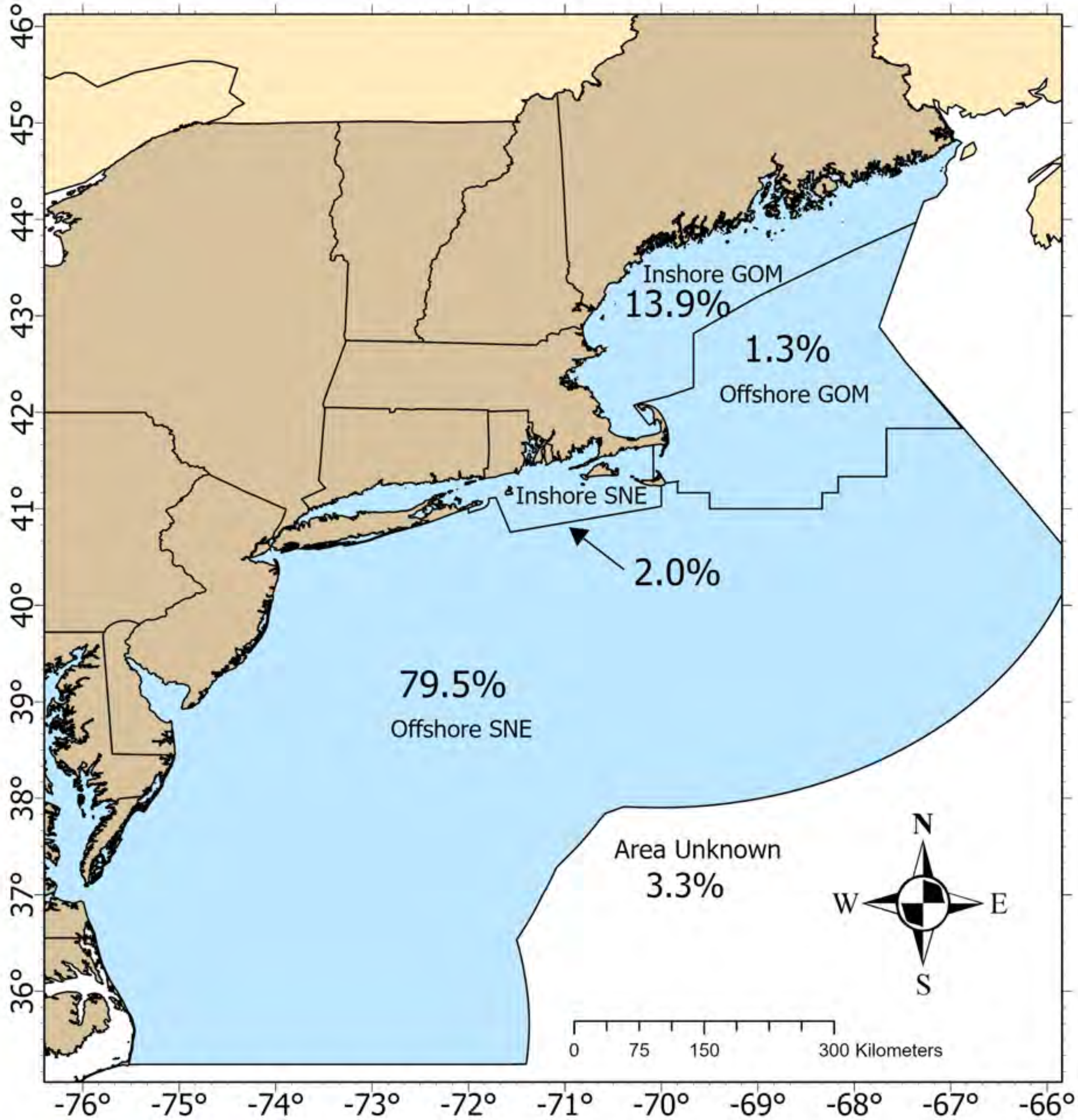

Figure 18. Percent of 2020 U.S. Jonah crab landings by stock area.

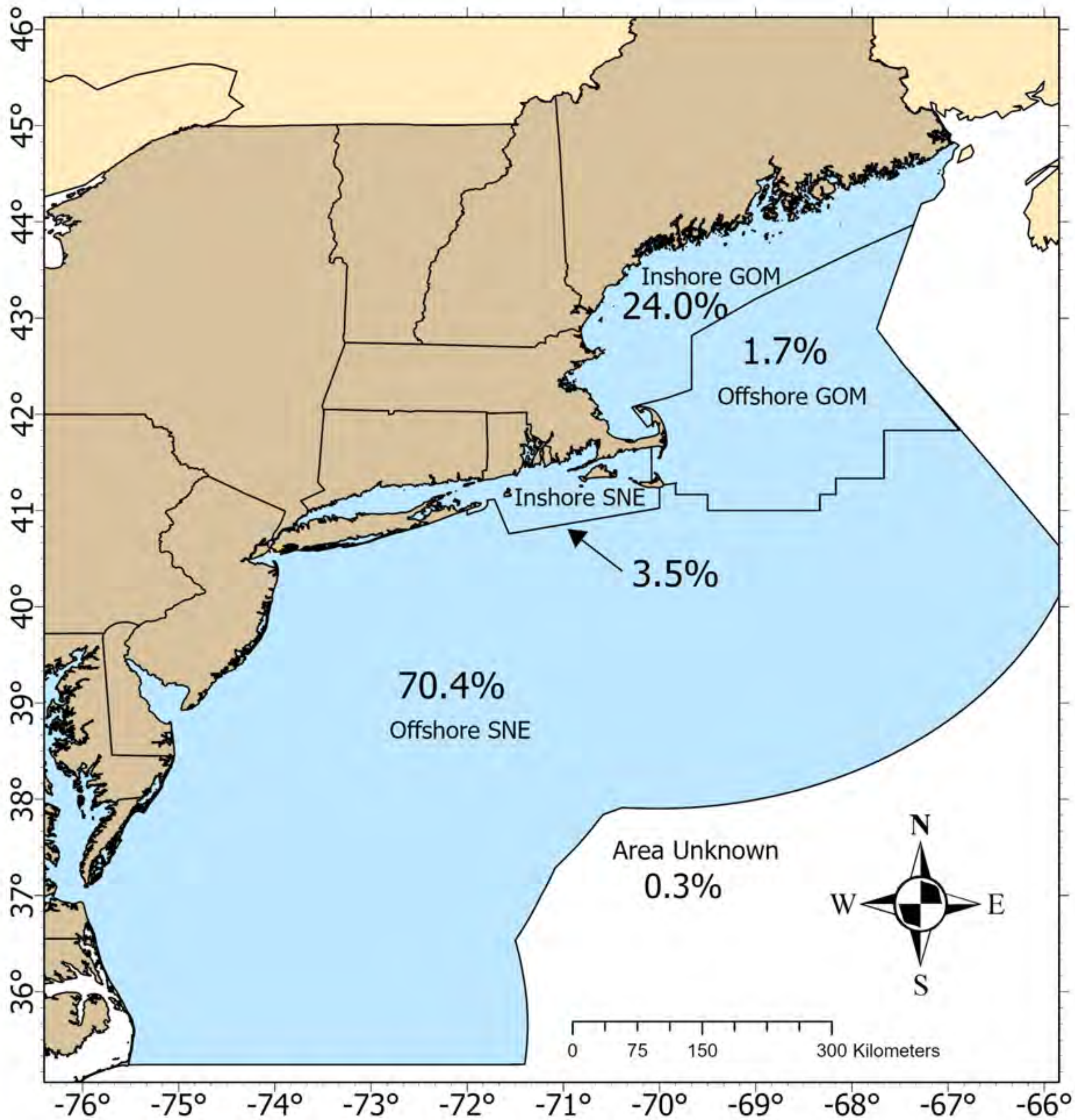

Figure 19. Percent of 2021 U.S. Jonah crab landings by stock area.

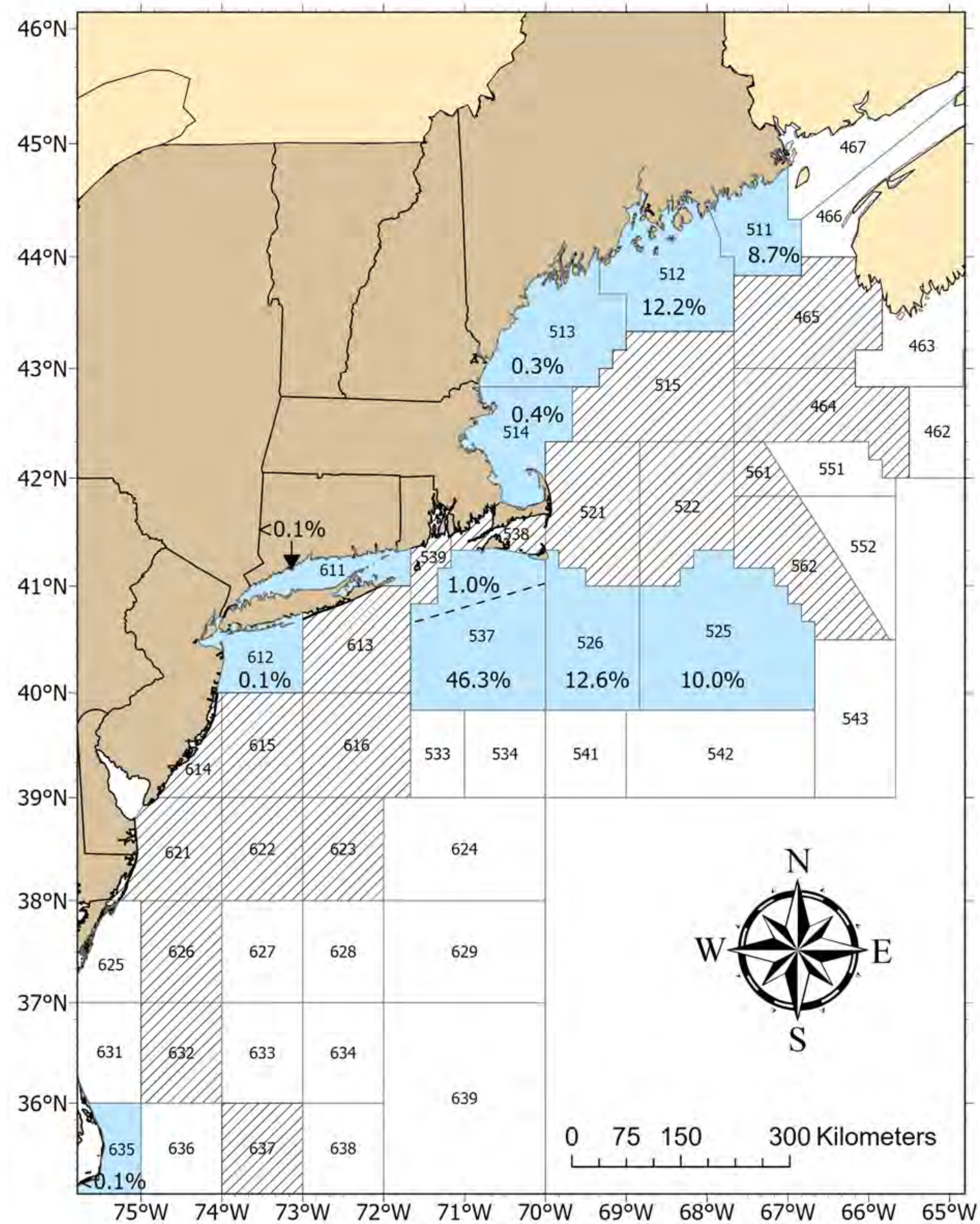

Figure 20. Percent of 2010 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

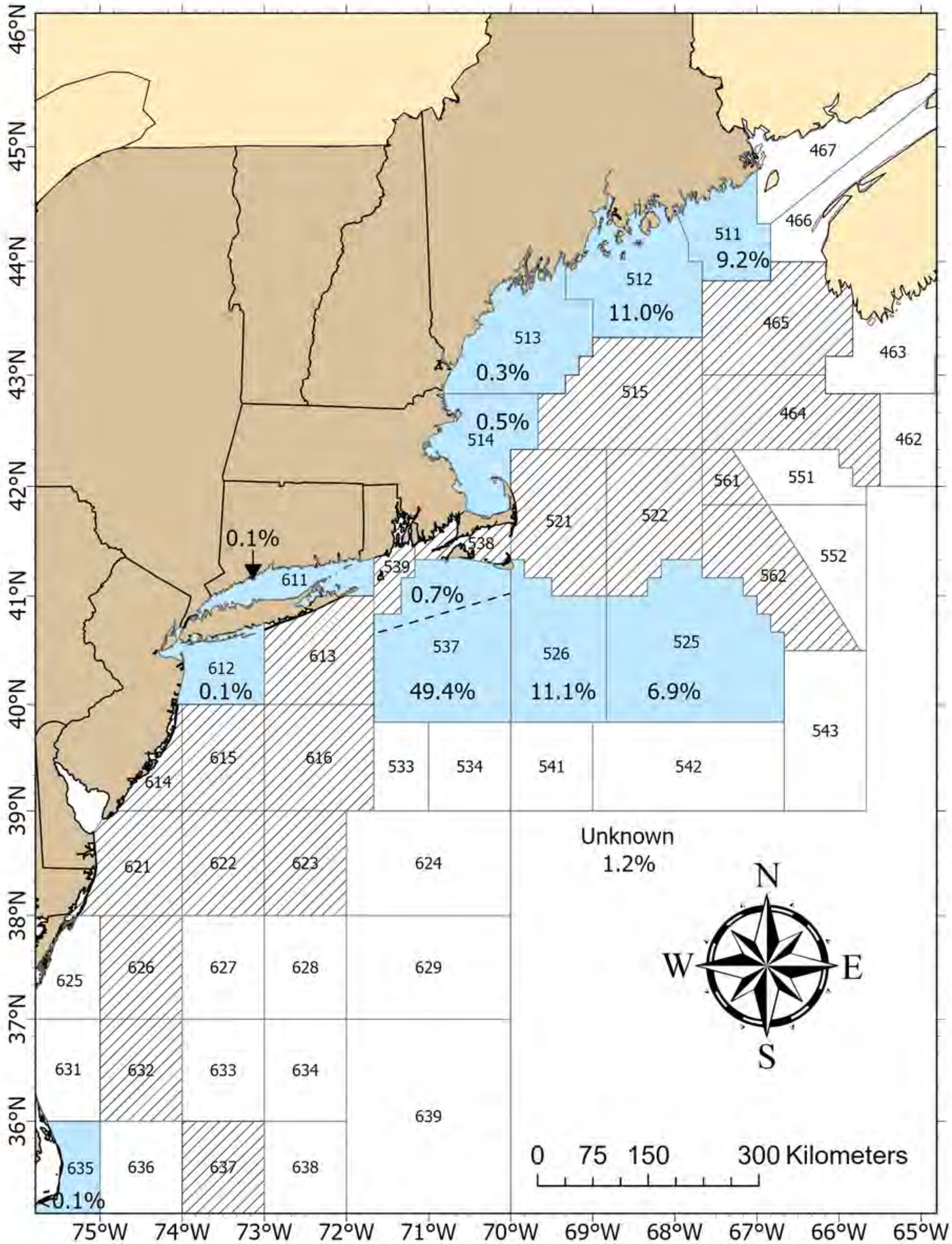

Figure 21. Percent of 2011 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

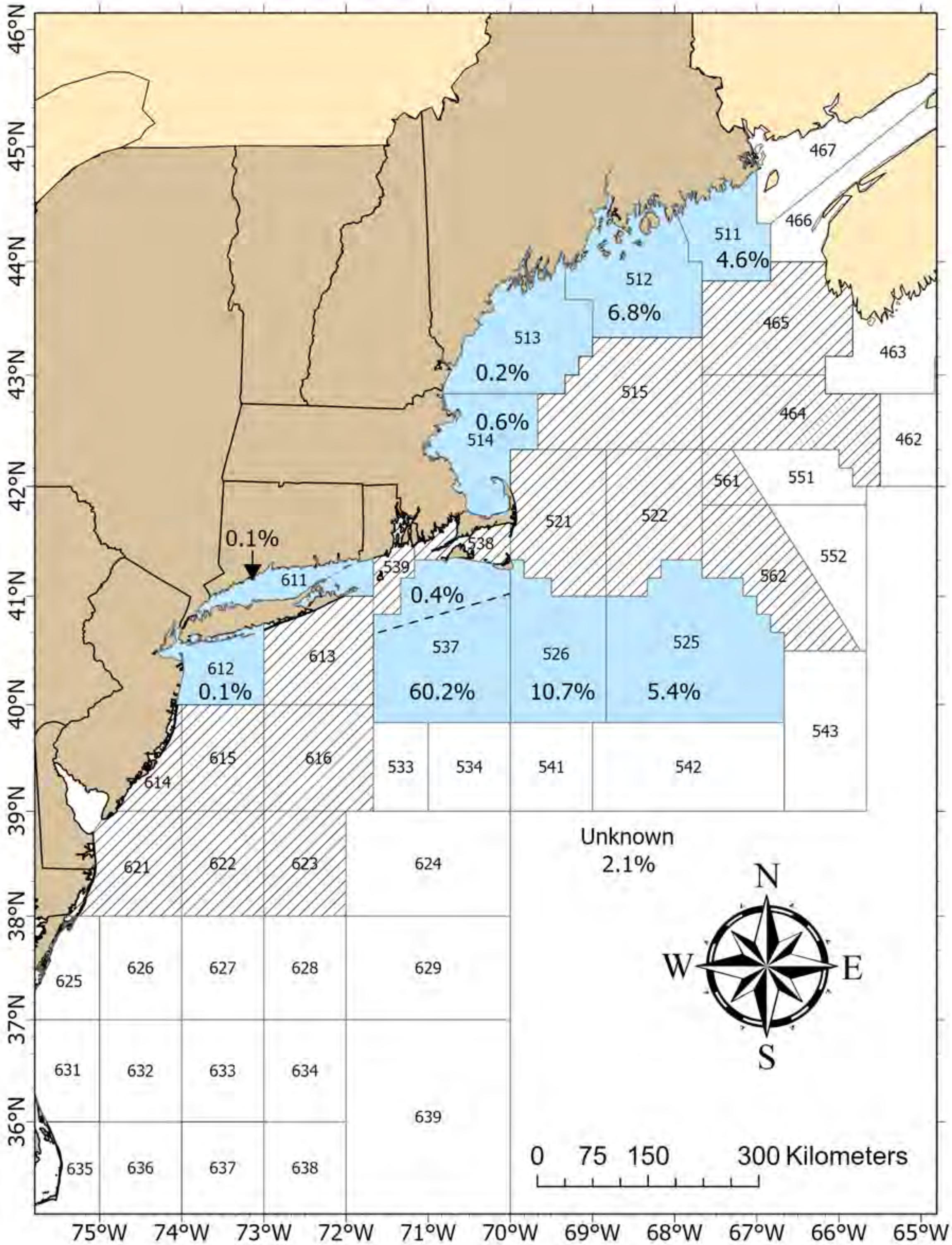

Figure 22. Percent of 2012 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

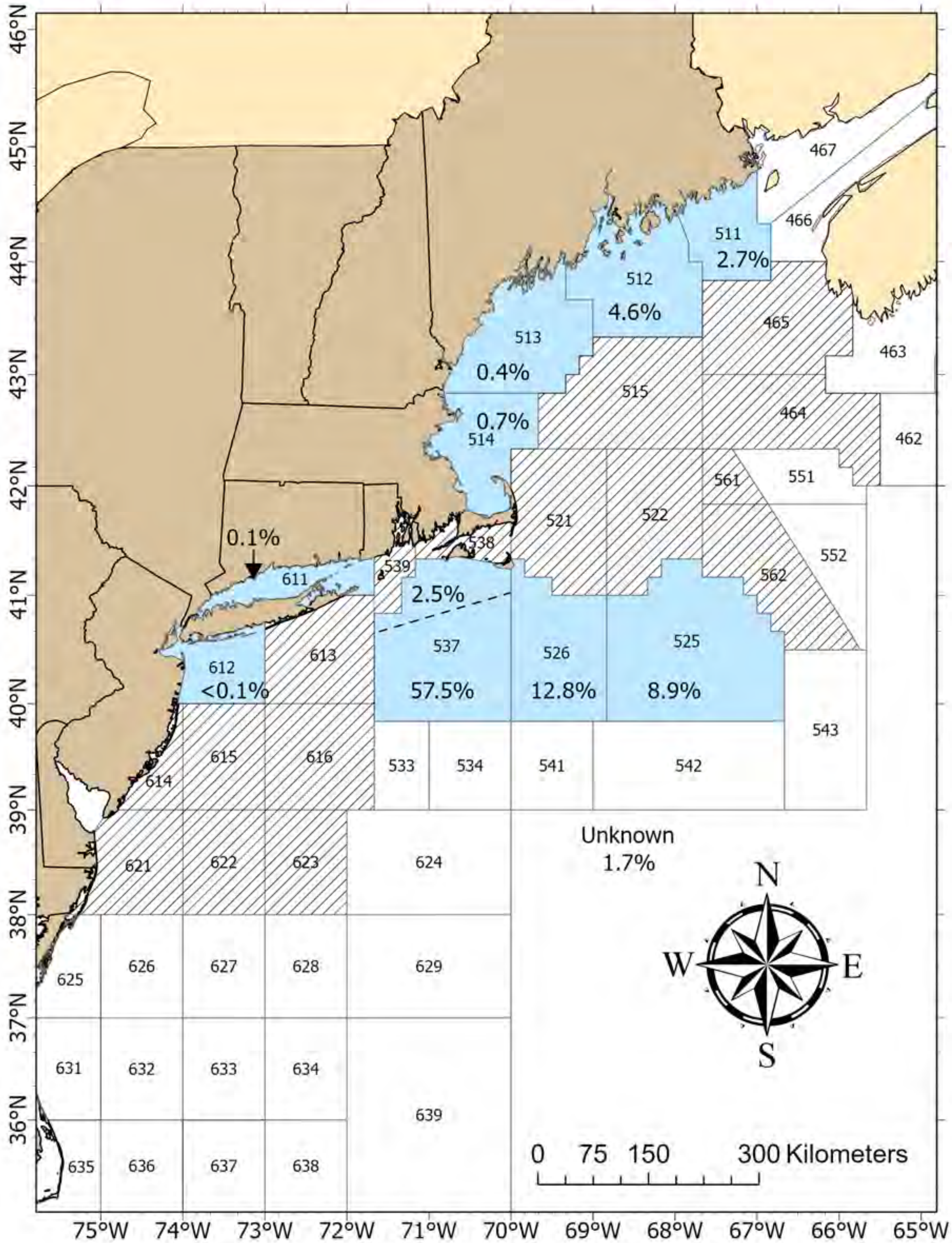

Figure 23. Percent of 2013 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

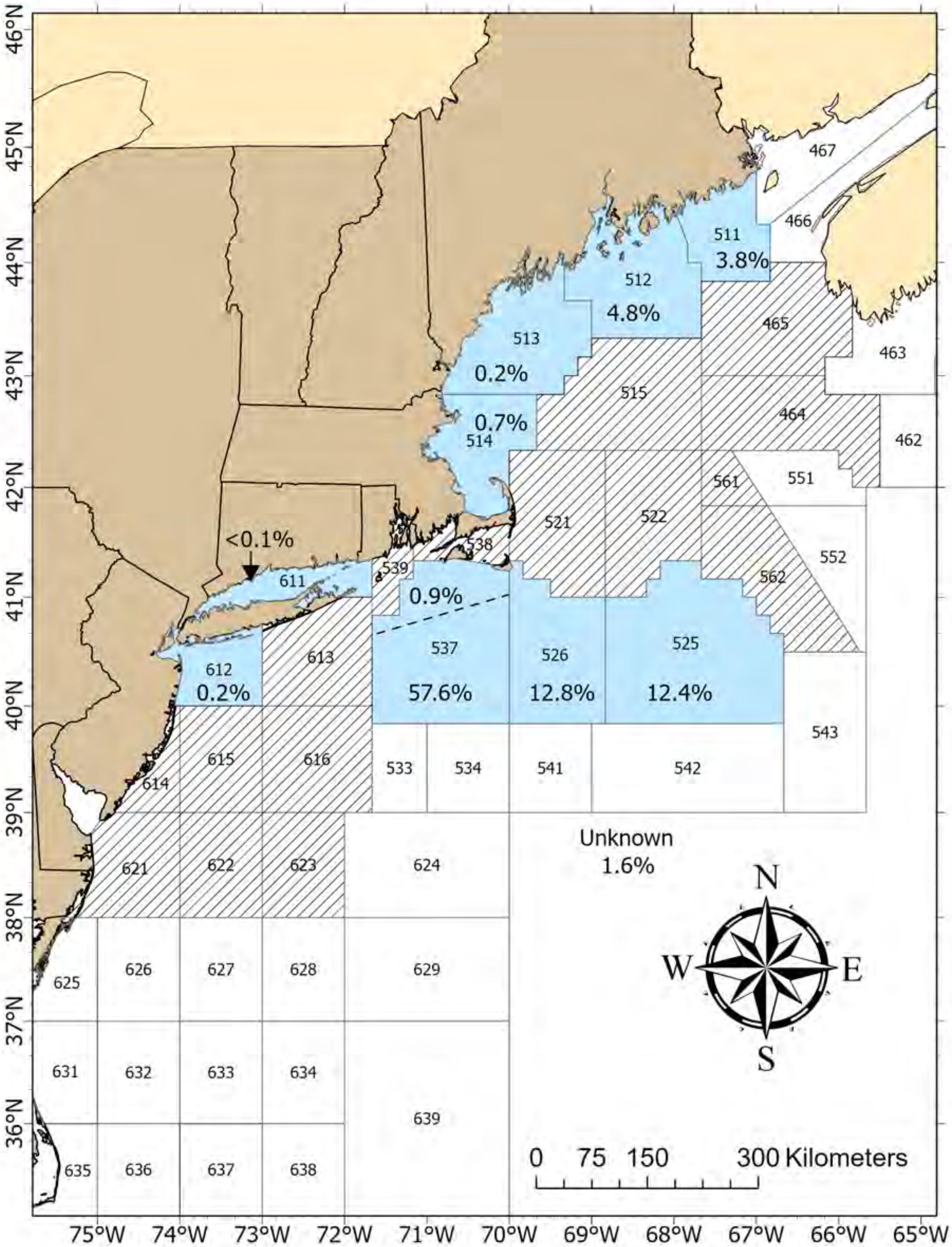

Figure 24. Percent of 2014 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

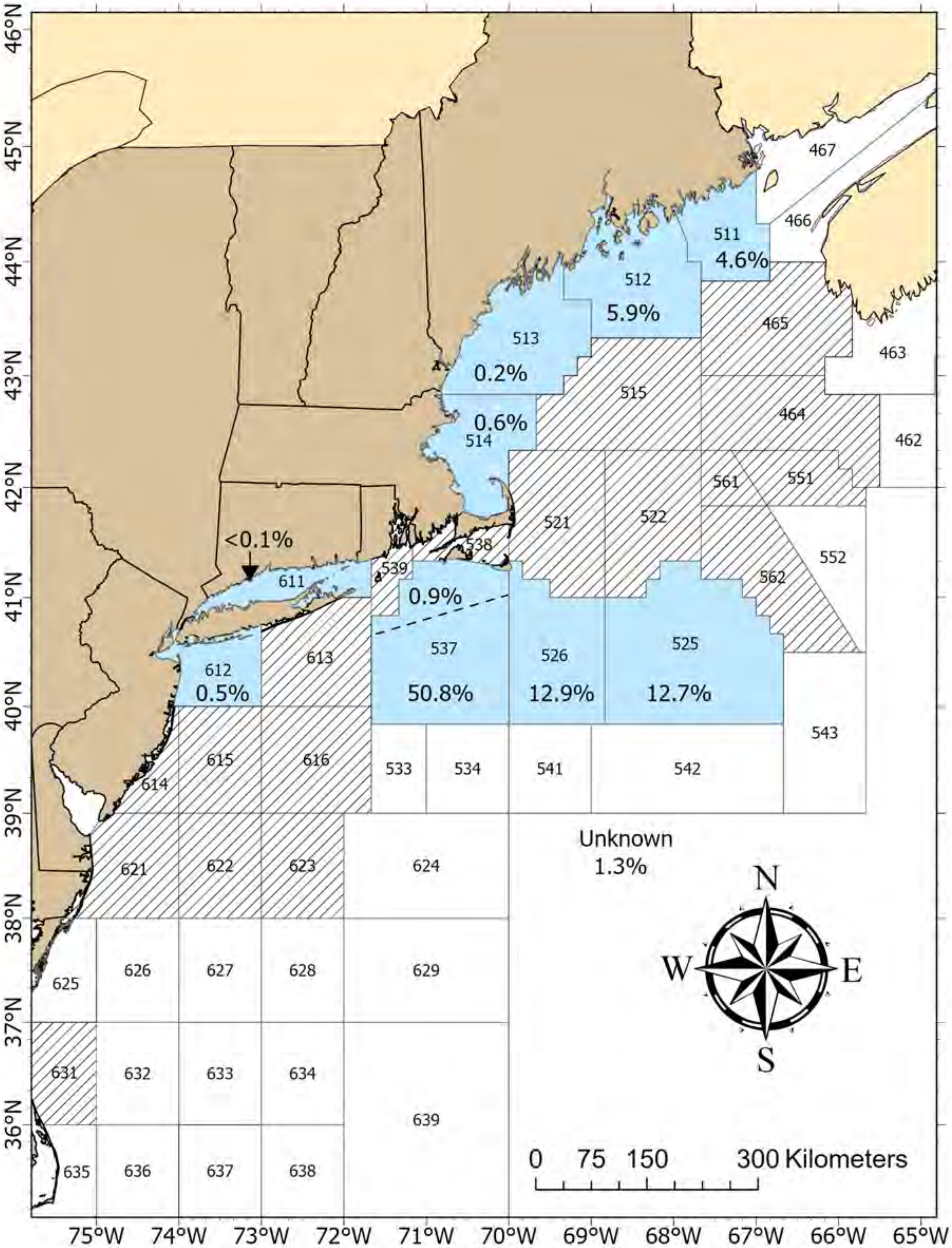

Figure 25. Percent of 2015 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

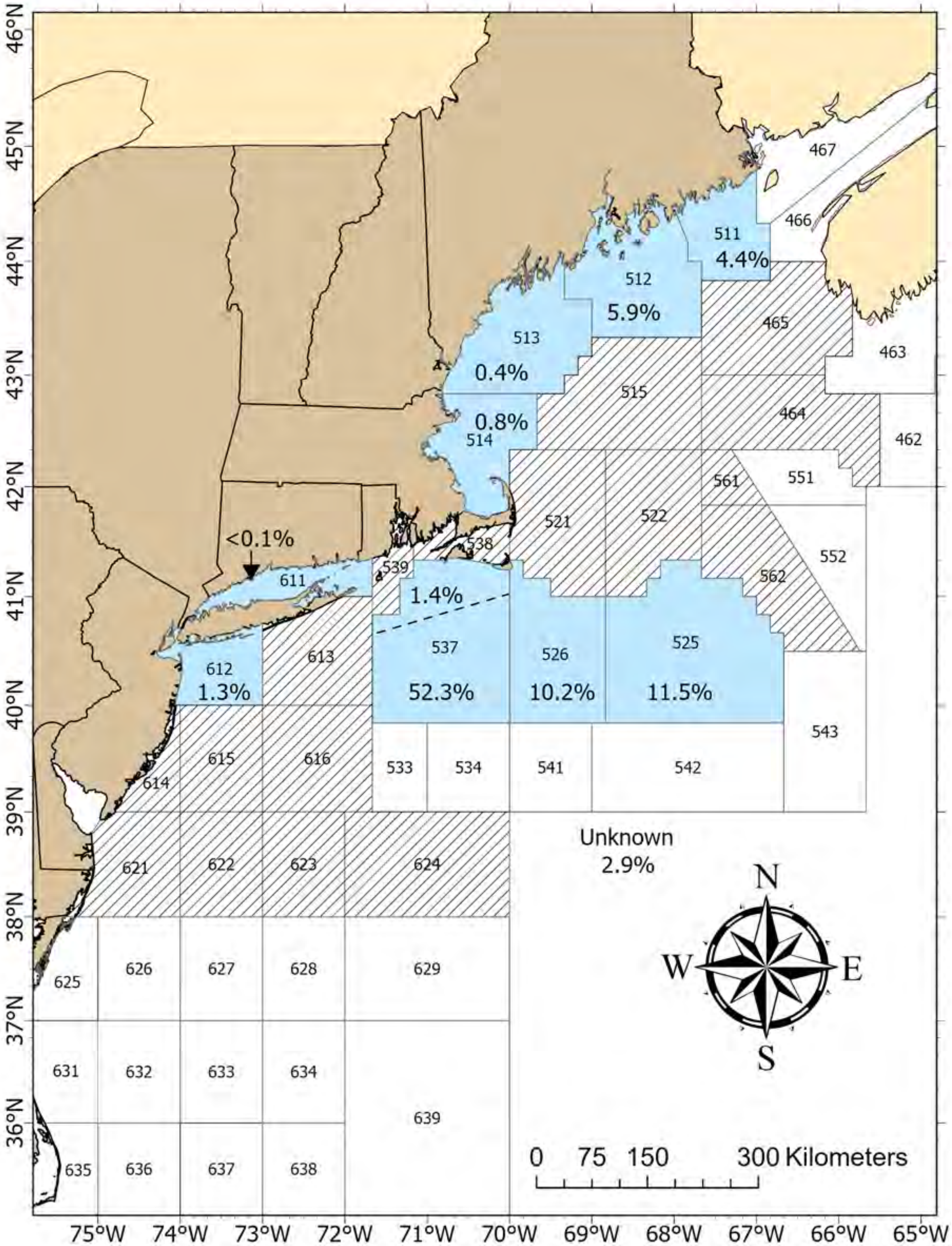

Figure 26. Percent of 2016 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

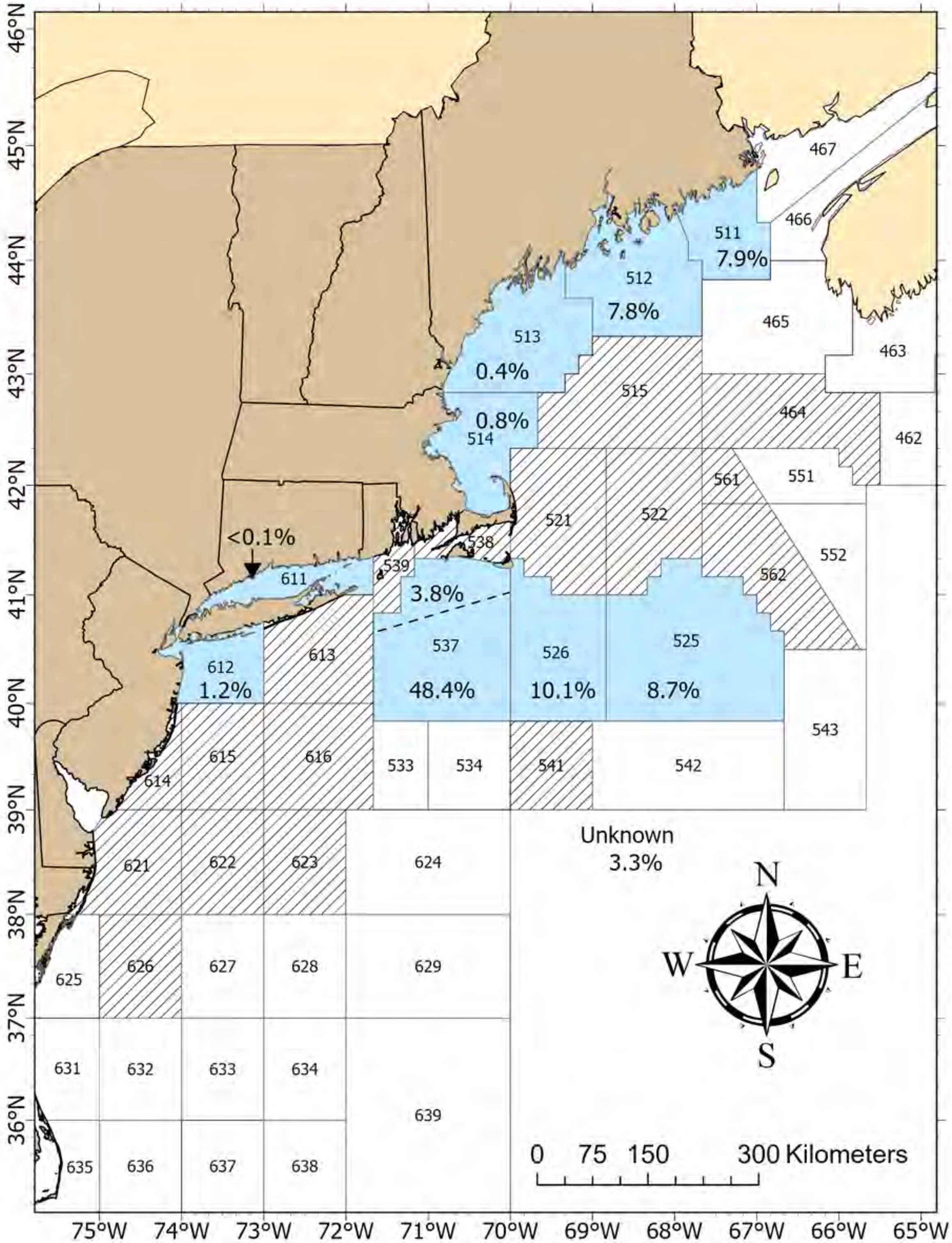

Figure 27. Percent of 2017 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

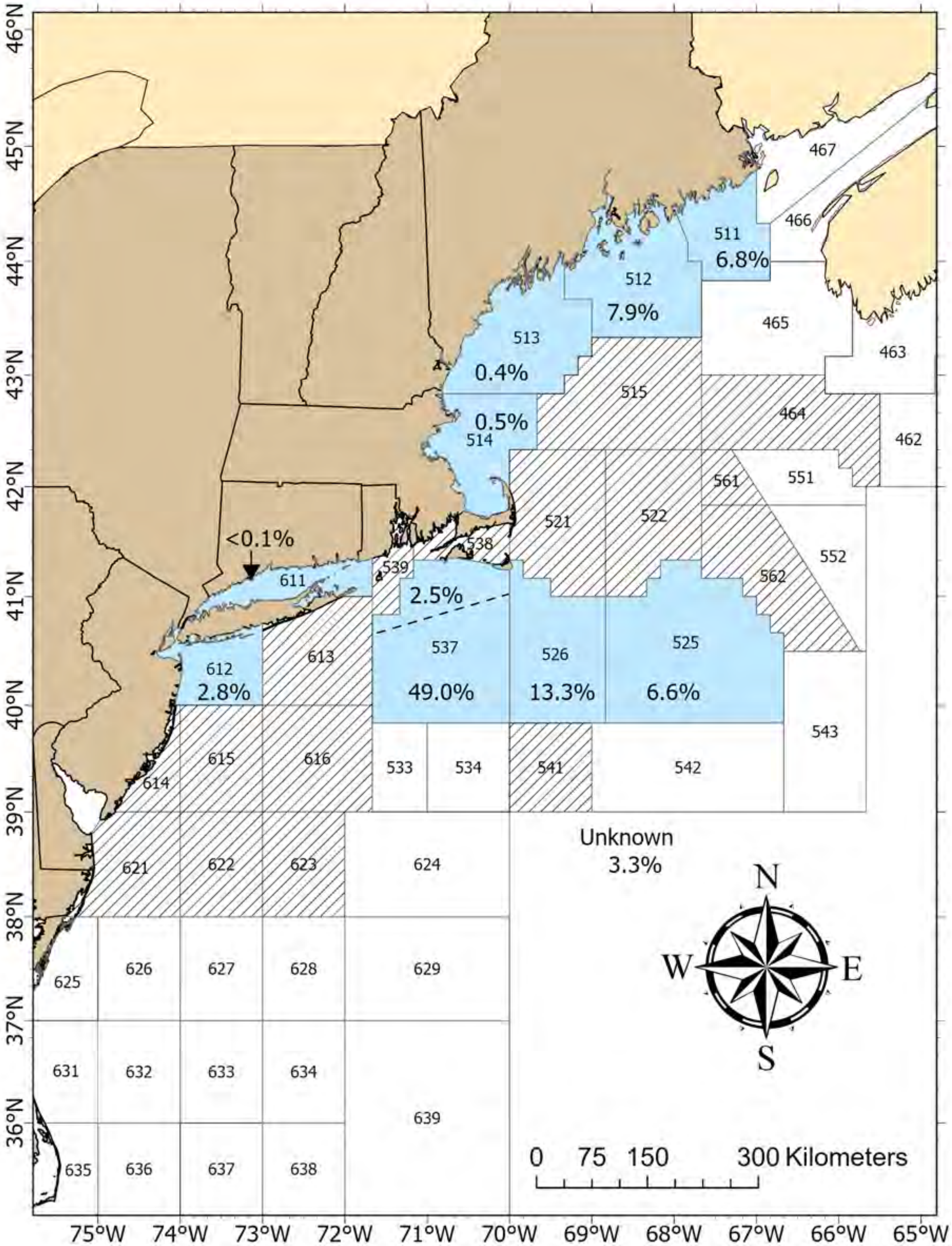

Figure 28. Percent of 2018 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

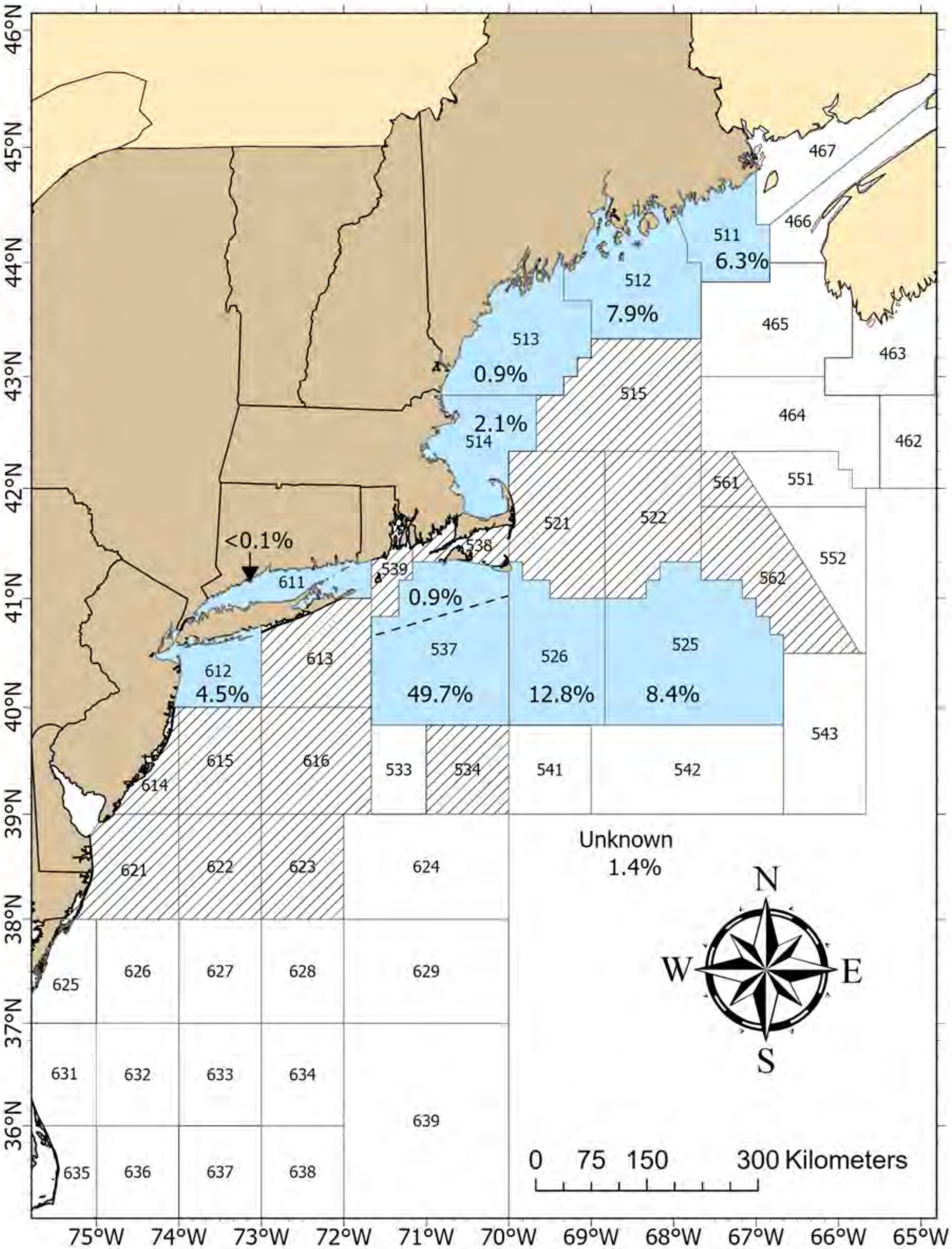

Figure 29. Percent of 2019 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

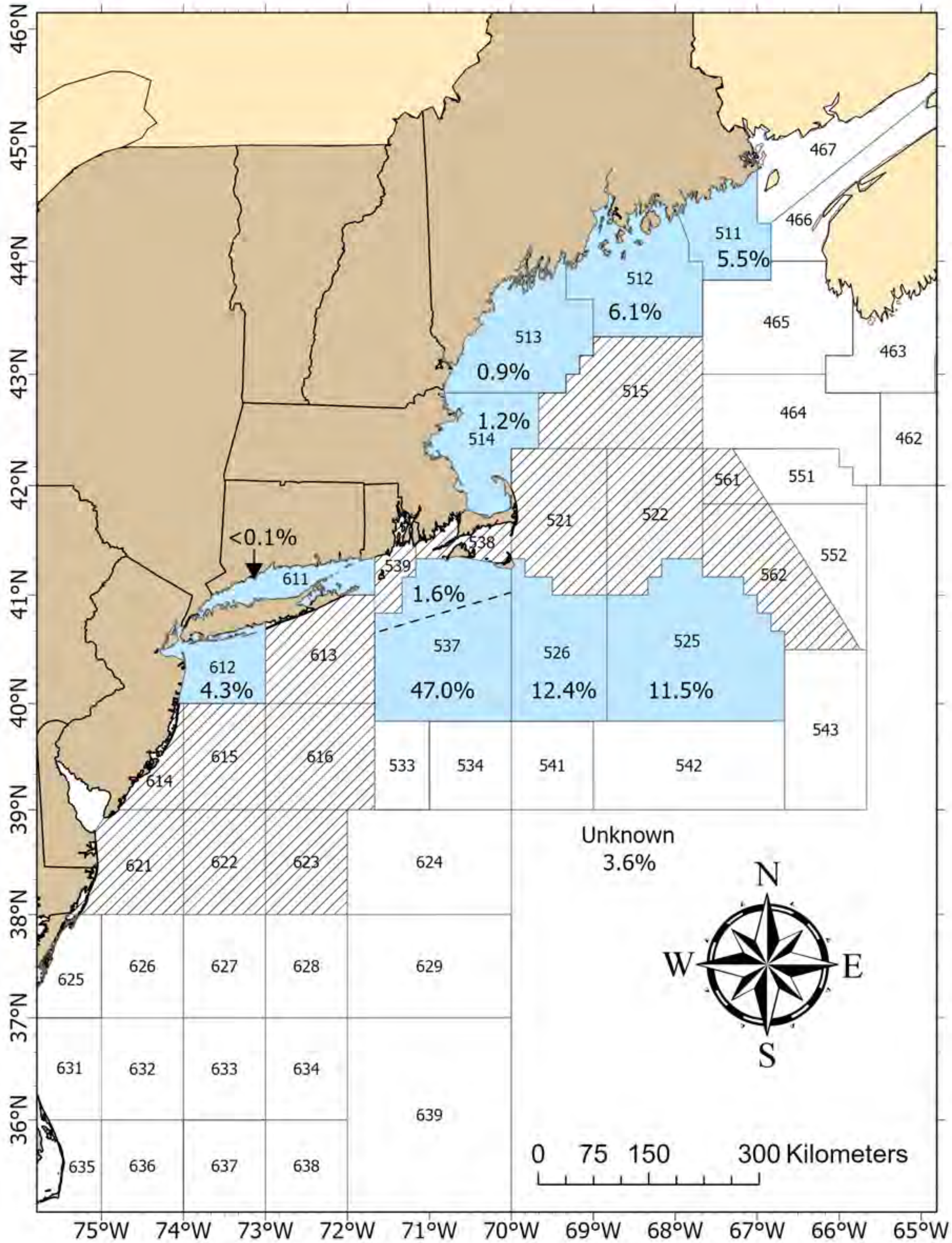

Figure 30. Percent of 2020 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

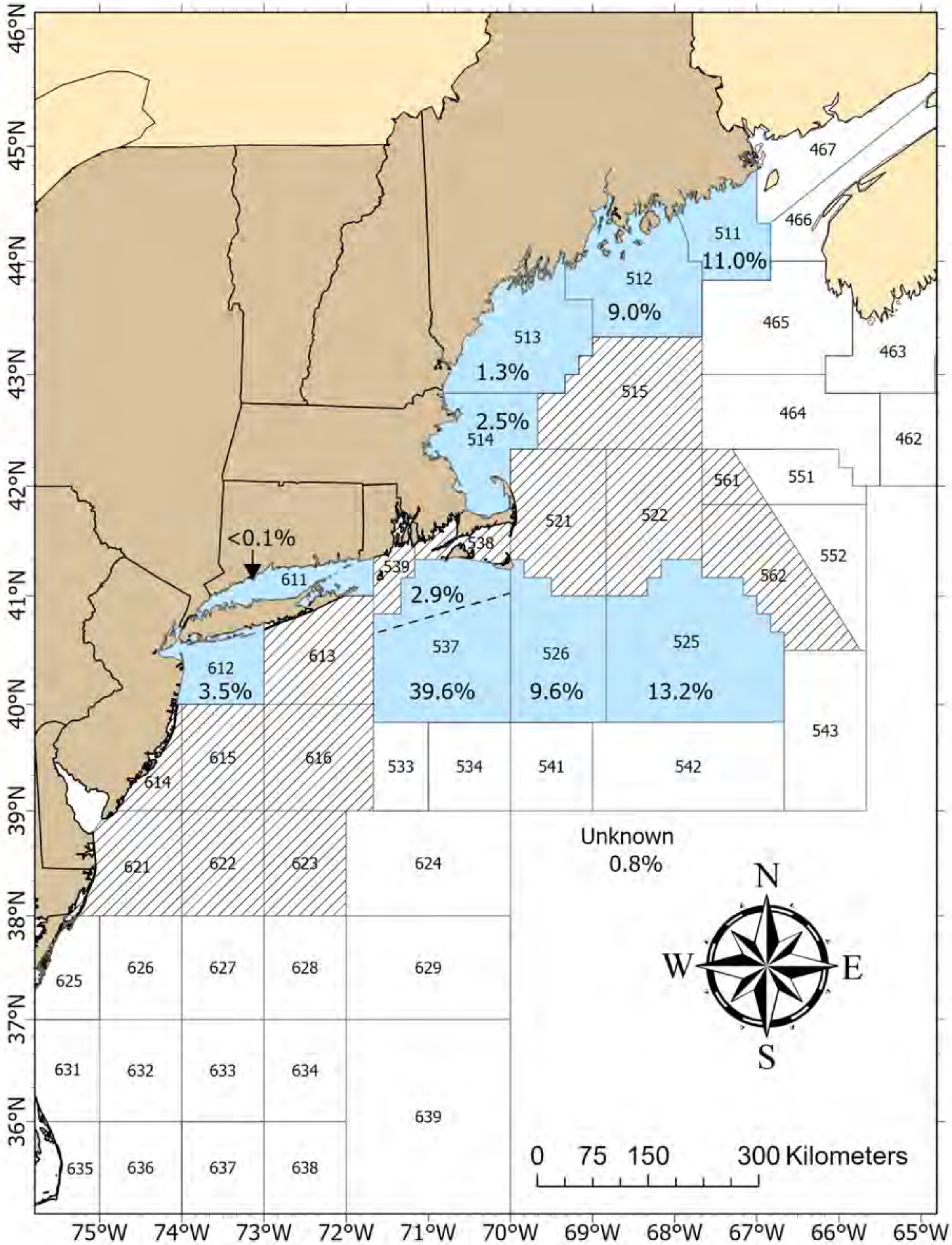

Figure 31. Percent of 2021 U.S. Jonah crab landings by NMFS statistical area. Statistical area 537 is divided (dashed line) into inshore (LMA 2) and offshore (LMA 3) regions. NMFS statistical areas with hash marks represent confidential data (fewer than three fishers reported landings). Areas with no reported landings are white.

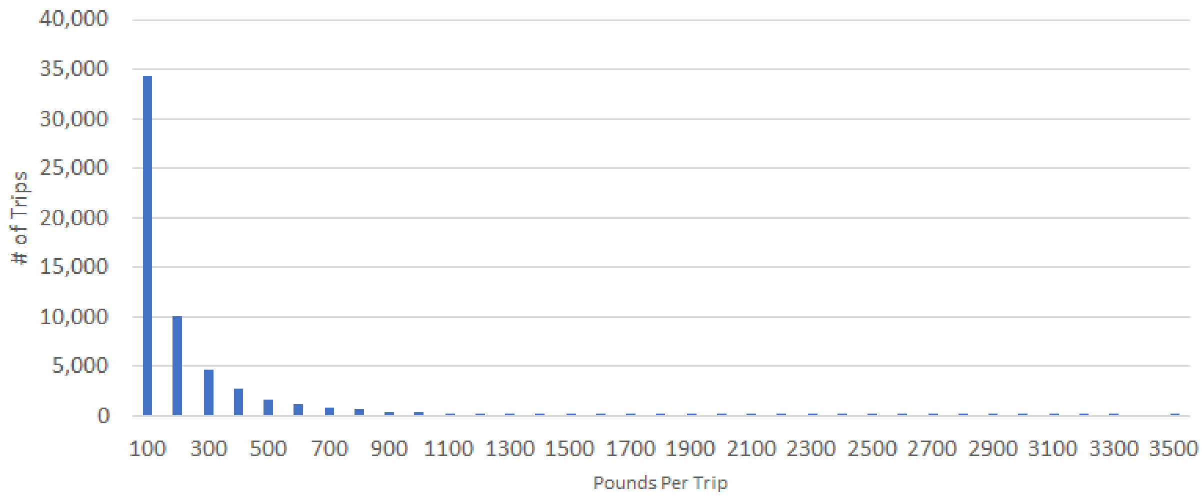

Figure 32. Landings per trip of Jonah crab for Maine trips, all ME trips landing Jonah crab, 2018-2021.

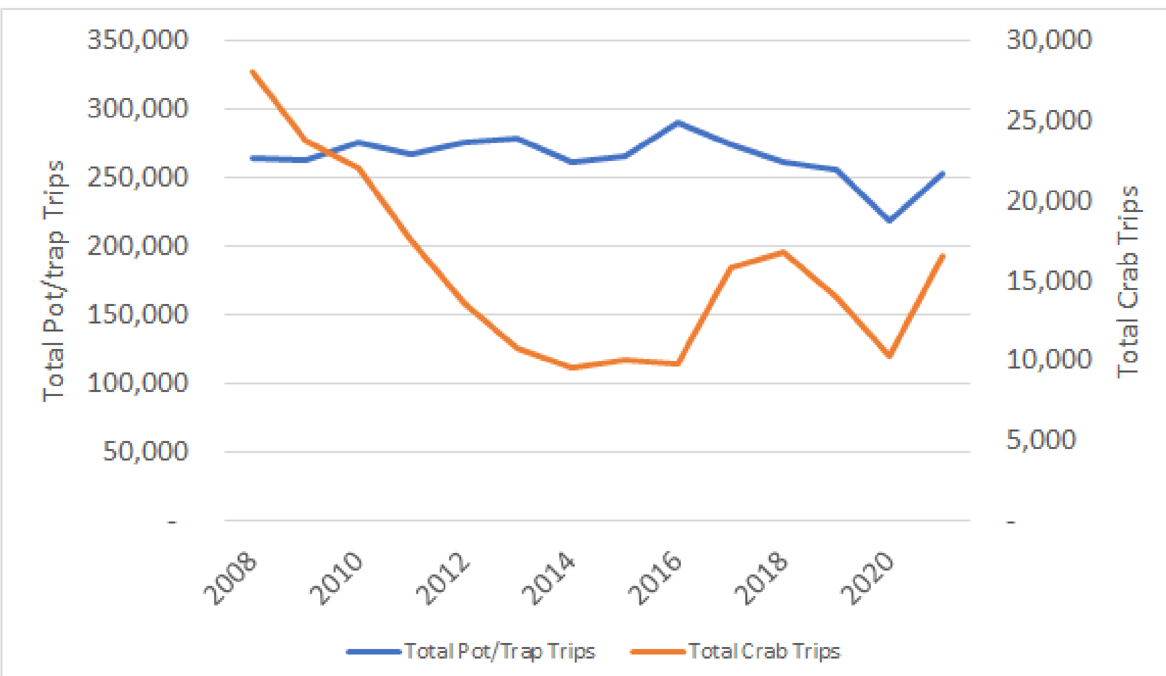

Figure 33. Total active trap/pot trips and total trips with Jonah crab 2008-2021.

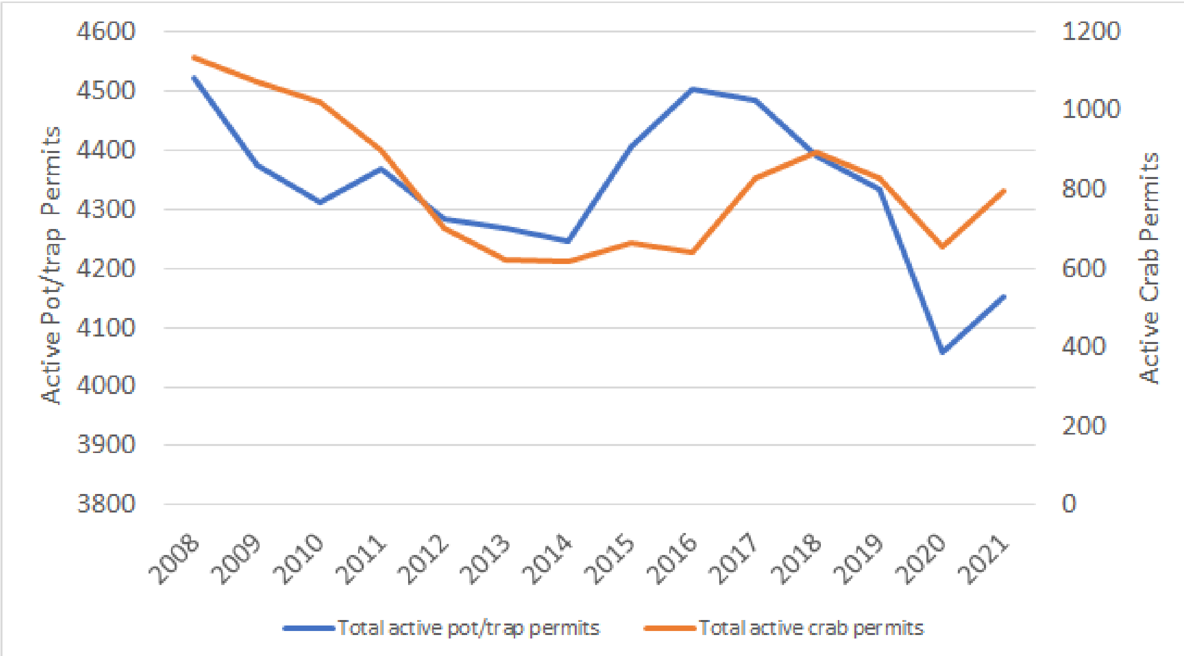

Figure 34. Total active trap/pot permits and active permits landing Jonah crab 2008-2021.

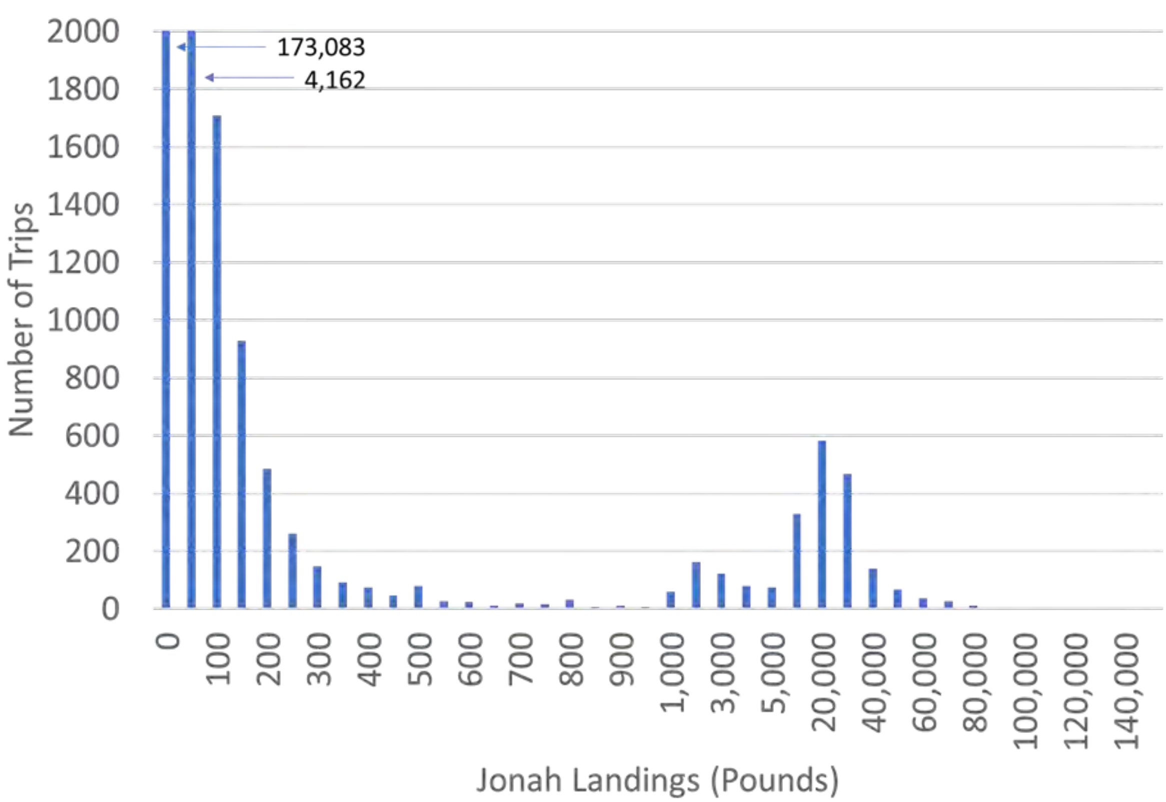

Figure 35. Number of Massachusetts lobster/edible crab pot trips landings Jonah crab pooled from 2018 through 2021. X-axis is discontinuous to account for high variability of trips with greater landings.

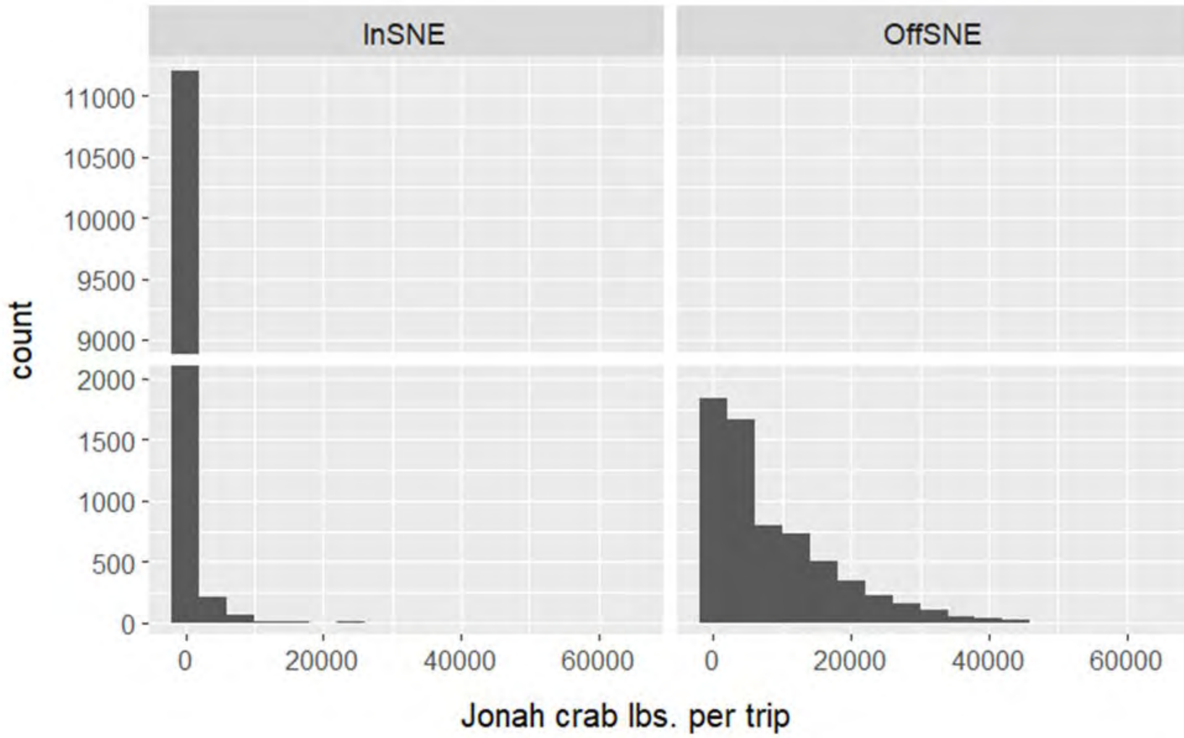

Figure 36. Histogram of landings per trip of Jonah crab for Rhode Island Inshore SNE and Offshore SNE trips, all RI trips landing Jonah crab, 2007-2021.

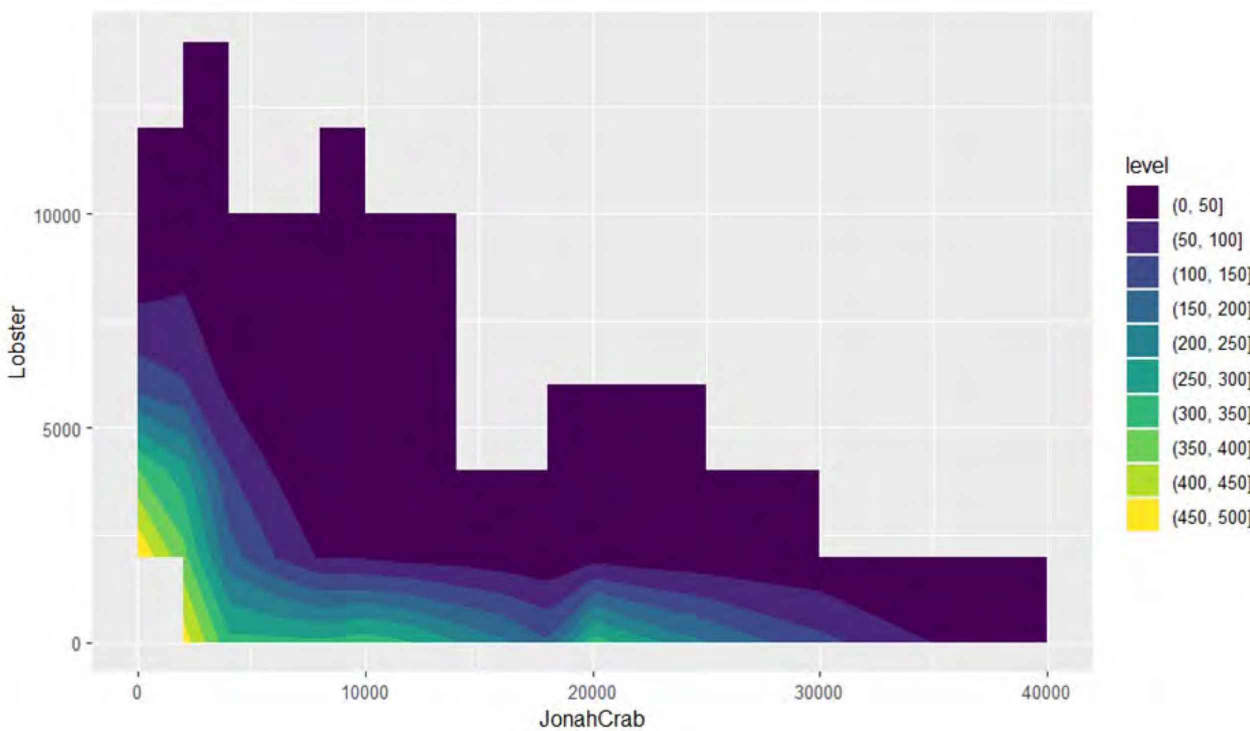

Figure 37. Density plot of Jonah crab versus lobster landings, all trips landing more than 500 lb. Jonah crab, 2007-2021.

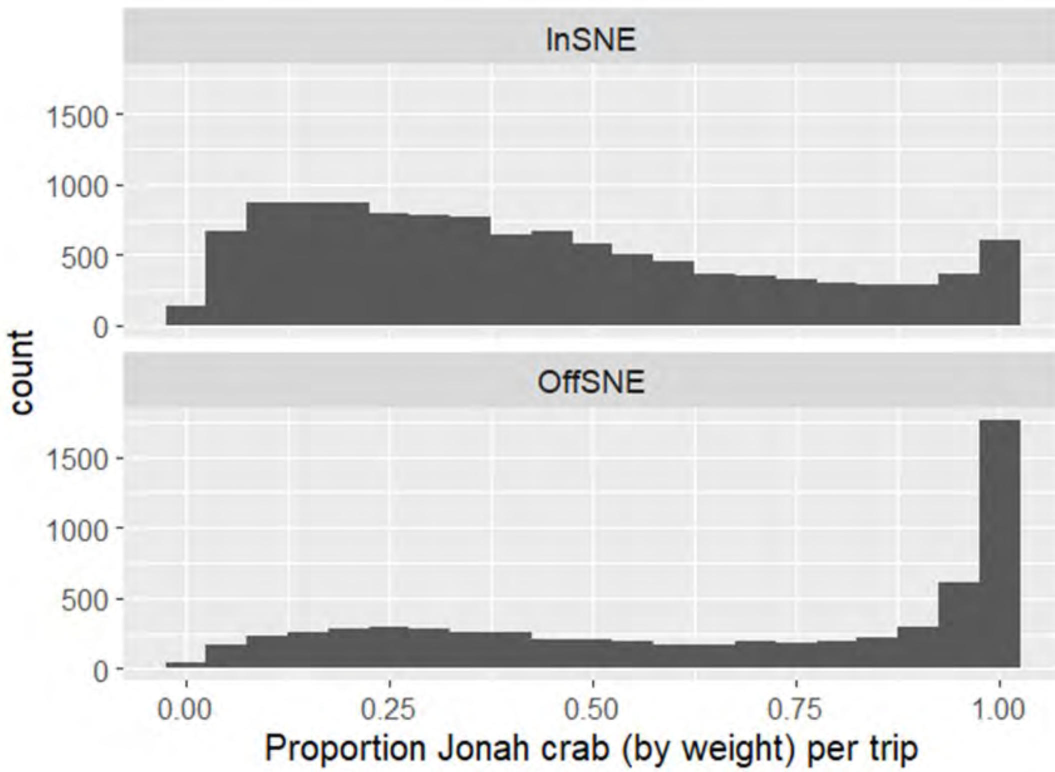

Figure 38. Histogram of Jonah crab proportion of harvest by weight (compared with lobster) for inshore and offshore SNE stocks. All RI trips landing Jonah crab, 2007-2021.

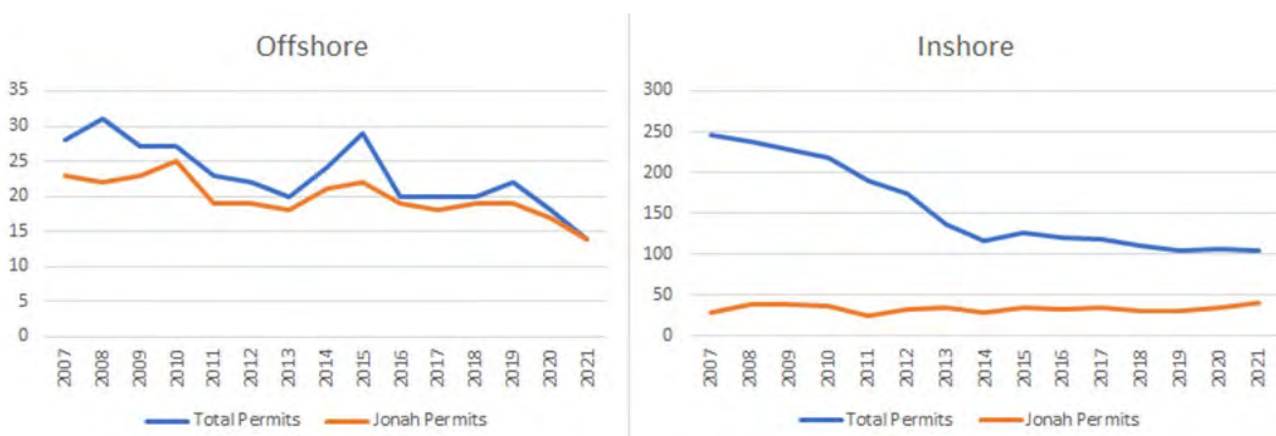

Figure 39. Number of active lobster permits and Jonah crab permits, Rhode Island Offshore SNE and Inshore SNE harvesters, 2007 to 2021.

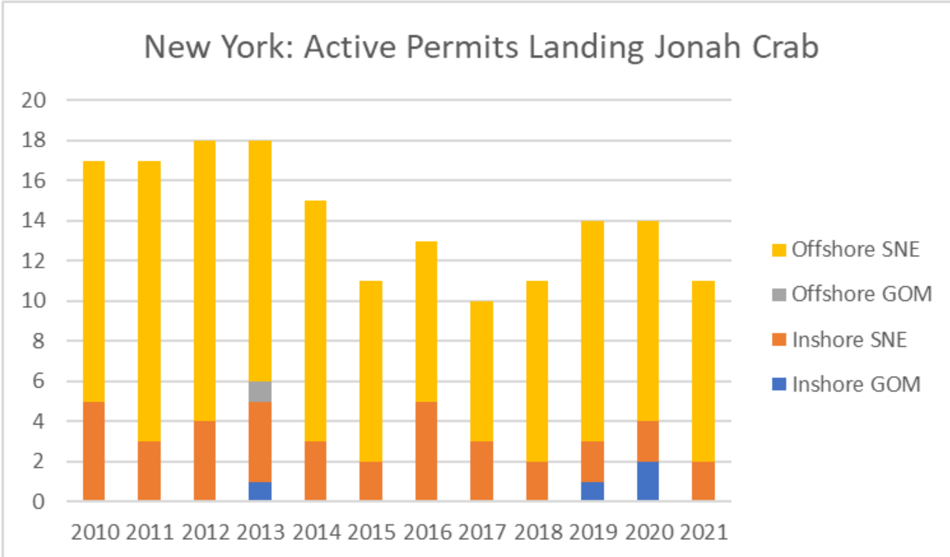

Figure 40. Active New York lobster/crab permits landings Jonah crab from each Jonah crab stock.

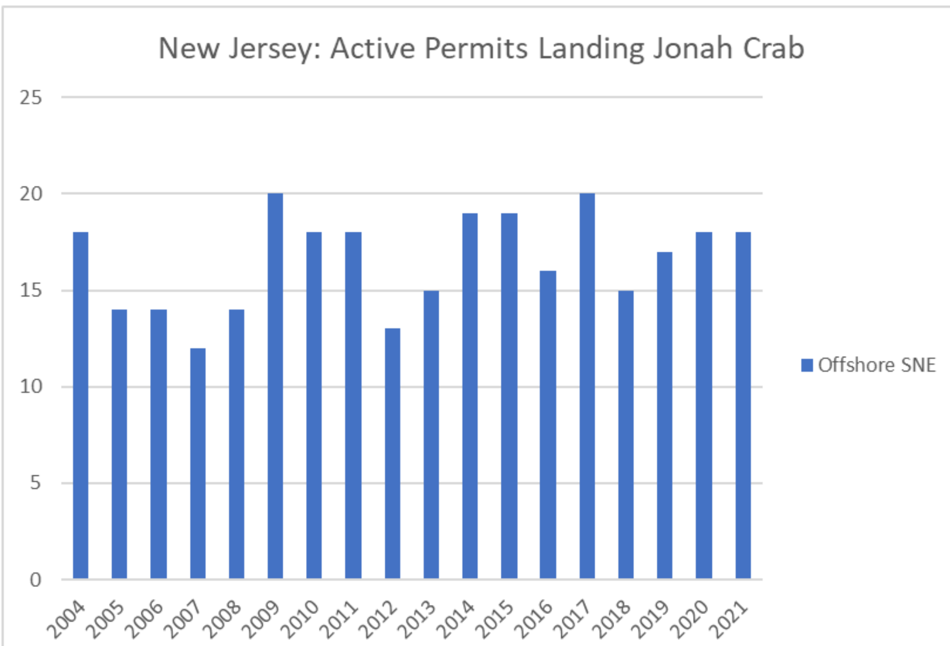

Figure 41. Active New Jersey lobster/crab permits landings Jonah crab from the OSNE Jonah crab stock.

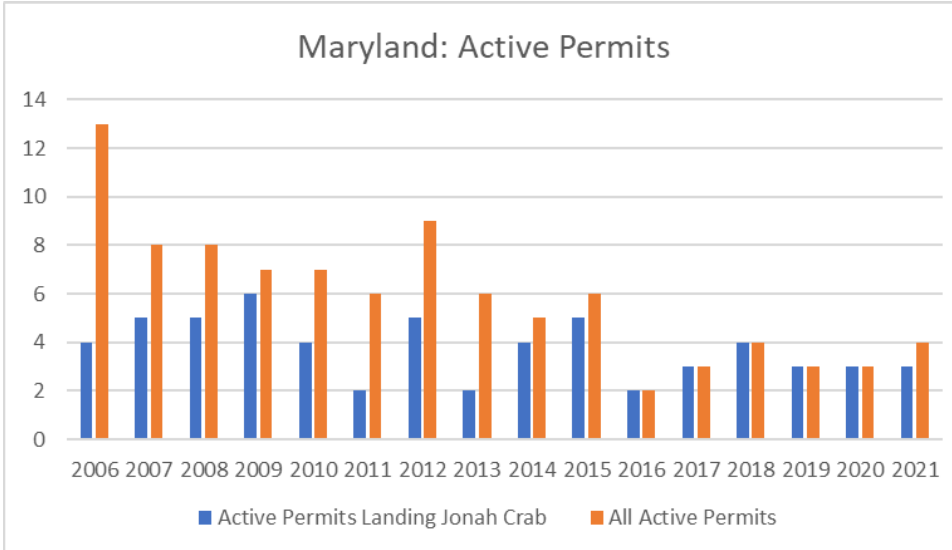

Figure 42. Maryland lobster/crab permit summary including those that have landed Jonah crab from the OSNE Jonah crab stock.

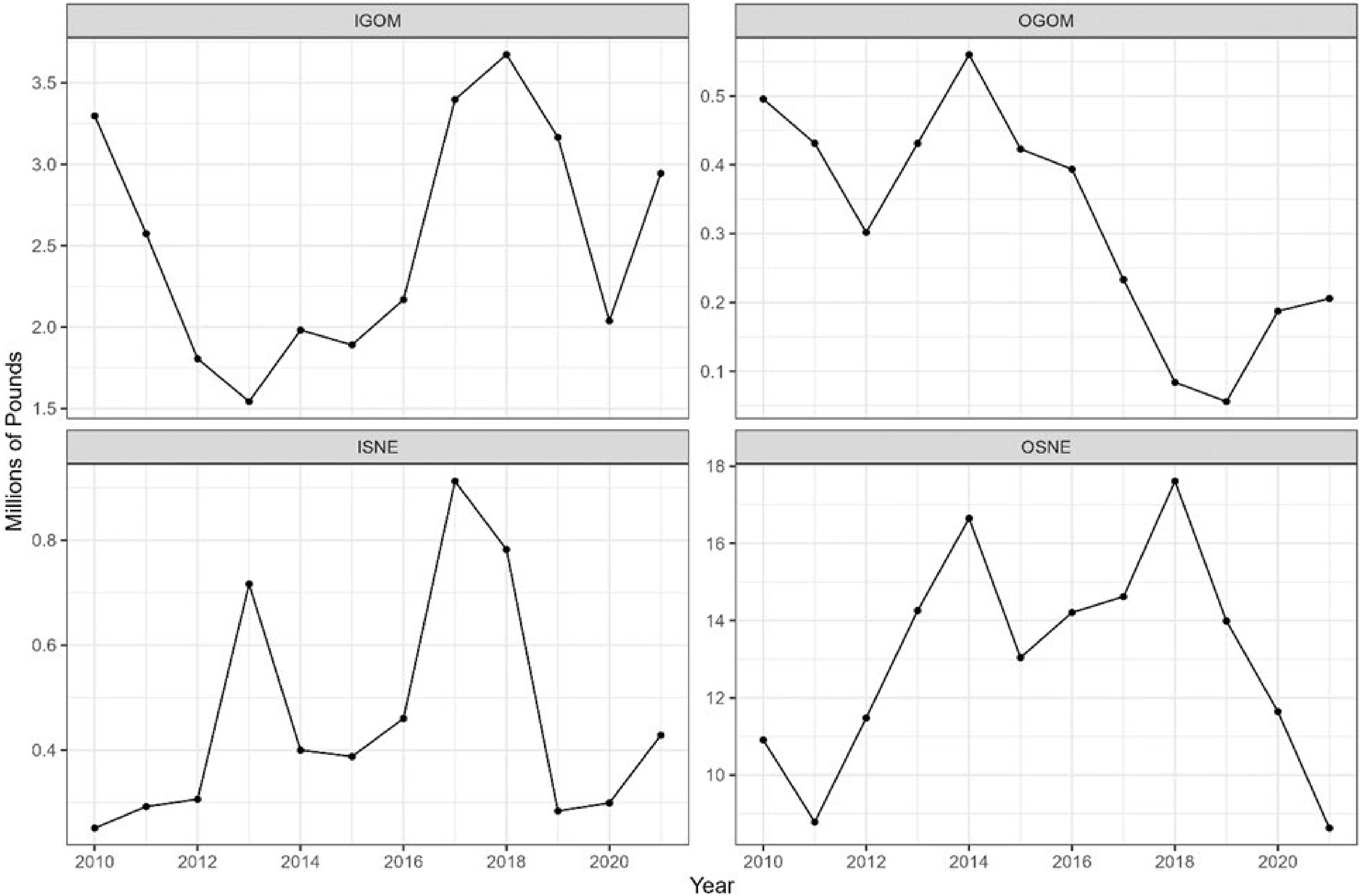

Figure 43. Stock-specific Jonah crab landings.

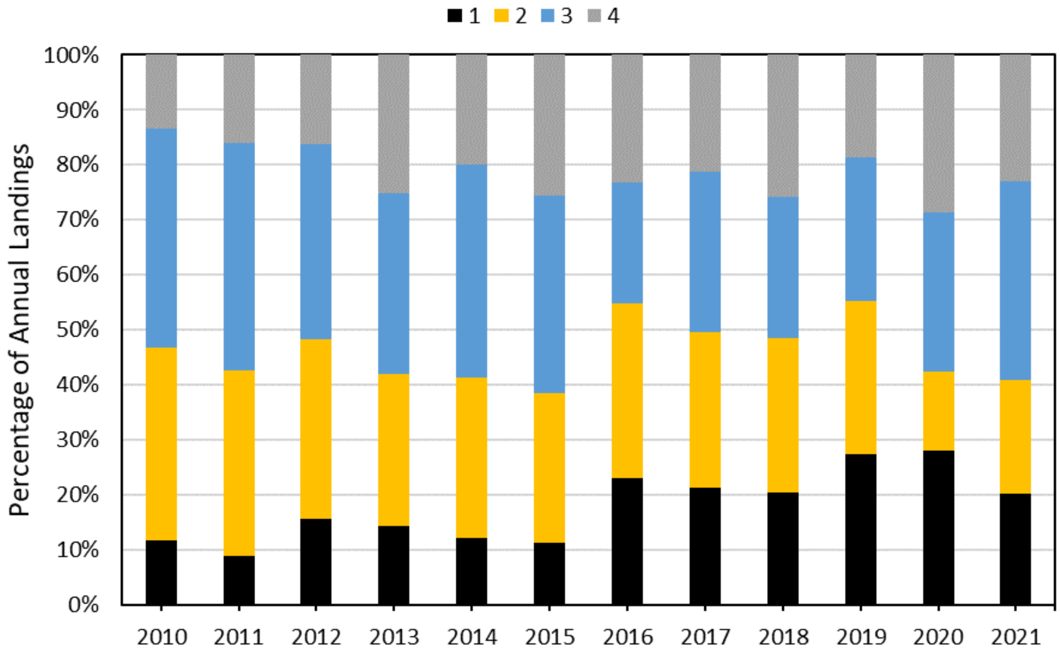

Figure 44. Quarterly breakdown of annual landings from the IGOM Jonah crab stock.

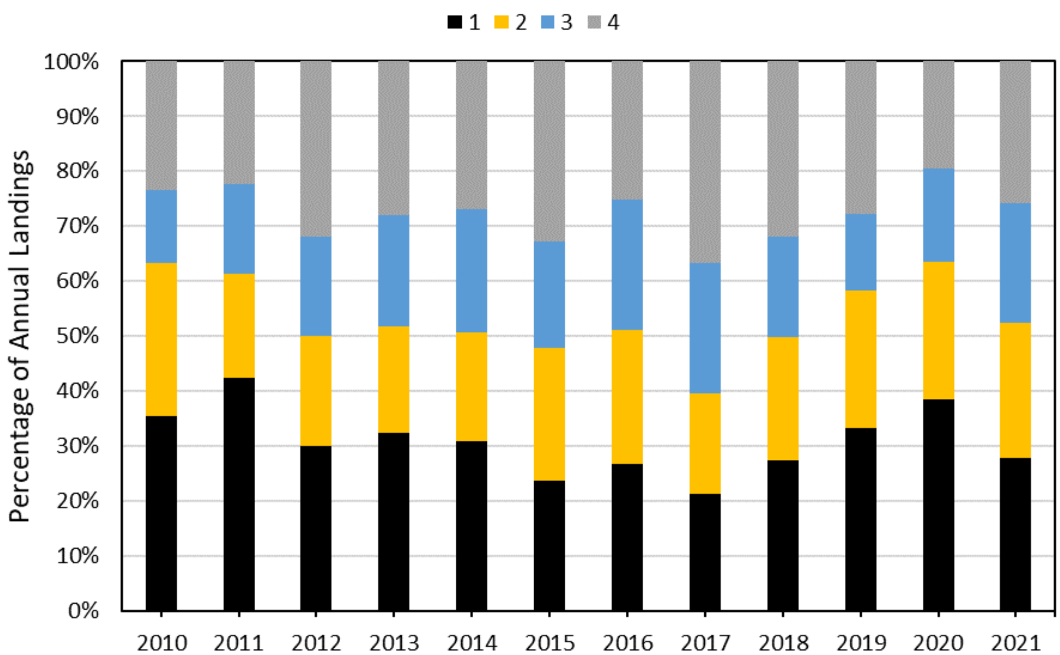

Figure 45. Quarterly breakdown of annual landings from the OSNE Jonah crab stock.

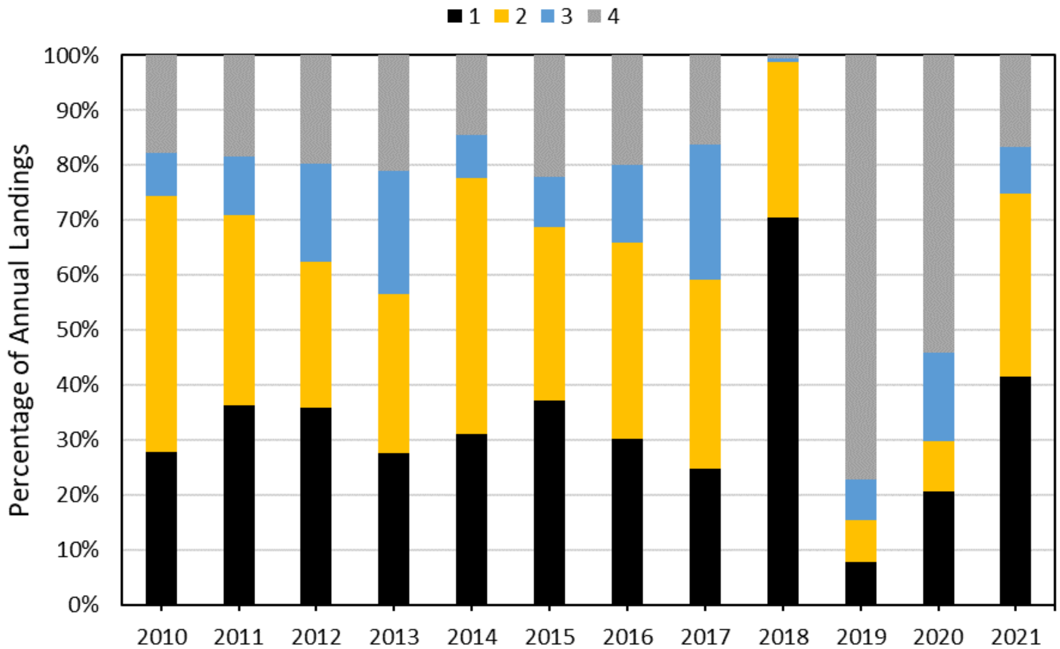

Figure 46. Quarterly breakdown of annual landings from the OGOM Jonah crab stock.

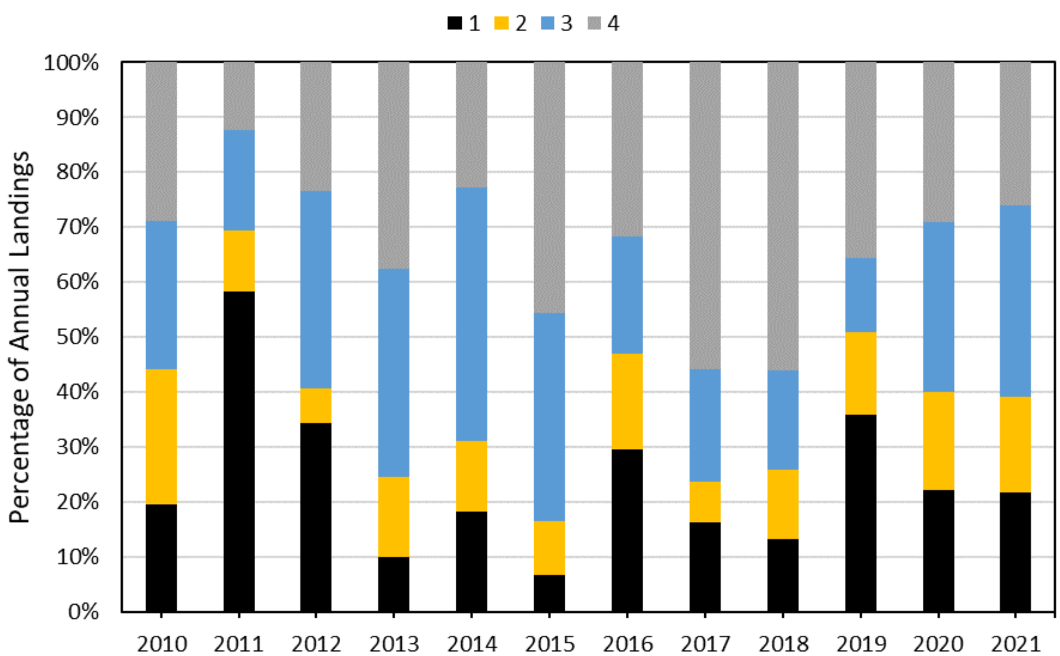

Figure 47. Quarterly breakdown of annual landings from the ISNE Jonah crab stock.

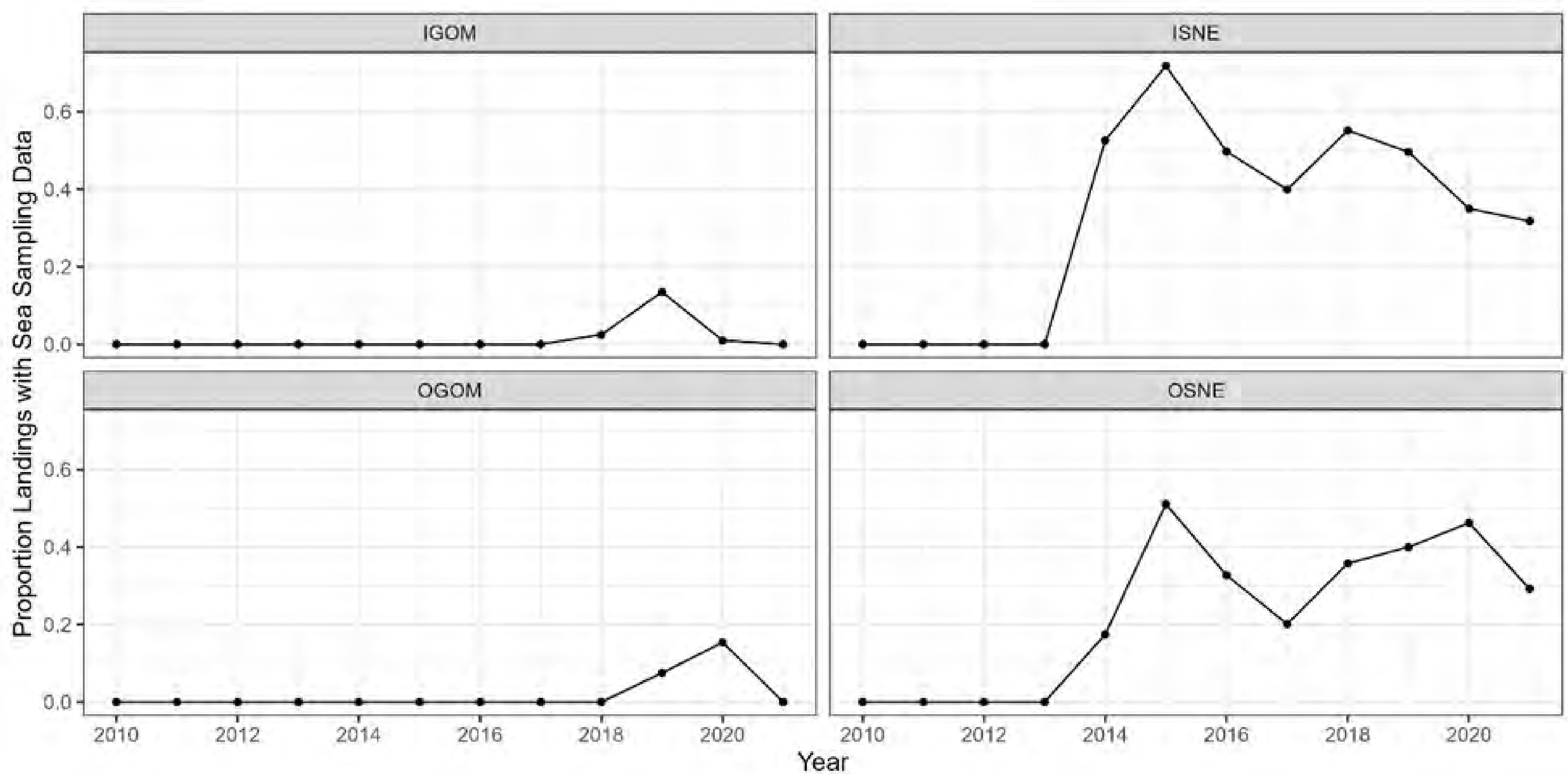

Figure 48. Proportion of landings with associated sea sampling data.

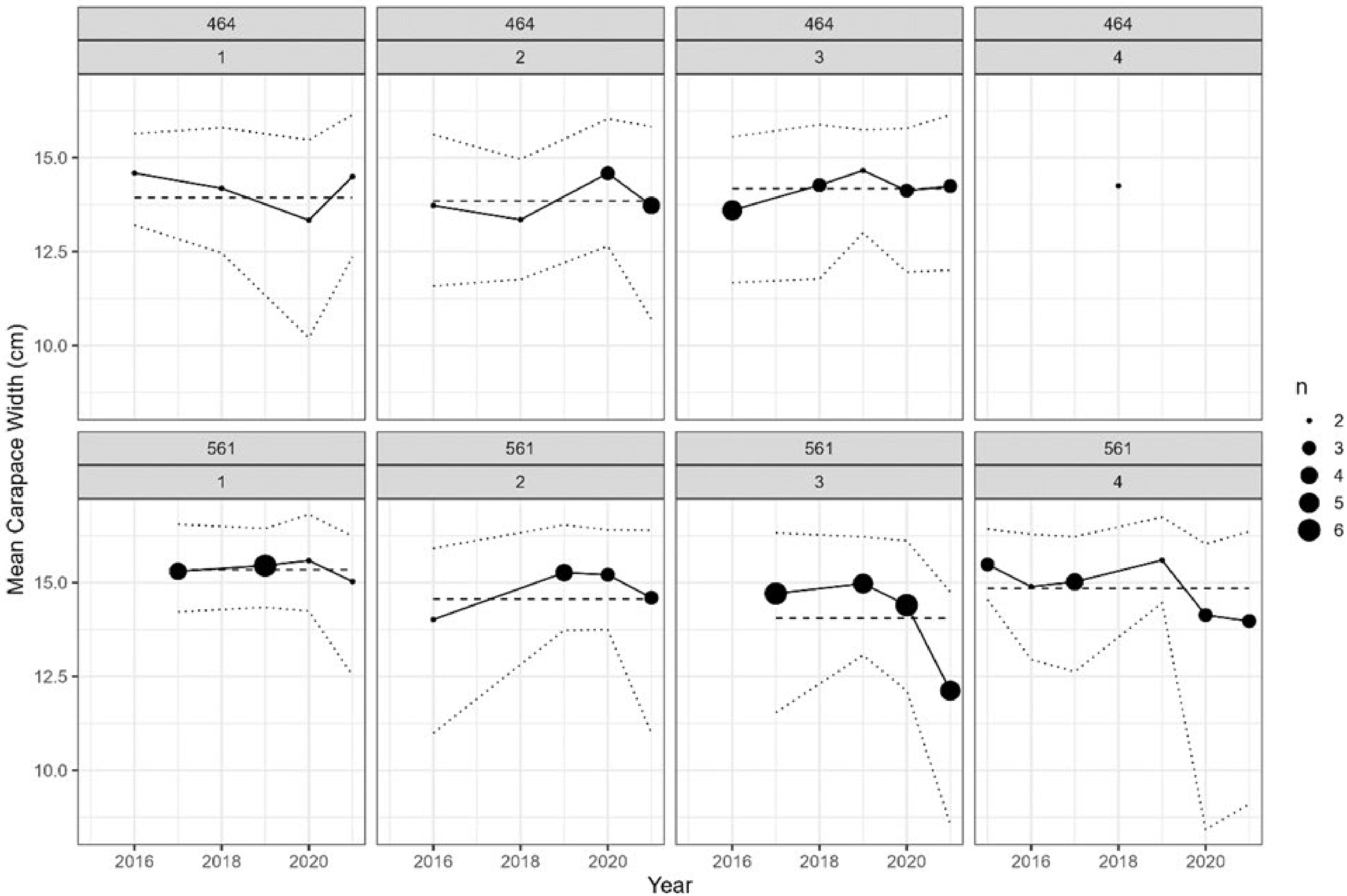

Figure 49. Mean CW (solid circles with size scaled to number of sampling trips) of males in the overall catch from OGOM sea sampling data by statistical area (top panel ribbon) and quarter (bottom panel ribbon). Dotted lines indicate the 5th and 95th percentile of CW and the dashed line indicates the mean CW across years. Data points from statistical areas 465, 511, 512, 515, and 522 are not included because there were no quarters in these statistical areas with at least five data points.

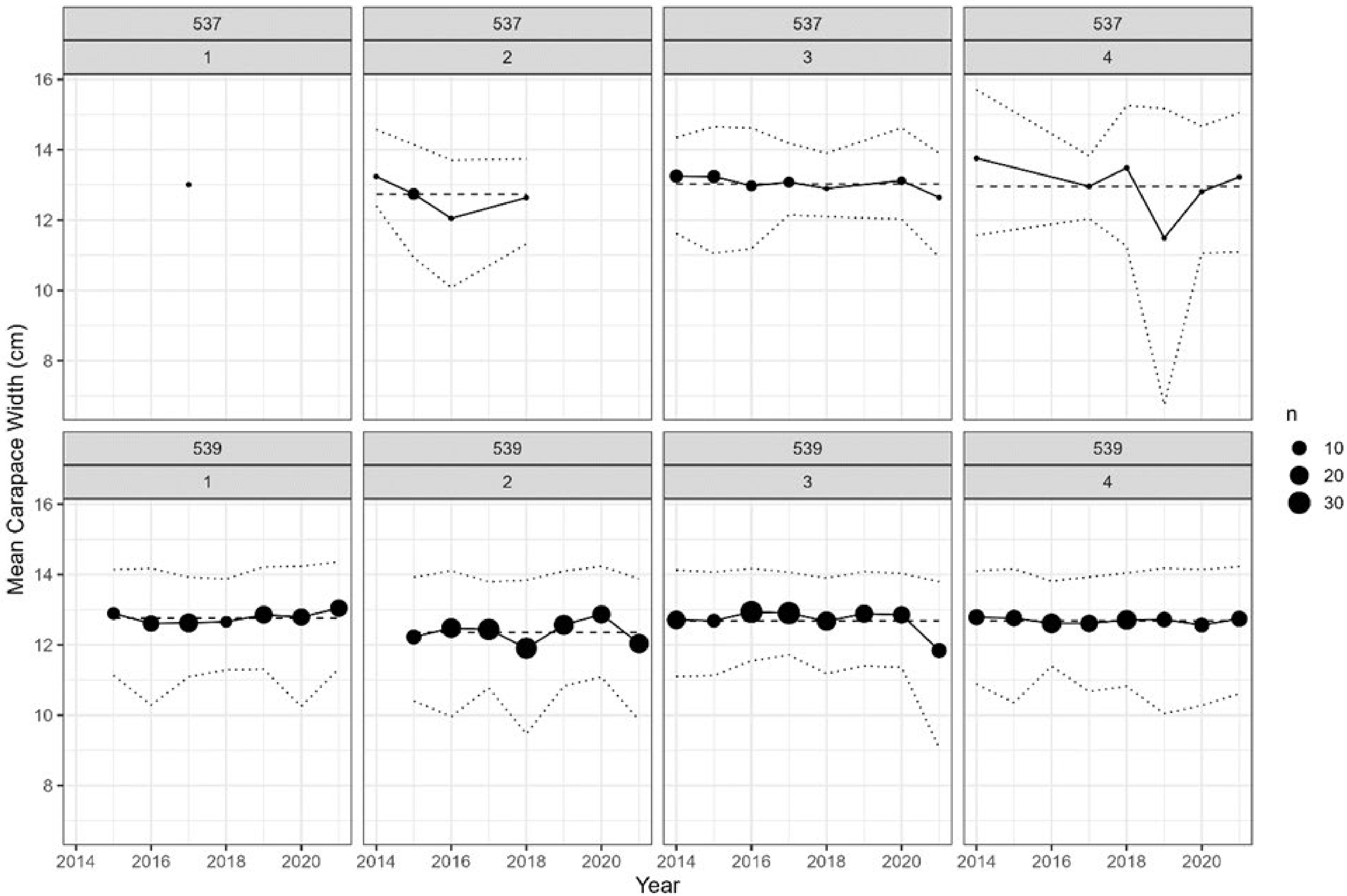

Figure 50. Mean CW (solid circles with size scaled to number of sampling trips) of males in the overall catch from ISNE sea sampling data by statistical area (top panel ribbon) and quarter (bottom panel ribbon). Dotted lines indicate the 5th and 95th percentile of CW and the dashed line indicates the mean CW across years.

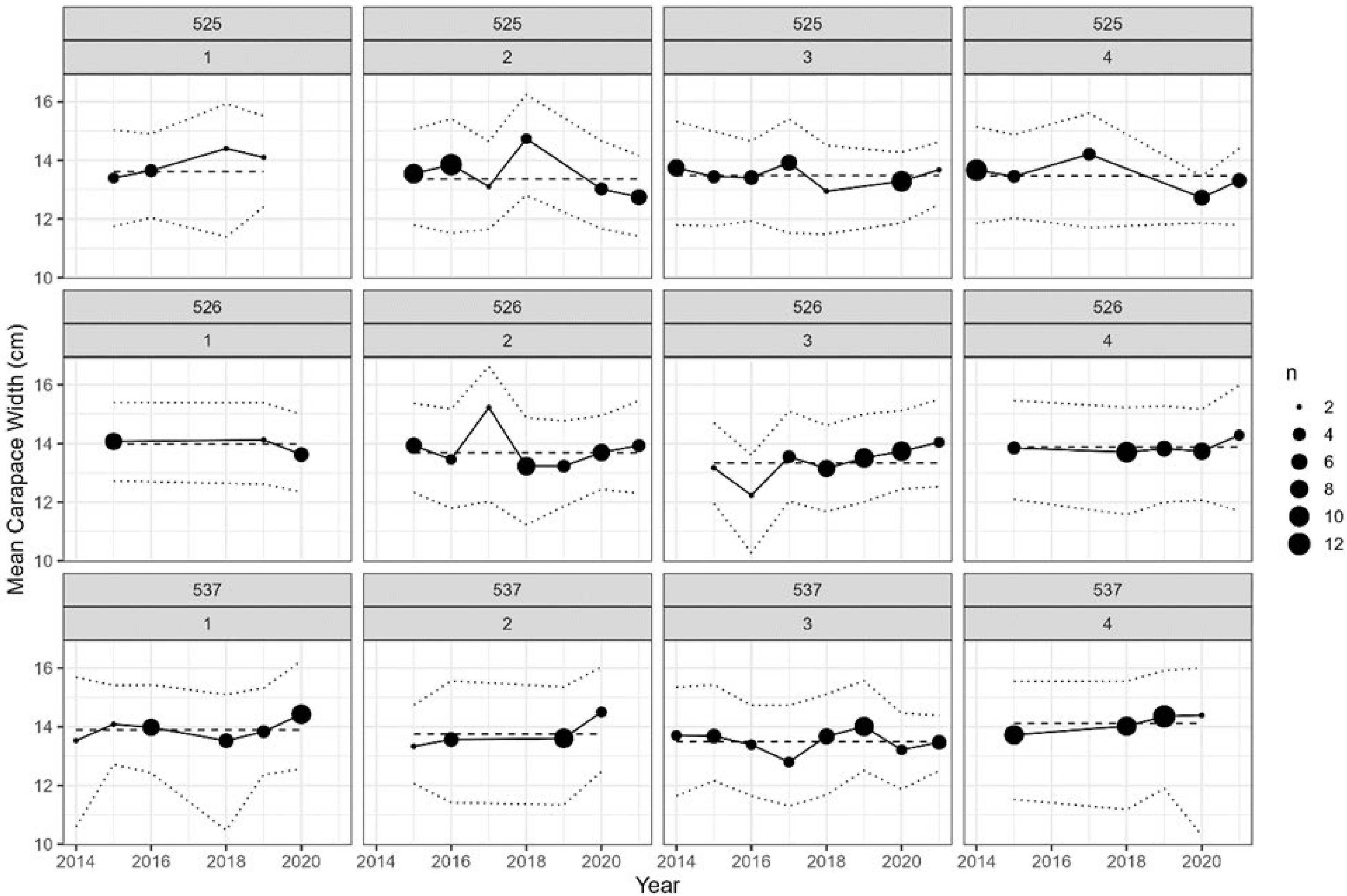

Figure 51. Mean CW (solid circles with size scaled to number of sampling trips) of males in the overall catch from OSNE sea sampling data by statistical area (top panel ribbon) and quarter (bottom panel ribbon). Dotted lines indicate the 5th and 95th percentile of CW and the dashed line indicates the mean CW across years. Data points from statistical areas 562, 613, 616, and 622 are not included because there were no quarters in these statistical areas with at least five data points.

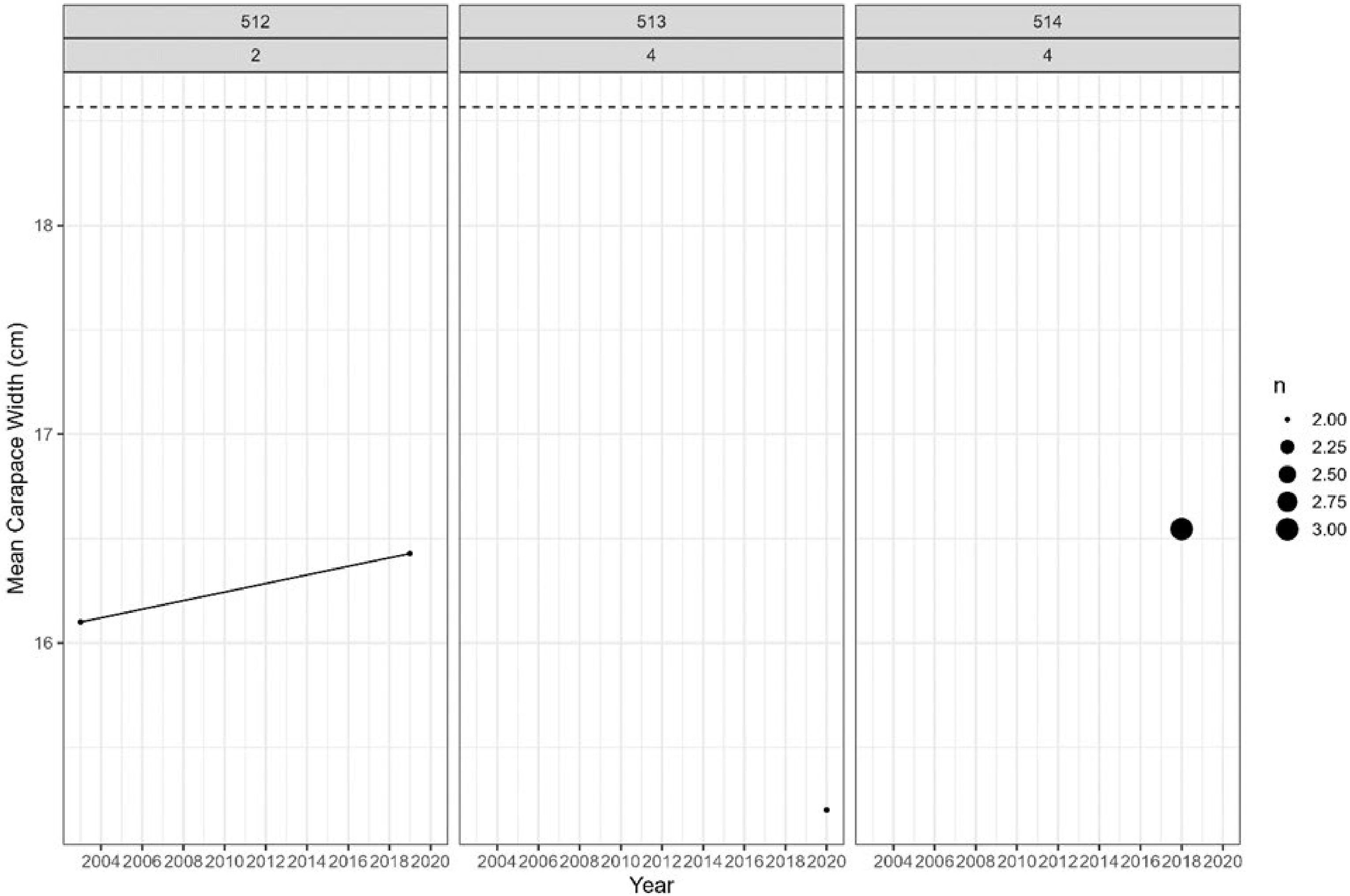

Figure 52. Mean CW (solid circles with size scaled to number of sampling trips) of the 5% largest males in the overall catch from IGOM sea sampling data by statistical area (top panel ribbon) and quarter (bottom panel ribbon). The dashed line indicates 90% of an Linf estimate for Mid-Coast, Maine males (C. Huntsberger, personal communication, October 11, 2022).

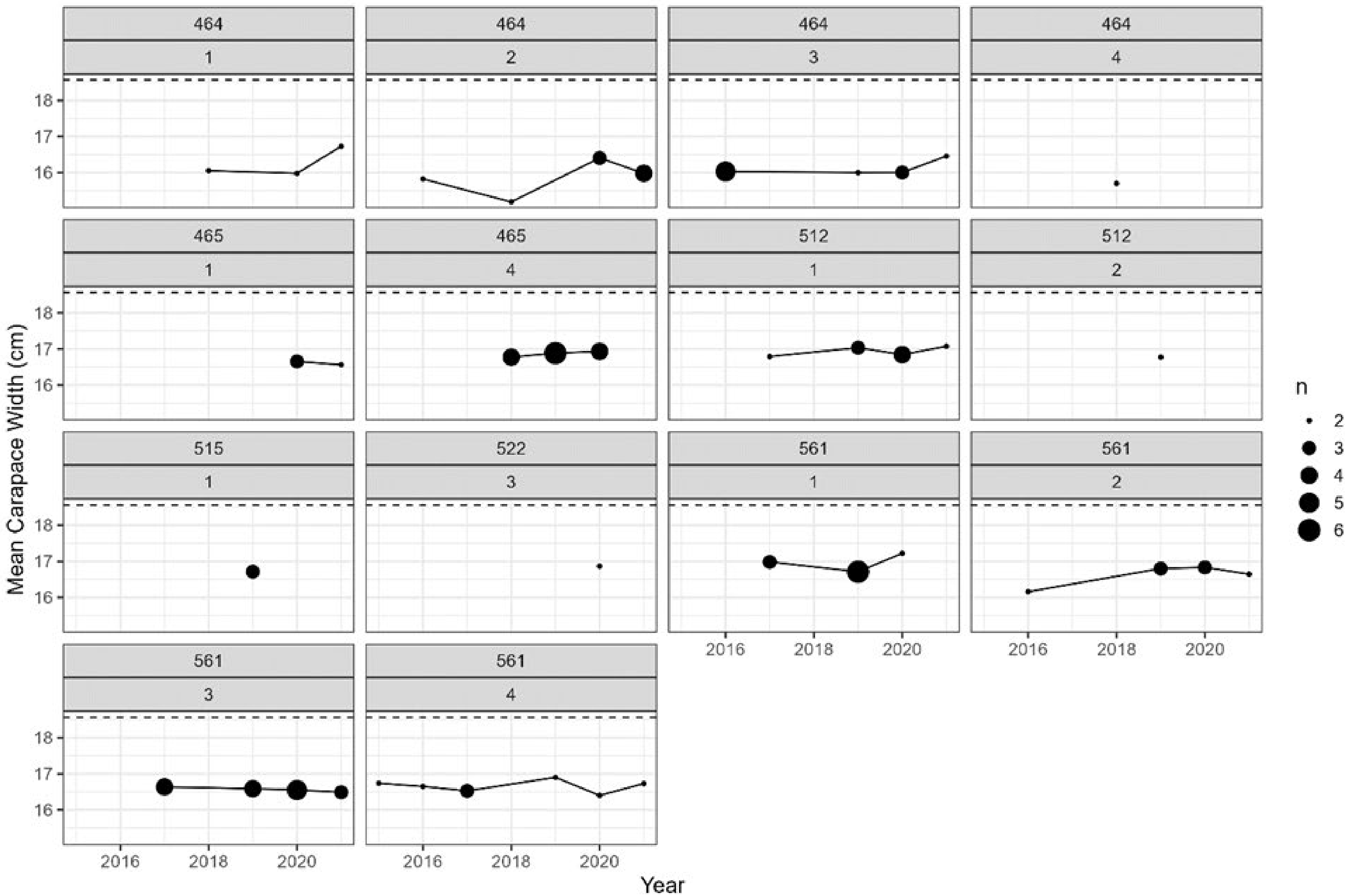

Figure 53. Mean CW (solid circles with size scaled to number of sampling trips) of the 5% largest males in the overall catch from OGOM sea sampling data by statistical area (top panel ribbon) and quarter (bottom panel ribbon). The dashed line indicates 90% of an Linf estimate for Mid-Coast, Maine males (C. Huntsberger, personal communication, October 11, 2022).

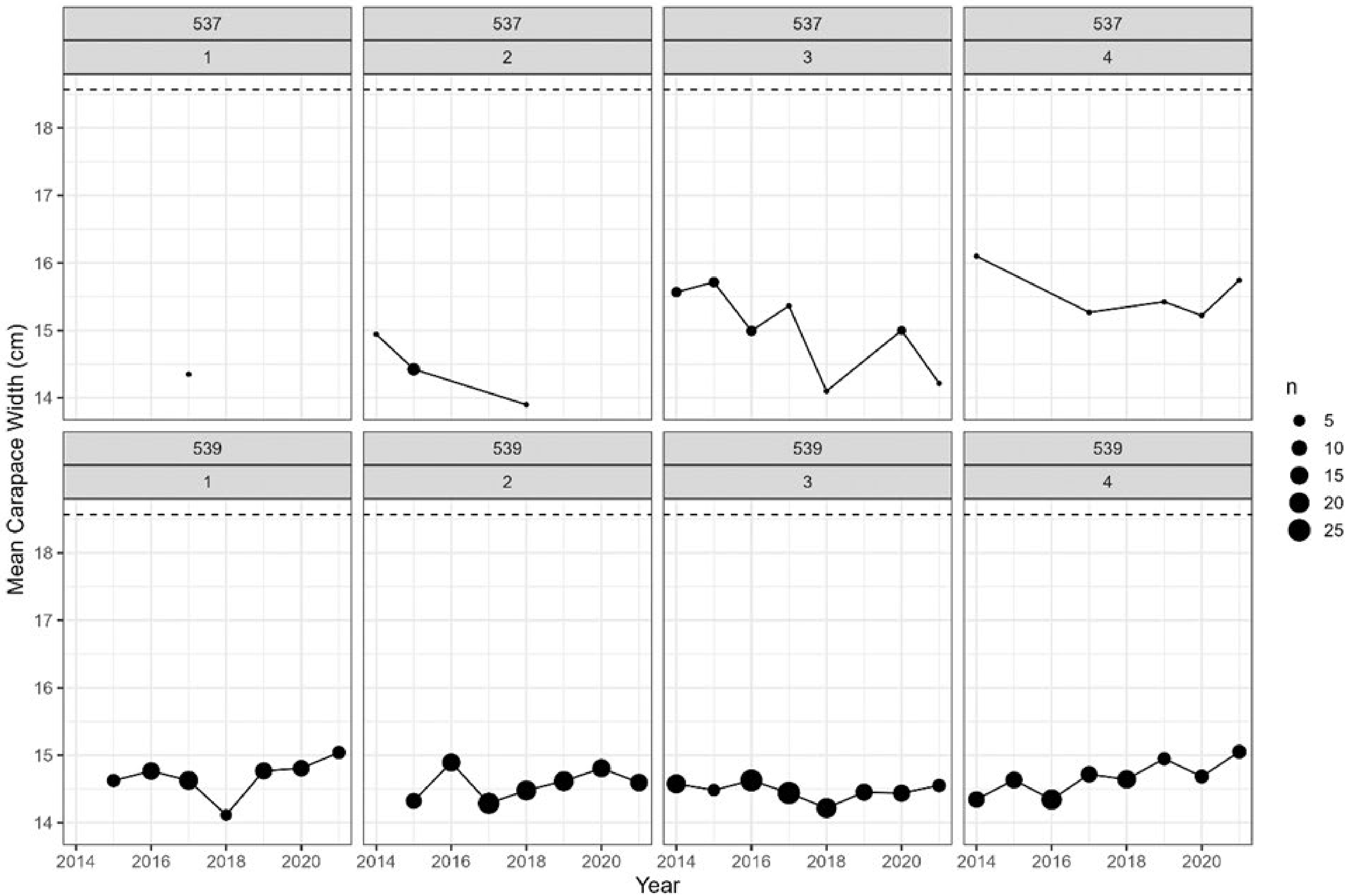

Figure 54. Mean CW (solid circles with size scaled to number of sampling trips) of the 5% largest males in the overall catch from ISNE sea sampling data by statistical area (top panel ribbon) and quarter (bottom panel ribbon). The dashed line indicates 90% of an Linf estimate for Mid-Coast, Maine males (C. Huntsberger, personal communication, October 11, 2022).

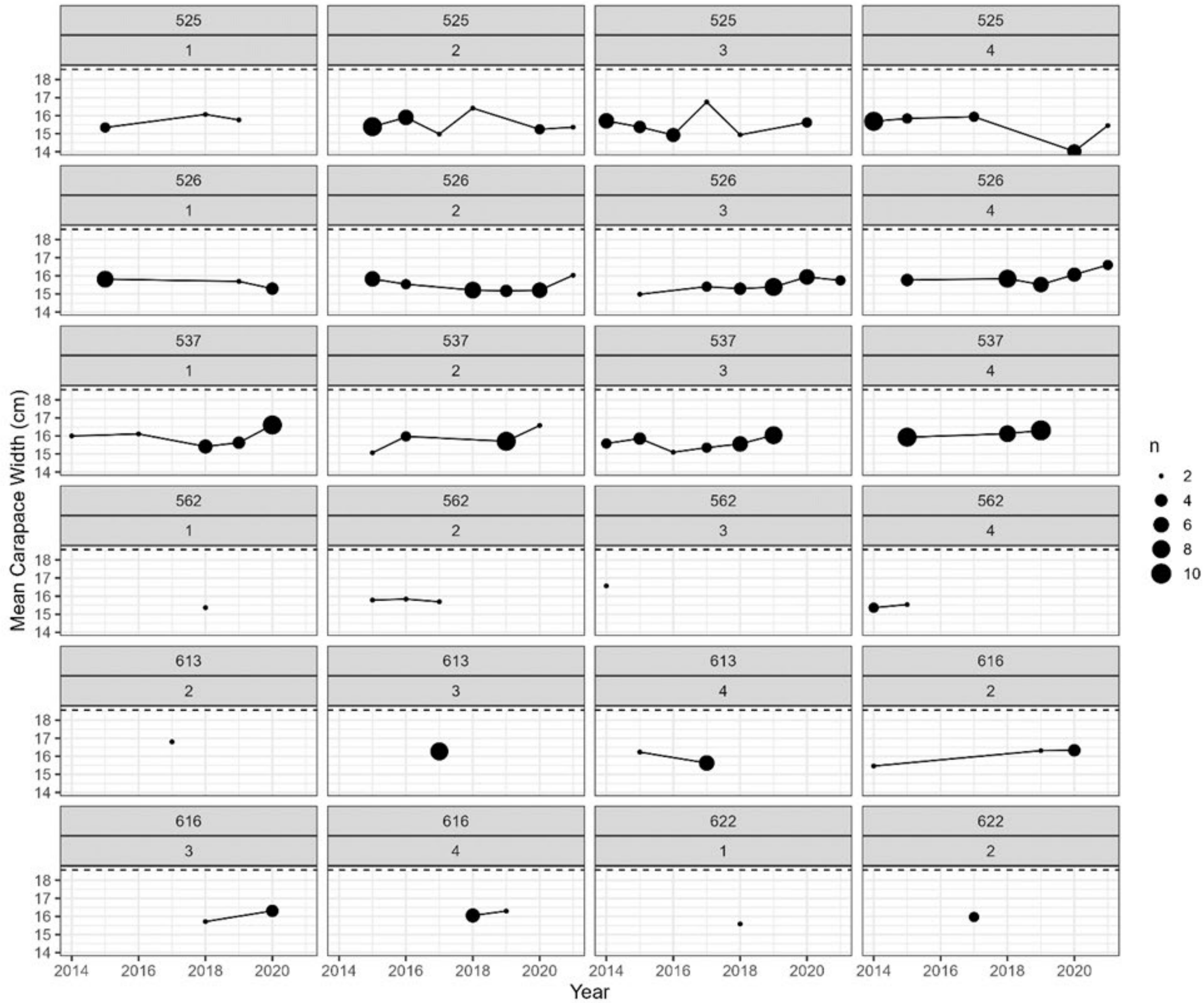

Figure 55. Mean CW (solid circles with size scaled to number of sampling trips) of the 5% largest males in the overall catch from OSNE sea sampling data by statistical area (top panel ribbon) and quarter (bottom panel ribbon). The dashed line indicates 90% of an Linf estimate for Mid-Coast, Maine males (C. Huntsberger, personal communication, October 11, 2022).

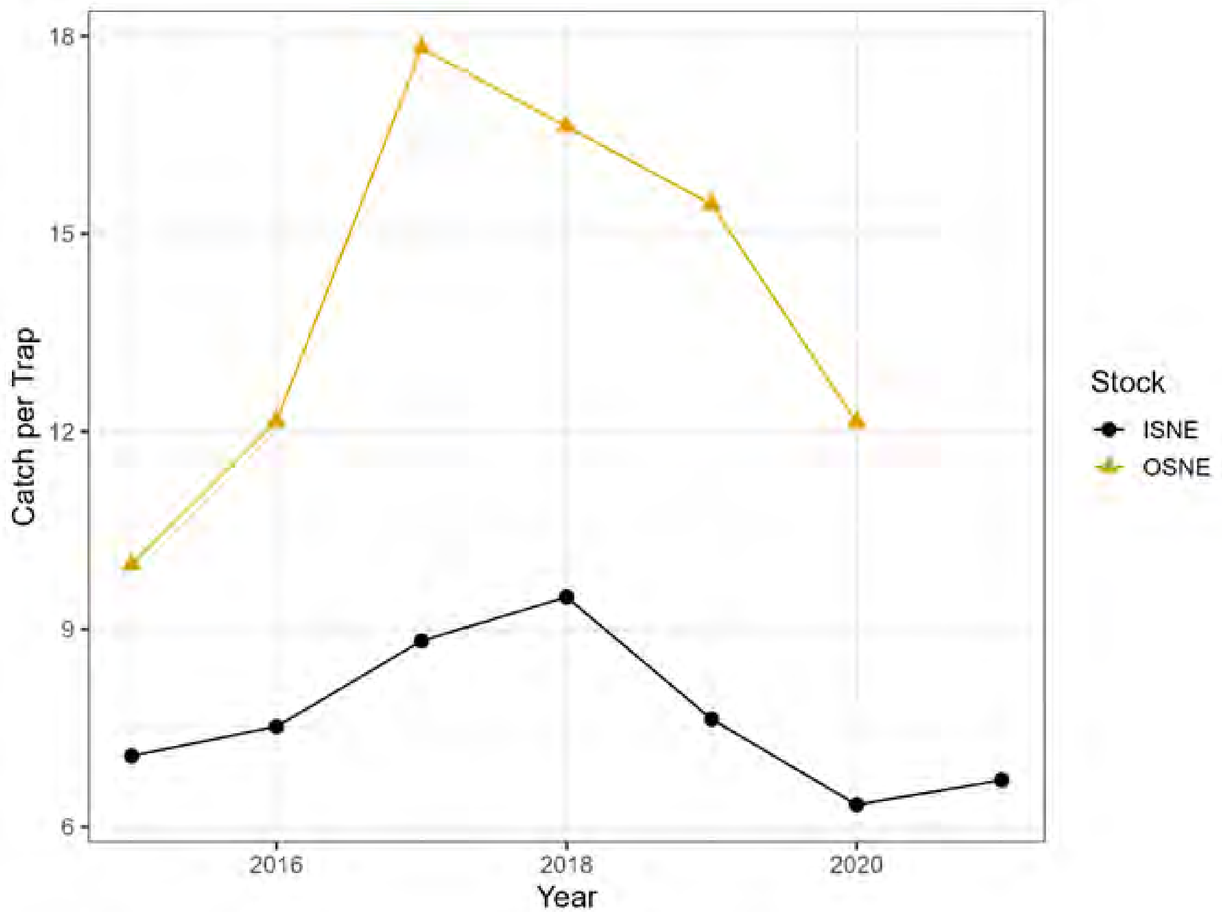

Figure 56. CFRF VTS CPUE for exploitable-sized (>121mm CW) male crabs.

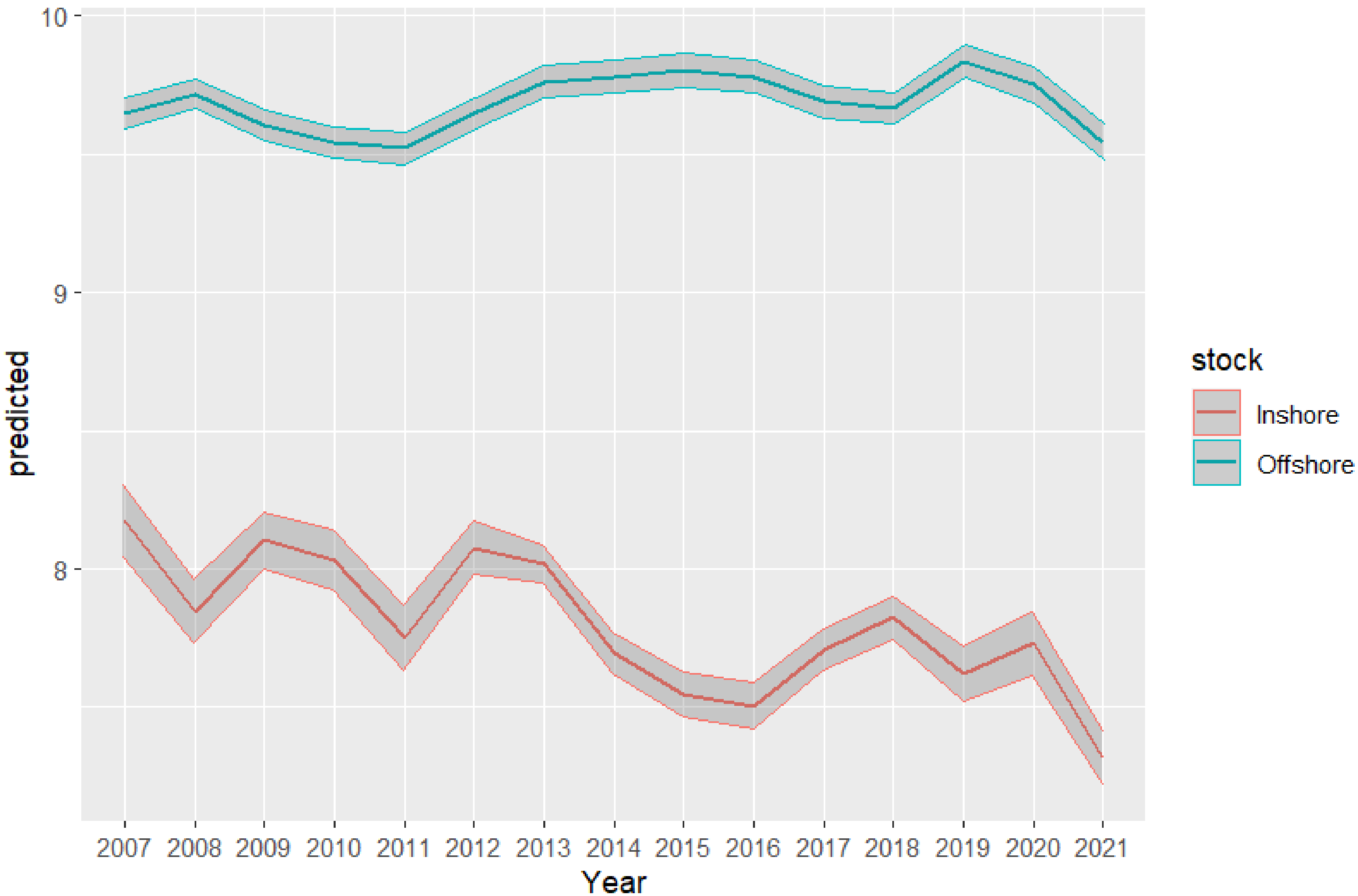

Figure 57. Jonah crab CPUE indices derived from directed residual model fitted to Rhode Island trip-level landings data.

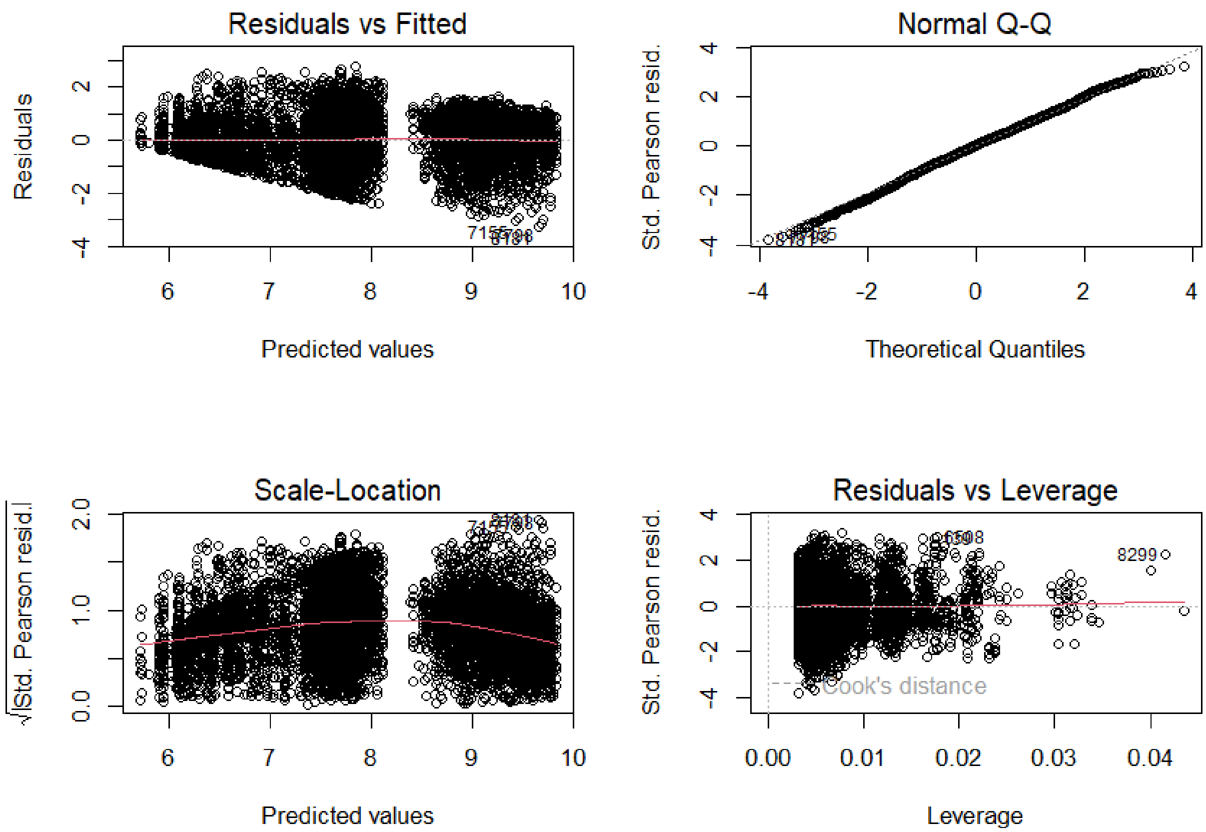

Figure 58. Diagnostic plots for selected DRM fitted to Rhode Island trip-level landings data.

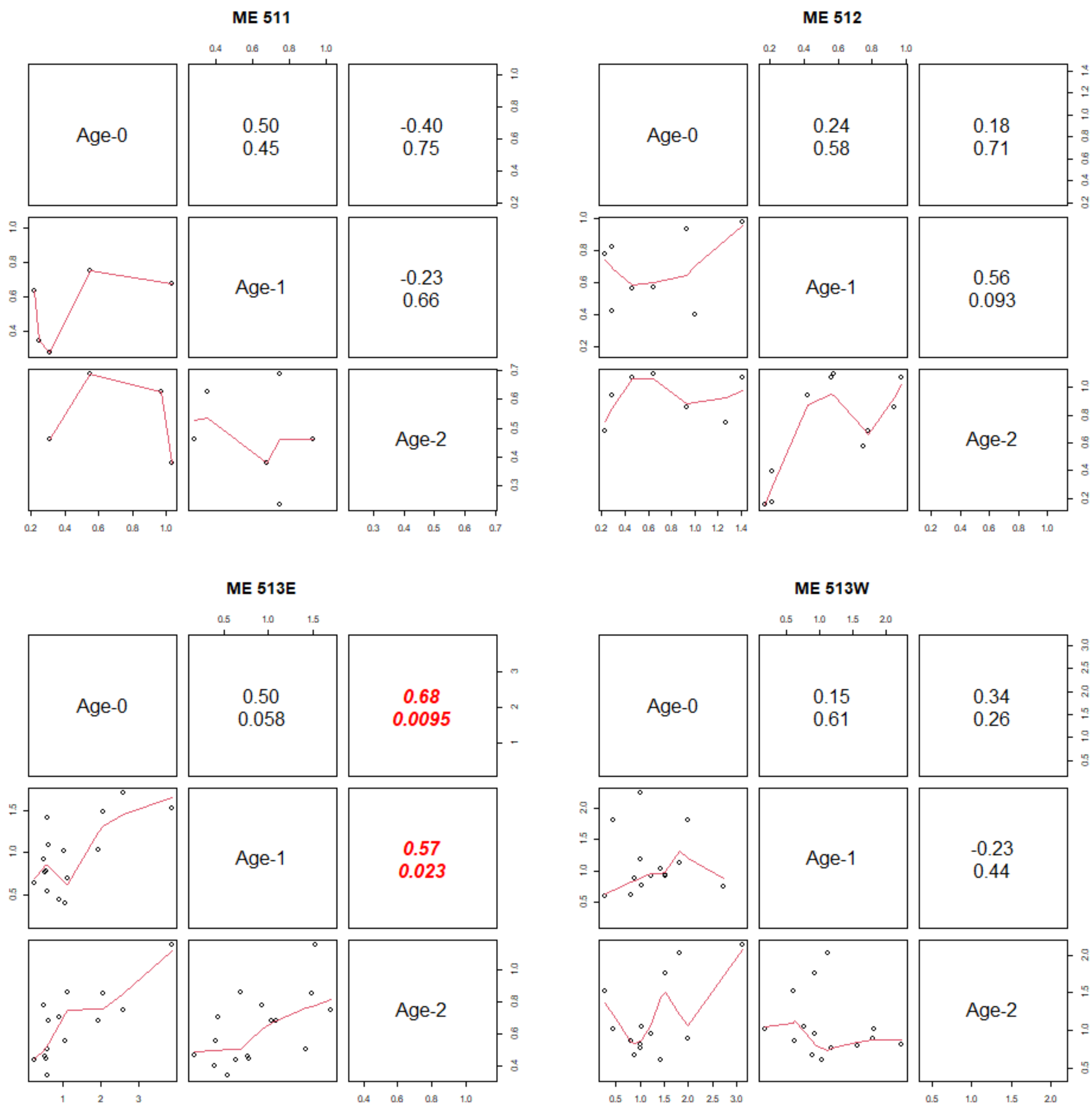

Figure 59. Spearman correlation results for age-specific settlement indices from the ME settlement surveys. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number.

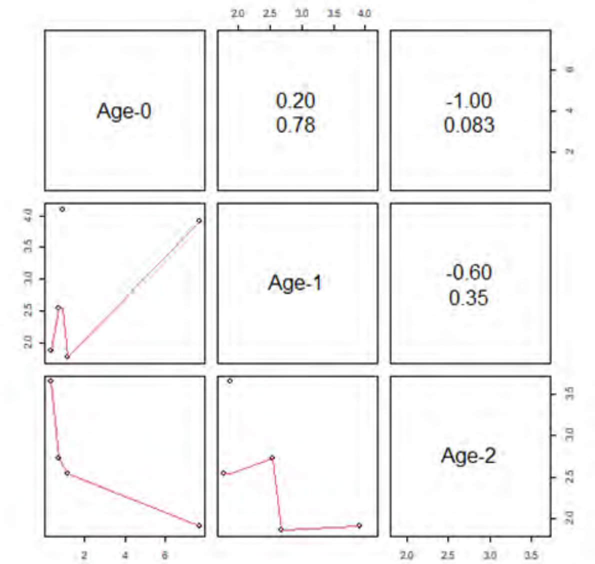

Figure 60. Spearman correlation results for age-specific settlement indices from the MA Statistical Area 514 settlement survey. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number.

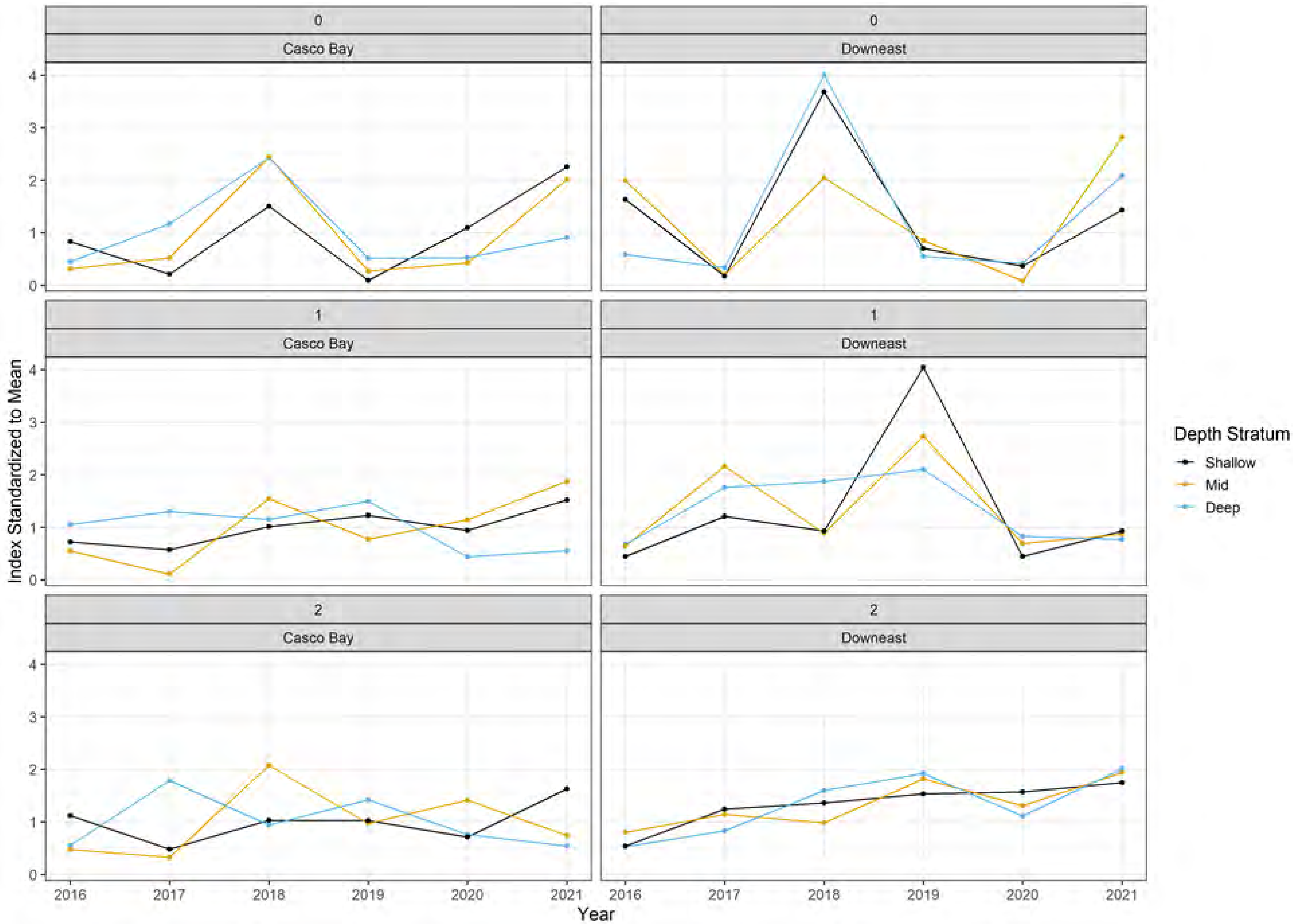

Figure 61. Comparison of depth specific indices from the University of Maine Deepwater Collector survey. Indices are age-specific (top ribbon in each panel) and region-specific (bottom ribbon in each panel).

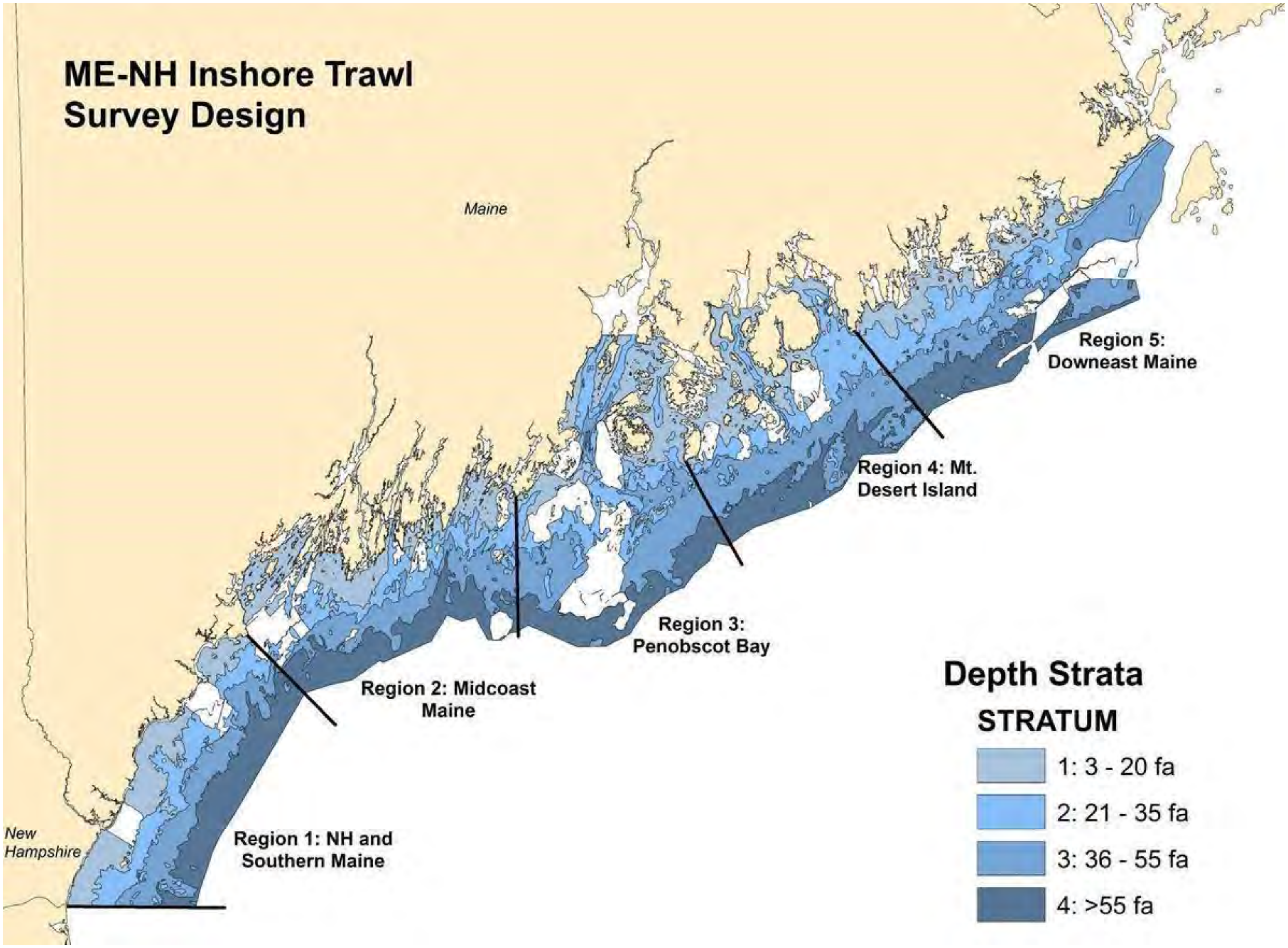

Figure 62. Sampling regions and depth strata for the Maine/New Hampshire trawl survey

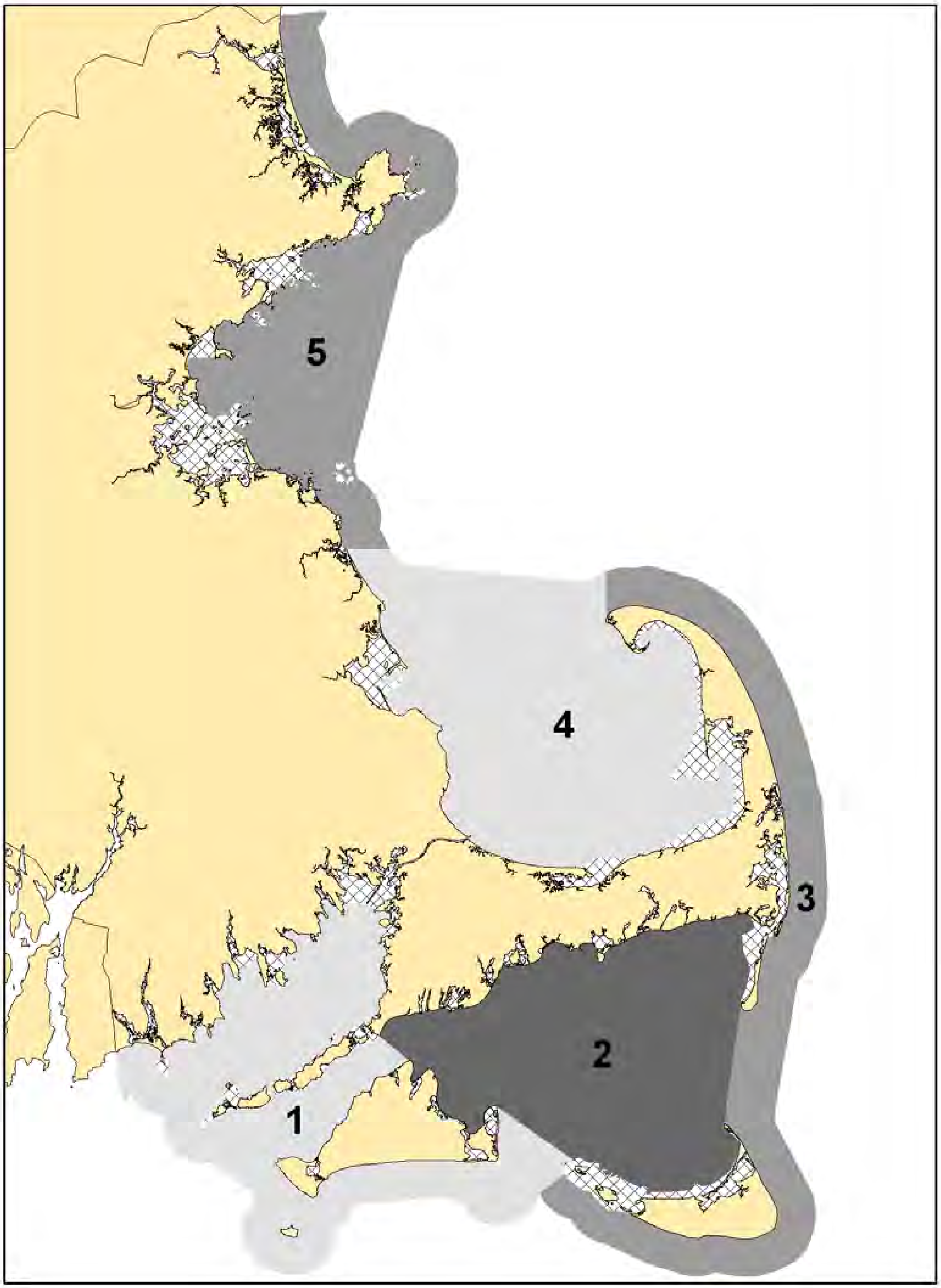

Figure 63. Sampling regions for the MA DMF trawl survey.

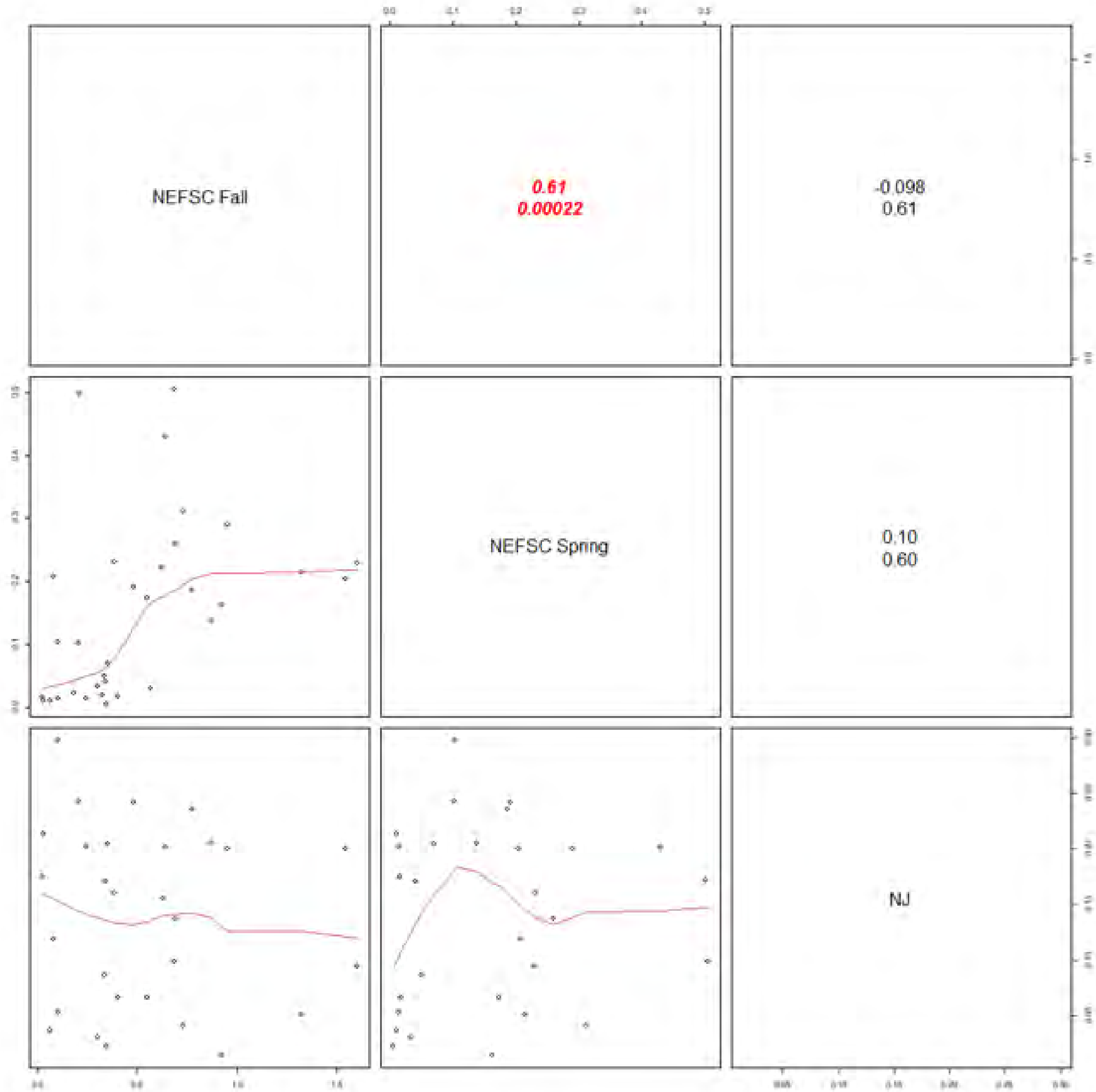

Figure 64. Spearman correlation results for sex- and size-aggregate indices from the NEFSC and NJ trawl surveys. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

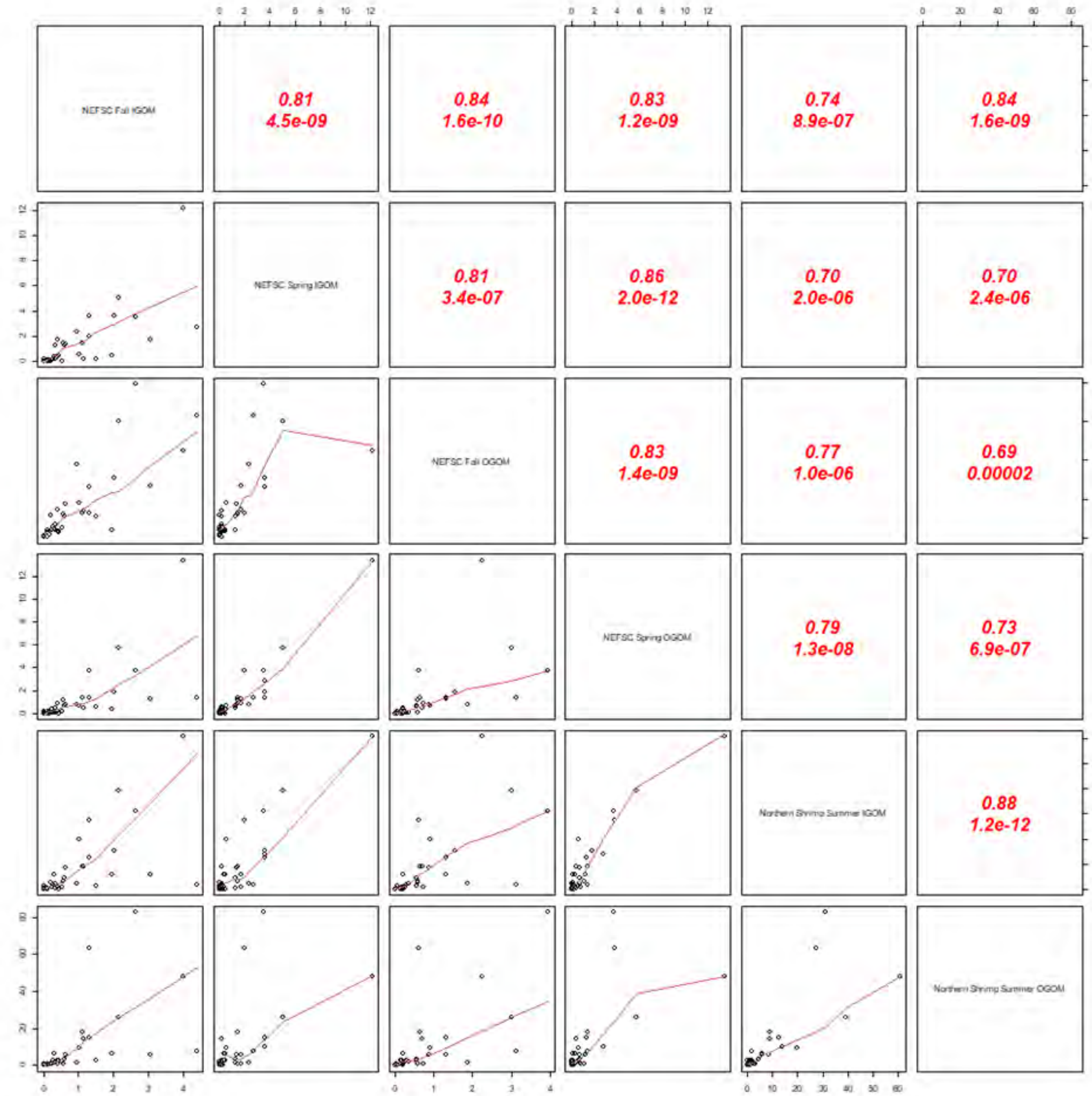

Figure 65. Spearman correlation results for sex- and size-aggregate indices from the NEFSC and Northern Shrimp trawl surveys. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

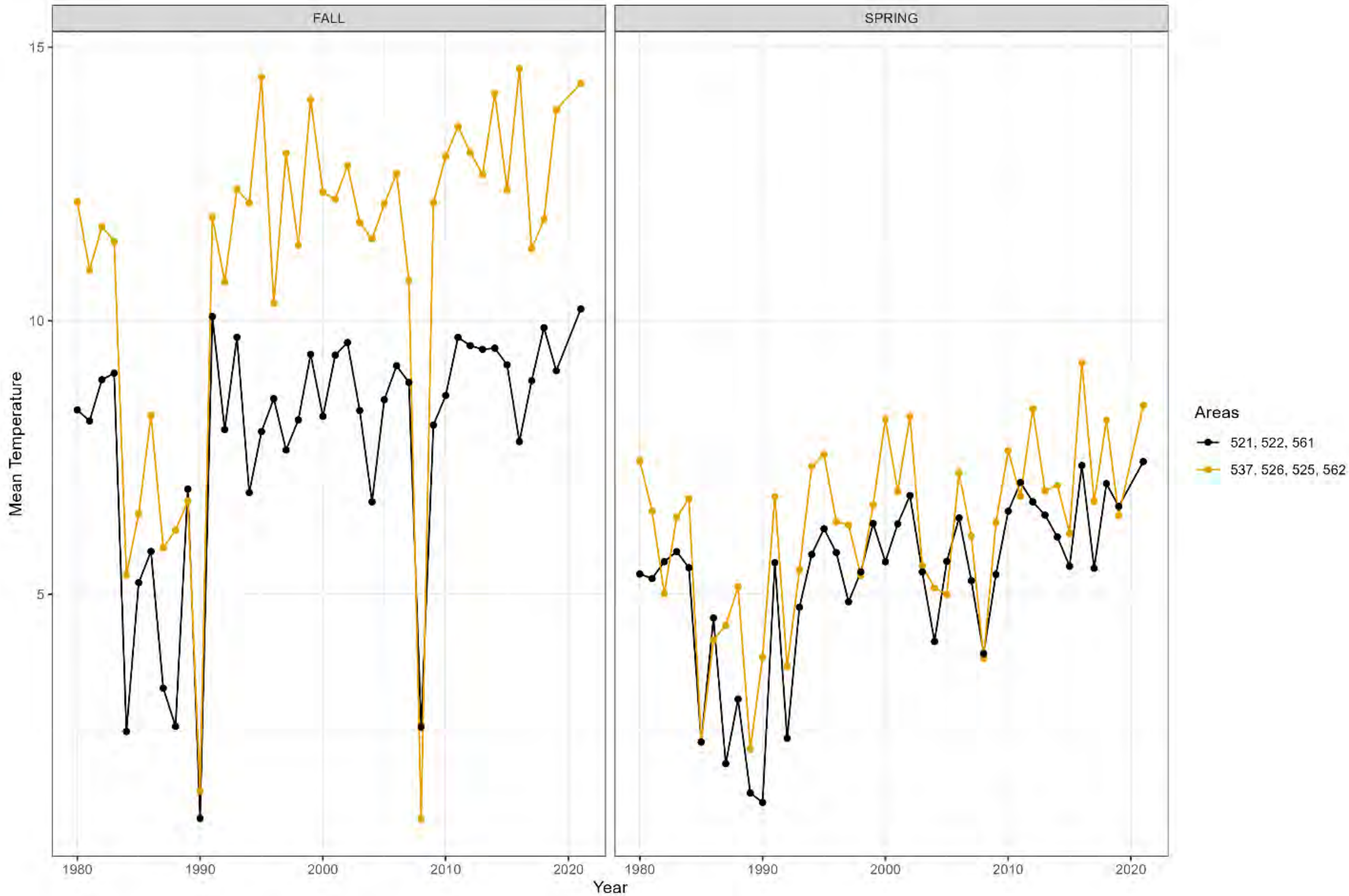

Figure 66. NEFSC Trawl Survey seasonal bottom temperature indices for adjacent NOAA statistical areas associated with high landings of Jonah crabs (Areas 537, 526, 525, 562) and low landings of Jonah crabs (Areas 521, 522, 561).

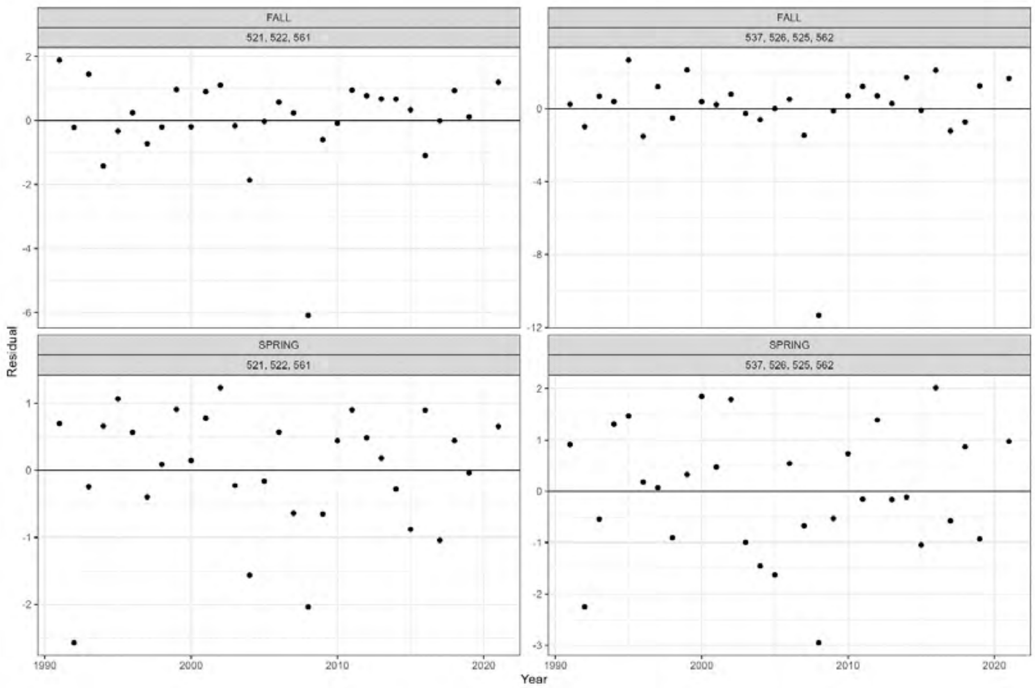

Figure 67. Residuals for linear regression fits to NEFSC Trawl Survey seasonal bottom temperature indices for adjacent NOAA statistical areas associated with high landings of Jonah crabs (Areas 537, 526, 525, 562) and low landings of Jonah crabs (Areas 521, 522, 561).

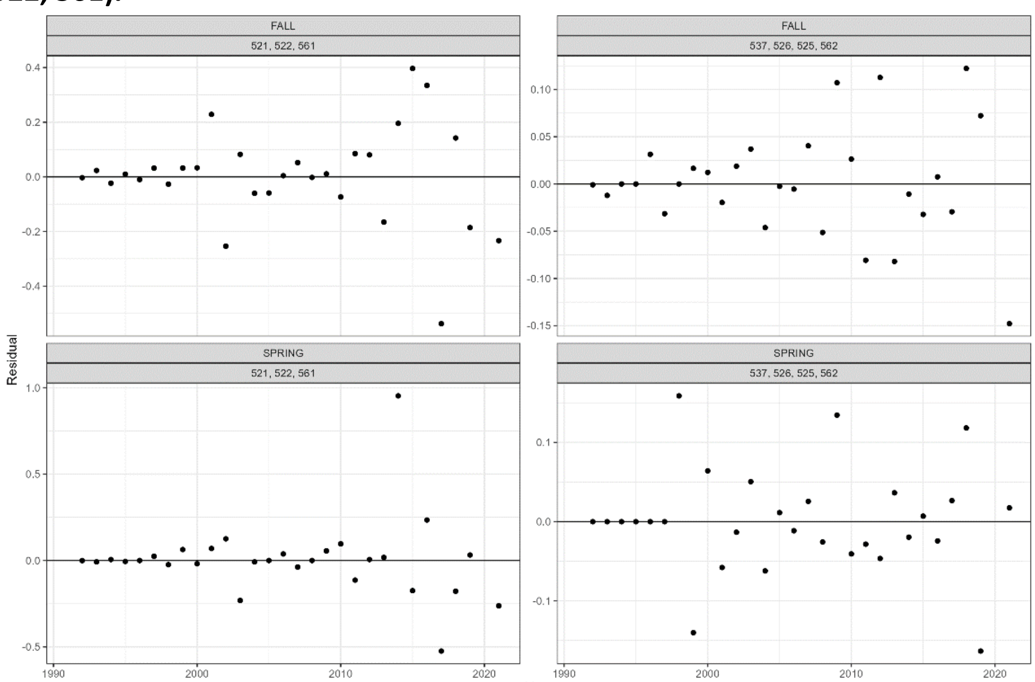

Figure 68. Residuals for two-year running average fits to NEFSC Trawl Survey seasonal exploitable abundance indices for adjacent NOAA statistical areas associated with high landings of Jonah crabs (Areas 537, 526, 525, 562) and low landings of Jonah crabs (Areas 521, 522, 561).

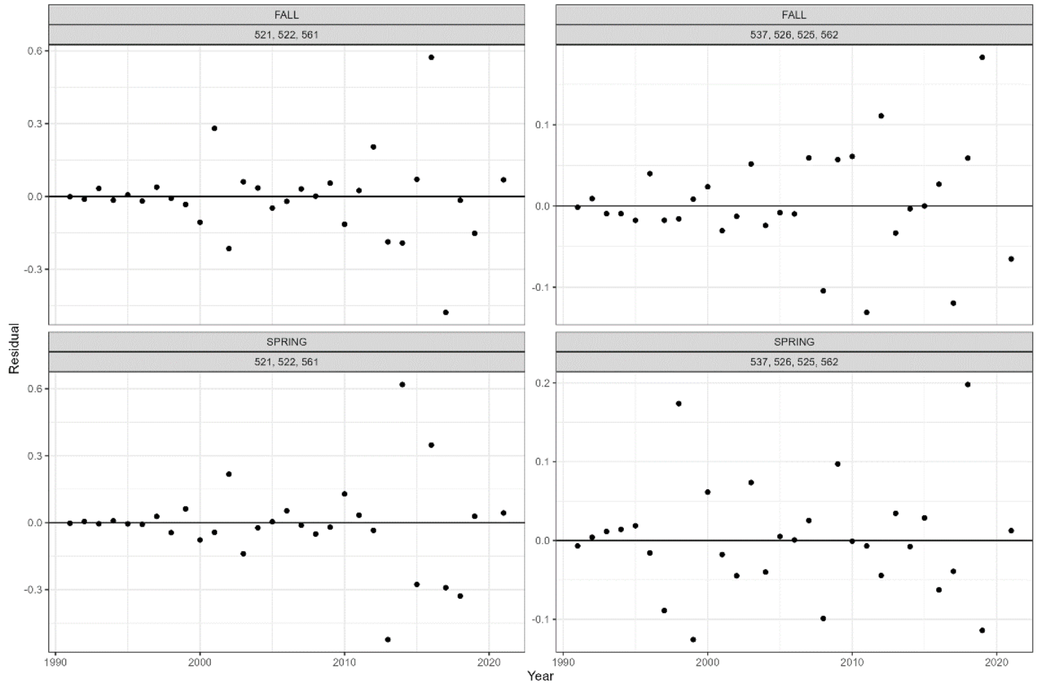

Figure 69. Residuals for LOESS smoother fits to NEFSC Trawl Survey seasonal exploitable abundance indices for adjacent NOAA statistical areas associated with high landings of Jonah crabs (Areas 537, 526, 525, 562) and low landings of Jonah crabs (Areas 521, 522, 561).

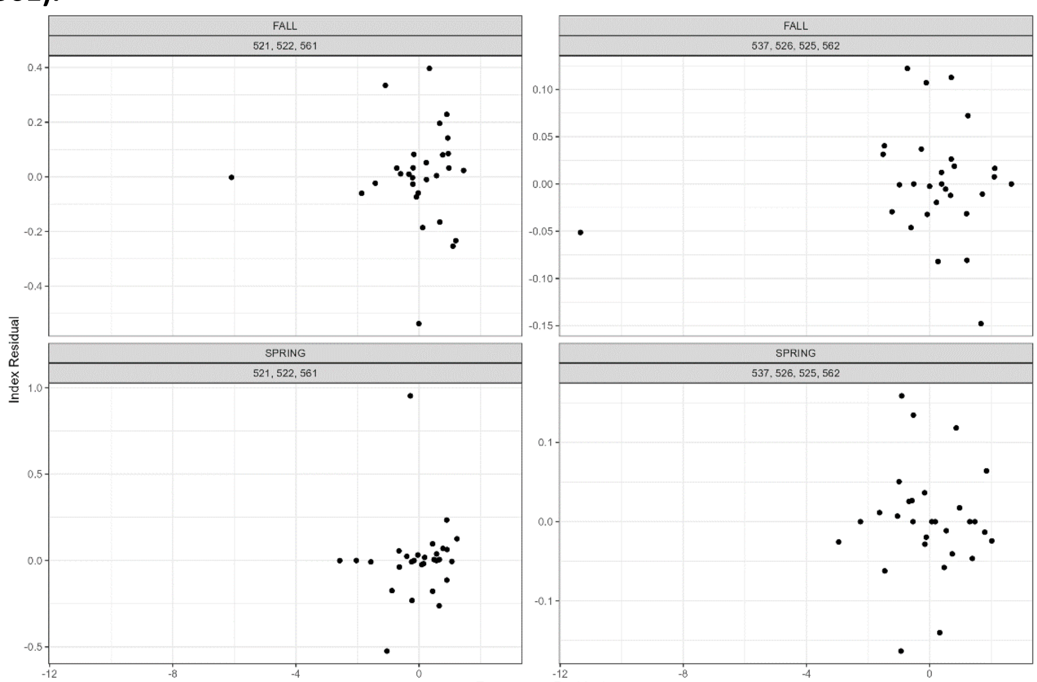

Figure 70. Residuals for NEFSC Trawl Survey seasonal exploitable abundance indices (using two-year running average fit) and temperature indices (using linear regression fit) for adjacent NOAA statistical areas associated with high landings of Jonah crabs (Areas 537, 526, 525, 562) and low landings of Jonah crabs (Areas 521, 522, 561).

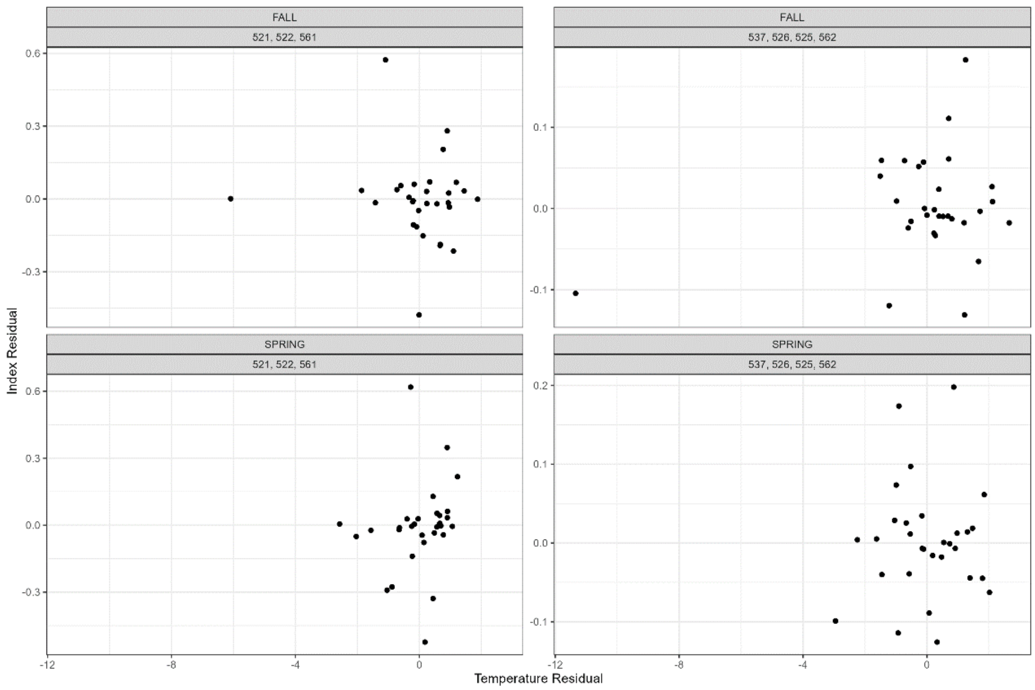

Figure 71. Residuals for NEFSC Trawl Survey seasonal exploitable abundance indices (using LOESS smoother fit) and temperature indices (using linear regression fit) for adjacent NOAA statistical areas associated with high landings of Jonah crabs (Areas 537, 526, 525, 562) and low landings of Jonah crabs (Areas 521, 522, 561).

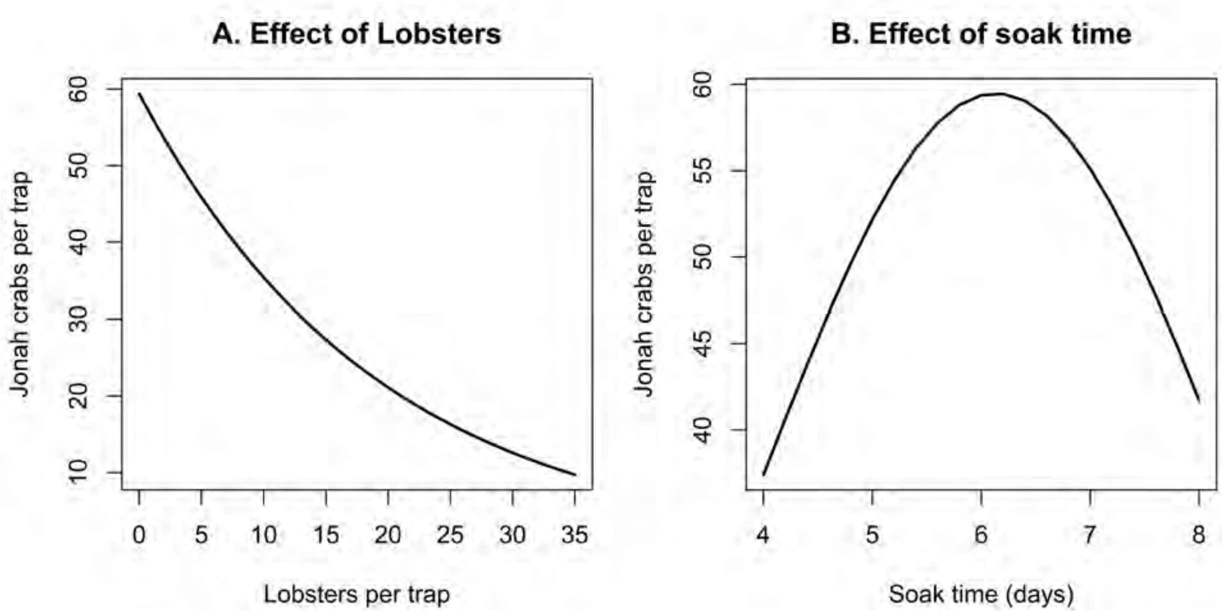

Figure 72. Results of negative binomial GLM fit to Jonah crab catch per trap. For predicting these effects, the values of other covariates were set as follows: trap_type=ventless, lat=41.2N, long=71W, habitat=sand, month=October. A. Partial effect of lobsters with soak_time=6. B. Partial effect of soak_time with lobsters=0.

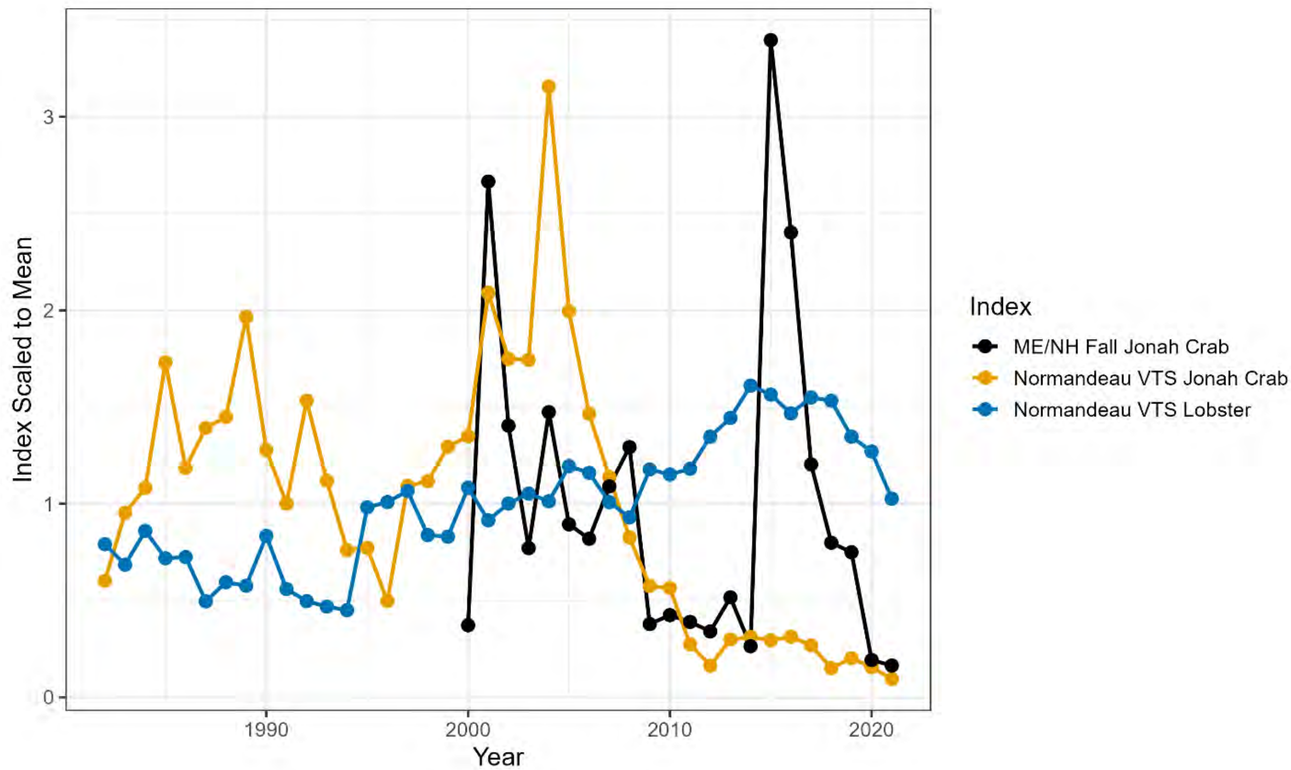

Figure 73. Comparison of nominal indices scaled to their time series mean for lobster and Jonah crab from the Normandeau Ventless Trap Survey (catch per trawl) and Jonah crab from the Maine/New Hampshire Trawl Survey (catch per tow).

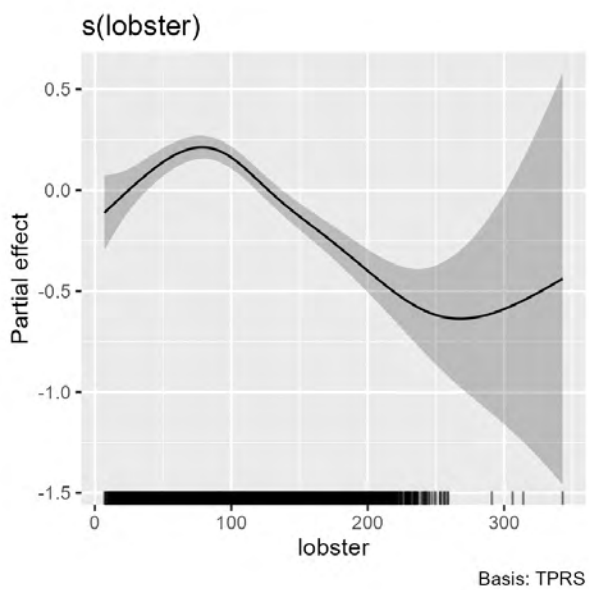

Figure 74. Estimated partial effect of lobster catch (x-axis) on Jonah crab catch (y-axis; on link scale) from generalized additive model applied to the Normandeau Ventless Trap Survey.

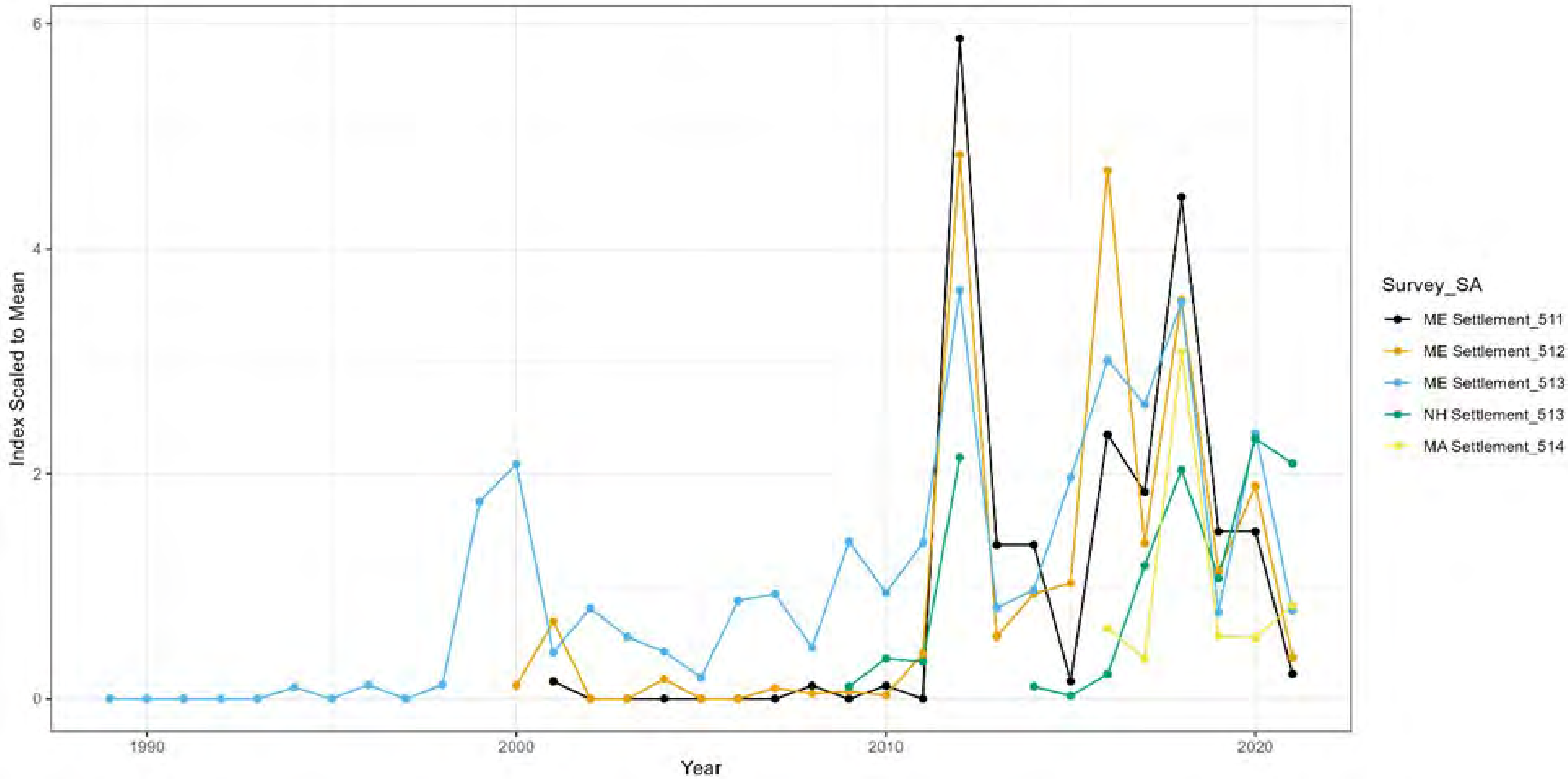

Figure 75. Jonah crab young-of-year settlement indices for the IGOM stock.

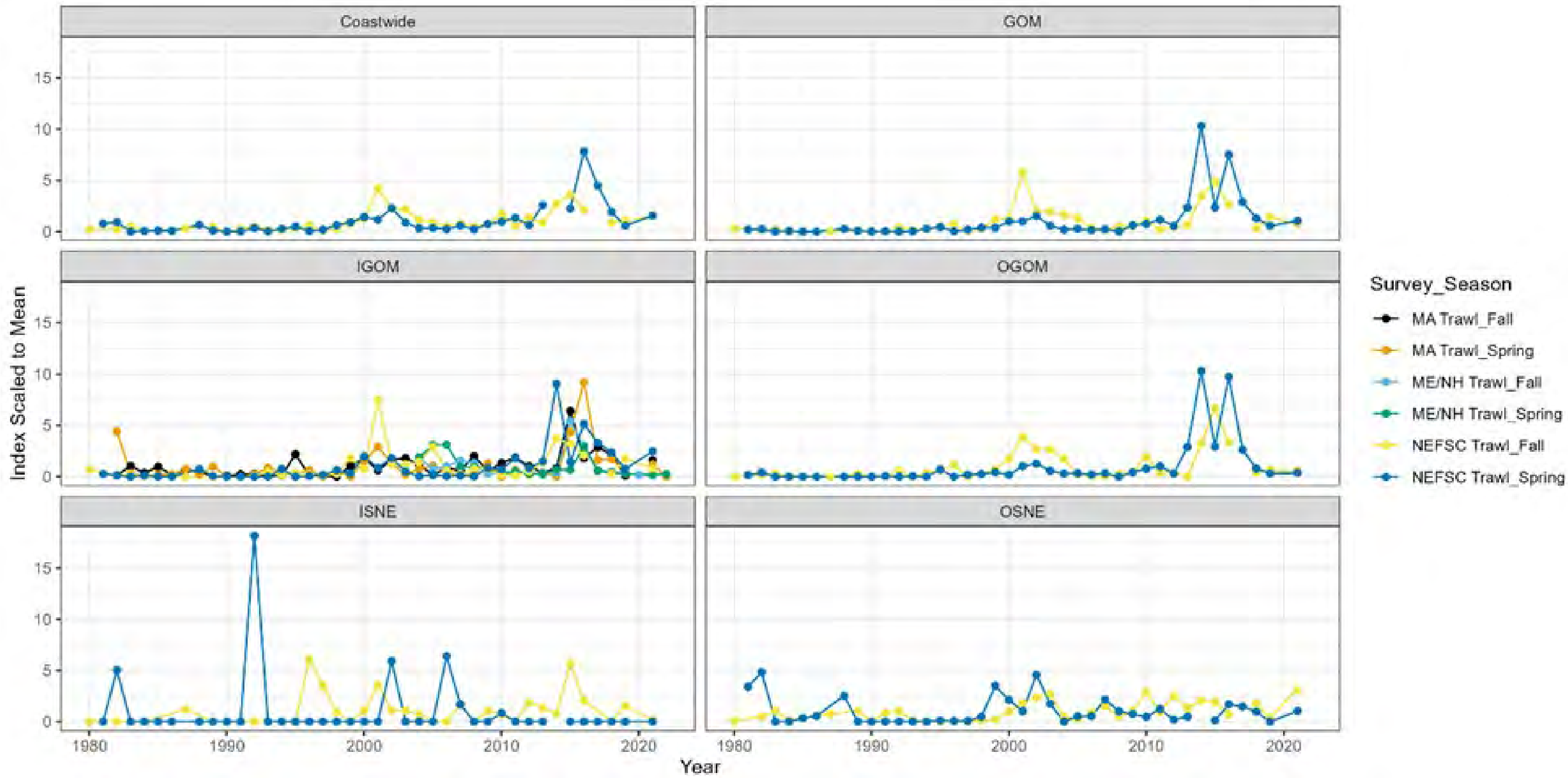

Figure 76. Jonah crab recruit abundance indices.

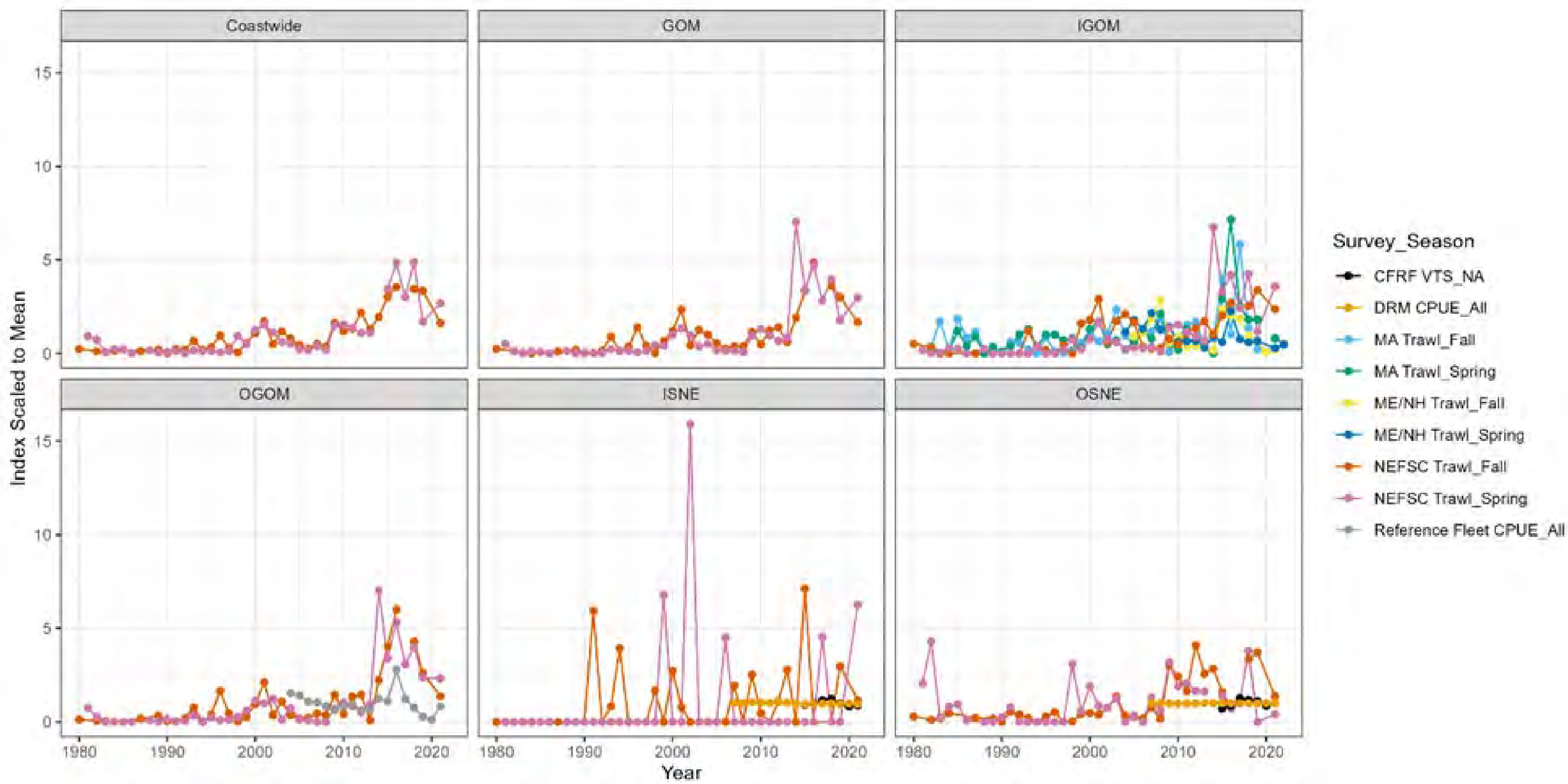

Figure 77. Jonah crab exploitable abundance indices.

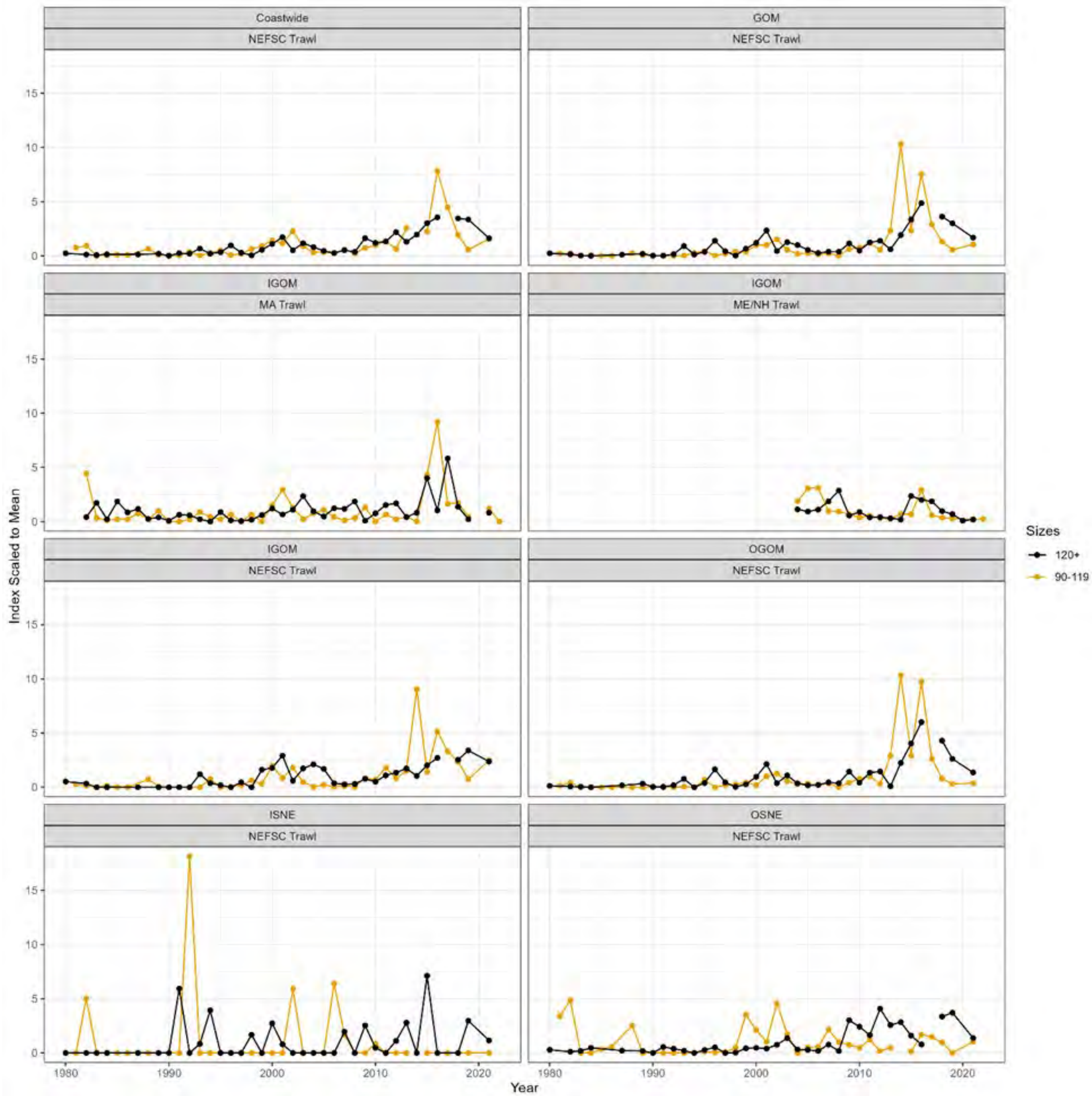

Figure 78. Jonah crab spring recruit abundance and fall exploitable abundance indices.

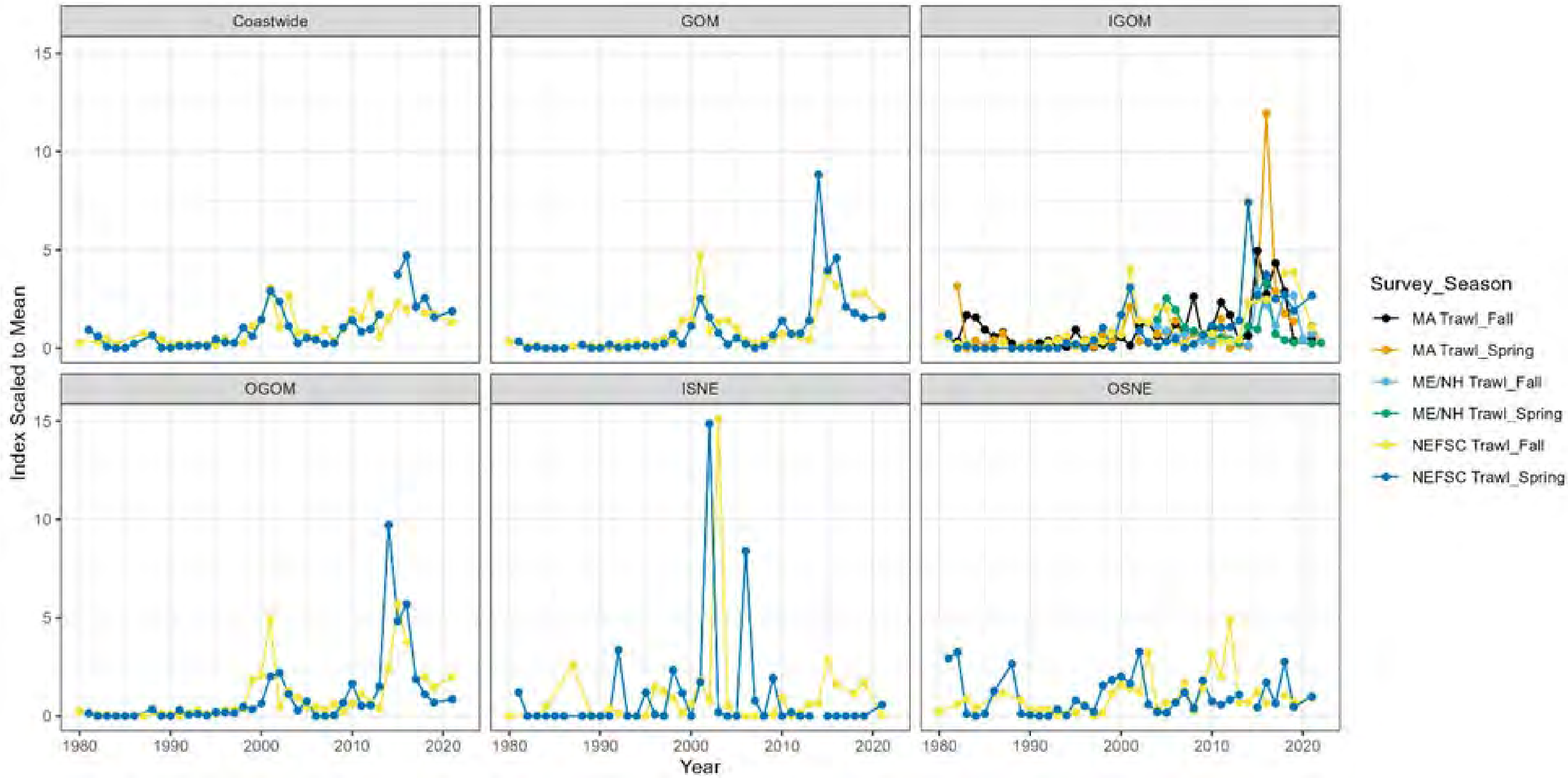

Figure 79. Jonah crab spawning abundance indices.

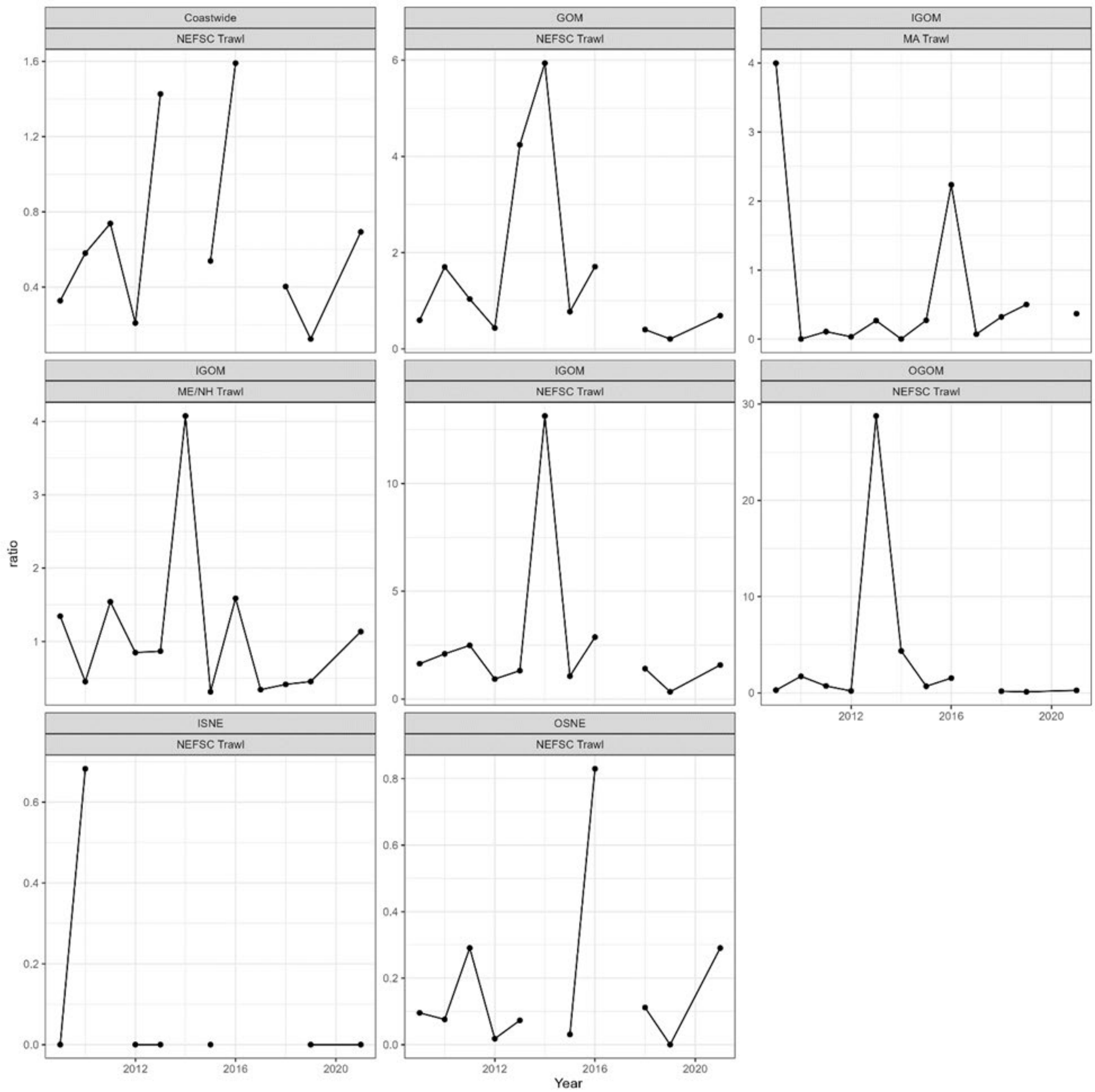

Figure 80. Jonah crab spring recruit abundance:fall exploitable abundance index ratios.

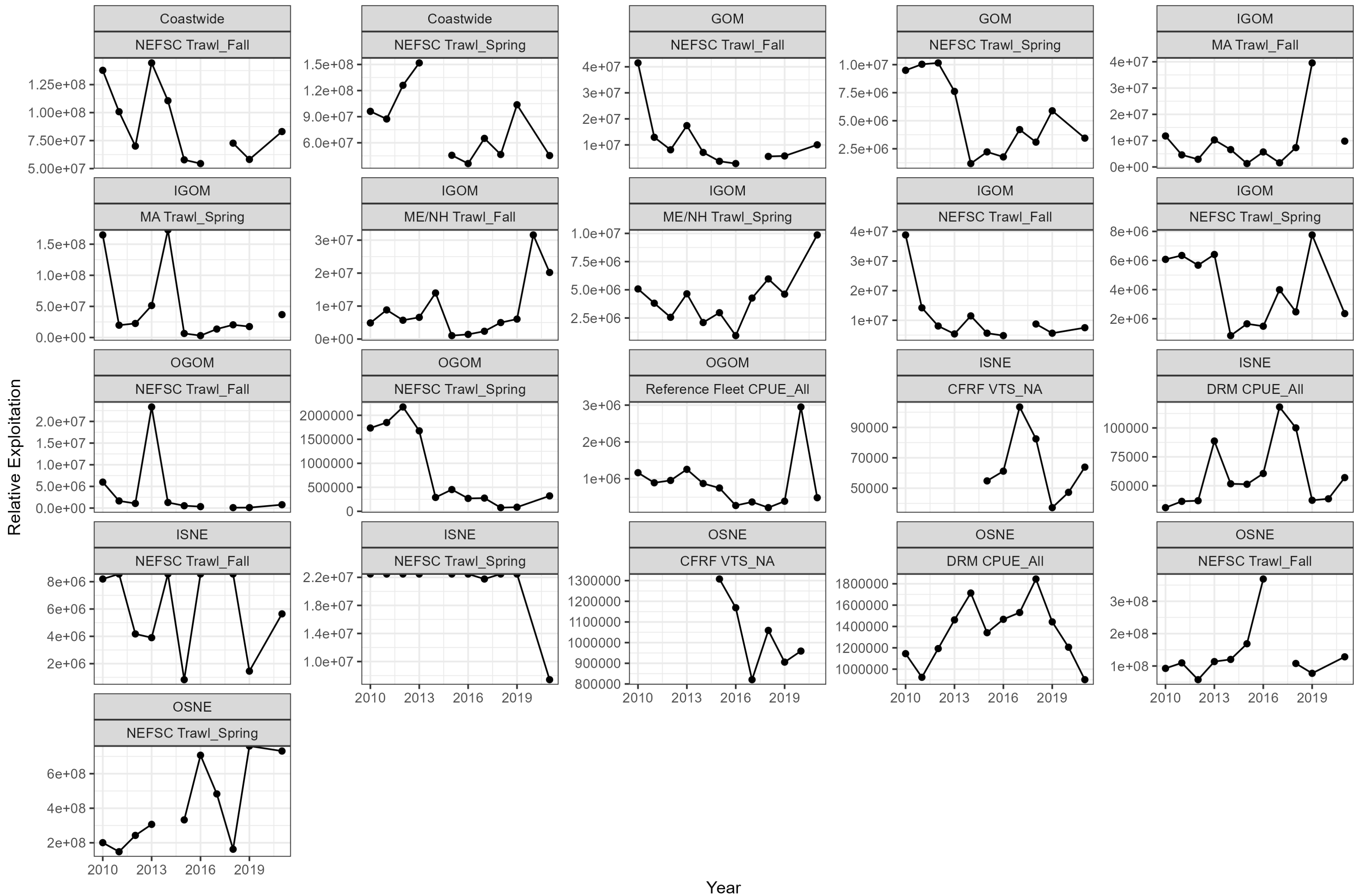

Figure 81. Jonah crab relative exploitation time series.

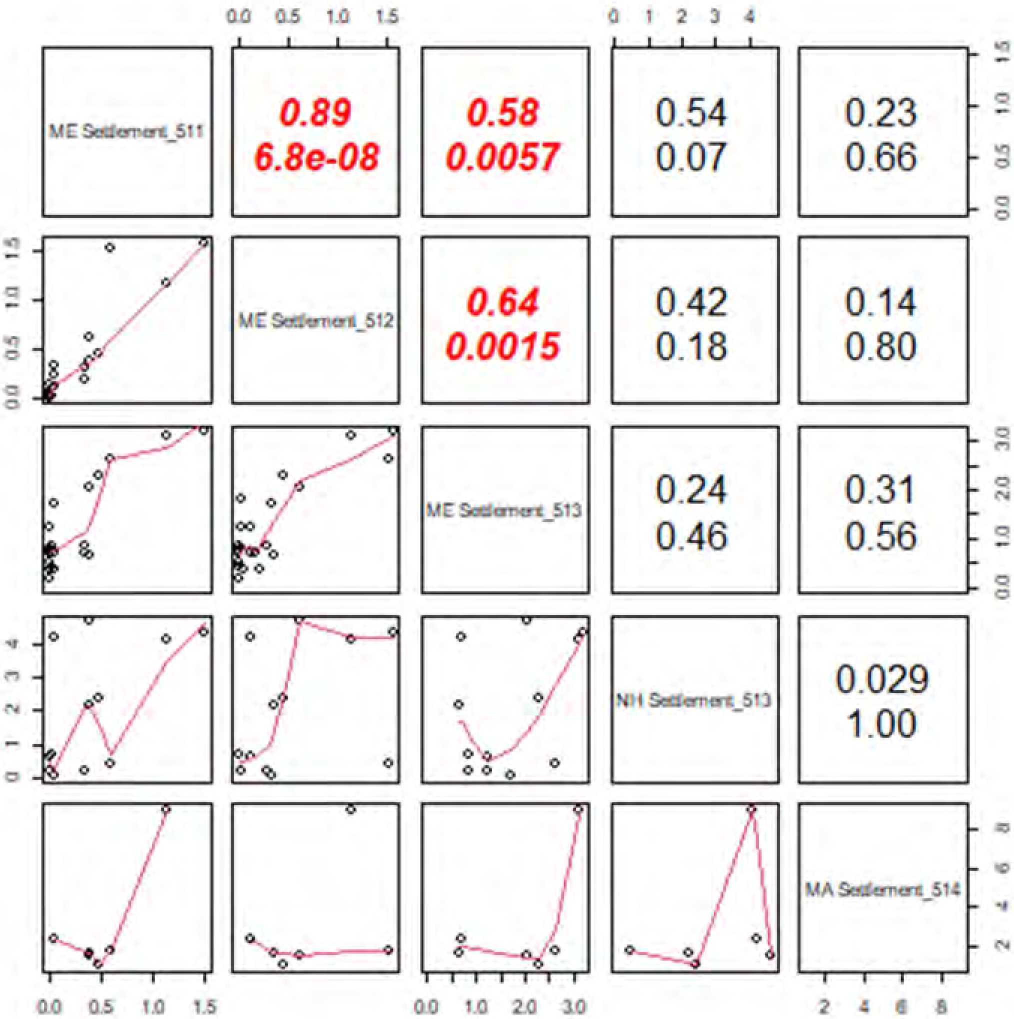

Figure 82. Spearman correlation results for young-of-year settlement indices for the IGOM stock. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

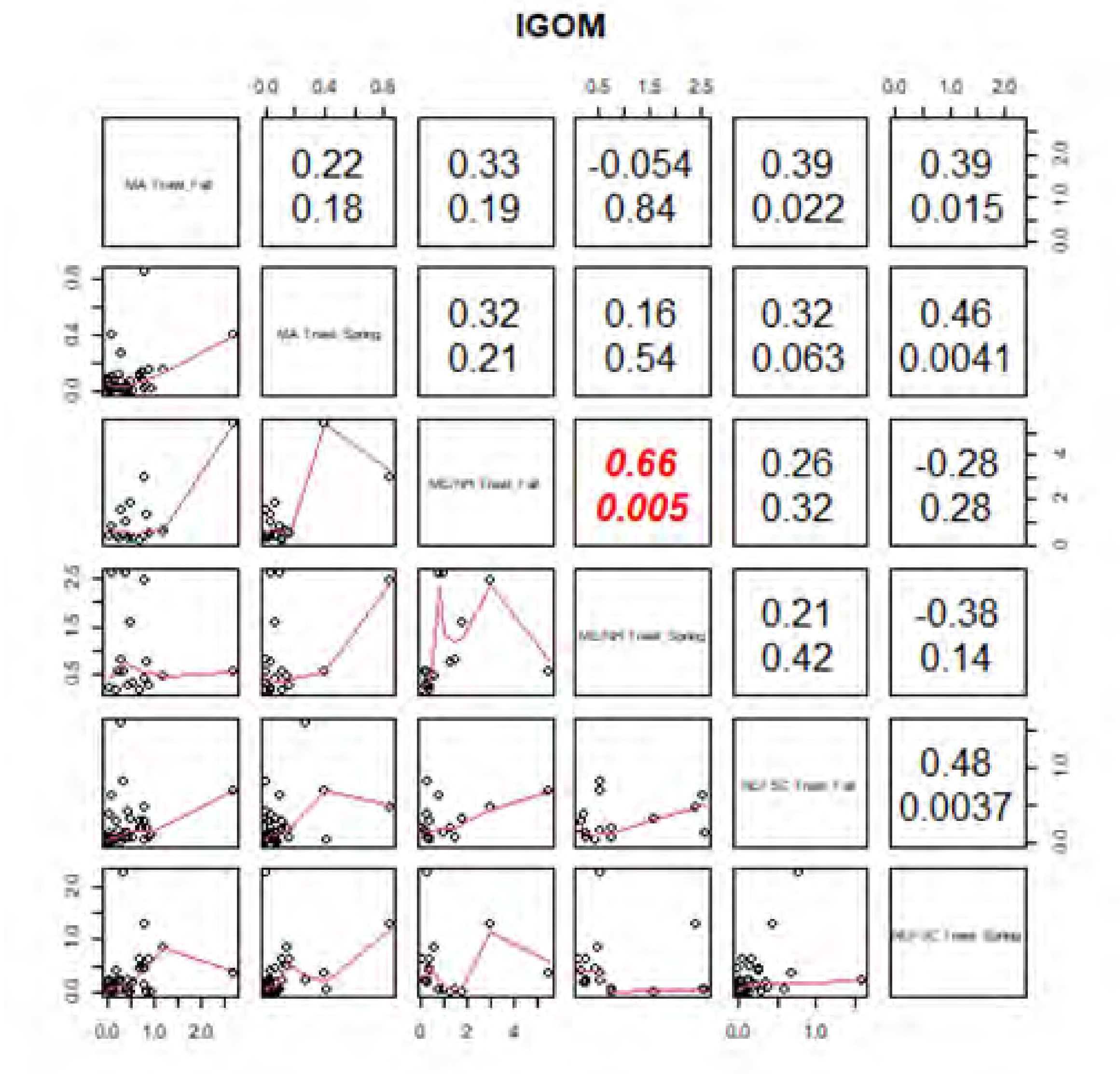

Figure 83. Spearman correlation results for IGOM recruit indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

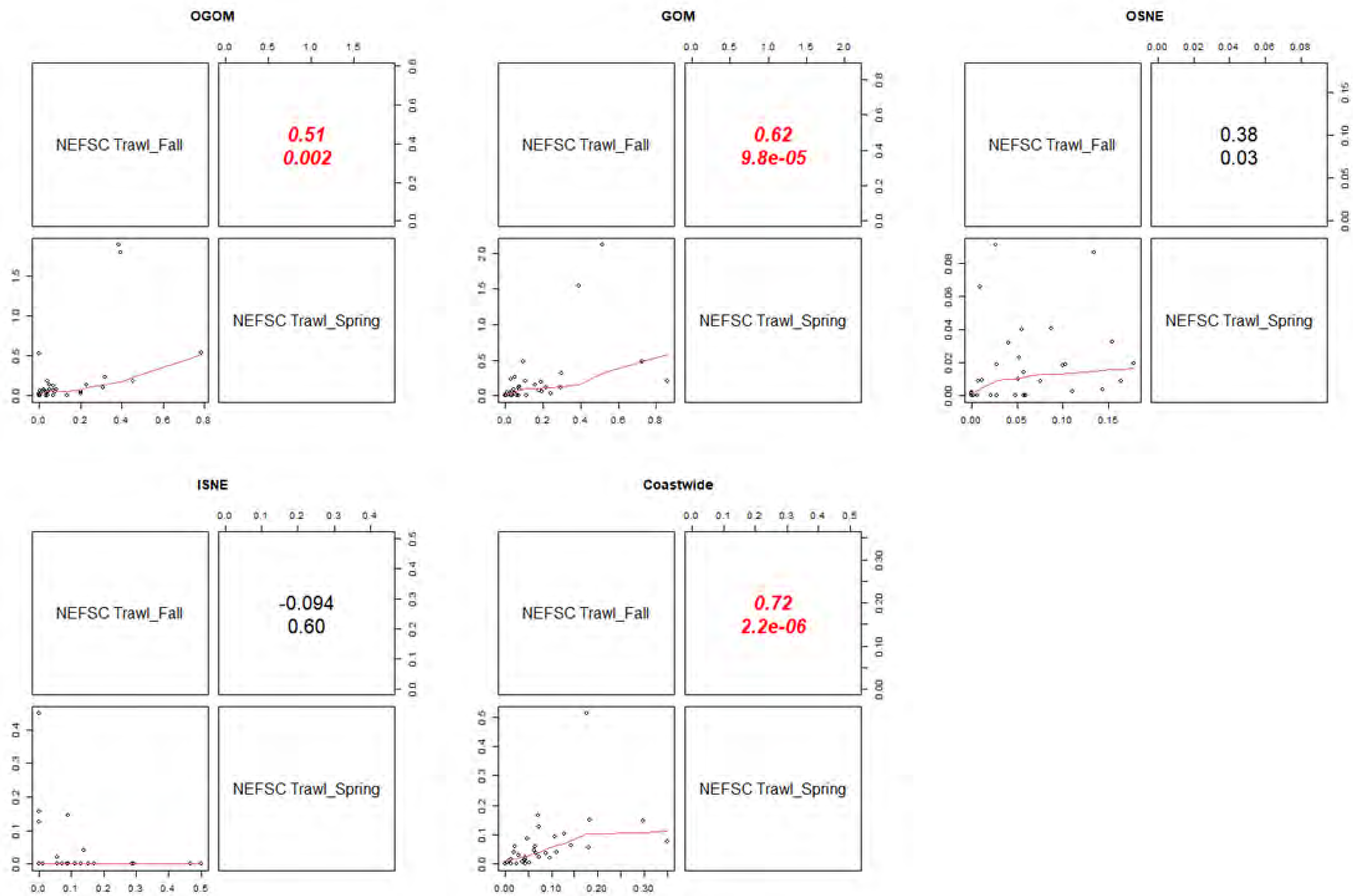

Figure 84. Spearman correlation results for OGOM, GOM, OSNE, ISNE, and coastwide recruit indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

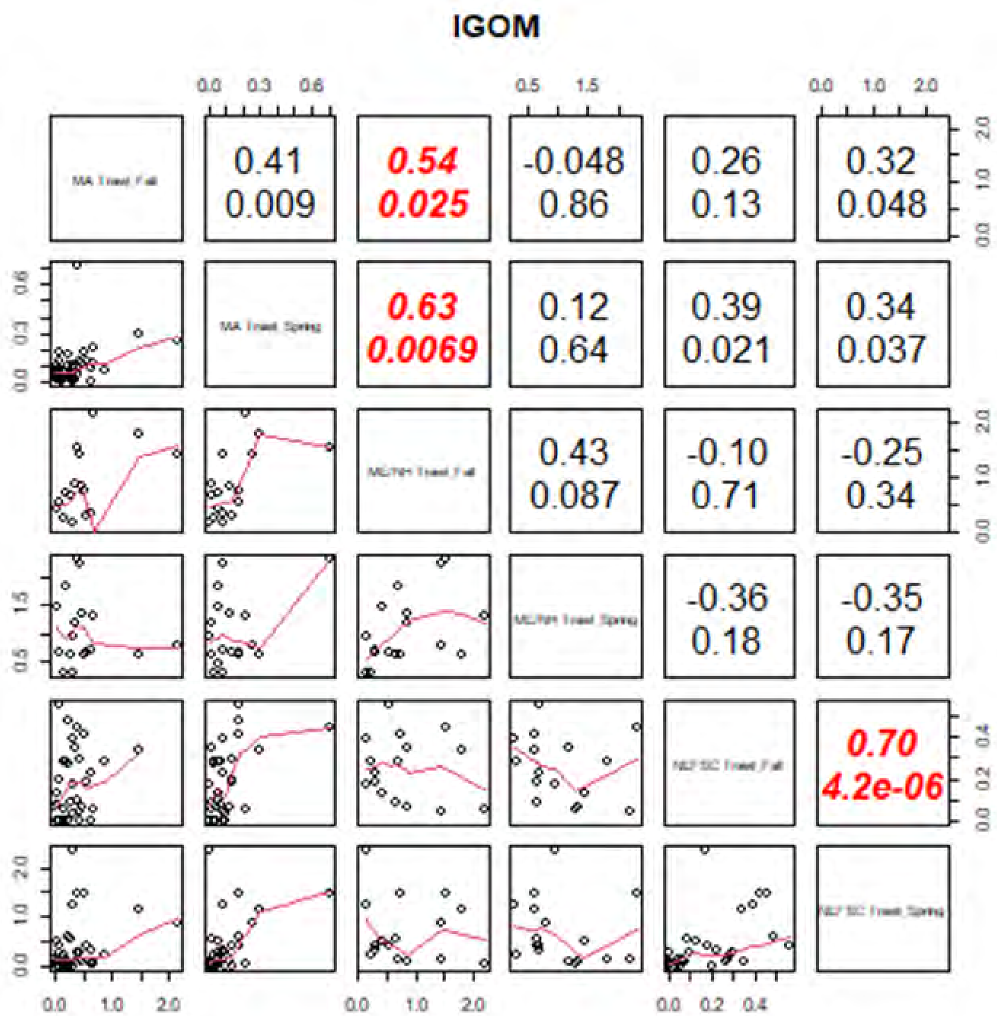

Figure 85. Spearman correlation results for IGOM exploitable abundance indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

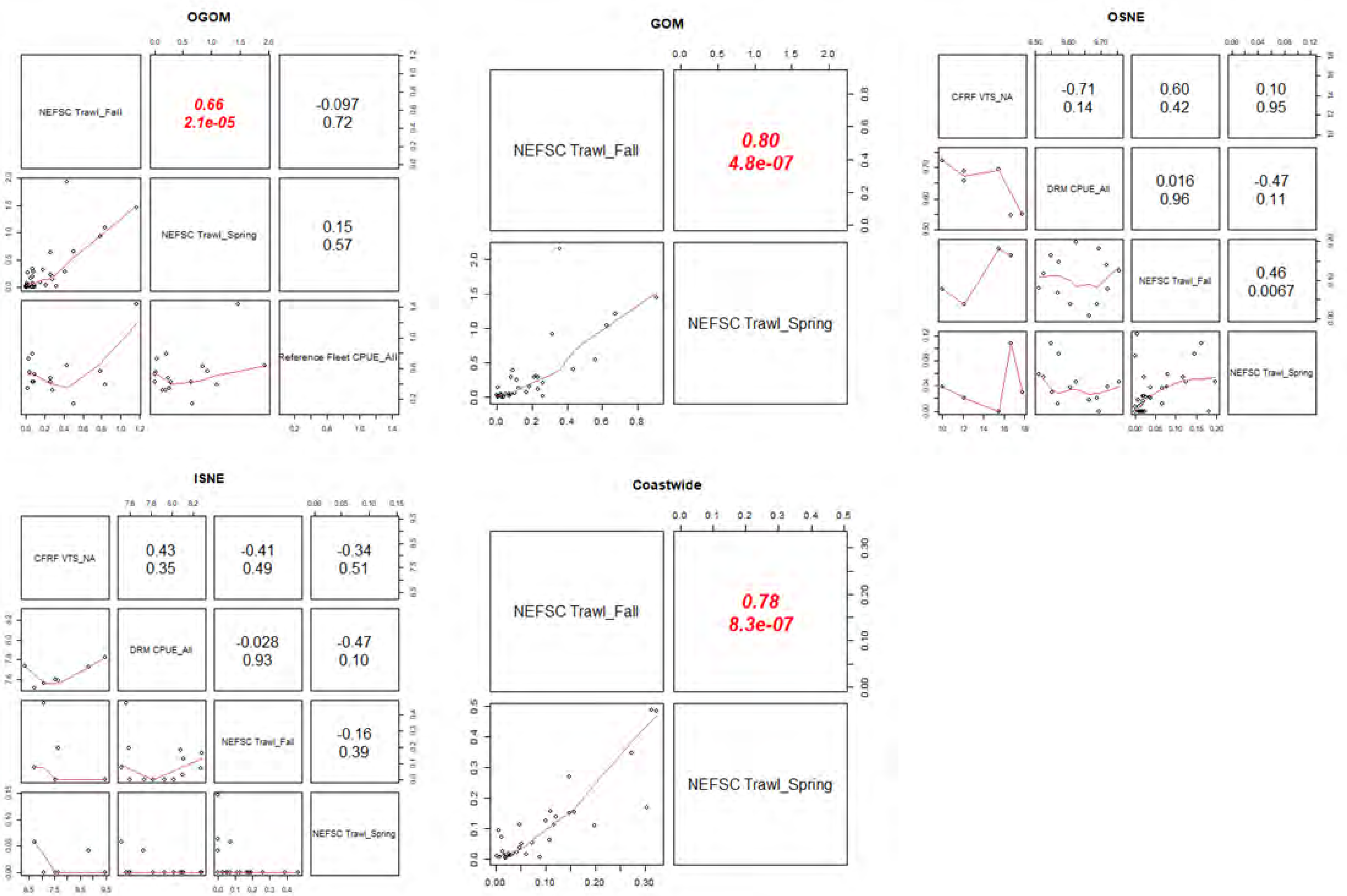

Figure 86. Spearman correlation results for OGOM, GOM, OSNE, ISNE, and coastwide exploitable abundance indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

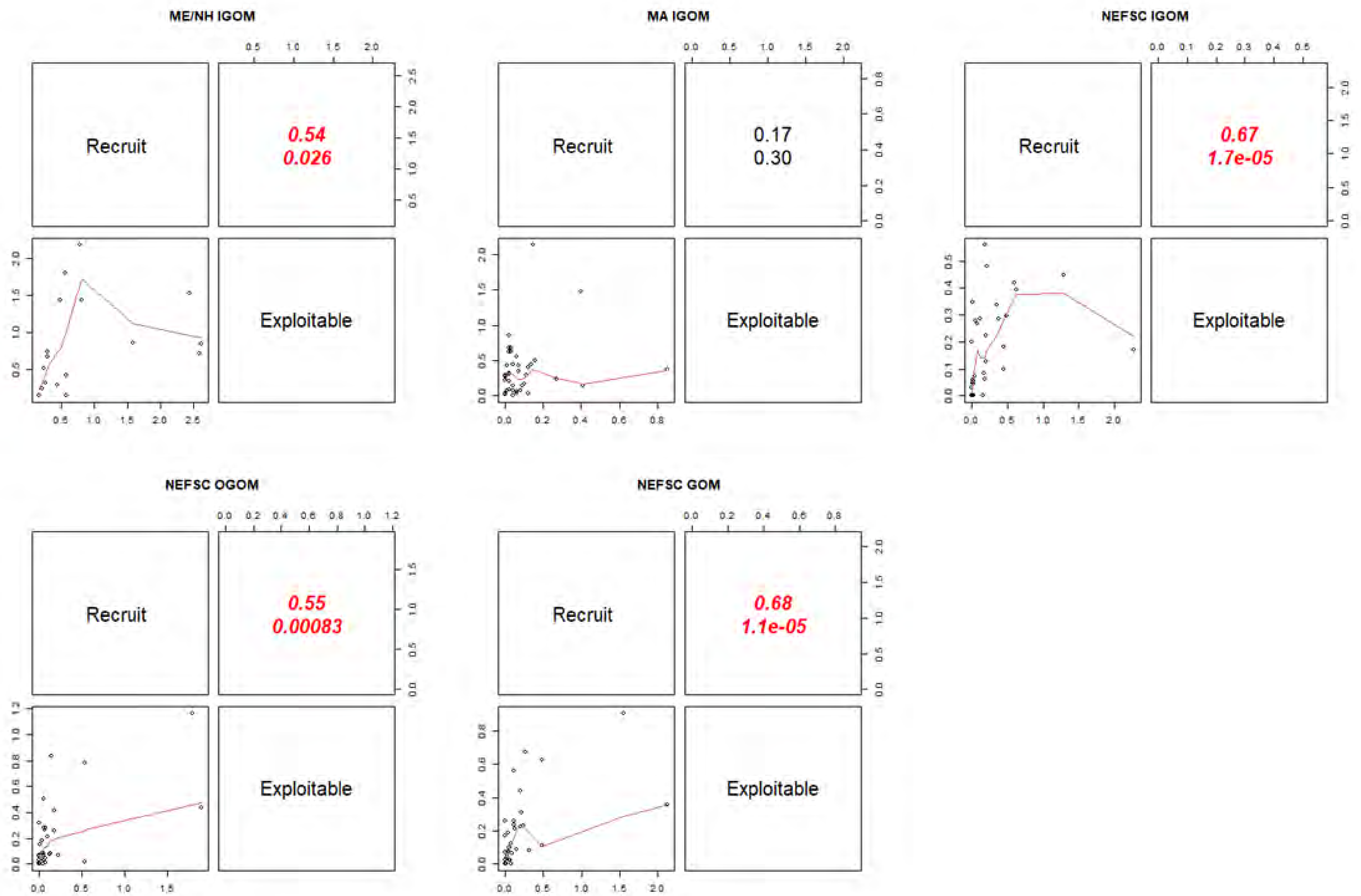

Figure 87. Spearman correlation results for IGOM, OGOM, and GOM spring recruit and fall exploitable abundance indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

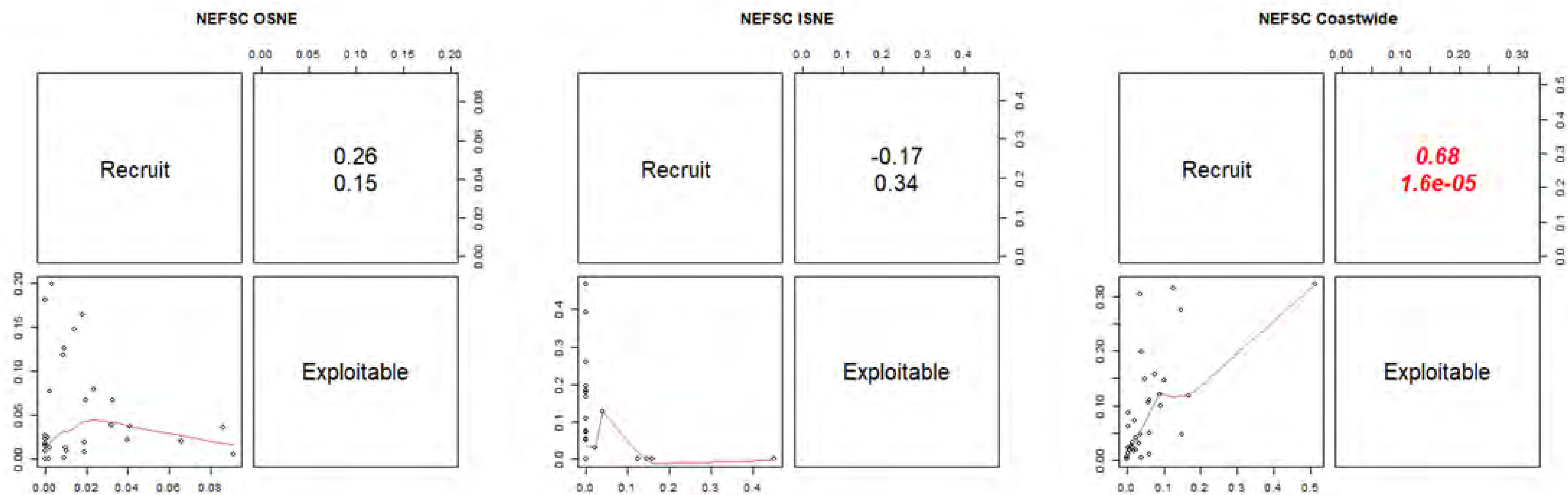

Figure 88. Spearman correlation results for OSNE, ISNE, and coastwide spring recruit and fall exploitable abundance indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

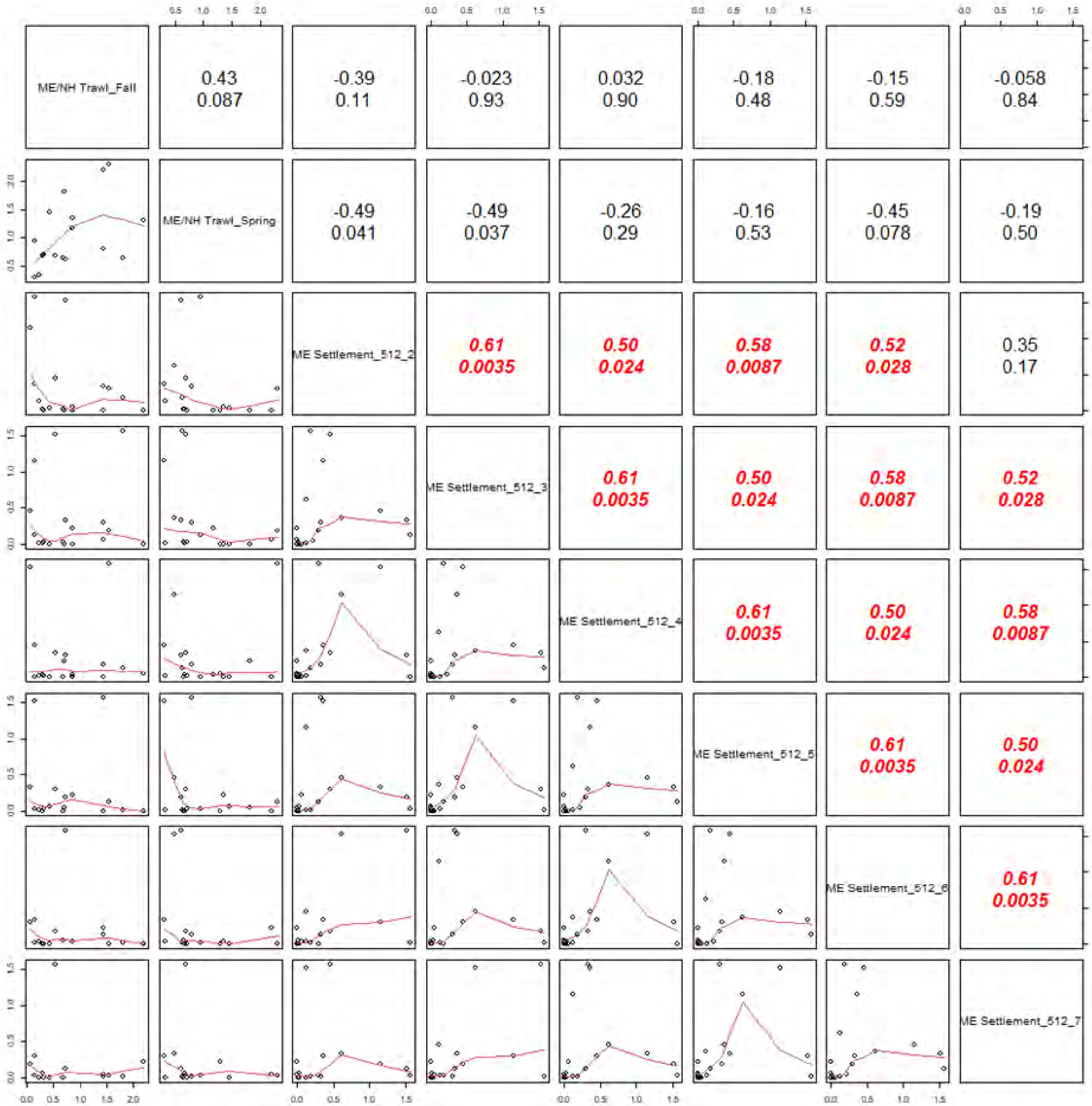

Figure 89. Spearman correlation results for ME/NH trawl survey exploitable abundance indices and lagged ME 512 settlement survey indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

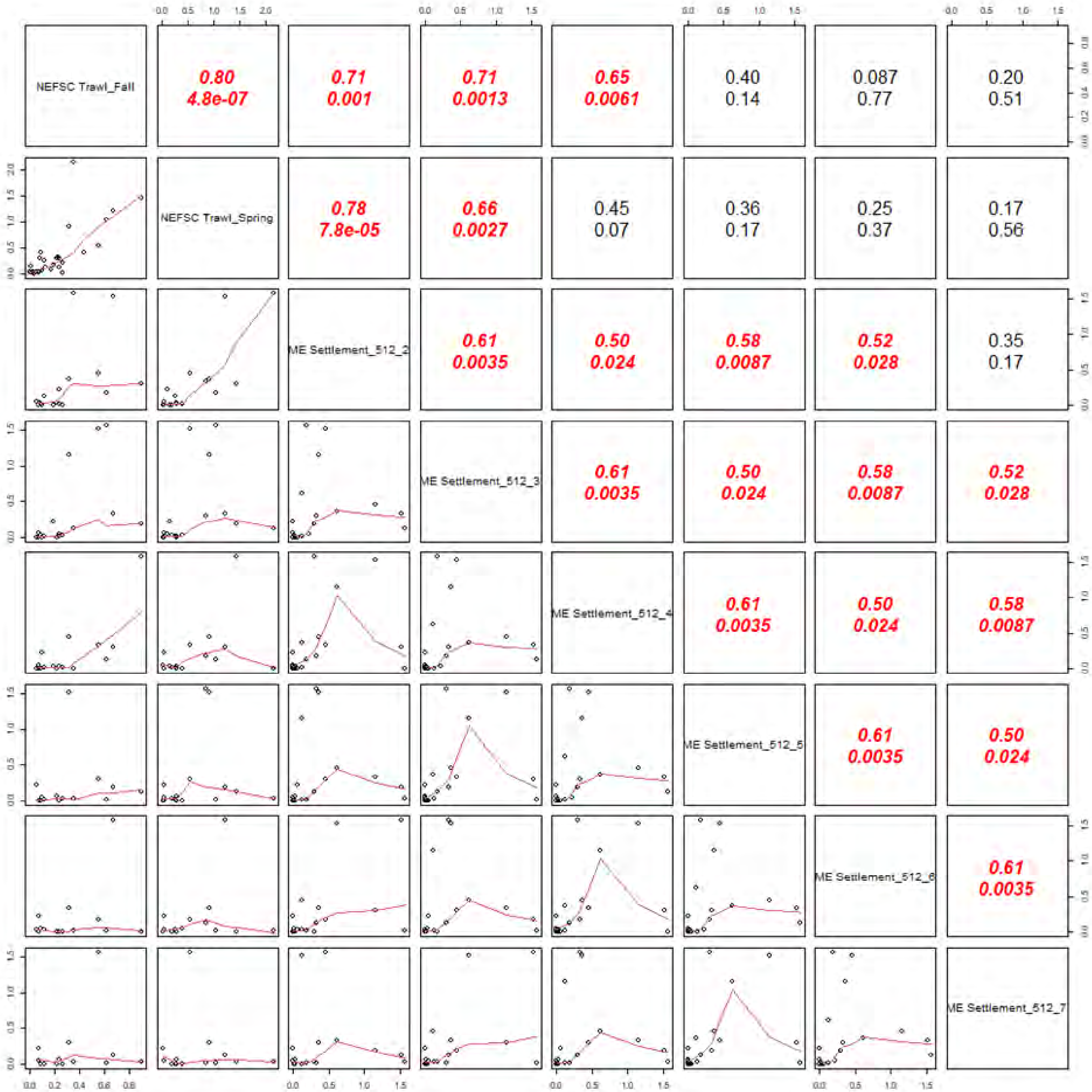

Figure 90. Spearman correlation results for NEFSC trawl survey exploitable abundance indices and lagged ME 512 settlement survey indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

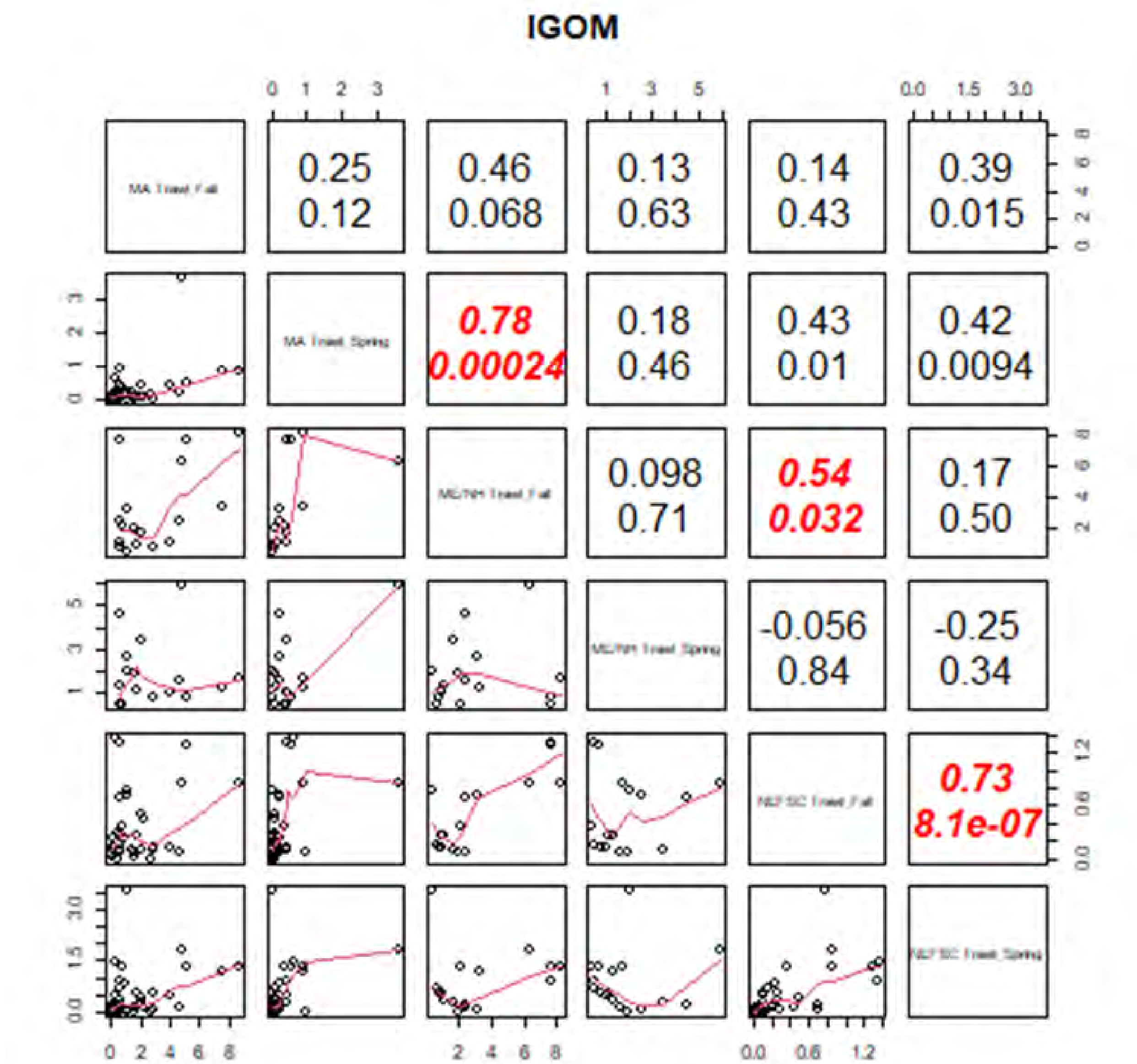

Figure 91. Spearman correlation results for IGOM spawning abundance indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

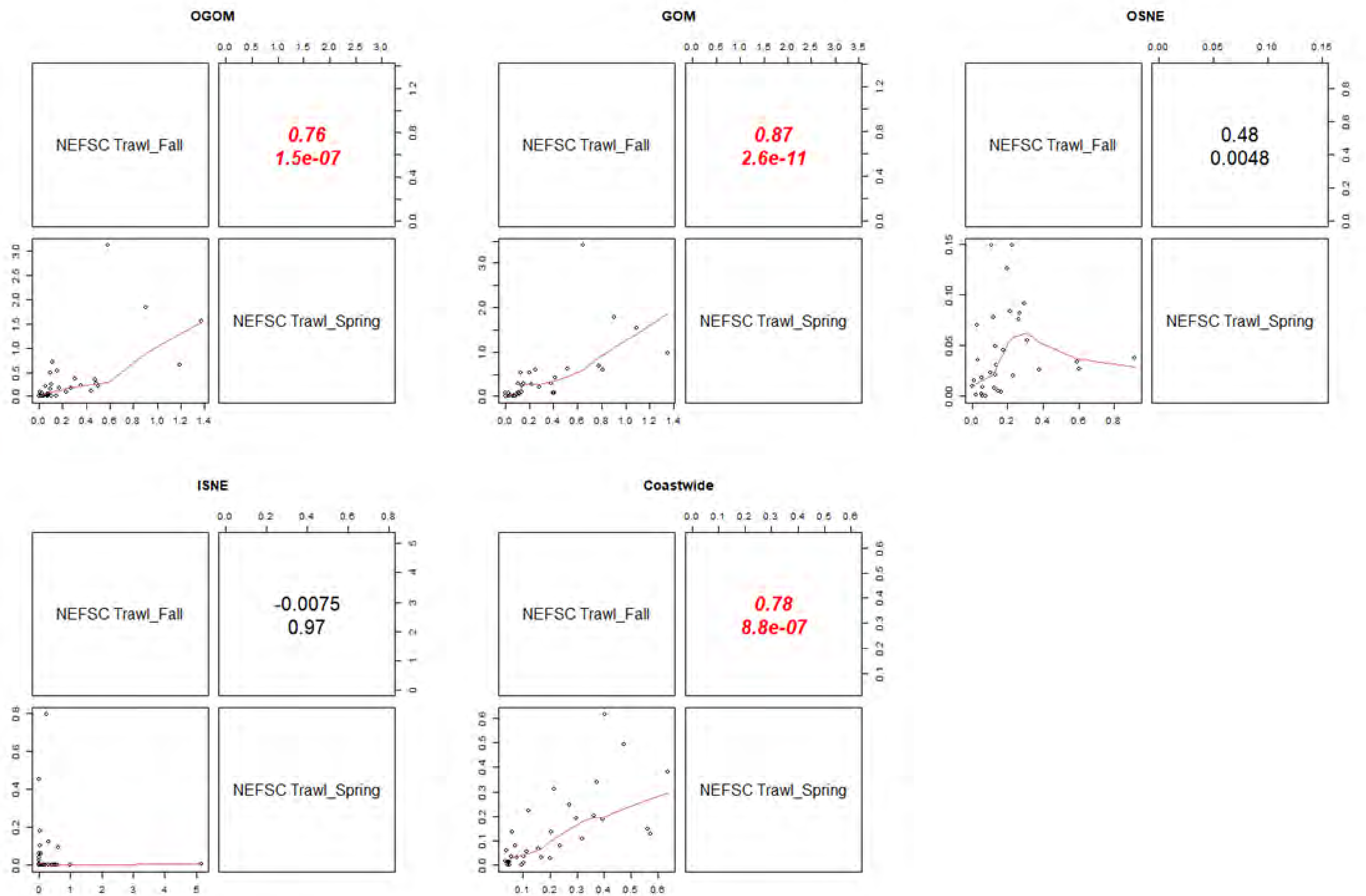

Figure 92. Spearman correlation results for OGOM, GOM, OSNE, ISNE, and coastwide spawning abundance indices. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

Figure 93. Spearman correlation results for GOM exploitable abundance indices and landings. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

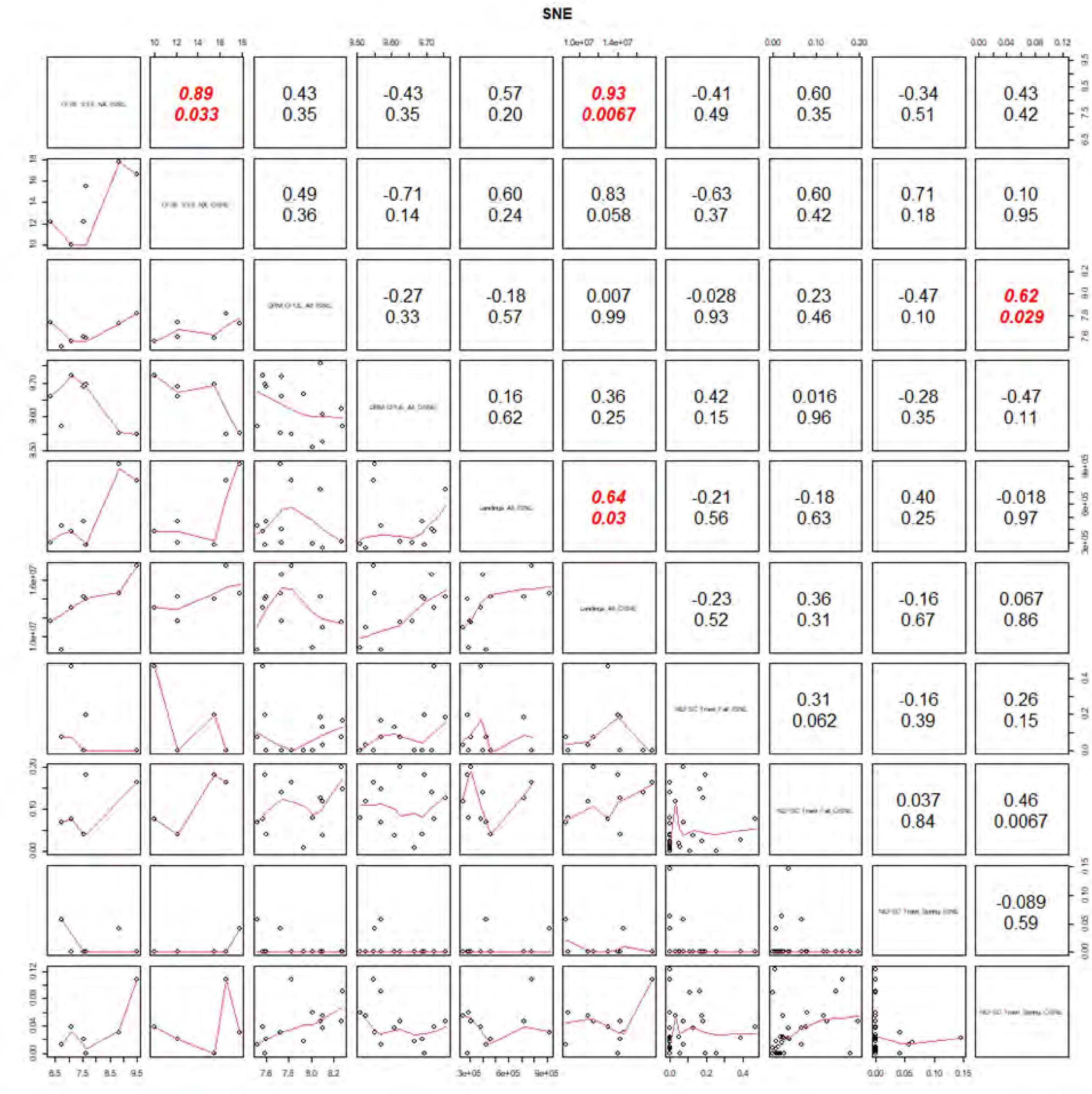

Figure 94. Spearman correlation results for SNE exploitable abundance indices and landings. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

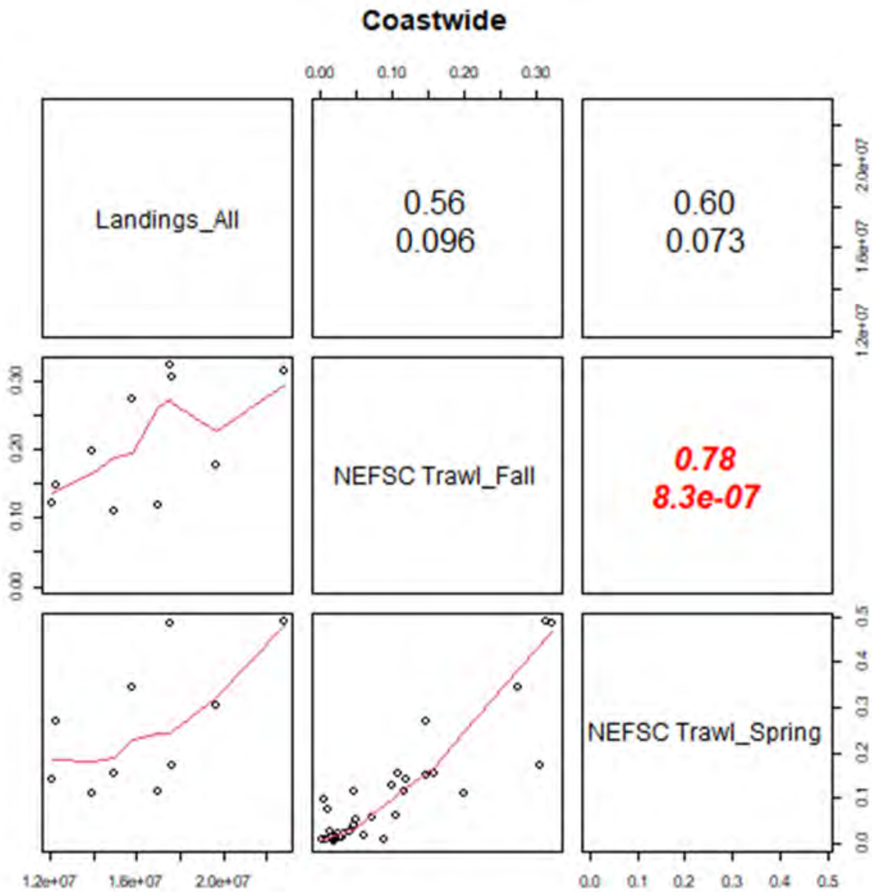

Figure 95. Spearman correlation results for coastwide exploitable abundance indices and landings. Panels above the diagonal include the Spearman's ρ as the top number and the p-value as the bottom number. Italicized and red numbers indicate significant correlations (p-value<0.05).

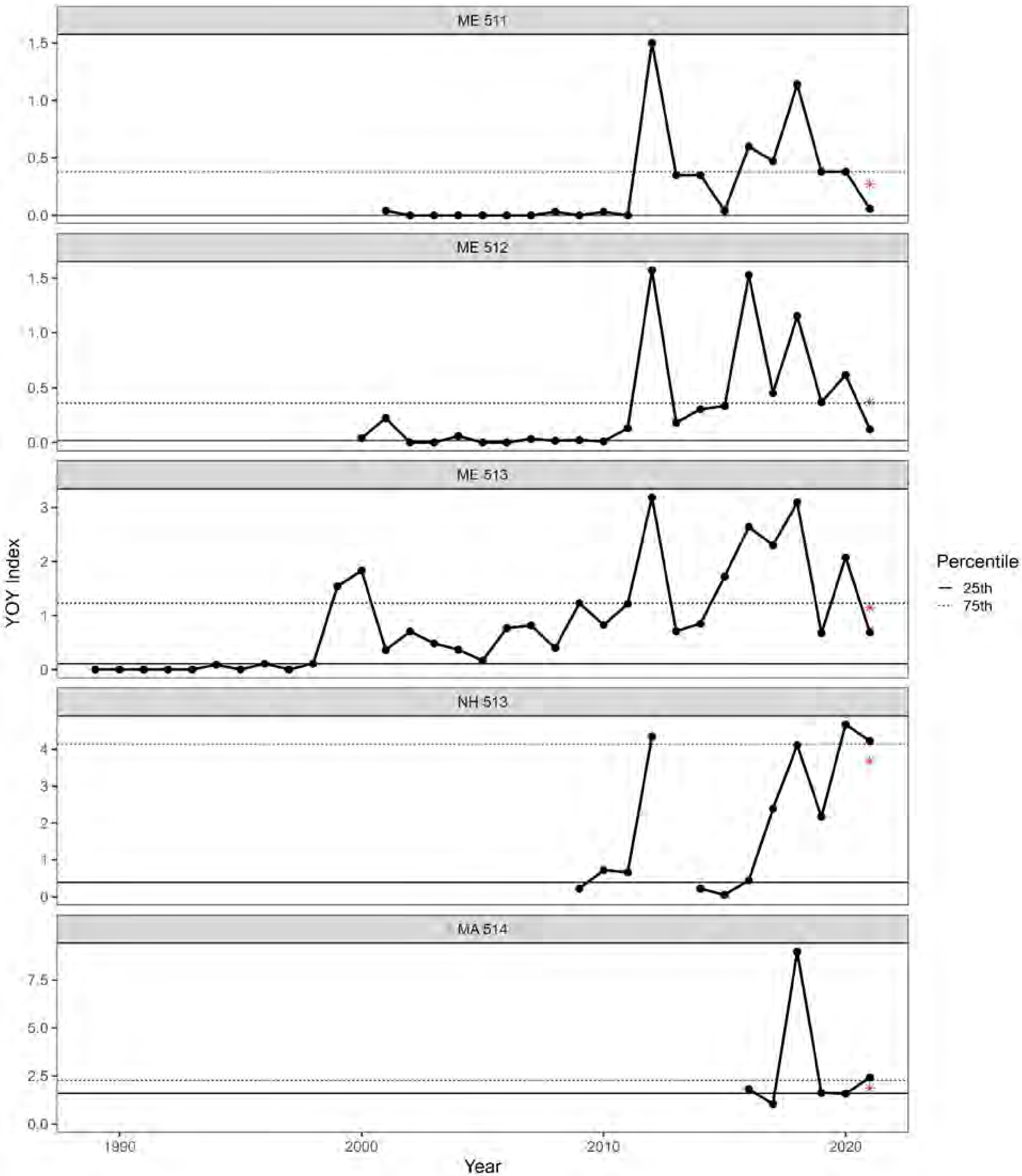

Figure 96. YOY settlement indicators for the IGOM Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

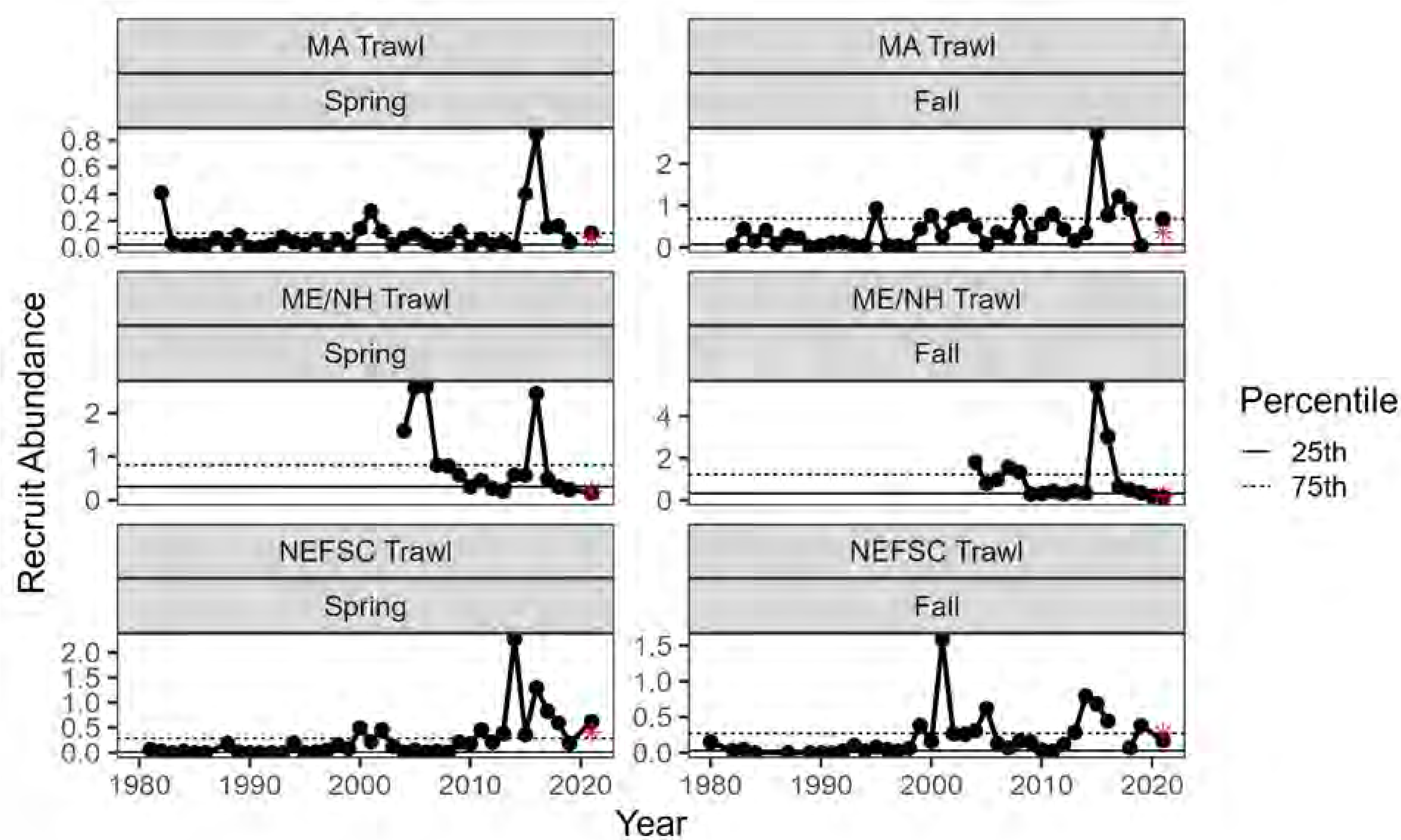

Figure 97. Recruit abundance indicators for the IGOM Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

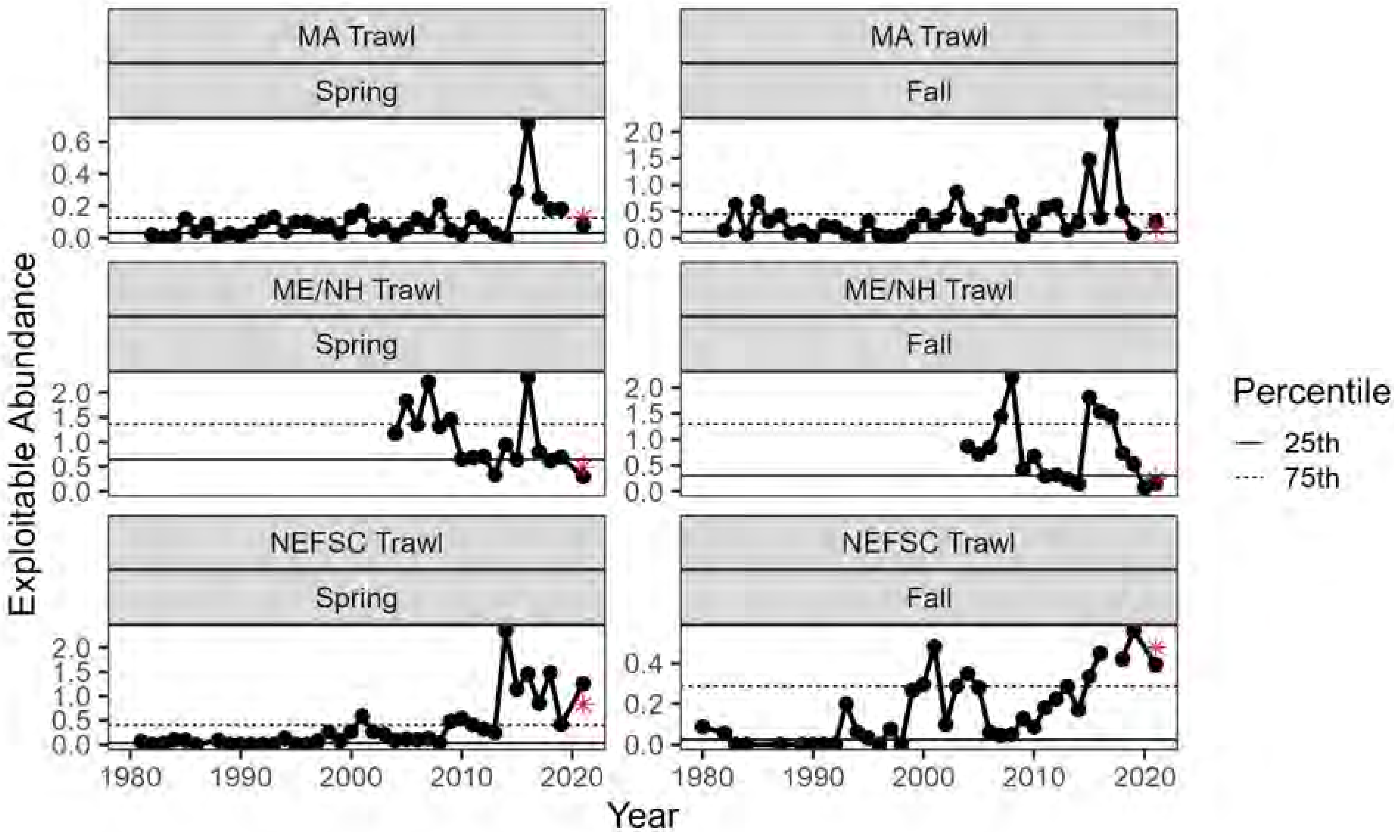

Figure 98. Exploitable abundance indicators for the IGOM Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

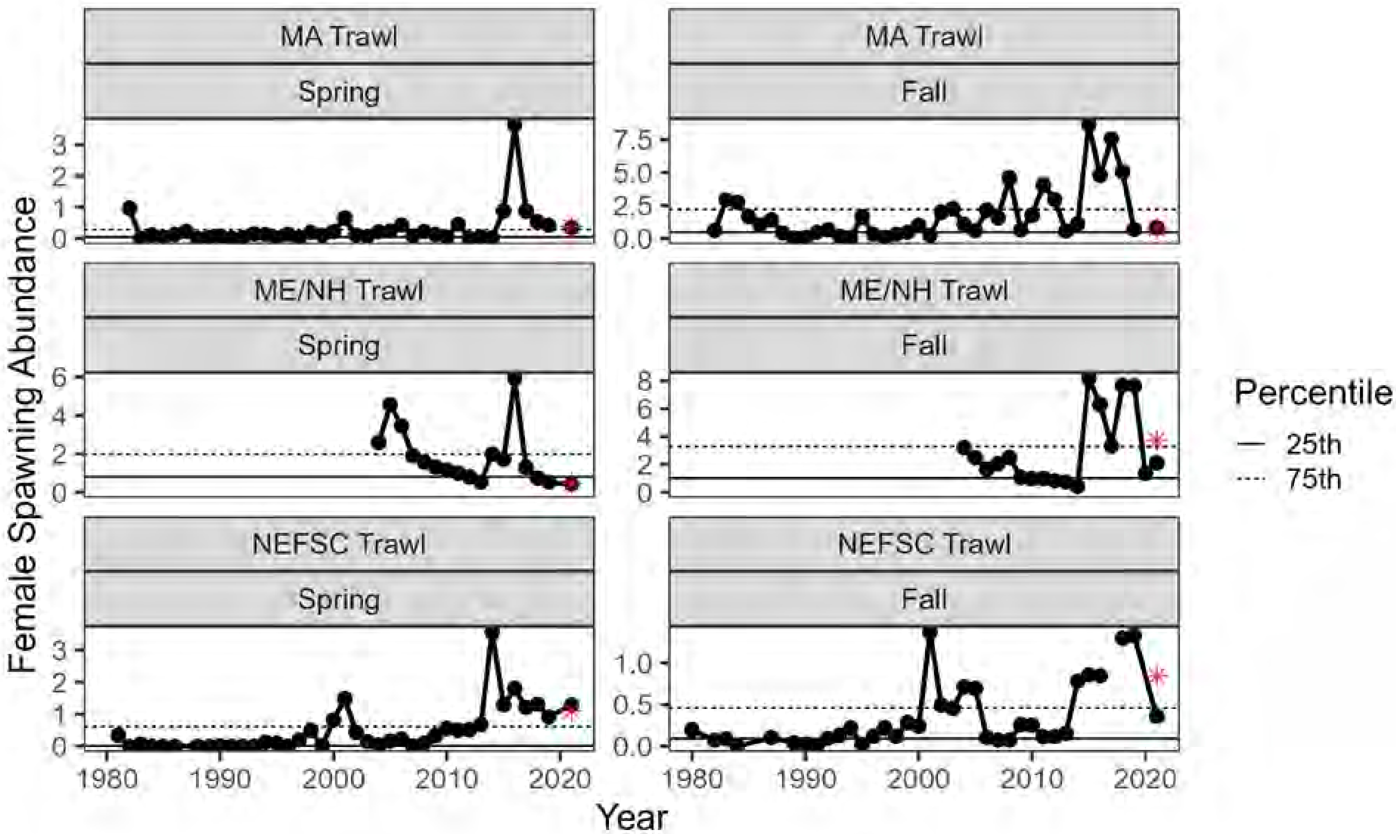

Figure 99. Spawning abundance indicators for the IGOM Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

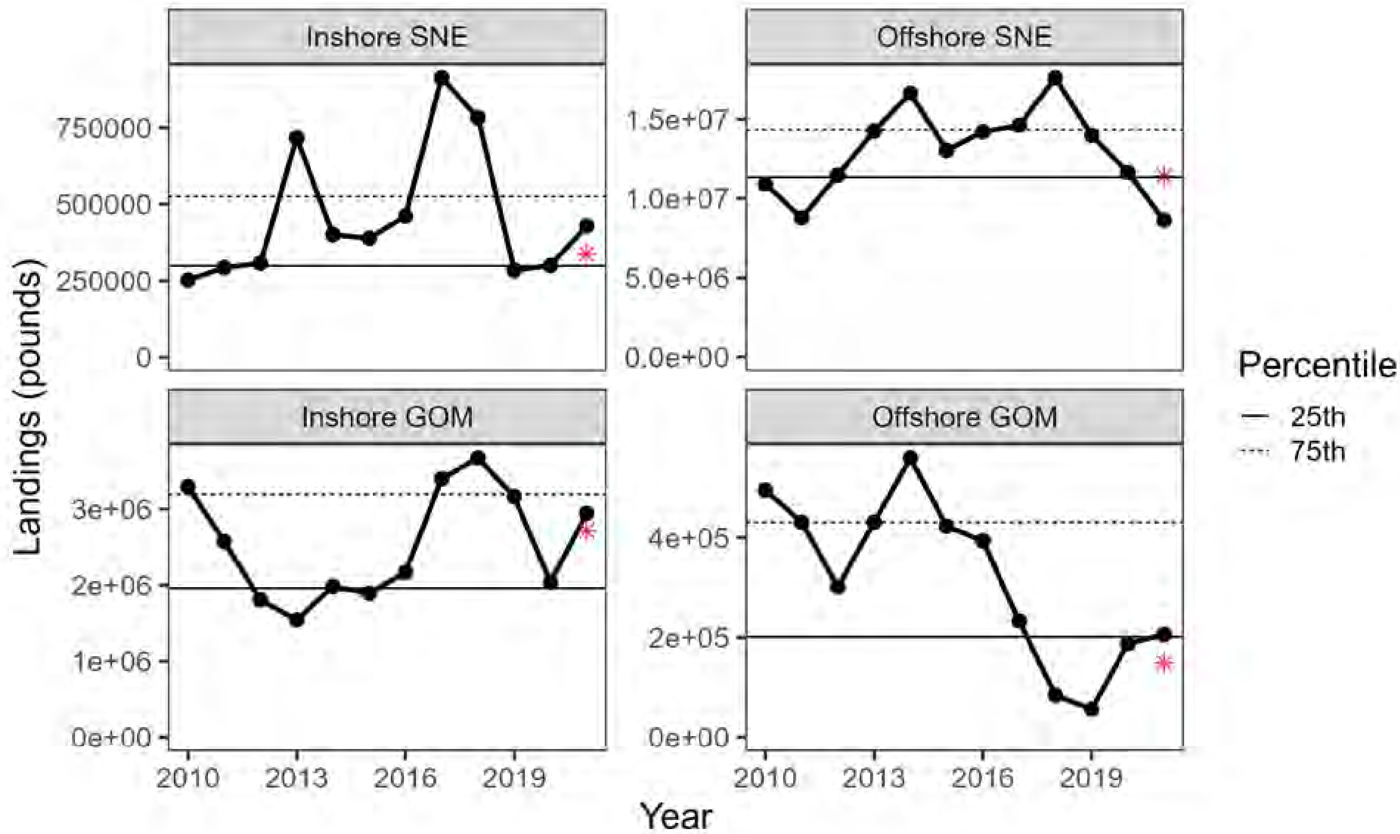

Figure 100. **Landings fishery performance indicators for the Jonah crab stocks. Red asterisks indicate the terminal three-year (2019-2021) average.**

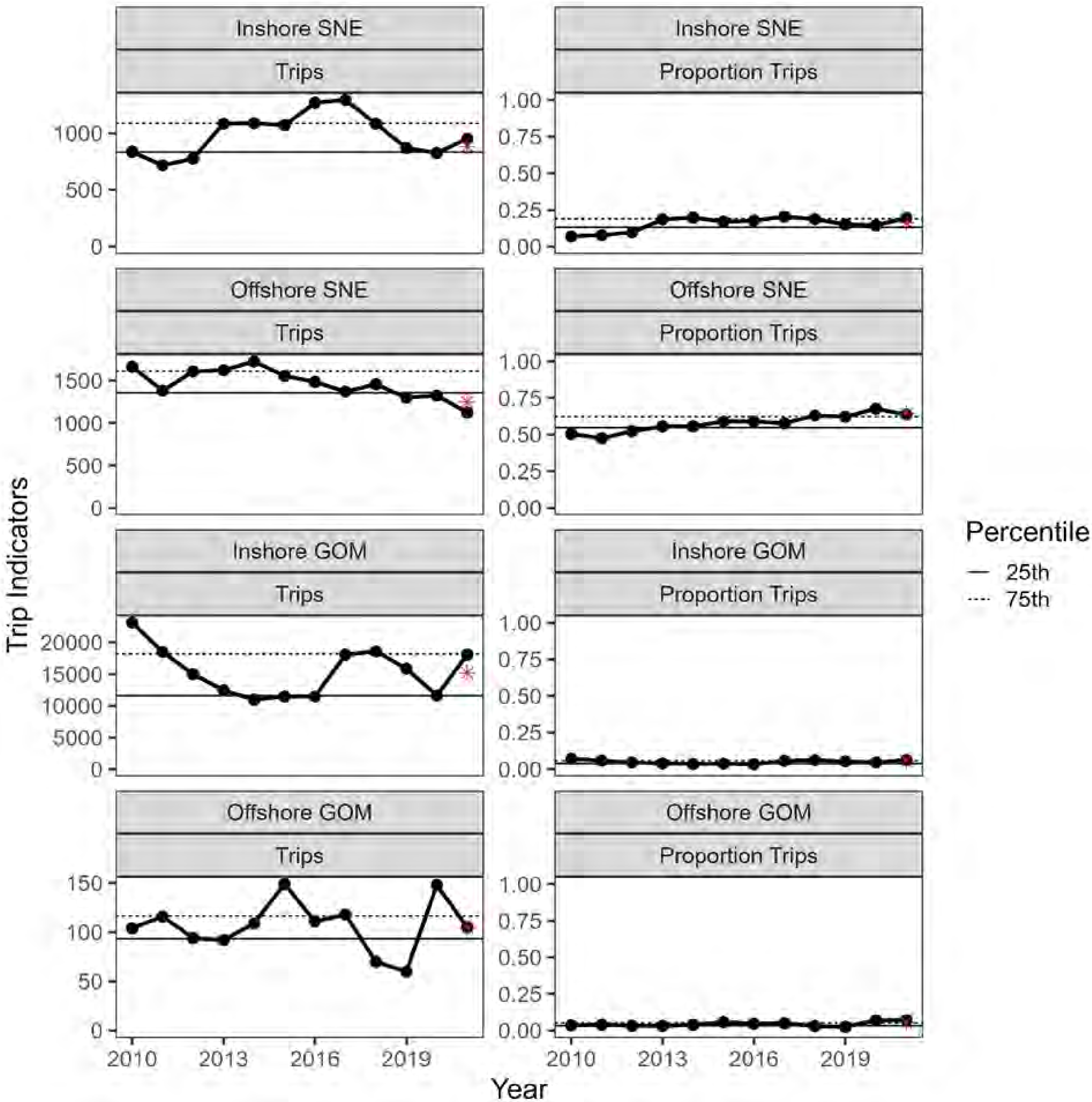

Figure 101. **Trip-based fishery performance indicators for the Jonah crab stocks. Red asterisks indicate the terminal three-year (2019-2021) average.**

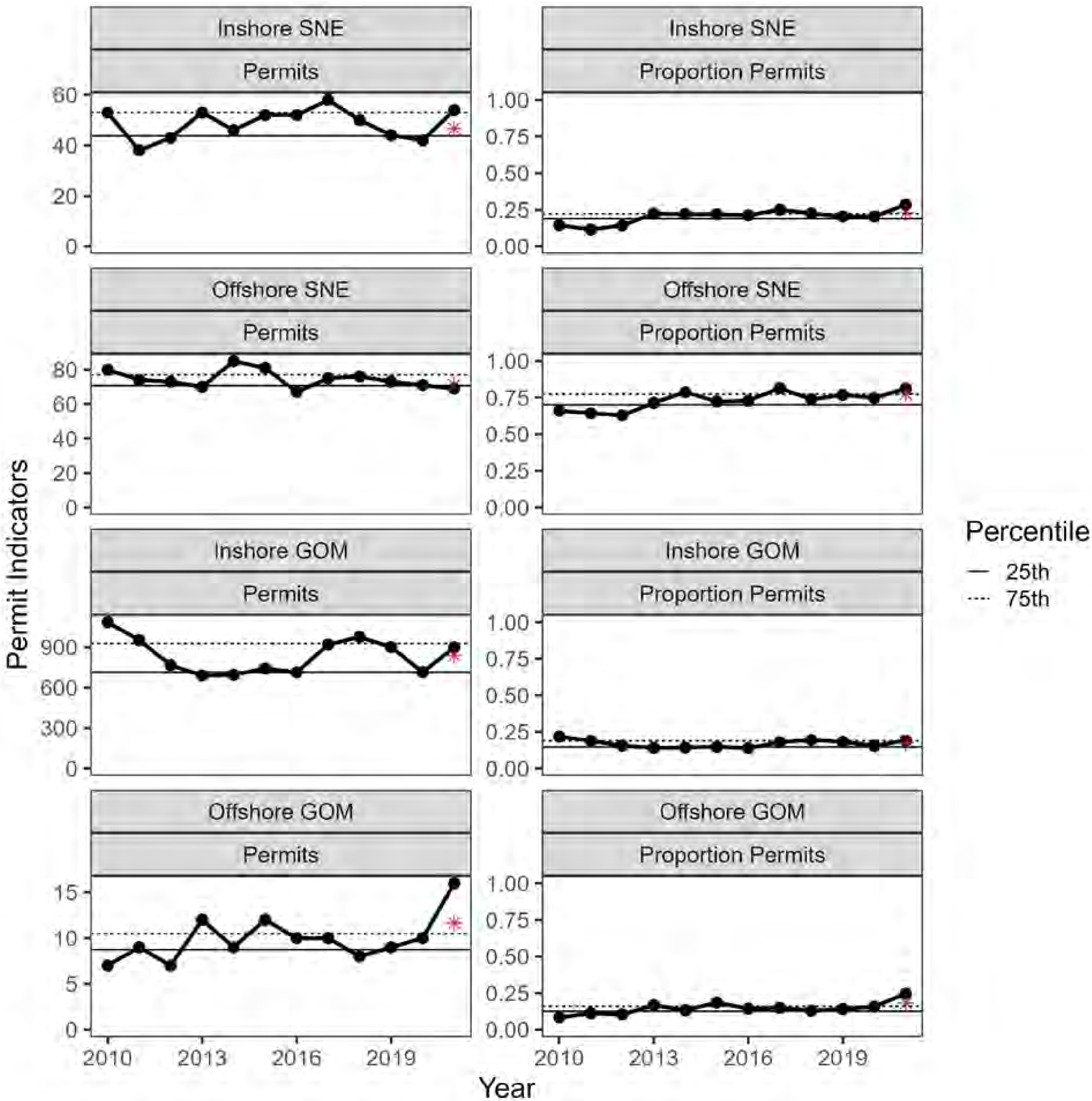

Figure 102. Permit-based fishery performance indicators for the Jonah crab stocks. Red asterisks indicate the terminal three-year (2019-2021) average.

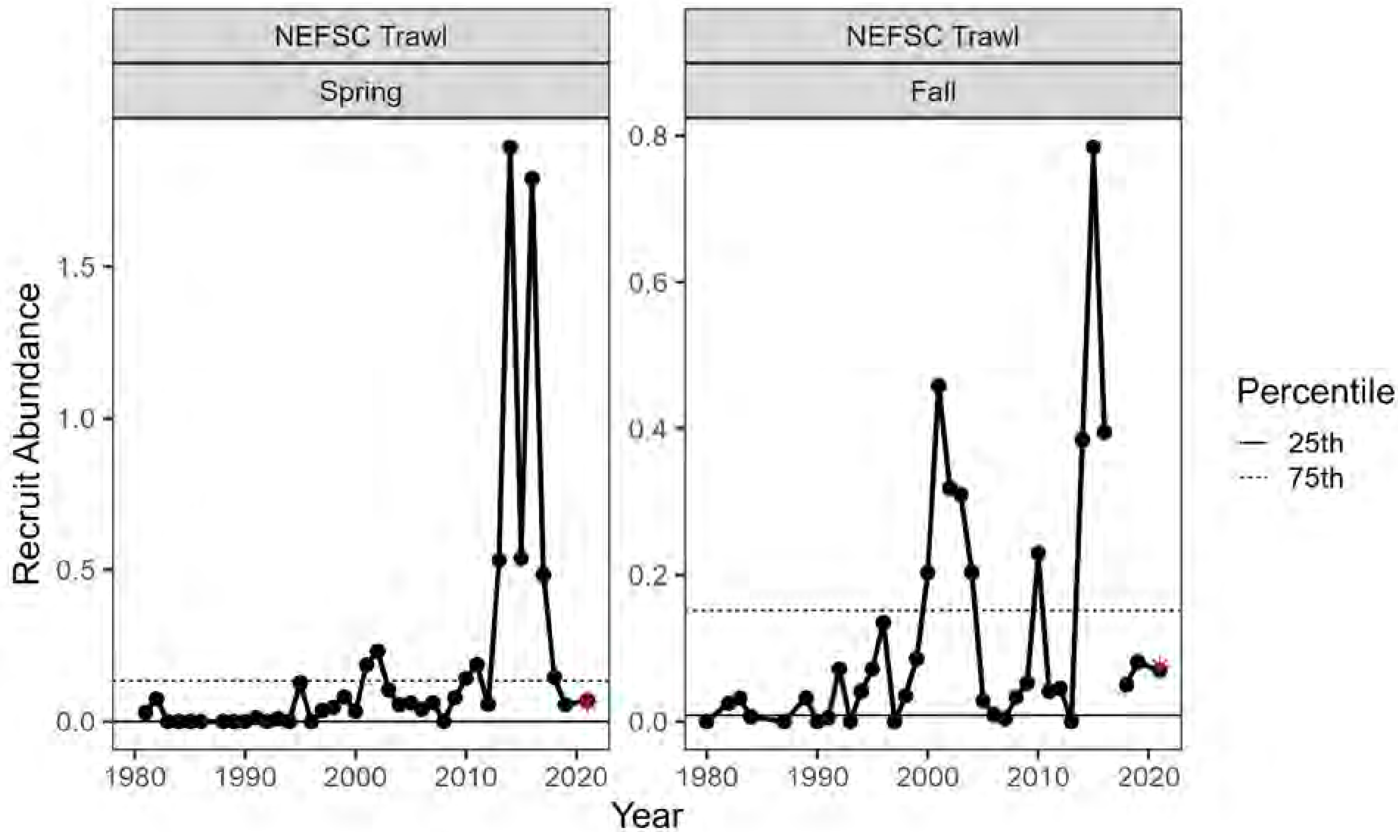

Figure 103. Recruit abundance indicators for the OGOM Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

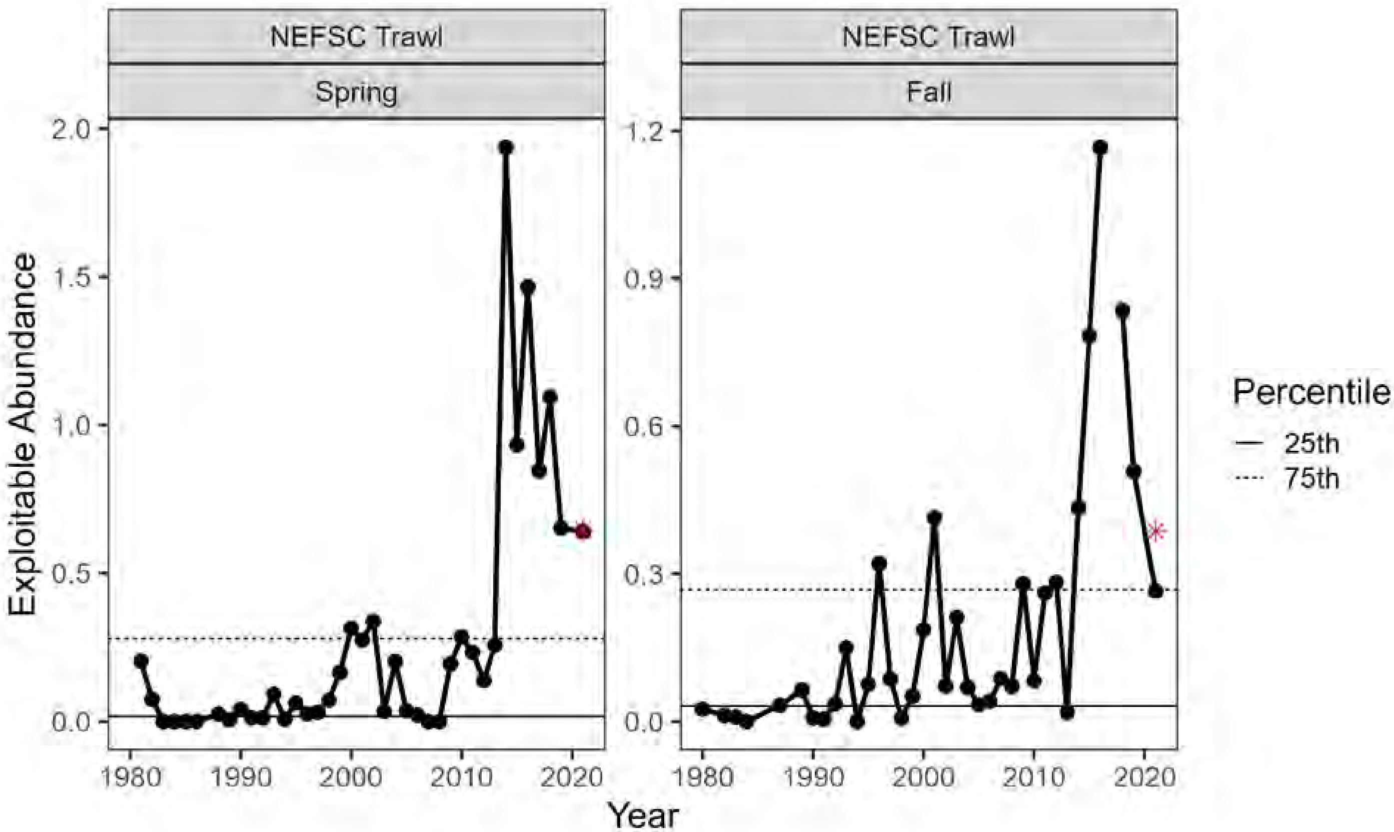

Figure 104. **Exploitable abundance indicators for the OGOM Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.**

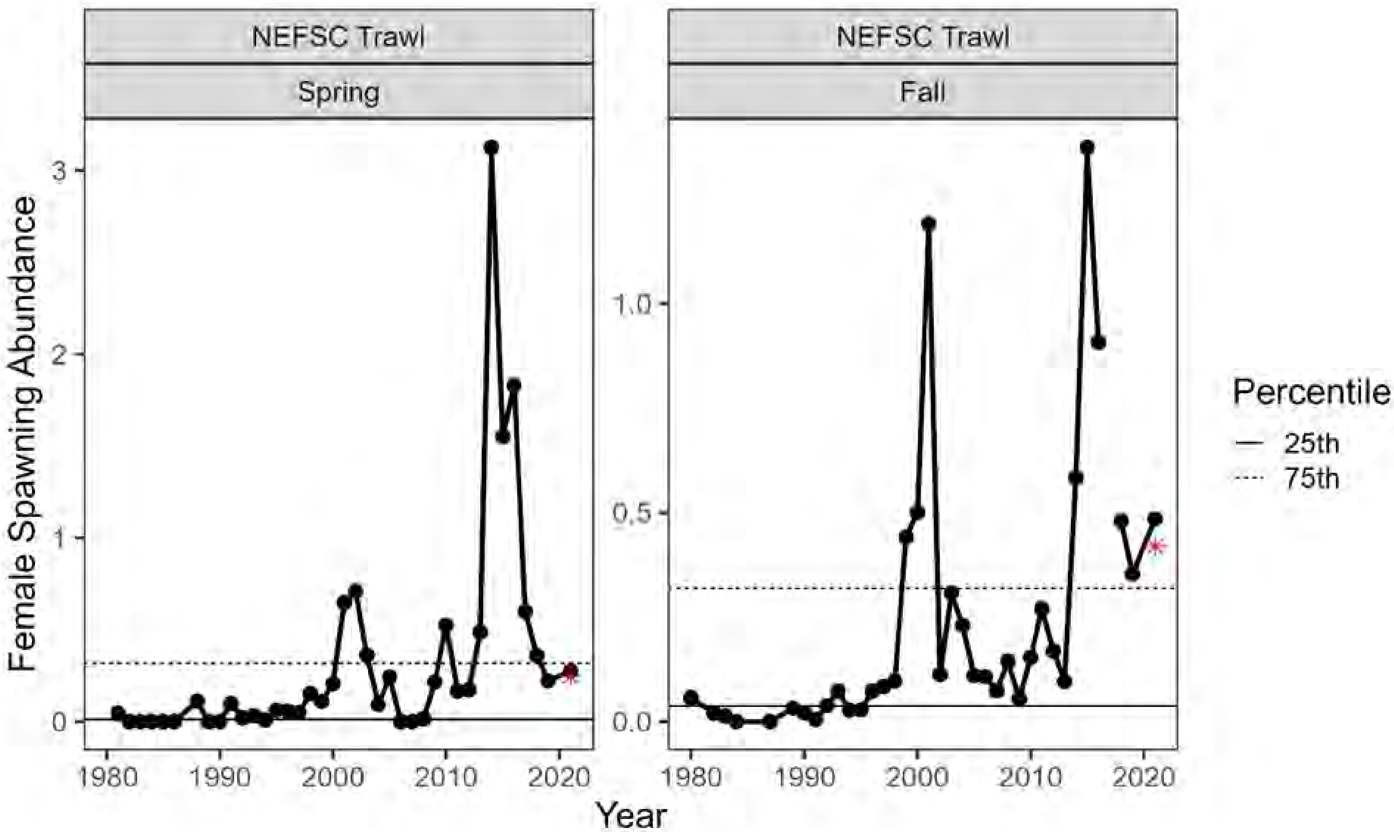

Figure 105. Spawning abundance indicators for the OGOM Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

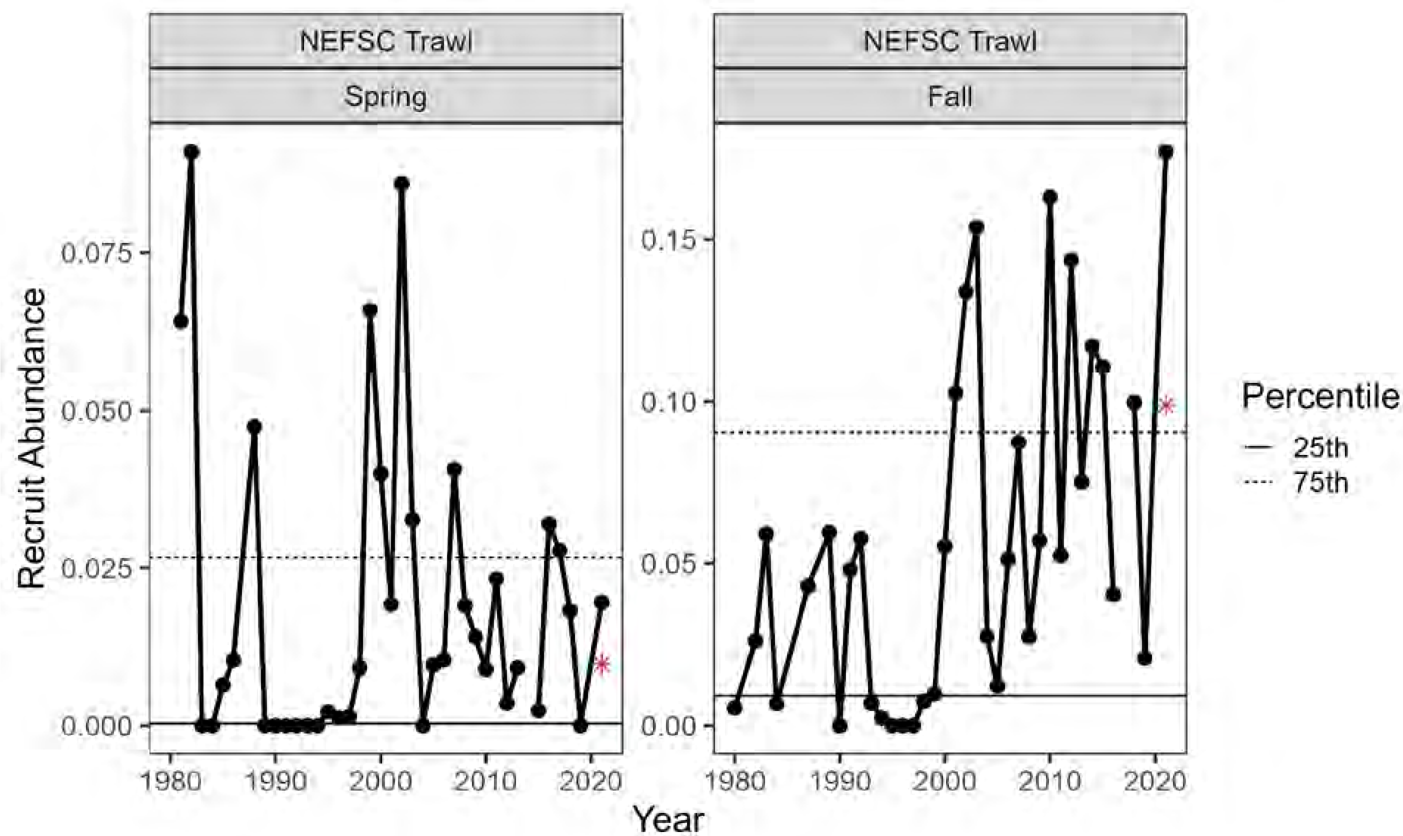

Figure 106. Recruit abundance indicators for the OSNE Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

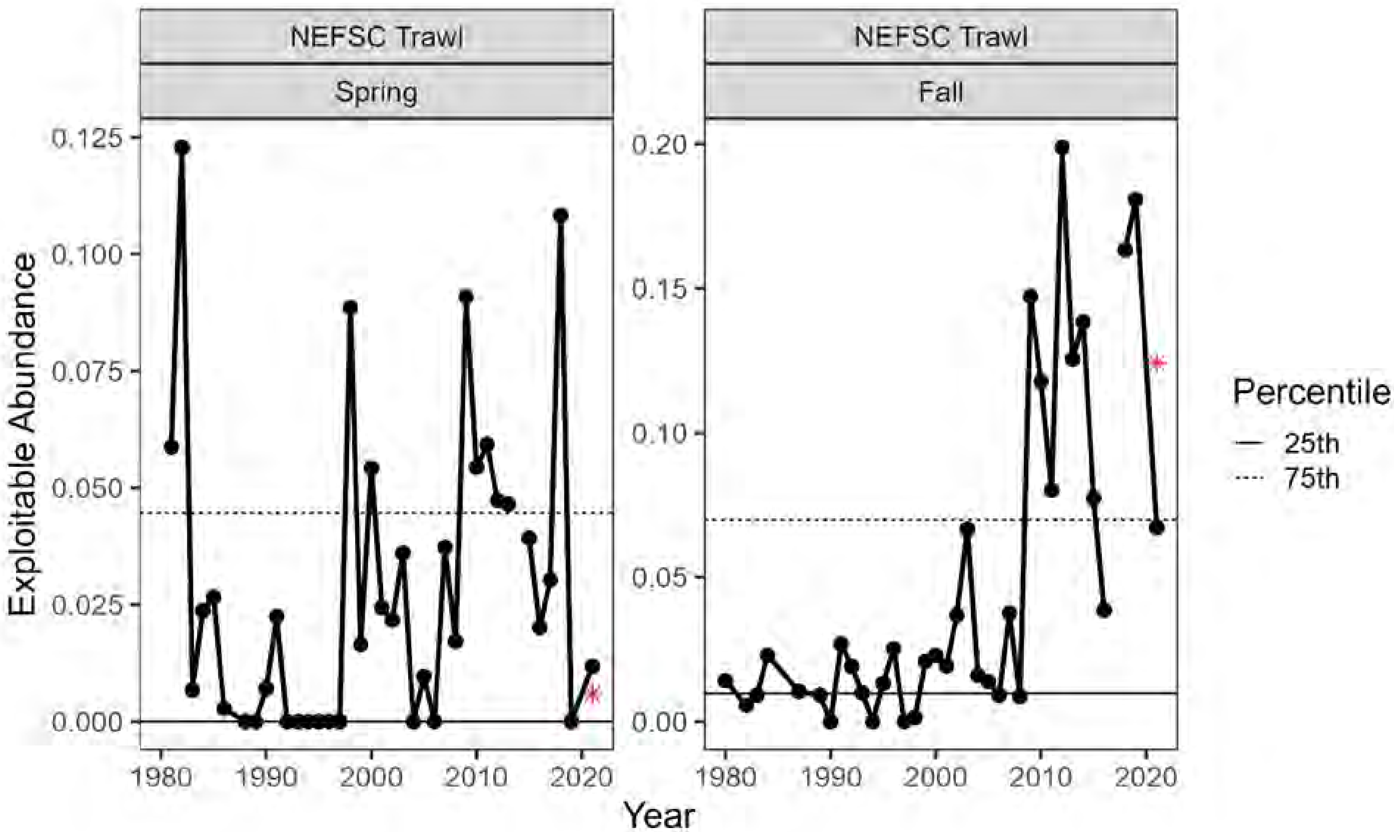

Figure 107. **Exploitable abundance indicators for the OSNE Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.**

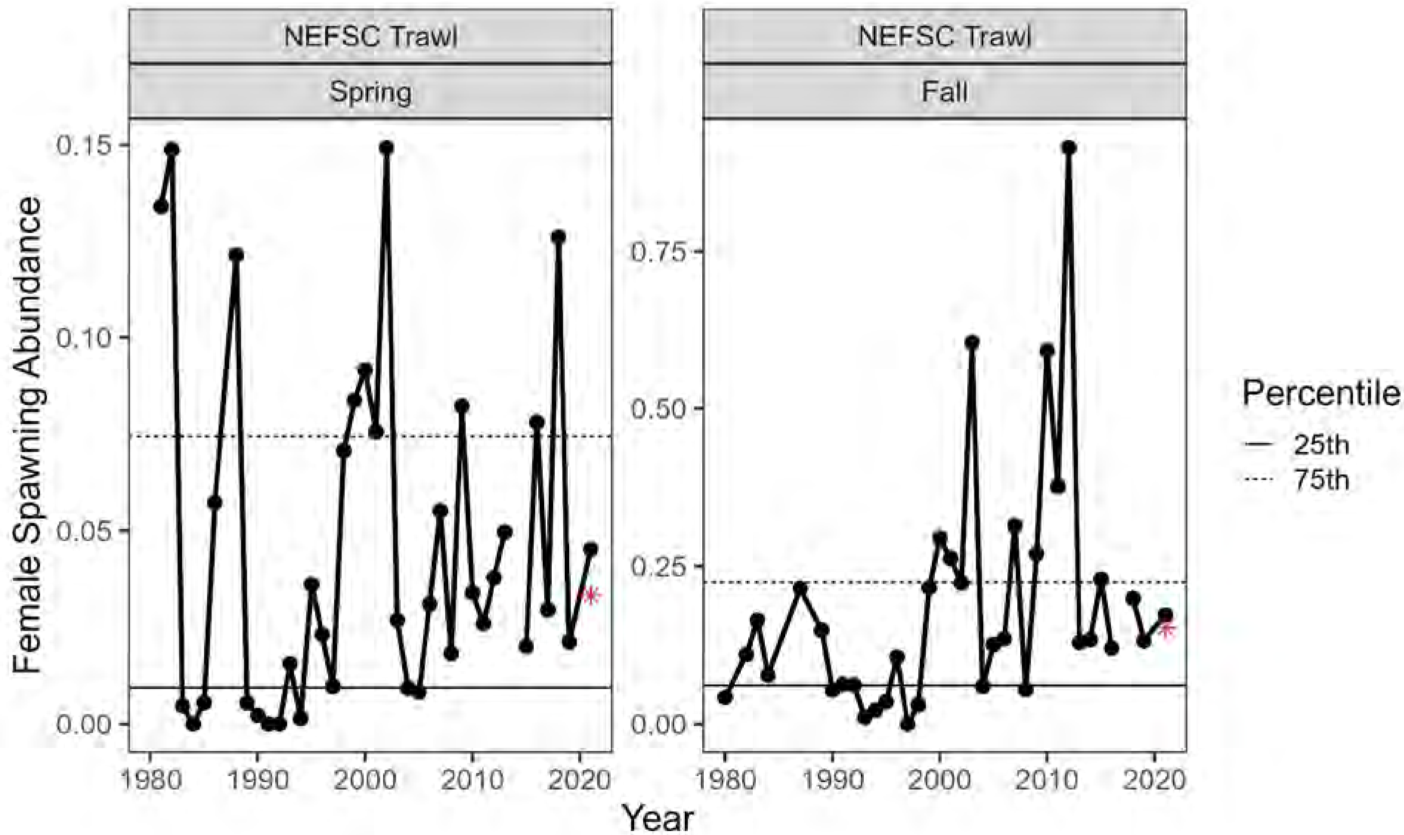

Figure 108. Spawning abundance indicators for the OSNE Jonah crab stock. Red asterisks indicate the terminal three-year (2019-2021) average.

14 APPENDICES

14.1 Index-Based Methods

Introduction

Simple index-based methods were applied to landings and exploitable abundance indices as an interim approach to generate management advice for the Jonah crab stocks until more robust data can be collected. These methods were considered ideal for Jonah crab because they rely on only a few years of data in the most recent years and do not require life history information, which is limited at this time for Jonah crab.

The typical objective of these methods is providing catch advice. However, Jonah crab and lobster fisheries are not currently managed with catch limits. Therefore, the objective of using these methods was to provide inference on exploitation levels that could be used for management advice such that catch advice that is lower than terminal year catch suggests an over-exploited stock and need for reduced exploitation, catch advice equal to terminal year catch suggests a fully-exploited stock and appropriate exploitation levels, and catch advice greater than terminal year catch suggests an under-exploited stock with potential to increase exploitation.

Three methods were evaluated including Islope, Plan B, and Skate. Islope was proposed in Geromont and Butterworth (2015) as a generic, empirical control rule using a recent abundance index trend to adjust observed catch. A log-linear regression is applied to a specified period at the end of the index time series and the estimated slope is used as a multiplier along with two additional predetermined multipliers (λ and *Cmult*) to adjust the average catch observed over the same time period. The catch advice in the form of an annual catch target (*ACT*) is calculated with equation 1:

$$Equation\ 1: ACT = Cmult * \overline{Catch} * (1 + \lambda * e^{slope})$$

where $\overline{Catch}$ is the average catch over the period selected for the log-linear regression, *slope* is the slope of the log-linear regression, and *Cmult* and λ are defined based on one of four versions proposed below ranging from least conservative (version 1) to most conservative (version 4).

$$\begin{gathered} version\ 1: \lambda = 0.4, Cmult = 0.8 \\ version\ 1: \lambda = 0.4, Cmult = 0.7 \\ version\ 1: \lambda = 0.4, Cmult = 0.6 \\ version\ 1: \lambda = 0.2, Cmult = 0.6 \end{gathered}$$

Plan B was developed for and used in assessments of multiple Northeast U.S. stocks including one Atlantic cod stock and two monkfish stocks. The method is conceptually similar to Islope with a key distinction being that the abundance index is first smoothed with a LOESS smoother and the log-linear regression is then applied to the smoothed values. The *ACT* is calculated with equation 2:

$$Equation\ 2: ACT = \overline{Catch} * e^{slope}$$

Skate is a custom method developed for Northeast U.S. skate stocks. For this method, both the catch and abundance index time series are smoothed with a running average. Relative exploitation (here denoted as *F*) is estimated by diving the smoothed index by the smoothed catch and the median relative exploitation is used as a multiplier for the smoothed index in a recent period to generate a catch limit. The use of the median relative exploitation is based on the assumption that the stock has been exploited appropriately, on average, across the time series. The catch limit can then be adjusted further to account for uncertainty with a specified multiplier to generate an *ACT* with equation 3:

$$ACT = median\ Relative\ F * s\left(\overline{Index}\right) * U_{buffer}$$

where $s\left(\overline{Index}\right)$ is the smoothed average index over the selected period and U_{buffer} is the multiplier to account for uncertainty.

Skate application has also used assumptions about abundance index percentiles to generate biomass reference points and status estimates from the recent index, but these components of the method were not used due to short time series of Jonah crab abundance indices.

All of these methods assume that the index of abundance used is reliably tracking the abundance signal and that there is a relationship between catch and the index such that increased catch will result in decreased abundance. Performance of these methods was evaluated with simulation analyses in a research track assessment conducted by NOAA's NEFSC (Legault et al. 2020). These are data-limited methods and similar methods can perform differently (Legault et al. 2020). Therefore, the ensemble method evaluated in the research track assessment, simply the median of catch advice across methods, is included as an alternative method influence by all other methods applied.

Data and Methods

Both spring and fall exploitable abundance indices from the NEFSC, MA, and ME/NH trawl surveys were used in the analysis. Seasonal indices were averaged for comparison to total annual catch in these methods. The fall index from year *y* and spring index from year *y+1* were averaged and compared to catch from year *y*. This averaging is done so the average index value approximates the January 1 index from year *y+1* that would reflect the impact from catch in year *y*. Two index values were zero and these were imputed to avoid computational errors by dividing the minimum observed positive index value over the time series by ten. There were also some missing data points, primarily due to covid-19 pandemic sampling restrictions. To impute these missing values, first the ratio of year *y* fall indices and year *y+1* spring indices were calculated for each survey (Figure A1). The mean ratio over the time series was then multiplied by the observed spring index to impute a missing fall index or divided by the observed fall index to impute a missing spring index. Season-averaged indices used in the methods are compared to each seasonal index with imputed values in Figure A2. For the IGOM stock where there are multiple trawl surveys, an additional index was calculated by scaling each trawl survey's index to its time series mean and averaging across surveys (average scaled survey indices).

No modifications were necessary for the catch time series.

Each method has a few specifications that typically include defaults used for analyses elsewhere, but that can be adjusted if there is information supporting doing so. As described previously, Islope requires specification of one of the four versions defining *Cmult* and λ. Version 3 was used in the original simulation study for this method which was applied to a severely depleted stock (Geromont and Butterworth 2015). Version 2 was used in this analysis because of the relatively recent development of the Jonah crab fisheries with no indication of severely depleted stocks while still recognizing uncertainty in stock status (i.e., not selecting version 1). The default period for the log-linear regression and average catch of five years was used in this analysis.

Specifications for Plan B are the LOESS smoother span (default=9.9/n years of index data) and time period used for log-linear regression and average catch (default=three years). These defaults were maintained in this analysis and the default time period offers an alternative to that used for the Islope method.

Specifications for Skate include the time period of the running average smoother and index value for catch advice (default=three years), the moving average type (default=current and preceding years), and the uncertainty buffer multiplier for generating a catch target (default=0.25). These defaults were also maintained in this analysis. Additionally, the assumption of appropriate exploitation, on average, across the time series can be relaxed by changing the percentile of relative *F* from the median. However, there was no good information to guide this change and it was maintained. Due to this, Skate was only applied to the OSNE stock that has supported the majority of landings and not the GOM stocks because they have experienced much lower landings and are not believed to be fully-exploited across the time series.

Results

IGOM

Catch advice was highly variable among methods but similar with MA and ME/NH indices (Figures A3-A4). Advice was least conservative with the NEFSC index and also more similar between methods (Figure A5). Slopes were actually positive with the NEFSC index, resulting in catch multipliers greater than 1 and a slight increase in catch from Plan B (Table A1). Similarities between the ME/NH and MA results drive the results of the average scaled index results (Figure A6).

OGOM

Catch advice was similar from both methods, being just slightly greater from Islope (Figure A7). This catch advice was similar to the terminal three-year average catch used for Plan B (Table A1) and was lower than catches observed during the first half of the time series.

OSNE

Catch advice varied widely among methods (Figure A8). Islope estimated the highest catch at 12.6 million pounds which is only a slight reduction from the five-year average catch used for this method (13.3 million pounds, Table A1), followed by Skate (and the ensemble estimate, 8.5 million pounds) which was just slightly lower than the terminal year catch, and finally Plan B which estimates catch advice lower than any catch observed during the time series at 7 million pounds. Skate estimates increasing relative *F* over the first half of the time series followed by decreasing relative *F* from 2017-2020. There was a slight uptick in 2021.

Discussion

The longer time period of Islope generally leads to the most optimistic catch advice because it includes the peak catch years and also a period of higher index values earlier in the time series leading to a flatter slope. Based on correlation analyses of trawl surveys and lagged settlement surveys done during the assessment that found stronger correlations for shorter lag times (2-3 years), the three-year averaging period specified for Plan B may better reflect a recruitment generation time than the longer five-year time period specified for Islope and provide a more appropriate averaging period for Jonah crab. Another appealing aspect of Plan B is lack of a subjective decision on addition multipliers needed for the Islope method. The Plan B and Skate methods are also better suited for noisy data such as that available for Jonah crab because they smooth the observations first before estimating the catch multiplier.

Despite the appealing aspects of some of these methods, during deliberations about the data sets used and apparent population dynamics of Jonah crabs, advice using these methods was not recommended. In the bycatch-driven fisheries of GOM, there may yet to be a defined relationship between catch and abundance that is necessary for robust catch advice estimates from these methods. Advice, particularly for the OGOM stock, appeared unintuitive given the low magnitude of landings from this stock and presumed low exploitation. This is influenced by the decline in indices near the end of the time series from time series highs. There was no clear indication that fishing was driving this decline and, rather, it appears there are intermittent pulses of abundance that occur over short durations that are driven by unknown factors. An additional concern for all stocks is the quality of the index data. Catch rates by trawl surveys are low and have often hovered around zero. Being a species that burrows in soft bottoms, trawls may not efficiently capture Jonah crabs and indices from these surveys may only provide coarse, qualitative information on abundance changes, particularly increases when catch rates can move away from the lower bound of zero.

References

Geromont, H.F. and Butterworth, D.S., 2015a. Generic management procedures for data-poor fisheries: forecasting with few data. ICES Journal of Marine Science, 72(1), pp.251-261.

Legault, C., R. Bell, J. Cournane, J. Deroba, G. Fay, A. Jones, T. Miller, B. Muffley, and J. Weidenmann. 2020. Draft report of the index based methods working group. 59 p.

Tables

Table A1. Index-based method results for Jonah crab stocks.

Stock	Survey	Method	Slope	exp(Slope)	Catch Advice	2019-2021 Average Catch	2017-2021 Average Catch
IGOM	MA Trawl	Plan B	-0.97	0.38	1,029,669	2,715,902	3,043,688
IGOM	MA Trawl	Islope	-0.35	0.70	2,728,777	2,715,902	3,043,688
IGOM	MA Trawl	Ensemble	NA	NA	1,879,223	2,715,902	3,043,688
IGOM	ME/NH Trawl	Plan B	-0.96	0.38	1,036,612	2,715,902	3,043,688
IGOM	ME/NH Trawl	Islope	-0.43	0.65	2,684,763	2,715,902	3,043,688
IGOM	ME/NH Trawl	Ensemble	NA	NA	1,860,688	2,715,902	3,043,688
IGOM	NEFSC Trawl	Plan B	0.08	1.08	2,944,041	2,715,902	3,043,688
IGOM	NEFSC Trawl	Islope	0.05	1.05	3,026,068	2,715,902	3,043,688
IGOM	NEFSC Trawl	Ensemble	NA	NA	2,985,055	2,715,902	3,043,688
IGOM	Average Scaled Survey Indices	Plan B	-0.40	0.67	1,826,671	2,715,902	3,043,688
IGOM	Average Scaled Survey Indices	Islope	-0.18	0.84	2,844,820	2,715,902	3,043,688
IGOM	Average Scaled Survey Indices	Ensemble	NA	NA	2,335,746	2,715,902	3,043,688
OGOM	NEFSC Trawl	Plan B	-0.25	0.78	116,431	149,600	153,131
OGOM	NEFSC Trawl	Islope	-0.17	0.85	143,480	149,600	153,131
OGOM	NEFSC Trawl	Ensemble	NA	NA	129,956	149,600	153,131
OSNE	NEFSC Trawl	Plan B	-0.49	0.61	7,008,359	11,419,689	13,298,001
OSNE	NEFSC Trawl	Islope	-0.14	0.87	12,551,963	11,419,689	13,298,001
OSNE	NEFSC Trawl	Skate	NA	NA	8,482,925	11,419,689	13,298,001
OSNE	NEFSC Trawl	Ensemble	NA	NA	8,482,925	11,419,689	13,298,001

Figures

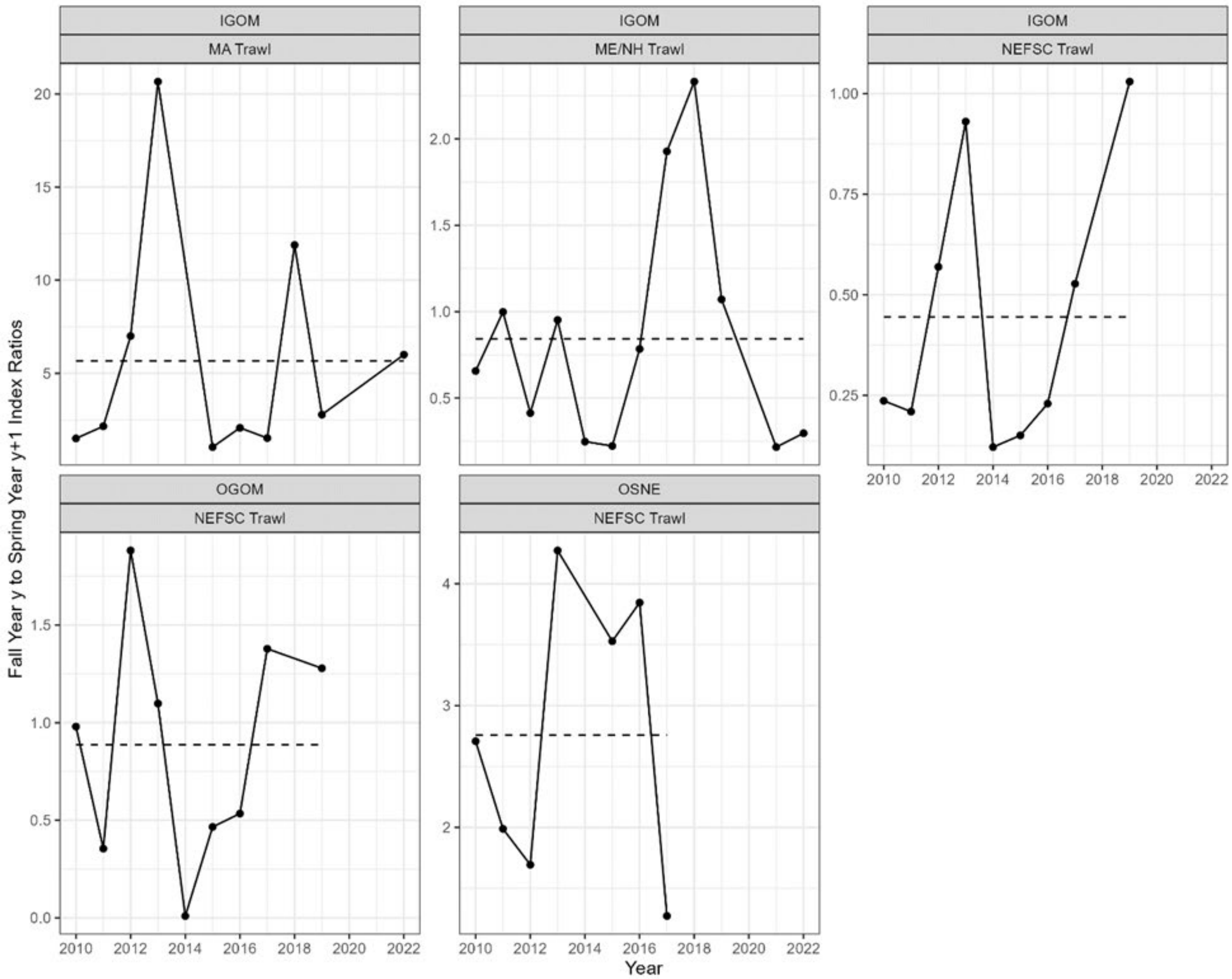

Figure A1. Ratios of fall indices in year *y* and spring indices in year *y+1.* The dashed line is the median ratio which was used to impute missing index values.

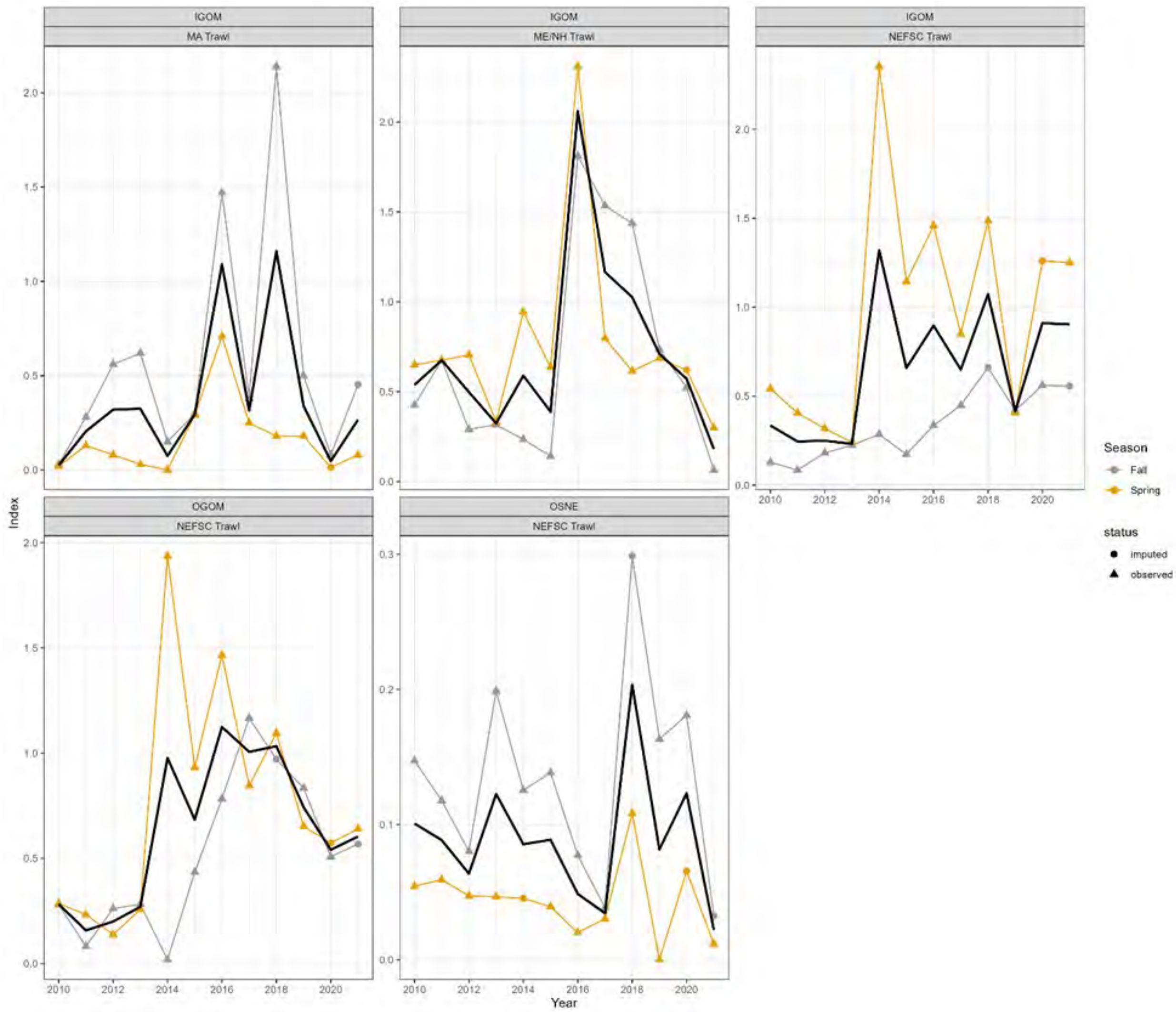

Figure A2. Final indices used in index-based methods (black line) compared to seasonal indices averaged to generate the final indices. Shapes for the seasonal index points indicate whether the value was observed or imputed.

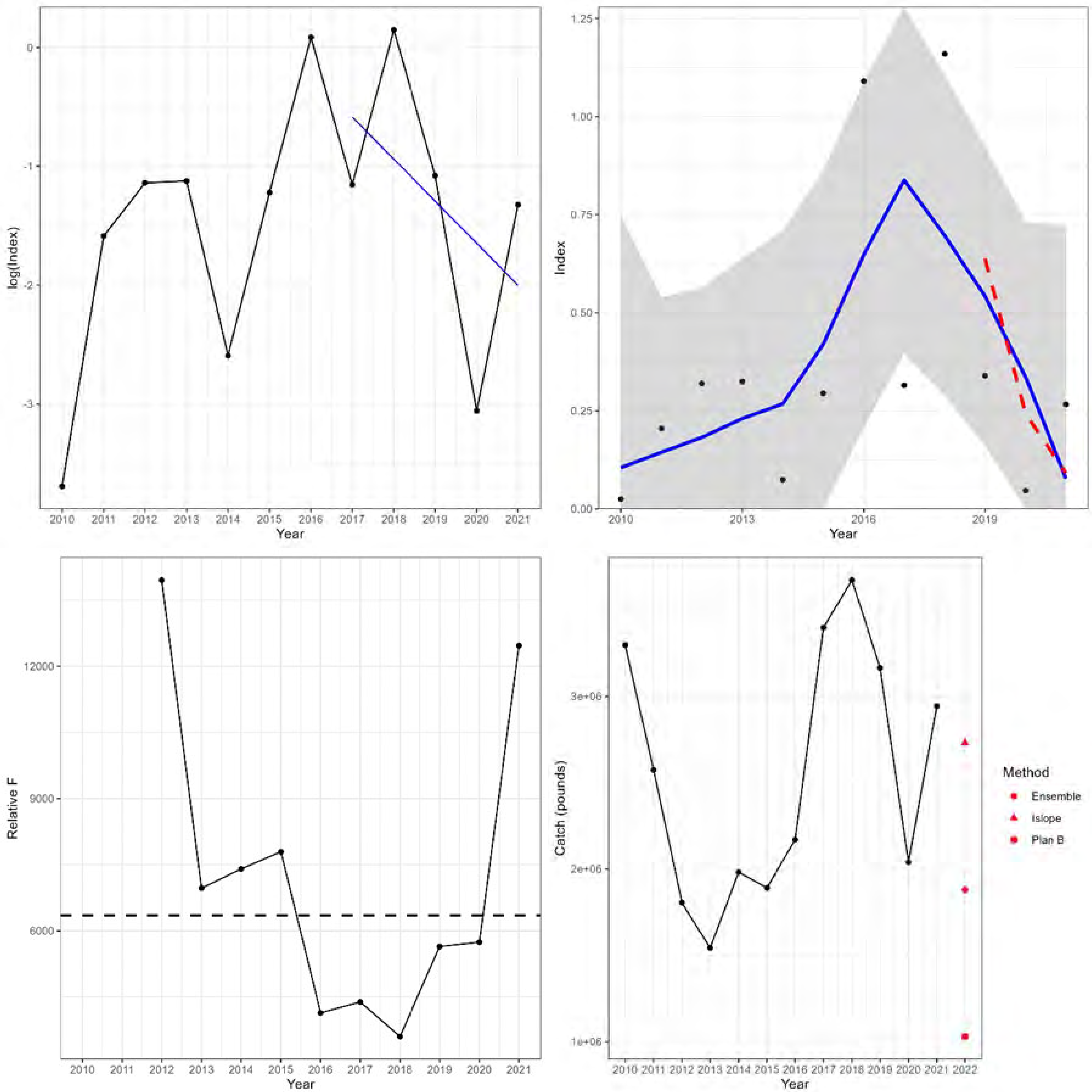

Figure A3. Index-based method results for the IGOM Jonah crab stock with the MA Trawl index including the Islope log-linear regression line and observed index on the log scale (upper left), Plan B log-linear regression line (transformed to original index scale) and LOESS smoother (blue line, upper right), Skate relative *F* time series and median (dashed line, lower left), and comparison of catch advice from all methods to the observed landings (lower right).

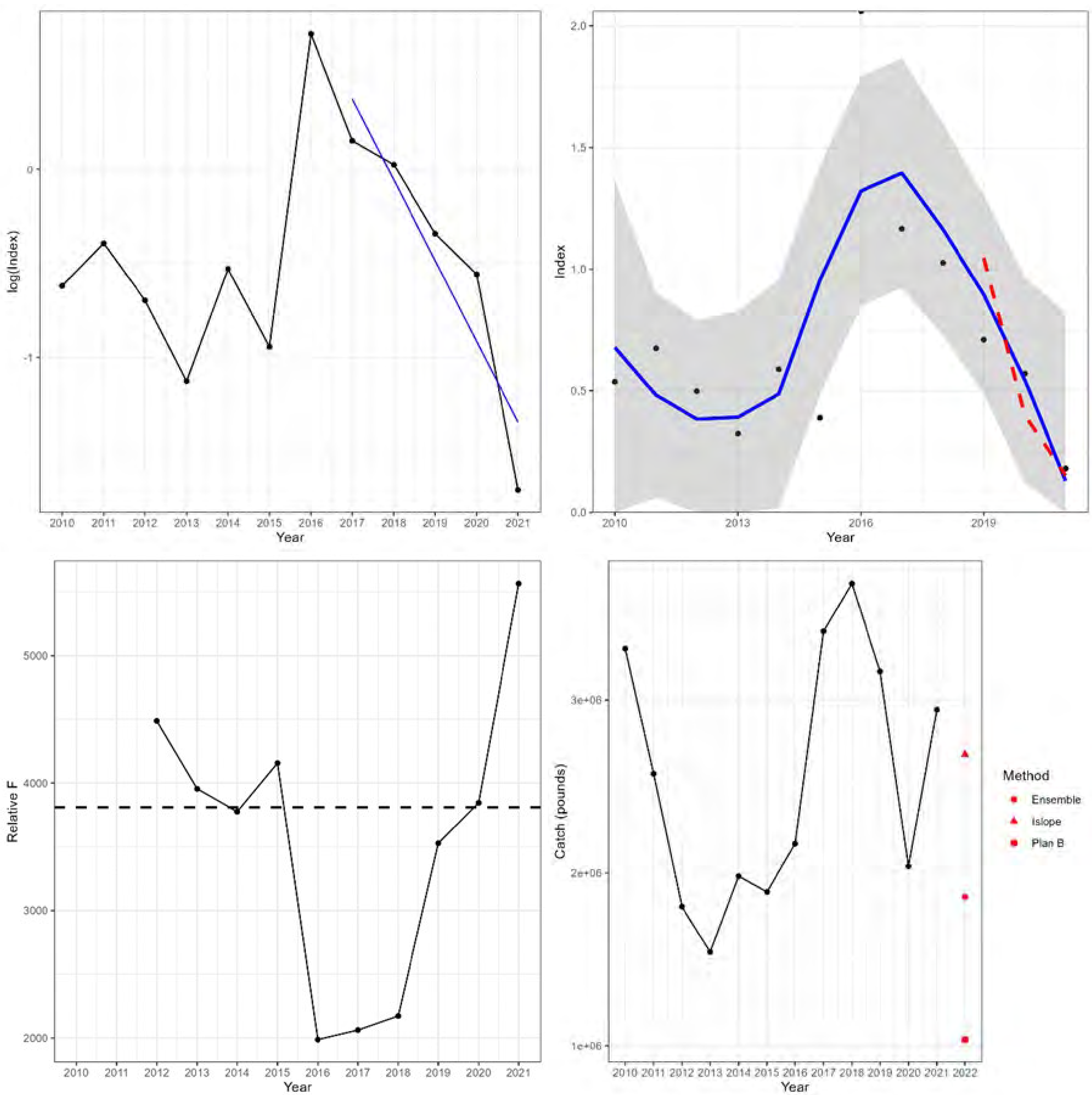

Figure A4. Index-based method results for the IGOM Jonah crab stock with the ME/NH Trawl index including the Islope log-linear regression line and observed index on the log scale (upper left), Plan B log-linear regression line (transformed to original index scale) and LOESS smoother (blue line, upper right), Skate relative *F* time series and median (dashed line, lower left), and comparison of catch advice from all methods to the observed landings (lower right).

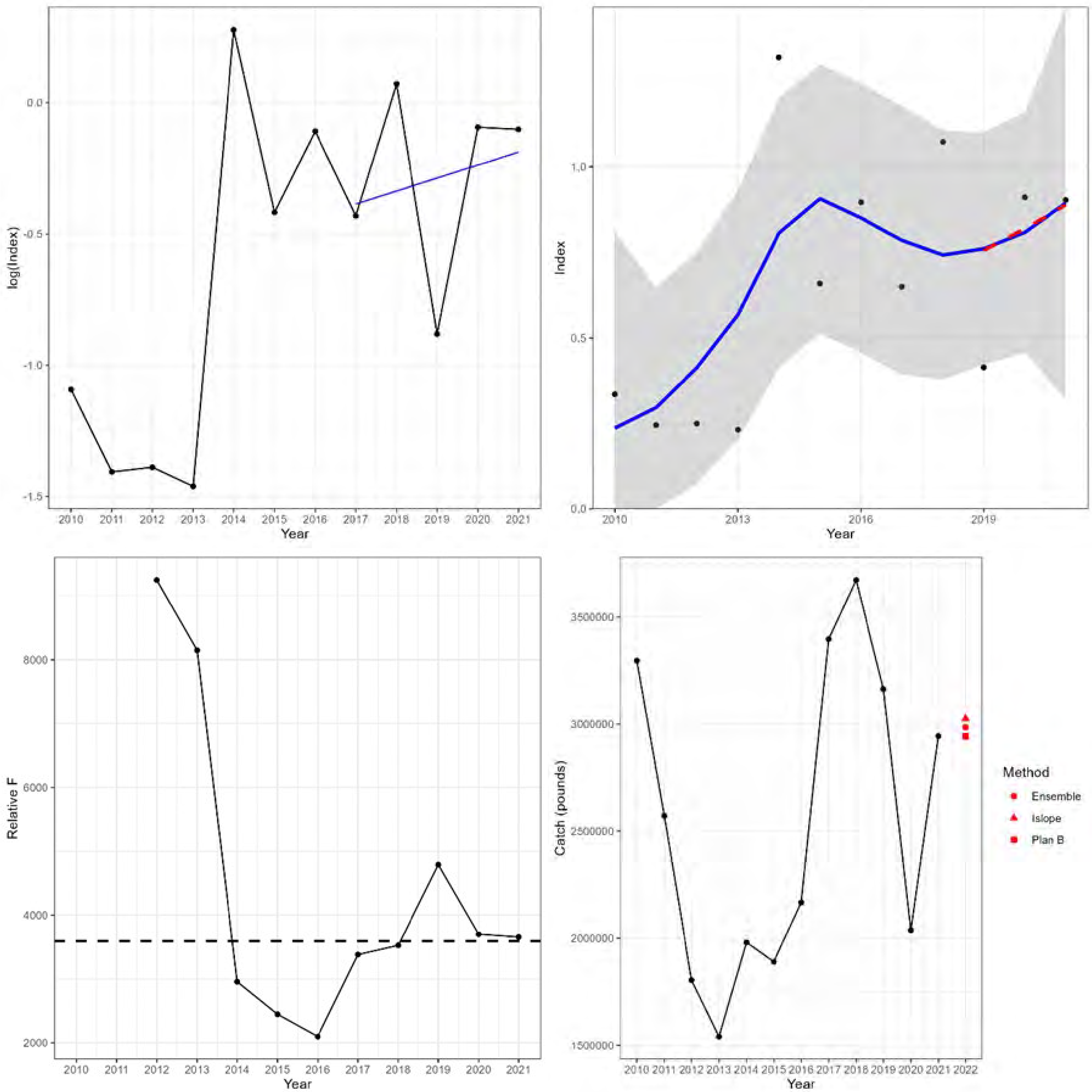

Figure A5. Index-based method results for the IGOM Jonah crab stock with the NEFSC Trawl index including the Islope log-linear regression line and observed index on the log scale (upper left), Plan B log-linear regression line (transformed to original index scale) and LOESS smoother (blue line, upper right), Skate relative *F* time series and median (dashed line, lower left), and comparison of catch advice from all methods to the observed landings (lower right).

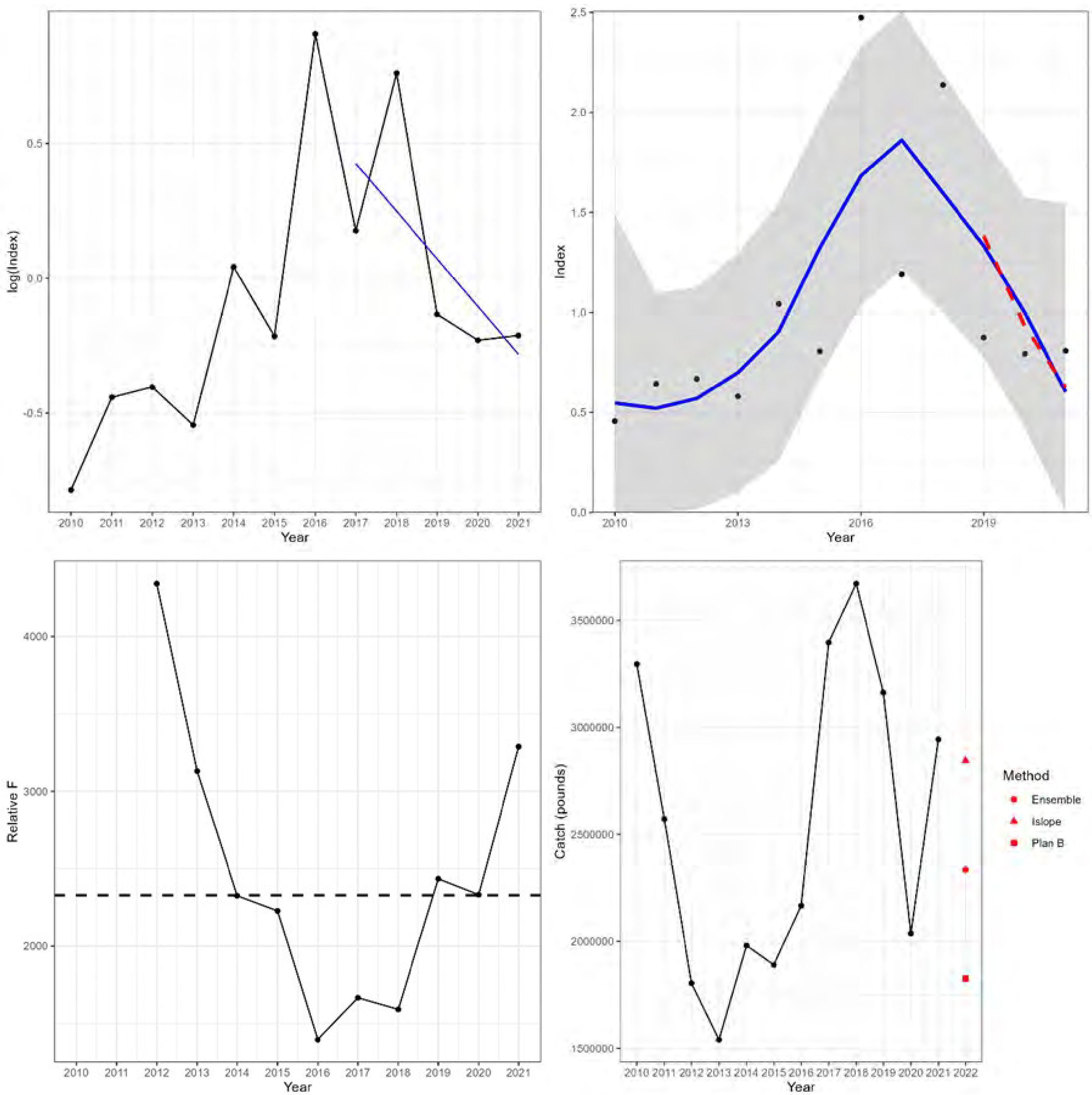

Figure A6. Index-based method results for the IGOM Jonah crab stock with the average scaled survey indices including the Islope log-linear regression line and observed index on the log scale (upper left), Plan B log-linear regression line (transformed to original index scale) and LOESS smoother (blue line, upper right), Skate relative *F* time series and median (dashed line, lower left), and comparison of catch advice from all methods to the observed landings (lower right).

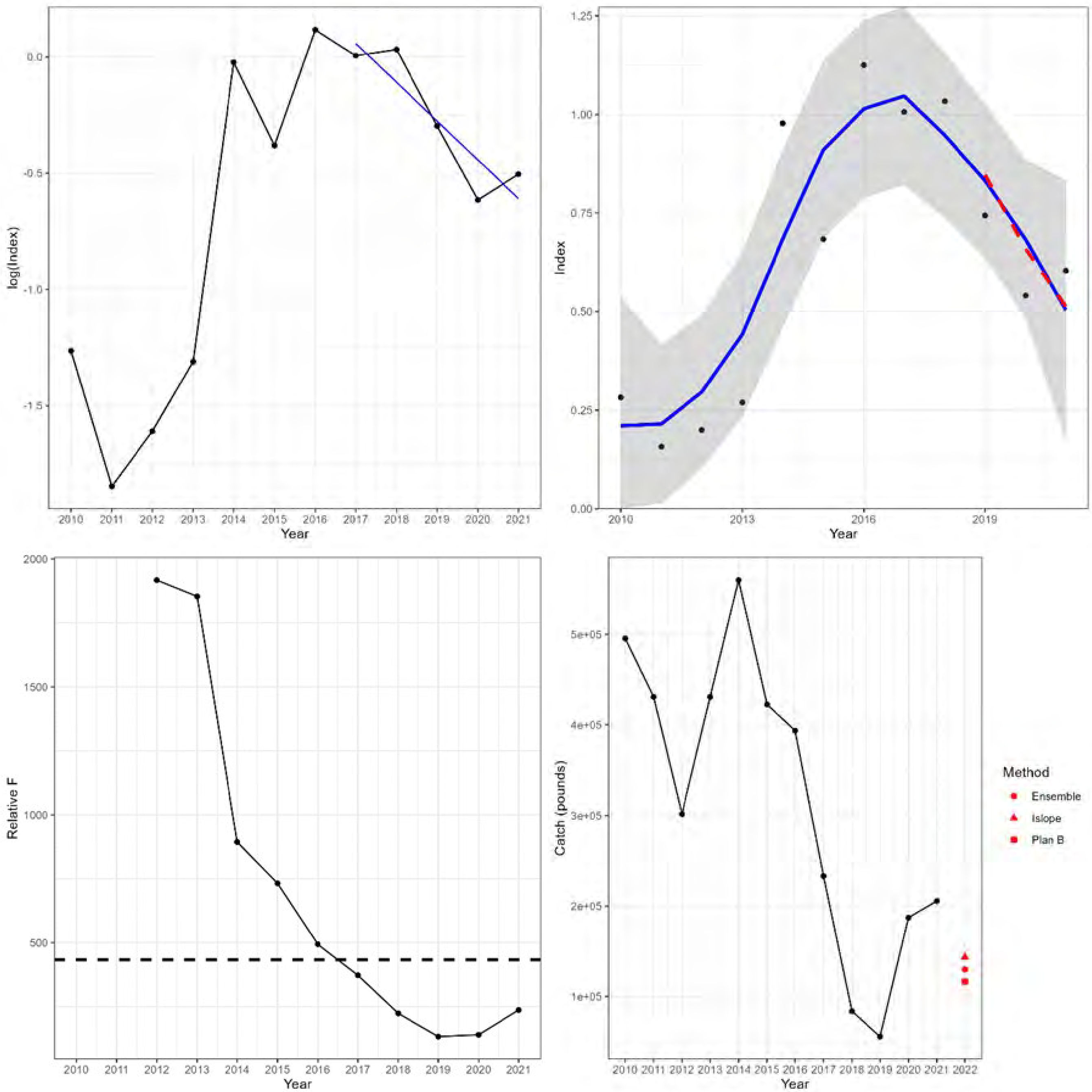

Figure A7. Index-based method results for the OGOM Jonah crab stock including the Islope log-linear regression line and observed index on the log scale (upper left), Plan B log-linear regression line (transformed to original index scale) and LOESS smoother (blue line, upper right), Skate relative *F* time series and median (dashed line, lower left), and comparison of catch advice from all methods to the observed landings (lower right).

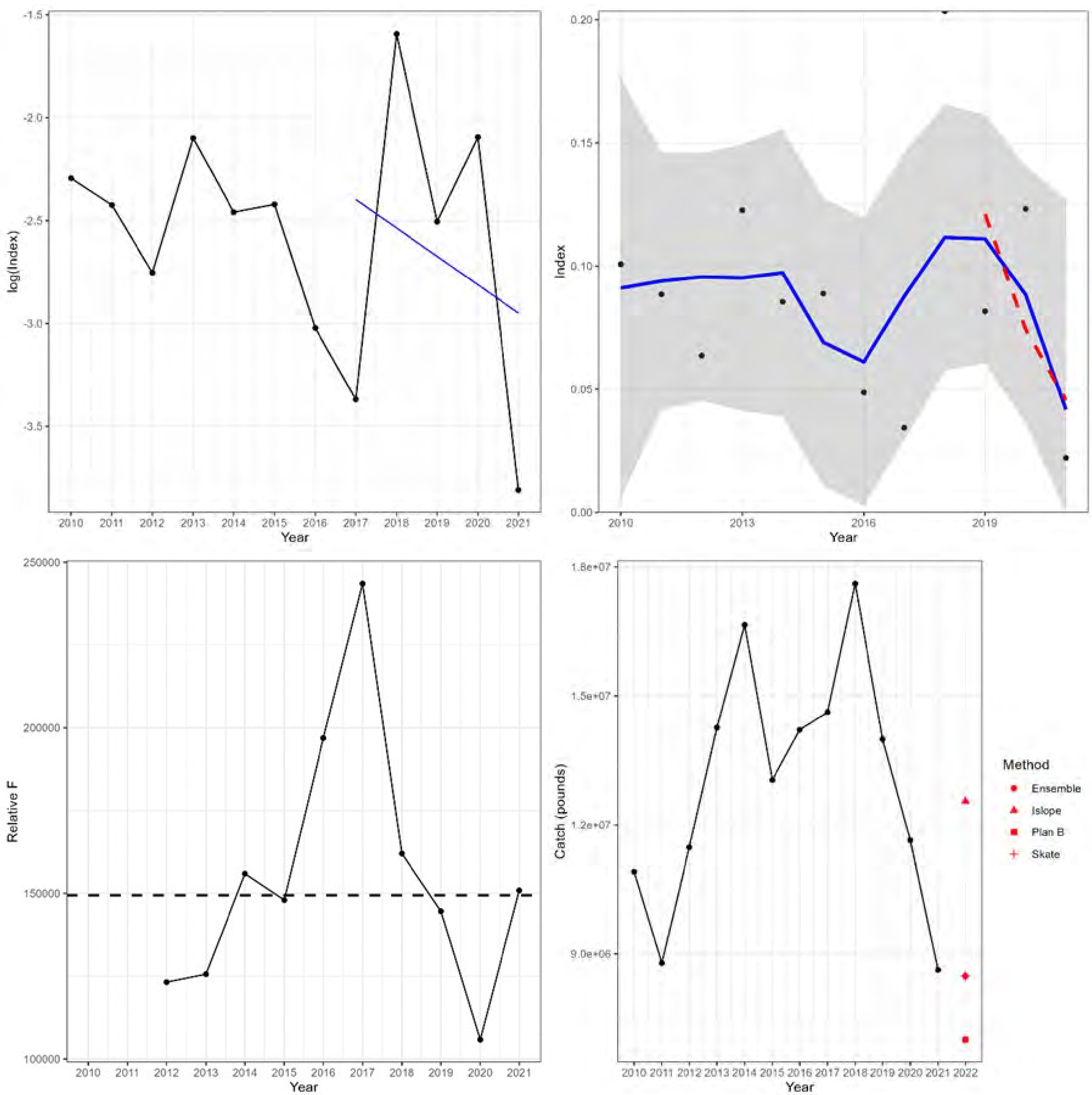

Figure A8. Index-based method results for the OSNE Jonah crab stock including the Islope log-linear regression line and observed index on the log scale (upper left), Plan B log-linear regression line (transformed to original index scale) and LOESS smoother (blue line, upper right), Skate relative *F* time series and median (dashed line, lower left), and comparison of catch advice from all methods to the observed landings (lower right).