Special Report No. 82
of the

Atlantic States Marine Fisheries Commission

Healthy, self-sustaining populations for all Atlantic coast fish species
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American Lobster Stock Assessment Model Technical Review

Terms of Reference & Panel Report

December 2004

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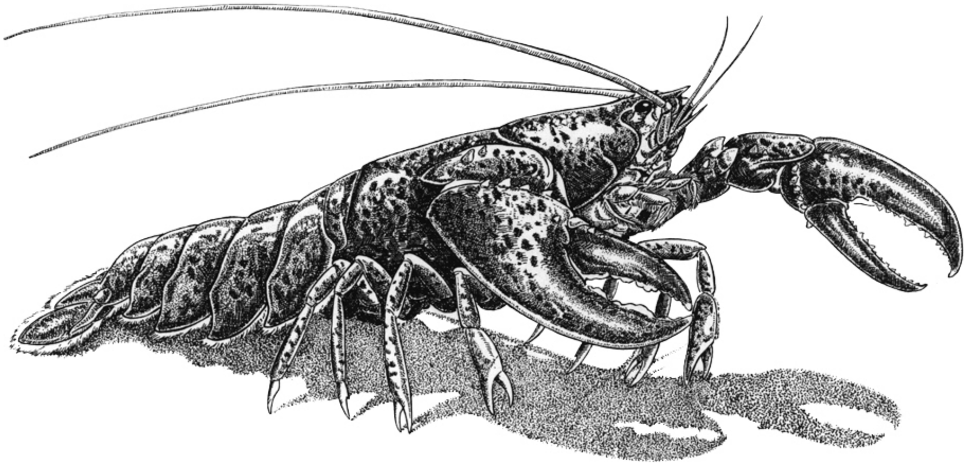

A report of the Atlantic States Marine Fisheries Commission pursuant to U.S. Department of Commerce, National Oceanic and Atmospheric Administration Award No. NA03NMF4740078.

December 2004

Acknowledgments

The Atlantic States Marine Fisheries Commission extends its gratitude to the many individuals who contributed to the Lobster Model Technical Review. The Commission greatly appreciates the time and effort expended by the Lobster Model Technical Review Panel (Dr. Ray Hilborn, Chair, University of Washington; Dr. Louis Botsford, University of California – Davis, Dr. Rick Deriso, Inter-American Tropical Tuna Commission; Dr. Mike Murphy, Florida Fish and Wildlife Conservation Commission; and Dr. Mike Sigler, National Marine Fisheries Service – Auke Bay Laboratory) to conduct the review and complete this report.

The Commission would also like to thank the individuals who developed the models reviewed by the Panel (Yong Chen, University of Maine; Victor Crecco, Connecticut Marine Fisheries Division; Penny Howell, Connecticut Marine Fisheries Division; Josef Idoine, National Marine Fisheries Service, Woods Hole; and Larry Jacobson, National Marine Fisheries Service, Woods Hole). Thanks are also extended to the Lobster Technical Committee, the Lobster Model Development Subcommittee and the Lobster Stock Assessment Subcommittee members. The Commission extends special thanks to Robert Glenn (Massachusetts Division of Marine Fisheries) for his work as Chair of both the Lobster Technical Committee and the Lobster Stock Assessment Subcommittee and to Kim McKown for her work as Chair of the Lobster Model Development Subcommittee.

Appreciation is given to the Commission staff dedicated to the performance of the Lobster Model Technical Review and the finalization of this report, specifically – Carrie Selberg and Patrick Kilduff.

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Introduction

The Atlantic States Marine Fisheries Commission, which has the responsibility for managing American lobsters, is preparing to conduct a lobster stock assessment. The Commission has been exploring and testing several new assessment models to accomplish this task. The Commission formed a Review Panel to provide an external review of this work. This report includes background on this process and the Review Panel's recommendations.

Lobster Model Development

The American Lobster Management Board has charged the Lobster Technical Committee (TC) with conducting a stock assessment. Two subcommittees of the TC have been developed to assist with this task. The Model Development Subcommittee (MDSC) has been charged to develop and test models to be used in the stock assessment, while the Stock Assessment Subcommittee (SASC) will conduct the stock assessment.

The five models developed by the MDSC to examine the lobster stocks include a size-structured Bayesian stock assessment framework, a revised Collie-Sissenwine model with uncertainty added to input parameters, a "tuned-up" Collie-Sissenwine model that incorporates additional data and a Bayesian statistical approach, a fishing independent of total mortality model, and a Lobster Life History model.

Additionally, an individual-based lobster fishery simulator was developed and the models have been tested using simulated data sets with eleven different scenarios. The MDSC did not evaluate the Life History Harvest Model using the simulated data, since it is an equilibrium based reference point model. The various simulated scenarios include differing recruitment patterns, bias in molt increments, observation errors in survey and catch data, and process errors in natural mortality estimation. The simulator calculated landings, size composition of landings, survey indices, and size composition of survey catch.

Report Organization

This Panel Report includes several sections. It provides background information and rationale for the review. This preliminary information includes the Terms of Reference for the review, an overview of the models, a discussion on the use of the outputs of the models, a review on the lobster fishery simulator, comments on the current status of data for lobster, and notes on the spatial scale of the assessment.

Next, the Panel comments on the lobster fishery simulator. Although the Panel was not asked to review the simulator and the use of simulated data, they provided several recommendations on how to improve this process. The next sections contain reviews of each model presented to the Panel. The first three Terms of Reference are discussed in a section devoted to each model. The Panel's comments on the fourth Term of Reference, outlines their recommendations for the upcoming assessment and future assessments. The Panel Report closes with a reference section and Appendices that contain summary figures and tables.

Purpose of Review & Terms of Reference

The Review Panel was asked to evaluate each model in its ability to assess American lobster stocks and to estimate population benchmarks given the available data and recommend those model(s) most appropriate for assessing American lobster stocks using the following Terms of Reference:

1. Evaluate the adequacy, appropriateness, application and uncertainty of models presented to assess American lobster and to estimate population benchmarks given the availability of the data; use the model formulation descriptions and lobster simulator results as a basis for this evaluation.

2. Recommend both short and long term changes to each model to improve its approach.

3. Review the pros and cons of each model developed by the Model Development Subcommittee and provide additional advice.

4. Recommend those models or combination of models most appropriate for assessing the American lobster stocks.

Overview of methods: How the models and methods relate to each other

The Panel was presented with a number of models to evaluate, including the Collie-Sissenwine model (CSM), size-structured Bayesian stock assessment framework, the “tuned up” Collie Sissenwine (TUCS), the fishing independent of total mortality (FIZ) model, and the life history (LH) model. These models are not all designed for the same purpose. The life history model is not an assessment model, but rather takes estimated fishing and natural mortality rates from an assessment model, and calculates eggs per recruit (EPR) reference points. The four “candidate” assessment models were the CSM, the size-structured model, FIZ and TUCS, although the TUCS model is not yet considered to be fully working and was not put forward as a candidate for the 2005 assessment. Of the remaining 3 models, the LF model is truly “stand alone” in that it uses the available data and can calculate the EPR. In contrast the CSM and FIZ models produce F and M outputs that then are put into the LH model to calculate EPR.

A lobster fishery simulation model was developed and used to generate data for testing of the other models and was not presented as an alternative assessment model.

Model Outputs: What assessments are used for & what do managers want?

The terms of reference ask for recommendations regarding assessment methods without specifying the specific uses for model outputs. ASMFC staff provided assistance and guidelines; the models have traditionally been used to calculate fishing mortality rate and egg per recruit, as well as a reference point $F_{10\%}$.

We noted that in practice the fisheries are managed by a combination of size limits and V-notching.

We also note that managers have a range of options for decision making and the choice of appropriate assessment model may depend on the type of decisions. Management decisions could be based on the following management options:

1. F10% thresholds: much like many marine fisheries, stocks could be declared overfished and rebuilding plans implemented if limit fishing mortality rate reference points were exceeded.
2. Biomass limit reference points: managers could choose specific biomass limit reference points and have harvest strategies depend on status relative to biomass reference points
3. Trends in relative EPR: management decisions could be based on trends in EPR or current EPR relative to recent historical EPR. For instance, management could attempt to increase EPR by increasing minimum size, reducing effort, or reducing catch without reference to any absolute level.
4. Trends in relative F: management could simply attempt to decrease F without explicit reference to any EPR or absolute biomass. This is similar to option 3 without going through the steps of calculating EPR.

While recommendations regarding appropriate management action is not within the Terms of Reference of this Panel, we do note that we found that none of the assessment methods were demonstrated to estimate absolute EPR or the F10% threshold with any reliability, and we would have to say that there is no possibility of using the models being considered, given the available data, to reasonably manage on this basis.

Absolute biomass of vulnerable individuals can be reasonably well estimated in an intense fishery such as the American lobster fishery simply because the catch is so high that the absolute biomass of vulnerable individuals is very similar to the total catch (see Appendix 1). This is based on the observation that few individuals in the catch have been above the size limit for more than one year. Thus mangers do have the ability to determine if the vulnerable stock was reaching a specific minimum biomass reference point.

We did find that the methods and data available could provide reasonably robust estimates of trends in EPR and F even if the absolute value of these quantities is measured with large uncertainty.

Thus, because of limitations in the assessment, estimation of $F_{10\%}$ is too difficult and really not a very robust estimate. A much better benchmark would be quantities based on relative quantities. A candidate for fishing mortality could be $F_{current}/F_{(average\ 1983\text{-}1987)}$ recognizing the fact that strong recruitment was generated by the spawners during those years. For the same reason, $N_{current}/N_{(average\ 1983\text{-}1987)}$ could serve as an abundance benchmark, although we recognize recruitment and natural mortality of adults could be strongly influenced by changes in the environment and we caution that management actions based on abundance indices may be inappropriate.

The role of data in the American lobster assessment

We found that the data available are woefully inadequate for the management needs of this fishery, and that the primary limitation on the ability to manage is limited data rather than choice of models. Throughout the world most well managed fisheries spend at least 2-5% of the landed value on data collection and analysis. For the Gulf of Maine (or GOM) component of this fishery alone this would suggest an annual investment of $4-10 million. Current estimates are that the current investment is much less. **Our strongest recommendation pertaining to the lobster stock assessment is that the quality of data needs to be upgraded significantly.**

This is particularly important in the spatial distribution of catch and length frequency. The assessments need to estimate the trends in stock size, fishing mortality and egg production in the inshore and offshore stocks and at the spatial resolution defined by stock boundaries, management regulations and size composition and this cannot be done at present due to data limitations. For example, in some cases catch data are not sufficient to assign catches to appropriate stock or management boundaries and, while there is concern that size distribution in offshore stocks has declined significantly, there are no consistent data to evaluate this trend.

The types of data programs that should be implemented include:

- Better effort, catch, and length frequency data especially spatially (see Appendix 2). For example, within each statistical area, catch, effort and length frequency data should be broken into an inshore and offshore component, sampling allocation should consider the historic length variation and historic level of landings within different sampling regions, and the number of trips and individuals sampled should be sufficient to provide for an effective sample size of several hundred individuals.
- Experimental validation of selectivity of commercial and survey gear is needed in all of the models, especially the survey catchabilities in the CSM. This would include side-by-side trawling, using a non-selective gear, cameras, and tangle nets.
- Tagging studies to estimate growth for pre-recruits and protected areas to estimate growth for fully recruited individuals.
- Analysis of the trawl survey data could use Generalized Linear Models (GLMs) or Generalized Additive Models (GAMs) to standardize for area effects (see Appendix 3 for fishery independent indices and landings over time). The Panel heard considerable discussion that certain areas were frequently the source of large catches and the use of GLM or GAM models is standard procedure in analysis of CPUE data.

Spatial scales of the assessment

The scale of the assessments and the scale of management actions are seriously mis-matched. A kaleidoscope of management regulations takes place on a different scale from the assessments. The assessments need to be done at the same spatial scale as the regulations, or a spatially explicit model needs to be used that can consider management regulations at the actual scale they are implemented. The Panel is quite concerned that reference points are being calculated from assessments that combine management areas with different size limits or V-notching regulations. This concern ties directly into the data limitations, where catches cannot be assigned to management areas. The spatial scale of data, regulations and models needs to be unified.

Comments on the Lobster Fishery Simulator Formulation and the Model Testing Process Using Simulated Data

While the testing procedure and simulator were not candidate assessment models, we provide a review of the process and make recommendations in case similar testing is repeated in the future.

Model Testing Process

We found there were a number of ways the model testing could have been improved. The model testers were not presented with the same information they would have had in actual estimation, and as a consequence the test was not actually "blind." The model testing process would be greatly improved if the model testers knew less about the data they used. As examples, the testers apparently knew which case they were testing. The simulator did not generate the data used by several of the models, but the model testers had to generate their own input data by adding measurement error. In some cases data that were used as model input to the simulator, such as the growth transition matrix, were also available as input to a model. The model testers should be supplied with a data set for each scenario that incorporates measurement errors, but has no other information, e.g., they should not know which scenario they are testing. As a result of these issues, we relied on the basic formulation of the model and our own experience with similar models more than the specific simulation testing results to evaluate alternative models.

Use of Simulator to Produce Simulated Data

1. Output Comparisons - Several examples of model output were given, but there were no comparisons to actual data. To assure that the simulator is realistically depicting the actual population characteristics, there needs to be more comparison between a variety of model outputs and actual data. One recommended example is a comparison of the model size distribution of the fishery catch with the actual data from the fishery. Given the complex, uncertain interactions between molting, double molting and maturity, it would be easy to get this wrong. Another recommended check is a comparison of the model size distribution of ovigerous females with actual data. These data have a unique distribution of sizes that results from the combination of molting rates and maturity (e.g., Krouse 1973). This would be a tougher test. These additional comparisons would test whether the modeling of growth and the interaction with maturity were giving realistic answers. Because molting, maturation and fishing occur continuously over the time during the year of entry into the fishery, the estimates made from the simulated data will depend critically on these details.

In addition to comparisons to actual data, there should be comparisons to the same kinds of "data" from the lobster life history model. This is especially important when testing the combination of the lobster life history model and the Collie-Sissenwine estimator to manage.

2. Simulator Description - The description of the simulator does not provide sufficient detail. It refers only to functions used, noting that they are the same as used in the lobster life history model. There needs to be a more complete explanation of how the simulator is related to the

data on which it is based. For example, molt period is based on observations of fractions molting from a certain size, but random molting at a constant decay is not necessarily the best way to represent that. This comment is also relevant to the use of this simulator to generate the growth matrix for the size-structured model.

Maturation appeared to be modeled incorrectly. The fraction becoming mature at each age was set to the fraction observed to be mature. This amounts to representing a probability density function by the associated cumulative distribution function.

The size increments in a molt should vary with size. Molt increment typically increases with size in crustaceans (Botsford 1985). It was unclear how was the specified variability in molt size was determined from data.

3. Variability - While this model was presented in the context of the advantages of individual based models, in many respects it became essentially a deterministic model because the Bernoulli trials are across so many individuals. Individual based models differ from more conventional distribution based models only when the number of individuals involved is relatively small (Botsford 1992). The Bernoulli trials are actually needed and meaningful in population processes which have small numbers (i.e., the variability is insignificant with N in the 100s or greater).

As a consequence, the variability in this model was essentially only demographic stochasticity, with no environmental stochasticity. Demographic stochasticity is quite small for numbers greater than 100. It seems reasonable to introduce some level of environmental variability in recruitment.

Also, there was no phenotypic variation between individuals. Most of the variability was random among identical individuals (e.g., as in the molt increments), rather than having fast and slow growers. This will affect the results of estimation because size selective fishing removes faster growers, in addition to larger individuals.

The known geographic variability in life history was not simulated. Life history characteristics such as growth and reproduction vary over the range of the lobster fishery. It would be instructive to illustrate the differences between regions.

Terms of Reference 1-3

Review of the Collie-Sissenwine Model (CSM)

General Model Description

The lobster version of CSM is a 2-stage pool model with pre-recruits and potentially vulnerable adults. The number of parameters estimated is t+2 (R_t, P_1, q). Assumed values are inputted for M and q-ratio (Φ). A least-squares objective function on residuals of process error, measurement error, and recruitment deviations is minimized to select parameter values. Measurement error is the difference between predicted model abundance of pre-recruits and potentially vulnerable adults and survey indices. The model is currently applied separately to each sex and region.

1. Evaluate the adequacy, appropriateness, application and uncertainty of models presented to assess American lobster and to estimate population benchmarks given the availability of the data; use the model formulation descriptions and lobster simulator results as a basis for this evaluation.

The CSM model has served as the basic stock assessment model for lobsters for several years.

The analyst used the same q-ratio (Φ) and range of natural mortality (M) in simulated data as in estimation. Thus tests of the model estimation ability are optimistic. The accuracy of the model parameter estimates are substantially affected by minor changes in assumed values for Φ and range of M. For example, the assumed values of Φ and M are 0.45 and 0.13 for configuration 1 and 0.5 and 0.15 for configuration 5 (Table 2 in Jacobson 2004a), while the %RMSE are 20% for configuration 1 and 95% for configuration 5 (Table 21 in Jacobson 2004a). Results show estimation of $F_{10\%}$ is also sensitive to small mismatches in natural mortality, q-ratio, and the number of moltings in the pre-recruit size class. Results are stable and robust to relative terms, such as $F_{current}/F_{1985}$ or $N_{current}/N_{1985}$.

2. Recommend both short and long term changes to each model to improve its approach.

The model is currently applied separately to each sex and region but empirical correlations from at least two surveys show that for the Gulf of Maine and area 514 there is correlation in survey estimates of recruitment of around 0.70 between regions for both sexes and above 0.90 for correlation of survey abundance between sexes but within region.

Generalization of CSM to multi-sex and secondly to multi-region is a high priority. Multi-region generalizations may improve parameter estimation and resolve to a large extent the uncertainty associated with q-ratio. The resolution of q-ratio would be achieved in the case of GOM by assuming that true recruitment in GOM and area 514 are correlated. Such a model could be written by modifying the equations in Appendix I of Jacobson (2004a) as follows:

a. Recruitment indices for both females and males could be assumed correlated within each region (empirical correlations in survey indices for the two sexes show correlations in excess of

0.90).

b. Recruitment between two regions could be assumed correlated (empirical correlations are in excess of 0.60).

c. The net result of points (a) and (b) is that the objective function for a 2-sex, 2-region model would modify the objective function in Jacobson (2004a; Appendix I) to read:

$$\begin{aligned}\Re &= \sum_{t,a,s} \lambda_{a,s,\varepsilon}\varepsilon_{a,t}^{2} + \sum_{t,a,s} \lambda_{a,s,\eta}\eta_{a,t}^{2} + \sum_{t,a,s} \lambda_{a,s,\delta}\delta_{a,t}^{2} \\ &+ \sum_{t,a} \lambda_{a,\Delta s}[\ln(r_{a,1,t} / \overline{r}_{a,1,.}) - \ln(r_{a,2,t} / \overline{r}_{a,2,.})]^{2} \\ &+ \lambda_{\Delta a} \sum_{t,} \; [\ln(r_{1,1,t} / \overline{r}_{1,1,.}) - \ln(r_{2,1,t} / \overline{r}_{2,1,.})]^{2}\end{aligned}$$

In the version above, the first three terms are simply a sum of four objective functions like those in Jacobson's Appendix I (one for each sex (*s*) and each region (*a*)), while the fourth and fifth terms build correlation between recruitment indices, first between sexes within a given region then between regions for a given sex (sex 1 is chosen but between sex correlation implies correlation for sex 2). The correlation structure is built on the logarithm of predicted recruitment relative to its mean. There are alternative ways to build this kind of structure by choosing other modifications of Jacobson's Appendix I, such as putting in a sample correlation coefficient formula and fitting it to an assumed correlation value. The modifications for correlation structure add a weighting term to be specified for each added structure and the analyst would likely need to try several alternatives to get a reasonable consistency with the empirical correlations from survey indices.

Note that down-weighting the $\lambda_{a,s,\varepsilon}$ penalty weights put less penalty on deviations in annual natural mortality rate, which is given by $M_t = M\, exp(\varepsilon_t)$, because process error in the CSM are deviations in natural mortality rate. Below we talk of how this can be used to examine some alternative hypotheses.

The least-squares objective function, which is minimized to select parameter values, can be made robust to avoid undue influence of outliers. That could be accomplished by replacing the least-squares criterion with equivalent normal density functions then optimizing within AD Model Builder with its robust modification to a normal density. In such a model the weighting factors could be replaced with variances determined by making assumptions about underlying coefficients of variation as explained in Jacobson (2004b).

Additional penalty terms need to be explored. The FIZ model (Crecco and Howell, 2004) provides an alternative hypothesis that total mortality has been constant over fixed periods of years which suggests a penalty term could be the deviations in total mortality from an average for fixed periods of years. Residual analysis could be used to decide how to partition the year periods and still obtain homogeneous residual patterns. Such a hypothesis of stable total mortality rate could be achieved by adding the penalty term, $+\sum \lambda_z [\tilde{Z}_{a,s,t} - \bar{Z}_{a,s,[t]}]^2$ to the objective function listed above in point 5(c). The weighting coefficient when set to a large number, relative to other weighting coefficients would cause total mortality rate to be constant over the intervals of years specified by the [t] notation. The resultant annual natural mortality rate, $M_t = M \exp(\varepsilon_t)$, would change depending on the magnitude of the weighting term above as well as the magnitude of the weighting term $\lambda_{a,s,\varepsilon}$. Intermediate degrees of stability of Z_t and M_t can be achieved by adjusting their penalty weighting terms in the objective function.

For the upcoming stock assessment, a reasonable goal would be to generalize the objective function to the one given above, at least to include both sexes, with the goal of the full generalization to multiple regions. The multiple region model likely would make it unnecessary to pre-specify the q-ratio in one of the regions, as long as it was specified in the other region.

In the longer term, stock assessments could be made with ADMB, a robust normal type density function, and a range of hypotheses about stability of total mortality versus stability of natural mortality over time. The resulting objective function is a form of penalized likelihood function. Penalized likelihood functions add terms to help avoid undesirable solutions by assigning large penalties to unfeasible parameter values (NRC 1998). Furthermore, confidence intervals on important output quantities can be programmed within ADMB and estimated routinely as part of the stock assessment. More discussion on penalized likelihoods can be found in the TUCS section.

3. Review the pros and cons of each model developed by the Model Development Subcommittee and provide additional advice.

Advantages of the CSM model include that it is both easy to use and understand. The model does not place large demands on computation power which facilitates large numbers of runs in a relatively short time period and permits the use of such techniques as bootstrapping of confidence intervals.

The fact that CSM does not utilize size composition is both a strength and weakness of this approach. The strength derives from the independence of the model from size selectivity of fishing gear and management regulations as long as the adult pooled classes contain all exploitation and the pre-recruits adequately describe input into the adult classes. Its weakness is that the model does not utilize size-structured information other than the partitioning of pre-recruits and adults.

Review of the Tuned-Up Collie-Sissenwine (TUCS) model

General Model Description

The TUCS model is a generalization of CSM and allows for a Bayesian perspective. The model differs from CSM by using Bayesian and maximum likelihood techniques. It accommodates both sexes and multiple regions. Model structure is provided for "priors" on all estimated parameters. TUCS has many more estimable parameters, as it does not assume that catch is known precisely – an assumption of the CSM model.

1. Evaluate the adequacy, appropriateness, application and uncertainty of models presented to assess American lobster and to estimate population benchmarks given the availability of the data; use the model formulation descriptions and lobster simulator results as a basis for this evaluation.

At present, the model is in a development stage and its testing has not been completed. In its current configuration it has been necessary to rely on the WinBUGS software package to estimate posterior probabilities of stock characteristics of interest.

Simulation testing showed the TUCS modeling approach performed well compared with CSM, but some of the comparisons were not between identical scenarios. Some problems were encountered with some of the "priors." No firm conclusions of model performance can be drawn at present except that this is a promising approach.

The Bayesian perspective may not be necessary for lobster assessments. However, penalized likelihood functions, such as suggested in the CSM section above are closely related to Bayesian analysis but avoid the issue of assignment of priors. Furthermore, confidence intervals on important output quantities can be programmed within ADMB and estimated routinely as part of the stock assessment. The TUCS model shows many parameters for which penalty terms can be naturally added to the objective function in the CSM section.

2. Recommend both short and long term changes to each model to improve its approach.

Until efficient numerical algorithms and model testing are completed this model could be viewed as a worthwhile venture but it is premature to judge its ultimate value. In part that decision would rely on feedback from management as to whether or not estimates of probabilities are important to their decision making or if instead they would prefer to stick with point estimates and accompanying confidence intervals. CSM does provide confidence intervals so there is a measure of uncertainty provided by that analysis, but those are not strictly interpretable as probabilities, such as the probability that the stock is below or above some reference level.

We do not believe it is desirable in general to have priors that are truncated. That can easily be remedied by adding tails to the distributions. Also it is usually a good idea to estimate parameters in logarithm space which keeps things positive definite in the back-transformed space.

The necessity of utilizing the WinBUGS software was unfortunate given the generally high regard given to ADMB software. Apparently the problem with ADMB was caused by poor solutions to the catch equation. That does not appear to be an insurmountable problem and we are optimistic that it can be corrected.

3. Review the pros and cons of each model developed by the Model Development Subcommittee and provide additional advice.

The main advantage to the Bayesian approach is that it provides probabilities associated with output quantities, such as probability that the stock fishing mortality is below the level from a reference year. Its disadvantage is that calculation of those probabilities ultimately relies on specification of “priors” for the PDF of parameters.

There are four main disadvantages to the current implementation of TUCS: firstly, difficulty in finding a “good” set of priors for all parameters; secondly, the model is very computationally demanding and so it runs quite slowly; thirdly, complexity of the model structure compared to CSM makes it both difficult for all scientists in the region to understand and use the model; and finally it is difficult to understand the separate effects of assumptions about each of the priors.

Review of Fishing Independent of Z (FIZ) Model for American lobster

General Model Description

The fishing independent of Z (FIZ) model uses a time series of Z estimates and relative F estimates to calculate a vector of plausible M estimates, with M restricted to exceed a predetermined minimum. Estimates of Z require indices of abundance for legal lobsters, recruits, and pre-recruits, with the latter two groups adjusted for their contribution to legal lobsters using catchability and growth transition coefficients. Estimates of relative F are calculated from catch and mean relative abundance. Relative abundance is calculated as the contribution of fall survey legal and spring survey legal, recruit, and pre-recruit lobsters to legal lobster abundance. Finally relative F values are scaled to absolute F.

1. Evaluate the adequacy, appropriateness, application and uncertainty of models presented to assess American lobster and to estimate population benchmarks given the availability of the data; use the model formulation descriptions and lobster simulator results as a basis for this evaluation.

The FIZ model is not a statistically based estimator of fishing mortality or natural mortality. More stable estimates of F and M were calculated using smoothed relative abundance indices or mean Z estimates (especially when Z was changing).

The FIZ model appears appropriate for measuring temporal changes in the F and M components of Z. It can be used to extract mortality rate information from catch and indices of abundance. The relative changes in M estimated within this model may be useful as the basis for sensitivity runs for other population dynamics models that may typically assume a constant M.

2. Recommend both short and long term changes to each model to improve its approach.

This approach is closely allied with the two-bin CSM used to assess lobster. This relationship should be investigated and the model should be put on a stochastic footing, including process error. The instantaneous mortality rates should be analyzed in log space to eliminate the occasional negative estimates.

The Panel found the FIZ model introduced an important feature of time varying natural mortality, and believes this concept is best incorporated by modifying the CSM and that further development of FIZ should be discontinued. As with the other models, the FIZ model's absolute estimates of F are more subject to biases than are fishing mortality ratios generated from these estimates. It follows that estimates of the relative changes in M are the most reliable information about M generated by this model.

3. Review the pros and cons of each model developed by the Model Development Subcommittee and provide additional advice.

Pros – (a) model concept is simple to explain and understand, (b) in the simulated scenarios its RMSE for F estimates were generally similar to that of the other models tested.

Cons – (a) somewhat data intensive (time series of pre-recruit, recruit, and legal lobster abundance and catchability coefficients for each group; two (2) growth transition coefficients; and annual catch), (b) *ad hoc* determination of periods for constant Z, (c) not stochastic.

Review of the size-structured stock assessment model for the American lobster, *Homarus americanus*

General Model Description

The size-structured model developed for American lobster is a type of model, statistical age- or size-structured model, commonly used in New Zealand and Australia for length-based lobster assessments and in Alaska for length-based crab assessments; these assessment models have been successfully reviewed. This model type is flexible, but also can be data-intensive, depending on the configuration. We recommend that this model be developed for the American lobster stock assessment in the long-term.

This model depends on time series of size data to track cohorts. The size data must span several years (not necessarily sequential) and also must be coherent (i.e. cohort strengths must be identifiable in successive years data). We do not know if there is sufficient, quality size data for a multi-compartment size-structured model to be successful. Catchability varies between years, so that cohorts are difficult to track through time. Size structure varies spatially, yet fine-scale data that captures this variation generally is not available.

The size-structured stock assessment model is a stochastic, length-structured, and sex-specific model describing the dynamics of the lobster population and fishery. Observational models relate the population dynamics model with observations made in surveys and the fishery. The model is explicitly size-structured, as organisms advance through size-classes by a size-specific growth transition matrix. The model is within the class of modern population dynamics models that attempt to mimic the population, surveys, and fishery in detail and as a result, has a large number of parameters to estimate. The modeling approach is flexible and allows incorporation of prior information and estimation of uncertainty of management parameters by Bayesian methods.

1. Evaluate the adequacy, appropriateness, application and uncertainty of models presented to assess American lobster and to estimate population benchmarks given the availability of the data; use the model formulation descriptions and lobster simulator results as a basis for this evaluation.

a) The model is explicitly size-structured with a growth transition matrix to advance animals through size classes. The number of estimated parameters is 122, including 16 for fishery catchability (q and γ), 8 for survey catchability, 8 for selectivity (6 for surveys, 2 for fishery), 1 for natural mortality, 70 for the initial size composition, and 19 for annual recruitments (including an autocorrelation parameter).

b) The model estimates a large number of parameters. Parameter estimates from large-parameter models sometimes are poorly defined. One useful diagnostic is scatterplots of the estimated values (e.g. survey catchability vs. natural mortality).

c) The growth transition matrix in the estimation model matches the matrix in the simulation model assuming no fishing or natural mortality. In practice, the growth transition matrix provided as input to the estimation model should be based on biological data and computed so that it is consistent with the way it is represented in the estimation model.

d) Selectivity parameters are poorly estimated. For example for scenario A-I, the estimated value of length of 50% selection ($L_{50,2}$) is 118.7 and the true value is 150; the estimated value of the slope at 50% selection (b_2) is 11.26 whereas the true value is 0.10 (Table 7, Chen et al. 2004).

e) The estimated value of natural mortality typically is larger than the true value. For example for scenario A-I, the estimated value is 0.0419 and the true value is 0.0359 (Table 7, Chen et al. 2004). The positively biased value of natural mortality in turn leads to the positively biased value of $F_{10\%}$, assuming all else (selectivity, growth) equal. This result may explain why the current fishing mortality estimates were less than $F_{10\%}$ in the figure shown in the oral presentation.

f) Fishery regulations have shifted fishery size selectivity over time. Model estimation of these shifts is significantly more difficult than estimating time-invariant selectivity.

g) Choosing the spatial scale of a size-structured model for American lobster is an important modeling issue. Finer-scale models than the current CSM model may be required because lobster size structure sometimes varies at small spatial scales. For example, the Tasmanian lobster fishery is modeled at the scale of one-degree squares because of fine-scale demographic variation (Punt and Kennedy 1998). Unfortunately, the fine-scale data that captures this variation for the American lobster fishery generally is not available and this lack may prevent successful completion of a multi-compartment size-structured model for American lobster.

2. Recommend both short and long term changes to each model to improve its approach.

a) Length sample sizes greater than 350 imply more precision than typically found for real length data because variation is added by spatial heterogeneity. We recommend that the analysts estimate effective sample sizes for the lobster size data and weight the size data with these values during parameter estimation. We also recommend that the analysts test a range of values of effective sample sizes common to our experience, 10, 50, and 100.

b) Reduce the number of sizes estimated in the initial size composition. The descending limb of either age or length compositions typically provides little information on year-class strength (i.e. they appear similar from year to year). We suggest three alternatives for reducing the number of sizes estimated in the initial size composition: 1) estimate abundance of an intermediate size, then compute abundance of larger size classes from abundance of the intermediate size using an equation like equation 10 on page 9 of Chen et al. 2004; 2) pool large size classes (Deriso et al. 1985, 1989; Kimura 1989, 1990; Sigler 1999); 3) fit a two-parameter function to the initial size composition.

c) The current configuration of the size-structured model is a multi-size compartment model. In contrast, the current model used in the stock assessment (CSM) is a two-size compartment model. An intermediate step between the CSM model and a multi-size compartment model is a compartmental model with a few size groups. We recommend that the analysts first estimate parameters with the size-structured model configured with a few size groups. This intermediate step will help the analysts better understand the results of a multi-size compartment model and will help educate managers and the fishing community.

d) The size-structured model provides a formal structure for representing growth (i.e. growth transition matrix), whereas the Collie-Sissenwine model requires external structuring of the data to account for growth transitions. We recommend the analysts explore combining the two approaches for the purpose of describing recruitment and possibly residence time in a second size compartment of a three-compartment model. The largest pooled size group could be fitted without making assumptions about selectivity by following the CSM approach. Most importantly, the typical observation of an ~80-90% drop in abundance from the second to the third size compartment may encapsulate the depletion effect of the fishery, thus estimating abundance without having to model the full size structure of the population.

e) Natural mortality is difficult to estimate. We recommend incorporation of a prior probability distribution for natural mortality into the estimation model.

f) We recommend that analysts estimate lobster growth rates from existing mark-recapture data. The growth transition matrix and size increment per year could be estimated. One approach is to fit the size-structured model (or a version of it) to the tagging data.

g) Scatterplots shown in the oral presentation demonstrate a strong positive correlation between average recruitment and natural mortality, but not fishery catchability and natural mortality. This likely occurs because fishery catchability is hyperstable (asymptotic relationship between fishery catch rate and lobster abundance) and the correlation instead occurs between the exponent parameter and natural mortality. Though not shown explicitly, survey catchability was not correlated with natural mortality. This does not make sense, especially given that average recruitment was correlated with natural mortality. We recommend that the analysts determine why survey catchability and natural mortality are not correlated, as expected.

h) Penalty functions typically are used to speed up parameter estimation without affecting estimated parameter values. We recommend that the analysts check that penalty function values do not affect parameter estimates.

i) The analysts model “other” selectivity with a normal distribution. We recommend that the analysts consider other functions to represent “other” selectivity and justify their final choice in biological terms. The analysts provided estimates of these values independently of the report; the parameters were not well-estimated.

j) Exploitation rate is computed as catch divided by estimated abundance. This implies that fishing mortality occurs in one instant of time and that catch is estimated without error. In fact, fishing mortality occurs over several months. The simplifying assumption of fishing mortality at one instant of time is reasonably accurate for low fishing mortality rates. However fishing mortality rate is high for lobster. We recommend that the analysts explore the sensitivity of parameter estimates to this assumption. The analysts can choose to assume catch has error with small variance, i.e. close to exact, if it seems reasonable. We note that parameter estimation likely will be faster if fishing mortality is estimated in a later "phase" of the estimation.

k) The relationship between fishery catch rate and lobster abundance is modeled as an exponential function. The function implies that lobster traps can "saturate" at high lobster abundance such that the catch rate remains unchanged once lobster abundance reaches a high-enough level. Understanding the catch rate – abundance relationship and, more generally, the interaction of the target species with the gear is essential for resource assessment (Gunderson 1993). We recommend that experiments be conducted to understand this relationship (e.g. Sigler 2000).

3. Review the pros and cons of each model developed by the Model Development Subcommittee and provide additional advice.

a) Pros

  i) The model appears able to estimate abundance, fishing mortality (though negatively biased), and the power function for fishery catch rate reasonably well as long as natural mortality or the growth transition matrix are not misspecified.

  ii) Statistical catch-at-length (-age) models like this one are very flexible. They can be configured to use all available data (e.g. add size data) and test hypotheses (e.g. consider time-varying natural mortality).

  iii) The size-structured model is the only estimation model presented that can internally produce the current reference point of $F_{10\%}$, whereas reference points must be developed in a separate model (e.g. the life history model) for the current assessment model (CSM).

b) Cons

  i) Application of this model depends on availability of long time series of size-structured data. There is enough size-structured data to apply this model to the Gulf of Maine stock (however see point iii below), but not enough size-structured data for application to Georges Bank and the offshore stock.

  ii) The size-structured model is a complicated model that is time-consuming to develop and difficult for the non-technical community to understand.

  iii) The size-structured model assumes fishing mortality is separable into a magnitude that changes from year-to-year and a size-selectivity function that is constant through time. This assumption may not be correct given changes in the lobster fishery over time. In principle, the assumption can be relaxed so that selectivity changes over time, but in practice the time-variation is difficult to estimate accurately. One apparently successful application is the Bering Sea Pollock stock assessment model (Ianelli et al. 2003), but far more age and relative abundance data are available for the pollock assessment than the lobster assessment.

Review of the Lobster Life History Model

General Model Description

The Life History Model is a simulation of the numbers of lobsters at different life history stages given a complete specification of the recruitment, growth and survival. It does not estimate any parameters from data, but relies on parameters either estimated from other models are best guesses from model users. It is primarily used to calculate equilibrium values of population size and EPR, but can also be used to calculate changes over time.

1. Evaluate the adequacy, appropriateness, application and uncertainty of models presented to assess American lobster and to estimate population benchmarks given the availability of the data; use the model formulation descriptions and lobster simulator results as a basis for this evaluation.

The Life History (LH) Model appears to be a generally good description of the lobster population, incorporating most of the important life history events. It appears to be well understood by all concerned that the model can only be used to calculate certain reference points from pre-specified population parameters, and that this model is not, in any sense, an assessment model that uses data observed from the populations to make any inference about (1) current population size, (2) current exploitation rates, or (3) biological reference points. Rather this model takes output from an assessment model such as the CSM model, as well as extensive biological parameter inputs (growth, maturity and natural mortality) to produce reference points. The natural role of the LH model is thus to use the estimated parameters from other models.

2. Recommend both short and long term changes to each model to improve its approach.

The Panel noted several issues of concern regarding dynamics of the model. First, there is no provision for handling mortality of lobsters returned from pots, nor is there provision for in-pot mortality. These two factors are thought to be significant in other lobster fisheries and should be included in the LH model.

Second, there is a mis-match of the spatial scale the when model is applied: the model is run for large areas where there may be different size limits in place. The fishing mortality estimates coming from the CSM model should be from a population that has a uniform minimum size, maximum size and V-notching policy. When the LH model is applied to estimates derived from areas with heterogeneous policies, we would expect that biases would occur that would carry through to the LH model.

We are also concerned about the basic data inputs into the LH model, particularly growth. It seems likely that the growth rates of lobster have changed as densities have changed, and as thousands of tons of bait have been put into pots, yet the growth rates used in the LH model are not recent. We have a similar concern about the assumptions regarding selectivity of pots to older lobsters, as the data do not appear to be particularly strong.

3. Review the pros and cons of each model developed by the Model Development Subcommittee *and provide additional advice.*

Pros:

The model captures the life history of the lobsters

The model can be used to calculate EPR reference points if that reference point is considered significant.

Cons:

The model does not use the data directly, but needs an F estimate from another model such as CSM.

The model does not attempt to capture the dynamic history of the fishery and cannot deal with the clear temporal changes in recruitment that have occurred, or temporal changes in natural mortality, although those could be easily incorporated.

Term of Reference 4: Recommend those models or combination of models most appropriate for assessing the American Lobster stocks

Recommended method for the 2005 assessment

There are really three options available for the 2005 assessment, continue with the Collie-Sissenwine model, or switch to the size-structured or the FIZ models. While the Panel felt that in the long term the size-structured model was likely to be the preferred approach, we found that for a number of reasons it is not yet ready to become the model for all assessments. These concerns include insufficient data to model all three areas, complexity of running the model, and lack of knowledge and ability to run the model in the regional scientific community. We found the FIZ model introduced an important feature of time varying natural mortality, but believe this is best incorporated by modifying the CSM. However, we believe this concept is best incorporated by modifying the CSM and further development of FIZ should be discontinued. Thus for the 2005 assessments we recommend the CSM be modified to allow for temporal changes in F and Z through the process error component (details specified under CSM review), and that this model be used for assessments in all areas in the 2005 round. The modified CSM will provide, we believe, reliable estimates of trends in relative F and abundance of potentially vulnerable individuals. The output of this modified CSM would then provide input to the LH model, as in the past, to estimate trends in relative EPR.

If time permits, the two sexes should be run simultaneously with the assumption of identical trends in recruitment for both sexes.

We recommend that years 1983-1987 be used as “reference years” for comparing relative F, EPR and potentially vulnerable biomass. Those years are chosen because the stock in those years produced good recruitments throughout the range of the stock *(please see section on recommendations for reference points for more discussion).*

Recommendations for future assessments

The size-structured model developed for American lobster is a type of model, statistical age- or size-structured model, commonly used in New Zealand and Australia for length-based lobster assessments and in Alaska for length-based crab assessments; these assessment models have been successfully reviewed. This model type is flexible, but also can be data-intensive, depending on the configuration. We recommend that this model be developed for the American lobster stock assessment in the long-term.

The size-structured model explicitly incorporates the multiple data sources, and integrates the parameter estimation with the entire life history, features that are consistent with the trend in assessment models for other lobsters and crabs around the world and is more appealing than the current split in function between the CSM and LH models. Based on several Panel members experience with such models in Alaska, New Zealand and Australia we felt that any technical difficulties could be overcome and the size-structured model would be appropriate.

We recommend that the full size-structured model should be implemented for the entire lobster stock once the necessary data is available and if the analysts can demonstrate sufficient information content in the size data. We suggest testing the full-size structured model by comparing it with a "few" bin model. The comparison would serve as a measure of the information content of the size data. Often there is little information in the descending limb of a size composition with the shape changing little between years. If this is true for lobster, little may be gained by the "full" bin model.

Thus we believe that it is likely the size-structured model is the way to proceed in the future after the improvements we suggested earlier in this report are implemented and it is clear if the changes in fishery selectivity can be estimated and accommodated. These limitations may be more data than model related.

The suggested improvements in the CSM may mean, that if it is believed that the data are not available for the size-structured model, or that the changes in fishery selectivity are too severe, that the CSM may be the model to continue to be used.

Regardless of the above decision, it would seem prudent to use the CSM in the next assessment (after 2005) as a check on the size-structured model if it is adopted.

Recommendations on models and management reference points

We found that none of the models using the available data could reliably estimate absolute EPR reference points. Thus we recommend that management agencies abandon the use of absolute EPR reference points as guides for the health of the fishery.

We recommend that the relative fishing mortality rate, compared to a base period such as 1983-1987 be used to track the changes in the fishery. We found that both the CSM and size-structured models could estimate relative fishing mortality rates reliably (given data at the appropriate spatial scale) and if management objectives can be formulated in terms of trends in fishing mortality, the stock assessment tools could provide the scientific advice on the trends in these quantities.

Recommendations regarding data

One cannot evaluate assessment models without considering the data that go into them. Thus while our task was to examine the performance of assessment models, we had to consider the data used. We recommend that the data system needs to be improved substantially to provide any form of management advice. We recommend three specific improvements to the data collection system.

1. Better effort, catch, and size-structured data especially spatially. For example, within each statistical area, catch, effort and length frequency data should be broken into an

inshore and offshore component, sampling allocation should consider the historic length variation and historic level of landings within different sampling regions, and the number of trips and individuals sampled should be sufficient to provide for an effective sample size of several hundred individuals.

2. Experimental validation of selectivity of commercial and survey gear as needed in all of the models. This would include side by side trawling, use of non-selective gear, cameras, and tangle nets.

3. An ongoing tagging program should be implemented in each management area to estimate trends in growth. Tagging should be conducted in areas closed to fishing in order to allow for a significant number of individuals to grow beyond the legal size limit

References

Botsford, L.W. 1985. Models of growth. Pp.171-188 in Factors in Adult Growth. A. M. Wenner, Editor.

Botsford, L.W. 1992. Individual state structure in population models. Chapter 10, pp 213-236 in Individual-Based Approaches in Ecology: Concepts and Models. D. DeAngelis and L. Gross, Editors. 525 pp.

Deriso, R.B., T.J. Quinn II, and P.R. Neal. 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42:815-824.

Deriso, R. B., P.R. Neal, and T. J. Quinn II. 1989. Further aspects of catch-age analysis with auxiliary information. In R. J. Beamish and G. A. McFarlane (ed.). Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. J. Fish. Aquat. Sci. 108.

Gunderson, D. R. 1993. Surveys of fisheries resources. John Wiley & Sons, Inc. New York. 248 p.

Ianelli, J. N., S. Barbeaux, G. Walters, and N. Williamson. 2003. Eastern Bering Sea Walleye Pollock Stock Assessment. http://www.afsc.noaa.gov/refm/stocks/assessments.htm.

Kimura, D. K. 1989. Variability, tuning, and simulation for the Doubleday-Deriso catch-at-age model. Can. J. Fish. Aquat. Sci. 46:941-949.

Kimura, D. K. 1990. Approaches to age-structured separable sequential population analysis. Can. J. Fish. Aquat. Sci. 47:2364-2374.

Krouse, J.S. 1973. Maturity, sex ratio and size composition of the natural populations of American lobster, Homarus americanus, along the Maine coast. Fish. Bull. U.S. 71: 165-173.

NRC. 1998. National Research Council. Improving fish stock assessments. National Academy Press, Washington, D.C.

Punt A.E. and R.B. Kennedy. 1998. Population modelling of Tasmanian rock lobster, *Jasus edwardsii*, resources. Marine and Freshwater Research. 48(8): 967-980.

Sigler, M. F. 1999. Abundance estimation of Alaskan sablefish, *Anoplopoma fimbria*, with an age-structured population model. Fish. Bull. 97: 591-603.

Sigler, M. F. 2000. Abundance estimation and capture of sablefish, *Anoplopoma fimbria*, by longline gear. Can. J. Fish. Aquat. Sci. 57: 1270-1283.

The following papers were the basis of this review effort and are available from the ASMFC, please contact the ASMFC for more information.

Chen, Y., M. Kanaiwa, and C. Wilson. 2004. Development and assessment of a size-structured stock assessment model for the American lobster, *Homarus americanus*. Chapter 6. ASMFC American lobster technical model review: Review Materials, August 2004.

Crecco, V. and P. Howell (2004). Test of the Fishing Independent of Z (FIZ) Model for American lobster with simulated data. Chapter 5. ASMFC American lobster technical model review: Review Materials, August 2004.

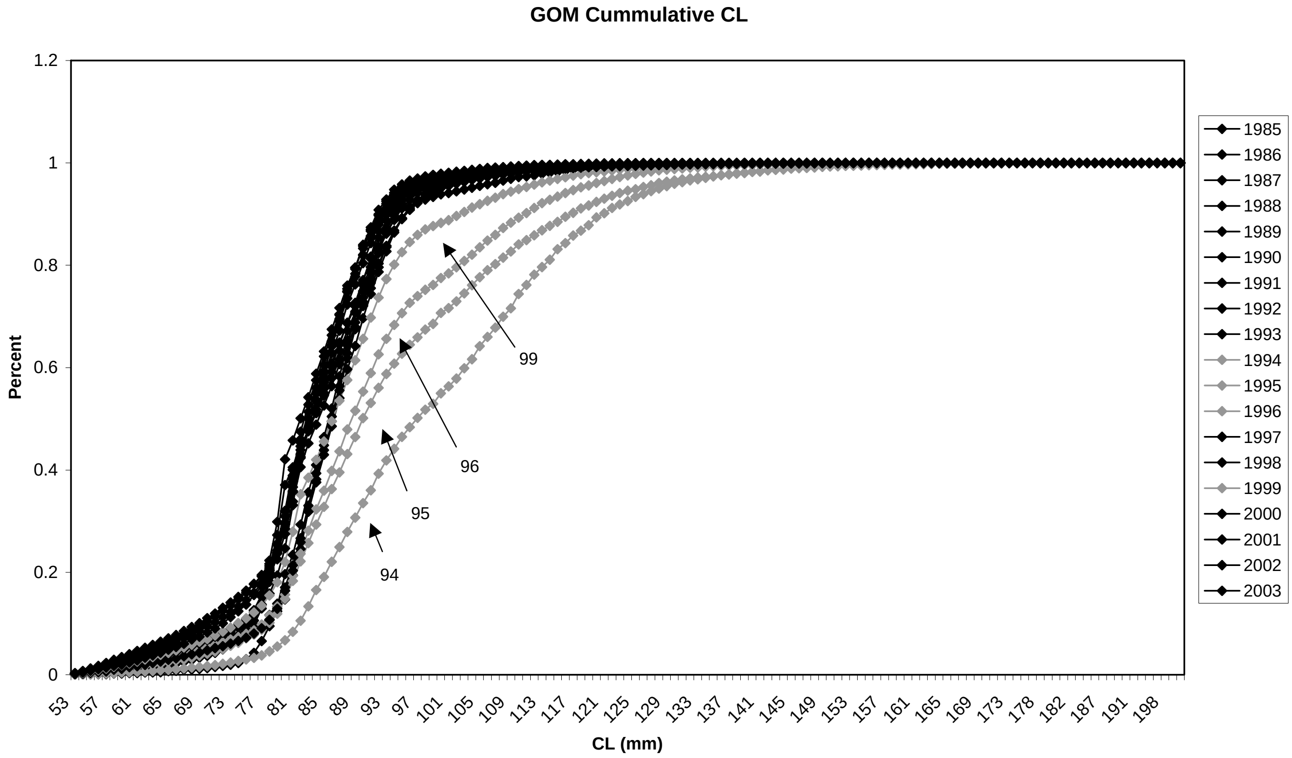
Idione, J.S., P.J. Rago, and D.S. Pezzack. 2004. Using an American lobster life history model to examine biological reference points. Chapter 8. ASMFC American lobster technical model review: Review Materials, August 2004.

Jacobson. 2004a. Performance of the Collie-Sissenwine stock assessment model in simulated lobster stock assessments. Chapter 4. ASMFC American lobster technical model review: Review Materials, August 2004.

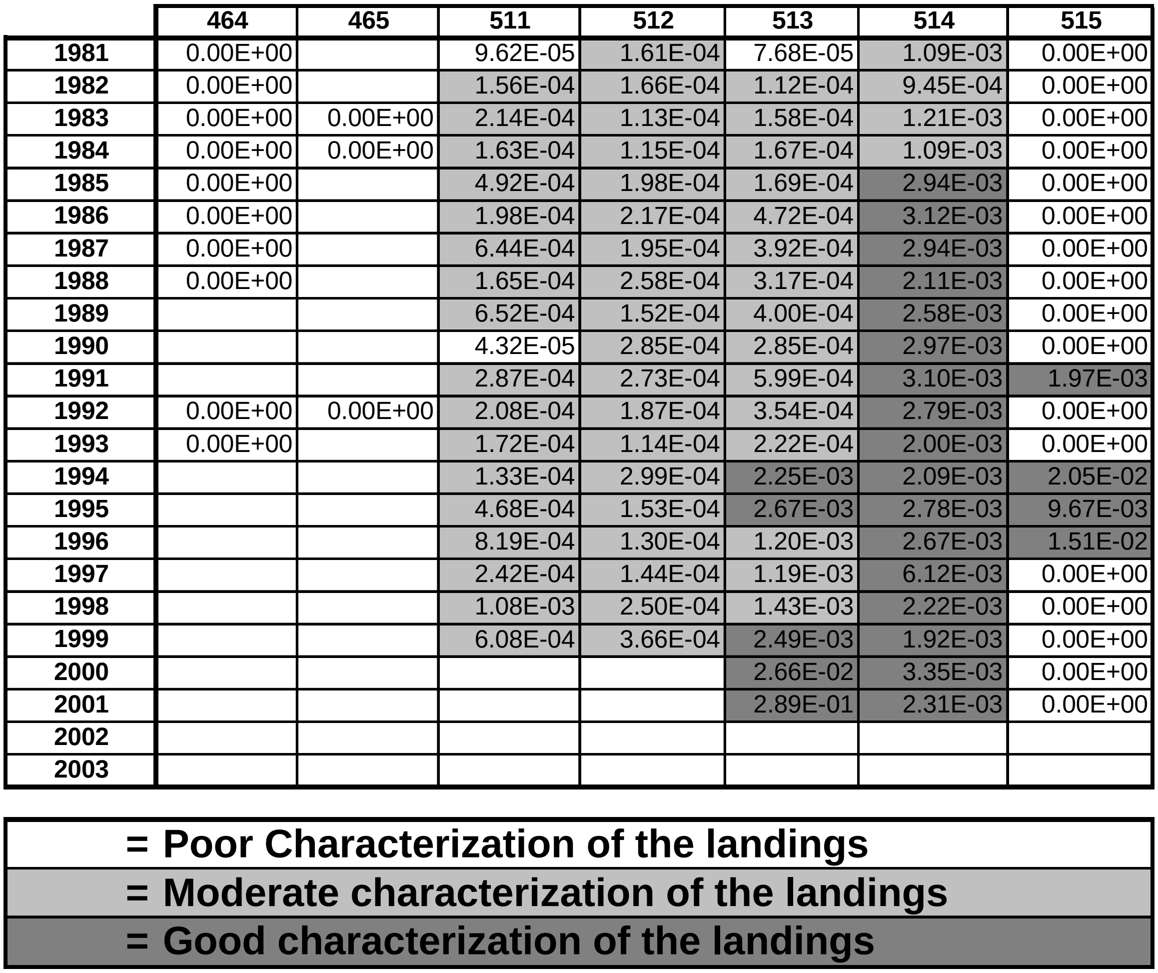
Jacobson. 2004b. TUCS: A “simple” Bayesian, spatially explicit, two-sex model for assessment of American lobster stocks. Chapter 7. ASMFC American lobster technical model review: Review Materials, August 2004.

Appendices

Appendix 1. Cumulative carapace length frequency distributions from the Gulf of Maine from biological sampling of commercial catch from 1985 –2003. The data series for the year 1994, 1995, 1996 and 1999 (in gray) are highlighted as these years had higher sampling in offshore locations.



Appendix 2. Ratio of the number of biological samples to commercial landings for the Gulf of Maine Stock Unit.



	464	465	511	512	513	514	515
1981	0.00E+00		9.62E-05	1.61E-04	7.68E-05	1.09E-03	0.00E+00
1982	0.00E+00		1.56E-04	1.66E-04	1.12E-04	9.45E-04	0.00E+00
1983	0.00E+00	0.00E+00	2.14E-04	1.13E-04	1.58E-04	1.21E-03	0.00E+00
1984	0.00E+00	0.00E+00	1.63E-04	1.15E-04	1.67E-04	1.09E-03	0.00E+00
1985	0.00E+00		4.92E-04	1.98E-04	1.69E-04	2.94E-03	0.00E+00
1986	0.00E+00		1.98E-04	2.17E-04	4.72E-04	3.12E-03	0.00E+00
1987	0.00E+00		6.44E-04	1.95E-04	3.92E-04	2.94E-03	0.00E+00
1988	0.00E+00		1.65E-04	2.58E-04	3.17E-04	2.11E-03	0.00E+00
1989			6.52E-04	1.52E-04	4.00E-04	2.58E-03	0.00E+00
1990			4.32E-05	2.85E-04	2.85E-04	2.97E-03	0.00E+00
1991			2.87E-04	2.73E-04	5.99E-04	3.10E-03	1.97E-03
1992	0.00E+00	0.00E+00	2.08E-04	1.87E-04	3.54E-04	2.79E-03	0.00E+00
1993	0.00E+00		1.72E-04	1.14E-04	2.22E-04	2.00E-03	0.00E+00
1994			1.33E-04	2.99E-04	2.25E-03	2.09E-03	2.05E-02
1995			4.68E-04	1.53E-04	2.67E-03	2.78E-03	9.67E-03
1996			8.19E-04	1.30E-04	1.20E-03	2.67E-03	1.51E-02
1997			2.42E-04	1.44E-04	1.19E-03	6.12E-03	0.00E+00
1998			1.08E-03	2.50E-04	1.43E-03	2.22E-03	0.00E+00
1999			6.08E-04	3.66E-04	2.49E-03	1.92E-03	0.00E+00
2000					2.66E-02	3.35E-03	0.00E+00
2001					2.89E-01	2.31E-03	0.00E+00
2002							
2003							

□ = Poor Characterization of the landings
▨ = Moderate characterization of the landings
■ = Good characterization of the landings

Appendix 2 (Continued). Ratio of the number of biological samples to commercial landings for the Southern New England Unit.

	538	539	611
1981	3.21E-03		0.00E+00
1982	1.75E-03	0.00E+00	2.00E-03
1983	3.65E-03	0.00E+00	4.72E-03
1984	3.44E-03	0.00E+00	3.19E-03
1985	3.96E-03	0.00E+00	8.01E-03
1986	8.17E-03	0.00E+00	4.87E-03
1987	7.11E-03	0.00E+00	4.76E-03
1988	9.20E-03	0.00E+00	4.83E-03
1989	7.06E-03	0.00E+00	3.19E-03
1990	1.37E-02	3.99E-04	2.50E-03
1991	1.51E-02	6.91E-03	1.59E-03
1992	1.76E-02	3.64E-03	1.89E-03
1993	1.94E-02	3.79E-03	3.89E-03
1994	7.18E-03	3.92E-03	3.67E-03
1995	5.51E-03	8.56E-03	1.00E-03
1996	5.62E-03	1.12E-02	5.66E-04
1997	4.59E-03	6.68E-03	4.73E-04
1998	5.91E-03	6.89E-03	8.34E-04
1999	7.89E-03	6.47E-03	8.39E-03
2000	2.11E-02	8.20E-03	6.52E-03
2001	1.51E-02	1.07E-02	3.11E-02
2002	8.20E-03	2.64E-01	2.76E-02

□ **= Poor Characterization of the landings**
░ **= Moderate characterization of the landings**
▓ **= Good characterization of the landings**

Appendix 2.(Continued). Ratio of the number of biological samples to commercial landings for the Georges Bank & South Stock Unit.

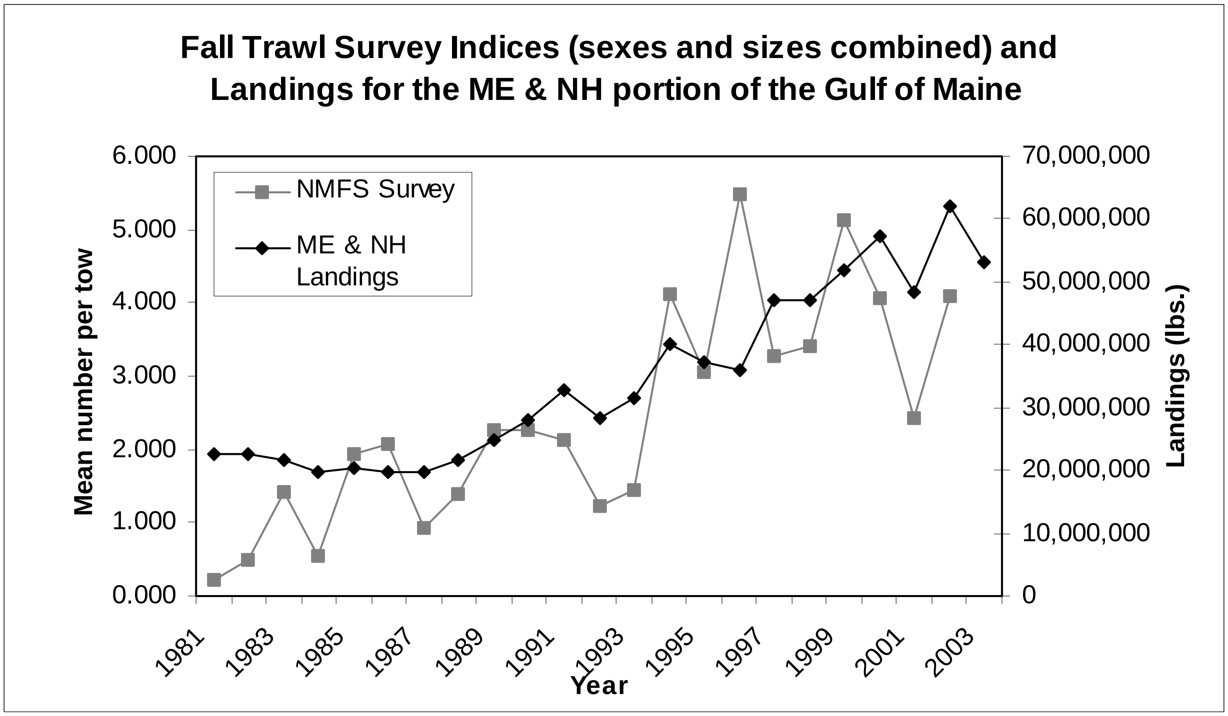
	521	522	525	526	537	561	562	612	613	614	615	616	621	622	623
1981	4.54E-03				0.00E+00			0.00E+00	0.00E+00			0.00E+00	0.00E+00		
1982	6.97E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1983	9.44E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1984	5.01E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1985	6.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1986	5.15E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1987	6.81E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00	0.00E+00
1988	6.70E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00	
1989	5.27E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1990	4.80E-03	0.00E+00	0.00E+00	0.00E+00	6.21E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.97E-03	0.00E+00	0.00E+00	0.00E+00
1991	3.51E-03	0.00E+00	6.18E-04	1.47E-03	1.73E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.72E-02	0.00E+00	0.00E+00	0.00E+00
1992	4.90E-03	0.00E+00	4.45E-04	2.37E-03	1.53E-03	0.00E+00	4.51E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.51E-02	0.00E+00	0.00E+00	0.00E+00
1993	3.80E-03	0.00E+00	1.19E-04	2.32E-03	7.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-02	0.00E+00	0.00E+00	0.00E+00
1994	3.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.04E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00		4.63E-02	0.00E+00	0.00E+00	0.00E+00
1995	3.26E-03	2.10E-03	5.47E-05	0.00E+00	3.67E-04	0.00E+00	1.26E-03	0.00E+00	0.00E+00	0.00E+00		4.10E-01	0.00E+00	0.00E+00	0.00E+00
1996	3.46E-03	0.00E+00	0.00E+00	4.59E-04	0.00E+00	0.00E+00	3.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E+01	0.00E+00	0.00E+00	0.00E+00
1997	3.03E-03	2.77E-04	0.00E+00	0.00E+00	6.68E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	6.63E+00	0.00E+00	0.00E+00	0.00E+00
1998	2.88E-03	3.24E-04	0.00E+00	1.11E-02	1.24E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+01	0.00E+00	0.00E+00	
1999	2.41E-03	0.00E+00	0.00E+00	1.94E-03	5.08E-04	1.66E-01	2.06E-02	0.00E+00	0.00E+00			6.42E+00	0.00E+00		0.00E+00
2000	3.23E-03	2.74E-04	3.99E-03	0.00E+00	3.14E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00			3.81E+01	0.00E+00		0.00E+00
2001	3.29E-03	0.00E+00	0.00E+00	0.00E+00	4.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00			2.20E+01	0.00E+00		0.00E+00
2002	3.03E-03	0.00E+00	5.30E-04	0.00E+00	2.23E-04	2.00E-04	1.41E-04		0.00E+00			4.20E+02			

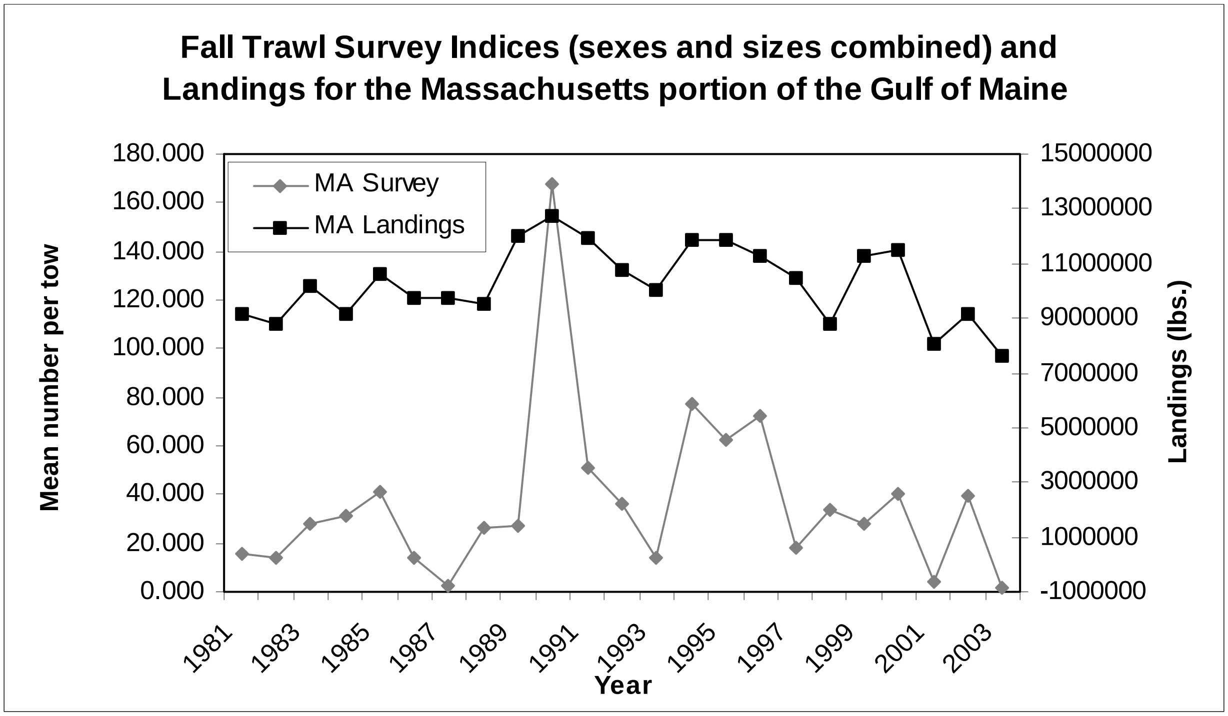
□ **= Poor Characterization of the landings**

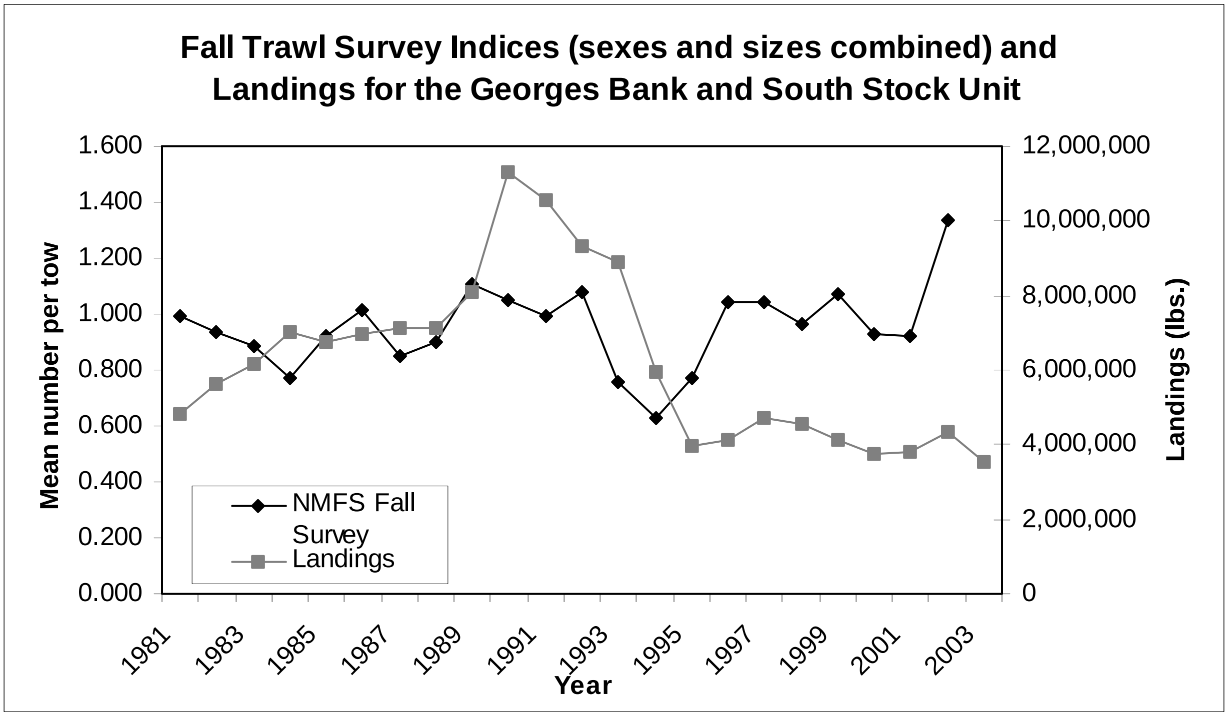
▨ **= Moderate characterization of the landings**

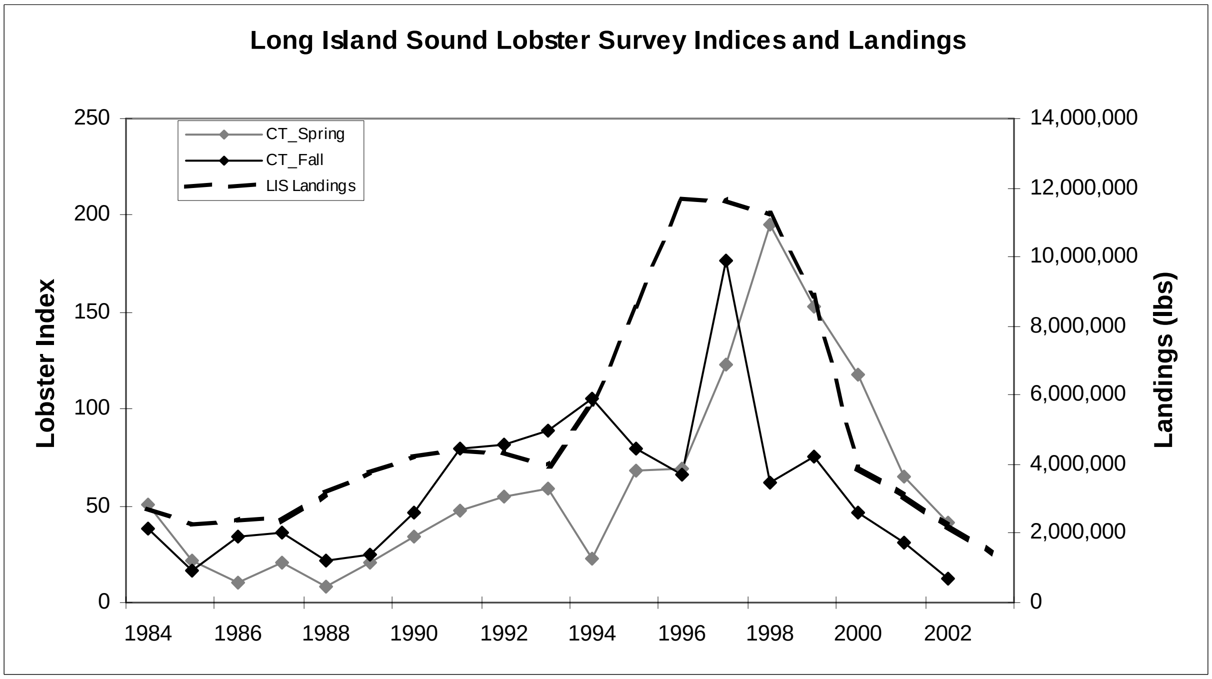
■ **= Good characterization of the landings**

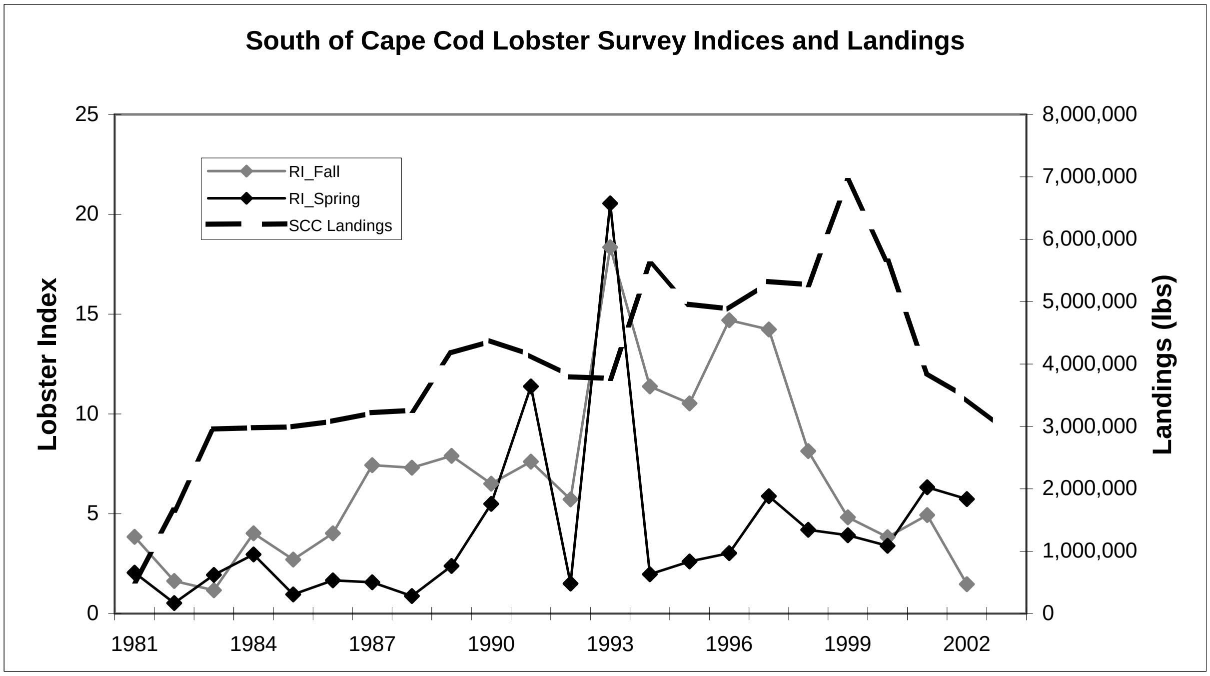
Appendix 3. Fishery independent indices vs. landings by area over time.

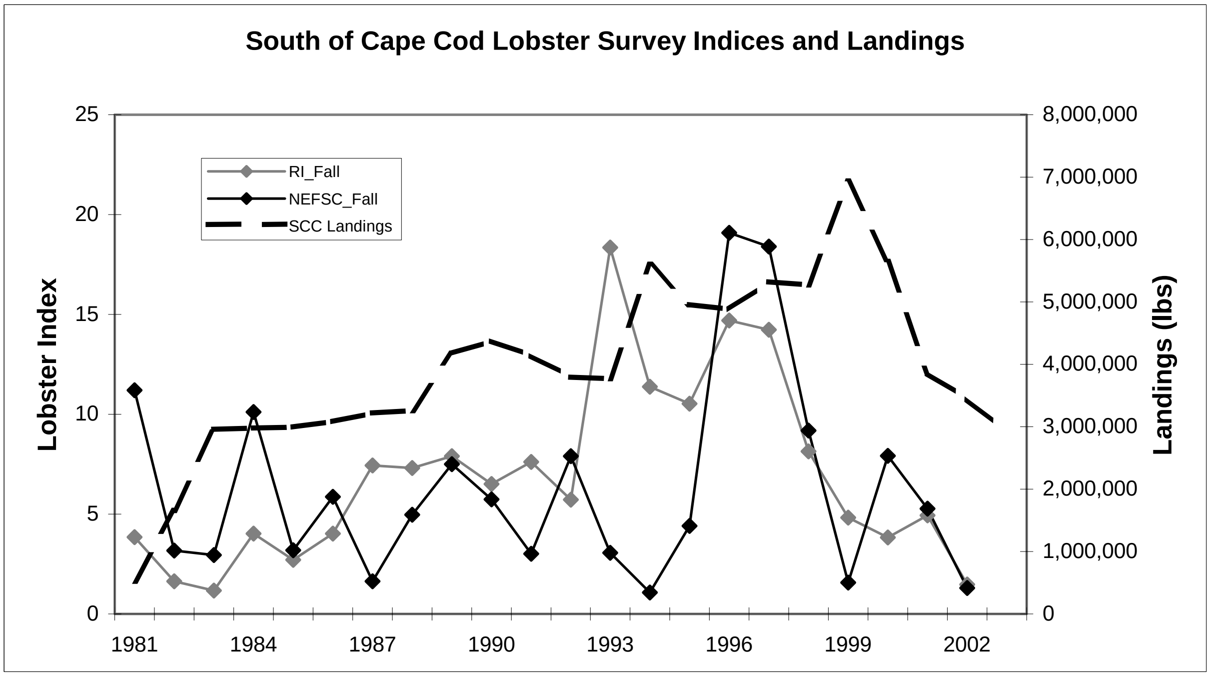





Fall Trawl Survey Indices (sexes and sizes combined) and Landings for the Georges Bank and South Stock Unit
Mean number per tow
Landings (lbs.)
Year
NMFS Fall Survey
Landings
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003


Long Island Sound Lobster Survey Indices and Landings
Lobster Index
Landings (lbs)
CT_Spring
CT_Fall
LIS Landings
250
200
150
100
50
0
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002


South of Cape Cod Lobster Survey Indices and Landings
RI_Fall
RI_Spring
SCC Landings
Lobster Index
Landings (lbs)
25
20
15
10
5
0
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1981
1984
1987
1990
1993
1996
1999
2002


South of Cape Cod Lobster Survey Indices and Landings
RI_Fall
NEFSC_Fall
SCC Landings
Lobster Index
Landings (lbs)
25
20
15
10
5
0
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1981
1984
1987
1990
1993
1996
1999
2002

Appendix 4. Panel and Committee members and affiliations.

Lobster Model Technical Review Panelists
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University of Maine

Victor Crecco
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Josef Idoine
North East Fisheries Science Center

Larry Jacobson
North East Fisheries Science Center

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Bob Glenn – Technical Committee and Stock Assessment Subcommittee Chair
Massachusetts Division of Marine Fisheries

Kim McKown – Model Development Subcommittee Chair
New York Department of Environment Conservation – Marine Fisheries

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Fisheries Research Specialist