

Research Priorities and Recommendations to Support Interjurisdictional Fisheries Management

AMERICAN LOBSTER

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FISHERY-DEPENDENT MONITORING

a. Port and Sea Sampling (High priority)

Accurate and comparable landings data are the principal data needed to assess the impact of fishing on lobster populations. The quality of landings data has not been consistent spatially or temporally. Limited funding, and in some cases, elimination of sea sampling and port sampling programs will negatively affect the ability to characterize catch and conservation discards, limiting the ability of the model to accurately describe landings and stock conditions. It is imperative that funding for critical monitoring programs continues, particularly for offshore areas from which a large portion of current landings originate in Southern New England (SNE). The Commercial Fisheries Research Foundation (CFRF) Lobster and Jonah crab Research Fleet has improved these data needs and will continue to be imperative in describing landings for future stock assessments. Programmatically, sea sampling should be increased in Long Island Sound (Statistical Area 611), and in the statistical areas in federal waters, particularly those fished by the Lobster Conservation Management Area (LCMA) 3 fleet, via a NMFS-implemented lobster-targeted sea sampling program. These fishery-dependent programs are essential for accurate lobster assessments and must have dedicated funding.

b. Commercial Data Reporting

Spatial Resolution (High Priority)

Spatial resolution and compliance of reporting have made it a challenge to understand how commercial harvest has varied through time. These data are paramount in understanding how landings align between statistical area and LCMAs. While this remains to be a major data need for the stock assessment, progress is anticipated to be made with Addendum 26, which will improve spatial resolution by implementing 10-minute square resolution reporting, require reporting the number of vertical lines used, and require 100% of lobster fishers to report in the near future. Vessel tracking is still in the pilot program phase, but, if found feasible and cost effective, is recommended for federal vessels. Once in place, the new spatial data should be analyzed for comparison to current spatial understanding of harvest.

Lobster versus Jonah Crab Effort (High Priority)

The growing Jonah crab fishery in SNE continues to complicate how to differentiate directed lobster versus Jonah crab effort. This phenomenon complicates understanding which species are targeted in a given trip. Truesdale et al. (2019) has begun data collection for differentiating via semi-structured interviews with fishers, but more data must be collected from sea sampling trips and reported landings to better differentiate the two fisheries' activities.

Bait Usage (Low Priority)

Shortage of Atlantic herring due to reduced herring recruitment and quotas has raised concerns on bait availability for the lobster fishery, particularly for the Gulf of Maine (GOM). However, fishers across both stocks use a variety of baits based on availability and prices. Bait use information collected as part of sea sampling trips and trip reports would provide better guidance on what is currently being used and could be included in future economic analyses of the lobster industry.

c. Catch-per-Unit-Effort (CPUE) Indices (Low Priority)

In SNE, lobsters appear to be shifting offshore and into deeper waters (Rheuban et al. 2017, Mazur et al. 2020, Tanaka et al. 2020); these regions have traditionally been minimally sampled, and existing surveys in the region may not fully be capturing this new redistribution in lobsters. This contraction or movement in and lack of survey overlap to the population is likely attributing to difficulties in modeling the population. CFRF ventless trap data should be explored to determine if a post-stratified CPUE index can be constructed to inform a metric of abundance trends in offshore waters.

FISHERT-INDEPENDENT MONITORING

a. Ventless Trap Survey (High Priority)

Calibration work to determine how catch in the ventless trap surveys relates to catch in the bottom trawl surveys remains an important and unaddressed topic of research. It is likely that at low densities, when trawl survey indices have dropped to near zero, ventless trap surveys will still catch lobsters due to the attractive nature of the gear and the ability to fish the gear over all habitat types. Conversely, it is possible that trawl surveys may be able to detect very high levels of lobster abundance, if trap saturation limits the capacity of the ventless traps. Ventless traps may be limited in their ability to differentiate between moderately high and extremely high abundance, and calibration with bottom trawl surveys may help to clarify how q might change with changes in lobster density. Currently, inference on these dynamics are limited to the estimated non-linear q values from the University of Maine Model (UMM), which for some surveys are sensitive and variable. A prospective starting place may be to examine the overlapping data between ventless trap and trawl catch rates in Long Island Sound (Dominion Nuclear Power Station) and Rhode Island state waters.

b. Early Benthic Phase Lobsters (Medium Priority)

To date, many indices for the lobster assessment have focused on spawning stock biomass, recruits, or young of the year. However, few annual abundance indices exist for early-benthic ($\leq 40\text{-}50\text{mm}$) and these trends have been largely unexamined by the Stock Assessment Subcommittee (SAS). Examination of available datasets and survey protocols (for consistency between surveys) should be undertaken, and if possible, such indices could be incorporated as model-free indicators in future assessments. These may better describe changes in lobster abundance in nursery habitats across a broader portion of their life cycle.

c. Northeast Area Monitoring and Assessment Program (NEAMAP) Trawl Survey Protocols (High Priority)

The SAS recommends that the NEAMAP Trawl Survey sampling protocol be modified for all lobsters caught to be sorted by sex. If a subsample is necessary, subsamples be taken by sex for additional biological data (size, egg presence and stage, vnotch, etc.) This modification would align the biological sampling methodology with other trawl surveys used in the assessment, and perhaps allow the survey to not be collapsed by sex into survey slots.

REPRODUCTIVE BIOLOGY

a. Maturity (Medium Priority)

Recent work has demonstrated that size at maturity changes over time (Waller et al. 2019, Haarr et al 2018), which has direct implications for estimating spawning stock biomass and lobster growth rates. Extensive efforts made since the previous assessment have updated maturity data in statistical areas from which significant landings originate (see Appendix 1 and Appendix 2 in the stock assessment report) resulting in more accurate spawning stock biomass estimates. Future maturity work should focus on additional statistical areas with large landings contributions. Exploration of non-invasive techniques to assess maturity are also desirable, allowing for more frequent and efficient updates to maturity estimates. Methods to allow for time-varying maturity in the assessment model should also be explored, to better capture the influence of a changing environment on lobster population dynamics. Finally, it is extremely important for the newly updated maturity data to be applied towards updating the growth matrix underlying the assessment model.

b. Mating Success (Medium Priority)

Depleted stock conditions in SNE and the female-skewed sex ratio observed in the Georges Bank (GBK) sub-stock raise questions about the mating and reproductive success in these systems. Low population abundance may cause a mate-finding Allee effect (Stephens et al. 1999, Gascoigne et al. 2009), and contributing to the dramatically reduced recruits per spawner relationship observed in SNE (Section 6.3.2 in the stock assessment report). More research to characterize reproductive success (mating activity and subsequent larval production) under the

current population and environmental conditions in SNE will be important to understanding the rebuilding potential of the stock. In the GBK sub-stock, there is limited information to describe the timing of events such as spawning, egg hatch, and molting; additional data from the CFRF fleet could improve understanding of reproductive cycles in this region. Further research incorporating the timing of these events and a characterization of the operational sex ratio during the molting/mating season should be initiated to increase understanding of reproductive dynamics in the GBK region. This will help to determine what role the GBK sub-stock plays in terms of source/sink dynamics of the overall GOMGBK stock, and whether the skewed sex ratios are negatively influencing reproductive output in the region.

AGE AND GROWTH

a. Time Varying Growth (High Priority)

Growth of American lobster has been found to change through time (McMahan et al. 2016), yet the ability to incorporate this dynamic in the assessment model currently is unavailable. Accounting for interannual changes in the growth matrix, including those in increment, probability, and seasonality, is imperative for model convergence. This issue was faced in ASMFC (2015a) when an early molt occurred in 2012 in GOM, leading to discrepancies in observed landings and predicted abundance. Data suggests that changes in growth may also be occurring for the SNE stock, where alterations in molt probability and increment with size in recent years could be causing challenges for describing recruitment size composition and survey's size selectivity. Modification to the assessment model is needed to allow for time varying growth matrices to be used to reflect changing growth in the stocks.

b. Expansion of Growth Matrices (High Priority)

The UMM currently has lobsters recruit into the population between 53 and 77mm. However, many of the processes driving recruitment are not captured by the input or model abundances given they happen at sizes less than 53mm. Exploration of expanding the model size structure to smaller sizes could allow to better capture changes in recruitment for the population by incorporating < 53mm lobster abundances from the surveys currently used, as well as incorporating additional surveys that currently are not model inputs for the assessment, such as those from the young of year settlement surveys. Due to decreased recruitment in SNE and some areas in GOMGBK, available survey data should be evaluated to determine whether current data sources for small sizes are sufficient for expanding the size structure and growth matrices.

ENVIRONMENTAL INFLUENCE ON LOBSTER LIFE HISTORY PROCESSES

a. Temperature-Molt Dynamics (High Priority)

Sea temperatures have direct impacts on the molting dynamics of American lobster (Section 2.1 in the stock assessment report). Growth is directly influenced by water temperatures, with

evidence in SNE suggesting increased temperatures have resulted in increased molt frequency and decreased molt increments (DNC 2013). Interannually varying and long-term increases in temperature through time suggest the molting dynamics have also changed over the last several decades. Understanding how the timing for molting, molt increments, and probability by size vary with temperature for all stocks would allow for more accurate and realistic depictions of growth via updated annual growth matrices. The work of Groner et al. (2018) should be expanded by using the Millstone data to specifically analyze how molt frequency and increment has changed seasonally and interannually.

b. Larval Ecology (High Priority)

Recent work has highlighted the importance of coastal oceanography and *Calanus finmarchicus* on the early life history of American lobster, with implications for their settlement and future recruitment (Carloni et al. 2018). The importance of ocean temperature and secondary productivity have also been correlated to adult abundances (Mazur et al. 2020), and major changes through time for these variables and the GOMGBK stock seem to co-occur (Section 2.9.5.1.1). To date, many of these analyses are based on a larval dataset with small spatial coverage in a relatively shallow area and are correlative in nature. This warrants spatial expansion of larval surveys and further testing particularly in areas like the eastern GOM and GBK that lack any studies of this nature. Studies that explore greater spatial coverage of larval sampling and examine lobster larval diets, in situ development time in current conditions, larval interactions with well-mixed versus stratified water columns, and varying growth and mortality with temperature would allow for greater context on these variables' influence on recruitment.

c. Deepwater Settlement (High Priority)

Settlement and YOY trends from inshore sampling sites have continued to reflect poor conditions despite record abundance levels for older, larger lobsters in the GOMGBK stock, a trend that has continued since the last assessment five years ago. Following work by Goode et al. (2019) indicating settlement trends might not be as poor as the inshore sites reflect if deeper, newly suitable settlement habitat was sampled and accounted for, there is a need to determine settlement success in habitat not currently sampled and its contribution to overall stock productivity. Industry supported work in the eastern and western regions of the Maine coast show evidence of settlement, but research needs to explore the levels of detectability, impact of stratification, and interannual temperature effects on the indices. The CFRF fleet provides another potential platform to sample presence/absence of deep-water settlement, but specifically designed fishery-independent monitoring is needed to characterize trends through time. Additionally, it will be important to understand whether there are differences in growth and survival in these deeper habitats, particularly relative to the desire to expand the growth matrix into smaller size ranges for modeling purposes.

POPULATION DYNAMICS AND ASSESSMENT MODELING

a. SNE Recruitment Failure (High Priority)

Many variables are attributed to the decline in the SNE stock, such as warming waters, predation pressure increases, and disease prevalence. However, the direct cause of the precipitous declines in recruitment under less variable spawning stock biomass is largely unknown. Research designed to understand the causes driving recruitment failure is vital for any efforts toward rebuilding the SNE stock. In addition, being able to predict similar conditions in GOMGBK could allow management the opportunity to respond differently. Such research could address: egg production and mating success, larval survival and connectivity to the early benthic phase, benthic habitat changes in historical SNE nursery grounds, predator-prey dynamics, and disease impacts (both lethal and sublethal).

b. Index Modeling (Moderate Priority)

Further expand Vector Autoregressive Spatio-Temporal (VAST) work that currently integrates survey indices into sex-specific stock-wide indices (Hodgdon et al. In Press) to construct accompanying stock and sex-specific time series of size composition.

c. Supporting Models (Moderate Priority)

For SNE, less data-intensive or data-limited models should be explored to compare recent trajectories of Reference Abundance and Exploitation to those produced by the UMM.

d. Modeling Program (High Priority)

Other software programs, such as Template Model Builder, should be evaluated as a new platform to host the UMM and allow more flexible, efficient coding capabilities across SAS members.

STOCK CONNECTIVITY

a. Stock Structure Working Group (High Priority)

There are a couple of ongoing studies that the SAS is aware of, and presumably others, to inform a re-assessment of stock boundaries that were not ready in time for this assessment. The SAS recommends that a workshop on stock boundaries be convened prior to the initiation of the next assessment to review results of any new research and re-evaluate appropriate stock boundaries. Inclusion of Canadian researchers at this workshop would be beneficial to share data and knowledge on this shared resource. Several research topics relevant to evaluation of stock boundaries are listed below, but this list could be expanded upon.

b. Spatial Analyses of Fisheries-Independent Data (High Priority)

Northeast Fisheries Science Center (NEFSC) trawl survey data remains one of the richest data sources to understand abundance and distribution patterns through time for lobsters by size and sex. While preliminary data analyses have been conducted, formal analyses should be performed and described for the Management Board and/or scientific peer-review. Deeper investigations should also be conducted for the ME/NH Trawl Survey. The Ecosystem Monitoring (EcoMon) Program's larval lobster information should also be considered. Integrating the former into analyses with the NEFSC Trawl may provide greater insight into coastal-offshore movement patterns with temperature. While EcoMon sampling techniques and seasonality may not best describe lobster larvae abundance and phenology, efforts to investigate its use in stock definitions remain worthwhile.

c. Tagging Studies (Medium Priority)

Ongoing tagging work to examine the movement of lobsters between GOM and GBK will be completed shortly and presented to the Technical Committee (TC) for incorporation into future discussions regarding stock boundaries. Additional tagging efforts that target specific areas, lobster demographics, and seasons that were not covered in this work would fill remaining gaps. Similar tagging studies in SNE would also be useful, as much of current understanding of lobster movement for this stock is based on information from decades before rapid warming.

d. Larval Transport (Medium Priority)

Transport modeling of lobster larvae has improved understanding in specific regions, such as inshore southern Massachusetts and coastal Maine-Massachusetts connectivity. However, there are several regions for which further research could greatly inform stock boundaries and connectivity. For example, determining whether larvae released in the offshore regions of GOM or GBK remain within that region or are transported to other stocks, especially to SNE locations, will identify the role offshore regions play in recruitment dynamics. Similar modeling exercises focusing on the fate of larvae released from offshore SNE can determine whether the offshore shift of the SNE stock is resulting in a larval sink, or whether there is a linkage to viable settlement habitat. Transport modeling work would benefit from a component that couples predicted destinations to an examination of habitat suitability for settlement success, and sampling to ground-truth results.

e. Genetics (Low Priority)

Additional genetics information would provide further insight on stock structure and on potential environmentally driven changes. For example, western Long Island Sound (LIS) lobsters were genetically distinct from those in other areas of LIS (Crivello et al. 2005b), raising the possibility that this is the result of selective forces producing lobsters adapted to the stressful environment of WLIS. Additional work to test this hypothesis and to examine in detail what might promote survival in that habitat could clarify whether lobsters in SNE might be able

to adapt to the new, warmer environment. Benestan et al (2016) similarly suggested future work should incorporate environmental variables to understand localized selective pressures and their influence on lobster population structure. Comparisons of lobsters from disparate areas, such as SNE and GBK canyons, GOM and Canadian deep waters, and the northern and southern portions of the SNE stock may shed additional light on connectivity and potential for localized adaptations. Work that links adult movements, ocean currents and larval dispersal, and genetic population structure should be explored in order to characterize source/sink dynamics and identify whether sub-populations exist that disproportionately influence recruitment.

NATURAL MORTALITY

a. Reevaluate Baseline Natural Mortality Rate (High Priority)

Natural mortality (M) has been estimated by a variety of methods such as life history approaches, cohort analysis and tagging. Estimates of M range from 0.02 to 0.35 (Fogarty and Idoine 1988, ASMFC 2000). Early stock assessments assumed $M=0.1$ (NEFSC 1992, 1993). Subsequent assessments utilized $M=0.15$ for assessment models and partitioned M into hardshell (0.10) and softshell (molting) (0.05) for egg per recruit reference points (NEFSC, 1966, ASMFC 2000). Besides the question regarding how well the current value used for M reflects the actual M experienced by the stocks, there are additional questions such as how has M changed through time, and how the interactive abiotic stressors that results from changing climate may exacerbate or mitigate mortality during all life stages. Further, while scientifically many acknowledge size varying mortality for lobsters, there is little data to support or quantify this and thus the assessment model currently uses the same mortality rate for all lobsters. Intensive hypothesis-driven sensitivity analyses should be conducted to evaluate the base mortality rate for both stocks by season and year. Canadian tagging data should be examined to determine how natural mortality rates derived from these data compare to the assumptions used currently in the model and sensitivity analyses. Exploration of additional time series representing natural mortality hypotheses (e.g. sea temperature, shell disease prevalence, predators) should be continued to either inform time-varying natural mortality or correlate to rates produced in sensitivity analyses.

b. Tagging Studies (Medium Priority)

A tagging study specifically designed to quantify natural mortality should be conducted for both stocks. Traditional tagging studies designed to document movement or growth often do not allow for generating sound estimates of natural mortality. A directed study on natural mortality would provide empirical data needed to understand total and size-specific rates.

c. Predation Studies (High Priority)

Lobsters are subject to a suite of predators, and the abundance of many of these predators have fluctuated substantially through time. As such, it is often suspected that a given predator's

role in lobster natural mortality has changed through time. Predation laboratory studies and gut content analyses would provide greater guidance on individual species' roles in lobster natural mortality. With this information, predation-indices as a function of predator annual abundances and their contribution to stock-specific lobster mortality would be immensely valuable, particularly in SNE.

d. Shell Disease (Medium Priority)

Many studies have aimed at describing epizootic shell disease, including its pathology, environmental correlates (e.g. warm sea temperatures), and demographics. The relative difference in mortality rates for lobsters with and without shell disease has been examined (Hoenig et al. 2017), but the existing datasets have limitations relative to scaling mortality estimates up to regional or population-level estimates. The true impact of shell disease on the population remains uncertain. Studies designed specifically to generate robust estimates of mortality for diseased lobsters that can be scaled up to the stock are necessary to understand the direct effect of this disease on mortality. Additionally, more work is needed to understand the impact(s) of sublethal effects of shell disease and other diseases on vital population rates (growth, reproduction, etc.). Sensitivity analyses for the SNE model included using shell disease time series data to inform interannual changes in natural mortality (Section 6.4.2 in the stock assessment report), but indices representing the totality of the stock would provide more sound inferences on disease's contribution to natural mortality.

MANAGEMENT AND ECONOMIC ANALYSES

a. Management Strategy Evaluation (High Priority)

Since the previous assessment, a projection tool was developed to assess how certain management actions may impact lobster populations. However, the projection tool lacks the ability to refit the model iteratively with new years' simulated data to best understand the feedback of a given suite of management measures. Developing a true management strategy evaluation tool that can iteratively project and refit the operating model would best inform future management discussions on rebuilding the SNE stock or providing resiliency for the GOM stock and fishery. Development of consensus statements by the Board with input from industry about management objectives will be critical to evaluating the results of any projection tool.

b. Economic Reference Points (High Priority)

The SAS developed new reference points using change point analyses to propose when management action should be taken for the different stocks recognizing there are different levels of productivity with changing environmental conditions. To trigger management action, previous target reference points for the GOMGBK, based on historical abundances prior to 2003, required a substantial population decline to occur and the downward trend to reach that level would likely be challenging to reverse in changing environmental conditions. Recognizing that the GOMGBK stock is currently in a high productivity regime and experiencing record high

abundances that may not be sustainable, the SAS proposed the Abundance Limit level based on the medium productivity regime, but was concerned that significant adverse economic impacts would be experienced before the population reached that Abundance Limit. The SAS proposed a new reference point to address this issue based on the high productivity regime but did not incorporate economic information that should be used to inform this Fishery/Industry Target. Economic analyses considering landings, ex-vessel value, costs, associated economic multipliers, number of active participants, and other factors are imperative to truly discern how declines in the population would impact the GOMGBK industry. The SAS strongly recommends a thorough economics analysis be conducted by a panel of experts to more properly inform economic-based reference points, and ultimately provide resiliency to both the GOMGBK stock and fishery.