Atlantic States Marine Fisheries Commission

2017 Atlantic Sturgeon
Benchmark Stock Assessment and Peer Review Report

Approved for Management Use
by the Atlantic Sturgeon Management Board
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Sustainably Managing Atlantic Coastal Fisheries

DEDICATION

Dr. Timothy L. King

This benchmark stock assessment is dedicated to Dr. Timothy L. King (1958-2016), who made outstanding contributions to the science, conservation, and management of sturgeons. His research on the genetics of these fish continues to shape our understanding of Atlantic sturgeon and guide recovery efforts

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PREFACE

The 2017 Atlantic Sturgeon Benchmark Stock Assessment and Peer Review Report is divided into five sections:

Section A – 2017 Atlantic Sturgeon Benchmark Stock Assessment Peer Review Report
PDF pages 6-34
This section provides a summary of the stock assessment results supported by the Review Panel. The Terms of Reference Report provides a detailed evaluation of how each Term of Reference was addressed by the Stock Assessment Subcommittee.

Section B – Supplemental Report to 2017 Atlantic Sturgeon Benchmark Stock Assessment
PDF pages 35-92
This section describes additional information and analysis requested by the Peer Review Panel during the Peer Review Workshop, and supplements the 2017 Atlantic Sturgeon Benchmark Stock Assessment.

Section C – Appendix to the Supplemental Report
PDF pages 93-110
The Peer Review Panel requested two sets of additional figures at the Review Workshop to help the Panel better evaluate the data and results. The first set was of the length frequency distributions of the fishery-independent indices, since they had only been described qualitatively in the Assessment Report. The second set was of the posterior distributions of the annual survival estimates from the tagging model, since only the confidence intervals had been presented. These figures are presented in this Appendix to provide supporting documentation for the Review Panel's discussions and conclusions.

Section D – 2017 Atlantic Sturgeon Benchmark Stock Assessment
PDF pages 111-374
This section describes the background information, data used, and analysis for the assessment submitted by the Technical Committee to the Review Panel. It contains a coastwide and DPS-specific analyses. For final coastwide and DPS-specific stock status findings, please see the table on PDF page 114.

Section E – Appendices to the 2017 Atlantic Sturgeon Benchmark Stock Assessment
PDF pages 375-456
This section includes Appendix A and B. Appendix A provides a detailed description of Atlantic sturgeon habitat while Appendix B provides DPS-specific background and life history information.

Atlantic States Marine Fisheries Commission

2017 Atlantic Sturgeon Benchmark Stock Assessment Peer Review Report

Conducted on
August 14-17, 2017
Raleigh, North Carolina

Prepared by the
ASMFC Atlantic Sturgeon Stock Assessment Peer Review Panel

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EXECUTIVE SUMMARY

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) are one of the largest and longest-lived anadromous fish in North America. They are broadly distributed along the Atlantic coast from Labrador, Canada to the St. Johns River, Florida. Adults spawn in tidal freshwater to riverine reaches of rivers. After hatching, juvenile Atlantic sturgeon reside in the freshwater portion of their natal river for their first year or two before beginning to transition into the estuary, and by ages 3-5 join the coastal migratory stock. Adults and sub-adults can range extensively along the coast, commonly comprising mixed stocks in both estuarine and coastal regions, though generally each natal river seems to support genetically distinct spawning populations. Relatively little is known regarding the maturity schedule and spawning frequency of Atlantic sturgeon. The limited data available suggest maturity occurs between 5 and 32 years of age with females spawning once every three years.

Atlantic sturgeon supported fisheries of varying magnitude along the Atlantic coast since before colonial times, though records of Atlantic sturgeon commercial harvest have only been kept since 1880. At that time, Atlantic sturgeon were among the top three species in weight of fish harvested commercially along the Atlantic coast, with coastwide landings peaking in 1890 at 3,348 metric tons (mt). As the commercial fishery serially depleted natal rivers, total fishery landings began declining and collapsed coastwide by 1901 (US Commission of Fish and Fisheries 1884-1905). Landings continued to decline and remained low relative to the historical peak through the mid-1990s. Acknowledging that restoration of the stock would not be realized without further management action, the Atlantic States Marine Fisheries Commission (ASMFC) implemented an Atlantic sturgeon Fishery Management Plan (FMP) in 1990. The FMP suggested the dramatic protracted decline in landings relative to the late 1800s was primarily caused by overfishing, although habitat loss and degradation, and impediments to spawning areas, likely also contributed to the decline. By 1996, Atlantic sturgeon fishery closures were instituted in ten states and jurisdictions along the Atlantic Coast. In 1998, ASMFC enacted a moratorium that banned harvest and possession of Atlantic sturgeon. In 2007, a Status Review Team (SRT) finalized its report on the status of U.S. Atlantic sturgeon, identifying five (Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic) distinct population segments (DPSs) with different physical, genetic, and physiological characteristics along the U.S. Atlantic coast. NOAA Fisheries published two final rules in February 2012, declaring the Gulf of Maine DPS as threatened and the remaining four DPSs as endangered; NOAA Fisheries has yet to develop a recovery plan for Atlantic sturgeon.

The purpose of the 2017 assessment was to evaluate the status of Atlantic sturgeon along the U.S. Atlantic coast. Data from a variety of fisheries-dependent and -independent sources were reviewed and used to develop bycatch, effective population size, and mortality estimates. An egg-per-recruit (EPR) model was developed as well as trend analyses and stock reduction analysis. The Review Panel accepted the suite of analyses presented in the 2017 assessment report as a body of evidence supporting *a stable to slowly increasing population of Atlantic sturgeon* following the 1998 moratorium. *The paucity of data available to develop reliable indices of abundance and the inability to distribute historical catches to specific rivers or DPSs* *precluded the application of traditional stock assessment methods, except at a coastwide level.* The nature of the assessment used (i.e., stock reduction analysis) and the nature of available data did not warrant the determination of conventional fisheries reference points.

The 2017 assessment indicates a *slight positive trend coastwide for Atlantic sturgeon since the 1998 moratorium with variable signs of recovery by DPS*. ARIMA trend modeling suggests, at the coastwide resolution, there is a moderate probability of Atlantic sturgeon abundance increase since the moratorium in 1998. The probability increased when binomial GLMs (Generalized Linear Models), as suggested by the Review Panel, were used to develop several fishery-independent relative abundance trends in place of the negative binomial GLMs initially posited by the SAS. The binomial GLMs were considered by the Review Panel to be appropriate because many of the fishery-independent surveys contained a low proportion of positive tows. *Results at the DPS level were more variable but in general suggest a positive increase in abundance, with notable exceptions for the Gulf of Maine and Chesapeake Bay DPSs*.

The EPR analysis was used to find the value of total mortality (Z) that resulted in an EPR that was 50% of the EPR at the unfished state for ages 4-21 ($Z_{50\%}$). Coastwide $Z_{50\%}$ ranged from 0.085 to 0.094 though the paucity of life history information lends uncertainty in these values. Tagging data suggest a coastwide estimate of Z of 0.04 (0.01-0.17). *Tagging analyses estimating Z coastwide and at the DPS level suggest Z is currently lower than the reference Z calculated through the EPR analysis though notable exceptions existed in the north and south of the range.* It is not clear if these exceptions are due to increased tagging model uncertainty owing to low sample sizes and potential emigration, or actually reflect lower survival in these areas.

Depletion-Based Stock Reduction Analysis (DBSRA) estimated historic capacity coastwide at a median estimate of 27,988 mt with a two-stanza (pre- and post-1950) capacity model having a median estimate for the first period of 27,724 mt and 12,777 mt post 1950. The stochastic Stock Reduction Analysis (sSRA) assessment produced a similar result for capacity as the single stanza DBSRA. *Neither method produced credible measures of current stock status though both methods predict a population increase in recent decades.* The recovery trajectories produced in both the DBSRA and sSRA assessments predict recovery rates that are more rapid than indicated by abundance indices, suggesting there may be unaccounted for sources of mortality impeding recovery or that existing survey are not adequate to capture the change in abundance.

Effective population size (N_e) estimates for 7 of 10 spawning populations distributed among the DPSs are less than the suggested minimum of $N_e = 100$ that is required to limit the loss in total fitness from in-breeding depression to <10% (Frankham et al. 2014). All N_e estimates lie below the suggested recommended minimum $N_e > 1000$ required to maintain evolutionary potential (Frankham et al. 2014).

Given historic removals and current effective population size estimates, the Atlantic sturgeon is currently depleted. The current analysis indicates that anthropogenic mortality (e.g., bycatch and ship strikes) may exceed acceptable levels, reducing recovery rates. There are indications that anthropogenic effects may be higher at the DPS level.

The following Review Report evaluates the data and approaches used to assess Atlantic sturgeon; gives recommendations on suitability of model inputs and model outputs, and provides recommendations for future research and data collection.

TERMS OF REFERENCE

1. Evaluate appropriateness of population structure(s) defined in the assessment

Overall, the stock assessment sub-committee (SAS) provides evidence supporting the idea that Atlantic sturgeon along the Atlantic coast of the U.S. exhibit a complex meta-population structure. It appears there are several small, semi-discrete sub-populations connected through migration. Evidence for this view of stock structure primarily stems from:

- Molecular analyses collected from river-resident juveniles (<500 mm TL) and adult (>1500 mm TL) Atlantic sturgeon used in the development and/or refinement of a genetic stock structure baseline
    - Genetic designations of DPSs are sound. The general delineations first suggested by the SRT in 2007 seem to accurately describe the geographic groups of Atlantic sturgeon encountered along the U.S. Atlantic coast, although sample size for the Carolinas DPS is particularly small
    - Cluster analysis of relative abundance trends in individual surveys support the current DPS stock structure
- Evidence of new spawning tributaries throughout the species range
- Identification of separate spring and fall spawning migrations in some tributaries of the Chesapeake Bay, Carolina, and South Atlantic DPSs via acoustic tagging and genetic analyses

The Review Panel concurs that the new research at a broad scale seems to support the meta-population construct implemented through NMFS' DPS classification, though they caution that refinements of this construct are likely necessary to better define spawning tributary membership within DPS units, particularly for the Carolina and South Atlantic units, in the coming years.

Despite the evidence of a meta-population structure along the Atlantic coast, several practical considerations present challenges to assessment of Atlantic sturgeon at the DPS or river level at this time. Chief amongst these are:

- A latitudinal gradient in life history parameters is expected but there are insufficient Atlantic sturgeon life history data to clearly define structure; therefore, assessments of the smaller DPS units are not tractable/feasible

- The current DPS level does not address life history characteristics specific to discrete river populations or groups of rivers
- Identification of new or more wide-spread spawning behaviors needs to be researched, including potential higher incidences of straying and the identification of fall spawning runs in some systems
- The lack of coordination between U.S. and Canadian Atlantic sturgeon assessment and research impedes our understanding of interactions between Canadian and U.S. populations and the effects of human activities on their status.
    - Significant mixing occurs between U.S. and Canadian origin Atlantic sturgeon
- Because affected animals are rarely genotyped, it is not possible to partition bycatch, ship strike, and/or other anthropogenic sources of mortality to individual DPSs

Given the data constraints, which increase the uncertainty at the DPS level, the Review Panel concurred with the SAS in their recommendation to focus on assessing trends and Z at a coastwide level. Data paucity suggests conventional stock assessment analyses at the DPS level are not appropriate and coastwide analyses are more appropriate, especially if the goal is to develop traditional stock assessment reference points. That said, there is concern that coastwide evaluation may increase uncertainty due to variability in local indices.

2. **Evaluate the adequacy, appropriateness, application of the data used, and the justification for inclusion or elimination of available data sources. Evaluate the methods used to calculate indices, other statistics, and associated measures of dispersion.**

Overall, the SAS produced a very thorough collection and evaluation of all available Atlantic sturgeon data. When afforded the opportunity, the SAS made conservative decisions on how to use, or not use, the available data. This was particularly true concerning decisions of when and where to use potential relative abundance indices. The SAS wanted to ensure relative abundance time series were of sufficient length to capture potential changes in abundance given the maximum age of Atlantic sturgeon and avoid including information from surveys where the probability of Atlantic sturgeon encounter was exceptionally low. The final subset of data used emphasizes the data poor situation of Atlantic sturgeon relative to many other U.S. managed marine and riverine resources. Specifically, there is a lack of data for the South Atlantic fish, adult fish are not adequately represented in most data sets, and the age structure is not sufficiently documented for any DPS. These data deficiencies do not allow for an update or extensive use of life history characteristics or monitoring for changes in stock composition with time.

Fishery Removals

The only source of information concerning fishery removals of Atlantic sturgeon presented was a historical commercial landings time series spanning 1880-1997. Since the moratorium, there have been no directed US fisheries targeting Atlantic sturgeon and hence no estimates of fishery removals. Several potential sources of bias that can result in uncertainty in annual fishery removals were identified by the SAS and confirmed by the Review Panel, including but not limited to:

- Incomplete catch history
    - Landings for Atlantic sturgeon began prior to the start of the commercial landings data series
- Annual landings estimates are influenced by under/over reporting or inappropriate survey methods
    - Highly uncertain due to poor spatial and temporal coverage, particularly in the earliest years of the time series, and inconsistent reporting
- Lack of information on the sizes of Atlantic sturgeon harvested
    - No size information means the removals series can only be used to provide a biomass benchmark

To account for uncertainty in the historical fishery removals in the DBSRA and sSRA analyses, the SAS allowed for changes in uncertainty regarding the removals time series by varying the assumed lognormal CV through time. To account for the possibility that Atlantic sturgeon were not at carrying capacity when the removals series began, sensitivity analyses of the DBSRA allowed for varying ratios of initial year biomass relative to carrying capacity. While the Review Panel commends the SAS for incorporating this uncertainty into analyses, the possibility that the removal series for much or all of the time series was biased low (i.e., actual landings greater than reported landings) was not fully accounted for during sensitivity analyses or uncertainty estimation. Researchers should evaluate the potential effect of such bias in the future.

Finally, the SAS and Review Panel agree the removals time series is hampered by an inability to separate the historical fishery removals by DPS. The inability to separate removals by DPS or at other spatial scales will in the future limit the opportunity to conduct traditional stock assessments on Atlantic sturgeon at a spatial resolution finer than the U.S. Atlantic Coast.

Indices of Relative Abundance

The SAS' choice of indices was objective and well done. They established a set of criteria used for evaluating data sets and developing indices of relative abundance for Atlantic sturgeon. The SAS used thorough consultation with data collectors to understand methods, changes in methods over time, and how best to use data in analyses. There were, however, very few surveys specifically designed to catch Atlantic sturgeon, causing the exclusion of many canvassed surveys, due to low encounter rates.

Though the Review Panel generally endorsed the SAS' treatment of relative abundance indices in the assessment, the Panel made two suggestions relative to the description of indices in the assessment report.

- Survey descriptions were absent/insufficient and index standardization descriptions were brief. The Review Panel had to request clarifying information during the Review Workshop, particularly concerning size frequency of Atlantic sturgeon encountered, annual number of deployments, annual number of positive deployments, and annual number of Atlantic sturgeon captured by each survey. Such information is vital to understanding which segments of the population each survey captured and to evaluate the general utility of each survey as a measure of population relative abundance. While representatives of the SAS were able to produce all requested information during the Review Workshop, much of this information should have been included in the initial assessment report.

- The utility of Table 9 in the assessment report could have been expanded if more information was included. Examples of information that would have been valuable for inclusion in the survey summary table include:
    - Quantitative descriptions of size of Atlantic sturgeon encountered
        - Review Panel could not easily discern what segments of the population each survey was capturing. This was exasperated by inconsistency and/or ambiguity in the definitions of sizes represented by the terms YOY, small juveniles, large juveniles, and adults in parts of the assessment report
    - General location (i.e., DPS)
    - Type of waters targeted (e.g., riverine, estuarine, coastal)
    - Survey gear
    - Survey design (e.g., fixed station or stratified random)
    - Standardization error distribution (e.g., Poisson, negative binomial, etc.)
    - Standardization covariates included in final model
    - Average number of fish caught and average proportion of survey gear deployments positive for Atlantic sturgeon annually

The Review Panel raised similar concerns regarding the description of the bycatch data sets used during the assessment (see below).

Beyond general assessment report structure, the Review Panel did note several additional concerns and made recommendations regarding the treatment of relative abundance indices in the assessment:

- Many surveys appear DPS-specific given the survey location and age range encountered. However, it is unclear what proportion of DPSs are actually encountered in mixed DPS surveys, requiring concurrent genetic sampling.
- Three potential relative abundance indices (New York State Department of Environmental Conservation Juvenile Atlantic Sturgeon Abundance Monitoring Program (NY JASAMP), Northeast Area Monitoring and Assessment Program Trawl Survey (NEAMAP), South Carolina Edisto River Sturgeon Monitoring Project Survey (SC Edisto)) were excluded from consideration by the SAS in trend analyses due to insufficient duration (years). *The Review Panel recommended using the NY JASAMP, NEAMAP, and the SC Edisto relative abundance indices in trend analyses even though the time series are shorter than the pre-determined 15 years*. The 10-12 year durations and frequent catches of primarily juvenile Atlantic sturgeon in these surveys are informative and should be emphasized.
- Of the nine indices recommended for use by the SAS, the *Review Panel recommended development of abundance indices using a binomial error structure on a subset of six*:
    - Maine-New Hampshire Inshore Groundfish Trawl Survey (ME-NH)
    - Connecticut Long Island Sound Trawl Survey (CT LIST)
    - New Jersey Ocean Trawl Survey (NJ OT)

  - NEAMAP
  - Virginia Institute of Marine Science Shad and River Herring Monitoring Survey (VIMS Shad)
  - US Fish and Wildlife Cooperative Tagging Cruise (US CoOp).
- *The Review Panel recommended the six newly standardized indices be used in subsequent trend analyses and in the development of the coastwide Conn index*. Given the infrequency of encounters, there was concern about the selection of error structure underlying the GLMs used in the generation of abundance trends for the six surveys. The Review Panel agrees the underlying error structure is likely negative binomial, or possibly zero inflated negative binomial, and under these assumptions, the assessment team effectively assessed the suitability of model structure given the metrics of dispersion calculated. However, the sparse nature of the positive encounters each year resulted in high error around the underlying relative abundance trend created. The ability to resolve the underlying error distributions fully, given the quantity of data available, is a primary consideration for the choice of error distribution during index standardization, as the uncertainty around resulting year effects can reduce the utility of subsequent analyses.
- The cluster and dynamic factor analyses provided by the SAS were useful when determining how abundance trends of individual indices related to DPSs. The Review Panel notes this work could be further refined to address the suitability of indices to track sub-components of the Atlantic sturgeon population. Future work should explore how the refined treatment of indices recommended by the Review Panel would affect the outcome of these analyses.
- The Review Panel has some concerns regarding the suitability of the Conn method to develop an overall coastwide relative abundance estimate. While the analysis provided in the Conn paper indicates that, on average, little bias is created when incorporating indices representing different proportions of the population, it is unclear under which conditions the method produces biased results. Further, the lack of data from the South Atlantic biases the overall abundance trend toward northern units. For now, however, the Conn analysis is the best estimate available for a coastwide trend estimation.
- The Review Panel will defer to the judgement of the SAS and Atlantic sturgeon Technical Committee regarding whether the three indices the Review Panel recommended to be used in the trend analyses (noted above) are also included in a newly developed Conn index. The decision should be made after consultation with personnel from the NY JASAMP, NEAMAP and SC Edisto surveys. Personnel from the surveys should be made aware of the changes requested by the Review Panel with regards to treatment of their respective index.

3. Evaluate the estimates of Atlantic sturgeon bycatch and methods used to develop them

Bycatch information is limited for Atlantic sturgeon due to low observer coverage in ocean fisheries and a paucity of information on bycatch in many inshore, estuarine, and river fisheries. Bycatch data that were available to this assessment derive from three primary sources:

- Northeast Fishery Observer Program (NEFOP) and the Northeast Fishery At-Sea Monitoring (NEASM) Program,
- North Carolina Gill-Net Fisheries, and
- South Carolina American Shad Gill-Net Fishery

For both the NEFOP/NEASM and North Carolina Gill-Net Fisheries data sets, the SAS developed a GLM framework to estimate Atlantic sturgeon discards in federal waters that were represented by the these data sets. The Review Panel agreed with the SAS that the three data sources posited are sufficient to characterize and quantify bycatch of juvenile Atlantic sturgeon in those fisheries, but the data should not be used as a time series of relative abundance due to inconsistencies in sampling, responses by industry to regulatory changes, and uncertainty about the DPS composition of observed catches.

The SAS considered other fishery-dependent data sources for inclusion in Atlantic sturgeon bycatch estimates but these were ultimately eliminated due to short time series, low catch rate or reporting, or limited access to the fishery after the listing.

The Review Panel agrees with the SAS that bycatch mortality is likely underestimated for Atlantic sturgeon. Reasons for this determination include:

- Current bycatch estimates are derived from only a subset of fisheries potentially interacting with Atlantic sturgeon
- identification of effective effort on unobserved trips is difficult, making expansion of observed bycatch to coastwide bycatch estimates difficult
- current bycatch mortality estimates do not account for potential delayed mortality of Atlantic sturgeon
- bycatch estimates are affected by underreporting or inappropriate survey methods, and
- the time series of bycatch is probably incomplete, with the earliest estimates acquired in 2000, though presumably bycatch of Atlantic sturgeon began prior to this time.

The primary use of bycatch data in the current assessment was in the DBSRA and sSRA, which require a complete removals time series. As such, bycatch estimates from the NEFOP (2000-2015) and North Carolina inshore gill-net monitoring program (2004-2015) were added to the commercial removals series. To account for uncertainty in bycatch estimates in the DBSRA and sSRA analyses, the SAS allowed for uncertainty regarding bycatch estimates by assuming a lognormal CV of 0.2 since 1996. While the Review Panel commends the SAS for incorporating uncertainty into analyses, the sensitivity analyses and uncertainty estimation did not fully account for the possibility that bycatch estimates were biased low (i.e., actual bycatch deaths greater than estimated bycatch deaths). Researchers should evaluate the potential effect of such bias.

Other specific comments/recommendations made by the Review Panel with regards to bycatch of Atlantic sturgeon are:

- Provide a summary table of the bycatch data used that includes size classes and modes, duration of survey, survey gear types, etc.
- Bycatch estimation may need to include additional fisheries in order to increase geographic scope, particularly in the Gulf of Maine, and in estuarine or riverine areas where DPS-specific bycatch may occur.
- DPS composition of bycatch is needed if assessment/management is to be at the DPS level.
    - Inability to separate bycatch by DPS or at other spatial scales will limit the opportunity to conduct stock assessments on Atlantic sturgeon at this finer spatial resolution into the future
- Bycatch mortality is poorly understood and needs further study. Specifically, bycatch in unmonitored fisheries that encounter sturgeon should be assessed, and delayed mortality has not been evaluated (see Beardsall et al. 2013 for estimates of trawl bycatch mortality rates).

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

a. Evaluate the choice and justification of the preferred model(s) or method(s) of calculation (i.e., was the most appropriate model or method chosen given available data and life history of the species?)

The suite of models available for consideration during the assessment were limited compared to other more traditional stock assessments due to the inability to conduct age-based analyses. The current age data available are insufficient. Given the limitations, the Panel agrees with the SAS's decision to 1) evaluate total mortality estimates from the acoustic tagging model relative to EPR based reference points as a means to assess current total mortality rates, and 2) use the ARIMA models to evaluate recent trends in abundance.

Acoustic Tagging Model Review Panel Findings

- As sample size and the length of time series increases, the confidence intervals around Z estimates for juveniles and adults at both the coastwide and DPS level will improve. However, there was discussion related to the categorization of adults and juveniles. There was concern, given the size distribution of tagged individuals, that spawning adults were underrepresented.
- The posterior distributions of the tagging models were informative and should always be shown. In cases where the posterior clearly indicates skewed distributions, a better measure of central tendency will be the median or posterior mode. The Review Panel recommended use of the median Z estimates in the current assessment.

ARIMA Model

- The Review Panel concurred with the SAS that the ARIMA model is most suitable for trend analysis because ARIMA accounts for autocorrelation and provides a mechanism for probabilistic determination of the likelihood of increase
- Preliminary assessment of the relative abundance trends using a power analysis is useful to determine the utility of the indices to detect population trends. In the future, a

power analysis method that accounts for autocorrelation in the data would be more suitable.

b. If multiple models were considered, evaluate the analysts' explanation of any differences in results

The SAS provided results from a number of assessment methods, including effective population size (N_e), Mann-Kendall trends analysis, index power analysis, index cluster analysis, index dynamic factor analysis (DFA), population viability analysis (MARSS PVA and Dennis Model), conventional tagging model, stock reduction analysis (DBSRA and sSRA), and egg per recruit (EPR). The Review Panel commends the SAS for considering all of the different model structures during the assessment process, which confirms the main limitation to the assessment was available data. Many of the analyses contributed to the weight of evidence suggesting stable to slightly increasing trends in relative abundance since the 1998 moratorium. Below are specific comments and recommendations made by the Review Panel regarding each method:

Effective Population Size (N_e)

- N_e is useful for defining abundance levels where populations are at risk of loss of genetic fitness. For Atlantic sturgeon there are indications that some stocks are at risk for inbreeding depression ($N_e < 100$) and all may be at risk of loss of evolutionary potential ($N_e < 1000$). These results reinforce that at both the coastwide and DPS level Atlantic sturgeon are depleted.
- N_e estimates, at either the coastwide or finer spatial scales, could be a consideration during development of recovery targets for Atlantic sturgeon. While we have general recommendations on N_e that put the stock at risk for inbreeding depression or loss of evolutionary potential (Frankham et al. 2014), a better understanding of the meta-population structure of Atlantic sturgeon along the coast is needed before the most appropriate scale for measuring N_e can be determined.

Mann-Kendall Trends Analysis

- Given the large variance in the standardized relative abundance indices, the Mann-Kendall trends analysis indicates a very low probability of detecting a trend in population abundance. Unless the variance around the standardized indices can be reduced through the removal of observation error, the Mann-Kendall trends analysis on the individual standardized abundance indices is unlikely to produce informative results until the available time series are much longer.
- Mann-Kendall was informative, however, when applied to results of the ARIMA analyses on both individual indices and the Conn index as it allowed for probabilistic assessments of increases in relative abundance trends relative to reference levels.

Dynamic Factor and Cluster Analyses

- Given data limitations, the DFA was not very informative. Results may be an indication of high noise to signal ratios in the input data or may reflect that there is really only a single coastwide trend in relative abundance.
- The DFA may be more informative in the future to identify indices that are representative of specific DPSs.

- Cluster analysis was more useful for supporting stock structure. For trends, it may give indication of where river stocks are diverging (i.e., helps define which indices to use within each cluster).

Population Viability Analysis

- Discontinue use of the Dennis method because it does not include observation error, which is clearly a component of the abundance indices.
- The MARSS PVA provides insights and should be explored further, although the analysis is premature without better input data. PVA provides an estimate of population growth rate that could be used in future assessments and/or as a recovery plan target reference point. In the future, the combination of census information and effective population size could be incorporated into PVAs to evaluate extinction risk.

Conventional Tagging Model

- The decision not to use the conventional tagging data for the development of mortality estimates should be reconsidered if there is a standardization of methods and data archiving in the future. A particularly fruitful avenue may be to explore the use of PIT tags, coupled with genetic data, to track migration movements and DPS specific mortality rates.

Stock Reduction Analysis

- The use of stock reduction analysis (both DBSRA and sSRA) was an attempt to use a more traditional data poor stock assessment technique with the available Atlantic sturgeon data. Both the DBSRA and the sSRA predicted an uptick in abundance since the moratorium, though the Review Panel is not confident in the magnitude of the signal. There is a lack of congruence between relatively higher recent population increases predicted by the SRA models and the suggested increase in relative abundance from the observational indices. This suggests there are additional population losses (i.e., mortality) not accounted for in the recent catch, or a time delay that has not been fully accounted for. Although the models were not useful for the development of credible measures of current stock status, both gave an indication of the historic capacity of the coastwide stock. Specific concerns:
    - The SAS did not specify if the assumed 5-20% current depletion level was relative to the first or second stage estimated carrying capacity in the two-stage DBSRA model. Sensitivity of the DBSRA to this assumption should be investigated in the future.
    - In the future, as data quality improves, add a retrospective analysis to stock reduction analysis models.
    - One of the challenges with the sSRA model is that the catch removal time series is taken to be deterministic and uncertainty in historic removals is not accounted for. As a result, the parameter space had to be constrained to produce trajectories that fit the relative abundance time series used. Given the uncertainty in historic and current removals from the population it may be necessary to more fully capture the uncertainty in removals in future sSRA assessment to avoid overly constraining the parameter space.
    - For both DBSRA and sSRA the current model does not carry forward uncertainty in life history characteristics fully.

Eggs per Recruit

- The Review Panel expressed concern about the robustness of EPR analyses and reliance of management on the point estimates of $Z_{50\%}$, due to two primary sources of uncertainty in the EPR analysis. The Review Panel nonetheless agrees with the primary outcome of the EPR analysis that Atlantic sturgeon are highly sensitive to human-induced mortality.
    - Life history inputs – the current analysis is based on stale, uncertain life history information that primarily derives from a single DPS (New York Bight), with some additional data from the Carolina DPS. Available, albeit limited, information indicates the biological traits of Atlantic sturgeon, notably growth rates and spawning behavior, vary considerably among rivers and among DPSs with latitude. The EPR model results, as reported by the SAS, are deterministic and do not account for variability in input life history parameters.
    - Bycatch and ship strike selectivity – For bycatch selectivity, the SAS attempted to derive a logistic selectivity curve based on empirical size frequency data. The resulting curve suggested a slowly increasing pattern of bycatch selectivity until it reached full selectivity at around 20+ yrs of age. For both, as is the case with the life history parameters, the EPR model is deterministic without allowing for uncertainty in selectivity patterns.
- At the coastwide scale, the SAS' initial parameterization of the EPR model suggested a median estimate of $Z_{50\%}$ for ages 4-21 of 0.089 (see Table 46). The Review Panel requested limited exploration regarding the impact that different assumptions about age-at-maturity (earlier age-at-maturity) and/or bycatch selectivity (dome-shaped and increased selectivity at younger ages) had on final coastwide $Z_{50\%}$ estimates for ages 4-21. The investigation suggests there is substantial uncertainty in the $Z_{50\%}$ (i.e., $Z_{50\%}$ estimates ranged from 0.086-0.107 or -3.4% to +20.2% relative to 0.089). Accounting for the full uncertainty in input parameters to the EPR model would likely suggest an even broader range of plausible $Z_{50\%}$ estimates, making exact specification of a threshold/target $Z_{50\%}$ to use as a biological reference point difficult.
- Justification is needed for the choice of $Z_{50\%}$ as the threshold/target EPR level. Literature suggests that EPR levels ranging from 10-60% may be needed to avoid recruitment overfishing in other species. Exploration of how sensitive the $Z_{xx\%}$ level is to different assumed threshold/target EPR levels is needed. The choice of the most appropriate $Z_{xx\%}$ threshold/target for Atlantic sturgeon will likely require additional research.
- The Review Panel recommends a probabilistic approach to defining EPR % levels, where a range of likely threshold values can be compared to a range of estimated mortality rates from tagging data. While more complex than a point-based management target, expressing the threshold and assessment results in probabilistic terms will better illustrate our understanding of stock status. Then, risk tolerance levels can be established to determine appropriate reference levels. Given the uncertainty in life history characteristics, the Z threshold could be chosen based on a specific quantile of the resulting EPR distribution (e.g., 20%) in relation to the desired EPR level (e.g., 50%).
- The Review Panel was satisfied with the assessment's exploration of sensitivity of EPR to bycatch selectivity, including additional work performed during the review.

c. **If appropriate, evaluate model parameterization and specification (e.g., choice of CVs, effective sample sizes, likelihood weighting schemes, calculation/specification of M, stock-recruitment relationship, choice of time-varying parameters, plus group treatment)**

In this section, only those parameters and specifications not already addressed above will be considered.

The Review Panel would like to re-emphasize that the life history data used in the EPR and sSRA analyses were based on older data from a limited geographic range. The representativeness of life history parameter estimates to the contemporary Atlantic sturgeon population, individual DPSs, or the general life history of the coastwide population is currently a significant source of uncertainty. A primary recommendation of the Review Panel is to collect contemporary life history information from all segments of the population such that one can better categorize DPS and coastwide life history parameters related to growth, size/age-at-maturity, annual fecundity, spawning frequency, etc. Until such information is available, it will be nearly impossible to fully characterize the uncertainty in the EPR Z reference point that the SAS posits (and the Review Panel in general supports) to use as the means to compare contemporary total mortality to sustainable rates.

A stock-recruitment relationship was not estimated, nor were reference points calculated from such an estimate. At this time, the current lack of credible juvenile and adult abundance indices for Atlantic sturgeon prohibits reliable estimation of a stock-recruitment curve.

The Review Panel agrees the selected point estimate of natural mortality (M) is reasonable but uncertainty in the value was not carried through in the assessment. Uncertainty in M will affect the results of the EPR and hence our understanding of how current Z compares to the EPR reference point Z. Further, uncertainty in M was not accounted for in the stock reduction analyses.

The coefficient of variation for the removals series used in stock reduction analyses were rough estimates that potentially under represent uncertainty in the data used. Such uncertainty could be more fully incorporated into the stock reduction analyses.

d. **Evaluate the diagnostic analyses performed, including but not limited to:**
   i. **Sensitivity analyses to determine stability of estimates and potential consequences of major model assumptions**
   ii. **Retrospective analysis**

Index Standardization

The SAS performed a fairly exhaustive evaluation of potential candidate models for the GLM standardization of abundance trends. Model selection was based on Akaike's Information

Criterion (AIC). Given the nature of the available data, AIC is likely an appropriate method for model selection, though use of AIC as an information criterion for model selection can lead to selection of over-parameterized models with large sample sizes. While an over-parameterized model will provide a better fit to the observed data, it can lead to higher uncertainty in the relative abundance trends. There was no indication in the data of strong spatial or temporal interactions amongst covariates, suggesting that year effects extracted and used as measures of relative abundance were appropriate.

There is concern within the Review Panel that the number of positive tows was limited in a number of the data sets used to develop relative abundance indices. Future work should explore how sensitive the error around the extracted year effects are to the number of positive tows each year. To alleviate this concern partially for the assessment, the Review Panel recommend the use of a binomial error distribution for several of the posited relative abundance indices investigated via Trends Analyses and used for the combined Conn coastwide index.

The application of a Power Analysis to the final relative abundance trends from each index was extremely informative and should be a regular part of future analyses. The ability to assess the probability of detecting a trend in the population when a given index is utilized provides an objective way to assess the apparent information content contained in each index, given the uncertainty in its predicted year effects.

Effective Population Size

No diagnostic/sensitivity analyses were performed on the results of the N_e analysis. The Review Panel did note the values of N_e reported in the document reinforced the overall portrayal of the US Atlantic sturgeon population as depleted to a concerning extent at both the coastwide and individual DPS levels. Future diagnostic work should be completed to help infer the robustness of these conclusions.

Bycatch Estimation

The SAS performed a thorough evaluation of potential candidate models for the GLM standardization and estimation of bycatch estimates from the northeast trawl and gill net fisheries and the NC gill net fishery. Model selection was based on AIC, with interactions amongst potential covariates being allowed in the final model. As was the case with the use of AIC for model selection for the relative abundance indices, and given the nature of available data, AIC is likely an appropriate method for model selection, though use of AIC as an information criterion for model selection can lead to selection of over-parameterized models with large sample sizes.

ARIMA Analysis

The retrospective analysis provided for the ARIMA analysis was appropriate and revealed some sensitivity of the results to the length of abundance index used. This was particularly apparent for time series that contained rapid changes at the start and end of the time series.

Acoustic Tagging Model Total Mortality Estimates
Limited information was provided to the Review Panel by the SAS regarding how sensitive estimates of annual mortality from the tagging model are to different model assumptions beyond a sentence stating, “a variety of modeling scenarios were evaluated with different temporal and DPS varying estimates of both survival and detection probability” with the “best model for each size group…selected using DIC.” If the acoustic tagging model is to remain a primary source of information concerning contemporary mortality rates relative to reference mortalities, more diagnostics regarding the candidate models should be provided in future assessments. However, at this time there is not sufficient concern within the Review Panel to invalidate the use of the acoustic tagging model as an estimate of current Atlantic sturgeon total mortality.

Stock Reduction Analyses
The Review Panel felt the sensitivity analyses conducted around the sSRA and DBSRA models were limited and could be improved in future assessments to include uncertainty in parameter inputs. However, these analyses were not used in the final assessment of current stock status.

Egg Per Recruit Calculation
Limited sensitivity analyses were provided in the assessment report for the egg per recruit analysis. Z estimates for only a single EPR reference point ($Z_{50\%}$) are provided, with no indication of how variable the estimate of Z would be if a different percentage relative to an unfished stock was chosen. Further, there was limited to no investigation presented in the report with regards to how robust Z reference points were to input assumptions. The Review Panel recommended that prior to final status determination relative to current mortality rates that the EPR model incorporate uncertainty into input parameters into the model and then develop probabilistic estimates of $Z_{50\%}$ based on the EPR model (see below).

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

Mortality Status
The acoustic tagging Cormack-Jolly-Seber model estimates of current Z, the preferred method for estimating contemporary Z by both the SAS and Review Panel, appropriately incorporates uncertainty into the recent Z estimates by using a Bayesian framework. The resulting posterior distribution of Z provides the relevant uncertainty information and the Review Panel recommends these be included in the assessment report. However, given the skewed distribution of the posteriors, the Review Panel did recommend using the median of the posterior as the measure of central tendency instead of the mean of the posterior.

Full uncertainty was not incorporated into the current mortality status determinations calculated in the EPR model, as noted above. As presented the EPR model was a deterministic function of input life history parameters and selectivity curves. The Review Panel recommended that uncertainty in the life history and selectivity curves be fully incorporated into the EPR model, such that the reference point calculation ($Z_{50\%}$) could be posited in a probabilistic framework. This, coupled with the posterior Z distributions, would allow for mortality status determinations to be assessed probabilistically (Tables 49 and 50).

Biomass/Abundance Status

ARIMA analysis, as applied in the current Atlantic sturgeon assessment, allows inference of population status relative to an index-based reference point (Helser and Hayes 1995). Specifically, the method uses a two-tiered approach for this evaluation, whereby the analyst specifies the probability of being above or below a reference point and the associated statistical level of confidence (i.e., 80%) in this specification. Therefore, the approach takes into account the uncertainty in both the value of the fitted survey index for a given year and the reference point to which the population level is compared (Helser and Hayes 1995). The result is that one can estimate the probability that a given index value is above a stated reference point. The probabilistic framework lends itself, once a risk tolerance is specified, to monitor population trends relative to an accepted reference point. Given these qualities, the Review Panel agrees the ARIMA approach is satisfactory for trend estimation.

In addition, the application of the Mann-Kendall test to the indices after being fitted using the ARIMA model allows for the probabilistic determination of monotonic trends in the time-series. The Review Panel felt this was useful in the detection of trends in the fitted indices.

6. **Evaluate recommended estimates of stock biomass, abundance (relative or absolute), mortality, and the choice of reference points from the assessment for use in management, if possible, or, if appropriate, recommend changes or specify alternative estimation methods**

Mortality Status

The contemporary Z estimates derived from the acoustic tagging Cormack-Jolly-Seber model are preferred over the $Z_{50\%}$ reference point derived from the EPR model and can be used to determine the current sustainability of Atlantic sturgeon Z. Frequent updates of current Z based on the tagging model could be used to monitor for changes in total mortality at both the coastwide and individual DPS level. This likely provides a better measure of the impact of anthropogenic mortality on recovery of the Atlantic sturgeon population than directly monitoring the occurrence of bycatch mortality, ship strike mortality, or other sources of anthropogenic mortality given current data limitations. Without significant investment in collection of basic life history information, expansion of Atlantic sturgeon monitoring efforts, etc., the utility of the more traditional stock assessment methodologies for monitoring mortality rates relative to reference points may not be feasible.

The utility of the tagging model Z estimates is expected to increase as the uncertainty in Z estimates is reduced due to more Atlantic sturgeon being acoustically tagged and fish previously tagged having longer detection histories. However, for these methods to be viable in the long term, there must be a sustained effort to tag additional Atlantic sturgeon coastwide and maintain/expand current acoustic receiver arrays. This will require continued significant financial resources by funding agencies.

The Review Panel has the following primary concerns regarding the proposed status assessment using tagging estimates of Z with $Z_{50\%}$ as a reference point:

- Choice of $Z_{50\%}$ as an appropriate reference point is not adequately justified
- Current Z, relative to the $Z_{50\%}$ reference point, is not presented in a probabilistic framework
- Uncertainty in the robustness of the EPR analyses exists due to uncertainty in input life history parameters and assumed selectivity curves is not expressed, and
- There is significant heterogeneity in the geographic representation of the acoustic tag data.

Future research addressing these concerns is likely to help inform potential mortality rate recovery targets in the future. The ultimate choice of EPR reference point and mortality status determination would benefit greatly from the specification of risk tolerance by managers.

Biomass/Abundance Status

The Review Panel agrees with the SAS that the best metric of biomass/abundance status currently available for Atlantic sturgeon derives from the results of the ARIMA analysis with respect to defined index based reference points. Uncertainty still exists as to the most appropriate index based reference point to use as a measure of current stock status. The current use of the 25th percentile of the ARIMA fitted index and comparison relative to the index value in 1998 (or index start year) are reasonable starting points, but alternative index reference point values could be chosen. E.g., pooling of 5-year periods at the beginning and end of time series as a more robust approach to measuring overall stock health. The Review Panel suggests the ultimate choice of appropriate index based reference points should be informed by management goals and/or recovery targets.

The Review Panel also finds more emphasis could be placed on the use of effective population size measures as an indication of abundance relative to levels that put the stock at risk for inbreeding depression or loss of genetic diversity. The Review Panel does not advocate using N_e as a reference point, but it could be considered as a recovery target.

The Review Panel agreed with the SAS that at this time one should not use the results of the stock reduction analyses as a measure of biomass/abundance status. Both the DBSRA and sSRA are predicting upward biomass trends in the terminal year that are not matched by the observed trends in any of the relative abundance indices. The Review Panel does not express confidence in this signal, and the mismatch between the increases suggested by the stock reduction analyses and relative abundance trends are suggestive of additional population losses in the recent period that are not captured in the removals series. Given the uncertainty in recent bycatch estimates and the acknowledgement that current bycatch estimates are likely underestimates, the results are not surprising. The main utility of the stock reduction analyses is to inform historical carrying capacity for the system.

Finally, the Review Panel supports the continued evaluation of the MARSS PVA as a means to evaluate percent change in the population over time. At this point, the analysis is not considered to be sufficiently robust owing to the poor quality of the input data. In future assessments, with data improvements, it could be used as a measure of population growth rate and in a recovery plan target reference point. In the future, the combination of census information and N_e could be incorporated into PVAs to evaluate extinction risk.

7. Evaluate stock status determination from the assessment, or, if appropriate, recommend changes or specify alternative methods/measures

The Review Panel agrees with the overall assessment that Atlantic sturgeon abundances are likely increasing slowly. The Panel also recognizes the difficulties posed by the paucity of information and lack of DPS-specific recovery targets for status determination. Clearly, Atlantic sturgeon remain depleted relative to historical levels. The Panel recommends additional research to identify appropriate reference points for future status determinations and recovery targets.

The Panel was concerned about the apparent certainty in the coastwide and DPS status determination table by the use of fixed thresholds, rather than probabilistic outputs. Because status and recovery targets have not been specified, and data uncertainty creates wide distributions of model results, the Panel recommends that the metrics used in status determination be presented as probabilities (Tables 1 and 2).

The Review Panel discourages reliance on traditional stock assessment models for the assessment of Atlantic sturgeon relative to mortality and biomass benchmarks at this time. Data limitations are likely to limit the utility of traditional methods in the near future. Further, until routine age data are collected from encountered Atlantic sturgeon, it will remain impossible to define a recovery target based upon an expansion of the population age structure.

Table 1: (Revised from Assessment Report Table 49) Estimates of Z from tagging relative to $Z_{50\%EPR}$ at the coastwide and DPS-level. Estimates of Z are for all tagged fish from each region/DPS, and $Z_{50\%EPR}$ values are N-weighted values for ages 4-21.

Region	**Z (95% credible interval)**	**$Z_{50\%EPR}$ (95% CIs)**	**$P(Z)>Z_{50\%EPR}$ 50%**	**$P(Z)>Z_{50\%EPR}$ 80%**	**$P(Z)>Z_{50\%EPR}$ 90%**
Coast	0.04 (0.01 - 0.17)	0.12 (0.10-0.15)	7.2%	6.5%	6.1%
Gulf of Maine	0.30 (0.01 - 1.90)		75.4%	73.5%	72.5%
New York Bight	0.09 (0.01 - 0.34)		34.6%	31.2%	29.4%
Chesapeake Bay	0.13 (0.01 - 0.78)		33.6%	30.0%	28.0%
Carolina	0.25 (0.01 - 0.94)		78.2%	75.4%	73.9%
South Atlantic	0.15 (0.01 - 0.62)		43.9%	40.2%	38.1%

Table 2: (Revised from Assessment Report Table 50) Stock status determination for the coastwide stock and DPSs based on morality estimates and biomass/abundance status relative to historic levels and the terminal year of indices relative to the start of the moratorium as determined by the ARIMA analysis. Refer to section 7.2 for a more thorough discussion of stock status in each DPS which includes this quantitative evaluation as well as qualitative evidence.

	Mortality Status	**Biomass/Abundance Status**	
Population	**P(Z)>$Z_{50\%EPR}$ 80%**	**Relative to Historical Levels**	**Average probability of terminal year of indices > median 1998 value**
Coastwide	6.5%	Depleted	0.95
Gulf of Maine	73.5%	Depleted	0.51
New York Bight	31.2%	Depleted	0.75
Chesapeake Bay	30.0%	Depleted	0.36
Carolina	75.4%	Depleted	0.67
South Atlantic	40.2%	Depleted	Unknown (no suitable indices)

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

In general, the Review Panel agrees with the research recommendations and priorities developed by the Atlantic sturgeon Technical Committee (see Assessment Report, Section 8, pp. 107-109). Currently there are severe data limitations restricting the type, scope, and usefulness of assessment methodologies that can be applied to Atlantic sturgeon. Most importantly, there is an incomplete accounting for temporal and spatial variability in life-history parameters, an imperfect understanding of the temporal and spatial organization of reproductively discrete spawning populations, and major uncertainties in the scope for direct harm arising from interaction with ongoing human activities (e.g., bycatch, ship strikes) to the recovery of Atlantic sturgeon. To assist in identifying areas with significant data gaps, the Review Panel created a data gaps table (Table 3) based on the current Atlantic sturgeon assessment report.

The Review Panel provides the following suggested changes to existing research priorities, as well as a set of new research recommendations that are critical to advancing Atlantic sturgeon science, modeling, and future stock assessments.

Future Research

<u>High Priority</u>

- Develop standardized methods that can be used to create reliable indices of abundance for adults and young juveniles (Age 1) to reflect the status of individual DPSs
    - A workshop is recommended to assess the efficacy of existing ‘sturgeon surveys’ (e.g., those presently conducted in NY, SC) and new approaches

- Expand and improve the genetic stock definitions of Atlantic sturgeon, including the continued development of genetic baselines that can be applied coastwide, within- and among-DPS's, and at the river-specific level. Consideration of spawning season-specific data collection will be required. Particular emphasis should be placed on collecting additional information from the Gulf of Maine and Carolina DPSs (Table 3).

<u>Moderate Priority</u>

- Determine a permitting process to enable authorizations to sample and collect biological materials from any dead Atlantic sturgeon encountered
    - Pectoral fin spines to support age determination are considered to be of high value
    - Additional materials could include gonad tissues to support development of maturation schedules for males and females and fecundity
- Evaluate potential reference point targets and their efficacy for Atlantic sturgeon. Options include (but are not limited too):
    - number of fish in spawning runs
    - number of rivers with sturgeon presence/absence (by DPS and coastwide)
    - frequency of catch in indices and/or observer sampling
    - evaluate rivers where you don't have sturgeon, setting minimum bar
- Determine freshwater, estuarine, and ocean habitat use by life history stage including adult staging, spawning, small and large juvenile residency, and larvae
- Identify spawning units, using appropriate techniques (genetics, tagging, eDNA, collections of eggs or larvae, etc.), along the Atlantic coast that best characterize the meta-population structure of U.S. Atlantic sturgeon
    - Recent search efforts both in previously un-sampled rivers/tributaries and rivers thought to have lost their native populations have revealed evidence of spawning activity that results in the production of young juveniles. Such instances require particular attention to determine whether they are the result of reproduction by self-sustaining populations
- Investigate the influence of warming water temperatures on Atlantic sturgeon, including the effects on movement, spawning, and survival

<u>Low Priority</u>

- Evaluate incidence of and the effects of predation on Atlantic sturgeon

Data Collection

<u>High Priority</u>

- Establish centralized data management and data sharing protocols and policies to promote greater use of all available Atlantic sturgeon data. Priority data sets include (but are not limited to):
    - genetics/tissue samples
    - pectoral fin spines and associated age estimates
    - acoustic tagging and hydrophone metadata
    - external and PIT tag data

Emphasis should be placed on extracting all available data in underrepresented DPSs. Concurrently, continue to support programs that provide data sharing platforms such as the Atlantic Cooperative Telemetry Network. These initiatives will benefit from the support of federal funding agencies enforcing the requirement to make data collected via federal funds part of the public record within a reasonable period of time. If not a current requirement of funded Atlantic sturgeon research, this should become a requirement.

- Implement directed monitoring of Atlantic sturgeon that is designed to support assessments both coastwide and at the DPS level and/or expand existing regional surveys to include annual Atlantic sturgeon monitoring. Monitoring two or more reproductively discrete populations within each recognized DPS is suggested. Use of emergent technologies such as validated side scan sonar surveys and acoustic tracking may allow for more cost effective monitoring of river runs.
    - Monitoring protocols that enable data gathering for a number of species (e.g., Shortnose sturgeon) is encouraged
    - Development of adult, YOY (or Age 1), and juvenile indices are a high priority, and considerations should be made for the use of appropriate survey gears
        - Associated length and age composition information is needed so that relative abundance-at-age information can be obtained from the adult and juvenile indices
    - See Table 8 in the assessment report for a list of surveys considered by the SAS during the assessment
    - See Table 3 of this report to see current data gaps identified by the Review Panel
- Continue to collect biological data, PIT tag information, and genetic samples from Atlantic sturgeon encountered on surveys that require it (e.g., NEAMAP). Consider including this level of data collection from surveys that do not require it. Push permitting agencies to allow sampling (to the extent possible) of all encountered Atlantic sturgeon via scientific research activities.
- Maintain and support current networks of acoustic receivers and acoustic tagging programs to improve the estimates of total mortality. Expand these programs in underrepresented DPSs, using a power analysis to define direction and magnitude of expansion, as required to support next assessment.
- Collect sub-population specific (river, tributary, or DPS level) life history information (e.g., age, growth, fecundity, maturity, spawning frequency). Where feasible, emphasis should be on collecting information by sex and for reproductive information by size/age. Particular focus should be on collecting information on Atlantic sturgeon from the South Atlantic DPS given less data and suspected regional life history differences (see Table 3).
- Improve monitoring of bycatch in other fisheries, gears, and locations (notably northern and southern range). When scaling up to unobserved trips, need better data/measures of effective effort that can be reasonably expected to encounter Atlantic sturgeon. This may include collection of more detailed information on type of gear deployed, locations of deployment, etc. To assess the potential for currently missing significant sources of Atlantic sturgeon bycatch, do a simple query of all observed fisheries to see if Atlantic sturgeon are encountered in other gears beyond gillnet and trawl (e.g., scallop dredges)

- Investigate and account for extra-jurisdictional sources of mortality. Include data on fish size, health condition, and number of fish affected.

Moderate Priority

- Collect more information on regional vessel strike occurrences, including mortality estimates. Identify hot spots for vessel strikes and develop strategies to minimize impacts on Atlantic sturgeon.
- Promote greater Canadian-US Atlantic sturgeon data sharing, cooperative research, and monitoring. Exploring interactions between Canadian and US Atlantic sturgeon may more fully explain mortality trends, particularly with regards to the Gulf of Maine DPS.

Assessment Methodology

High Priority

- Establish recovery goals and risk tolerance for Atlantic sturgeon to measure progress of and improvement in the population since the moratorium and ESA listing
- Expand the acoustic tagging model to incorporate movement
- Conduct a power analysis to determine sufficient acoustic tagging sampling sizes by DPS

Moderate Priority

- Evaluate methods of imputation to extend time series with missing values. ARIMA models were applied only to the contiguous years of surveys due to the sensitivity of model results to missing years observed during exploratory analyses.
- Explore feasibility of combining telemetry tagging and sonar/acoustics monitoring to generate abundance estimates

Table 3: Data gaps for Atlantic sturgeon as compiled by the Review Panel. ✓= data available, --- = no data available or not presented in assessment report.

	Life History				Surveys/Monitoring (# of surveys ≥10 yrs)					
DPS	**Length-Weight**	**Age-Length***	**Maturation**	**Fecundity/ Spawning Frequency**	**Small Juveniles**	**Juvenile/ Adult**	**Spawning Adults**	**Local (DPS-level) bycatch monitoring**	**# of Acoustic Tags used in Z-estimation**	**Genetic Samples (N_e estimation, DPS ID)**
Gulf of Maine	✓	2015 (Canada)	---	---	0	1	0	---	153	113
New York Bight	✓	1998, 2000, 2005, 2016	1988	1998	3	1	0	---	657	518
Chesapeake	✓	2012	---	---	2	0	0	---	275	482
Carolinas	✓	2015	---	1982	7	1	0	✓	99	37
South Atlantic	---	2015	---	---	1	0	0	✓	147	508

*sex-specific growth information not presented in report but is available in some studies.

ADVISORY REPORT

1. Status of Stocks: Current and projected

Given historic removals and estimated effective population sizes, Atlantic sturgeon are currently depleted. The current analysis indicates that anthropogenic mortality (e.g., bycatch and ship strikes) may exceed acceptable levels, reducing recovery rates. There are indications that anthropogenic effects may be higher at the DPS level, though this is confounded with greater uncertainty in tagging model total mortality Z estimates.

The quality and quantity of data available to determine stock status degrades progressing from coastwide to DPS to river level. The inability to distinguish DPS origin of historical catches and many current anthropogenic sources of mortality (e.g., bycatch in coastal fisheries) precludes the use of conventional stock assessment methods at any spatial resolution other than coastwide. The only quantitative assessment which could produce conventional metrics of stock status was the stochastic stock reduction analysis. Results for sSRA should not be used to determine stock status given the uncertainty in historical catches, potential changes in productivity and carrying capacity, and concerns as to the suitability of the derived coastwide index of abundance.

The 1998 assessment determined that populations of Atlantic sturgeon throughout the species range are either extirpated or at historically low abundance. The 2017 assessment, an exhaustive evaluation of available data, provides evidence that at the coastwide scale there has been some population recovery since the moratorium in 1998. Evidence for the beginning of population recovery at the DPS level is mixed. Significant improvements in the quality of data available to assess sturgeon must be made if stock status is to be credibly determined at any spatial resolution.

Projections were not required in the terms of reference of the assessment as there were no defined reference points.

2. Stock Identification and Distribution

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) is one of the largest and longest-lived anadromous fish in North America and can be found along the entire Atlantic coast from Labrador, Canada to the St. Johns River, Florida. In general, each river supports a unique spawning population. Based on the observed levels of genetic differentiation, populations are expected to be demographically independent among natal rivers. Recent work suggests separate genetically discrete spring and fall spawning runs in several systems (e.g., Edisto River in South Carolina and James River in Virginia). There is also increasing evidence of adults visiting multiple spawning tributaries during the same spawning season, suggesting a degree of straying particularly between adjacent rivers which may be indicative of a meta-population structure.

Future consideration should be given to the transboundary movement of individuals into Canadian waters in the Gulf of Maine and potentially into the Gulf of St. Lawrence.

3. Management Unit

In 2007, the Status Review Team identified five distinct population segments (DPSs) with different physical, genetic, and physiological characteristics along the Atlantic coast: Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic. Currently Atlantic sturgeon are listed under the Endangered Species Act using the DPS designations. Recent genetic information indicates there is the possibility of a meta-population structure within the range as well as discrete spring and fall spawning sub-populations within some rivers. Given current information it seems reasonable to manage at the DPS level although the current data streams are insufficient to provide information at this resolution.

Additional work is needed to further define the boundary between the Carolina and South Atlantic DPSs. Work would require additional genetic baseline samples to be primarily collected from the Carolina DPS to widen geographic coverage.

4. Landings

Atlantic sturgeon are known to have been taken for food by humans for at least 3,000-4,000 years and have supported fisheries of varying magnitude along the Atlantic coast since colonial times. Records of commercial landings were initiated by the Federal government in 1880 through the US Commission of Fish and Fisheries (also known as the US Fish Commission), which collected landings data from fishers and port agents. The historical dataset represents the best available information on landings from this period though there is uncertainty in species identification and lack of temporal and geographical coverage.

Through the 1900s, data collected on sturgeon landings improved and data in the later part of the century are thought to be reasonably accurate as most states had implemented some form of dealer reporting. Several states closed their sturgeon fisheries in the mid to late 1990s, and a coastwide moratorium was implemented in 1998, ending the directed sturgeon landings time series. Missing data in the early part of the time series used in the sSRA and DBSRA models were imputed using a loess smoother. The Review Panel felt this was an acceptable approach though there is the potential for more investigative work to be done on improving historical records.

5. Data and Assessment

The quality and quantity of data available to determine stock status degrades progressing from coastwide to DPS to river level (Table 1). Significant improvements in the quality of data available to assess Atlantic sturgeon must be made if stock status is to be credibly determined at any spatial resolution.

Reliable life history information is required to support the assessment and status determination for Atlantic sturgeon. Basic information on sex-specific growth rates, maturation, and frequency of reproduction is old, limited to a single population, or unrepresentative of DPS units. In particular, there is a need for verification of life history traits of fish from southern DPS units.

ARIMA modeling suggests that, at the coastwide resolution, there is a moderate probability of sturgeon abundance increase since the moratorium in 1998. The probability increased when binomial GLMs were used in place of negative binomial GLMs. Careful consideration needs to be given to the choice of GLM relative to the availability of data. In a number of instances the amount of data available each year was insufficient to clearly determine the underlying error structure. Results at the DPS level were more variable but in general suggest a positive increase in abundance, with notable exceptions for the Gulf of Maine and Chesapeake Bay. It is unclear if the exceptions are a reflection of underlying data quality for the DPSs, or actual trends in abundance.

An egg-per-recruit (EPR) analysis was used to find the value of Z resulting in an EPR that was 50% of the EPR at the unfished state for ages 4-21. Coastwide the reference value was determined to range between 0.085 to 0.094 though there is uncertainty in the values due to the paucity of life history information. Further support for the selection of the 50% level is warranted.

Tagging data suggest a coastwide estimate of total mortality of 0.04 (0.01-0.17). Tagging analyses estimating total mortality (Z) coast wide and at the DPS level suggest Z is lower than the reference Z calculated through the EPR analysis though notable exceptions existed in the north and south of the range. It is not clear if the exceptions are due to increased tagging model uncertainty owing to lower sample sizes and potential emigration, or actually reflect lower survival in these areas. Further work is required to determine sufficient sample sizes and model structure if mortality is to be used as a metric to assess stock status.

The uncertainty in the description of life history characteristics throughout the range of Atlantic sturgeon combined with weakly informative relative abundance indices and indiscernible historic catches makes the application of traditional stock assessment methods unproductive for assessing the current status of Atlantic sturgeon. The DBSRA and sSRA models applied coast wide did provide context for historic population abundance. Changes in carrying capacity coast wide are unknown, though it is assumed freshwater habitat has declined in quality and/or quantity. The DBSRA provided better fits when carrying capacity was allowed to change after 1950. DBSRA estimated historic capacity coast wide at a median estimate of 27,988 mt with a two-stanza (pre- and post-1950) capacity model having a median estimate for the first period of 27,724 mt and 12,777 mt post-1950. The sSRA assessment produced a similar result for capacity as the single stanza DBSRA.

Effective population size (N_e) estimates for 7 of 10 spawning populations distributed among the DPSs are less than the suggested minimum ($N_e = 100$) required to limit the loss in total fitness resulting from in-breeding depression to less than 10%. All N_e estimates lie below the suggested minimum ($N_e > 1000$) required to maintain population evolutionary potential.

6. Biological Reference Points

Suitable biological reference points must be established for Atlantic sturgeon.

7. Fishing Mortality

No fishing mortality, other than bycatch, is assumed to occur since the moratorium. Fishing mortality estimates were produced in the sSRA and DBSRA assessment but are not reliable estimates given the nature of the assessment methods and data utilized. Bycatch and ship strike mortality are included in the Z estimates from acoustic tagging (see below).

8. Recruitment

Limited information is available to determine the abundance and/or trend in young-of-the-year (YOY <500mm) recruitment throughout the range of Atlantic sturgeon. Sampling programs intercepting appreciable numbers of YOY exist in the NY, NC, and SC units (i.e., NYDEC JASAMP, SC Edisto, NC p135). Juveniles (500-1300mm) are encountered in low numbers in non-directed sampling programs throughout the distribution with poor representation in the South Atlantic unit. Currently the data are insufficient to determine abundance and recruitment trend of YOY at the DPS level and provides only weak information of the trend in juveniles.

9. Spawning Stock Biomass

The spawning stock biomass (SSB) is undocumented for all river systems due to the lack of adult abundance indices.

10. Bycatch and Incidental Mortality

Information on bycatch comes from the Northeast Fisheries Observer Program (NEFOP) and the Northeast Fishery At-sea Monitoring (ASM) Program, North Carolina Gillnet Fisheries, South Carolina American Shad Gillnet Fishery, and nine federal or state-conducted surveys. Generalized Linear Models were used to expand bycatch estimates using the NEFOP/ASM observer coverage on commercial fishing boats from Maine to North Carolina since 1989 (ASM began in 2010) as well as the North Carolina Gillnet Fisheries onboard observers from the fall flounder fishery. The GLMs were used to expand bycatch and bycatch mortalities over the two fisheries. Estimates of bycatch related mortality are likely underestimated as all fishery-dependent sources were not considered, as noted in the assessment report. In addition, the estimates did not account for delayed mortality. There is concern that mortality due to ship strikes may be increasing and is poorly documented.

11. Other Comments

The Review Panel acknowledges the data available to assess Atlantic sturgeon make the determination of status a highly challenging task. The Panel commends the Atlantic sturgeon Stock Assessment Subcommittee for the exemplary work they have done to try to meet the assigned terms of reference. The Panel also appreciates the responsiveness of the committee to exploring additional assessment analyses requested by the Panel.

REFERENCES

Beardsall, J.W., McLean, M.F., Cooke, S.J., Wilson, B.C., Dadswell, M.J., Redden, A.M. and Stokesbury, M.J., 2013. Consequences of incidental otter trawl capture on survival and physiological condition of threatened Atlantic sturgeon. *Transactions of the American Fisheries Society*, *142*(5), pp.1202-1214.

Conn, P.B., 2009. Hierarchical analysis of multiple noisy abundance indices. *Canadian Journal of Fisheries and Aquatic Sciences*, *67*(1), pp.108-120.

Frankham, R., Bradshaw, C.J. and Brook, B.W., 2014. Genetics in conservation management: revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. *Biological Conservation*, *170*, pp.56-63.

Helser, T.E. and Hayes, D.B., 1995. Providing quantitative management advice from stock abundance indices based on research surveys. *Fishery Bulletin*, *93*(2), pp.290-298.

US Commission of Fish and Fisheries. 1884-1905. Reports of the Commissioner, 1882-1905.

Atlantic States Marine Fisheries Commission

Supplemental Report to the 2017 Atlantic Sturgeon Benchmark Stock Assessment

Prepared by the
Atlantic Sturgeon Stock Assessment Subcommittee and
Technical Committee

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1 OVERVIEW

This report serves as supplemental material to the Atlantic Sturgeon 2017 Benchmark Stock Assessment and the Terms of Reference and Advisory Report of the Atlantic Sturgeon Benchmark Stock Assessment Peer Review Reports (ASMFC 2017). During the Peer Review Workshop in August 2017, the Peer Review Panel (Review Panel) requested additional information and configurations of the analyses to support or revise portions of the stock assessment draft report for peer review. A description of the additional information, analysis, and conclusions follows, but refer to ASMFC 2017 for a more thorough discussion of the life history, habitat use, available data sources, analysis background, and stock status discussions for the Atlantic sturgeon.

2 METHODS AND RESULTS

2.1 Indices of Relative Abundance Standardization

The Review Panel requested additional information during the Review Workshop regarding the size frequency of Atlantic sturgeon encountered, annual number of deployments, annual number of positive deployments, and annual number of Atlantic sturgeon captured by each survey. After reviewing the supporting data from the surveys, the Review Panel recommended that the following be re-standardized using the binomial error structure for the generalized linear model (GLM) framework: Maine-New Hampshire Inshore Groundfish Trawl Survey (ME-NH Trawl), Connecticut Long Island Sound Trawl Survey (CT LIST), New Jersey Ocean Trawl Survey (NJ OT), Northeast Area Monitoring and Assessment Program Trawl Survey (NEAMAP), Virginia Institute of Marine Science Shad and River Herring Monitoring Survey (VIMS Shad), and the US Fish and Wildlife Cooperative Tagging Cruise (USFWS Coop). Index standardization for the New York State Department of Environmental Conservation's (NYDEC) Juvenile Atlantic Sturgeon Abundance Monitoring Program (JASAMP), North Carolina Program 135 (NC p135), and South Carolina Edisto Sturgeon Monitoring Program (SC Edisto) was unchanged from ASMFC 2017 and these surveys were used in the analyses in this report. A description of the revised indices with the binomial error structure follows. For a full description of surveys that were used in analyses, see Section 5 of ASMFC 2017.

2.1.1 Maine-New Hampshire Inshore Trawl Survey

An index of relative abundance was previously developed from a subset of regions, strata, and months as described in ASMFC 2017. A full model that predicted catch as a linear function of year, month, region, depth, and stratum was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial with year, region, and stratum and was used in ASMFC 2017. This survey had a low percentage of positive tows annually (Table 1) and the Review Panel suggested a binomial error structure be used during the GLM standardization. The covariates in the model with the lowest AIC was unchanged (Table 2) although the index of relative abundance developed did exhibit some differences in the beginning of the time series from the previous index (Figure 1 and Table 3). Both fall and spring seasons caught large juveniles, but adults were also present in the survey (Appendix R1 Figure 1).

2.1.2 Connecticut Long Island Sound Trawl Survey

Both a nominal and a GLM standardized index with a negative binomial error structure were explored for ASMFC 2017. Since the nominal index provided a longer time series (1984-2014) because environmental covariates were only collected from 1992-2014 and not continuously, the nominal index was the preferred index for ASMFC 2017. This survey had a low percentage of positive tows annually (Table 1) and the Review Panel suggested a binomial error structure. A full model that predicted catch as a function of year, temperature, salinity, depth, site number, latitude, longitude, and bottom type was compared with nested submodels using AIC. The model including year and depth with a negative binomial error structure was selected for ASMFC 2017 because it produced the lowest AIC out of the models tested. When standardized with a binomial error structure, the model including year, depth, and temperature was selected (Table 5). A comparison of the nominal, negative binomial, and binomial indices can be found in Figure 2 and Table 6. A few high points due to large tows in 1993, 1994, and 2006 were decreased by using the binomial error structure but otherwise the pattern was similar to the previous index. Based on the length frequency, both spring and fall seasons primarily caught juveniles (Appendix R1 Figure 2).

2.1.3 New Jersey Ocean Trawl Survey

A standardized index of relative abundance was developed from a subset of years (1990-2015), months (April, June, October, and January), and strata (mid-shore and inshore) for ASMFC 2017. A full model that predicted catch as a linear function of year, stratum, depth, cruise, bottom salinity, bottom temperature, and bottom dissolved oxygen was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial that included year, stratum, and bottom temperature and was used in ASMFC 2017. Due to the low proportion of positive tows (Table 7), the Review Panel suggested the use of the binomial error structure and the index was re-standardized for this report. When standardized with a binomial error structure, the model including year, stratum, depth, and bottom temperature was selected (Table 9). The binomial and negative binomial indices were very similar, with some decreased values in the early part of the time series and increased values in the late 2000s in the binomial index (Figure 3 and Table 8). On average this survey captured juveniles during the months used in the index, but adults were also captured (Appendix R1 Figure 4).

2.1.4 Northeast Area Monitoring and Assessment Program Trawl Survey

The fall portion of the NEAMAP survey was standardized using a GLM approach and negative binomial error structure for ASMFC 2017. The survey had a low proportion of positive tows (Table 7) and was re-standardized for this report using a binomial error structure. A full model that predicted catch as a function of year, dissolved oxygen, salinity, water temperature, air temperature, strata, wind speed, barometric pressure, and depth was compared with nested submodels using AIC. The model including year and water temperature with a negative binomial error structure was selected for ASMFC 2017 because it produced the lowest AIC out of the models tested. When standardized with a binomial error structure, the model including year, depth, dissolved oxygen, and water temperature was selected (Table 11). The revised index of abundance has peaks in 2008 and 2012 and low abundance in 2010 and 2013-2015

(Figure 4 and Table 12). The large peak in 2014 for the previous index that was developed was due to one large tow that year which was decreased by using the binomial. Both spring and fall seasons of the survey caught large juveniles on average, but adults were present in the sampling based on the length distribution (Appendix R1 Figure 5).

2.1.5 Virginia Institute of Marine Science Shad and River Herring Monitoring Survey

A standardized index of relative abundance of Atlantic sturgeon was developed from this survey using only the months of March and April. The survey had a low proportion of positive tows (Table 13) and was re-standardized for this report using a binomial error structure. A full model that predicted catch as a linear function of year, river, salinity, water temperature, and air temperature was compared with nested submodels using AIC. The model with a negative binomial error structure that included year, river, and water temperature was selected for ASMFC 2017 because it produced the lowest AIC out of the models tested. When standardized with a binomial error structure, the model including year, river, and water temperature was selected (Table 14). The relative abundance from the revised index is very similar to the previous index but the large peak in 2006 from one tow that caught several sturgeon was reduced and there was a slight decrease in abundance in the terminal year that was not present in the negative binomial model (Figure 5 and Table 13). The survey predominantly caught juveniles in all of the rivers sampled in the spring (Appendix R1 Figure 6).

2.1.6 US Fish and Wildlife Cooperative Tagging Cruise

A standardized index of relative abundance from this survey was developed for and used in ASMFC 2017. A full model that predicted catch as a linear function of year, depth, air temperature, water temperature, salinity (although not complete throughout the time series), and latitude and longitude was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial that included year and depth and was used in ASMFC 2017. After reviewing the low proportion of positive tows from this survey (Table 16), the Review Panel suggested that the survey be re-standardized using the GLM approach with a binomial error structure. Year and depth were still the significant covariates (Table 17) and while the revised index had a similar pattern as the previous index (Figure 6 and Table 18) there were some differences in magnitude in some index values in the early 1990s and mid to late 2000s. The survey caught juveniles on average, but there were adults captured as well (Appendix R1 Figure 9).

2.1.7 Summary of Indices

The SAS supported the recommendations of the Review Panel to use the binomial error structure for the surveys described in this section. Due to the small proportion of positive tows in these surveys, a presence-absence approach was likely more appropriate for these surveys. With time, if the surveys begin to more consistently capture Atlantic sturgeon on an annual basis, the SAS recommends re-exploring the error structure of the GLM models to find the most appropriate standardization during the next update or benchmark stock assessment process.

NYDEC JASAMP, NC p135, and SC Edisto indices were unchanged from ASMFC 2017 for this supplemental report. The revised indices for ME-NH Trawl, CT LIST, NJ OT, NEAMAP, VIMS Shad and River Herring Monitoring, and USFWS Coop were used in this supplemental report in analyses that follow.

2.2 Conn Method

For a detailed description of the Conn method, refer to Section 6.6 of ASFMC 2017. The coastwide Conn index was recalculated using the same methods but with revised indices as described in this supplemental report. In addition to the indices used in ASMFC 2017 (USFWS Coop, ME-NH Trawl, CT LIST, NJ Ocean Trawl, VIMS Shad and River Herring Monitoring, and NC p135), three additional indices were included in the Conn index: SC Edisto, NYDEC JASAMP, and NEAMAP. These surveys were not previously included in the Conn method due to their short time series (<15 years of data). The inclusion of these surveys was recommended by the Review Panel since these three surveys primarily capture juveniles and therefore <15 years of data may reflect juvenile abundance in those regions. Additionally, the Review Panel noted that two of these surveys – NYDEC JASAMP and SC Edisto – should be used because they specifically target Atlantic sturgeon. The inclusion of these surveys was discussed with the TC and SAS for their approval.

The hierarchical model developed from all the available abundance indices showed varying abundance with time (Figure 7). Using the revised abundance indices resulted in shorter time series and thus the revised Conn index was for 1990-2015, not 1984-2015 as previously presented. The overall pattern of the revised Conn index was similar to the Conn index calculated for ASMFC 2017 but using the revised indices appeared to smooth some of the higher and lower values.

2.3 Power Analysis

For a detailed description of the power analysis, refer to Section 6.4 of ASMFC 2017. The power analysis was replicated for this supplemental report to evaluate the revised abundance indices and associated standard errors. All fishery-independent surveys that were developed into abundance indices and used in the revised Conn index were tested in the power analysis.

Median CVs, or proportional standard error, ranged from 0.202–1.146 for the surveys analyzed and power values ranged from 0.89 to 0.98 (Table 19). In general, using the binomial error structure for standardizing select surveys did decrease the median CV associated with the abundance estimates, therefore increasing the power of the surveys.

2.4 Autoregressive Integrated Moving Average (ARIMA)

For a detailed description of the ARIMA analysis, refer to Section 6.9.2 of ASMFC 2017. Per the Review Panel's request, the ARIMA methods were replicated for each of the revised indices, as well as indices not used as part of ASMFC 2017. Unlike ASMFC 2017, ARIMAs on data subset to a common set of years were not re-run due to the very short length of some time series (e.g., 9 years; Table 21). An arithmetic average of the probabilities of all available indices within a given DPS were used to judge whether a DPS was credibly above the 25th percentile or index value from 1998 (or first year of survey; average probabilities from Table 21, by DPS, are reported in

Table 22). The significance of trends in each fitted index was evaluated by following the Mann-Kendall methods described in Section 6.3 of ASMFC 2017.

The original, revised, and new indices are provided in Figure 8 and Figure 9. Descriptive statistics from all model runs are provided in Table 20 and Table 21. When adjusted for multiple tests (Holm 1979; RCT 2017), residuals from all model fits were normally distributed (Table 20). Correlations among all indices are provided in Figure 11.

2.4.1 ARIMA Model Results

Overall, terminal year indices from all revised and new fitted indices were credibly above the 25th percentile of their respective time series, with the exception of NEAMAP (mean from Table 22), though the probability of NEAMAP being below the 25th percentile was 0.49. In ASMFC 2017, indices from the SA or combined New York Bight-Chesapeake Bay-Carolina DPSs were not used, but for all other DPSs the probability that a DPS was above the 25th percentile were all > 0.50 (Table 30 from ASMFC 2017).

The situation with respect to terminal year index values compared to the respective 1998 (or surrogate) index is more mixed. The Conn Index (coastwide index), Gulf of Maine (GOM), New York Bight (NYB), and Carolina DPSs are credibly above the respective 1998 (or start year of survey if survey starts after 1998) index values (mean from Table 22). The Chesapeake Bay (CB), South Atlantic (SA), and multi-DPS region (NEAMAP) are not credibly above the 1998 index values. In ASMFC 2017, indices from the SA or combined NYB-CB-Carolina DPSs were not used. The conclusions are unchanged from ASMFC 2017 for all DPSs, save GOM (where this DPS changed from not credibly above the reference year to credibly above the reference year; mean from Table 22); the SA and the combined NYB-CB-C DPSs were not used in ASMFC 2017.

In some cases the revised index model fit was very similar to the original index model fit (Figure 10). For example, the revised indices for the CT LIST spring trawl, NJ OT, VIMS Shad, and the Conn Index are all very strongly[1] correlated with the original indices (all Spearman correlation ≥ 0.74; most ≥ 0.93). In the remaining cases, the revised indices were either modestly correlated with the original index (e.g., USFWS Coop, Spearman correlation = 0.50) or uncorrelated with the original index (e.g., ME-NH Trawl, Spearman correlation = -0.02). Discussion below focuses on these remaining cases where trends and correlations between the original and revised indices are considerably different than those reported in ASMFC 2017.

2.4.1.1 Coastwide Index (Conn Index)

The revised fitted Conn index is very similar to the original Conn index (Figure 10) and trends are similar (Figure 8 and Figure 9). Not surprisingly, the Conn index is strongly positively correlated with most indices, though there are exceptions (Figure 11). One notable exception is

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[1] Consistent with ASMFC (2017), strong positive correlations were arbitrarily defined as ≥ +0.60; strong negative correlations were arbitrarily defined as ≤ -0.60.

the strong negative correlation with NEAMAP (Figure 11). There was a significant (α=0.05) strong negative trend in the fitted NEAMAP index, while there was a significant positive trend in the Conn index (Table 21). The Conn index is credibly above both the 25th percentile of the time series and the index value in 1998 (Table 21).

2.4.1.2 Maine-New Hampshire Inshore Groundfish Trawl Survey

The ME-NH Trawl revised index is not correlated with the original index (Figure 10), nor is it strongly correlated (positively or negatively) with any other index (Figure 11). This index tends to be weakly negatively correlated with most indices (Figure 11). The revised index oscillates with a downward, though not significant, trend (Figure 9). The terminal year of the revised index is credibly above the 25th percentile of the time series, as was the case with the original index. The terminal year of the revised index is credibly above the index value in 2000; this was not the case with the original index.

2.4.1.3 Connecticut Long Island Sound Trawl Survey (spring, fall and combined indices)

The revised fitted spring CT LIST index is strongly correlated with the original fitted index, though of considerably shorter duration (Figure 10). The fitted terminal year index is credibly above the 25th percentile of the time series, and not credibly above the 2000 index value.

The revised fitted fall CT LIST index is weakly negatively correlated with the original fitted index (Figure 10). The revised fitted terminal year index is credibly above both the 25th percentile of the time series and 2000 index value.

The revised combined (spring and fall) CT LIST index is strongly positively correlated with the CT LIST fall index, and so trends are very similar. However, the revised fitted index is weakly correlated with the original index, and of substantially shorter duration (Figure 8 and Figure 10). Of note, the revised fitted combined spring and fall index has a significant (α = 0.05) negative trend (Table 21). Nevertheless, the revised fitted index is credibly above both the 25th percentile of the time series and the 2000 index value.

2.4.1.4 New York State Department of Environmental Conservation's Juvenile Atlantic Sturgeon Abundance Monitoring Program

The NYDEC JASAMP fitted index started at its nadir in 2006, and has been, with one exception in 2013, increasing over its duration. This index has a significant (α = 0.05) positive trend and is credibly above both the 25th percentile of the time series and the 2006 index value.

2.4.1.5 South Carolina Edisto Sturgeon Monitoring Program

The fitted index started at its peak in 2004 and generally declined through 2011 before rising through 2014, and declining slightly in 2015 (Figure 8). The SC Edisto fitted index tended to be negatively correlated with Carolina DPS juvenile indices, but positively correlated with Carolina DPS young-of-year indices (Figure 11). In the NYB DPS, the SC Edisto fitted index tended to be positively correlated with fall indices and negatively correlated with spring indices (Figure 11). The fitted index in the terminal year is credibly above the 25th percentile of the time series, but not credibly above the 2004 index value (Table 21).

2.4.1.6 Northeast Area Monitoring and Assessment Program (NEAMAP)

The NEAMAP samples nearshore coastal waters from Rhode Island/Massachusetts to Cape Hatteras, North Carolina. The Review Panel encouraged use of this index for the assessment of trends in Atlantic sturgeon abundance.

The fitted index started in 2007, rose in 2008, and has been declining since. The downward trend in this index is significant ($\alpha = 0.05$; Table 21). The terminal year index is not credibly above either the 25th percentile of the time series or the 2007 index value (Table 21).The fitted index tended to be strongly negatively correlated with several coastal estuary surveys in the Carolina and NYB DPSs (Figure 11). The fitted index is strongly positively correlated with the combined spring and summer CT LIST, and marginally positively correlated with the NJ trawl survey (Figure 11).

2.5 Egg-per-Recruit Analysis

The Review Panel was concerned that the deterministic EPR analysis conducted for the benchmark stock assessment did not fully represent the scale of the uncertainty in Atlantic sturgeon biological data. Sensitivity analyses during the benchmark and at the review workshop only included point estimates of alternative inputs (e.g., growth curves, M, selectivity, etc.), rather than incorporating the uncertainty in those inputs.

The panel recommended a resampling approach to more fully explore the effects of data uncertainty on the $Z_{50\%EPR}$ estimates and to better characterize the uncertainty of that reference point.

For this analysis, a stochastic EPR model was developed in R. The underlying population model was the same as used in the benchmark; for a detailed description of model configuration, refer to Section 6.14.2 of the 2017 Atlantic Sturgeon Benchmark Assessment Report.

To calculate EPR for Atlantic sturgeon, a number of different inputs are required (Table 23). To carry through the uncertainty in these inputs, distributions of the parameters were developed and sets of parameters were drawn (Figure 12 and Figure 13). Von Bertalanffy growth parameters were sampled as sets from literature values with error, including ASMFC (2017) for females or pooled sex data (Table 24); L_∞ was converted to total length where necessary using the equation derived for the benchmark (ASMFC 2017). Length-weight parameters were drawn from lognormal distributions with the mean and standard deviation as estimated in ASMFC (2017). The age of 50% maturity was drawn from a Poisson distribution with a mean of 15, based on the curve presented in Kahnle and Hattala (2007). Distributions for fecundity parameters were based on van Eenannaam and Doroshov (1998); when the associated length-at-age for a given draw was too small (resulting in negative estimates of fecundity), Smith et al.'s (1982) parameters were used. Lorenzen's parameters to describe M as a function of weight were used to calculate natural mortality, which was then scaled to ensure a specific proportion of the population remained alive at Amax. This proportion was also drawn from a lognormal distribution with a mean of 0.015 (Hewitt and Hoenig, 2005). Bycatch selectivity was described as a double-logistic curve, with the age of 50% selection for the ascending limb drawn from a Poisson distribution with a mean of 3 and for the descending limb from a Poisson distribution with a mean of 25, based on the age-distribution of measured bycatch fish in ASMFC (2017). Ship strike selectivity was described as knife-edged with the age of first vulnerability being drawn from a Poisson distribution with a mean of 3 (following Brown and Murphy (2010)); 1 was added to this distribution to prevent the age of first vulnerability being 0.

Life history parameters were drawn independently, without regards to potential correlations between parameters (e.g., maximum age and L_∞). This likely a conservative approach which increases the range of parameter combinations examined and therefore widens the final distribution of $Z_{50\%EPR}$ values.

For each set of life history parameters, the estimate of $Z_{50\%EPR}$ for differing levels of bycatch and ship strike mortalities was calculated and a distribution of $Z_{50\%EPR}$ was created. The value of $Z_{50\%EPR}$ was reported as the N-weighted average Z over ages 4-21 to be most comparable to the estimate of Z from the tagging model.

The posterior distributions of Z estimates from the tagging model were compared to the median $Z_{50\%EPR}$ and the 80th and 90th percentiles to determine what the probability was that Z was above the $Z_{50\%EPR}$ threshold.

Separate analyses were not conducted for different DPSs, and instead uncertainty in life history trajectories due to DPS-level effects were incorporated into the distributions for the parameters, particularly in terms of maximum age, growth parameters, and fecundity parameters.

2.5.1 Egg-per-Recruit Model Results

The median estimate of $Z_{50\%EPR}$ was 0.123, with 95% confidence interval of 0.096 – 0.155 (Figure 14).

For the coast, only 7% of the tagging model estimates of Z were above the median $Z_{50\%EPR}$ estimate, indicating there is a very low probability that the coastwide meta-population is exceeding the Z threshold. The New York Bight, Chesapeake Bay, and South Atlantic DPSs had a less than 50% chance of being above the median $Z_{50\%EPR}$ threshold (34.6% for the New York Bight, 33.6% for the Chesapeake Bay, and 44.0% for the South Atlantic). The Gulf of Maine and Carolina DPSs had much higher probabilities of being above the median estimate of $Z_{50\%EPR}$ (75.4% for the Gulf of Maine and 78.2% for the Carolina DPS). The percent of posterior estimates of Z that are above the 50th, 80th, and 90th percentile of the $Z_{50\%EPR}$ distribution are shown in Table 25 and Figure 15 - Figure 20.

3 DISCUSSION AND STOCK STATUS DETERMINATION

For ASMFC 2017, quantitative stock status was determined via the probability that the terminal year of the indices for a given DPS was greater than the index values from the start of the moratorium in 1998 (as evaluated by the ARIMA analysis), and by comparing estimates of total mortality from the tagging model to estimates of $Z_{50\%EPR}$. However, the stock status evaluations were presented as simply “above” or “below” the reference points. The Review Panel recommended modifications to how some indices were calculated (discussed above) and to how the stock status was presented.

The Review Panel recommended that stock status be presented in a more quantitative manner. Mortality status was determined based on the probability of the mortality from the tagging model being greater than the estimates of $Z_{50\%EPR}$. For this supplemental report, the probability of being above or below a reference point and the associated statistical level of confidence (i.e., 80%) was specified (Table 26). The coastwide meta-population had a very low probability of exceeding the Z threshold, while at the DPS-level the probabilities were greater. New York Bight, Chesapeake Bay, and South Atlantic DPSs had a less than 50% chance of being above the 80th percentile of $Z_{50\%EPR}$ threshold, but the Gulf of Maine and the Carolina DPS had a greater than 70% chance of being above the 80th percentile of the Z threshold. These higher levels at the DPS reflect both low sample sizes – the greater the sample size, the lower the probability of being above the threshold, as the estimates become more precise – and potentially differences in mortality rates due to DPS-specific factors.

Biomass and abundance status for the coastwide population and each DPS relative to historical levels remains the same as ASMFC 2017 at depleted. Instead of assigning an “above” or “below” status to the regions relative to the start of the moratorium in 1998, the average probability that the terminal year of the indices in that region are greater than their 1998 values (or equivalent reference year) from the ARIMA was supplied. Based on the average probabilities, the results indicate that the conclusions of ASMFC 2017 are unchanged except for the Gulf of Maine DPS which improved from below to above the reference year using the revised index. While the South Atlantic DPS does have one survey in the region, the SAS did not base stock status on that survey due to concerns about survey design and the limited time series.

Given the limited data available to establish quantitative metrics to determine stock status, the SAS also considered more qualitative criteria such as the appearance of Atlantic sturgeon in rivers where they had not been documented in recent years, discovery of spawning adults in rivers they had not been documented before, and increases in anecdotal interactions such as reports of jumping Atlantic sturgeon by recreational angler and ship strikes. These qualitative metrics come with the caveat that these increases in documented Atlantic sturgeon abundance may in some cases be the result of increased research and attention, not a true increase in abundance. However, this kind of qualitative information is still important in describing the current status of Atlantic sturgeon. Please refer to the main assessment report (ASMFC 2017) for this supporting material as it is not discussed here.

4 REFERENCES

Armstrong, J.L. 1999. Movement, habitat selection, and growth of early-juvenile Atlantic sturgeon in Albemarle Sound, North Carolina. M.S. Thesis, North Carolina State University, Raleigh. 77 p.

Atlantic States Marine Fisheries Commission (ASMFC). 2013. Atlantic States Marine Fisheries Commission, 2013 Horseshoe Crab Stock Assessment Update. 68 pp.

Atlantic States Marine Fisheries Commission (ASMFC). 2017. Atlantic Sturgeon 2017 Benchmark Stock Assessment and the Terms of Reference and Advisory Report of the Atlantic Sturgeon Stock Assessment Peer Review Reports. Arlington, VA.

Atlantic Sturgeon Status Review Team (ASSRT). 2007. Status review of Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus). Report to the National Marine Fisheries Service, Northeast Regional Office, Gloucester, MA, pp 187.

Conn, P. B. 2010. Hierarchical analysis of multiple noisy abundance indices. Canadian Journal of Fisheries and Aquatic Sciences, 67(1): 108-120.

Dunton, K.J., A. Jordaan, D.H. Secor, C.M. Martinez, T. Kehler, K.A. Hattala, J.P. Van Eenennaam, M.T. Fisher, K.A. McKown, D.O. Conover, and M.G. Frisk. 2016. Age and growth of Atlantic sturgeon in the New York Bight. North American Journal of Fisheries Management 36(1):62-73.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6:65-70.

Johnson, J.H., J.E. McKenna Jr., D.S. Dropkin, and W.D. Andrews. 2005. A novel approach to fitting the von Bertalanffy relationship to a mixed stock of Atlantic sturgeon harvested off the New Jersey Coast. Northeastern Naturalist 12(2):195-202.

Nelson, G. A. 2017. fishmethods: Fishery Science Methods and Models in R. R package version 1.10-1. https://CRAN.R-project.org/package=fishmethods

R Core Team (RCT). 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Stevenson, J.T., and D.H. Secor. 1999. Age determination and growth of the Hudson River Atlantic sturgeon, *Acipenser oxyrinchus*. Fishery Bulletin 98(1):153-166.

Stewart, N.D. M.J. Dadswell, P. Leblanc, R.G. Bradford, C. Ceapa, and M.J.W. Stokesbury. 2015. Age and growth of Atlantic sturgeon from the Saint John River, New Brunswick, Canada North American Journal of Fisheries Management 35(2):364-371.

Van Eenennaam, J.P., and S.I. Doroshov. 1998. Effects of age and body size on gonadal development of Atlantic sturgeon. Journal of Fish Biology 53(3):624-637.

5 TABLES

Table 1. Number of positive, number of total, and percent positive tows annually for the ME-NH Trawl survey for 2000-2015.

Year	Number of positive tows	Total number of tows	% Positive
2000	1	29	3.4
2001	1	45	2.2
2002	3	66	4.5
2003	2	48	4.2
2004	1	58	1.7
2005	1	52	1.9
2006	2	66	3.0
2007	1	58	1.7
2008	2	54	3.7
2009	3	62	4.8
2010	1	60	1.7
2011	1	57	1.8
2012	2	49	4.1
2013	1	52	1.9
2014	1	54	1.9
2015	4	54	7.4

Table 2. Model selection results for the GLM standardized indices for the fall portion of the ME-NH Trawl survey.

Available Covariates	Model Selected	Error structure	AIC	% Deviance	Dispersion
Year, Month, Depth, Region, Stratum	Year, Region, Stratum	NB	310.5	38.28	1.05
	Year, Region, Stratum	Binomial	241.86	15.37	0.99

Table 3. Comparison between the GLM standardized indices and standard errors using a negative binomial and binomial error structure for the ME-NH Trawl survey.

	Negative Binomial		Binomial	
Year	**Index**	**SE**	**Index**	**SE**
2000	0.0375	0.0463	0.0175	0.0204
2001	0.0666	0.0654	0.0080	0.0096
2002	0.0452	0.0392	0.0231	0.0186
2003	0.0364	0.0370	0.0225	0.0204
2004	0.0061	0.0086	0.0081	0.0094
2005	0.0074	0.0107	0.0102	0.0119
2006	0.0329	0.0310	0.0178	0.0160
2007	0.0073	0.0102	0.0095	0.0109
2008	0.0243	0.0265	0.0224	0.0202
2009	0.0278	0.0273	0.0267	0.0214
2010	0.0112	0.0133	0.0080	0.0092
2011	0.0096	0.0121	0.0089	0.0102
2012	0.0240	0.0271	0.0205	0.0193
2013	0.0072	0.0102	0.0093	0.0109
2014	0.0295	0.0299	0.0098	0.0113
2015	0.0503	0.0475	0.0421	0.0318

Table 4. Number of positive, number of total, and percent positive tows annually for the fall portion of the CT LIST survey for 1992-2014. The survey did not operate in the fall of 2010.

Year	Number of positive tows	Total number of tows	% Positive
1992	5	80	6.3
1993	6	120	5.0
1994	3	120	2.5
1995	2	80	2.5
1996	1	80	1.3
1997	2	80	2.5
1998	1	80	1.3
1999	5	80	6.3
2000	3	80	3.8
2001	5	80	6.3
2002	4	80	5.0
2003	6	75	8.0
2004	2	80	2.5
2005	3	80	3.8
2006	2	40	5.0
2007	2	80	2.5
2008	2	40	5.0
2009	6	80	7.5
2010			
2011	2	80	2.5
2012	2	80	2.5
2013	1	80	1.3
2014	2	79	2.5

Table 5. Model selection results for the GLM standardized indices for the fall portion of the CT LIST survey.

Available Covariates	Model Selected	Error structure	AIC	% Deviance	Dispersion
Year, Bottom Temp, Bottom Salinity, Depth, Site Number, Lat, Long, Bottom Type	Year, Depth	NB	774.593	24.643	0.727
	Year, Temp, Depth	Binomial	530.133	6.476	0.945

Table 6. Comparison of the nominal abundance index and the GLM standardized indices and standard errors using a negative binomial and binomial error structure for the fall portion of the CT LIST data set.

Year	Negative Binomial		Nominal		Binomial	
	Index	SE	Index	SE	Index	SE
1992	0.1014	0.0568	0.2750	0.1940	0.0567	0.0232
1993	0.3516	0.2100	0.4750	0.3932	0.0429	0.0168
1994	0.2600	0.2031	0.4417	0.3851	0.0182	0.0106
1995	0.0158	0.0114	0.0375	0.0278	0.0274	0.0179
1996	0.0175	0.0251	0.0125	0.0125	0.0114	0.0119
1997	0.0296	0.0234	0.0375	0.0278	0.0211	0.0147
1998	0.0000	0.0000	0.0375	0.0375	0.0000	0.0000
1999	No environmental data		0.1500	0.0855	No environmental data	
2000	0.0335	0.0244	0.0375	0.0214	0.0328	0.0187
2001	0.1872	0.1063	0.1875	0.1039	0.0637	0.0284
2002	0.0851	0.0557	0.1000	0.0579	0.0463	0.0238
2003	0.1922	0.1399	0.3867	0.2959	0.0520	0.0235
2004	0.0797	0.0623	0.1000	0.0882	0.0194	0.0133
2005	0.0270	0.0152	0.0375	0.0214	0.0320	0.0173
2006	0.5631	0.5983	0.3225	0.2429	0.0546	0.0402
2007	0.0932	0.0642	0.1625	0.1145	0.0278	0.0185
2008	0.1013	0.0783	0.1250	0.0891	0.0338	0.0266
2009	0.1357	0.0732	0.2125	0.0969	0.0593	0.0225
2010	No fall data		No fall data		No fall data	
2011	0.0128	0.0095	0.0250	0.0176	0.0248	0.0160
2012	0.0307	0.0216	0.0375	0.0278	0.0243	0.0169
2013	0.0086	0.0092	0.0125	0.0125	0.0122	0.0125
2014	0.1578	0.1182	0.1646	0.1412	0.0246	0.0172

Table 7. Number of positive, number of total, and percent positive tows annually for the NJ OT survey for 1990-2015.

Year	Number of positive tows	Total number of tows	% Positive
1990	9	79	11.4
1991	7	89	7.9
1992	6	91	6.6
1993	2	86	2.3
1994	0	87	0.0
1995	2	87	2.3
1996	3	88	3.4
1997	3	88	3.4
1998	1	89	1.1
1999	6	87	6.9
2000	1	87	1.1
2001	3	87	3.4
2002	5	89	5.6
2003	10	89	11.2
2004	7	87	8.0
2005	10	87	11.5
2006	9	87	10.3
2007	12	87	13.8
2008	9	87	10.3
2009	7	87	8.0
2010	8	87	9.2
2011	3	85	3.5
2012	2	85	2.4
2013	7	84	8.3
2014	5	84	6.0
2015	9	83	10.8

Table 8. Model selection results for the GLM standardized indices for the NJ OT survey.

Available Covariates	Model Selected	Error structure	AIC	% Deviance	Dispersion
Year, Stratum, Depth, Bottom Salinity, Bottom DO, Cruise, Month, Bottom Temperature	Year, Stratum, Bottom Temp	NB	1365.9	35.42	0.87
	Year, Stratum, Depth, Bottom Temp	Binomial	979.4	16.31	0.90

Table 9. Comparison between the GLM standardized indices and standard errors using a negative binomial and binomial error structure for the NJ OT survey.

Year	Negative Binomial		Binomial	
	Index	SE	Index	SE
1990	1.8658	0.8904	0.1288	0.0534
1991	1.0721	0.5180	0.0895	0.0401
1992	0.9730	0.4775	0.0744	0.0355
1993	0.3850	0.2522	0.0265	0.0201
1994	0.0000	0.0000	0.0000	0.0000
1995	0.1628	0.1257	0.0212	0.0163
1996	0.2605	0.1822	0.0356	0.0229
1997	0.5043	0.2893	0.0317	0.0209
1998	0.0725	0.0785	0.0133	0.0138
1999	0.9752	0.4851	0.0820	0.0382
2000	0.0752	0.0785	0.0140	0.0144
2001	0.3680	0.2287	0.0465	0.0285
2002	0.3986	0.2316	0.0794	0.0382
2003	1.3698	0.6576	0.1692	0.0600
2004	1.0986	0.5530	0.1240	0.0515
2005	1.8252	0.8496	0.1884	0.0642
2006	1.5350	0.7161	0.1750	0.0614
2007	1.5662	0.7278	0.2309	0.0692
2008	1.3874	0.6605	0.1745	0.0611
2009	0.7775	0.4098	0.1387	0.0547
2010	0.9820	0.4996	0.1518	0.0569
2011	0.2641	0.1820	0.0571	0.0344
2012	0.1594	0.1271	0.0374	0.0273
2013	1.0456	0.5253	0.1346	0.0536
2014	0.6278	0.3549	0.0567	0.0332
2015	1.9230	0.8934	0.1616	0.0599

Table 10. Number of positive, number of total, and percent positive tows annually for the fall portion of the NEAMAP survey for 2007-2015.

Year	Number of positive tows	Total number of tows	% Positive
2007	2	122	1.6
2008	10	140	7.1
2009	10	142	7.0
2010	6	120	5.0
2011	7	134	5.2
2012	10	125	8.0
2013	4	138	2.9
2014	4	135	3.0
2015	5	112	4.5

Table 11. Model selection results for the GLM standardized indices for the fall portion of the NEAMAP survey.

Available Covariates	Model Selected	Error structure	AIC	% Deviance	Dispersion
Year, DO, Salinity, Water temp, Air temp, Strata, Windspeed, BaroPres, Depth	Year, Water Temp	NB	521.12	11.96616	1.159451
	Year, Depth, DO, Water Temp	Binomial	416.279	4.832445	0.9602982

Table 12. Comparison between the GLM standardized indices and standard errors using a negative binomial and binomial error structure for the fall portion of the NEAMAP survey.

Year	Negative Binomial		Binomial	
	Index	SE	Index	SE
2007	0.0332	0.0250	0.0448	0.0330
2008	0.0858	0.0296	0.0691	0.0194
2009	0.0681	0.0288	0.0488	0.0172
2010	0.1228	0.0737	0.0251	0.0127
2011	0.0536	0.0213	0.0577	0.0222
2012	0.0818	0.0342	0.0851	0.0354
2013	0.0231	0.0123	0.0168	0.0088
2014	0.3075	0.2750	0.0314	0.0149
2015	0.0276	0.0155	0.0202	0.0108

Table 13. Number of positive, number of total, and percent positive tows annually for the spring portion of the VIMS Shad and River Herring Monitoring survey for 1998-2015.

Year	Number of positive tows	Total number of tows	% Positive
1998	13	40	32.5
1999	10	47	21.3
2000	8	54	14.8
2001	2	49	4.1
2002	1	54	1.9
2003	3	54	5.6
2004	2	46	4.3
2005	9	50	18.0
2006	17	52	32.7
2007	16	54	29.6
2008	7	52	13.5
2009	4	52	7.7
2010	8	66	12.1
2011	4	46	8.7
2012	3	43	7.0
2013	10	54	18.5
2014	14	50	28.0
2015	5	21	23.8

Table 14. Model selection results for the GLM standardized indices for the spring portion of the VIMS Shad and River Herring Monitoring survey.

Available Covariates	Model Selected	Error structure	AIC	% Deviance	Dispersion
Year, River, Salinity, Water temp, Air temp	Year, River, Water Temp	NB	693.6300	44.4480	1.1835
	Year, River, Water Temp	Binomial	474.2500	28.3812	1.0614

Table 15. Comparison between the GLM standardized indices and standard errors using a negative binomial and binomial error structure for the spring portion of the VIMS Shad and River Herring Monitoring survey.

Year	Negative Binomial		Binomial	
	Index	SE	Index	SE
1998	1.4772	0.3995	0.8429	0.1644
1999	0.9316	0.4007	0.4715	0.1918
2000	1.1127	0.6786	0.7977	0.5414
2001	0.1390	0.1164	0.1449	0.1195
2002	0.0588	0.0425	0.0588	0.0425
2003	0.1515	0.0736	0.1589	0.0759
2004	0.1317	0.0982	0.1344	0.0843
2005	1.1565	0.3541	0.5179	0.1253
2006	1.7627	0.3469	0.6875	0.1139
2007	1.4030	0.3529	0.6443	0.1211
2008	0.4405	0.1951	0.3371	0.1123
2009	0.1774	0.0811	0.1837	0.0750
2010	0.1779	0.0623	0.1783	0.0609
2011	0.3497	0.1548	0.1767	0.0713
2012	0.1573	0.0840	0.1631	0.0777
2013	0.5419	0.1688	0.4607	0.1199
2014	0.9026	0.2012	0.6178	0.1324
2015	1.2113	0.5407	0.5676	0.1883

Table 16. Number of positive, number of total, and percent positive tows annually for the USFWS Coop survey for 1988-2010.

Year	Number of positive tows	Total number of tows	% Positive
1988	22	141	15.6
1989	2	174	1.1
1990	8	72	11.1
1991	3	161	1.9
1992	3	53	5.7
1993	0	55	0.0
1994	6	96	6.3
1995	0	57	0.0
1996	13	204	6.4
1997	5	131	3.8
1998	1	64	1.6
1999	2	146	1.4
2000	6	141	4.3
2001	4	161	2.5
2002	17	226	7.5
2003	8	227	3.5
2004	1	244	0.4
2005	1	141	0.7
2006	17	291	5.8
2007	10	184	5.4
2008	31	330	9.4
2009	22	206	10.7
2010	1	200	0.5

Table 17. Model selection results for the GLM standardized indices for the USFWS Coop survey.

Available Covariates	Model Selected	Error structure	AIC	% Deviance	Dispersion
Year, Depth, Water Temperature, Salinity	Year, Depth	NB	1194.3	16.36	1.02
	Year, Depth	Binomial	1299.22	15.37	1.04

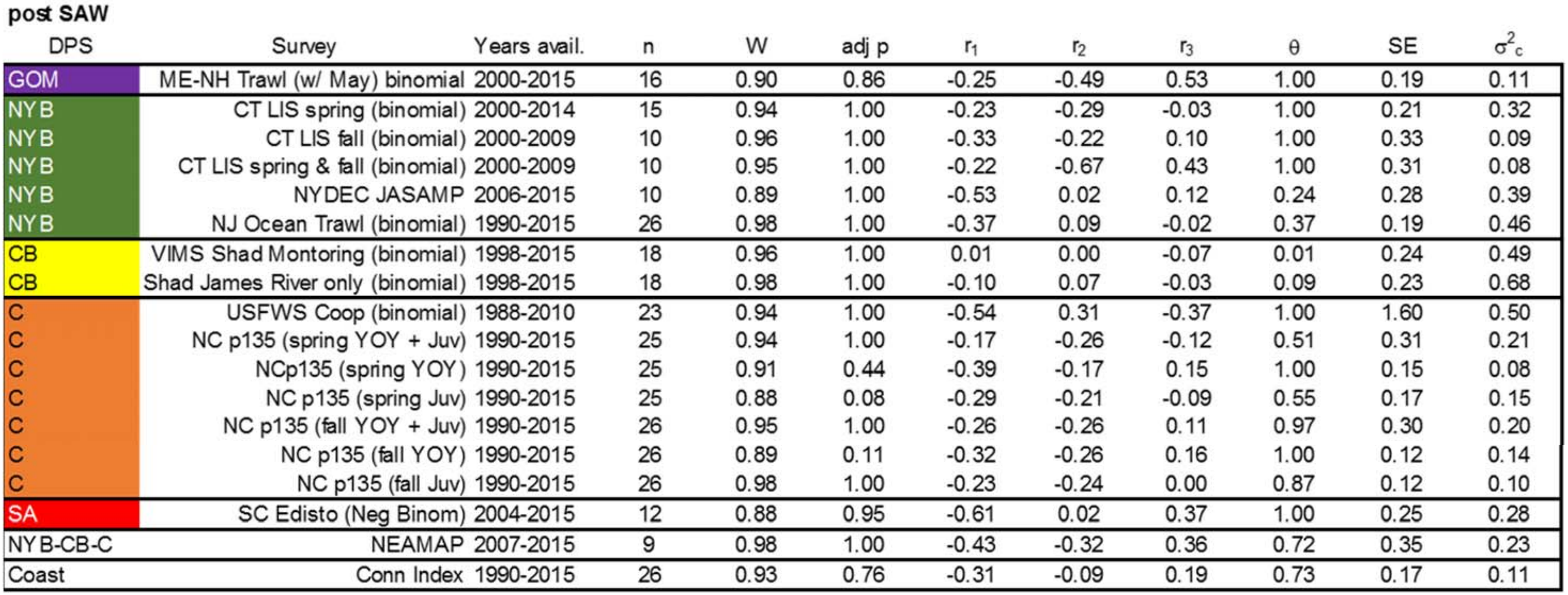
Table 18. Comparison between the GLM standardized indices and standard errors using a negative binomial and binomial error structure for the USFWS Coop survey.

	Negative Binomial		Binomial	
Year	Index	SE	Index	SE
1988	0.0659	0.0175	0.0649	0.0160
1989	0.0072	0.0051	0.0067	0.0048
1990	0.0365	0.0182	0.0339	0.0162
1991	0.0112	0.0067	0.0102	0.0060
1992	0.0116	0.0118	0.0318	0.0186
1993	0.0000	0.0000	0.0000	0.0000
1994	0.0160	0.0116	0.0423	0.0176
1995	0.0000	0.0000	0.0000	0.0000
1996	0.0542	0.0173	0.0629	0.0173
1997	0.0388	0.0179	0.0388	0.0171
1998	0.0173	0.0175	0.0172	0.0171
1999	0.0132	0.0094	0.0126	0.0089
2000	0.0285	0.0145	0.0413	0.0166
2001	0.0265	0.0135	0.0261	0.0129
2002	0.0526	0.0146	0.0554	0.0138
2003	0.0305	0.0127	0.0345	0.0129
2004	0.0043	0.0043	0.0042	0.0042
2005	0.0095	0.0095	0.0098	0.0097
2006	0.0823	0.0171	0.0485	0.0119
2007	0.0459	0.0169	0.0558	0.0175
2008	0.0521	0.0141	0.1021	0.0176
2009	0.0574	0.0159	0.0776	0.0173
2010	0.0062	0.0062	0.0063	0.0063

Table 19. Results of the power analysis by survey for linear and exponential trends in Atlantic sturgeon abundance indices over a twenty-year period. Power was calculated as the probability of detecting a 50% change.

Survey	Years	Season	Life Stage	Median CV	Linear Trend		Exponential Trend	
					+50%	-50%	+50%	-50%
ME-NH Trawl	2000-2015	Year-round	Juvenile & Adult	1.146	0.13	0.16	0.15	0.22
CT LIST	1992-2014	Fall	Juvenile	0.644	0.23	0.32	0.25	0.37
NYSDEC	2006-2015	Spring	Juvenile	0.204	0.89	0.98	0.89	0.98
NJ Ocean Trawl	1990-2015	Year-round	Juvenile & Adults	0.472	0.34	0.48	0.36	0.53
VIMS Shad Monitoring	1998-2015	Spring	Juvenile	0.372	0.47	0.65	0.49	0.68
NEAMAP	2007-2015	Fall	Adult	0.476	0.34	0.48	0.36	0.52
USFW Coop	1988-2010	Winter	Juvenile & Adult	0.478	0.34	0.47	0.36	0.52
NC p135	1990-2015	Fall	YOY & Juveniles	0.211	0.87	0.97	0.87	0.98
SC Edisto	2004-2015	May-Nov	Juvenile	0.202	0.89	0.98	0.90	0.98

Table 20. Summary statistics for ARIMA model results. N = number of years in time series, W = Shapiro-Wilk statistics for normality, adj p = Holm-adjusted probability of rejecting the null hypothesis regarding normality of model residuals, r1, r2, and r3 = the first three sample autocorrelations for the first differenced logged series, (θ) = moving average parameter, SE = standard error of theta, and σ^2 = variance of index. VIMS Shad Monitoring (binomial) = James, York, and Rappahannock rivers. SAW = Stock Assessment Review Workshop.



post SAW

DPS	Survey	Years avail.	n	W	adj p	r_1	r_2	r_3	θ	SE	σ^2_c
GOM	ME-NH Trawl (w/ May) binomial	2000-2015	16	0.90	0.86	-0.25	-0.49	0.53	1.00	0.19	0.11
NYB	CT LIS spring (binomial)	2000-2014	15	0.94	1.00	-0.23	-0.29	-0.03	1.00	0.21	0.32
NYB	CT LIS fall (binomial)	2000-2009	10	0.96	1.00	-0.33	-0.22	0.10	1.00	0.33	0.09
NYB	CT LIS spring & fall (binomial)	2000-2009	10	0.95	1.00	-0.22	-0.67	0.43	1.00	0.31	0.08
NYB	NYDEC JASAMP	2006-2015	10	0.89	1.00	-0.53	0.02	0.12	0.24	0.28	0.39
NYB	NJ Ocean Trawl (binomial)	1990-2015	26	0.98	1.00	-0.37	0.09	-0.02	0.37	0.19	0.46
CB	VIMS Shad Montoring (binomial)	1998-2015	18	0.96	1.00	0.01	0.00	-0.07	0.01	0.24	0.49
CB	Shad James River only (binomial)	1998-2015	18	0.98	1.00	-0.10	0.07	-0.03	0.09	0.23	0.68
C	USFWS Coop (binomial)	1988-2010	23	0.94	1.00	-0.54	0.31	-0.37	1.00	1.60	0.50
C	NC p135 (spring YOY + Juv)	1990-2015	25	0.94	1.00	-0.17	-0.26	-0.12	0.51	0.31	0.21
C	NCp135 (spring YOY)	1990-2015	25	0.91	0.44	-0.39	-0.17	0.15	1.00	0.15	0.08
C	NC p135 (spring Juv)	1990-2015	25	0.88	0.08	-0.29	-0.21	-0.09	0.55	0.17	0.15
C	NC p135 (fall YOY + Juv)	1990-2015	26	0.95	1.00	-0.26	-0.26	0.11	0.97	0.30	0.20
C	NC p135 (fall YOY)	1990-2015	26	0.89	0.11	-0.32	-0.26	0.16	1.00	0.12	0.14
C	NC p135 (fall Juv)	1990-2015	26	0.98	1.00	-0.23	-0.24	0.00	0.87	0.12	0.10
SA	SC Edisto (Neg Binom)	2004-2015	12	0.88	0.95	-0.61	0.02	0.37	1.00	0.25	0.28
NYB-CB-C	NEAMAP	2007-2015	9	0.98	1.00	-0.43	-0.32	0.36	0.72	0.35	0.23
Coast	Conn Index	1990-2015	26	0.93	0.76	-0.31	-0.09	0.19	0.73	0.17	0.11

Table 21. ARIMA and trend analysis results for Atlantic sturgeon indices of abundance. Shown are the probability that the terminal year of an index is greater than the 25th percentile of a time series and the probability that the terminal year of an index is greater than the index value in 1998 (or surrogate reference year; green shading indicates >50% probability); the Mann-Kendall tau (τ) statistics, the Holm-adjusted probability of the Mann-Kendall time series trend being significant, and whether the trend is increasing (+), decreasing (-), or not significant (n.s.). Terminal years other than 2015 and yrAsRefPoint other than 1998 are highlighted in yellow. Light grey font indicates a strong within-survey correlation (e.g., CT LIST spring and fall binomial index is strongly correlated with CT LIST fall binomial index). VIMS 3R = VIMS Shad Monitoring (binomial) = James, York, and Rappahannock rivers. SAW = Stock Assessment Review Workshop.

All years available (post SAW)

										Trend analysis results		
DPS	Survey	Months	Ages	P(terminal yr > 25th Pctl)	P(terminal yr > yrAsRefPt index)	n	First year	Terminal yr	yrAsRefPt	M-K τ	M-K p_adj	Trend
GOM	ME-NH Trawl (binomial)	5,10,11	Juvenile & Adult	0.61	0.51	16	2000	2015	2000	-0.12	1.0000	n.s.
NYB	CT LIS spring (binomial)	5-6	Juvenile	0.58	0.37	15	2000	2014	2000	-0.12	1.0000	n.s.
NYB	CT LIS fall (binomial)	9-11	Juvenile	0.65	0.66	10	2000	2009	2000	-0.24	1.0000	n.s.
NYB	CT LIS spring & fall (binomial)	5-6,9-11	Juvenile	0.66	0.60	10	2000	2009	2000	-0.81	0.0005	-
	NYDEC JASAMP	3, 4	YOY & Juvenile	1.00	1.00	10	2006	2015	2006	0.91	0.0045	+
NYB	NJ Ocean Trawl (binomial)	1, 4, 6, 10	Juvenile & Adult	0.95	0.96	26	1990	2015	1998	0.38	0.0717	n.s.
CB	VIMS 3 R	3-4	YOY & Juvenile	0.95	0.34	18	1998	2015	1998	-0.03	1.0000	n.s.
CB	VIMS James River only	3-4	YOY & Juvenile	0.96	0.36	18	1998	2015	1998	0.01	1.0000	n.s.
C	USFWS Coop (binomial)	1-2	Juvenile & Adult	0.53	0.43	23	1988	2010	1998	0.09	1.0000	n.s.
C	NCp135 (spring YOY + Juv)	Spring	YOY & Juvenile	1.00	0.98	25	1991	2015	1998	0.69	0.0000	+
C	NCp135 (spring YOY)	Spring	YOY	0.81	0.78	25	1991	2015	1998	0.35	0.1453	n.s.
C	NCp135 (spring Juv)	Spring	Juvenile	1.00	1.00	25	1991	2015	1998	0.88	0.0000	+
C	NCp135 (fall YOY + Juv)	Fall (11-2)	YOY & Juvenile	0.57	0.51	26	1990	2015	1998	0.50	0.0045	+
C	NCp135 (fall YOY)	Fall (11-2)	YOY	0.54	0.44	26	1990	2015	1998	-0.03	1.0000	n.s.
C	NCp135 (fall Juv)	Fall (11-2)	Juvenile	0.73	0.71	26	1990	2015	1998	0.61	0.0002	+
SA	SC Edisto (Neg Binom)	5-9	YOY, Juvenile, & Adult	0.51	0.28	12	2004	2015	2004	-0.36	0.9181	n.s.
NYB-CB-C	NEAMAP	9-11	YOY, Juvenile, & Adult	0.49	0.33	9	2007	2015	2007	-0.89	0.0135	-
Coast	Conn Index	Year round	YOY, Juvenile, & Adult	0.95	0.95	26	1990	2015	1998	0.74	0.0000	+

Table 22. Summary of tally and percentage of surveys, by DPS, where terminal year index is greater than the reference value , either the 25th percentile of a given time series or the index value in 1998 (or start year of survey, whichever is later) for a given index. Mean probabilities from ASMFC (2017) are provided in parentheses for comparative purposes.

Summary

	DPS	P(terminal year index > 25th Pctl)	P(terminal year index > 1998* index)
Tally	GOM	1 of 1	1 of 1
	NYB	4 of 4	3 of 4
	CB	1 of 1	0 of 1
	C	5 of 5	3 of 5
	SA	1 of 1	0 of 1
	NYB-CB-C	0 of 1	0 of 1
	Coast	1 of 1	1 of 1

	DPS	P(terminal year index > 25th Pctl)	P(terminal year index > 1998* index)
Pct	GOM	100%	100%
	NYB	100%	75%
	CB	100%	0%
	C	100%	60%
	SA	100%	0%
	NYB-CB-C	0%	0%
	Coast	100%	100%

	DPS	P(terminal year index > 25th Pctl)	P(terminal year index > 1998* index)
Mean	GOM	(0.73) 0.61	(0.28) 0.51
	NYB	(0.85) 0.80	(0.80) 0.75
	CB	(0.95) 0.96	(0.39) 0.36
	C	(0.76) 0.72	(0.72) 0.67
	SA	(NA) 0.51	(NA) 0.28
	NYB-CB-C	(NA) 0.49	(NA) 0.33)
	Coast	(0.62) 0.95	(0.55) 0.95

* If survey started after 1998, then 1st year of survey
See report for first and last years of each survey

Table 23. Life history parameters and relationships necessary to calculate $Z_{50\%EPR}$.

Input	Formula	Parameters
Maximum age	A_{max}	A_{max}
Length-at-age	$L_a = L_\infty\ (1-e^{-(K(a-t0))})$	L_∞, K, t_0
Length-weight relationship	$W_L = \alpha \cdot L^\beta$	α, β
Natural mortality at age	$M_a = M_u \cdot W_a^b$	M_u, b, proportion left alive at A_{max}
Maturity at age	$pMature_a = \dfrac{1}{1+e^{-(a-a50)/b}}$	a_{50}, b
Fecundity at age	$Fecundity_a = \alpha + \beta \cdot L_a$	α, β
Bycatch selectivity	$selectivity_a = \left(\dfrac{1}{1+e^{-(a-\alpha 1)/b1}}\right) \cdot \left(1-\dfrac{1}{1+e^{-(a-a2)/b2}}\right)$	$a1_{50}$, $a2_{50}$, b1, b2
Ship strike selectivity	$selectivity_a = 0$ when $a < A_{sel}$ and 1 when $a \geq A_{sel}$	A_{sel}

Table 24. Literature von Bertalanffy parameters sampled for stochastic EPR analysis.

Source	Location	Sex	Length Type	Linf	K	t0
Stevenson and Secor (2000)	Hudson River & New York Bight (NY)	female	Total	256	0.07	-3.23
Johnson et al. (2005)	Atlantic Ocean (NJ coast)	female	Total (converted)	225	0.12	0.00
Dunton et al. (2016)	Atlantic Ocean, Hudson River (NY), Delaware River and Bay (DE)	pooled	Total	279	0.06	-1.28
Stewart et al. (2015)	Saint John River (Canada)	female	Total	264	0.04	-0.94
Armstrong (1999)	Albemarle Sound (NC)	pooled	Total (converted)	304	0.09	-0.15
ASMFC 2017	Coast	pooled	Total	286	0.06	-0.34
ASMFC 2017	NYB	pooled	Total	299	0.05	-1.82
ASMFC 2017	CAR	pooled	Total	181.9	0.17	-0.76

Table 25. Estimates of Z from tagging model relative to $Z_{50\%EPR}$ at the coastwide and DPS-level. Estimates of Z are the median of the posterior distribution for all tagged fish from each region/DPS, and $Z_{50\%EPR}$ values are N-weighted values for ages 4-21. (Revised Table 49 from ASMFC 2017)

Region	**Z (95% credible interval)**	**$Z_{50\%EPR}$ (95% CIs)**	**$P(Z)>Z_{50\%EPR}$ 50%**	**$P(Z)>Z_{50\%EPR}$ 80%**	**$P(Z)>Z_{50\%EPR}$ 90%**
Coast	0.03 (0.003 - 0.33)	0.12 (0.10 – 0.15)	7.2%	6.5%	6.1%
Gulf of Maine	0.31 (0.01 - 2.07)		75.4%	73.5%	72.5%
New York Bight	0.08 (0.004 - 0.53)		34.6%	31.2%	29.4%
Chesapeake Bay	0.08 (0.01 - 0.46)		33.6%	30.0%	28.0%
Carolina	0.26 (0.01 - 1.25)		78.2%	75.4%	73.9%
South Atlantic	0.10 (0.01 - 0.76)		43.9%	40.2%	38.1%

Table 26. Stock status determination for the coastwide stock and DPSs based on mortality estimates and biomass/abundance status relative to historic levels, and the terminal year of indices relative to the start of the moratorium as determined by the ARIMA analysis. Refer to ASMFC 2017 section 7.2 for a more thorough discussion of stock status in each DPS which includes this quantitative evaluation as well as some qualitative evidence (Revised Table 50 from ASMFC 2017).

	Mortality Status	**Biomass/Abundance Status**	
Population	**$P(Z)>Z_{50\%EPR}$ 80%**	**Relative to Historical Levels**	**Average probability of terminal year of indices > 1998 value***
Coastwide	7%	Depleted	95%
Gulf of Maine	74%	Depleted	51%
New York Bight	31%	Depleted	75%
Chesapeake Bay	30%	Depleted	36%
Carolina	75%	Depleted	67%
South Atlantic	40%	Depleted	Unknown (no suitable indices)

*: For indices that started after 1998, the probability included in the average is the probability that the index in the terminal year is greater than the start year of the index.

6 FIGURES

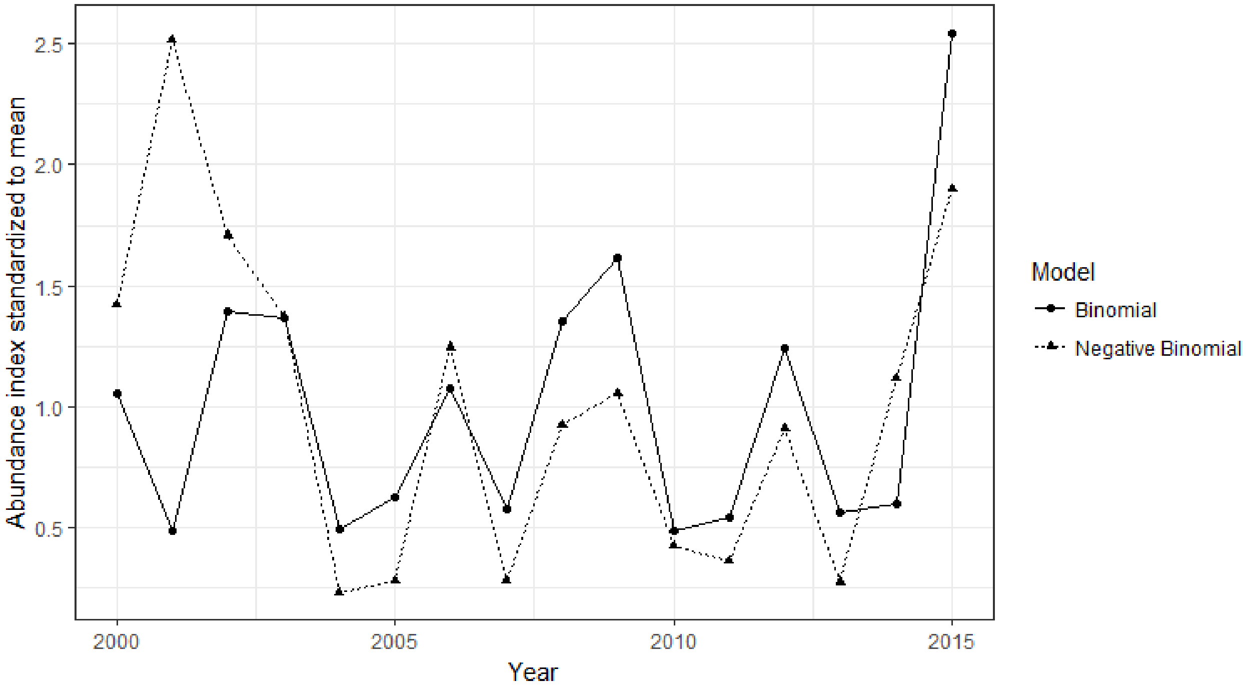


Figure 1. Comparison between the GLM standardized indices using the negative binomial and binomial error structure for the ME-NH Trawl survey for 2000-2015.

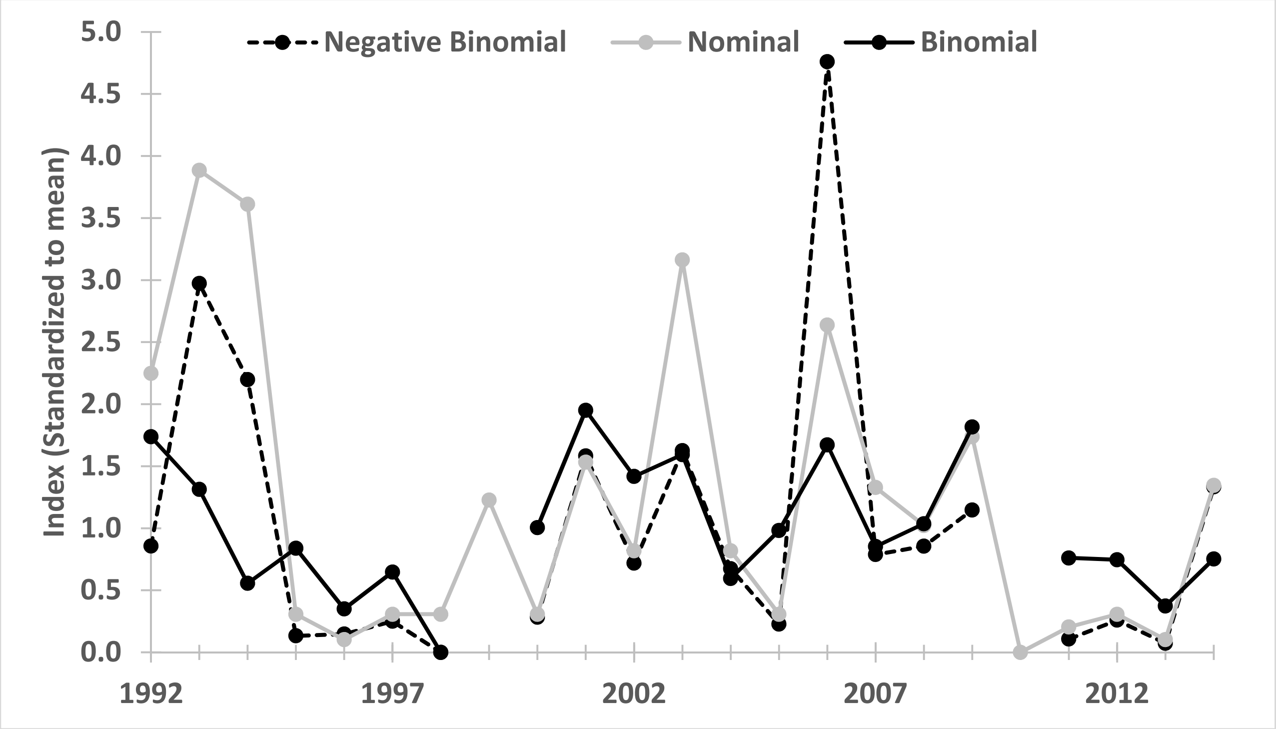


Figure 2. Comparison of the nominal abundance index and the GLM standardized indices using the negative binomial and binomial error structure for the fall portion of the CT LIST survey for 1992-2014.

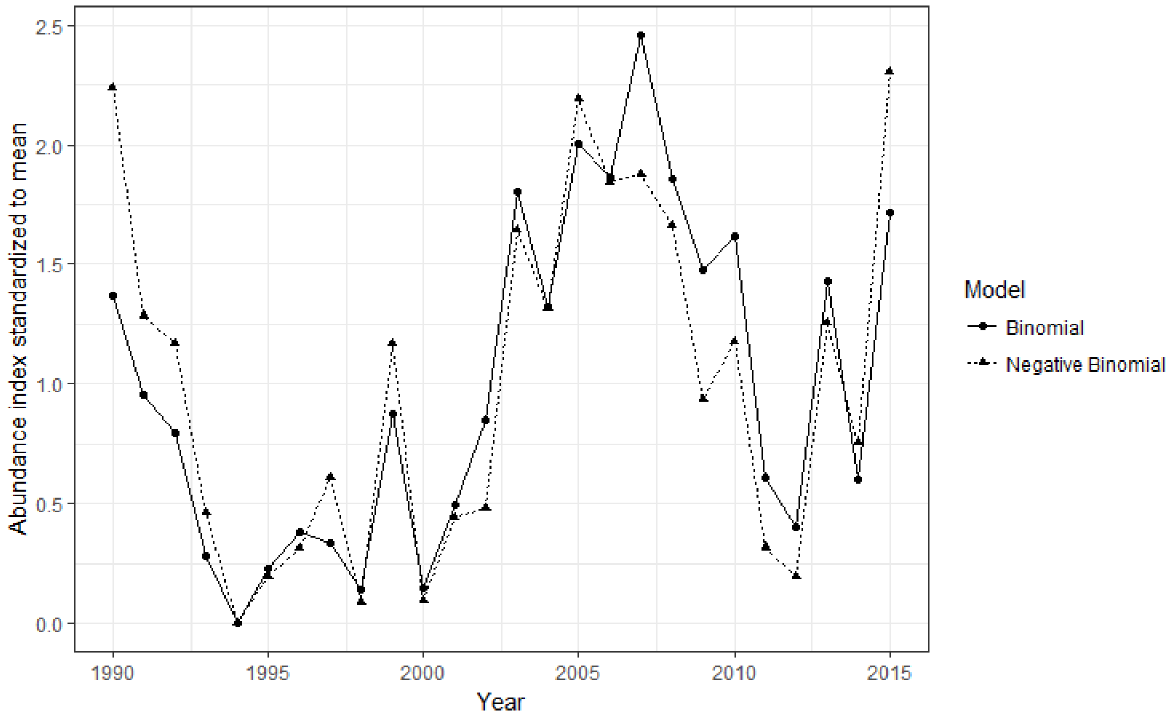


Figure 3. Comparison between the GLM standardized indices using the negative binomial and binomial error structure for the NJ OT survey for 1990-2015.

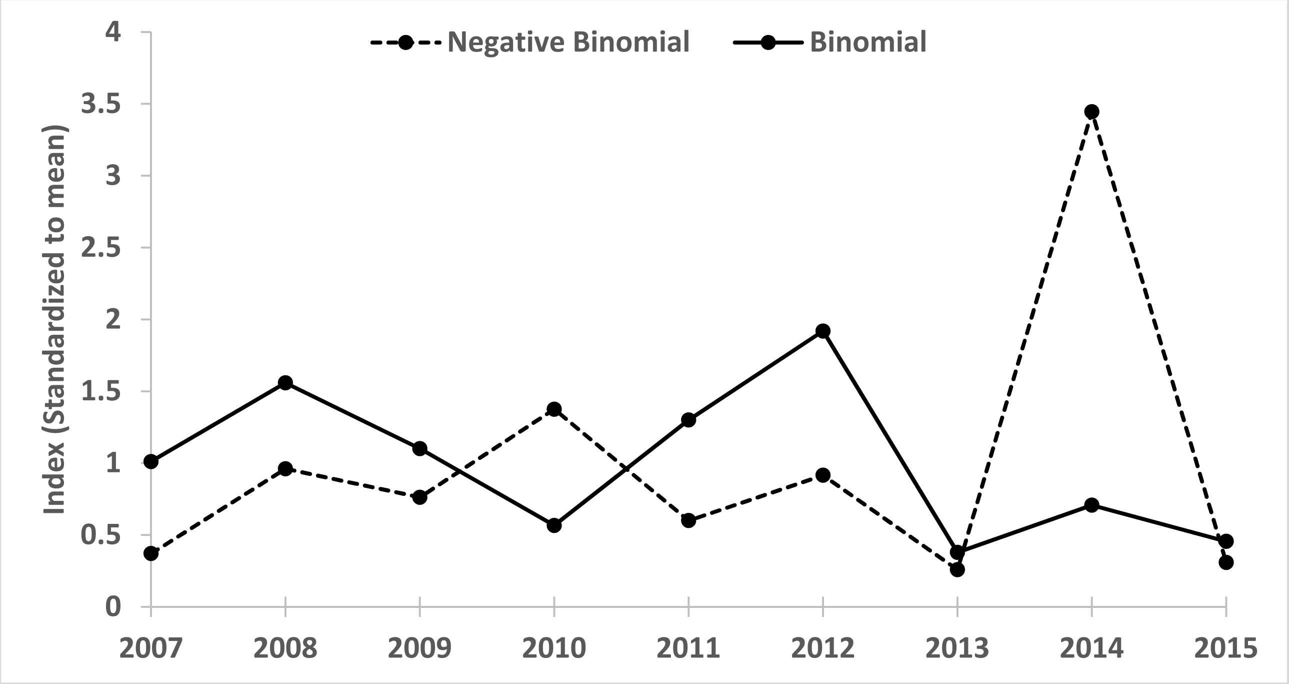


Figure 4. Comparison between the GLM standardized indices using the negative binomial and binomial error structure for the fall portion of the NEAMAP survey for 2004-2015.

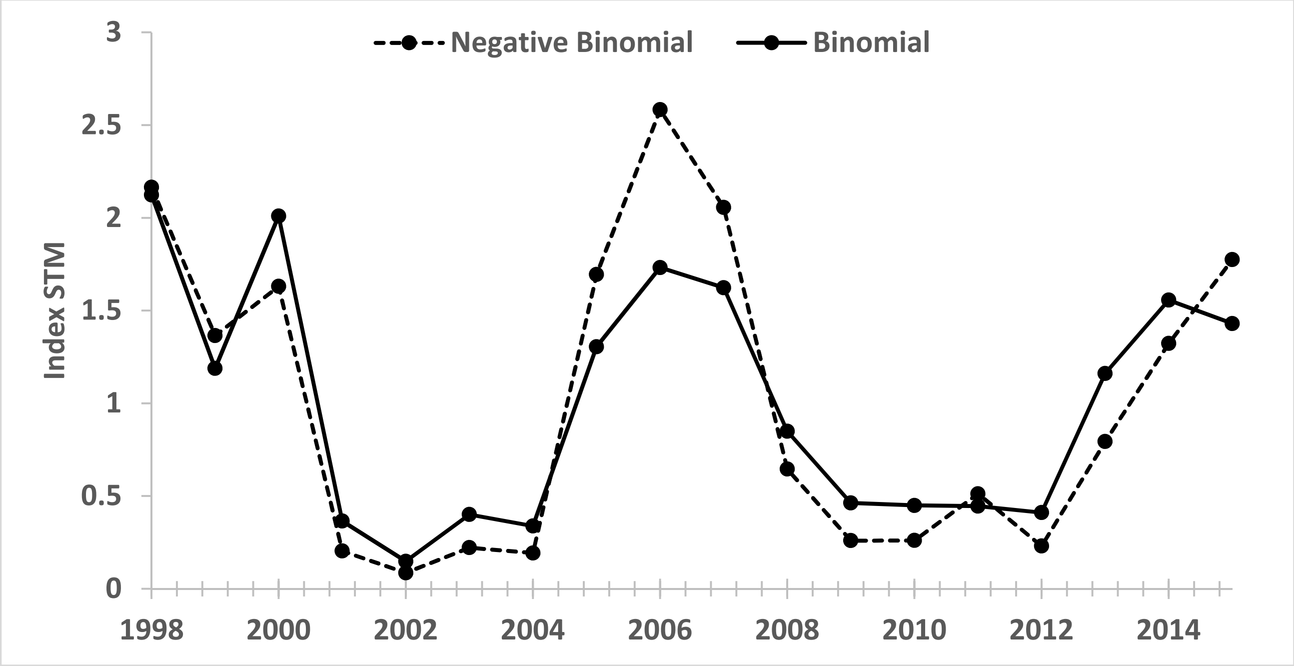


Figure 5. Comparison between the GLM standardized indices using the negative binomial and binomial error structure for the spring portion of the VIMS Shad and River Herring Monitoring survey for 1998-2015.

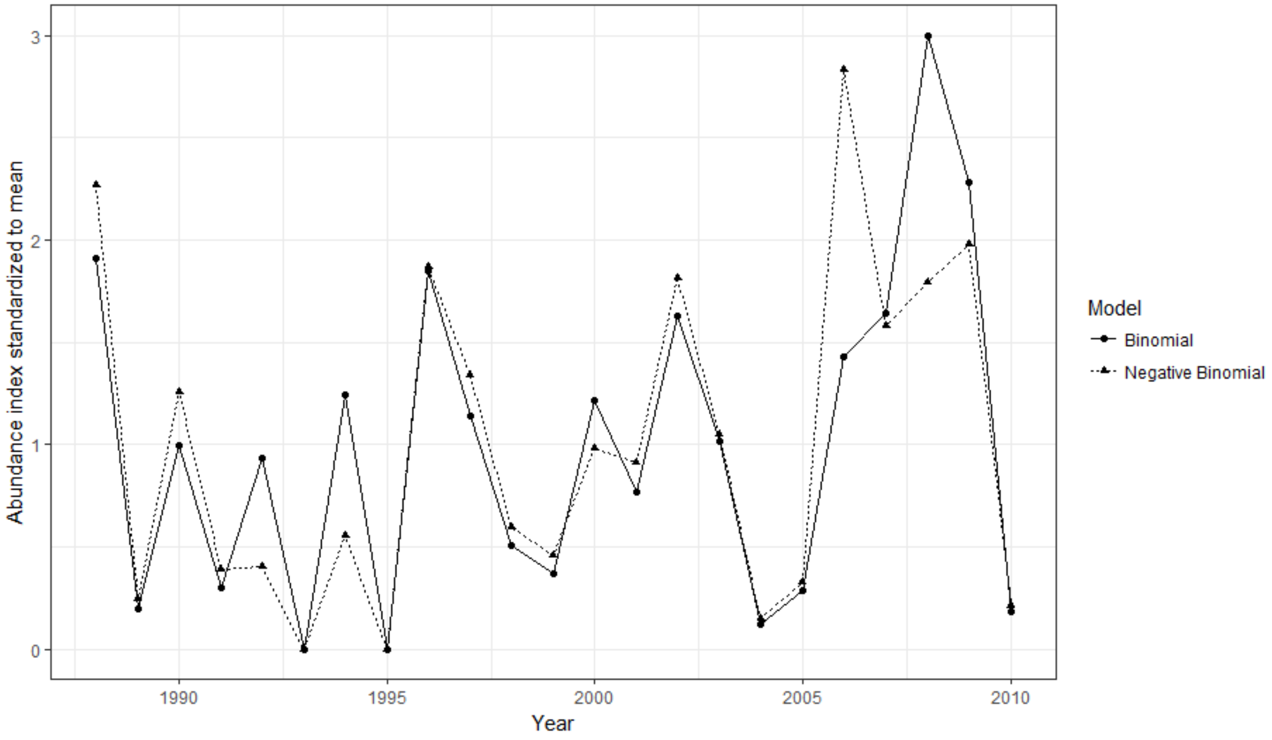


Figure 6. Comparison between the GLM standardized indices using the negative binomial and binomial error structure for the USFWS Coop survey for 1988-2010.

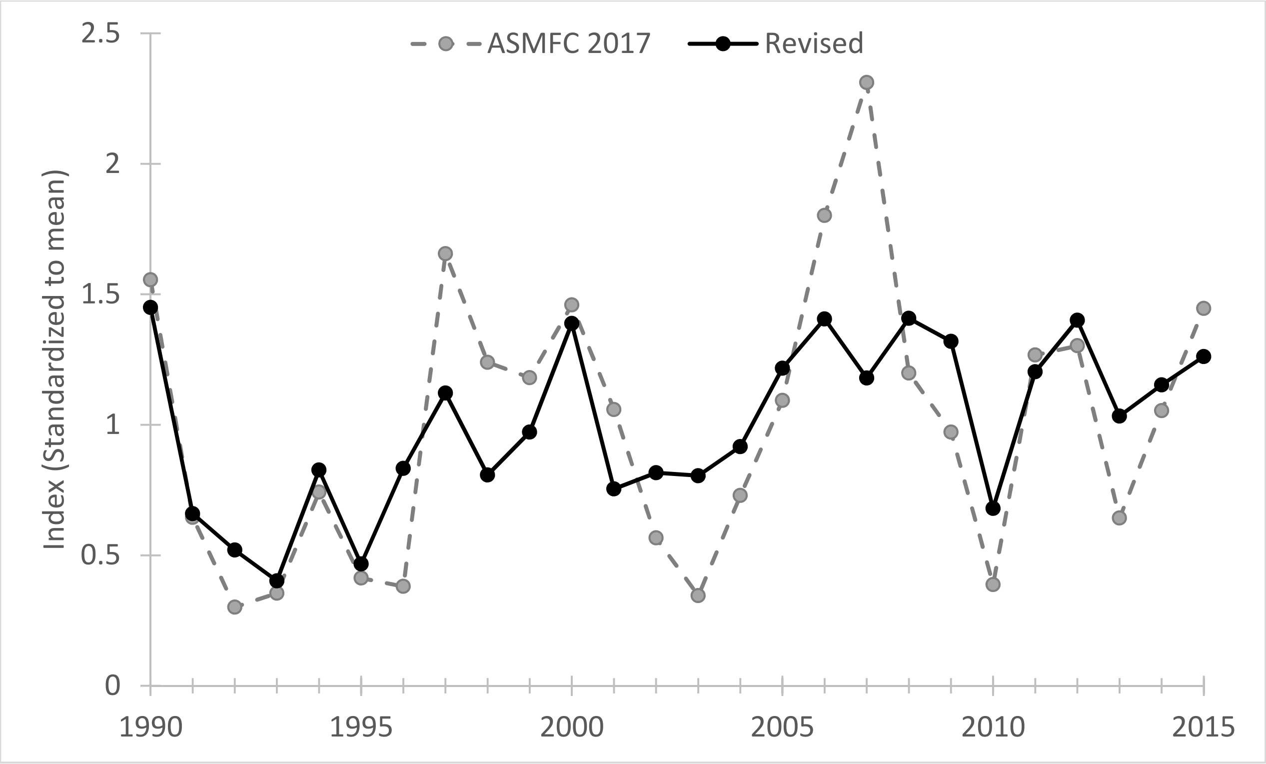


Figure 7. Time series of coastwide Atlantic sturgeon relative abundance as estimated from Conn (2010) hierarchical analysis using the revised indices for this supplemental report. The previous Conn index calculated for ASMFC 2017 is also shown for comparison.

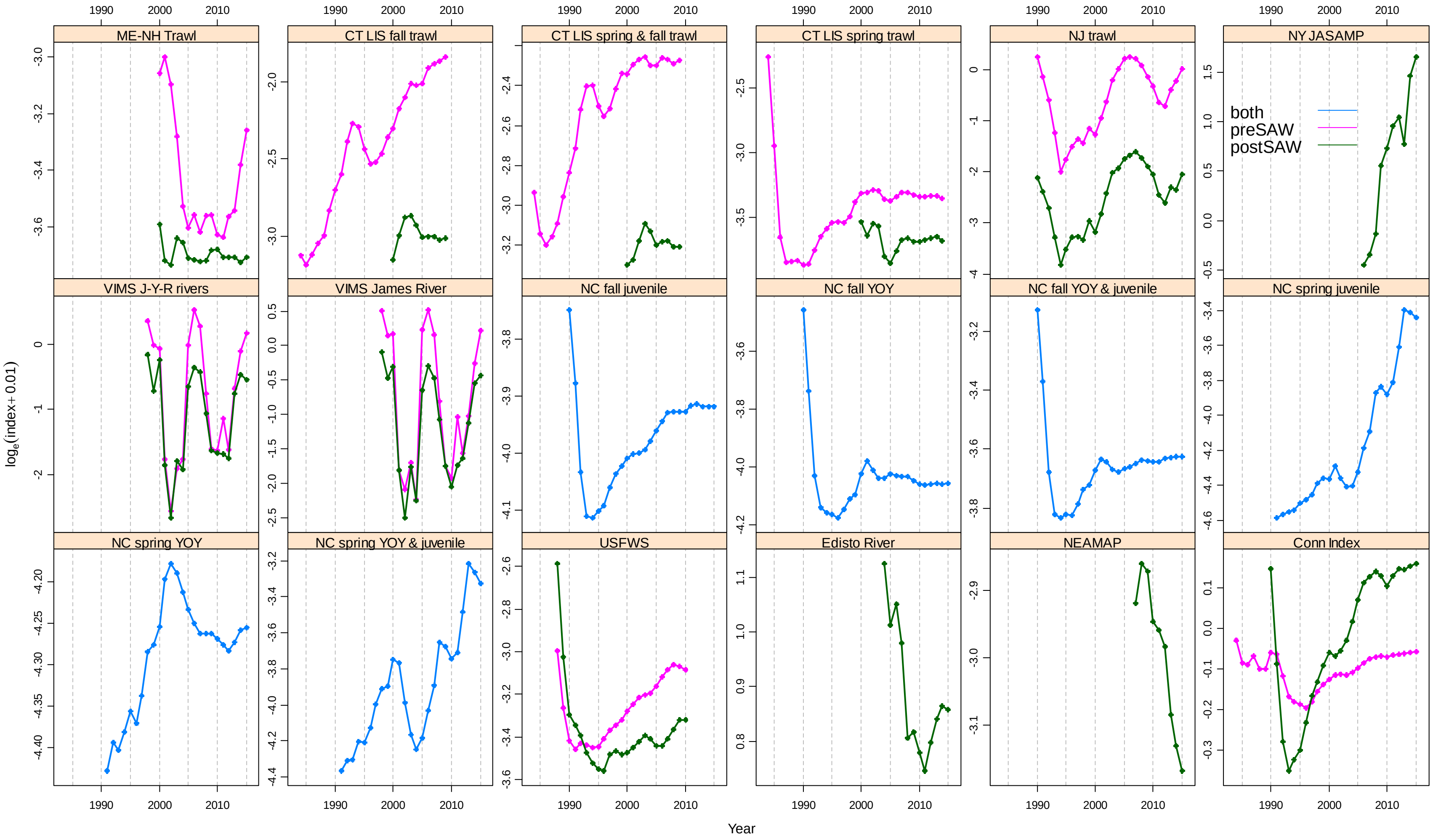


Figure 8. ARIMA fitted indices, pre- and post-SAW indices plotted together. Note that y-axes differ among plots (all share a common x-axis). preSAW = index used prior to August 2017 stock assessment review workshop (SAW); postSAW = index as used after August 2017 SAW. Both = no change in index after SAW.

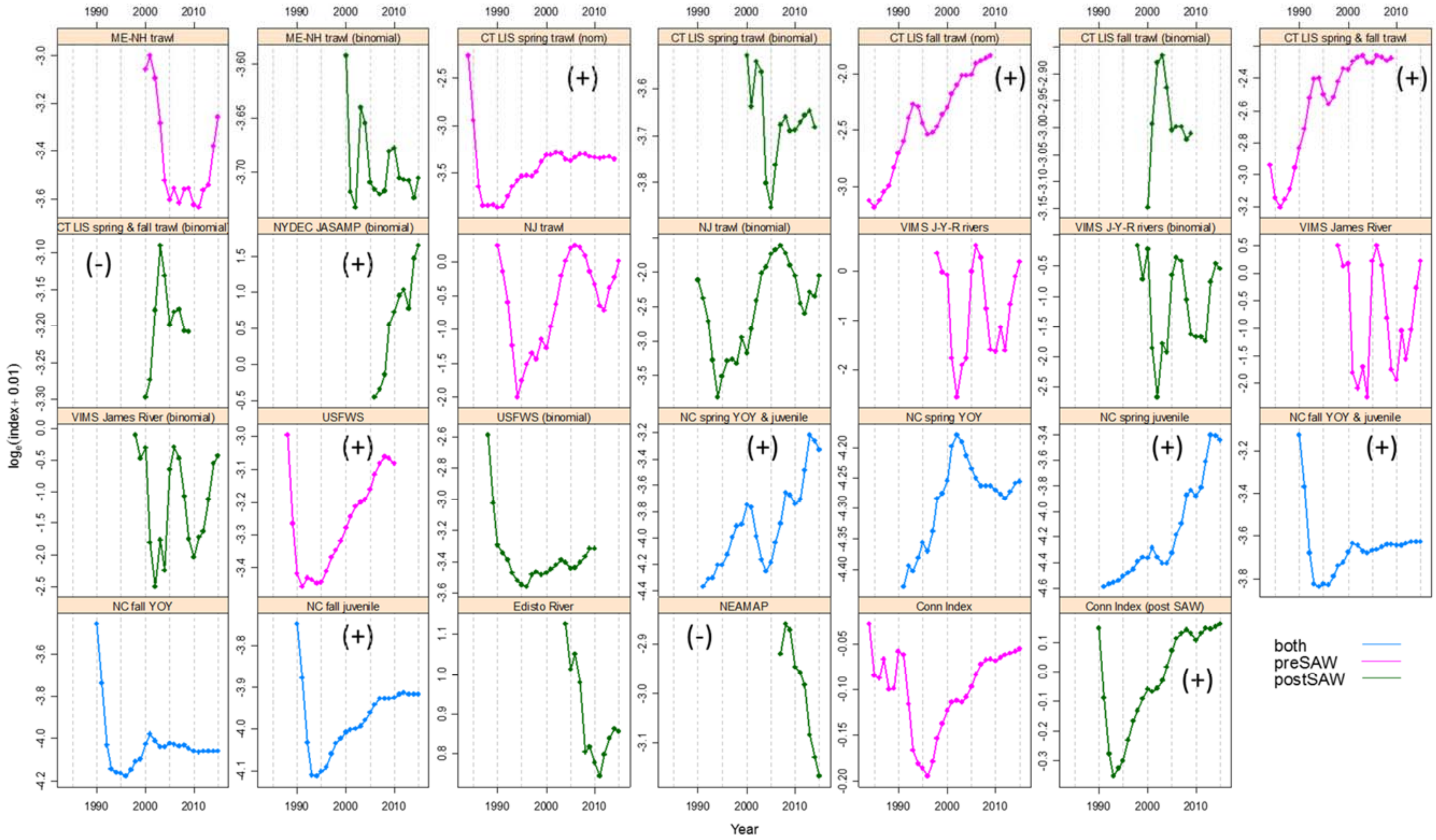


Figure 9. ARIMA fitted indices, pre- and post-SAW indices plotted separately. Note that y-axes differ among plots (all share a common x-axis). Plus/minus signs have been added to indices with significant increasing or decreasing trends (alpha = 0.05, Mann-Kendall test), respectively. preSAW = index used prior to August 2017 stock assessment review workshop (SAW); postSAW = index as used after August 2017 SAW. Both = no change in index after SAW.

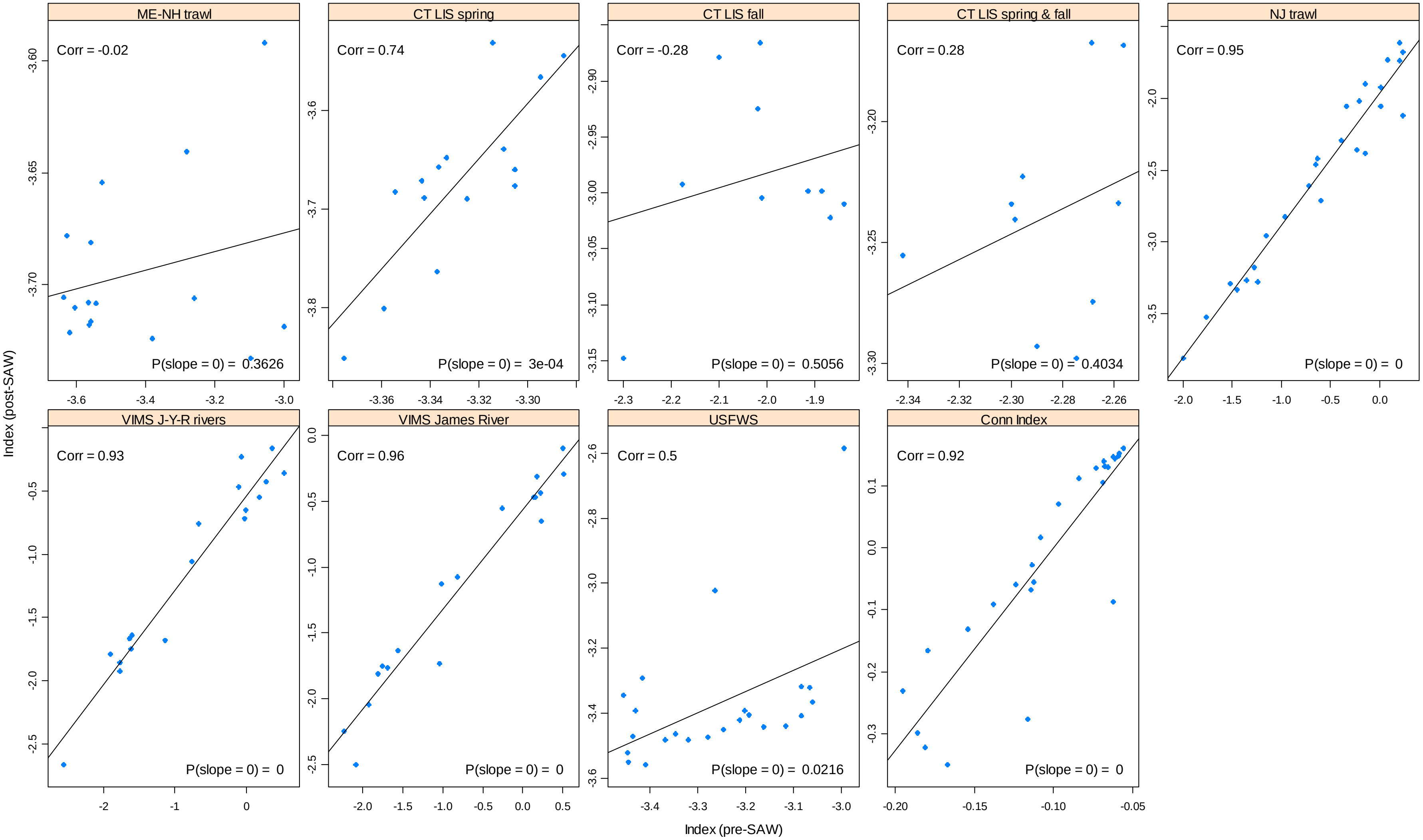


Figure 10. Scatter plots of indices revised after August 2017 stock assessment review workshop. Spearman rank correlation is provided in upper left of each scatterplot; Pr(least squares regression slope = 0) is provided at bottom right; linear regression line is fit through scatterplot.

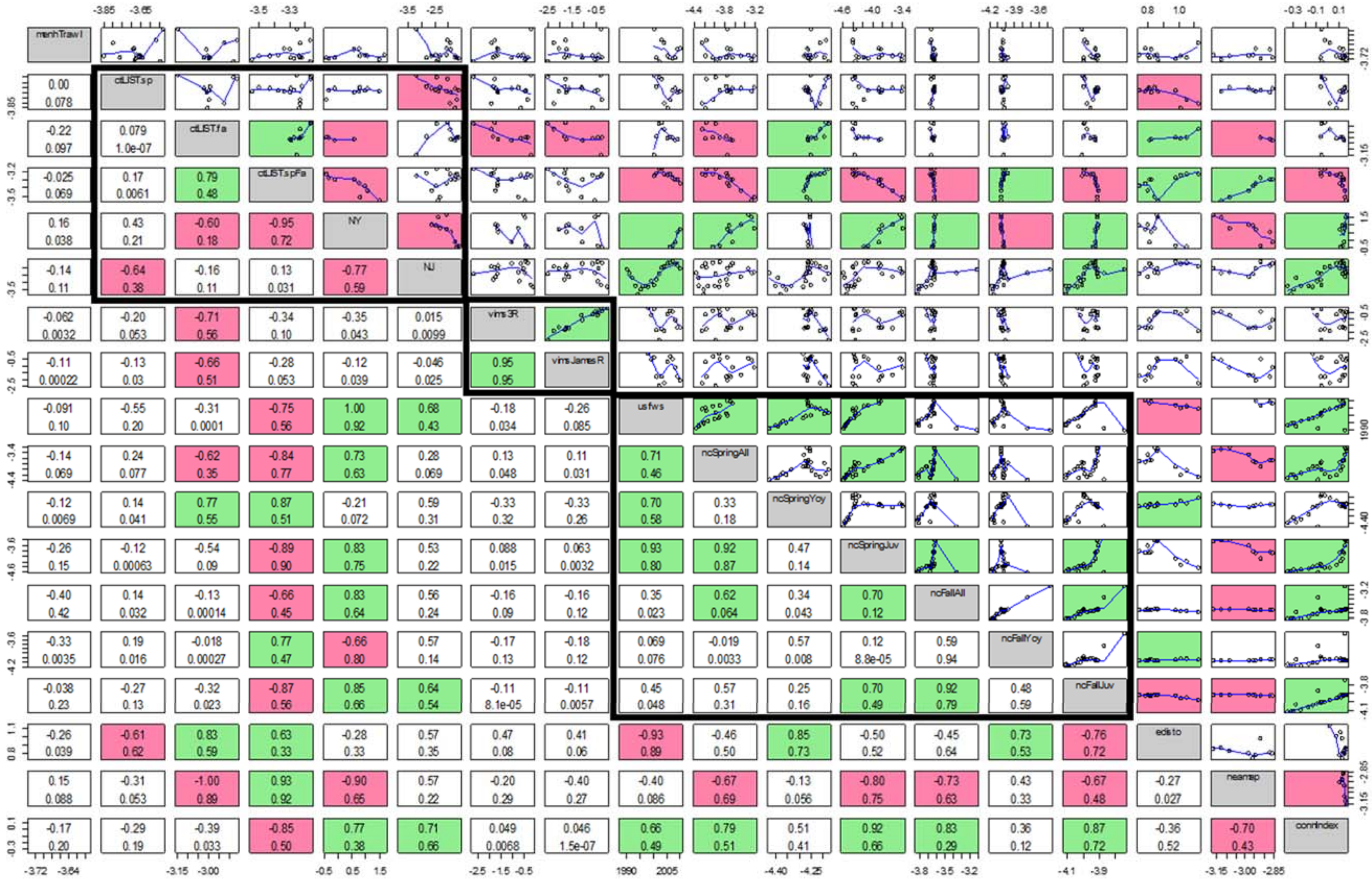


Figure 11. Correlation matrix of surveys. Spearman correlations (top) and coefficients of determination (r^2; bottom) below diagonal, notable correlations (>=0.60 or <=-0.60) are indicated in green or red, respectively. Lowess smoother added to scatterplots above diagonal. Abbreviated index names are along the diagonal. Black boxes drawn around surveys within DPSs (save ME-NH Trawl, Edisto, NEAMAP, Conn index, where each are in their own DPS).

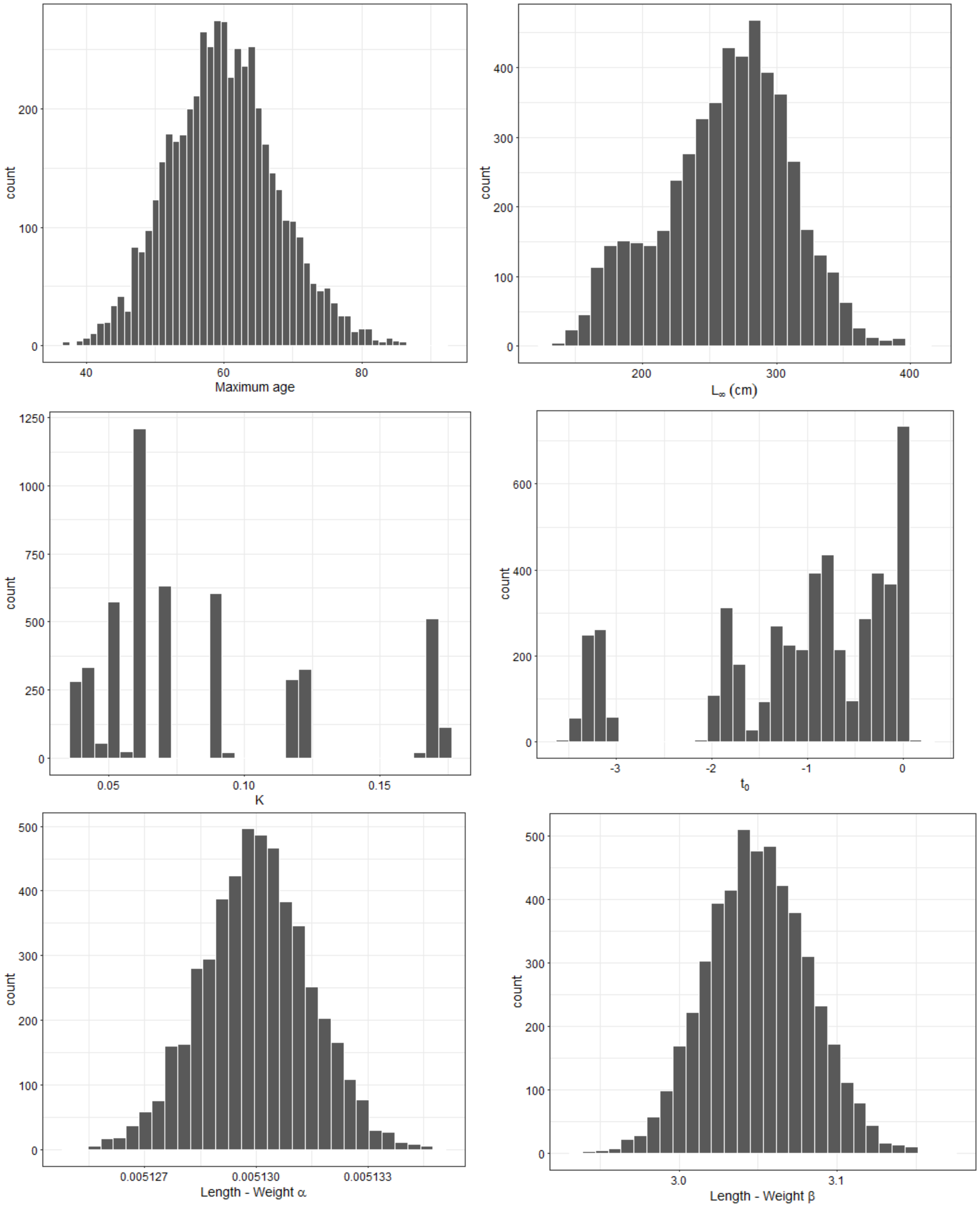


Figure 12. Histograms of drawn life history parameters for stochastic EPR.

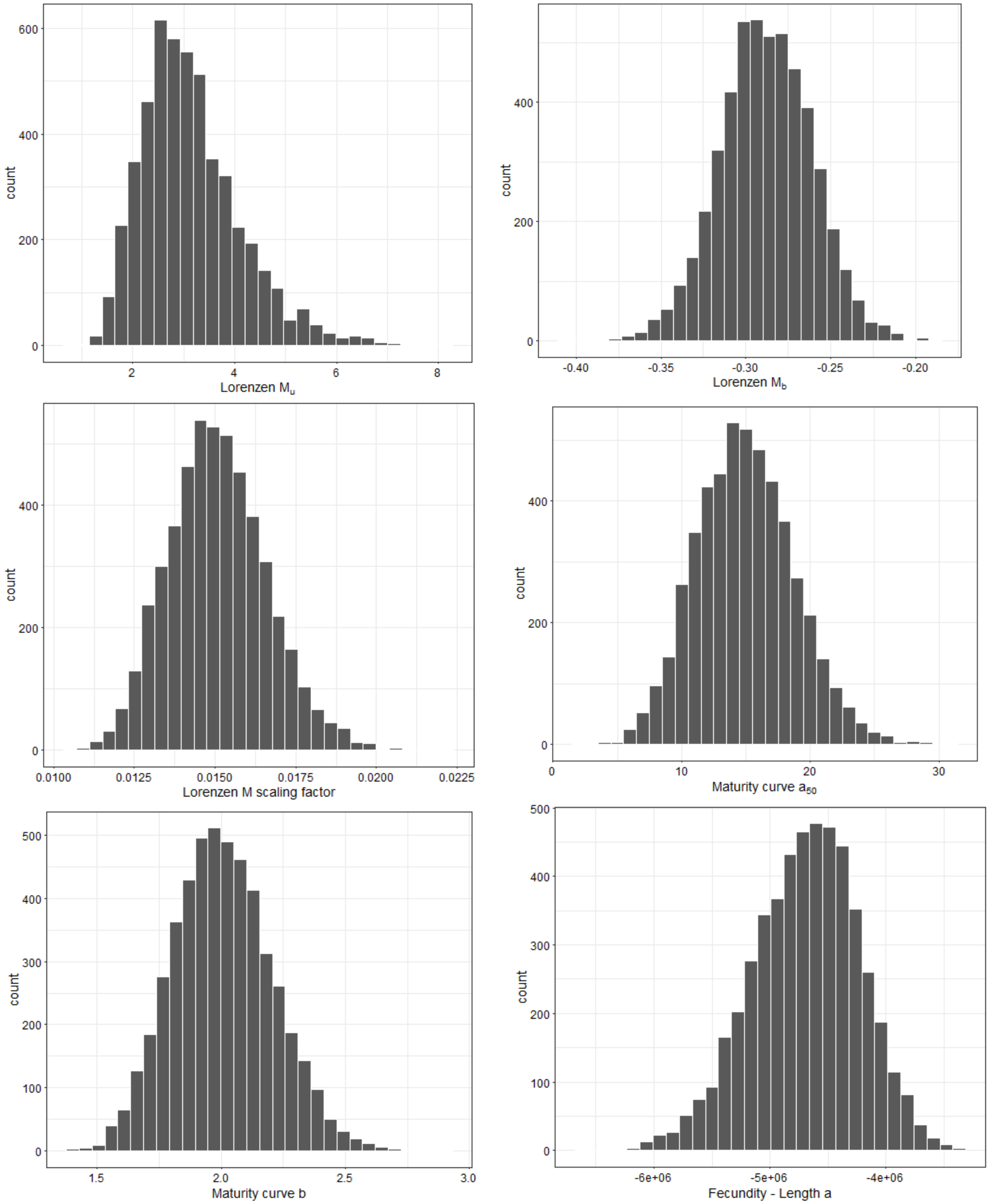


Figure 12 (cont.)

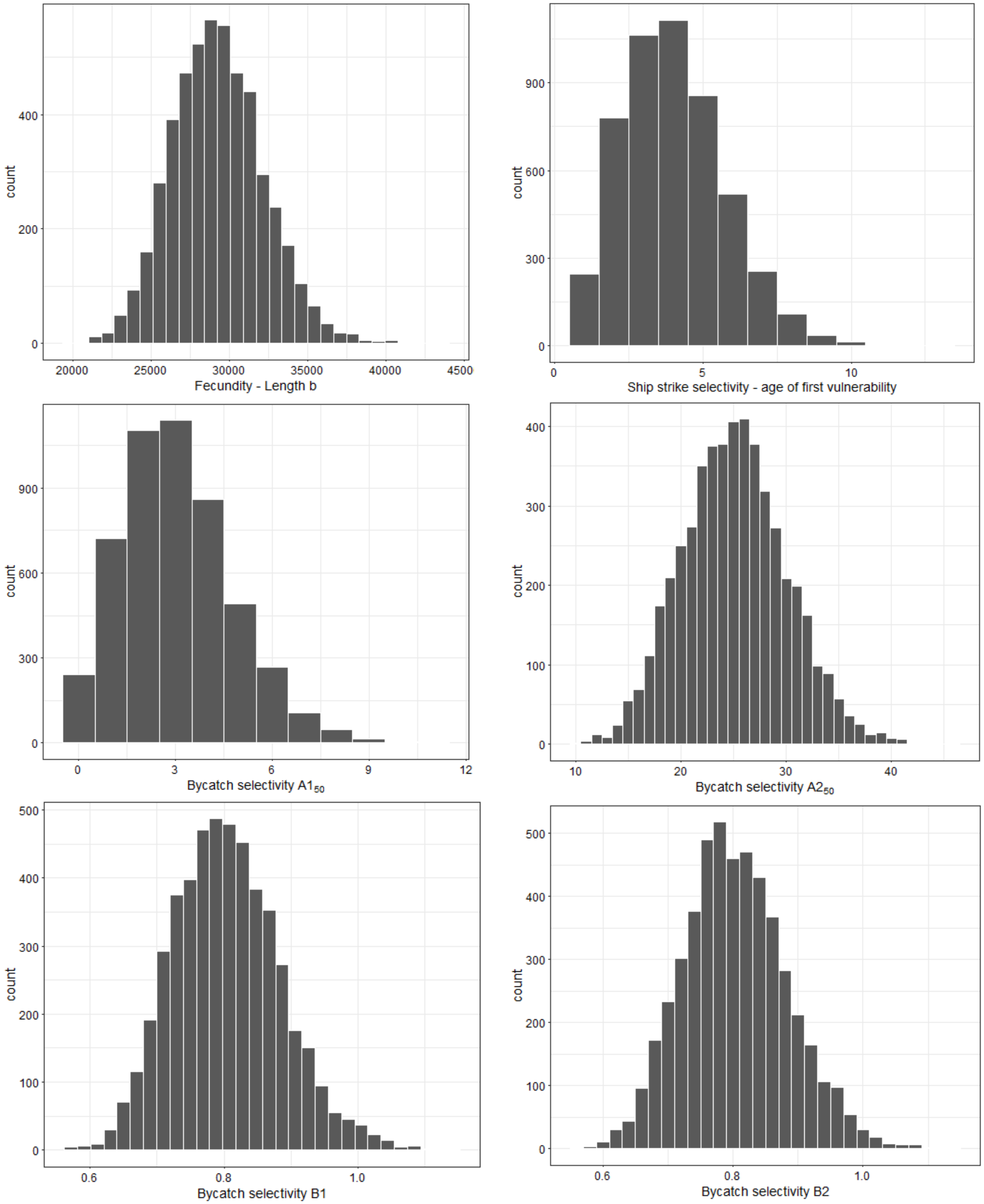


Figure 12 (cont.)

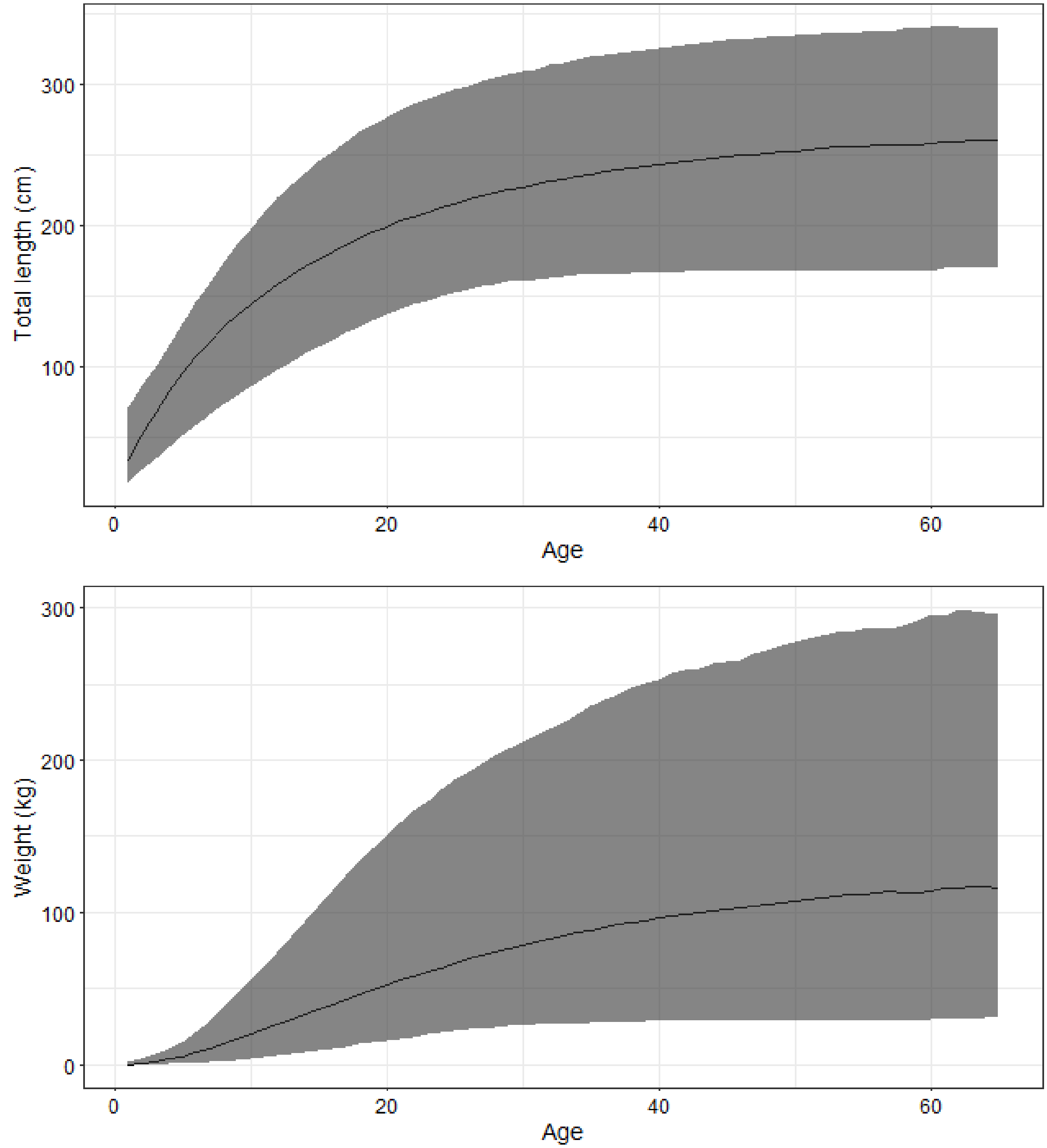


Figure 13. Median life history quantities at age for the stochastic EPR. Shaded area indicates 5th and 95th percentiles of calculated parameters.

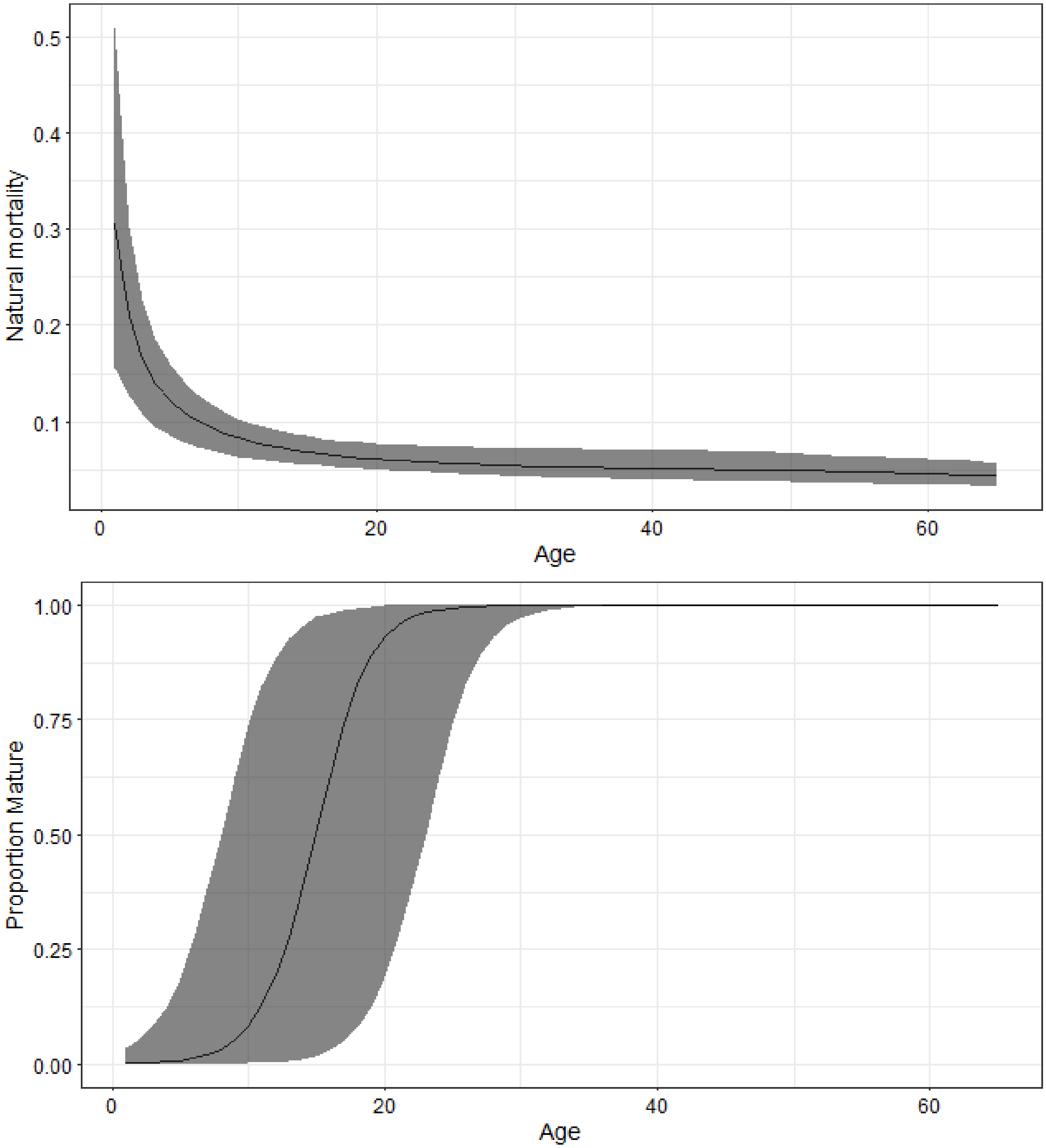
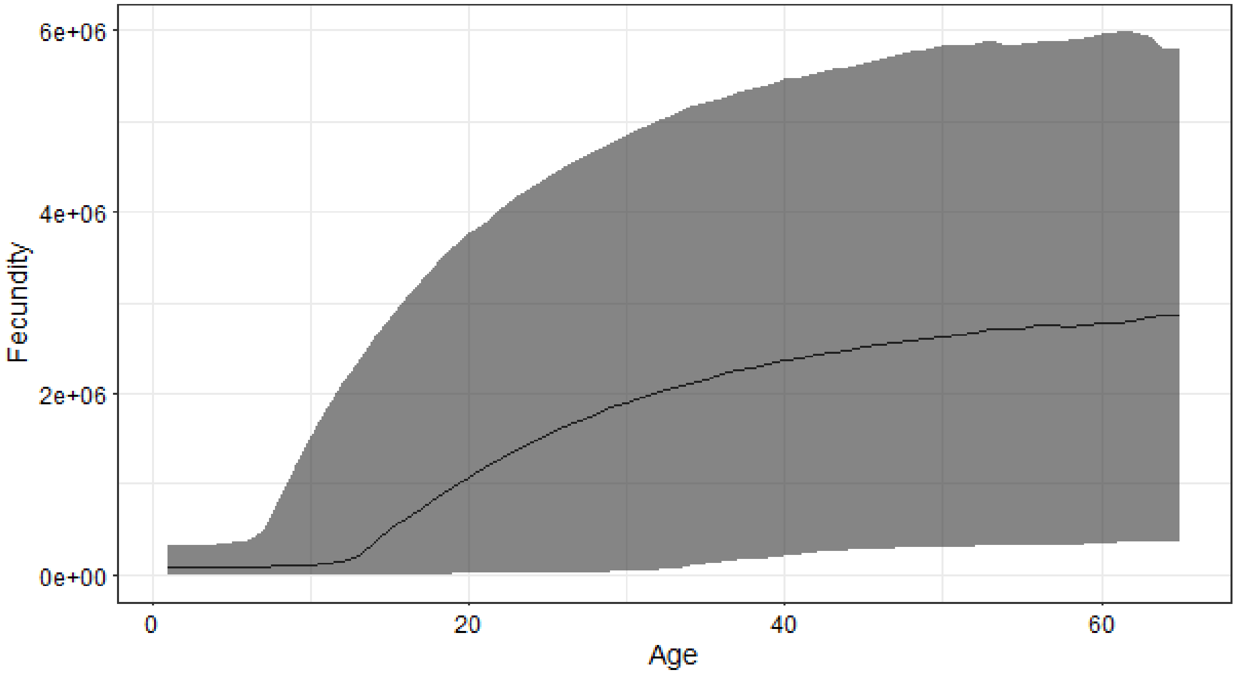
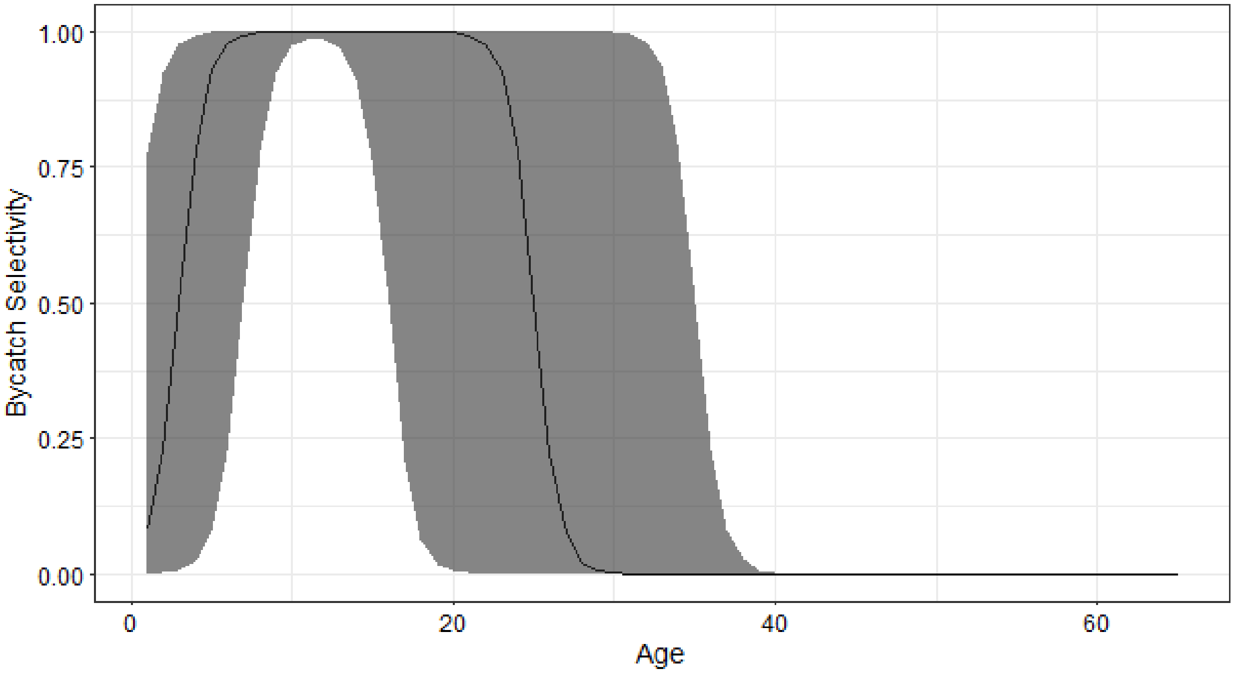


Figure 13 (cont.)





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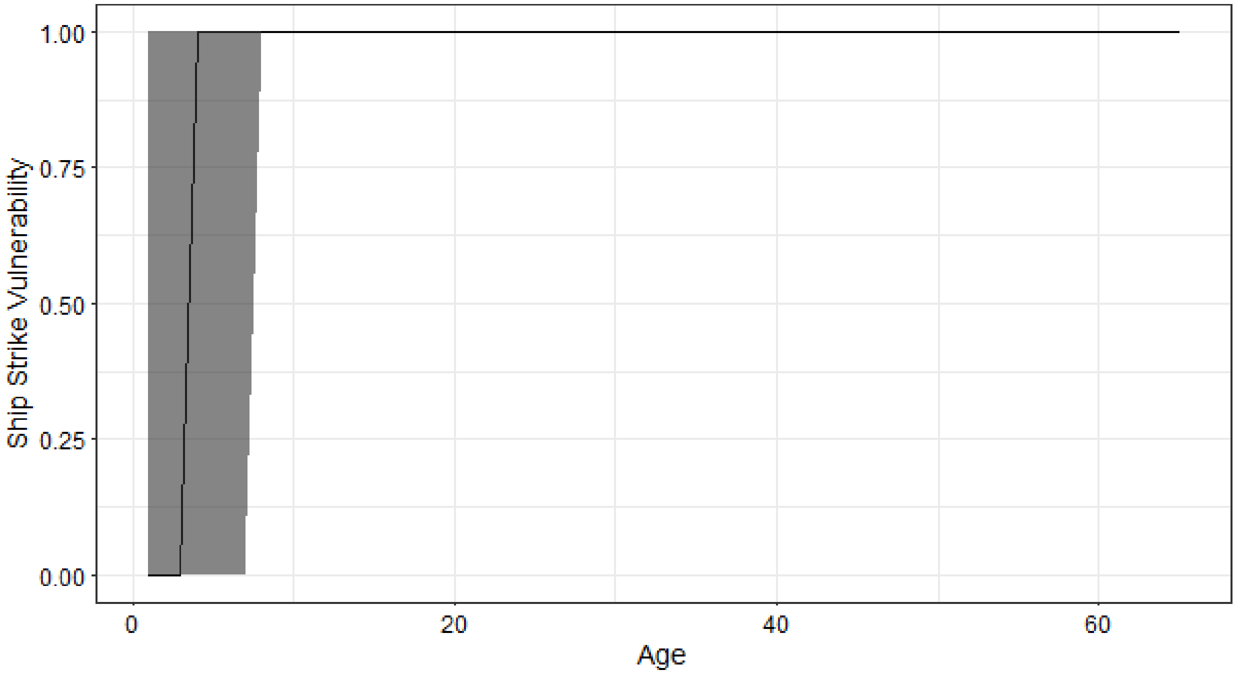


Figure 13 (cont.)

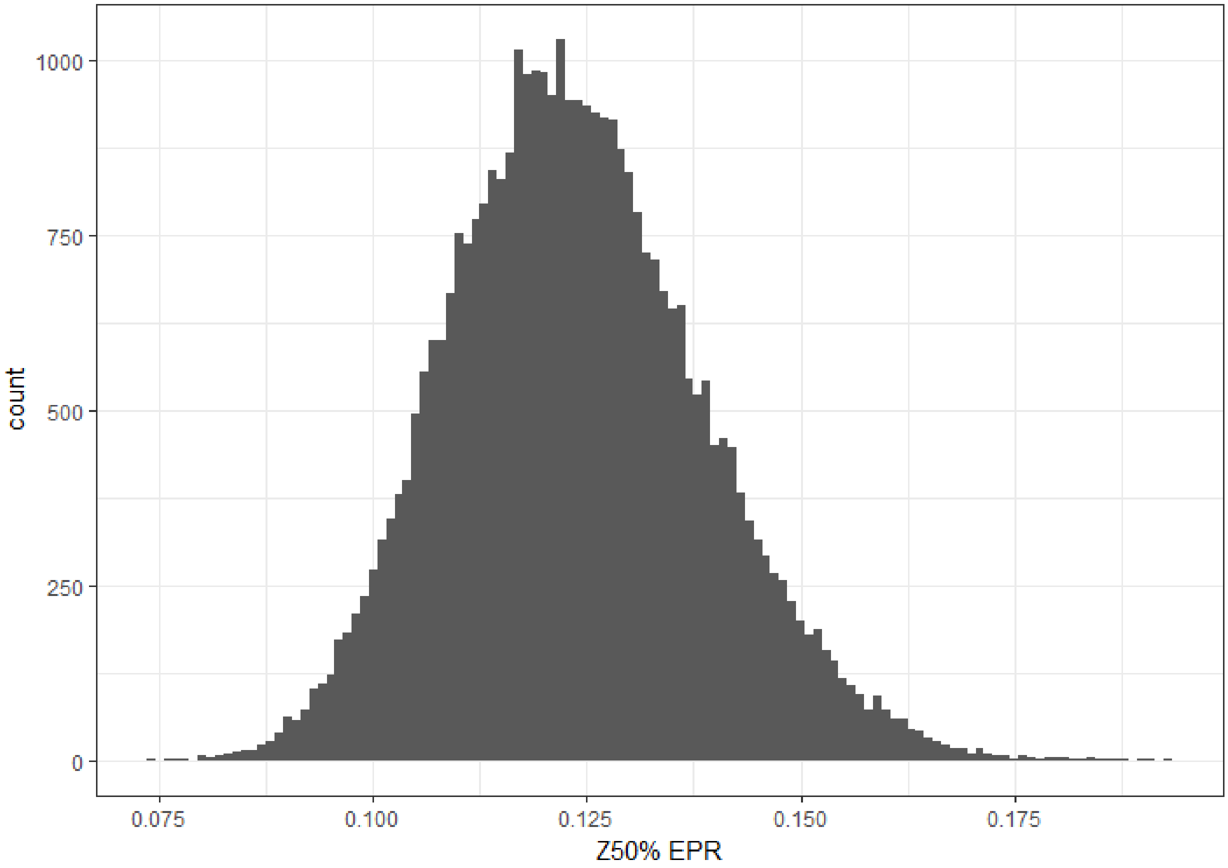


Figure 14. Histogram of $Z_{50\%EPR}$ estimates from the stochastic EPR analysis.

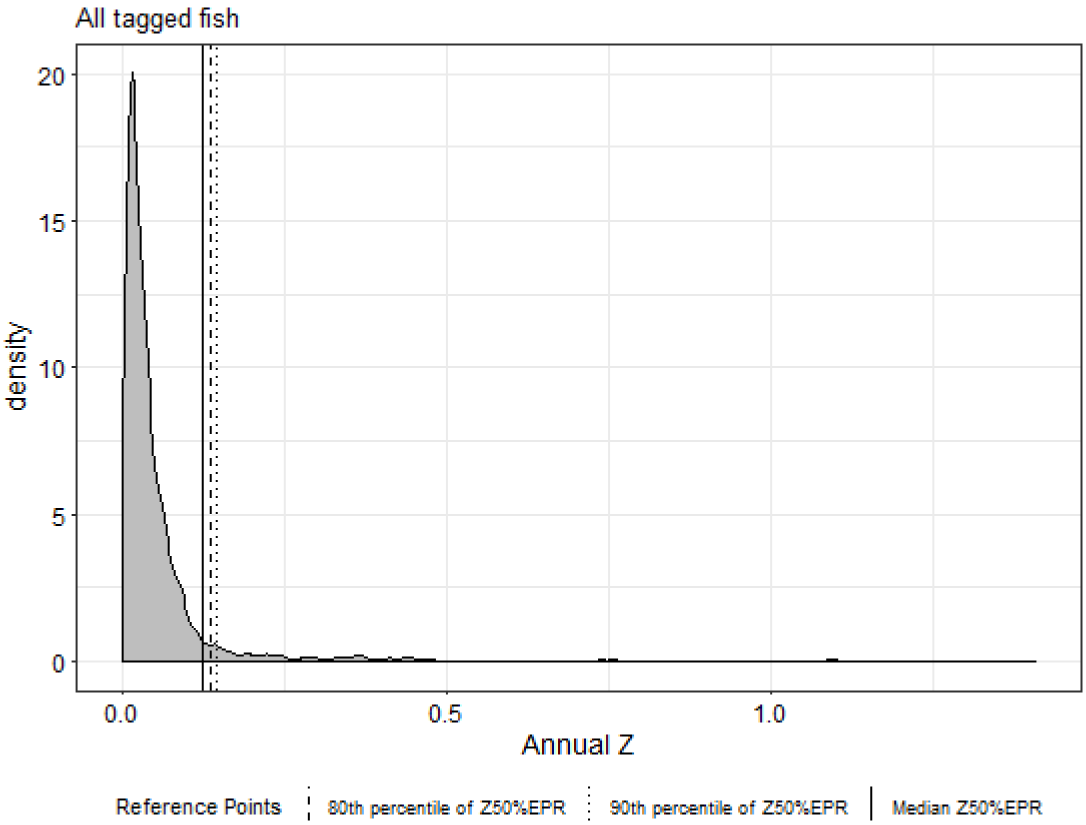


Figure 15. Posterior distribution of Z estimates for the acoustic tagging model for all tagged fish, plotted with the 50th, 80th, and 90th percentile of the $Z_{50\%EPR}$ distribution.

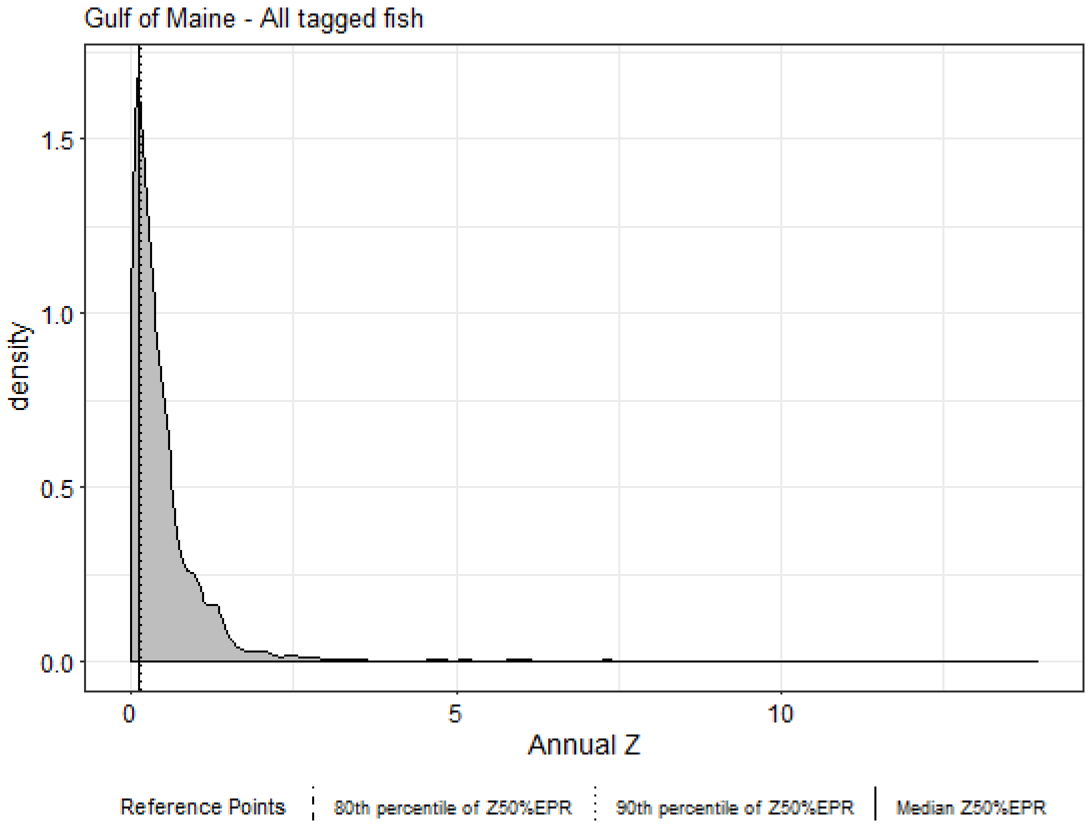


Figure 16. Posterior distribution of Z estimates for the acoustic tagging model for all tagged fish from the Gulf of Maine DPS, plotted with the 50th, 80th, and 90th percentile of the $Z_{50\%EPR}$ distribution.

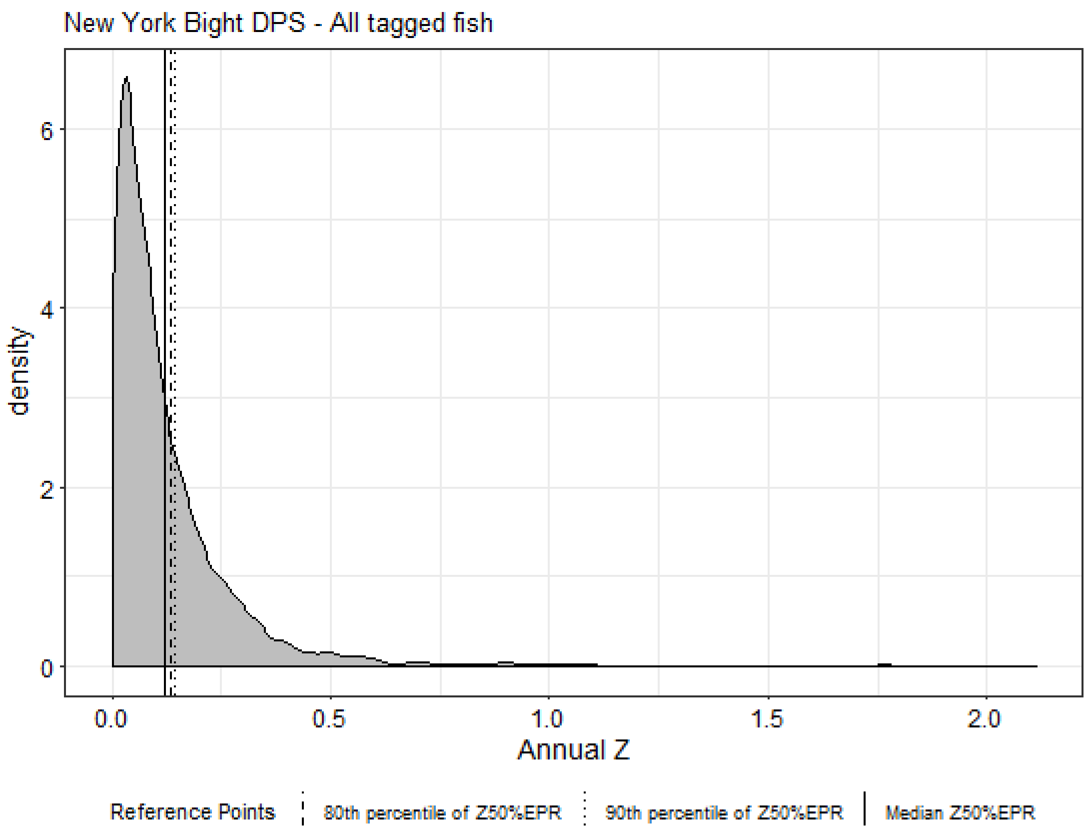


Figure 17. Posterior distribution of Z estimates for the acoustic tagging model for all tagged fish from the New York Bight DPS, plotted with the 50th, 80th, and 90th percentile of the $Z_{50\%EPR}$ distribution.

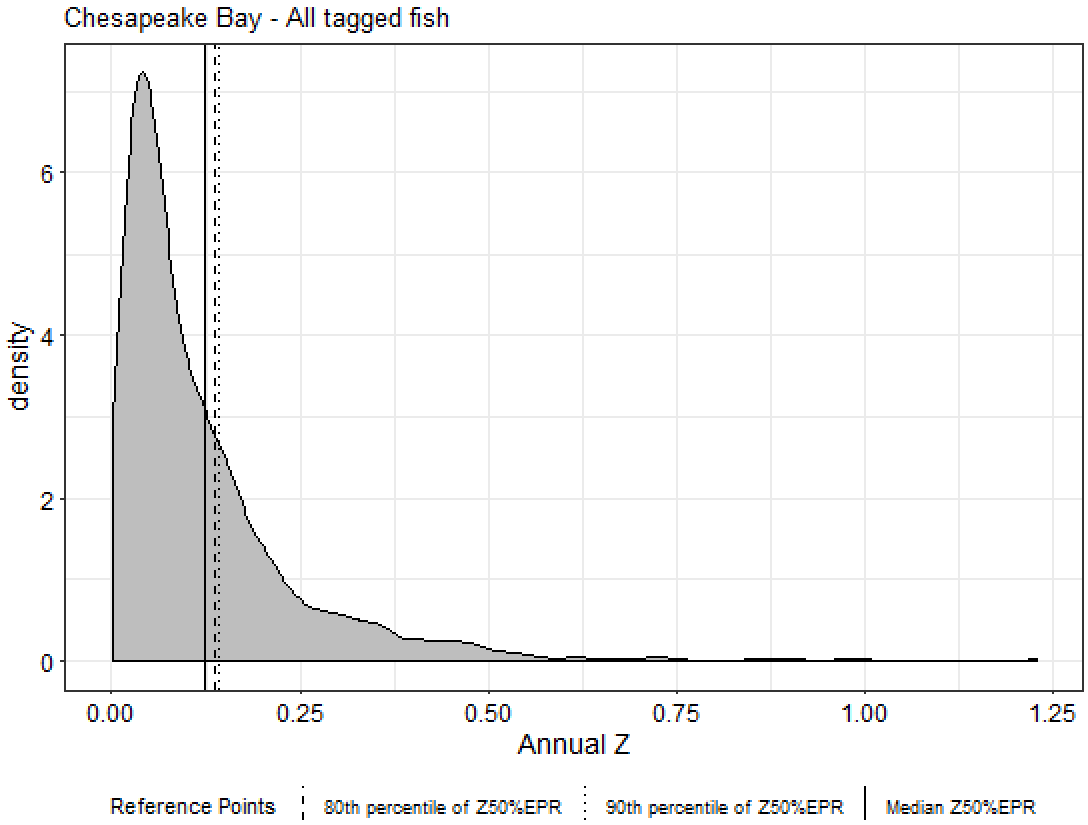


Figure 18. Posterior distribution of Z estimates for the acoustic tagging model for all tagged fish from the Chesapeake Bay DPS, plotted with the 50th, 80th, and 90th percentile of the $Z_{50\%EPR}$ distribution.

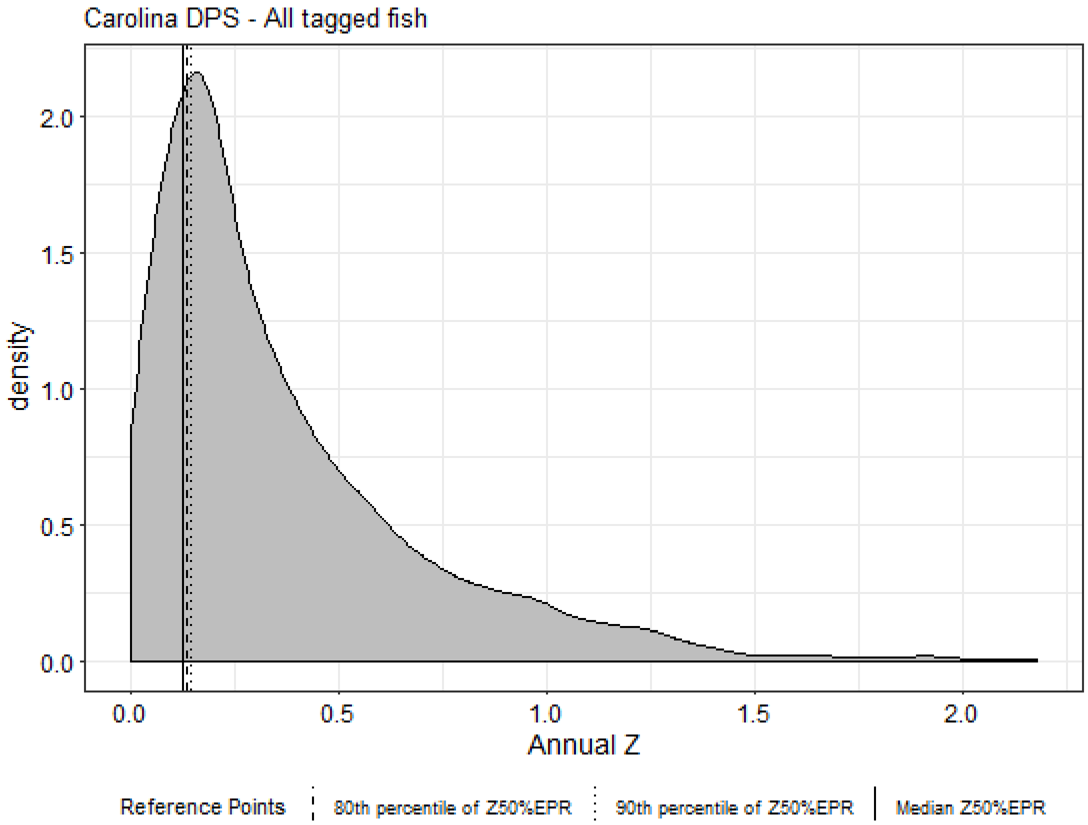


Figure 19. Posterior distribution of Z estimates for the acoustic tagging model for all tagged fish from the Carolina DPS, plotted with the 50th, 80th, and 90th percentile of the $Z_{50\%EPR}$ distribution.

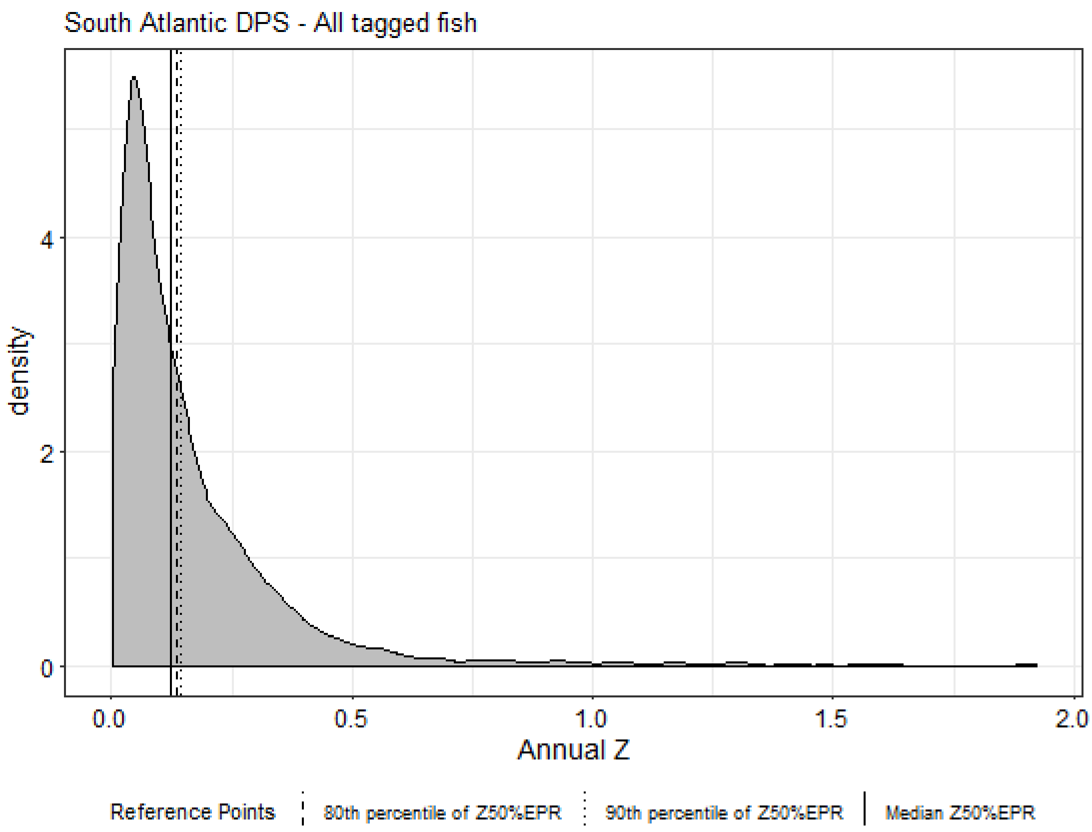


Figure 20. Posterior distribution of Z estimates for the acoustic tagging model for all tagged fish from the South Atlantic DPS, plotted with the 50th, 80th, and 90th percentile of the $Z_{50\%EPR}$ distribution.

Atlantic States Marine Fisheries Commission

Appendix to the Supplemental Report to the 2017 Atlantic Sturgeon Benchmark Stock Assessment

Additional Figures Requested at the Review Workshop

The Peer Review Panel requested two sets of additional figures at the review workshop to help them better evaluate the data and the results. The first set was of the length frequency distributions of the fishery independent indices, since they had only been described qualitatively in the Assessment Report. The second set was of the posterior distributions of the annual survival estimates from the tagging model, since only the confidence intervals had been presented.

These figures are presented in this Appendix to provide supporting documentation for the Review Panel's discussions and conclusions.

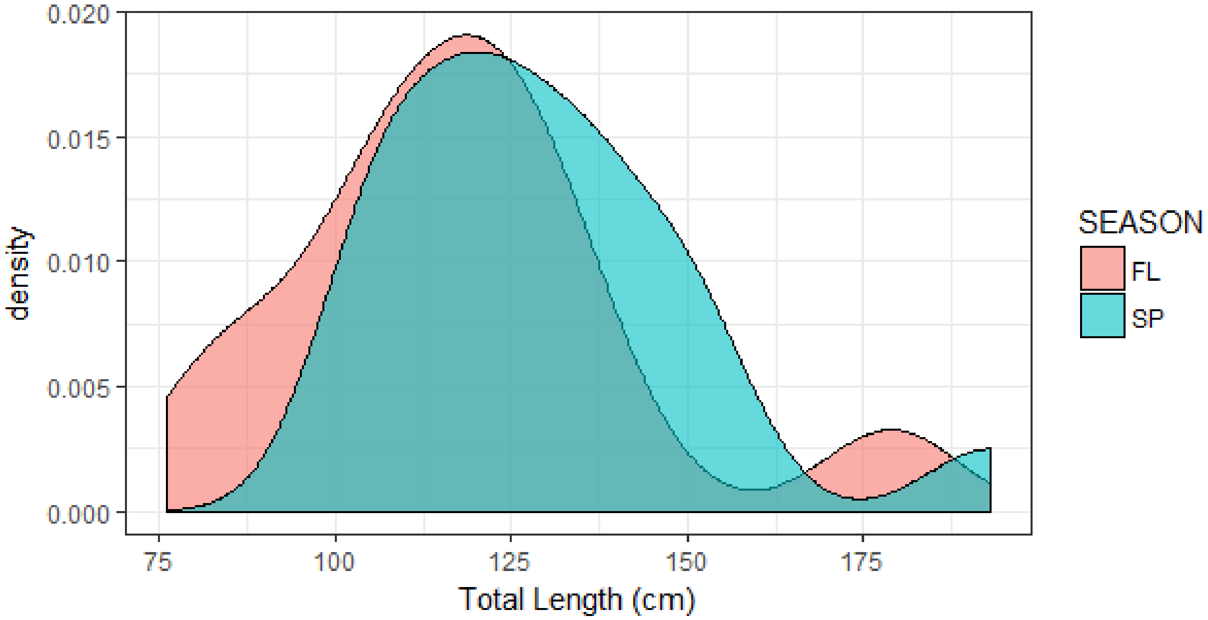


Figure 1. Length distribution of Atlantic sturgeon caught in the ME-NH Trawl survey by fall (FL) and spring (SP) seasons.

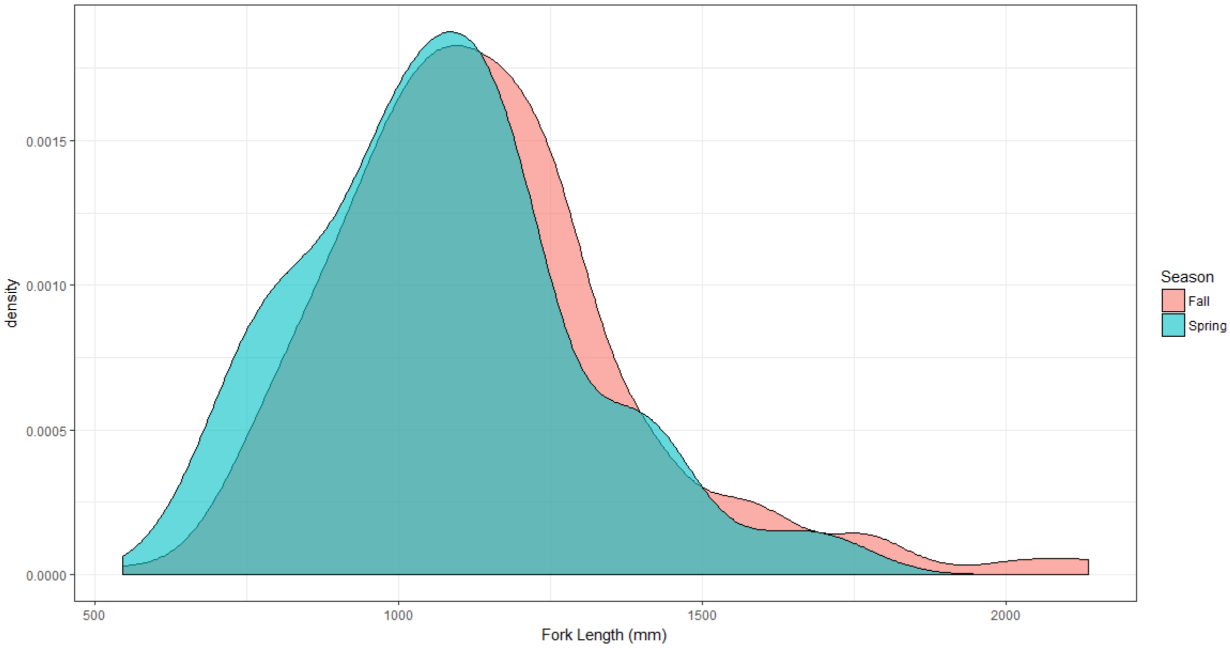


Figure 2. Length distribution of Atlantic sturgeon caught in the CT LIST survey by season.

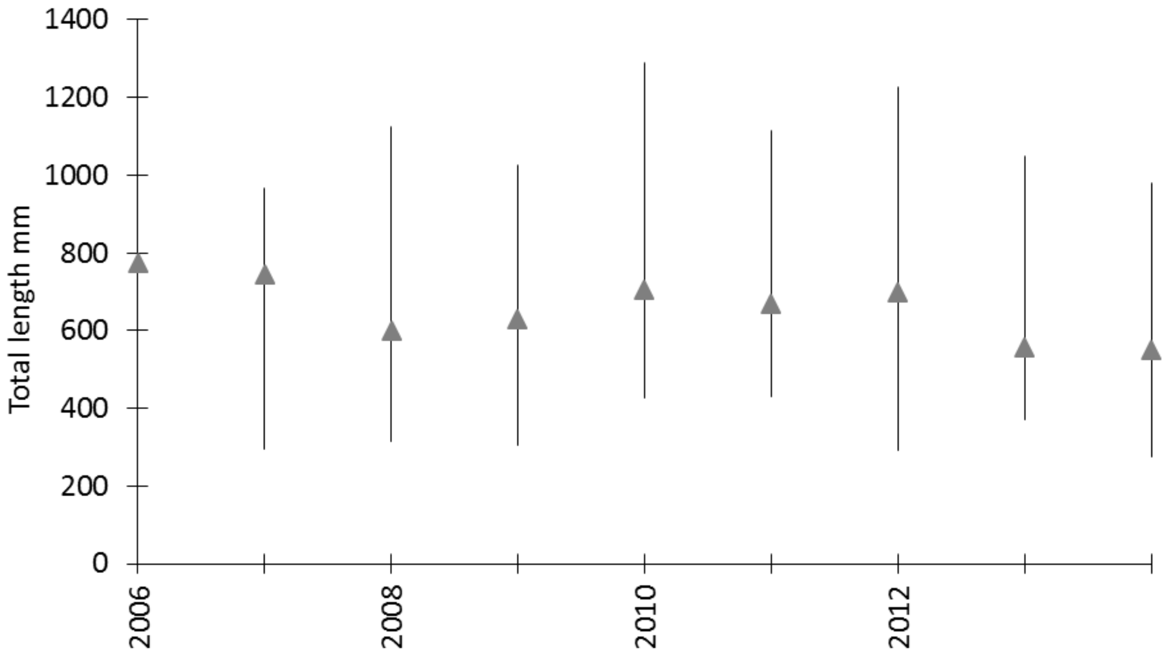


Figure 3. Mean and standard deviation of the lengths of Atlantic sturgeon collected by the NY JASAMP survey.

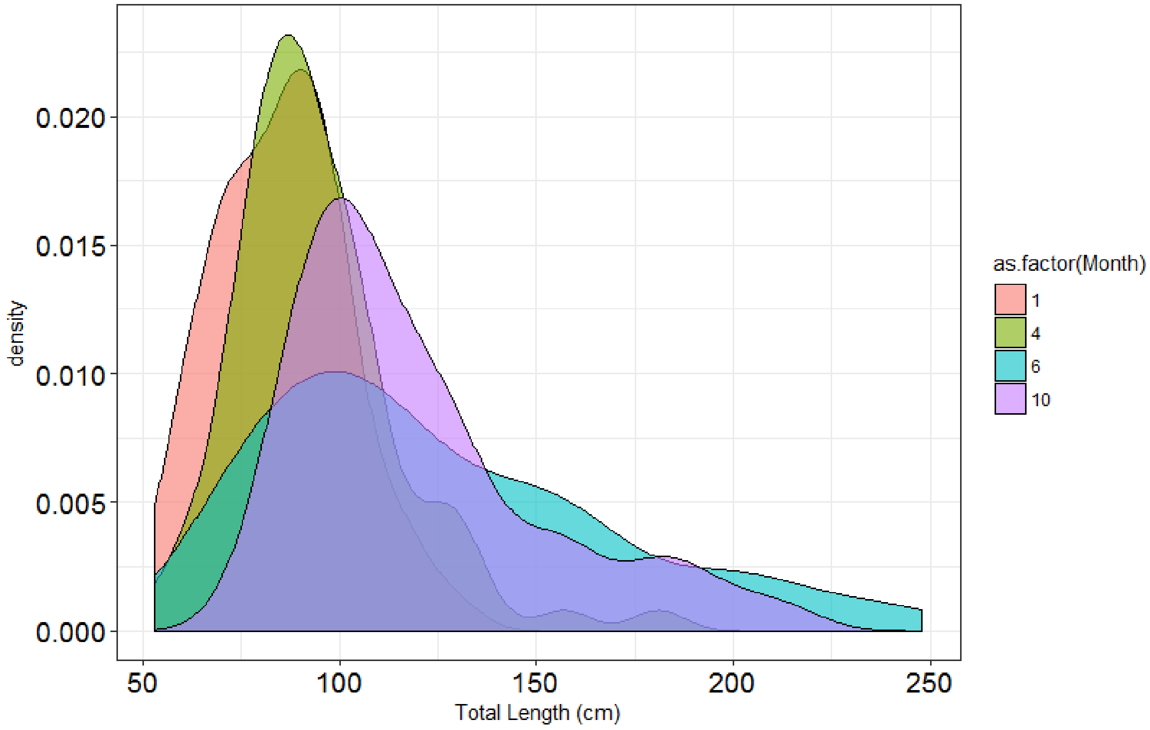


Figure 4. Length distribution of Atlantic sturgeon caught in the NJ OT survey by sampling month.

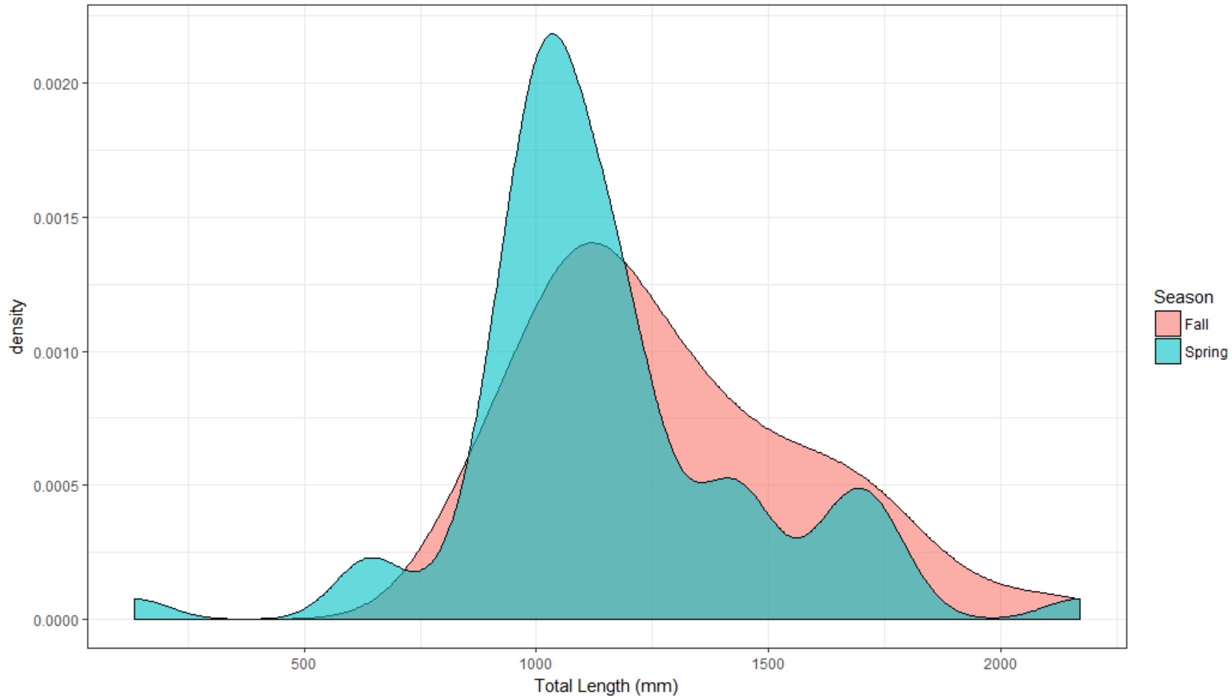


Figure 5. Length distribution of Atlantic sturgeon caught in the NEAMAP survey by season.

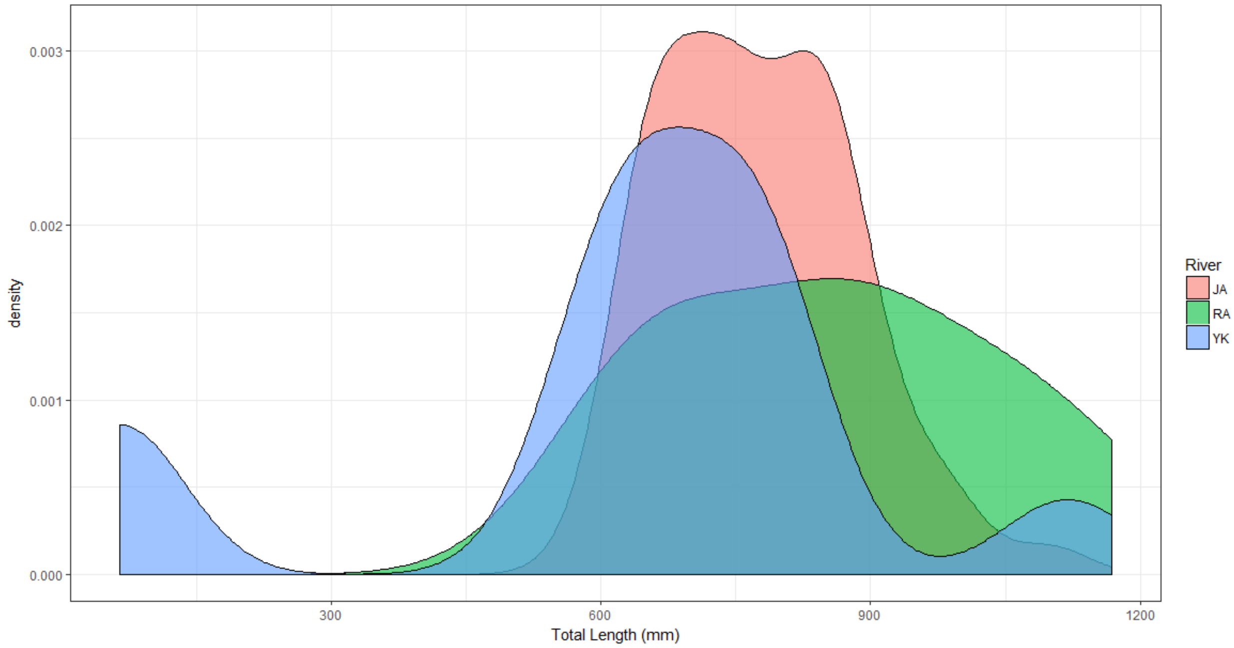


Figure 6. Length distribution of Atlantic sturgeon caught by the VIMS Shad and River Herring Monitoring Program in the James, Rappahannock, and York Rivers.

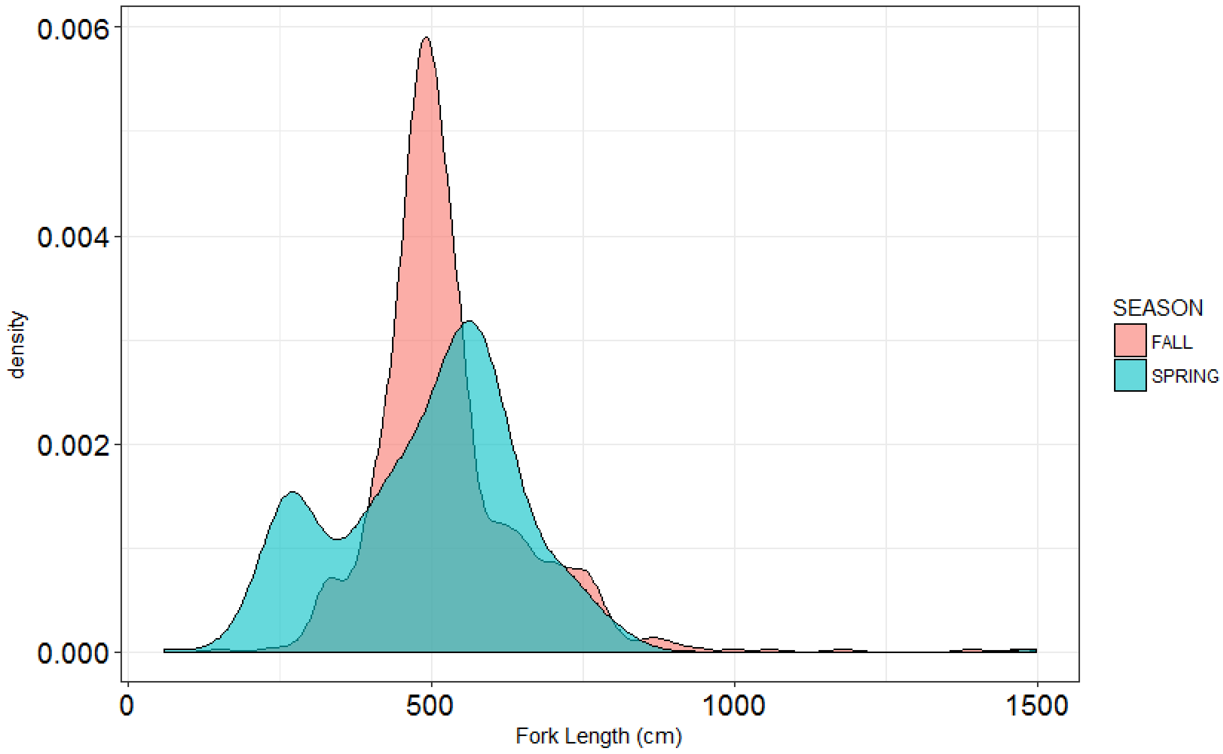


Figure 7. Length distibution of Atlantic sturgeon caught by the NC Program 135 survey.

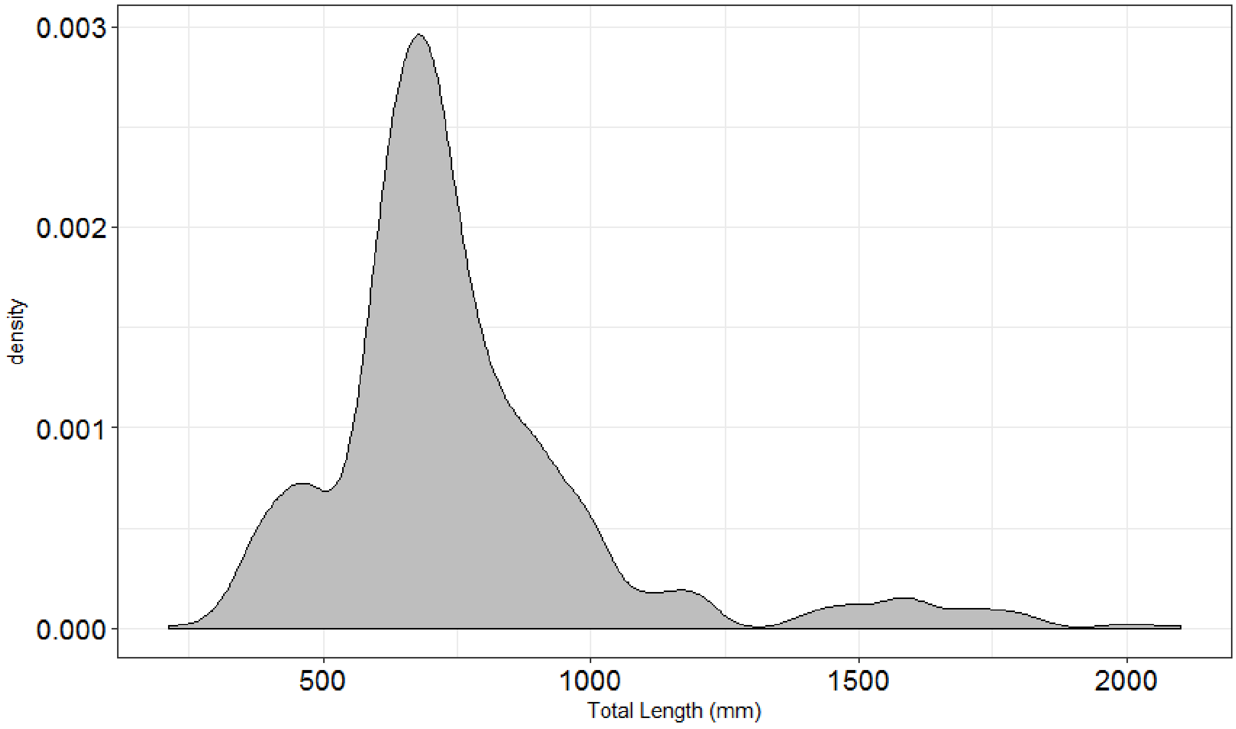


Figure 8. Length distibution of Atlantic sturgeon caught by the SC Edisto survey.

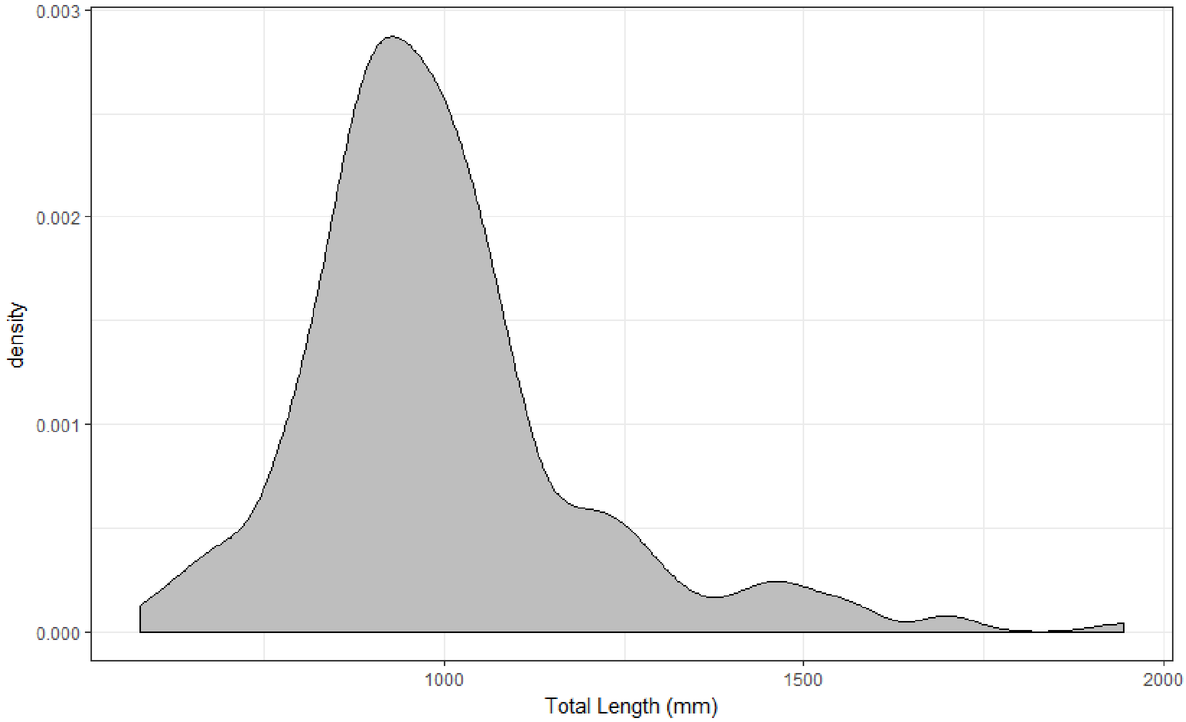


Figure 9. Length distribution of Atlantic sturgeon caught by the USFWS Coop survey.

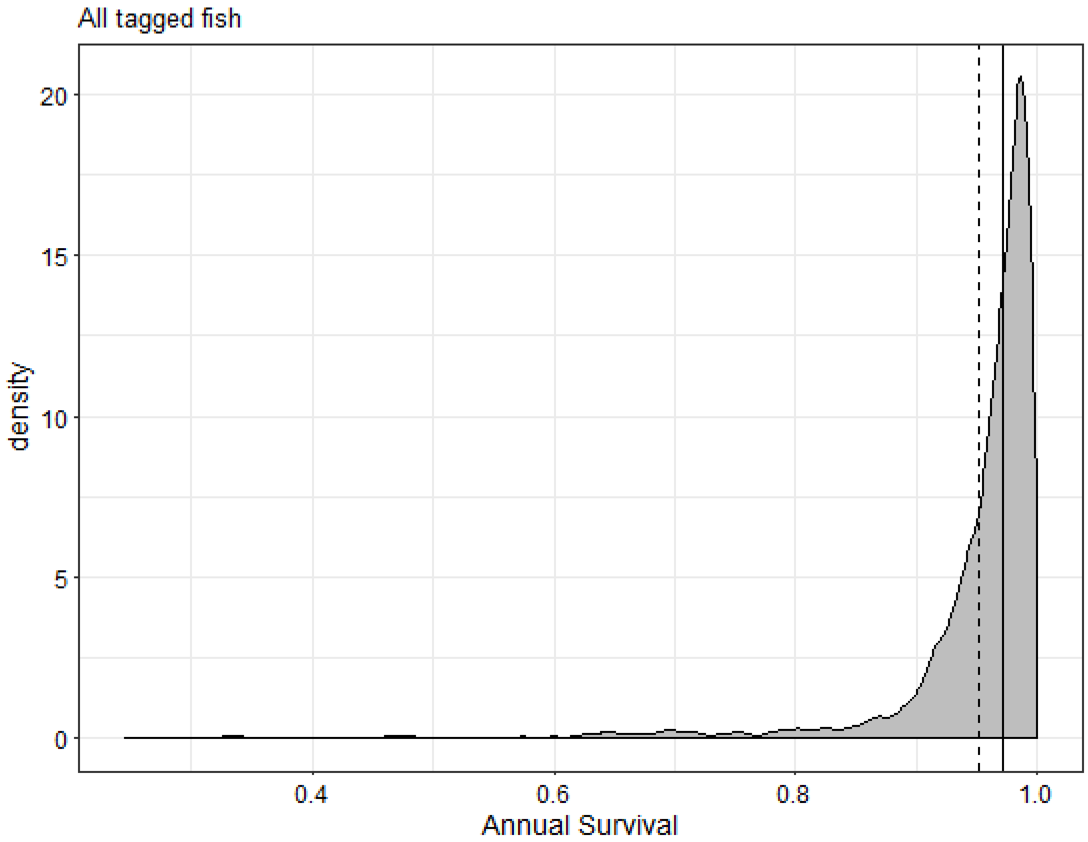


Figure 10. Posterior distribution of annual survival estimates from the acoustic tagging model for all tagged fish. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

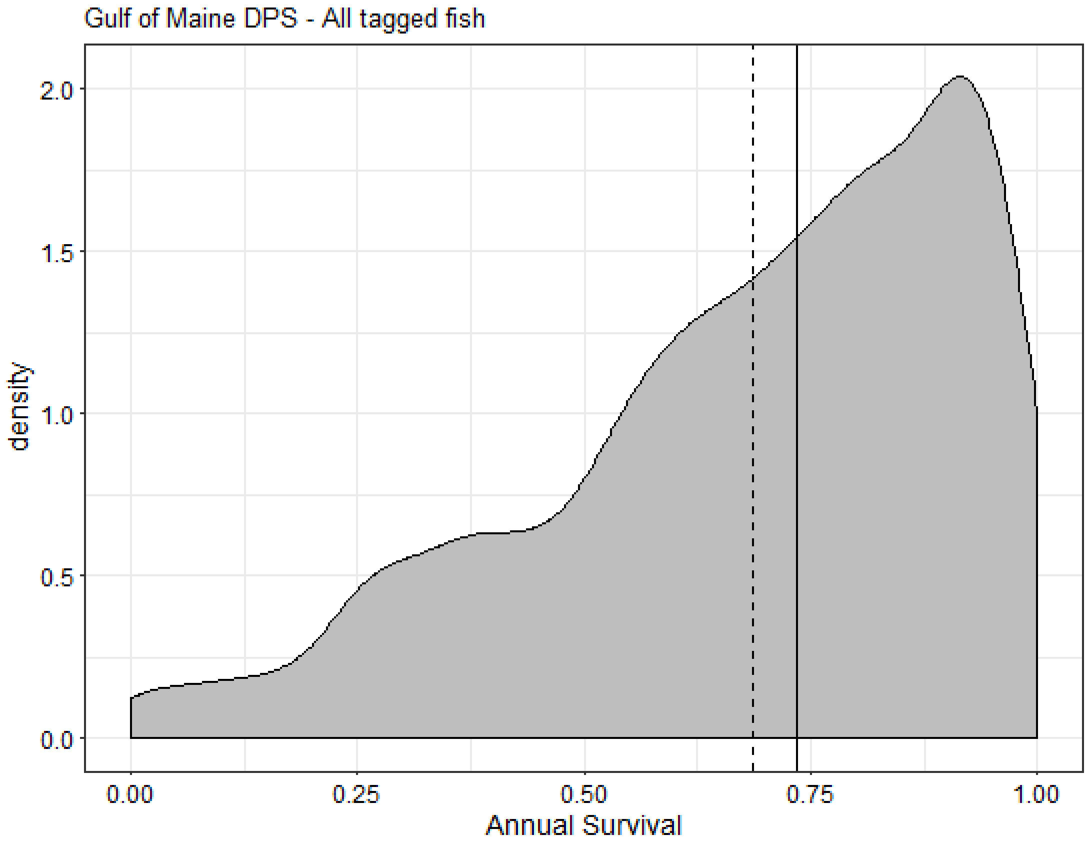


Figure 11. Posterior distribution of annual survival estimates from the acoustic tagging model for all tagged fish from the Gulf of Maine DPS. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

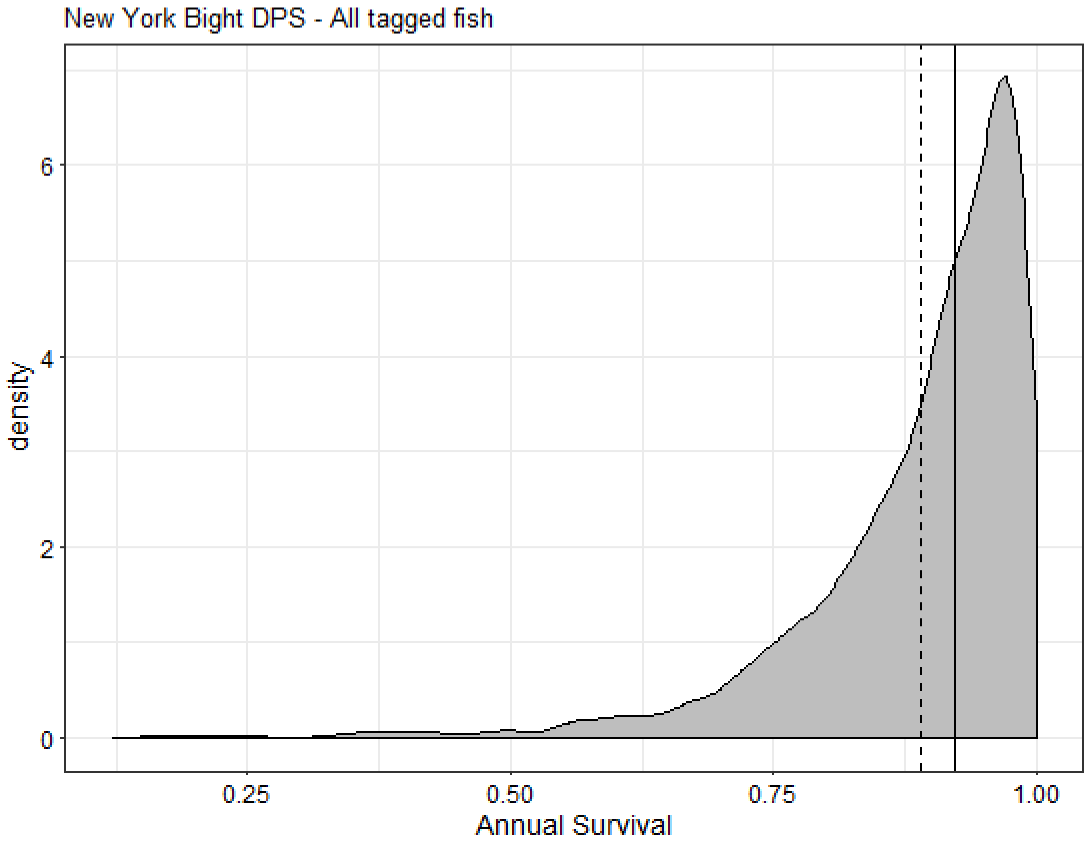


Figure 12. Posterior distribution of annual survival estimates from the acoustic tagging model for all tagged fish from the New York Bight DPS. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

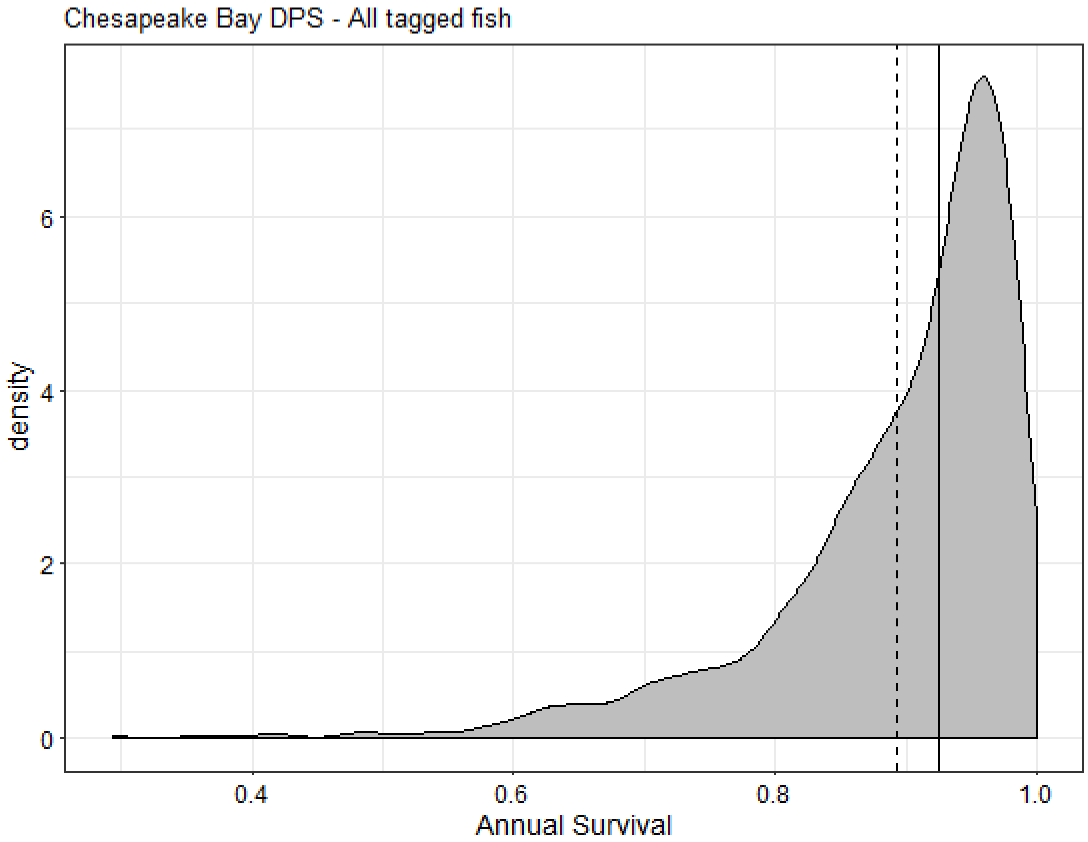


Figure 13. Posterior distribution of annual survival estimates from the acoustic tagging model for all tagged fish from the Chesapeake Bay DPS. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

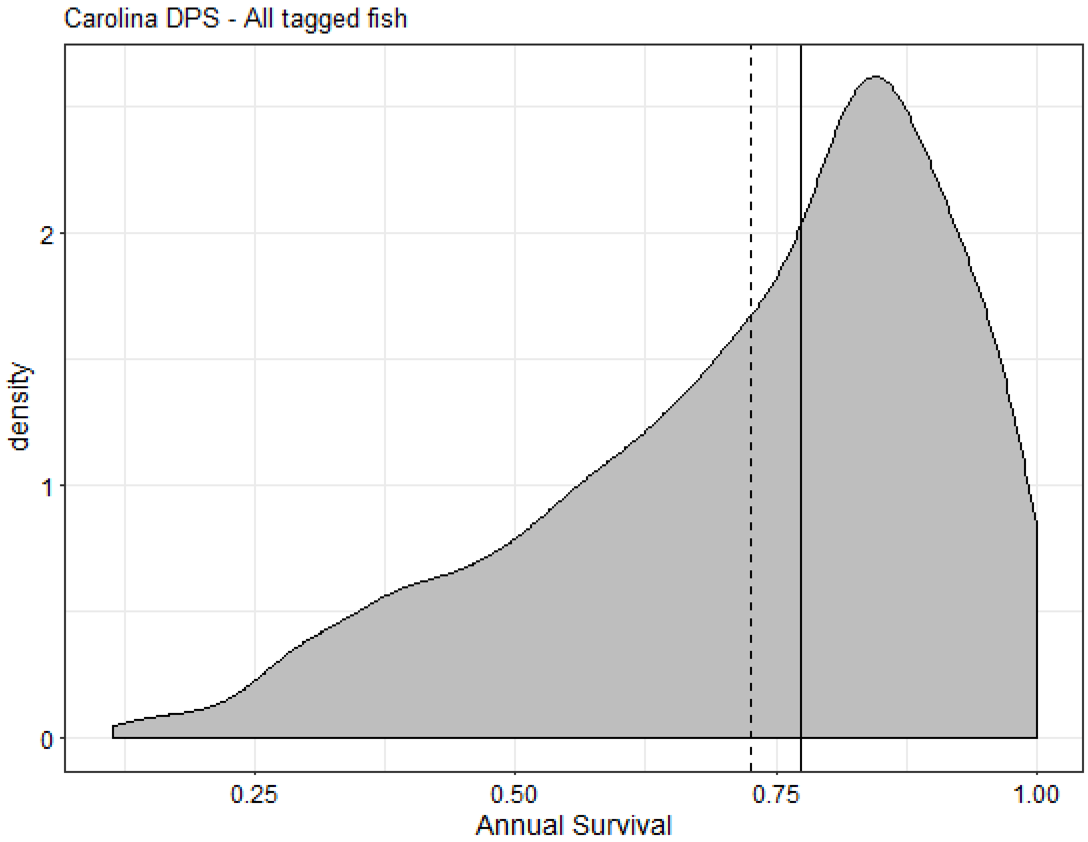


Figure 14. Posterior distribution of annual survival estimates from the acoustic tagging model for all tagged fish from the Carolina DPS. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

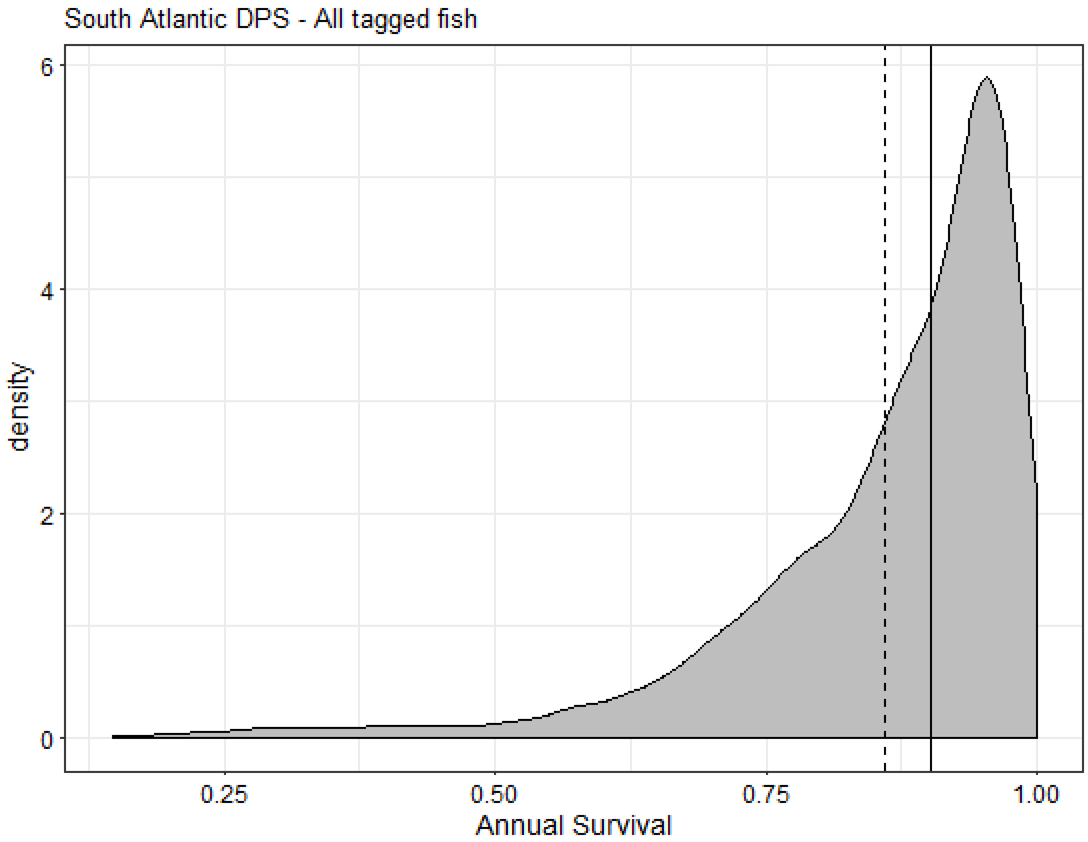


Figure 15. Posterior distribution of annual survival estimates from the acoustic tagging model for all tagged fish from the South Atlantic DPS. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

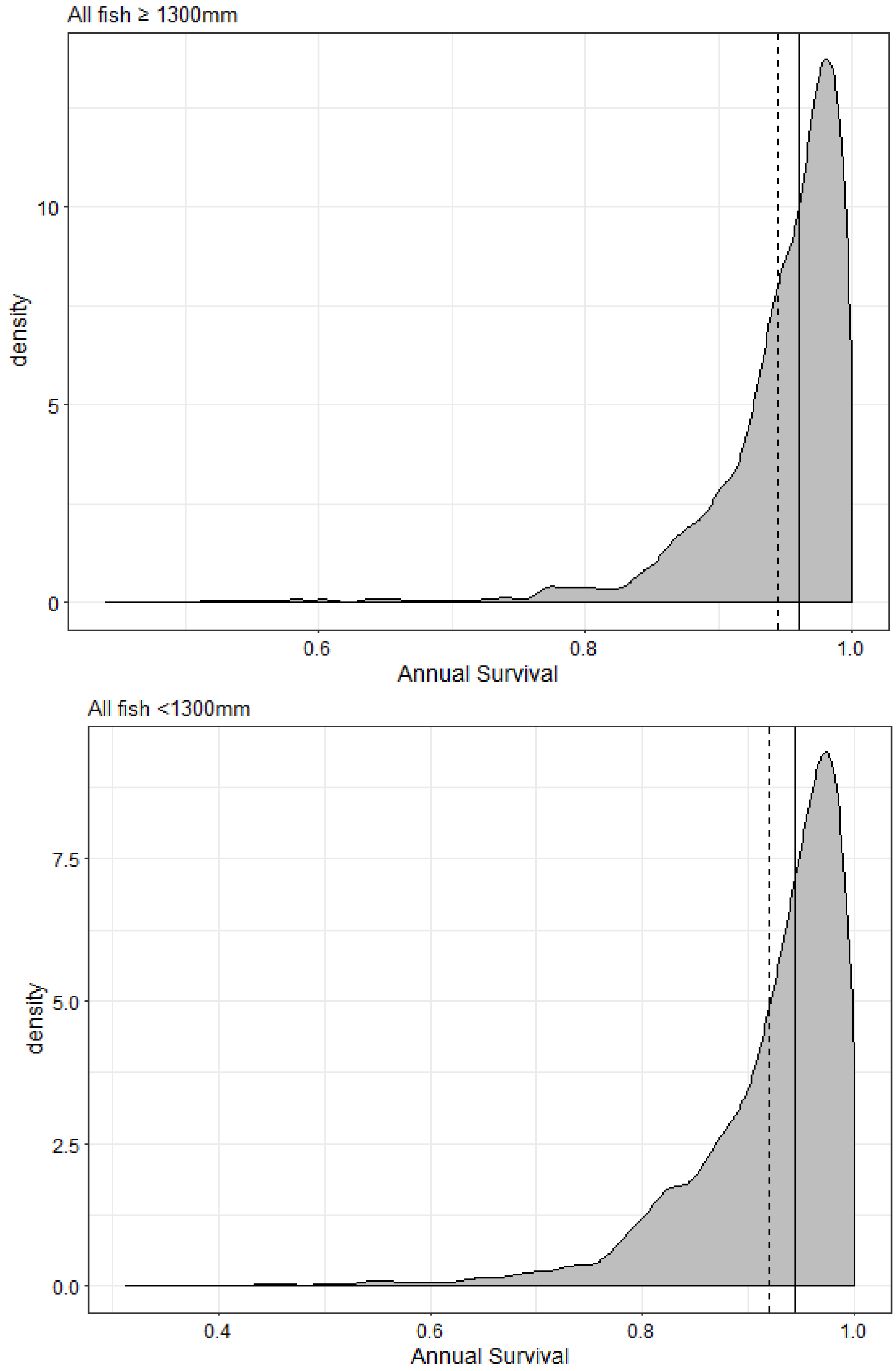


Figure 16. Posterior distribution of annual survival estimates from the acoustic tagging model for adult (top) and juvenile (bottom) tagged fish from all DPSs. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

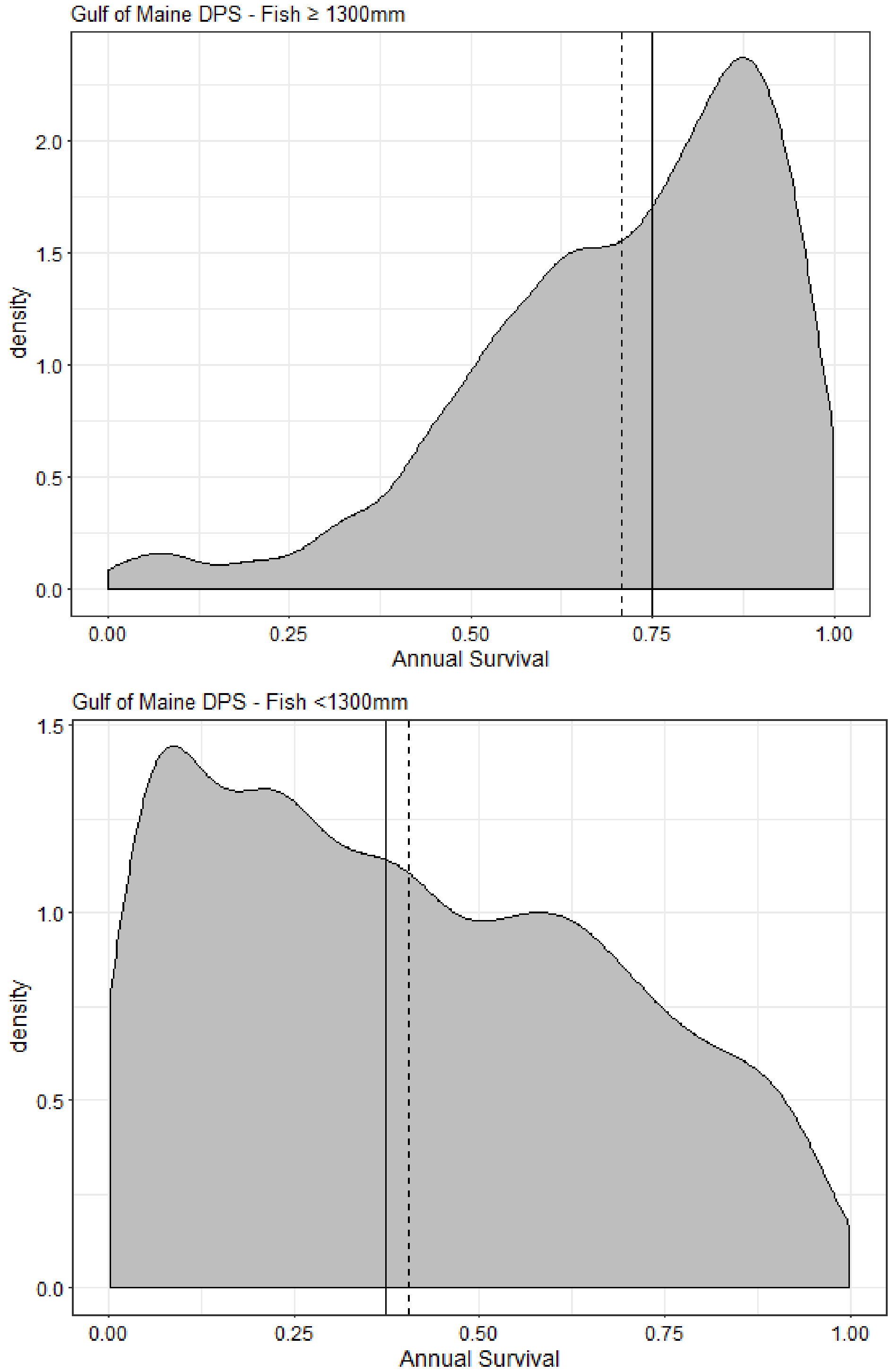


Figure 17. Posterior distribution of annual survival estimates from the acoustic tagging model for adult (top) and juvenile (bottom) tagged fish from the Gulf of Maine DPSs. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

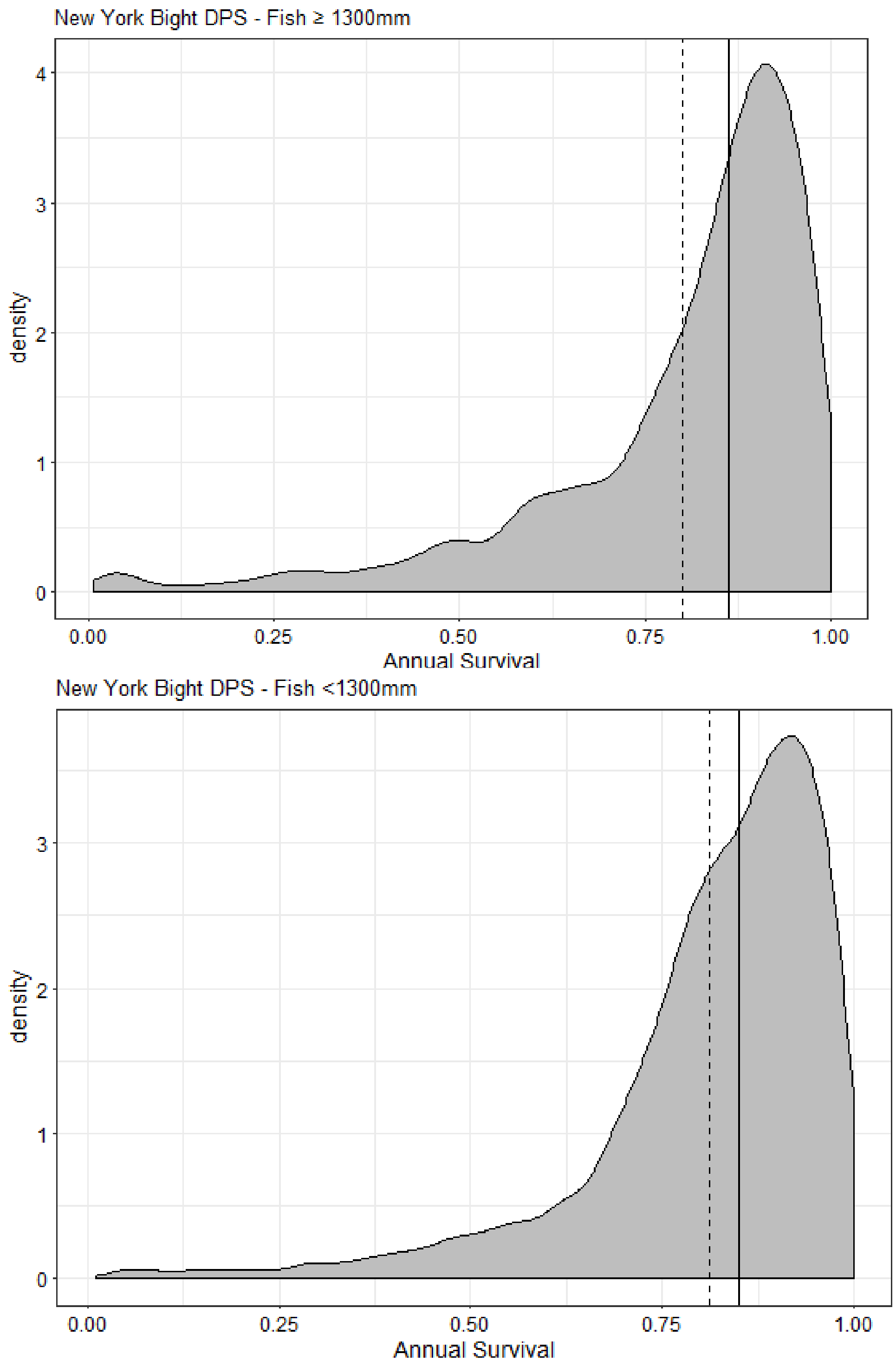


Figure 18. Posterior distribution of annual survival estimates from the acoustic tagging model for adult (top) and juvenile (bottom) tagged fish from the New York Bight DPSs. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

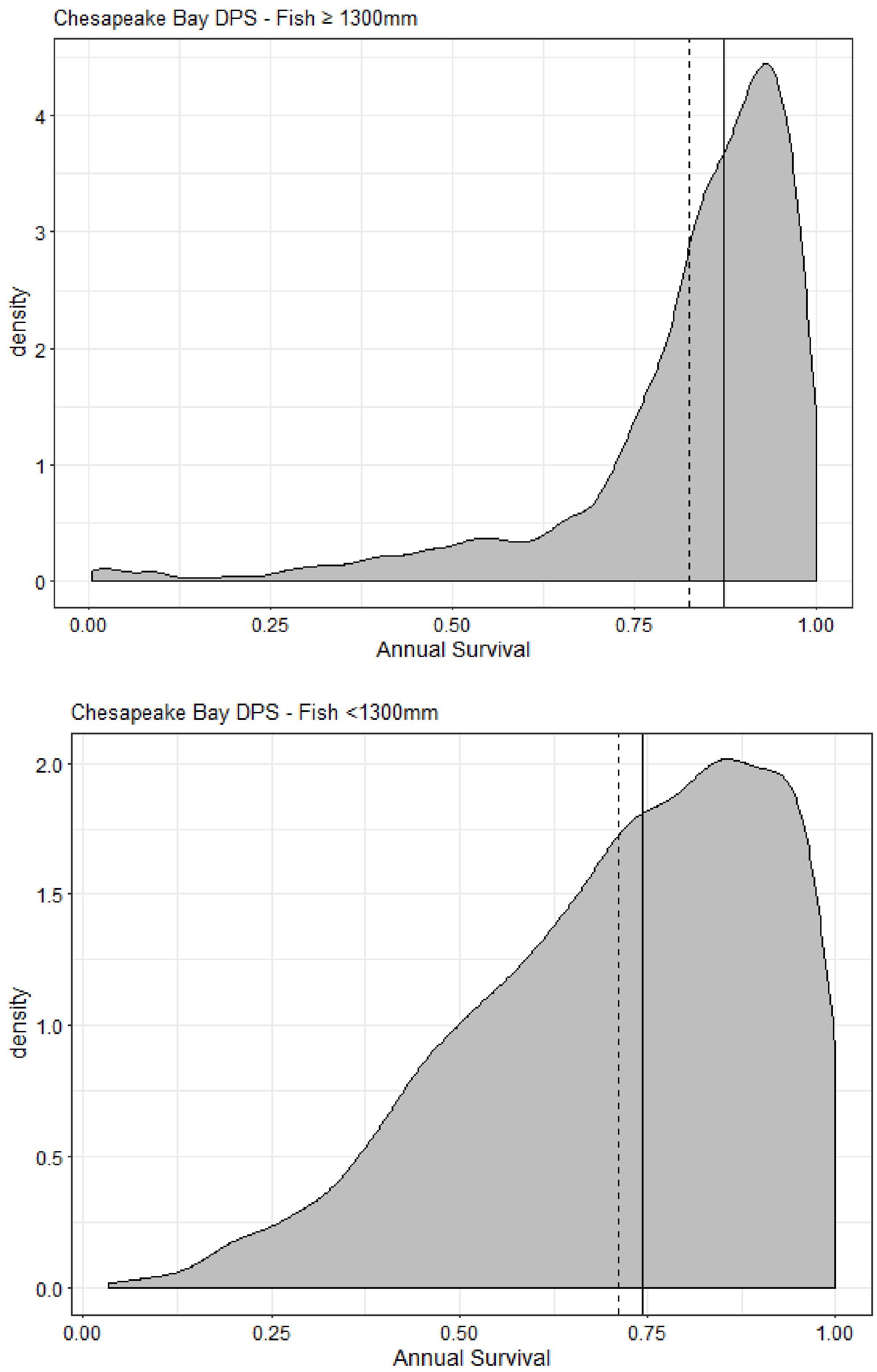
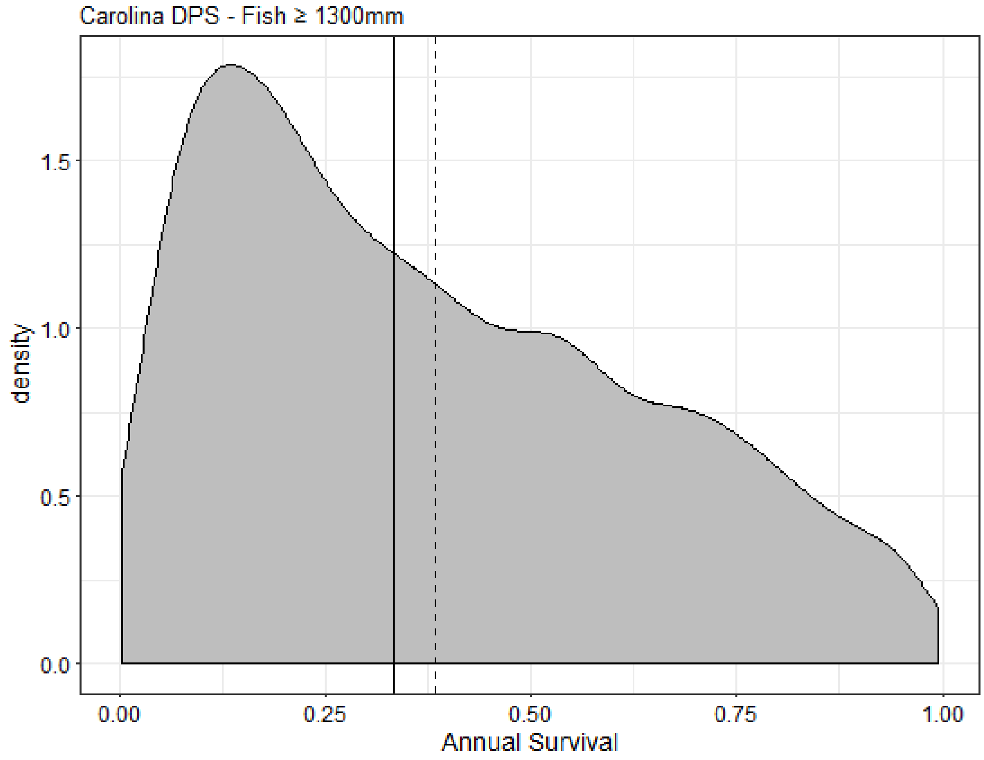


Figure 19. Posterior distribution of annual survival estimates from the acoustic tagging model for adult (top) and juvenile (bottom) tagged fish from the Chesapeake Bay DPSs. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.



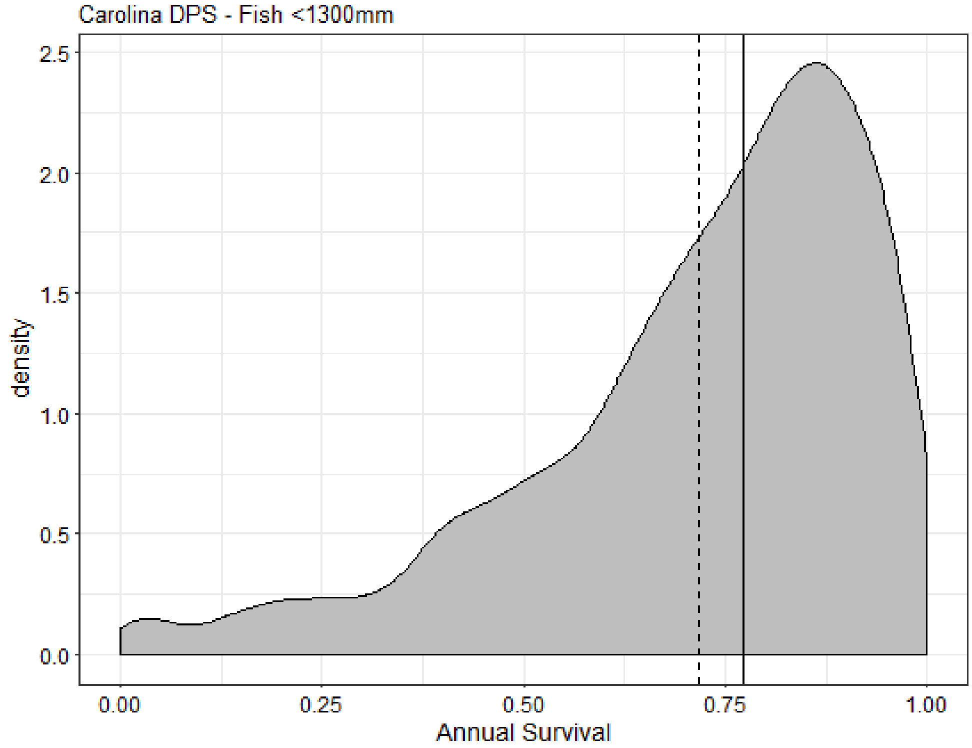


Figure 20. Posterior distribution of annual survival estimates from the acoustic tagging model for adult (top) and juvenile (bottom) tagged fish from the Carolina DPSs. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

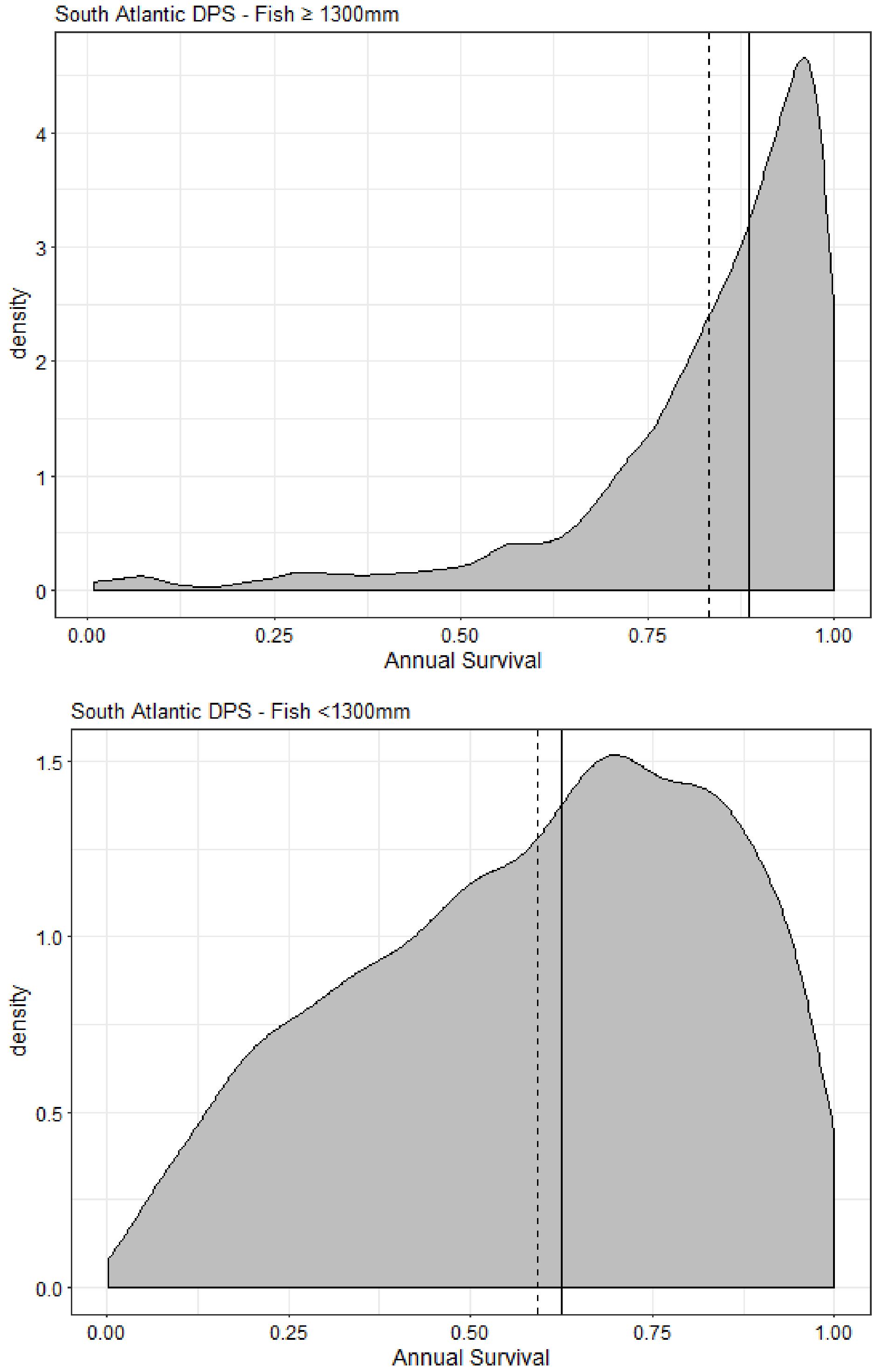
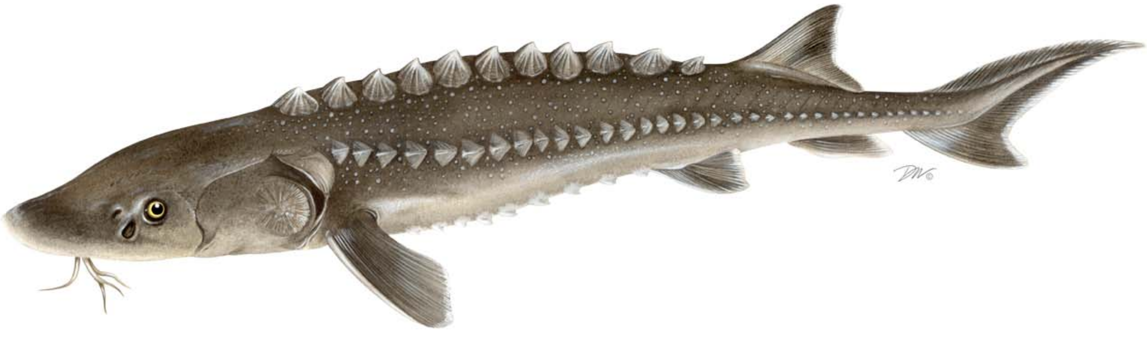


Figure 21. Posterior distribution of annual survival estimates from the acoustic tagging model for adult (top) and juvenile (bottom) tagged fish from the South Atlantic DPSs. The solid vertical line is the median of the posterior distribution and the dashed vertical line is the mean.

Atlantic States Marine Fisheries Commission

2017 Atlantic Sturgeon Benchmark Stock Assessment



Prepared by the
Atlantic Sturgeon Stock Assessment Subcommittee and
Technical Committee

EXECUTIVE SUMMARY

The purpose of this assessment was to evaluate the current status of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) along the U.S. Atlantic coast. Data from a variety of fisheries-dependent and -independent sources were reviewed and used to develop bycatch, effective population size, and mortality estimates as well as perform trend analyses, stock reduction analysis, and an egg-per-recruit model.

Stock Identification and Management Unit

The Atlantic States Marine Fisheries Commission (ASMFC) has managed Atlantic sturgeon as a single stock. In 2012, as part of the Endangered Species Act listing, the National Marine Fisheries Service (NMFS) identified five Distinct Population Segments (DPS) based on genetic analysis of Atlantic sturgeon in U.S. waters: Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic. This assessment evaluated Atlantic sturgeon on a coastwide level as well as a DPS-level when possible. Additionally, a mixed stock analysis of mid-Atlantic shelf aggregations vulnerable to fishery bycatch indicated the presence of multiple populations and DPS units, indicating that bycatch mortality has continued to occur on a coastwide basis since ASMFC implemented a moratorium on the species.

Landings

Atlantic sturgeon are one of the largest and longest-lived anadromous fish in North America and have supported fisheries of varying magnitude since colonial times. Colonists harvested Atlantic sturgeon for export from New England and the Chesapeake Bay as early as the 1600s. Records of commercial landings were available from 1880 through the mid- to late-1990s. Available data suggest that coastwide landings peaked in the late 1800s and declined precipitously to low levels in the early 20th Century. Based on concerns of overfishing and bycatch mortality, the ASMFC instituted a coastwide moratorium in 1998. Landings data were not available for this assessment after the moratorium, therefore the assessment relies upon data from fisheries-independent sources and NMFS observer data.

Indices of Relative Abundance

While there are no surveys designed to directly monitor Atlantic sturgeon abundance, this assessment used nine fishery-independent surveys along the coast to develop indices of relative abundance. Three of the nine surveys were not used in modeling approaches due to their limited time series. Many of the criteria for survey selection had to be relaxed and therefore surveys developed into indices only encountered sturgeon in 1-3% of the tows and had high standard errors associated with the estimates.

Abundance and Biomass

Several trend analysis approaches were explored by the stock assessment subcommittee (SAS) to detect the presence of significant increasing or decreasing trends in the regional and coastwide abundance indices and the ability to identify DPS-level trends in the available data sets. Approaches included a Mann-Kendall test, Autoregressive Integrated Moving Average

(ARIMA) model, and power, cluster, dynamic factor, and population viability analyses. Several of these approaches indicated that there were no significant trends in the various time series with some exceptions. Both the Mann-Kendall test and population viability analysis detected a significant upward trend in one of the abundance indices developed from North Carolina's Program 135 survey. Cluster and dynamic factor analyses indicated that DPS-level clustering in the data sets could not be detected and that there was only one trend in the abundance indices, suggesting a coastwide rather than DPS-structured stock based on the indices. The ARIMA model indicated that when using all available years of data for all indices, the terminal year index values were all credibly above the 25^{th} percentile of their respective time series and either had no significant trend or an increasing trend.

Coastwide abundance or population size estimates were not available, although the SAS did estimate effective population size using genetic data. Additionally, stock reduction analysis was used to explore the population dynamics of Atlantic sturgeon. While the results from the analysis could not be used to evaluate stock status, it did indicate that the population declined rapidly at the beginning of the time series through the early 1900s to a low but stable abundance, with the population beginning to increase again from the late 1990s onwards.

Mortality Estimates

Estimates of total mortality produced from an acoustic tagging model were compared to total mortality thresholds defined as the value of total mortality, Z, that results in an egg-per-recruit (EPR) that is 50% of the EPR of an unfished stock, $Z_{50\%EPR}$, at both the coastwide and DPS-level. The results of this comparison suggest that coastwide total mortality ($Z_{coast\text{-}2015} = 0.04$) is below the coastwide threshold for total mortality ($Z_{50\%EPR,\ coast} = 0.09$). The point estimate of Z for the New York Bight DPS ($Z_{NYB\text{-}2015} = 0.09$) was below the northern region Z threshold ($Z_{50\%EPR,\ north} = 0.10$). The point estimates of Z for the other DPS areas were above the region-specific Z thresholds; however, the DPS-level estimates of Z from the tagging model had wide credible intervals that included the Z threshold in all cases, so one cannot conclude with statistical certainty whether the DPS-level estimates of Z are above or below its respective thresholds.

Stock Status

Although Atlantic sturgeon received full protection as a federally Endangered Species, there remains no Recovery Plan against which to evaluate Atlantic sturgeon status at the coastwide or DPS-level. For this assessment, stock status was assessed relative to relative abundance and total mortality on both a coastwide and DPS basis.

All DPSs were considered depleted relative to historical levels of abundance. For population size, status determination was made qualitatively relative to the historical abundance and relative to 1998, the start of the coastwide moratorium when more quantitative datasets were available. The 2015 (terminal year) index values of the selected fisheries-independent surveys were compared to the 25th percentile of the time series and to the index value that occurred during 1998 (year of coastwide implementation of the Atlantic sturgeon moratorium). The terminal year values for all indices were above the 25th percentile of their respective time series. The results of the comparison of terminal year index values to the 1998 value were mixed, with some above and some below the 1998 value.

The coastwide estimate of total mortality was below the $Z_{50\%EPR}$ threshold, suggesting current levels of mortality for the entire meta-population are sustainable. DPS-level estimates were generally above the *Z* threshold, but those estimates were highly uncertain.

		Biomass/Abundance Status	
Population	Mortality Status	Relative to Historical Levels	Terminal year of indices relative to start of Moratorium (1998)
Coastwide	Below *Z* threshold*	Depleted	Above
Gulf of Maine DPS	*Above Z threshold (highly uncertain)*	Depleted	Below**
New York Bight DPS	*Below Z threshold (highly uncertain)*	Depleted	Above
Chesapeake Bay DPS	*Above Z threshold (highly uncertain)*	Depleted	Below
Carolina DPS	*Above Z threshold (highly uncertain)*	Depleted	Above
South Atlantic DPS	*Above Z threshold (highly uncertain)*	Depleted	Unknown (no available indices)

*: Credible interval of *Z* includes threshold
**: ME-NH trawl survey index begins in 2000

The SAS concluded that the primary threats to the recovery of Atlantic sturgeon stocks include bycatch mortality, ship strikes, and habitat loss and degradation. Several research recommendations were made to address data and modeling limitations as well as threats and barriers to recovery.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

TERMS OF REFERENCE (TOR) REPORT SUMMARY

TOR1. Define population structure based on available genetic and tagging data. If alternative population structures are used in models (e.g., DPS, coastwide, river system), justify use of each population structure.

Historically, ASMFC has managed Atlantic sturgeon as a single stock, although they were evaluated on a river-by-river basis in the most recent assessment (ASMFC 1998). In 2012, as part of the Endangered Species Act listing, NMFS identified five Distinct Population Segments (DPS) of Atlantic sturgeon in US waters: Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic. These DPS designations were based on genetic analysis.

Since the last ASMFC assessment and NMFS status review, there is evidence of new spawning tributaries throughout the species range. Most of these newly discovered populations are likely low in abundance and some show strong connectivity to other spawning tributaries through the movements of adults during putative spawning periods. Additionally dual fall and spring runs have been noted in some tributaries for the Chesapeake, Carolina, and South Atlantic DPSs. Molecular research supports separate lineages for juveniles and adults found in these new spawning tributaries.

An overall pattern of small sub-populations connected through migration is emerging, which contrasts with the previously held view of a small number of discrete populations. Genetic evidence also supports that these sub-populations can be nested within the existing DPS classification. Overall, recent research supports the meta-population construct implemented through NMFS's DPS classification but revisions to spawning tributary membership in particular DPS units are likely in the coming years.

Since many available data sets, including historical landings and indices of abundance, cannot be separated to the DPS or river level, an alternative coastwide definition of stock was implemented in the ASMFC stock assessment. This stock structure definition is more operational than ecologically based but permitted assessment on overall coastwide trends in abundance and threats, but curtails full consideration of conservation risks that occur on individual sub-populations.

TOR2: Characterize the precision and reliability of fishery-dependent and fishery-independent data, including tagging data that are used in the assessment, including the following but not limited to:

a. Provide descriptions of each data source (e.g., geographic location, sampling methodology, and potential explanation of anomalous data).

Atlantic sturgeon fisheries-dependent and -independent data were evaluated from several sources: historical landings, Northeast Fisheries Observer Program (NEFOP) and the Northeast Fishery At-sea Monitoring (ASM) Program, North Carolina Gill-Net Fisheries, South Carolina

American Shad Gill-Net Fishery, and nine federal or state-conducted surveys. Historical landings were available from the commercial harvest along the Atlantic coast beginning in 1880 when the federal government initiated consistent records. While this data set represents the best available data, there are years of missing data likely due to reporting issues, there is missing coverage in some geographic areas, and the dataset ends in 1998 when the moratorium was implemented. NEFOP/ASM had provided observer coverage on commercial fishing boats from Maine to North Carolina since 1989 (ASM began in 2010) and supplied this assessment with biological information and bycatch data for Atlantic sturgeon. The North Carolina Gill-Net Fisheries dataset comes from at-sea onboard observers from the fall flounder fishery as well as other large and small mesh fisheries in the state. Like NEFOP/ASM, this dataset provided bycatch and biological data. South Carolina instituted mandatory catch and effort reporting from licensed fishermen for the American shad gill-net fishery in 1998 and began requiring reporting of Atlantic sturgeon bycatch in 2000. There are reporting issues with this dataset in some river systems, but it does provide meaningful bycatch data for South Carolina. Delaware State University designed a research project to study methods for reducing Atlantic sturgeon bycatch in gill-nets. Atlantic sturgeon lengths from this project were supplied and used in the egg-per-recruit model. See section 4 for a more thorough description of the fishery-dependent data sets.

Fifty fishery-independent and -dependent surveys were considered for this stock assessment for developing indices of abundance and the stock assessment subcommittee (SAS) narrowed it down to nine fishery-independent surveys. Fishery-independent surveys were evaluated and accepted or rejected for use based on criteria developed by the SAS including survey length, geographic range, sampling methodology, and prevalence of Atlantic sturgeon in catches. There were no surveys available that were designed to capture and monitor Atlantic sturgeon, so several of the selected datasets had low detection rates (i.e., 1-3% positive tows). The surveys selected represented all 5 DPSs for Atlantic sturgeon and most were statistically designed random sampling programs. For more information on the fishery-independent surveys used for developing indices of abundance, see section 5.

Coastwide conventional tagging data for Atlantic sturgeon was available from the US Fish and Wildlife Service database. The decision was made not to analyze these data as a result of concerns about collection methods, completeness, and various errors within the database. Atlantic sturgeon have been implanted with acoustic transmitters by a number of researchers throughout the Atlantic Coast and this data was available from 2006-2015 and used in this assessment for estimating survival rates at the coastwide and DPS-level (section 6.12.2).

b. Describe calculation and standardization (if performed) of abundance indices and other statistics including measures of uncertainty.

For the NEFOP/ASM data set, a generalized linear model (GLM) framework was developed to estimate Atlantic sturgeon discards from the federal waters. The GLM modeled Atlantic sturgeon takes on each trip as a function of the trip-specific species mix, year, and quarter. Candidate models were fit separately to all observed bottom otter trawl and gill-net (sink and drift) trips for 2000-2015 (section 6.2.1). The North Carolina Gill-Net Fisheries dataset estimated bycatch using a GLM approach (section 6.2.2). South Carolina calculated an average annual catch per unit effort (CPUE) of Atlantic sturgeon per net yard per hour from the American shad gill-net fishery dataset (section 6.2.3).

Fishery-independent survey data were standardized using GLMs incorporating environmental and methodological covariates so as to account for species-specific drivers that may not be captured by the survey's statistical design. Nominal indices of abundance were developed for two of the nine surveys because one provided a longer time-series and the other only had 'year' as a significant cofactor. For a more detailed description of each standardized index and the model used, see section 5.

The acoustic tagging model was designed based on Kéry and Schaub (2012) and Hightower et al. (2015) and a simulation study was used to evaluate model performance. Uncertainty in annual and monthly survival rates for Atlantic sturgeon was characterized using 95% credible intervals.

c. Discuss trends and associated estimates of uncertainty (e.g., standard errors).

The analysis of the NEFOP/ASM bycatch data found that most trips that encountered Atlantic sturgeon were in depths less than 20 meters and water temperatures between 45-60°F. While the annual Atlantic sturgeon take for bottom otter trawls was variable from 2000-2015 and dead discards averaged 4% of the take, there was an overall decreasing trend across the time series. For gillnets, there was more variability and no overall detectable trend and dead discards were higher for this gear at an average of 30%. Standard errors were calculated for the estimates and were higher for gillnets than bottom otter trawls (section 6.2.1). Predicted Atlantic sturgeon bycatch numbers from the North Carolina data set for 2004-2015 ranged from 1,286-13,668 a year, although generally the most recent years were lower than estimates in the earlier years (section 6.2.2). The annual average CPUE for Atlantic sturgeon caught in South Carolina's American shad fishery ranged from 0.000013-0.00035 depending on the river. Shad regulations changed in 2013 and CPUE had decreased significantly since then, with some South Carolina rivers now reporting no Atlantic sturgeon bycatch (section 6.2.3).

For abundance indices developed from fishery-independent surveys, trends in abundance and standard errors fluctuated over various time series. Many surveys had very large standard errors associated with them, likely due to the fact that none of the surveys target Atlantic sturgeon and annual numbers were very low in some cases. Trend analysis did indicate most surveys analyzed had no significant trend in the data with a few exceptions. All abundance surveys were combined using a hierarchical analysis from Conn (2010) to develop a coastwide index which indicated a relatively stable abundance trend from 1984-2015, with higher errors associated in the early years of the time series than later years.

Uncertainty in the acoustic tagging model's mortality rates was substantially lower for coast wide estimates versus DPS-specific estimates. Coastwide, annual survival was high for both juvenile and adult Atlantic sturgeon. For individual DPS mean survival estimates, survival was variable and lower than the coastwide estimates and was sensitive to the amount of data available by region, as expected.

d. Justify inclusion or elimination of available data sources.

Approximately fifty fishery-independent and -dependent surveys were considered by the SAS for inclusion in the analyses. Many were ruled out due to not reliably encountering Atlantic sturgeon and the remaining data sets were further evaluated and several were excluded due to limited or broken time series, limited spatial coverage, or were not designed in a statistical framework (Table 15). Conventional tagging data was not used because of concerns about collection methods, completeness, and various errors within the database and therefore the acoustic tagging data was used.

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

Each DPS had at least one survey operating in the region that was developed into an abundance index, although not all surveys could be used in trend analysis due to their short length (<15 years of data). Because these surveys did not target Atlantic sturgeon, most had low detection rates and high standard errors associated with relative abundance estimates. For the bycatch data, overall the three data sets used for estimating bycatch represented areas along the coast. For the acoustic tagging model, coastwide estimates were robust and similar for juveniles and adults. For some DPSs, estimates had very high 95% credible intervals and estimates for those regions were not deemed as reliable by the SAS.

TOR3: Develop biological reference points for Atlantic sturgeon populations.

The traditional approach for determining stock status is to identify a reference point for a stock characteristic (e.g., stock size, fishing mortality) and compare a recent estimate of that characteristic to the selected reference point. Thresholds are typically used for the definition of stock status (i.e., overfished and overfishing) while targets identify a desirable level of fishing mortality or biomass.

Reference points selected for evaluation were relative abundance and total mortality. Reference points for relative abundance were developed based on ARIMA modeling (see section 6.9). The terminal year from indices of relative abundance were compared to two threshold reference points: (1) the 25th percentile of the fitted time series and (2) the fitted index value that occurred during 1998 (year of coastwide implementation of the Atlantic sturgeon moratorium).

Total mortality (Z) reference points were developed based on a series of eggs-per-recruit analyses (see section 6.14). Z thresholds were defined as the value of Z that results in an EPR that is 50% of the EPR of an unfished stock, $Z_{50\%EPR}$. These total mortality thresholds were developed at the coastwide level and for both northern and southern DPS areas. The thresholds represent a numbers-weighted value for ages 4 to 21, the ages represented in the tagging model (see section 6.12). The coastwide estimate of $Z_{50\%EPR}$ ranged from 0.085 to 0.094 depending on the assumed level of ship strike and bycatch mortalities. The SAS chose a mid-point value of 0.09 for the coastwide $Z_{50\%EPR}$. For the northern DPS area, the value of $Z_{50\%EPR}$ ranged between 0.10 and 0.11 depending on the assumed level of ship strike and bycatch mortalities. Erring on the conservative side puts the value at 0.10 for the northern DPS area. The value of $Z_{50\%EPR}$ in the southern DPS area ranged between 0.12 and 0.13. A value of 0.12 was selected for $Z_{50\%EPR}$ in the southern DPS area to take a slightly more conservative approach.

Depletion-based stock reduction analysis (DBSRA) was used to estimate unexploited stock size of Atlantic sturgeon. DBSRA uses a time-series of historical landings in conjunction with information on sturgeon life history and expert opinion on current stock size relative to the population's carrying capacity to estimate what unexploited stock size would have to have been to sustain the observed removals without going extinct. Because historical landings cannot be separated to DPS this analysis could only be conducted at the coastwide level. Atlantic sturgeon unexploited stock size was estimated to be 27,760 mt, with a B_{MSY} of 11,047 mt. Exploration of a multi-stanza carrying capacity model supports the idea that carrying capacity or stock productivity has declined since the beginning of the time-series.

TOR4: Review existing estimates of Atlantic sturgeon bycatch (retained and discarded) and, if possible, develop a time-series of bycatch in monitored fisheries, and discuss the assumptions and applicability of such estimates to reference points.

Estimates of Atlantic sturgeon bycatch were developed from two observer programs: the NEFSC Northeast Fisheries Observer Program, which observes trips in primarily federal waters from Maine to North Carolina, and the North Carolina Division of Marine Fisheries' (NCDMF) Sea Turtle Bycatch Monitoring Program (Program 466) and Alternative Platform Observation Program (Program 467), which observe trips in North Carolina's estuarine gillnet fisheries.

A generalized linear model (GLM) framework was developed to estimate Atlantic sturgeon discards in federal waters from the NEFOP/ASM data (Miller and Shepherd 2011). For this assessment, a quasi-Poisson assumption was used for modeling Atlantic sturgeon takes as a function of species landed, year, and quarter. Models were fit to a subset of observer trips between 2000 and 2015 that included all coastal statistical areas and those observer programs that encountered Atlantic sturgeon and had a representative geographic range. Gillnet trips and trawl trips were modeled separately. To predict Atlantic sturgeon catch for all commercial landings, landings for each trip between 2000 and 2015 in the VTR database were determined for each species covariate. Using the estimated coefficients from the best performing model for each gear, the expected Atlantic sturgeon take was predicted for each VTR trip where information was available on whether the species was landed, and, if necessary, year and quarter. Dead discards were estimated by calculating the proportion of observed Atlantic sturgeon recorded as dead and applying this proportion to the total catch estimate.

The best performing model for each gear type was applied to vessel trip reports to predict Atlantic sturgeon take for all trips. The total bycatch of Atlantic sturgeon from bottom otter trawls ranged between 624–1,518 fish over the time series. The proportion of the encountered Atlantic sturgeon recorded as dead ranged between 0–18% and averaged 4%. This resulted in annual dead discards ranging from 0–209 fish. Likewise, the total bycatch of Atlantic sturgeon from sink and drift gill nets ranged from 253–2,715 fish. The proportion of Atlantic sturgeon recorded as dead ranged between 12–51% and averaged 30%, resulting in annual dead discards ranging from 110–690 fish. Since 2000, there has been little overall change in annual dead discard numbers.

A generalized linear model (GLM) framework was used to predict Atlantic sturgeon interactions in North Carolina's estuarine gill-net fishery based on data collected during 2004 through 2015. The numbers of Atlantic sturgeon occurring as bycatch was modeled by a set of explanatory variables and an offset term for effort using a standard Poisson model. The variables best fitting model included year, mesh size, season, and management unit, all of which were treated as categorical variables. Predicted numbers of Atlantic sturgeon bycatch were computed using the best-fitting GLM and assuming effort levels equivalent to those observed in 2004 through 2015. The GLM coefficients were applied to the corresponding predictor variables in the trip-level effort data to predict bycatch numbers.

Predicted total bycatch numbers for 2004 to 2015 ranged from a low of 1,286 Atlantic sturgeon in 2011 to a high of 13,668 Atlantic sturgeon in 2008. The proportion of fish observed dead was applied to the estimates of total bycatch to obtain estimates of dead discards. The percent of observed Atlantic sturgeon recorded as dead ranged from 0 - 20%, with an overall mean of 6%. Estimates of dead discards ranged from 0 – 424 fish. Estimates of total bycatch in the most recent years (2010-2015) were generally lower than estimates for the earlier years (2004-2009).

The estimates of total bycatch from the North Carolina estuarine gillnets were higher than the estimates of bycatch from the coastal gillnets, but the observed proportion dead in the North Carolina data was lower than in the NEFOP/ASM data, resulting in similar estimates of dead discards. The biological data collected by these two programs indicated the North Carolina estuarine fisheries were operating on a different component of the population than the coastal fisheries. The mean size of Atlantic sturgeon caught in the North Carolina estuarine gillnet fisheries was 65 cm TL and 2.12 kg, while the mean size of Atlantic sturgeon caught in the coastal gillnet fisheries was 132 cm TL and 20.1 kg. Atlantic sturgeon caught in the coastal trawl fisheries were a similar size, with a mean length of 143 cm TL and a mean weight of 24.7 kg.

Bycatch numbers could not be allocated to populations or DPS units for either analysis, but coastal aggregations which are intercepted by trawl and gillnet fisheries are known to comprise mixed populations from all DPS units.

TOR5: If possible, develop models to estimate population parameters (e.g., F or Z, biomass, and abundance) and analyze model performance and stability.

A Cormack–Jolly–Seber (CJS) model was applied to acoustic tagging data to estimate survival at the coastwide and DPS level. Data for this analysis were provided by 12 different researchers and state agencies from all five DPSs. A total of 1,331 tagged Atlantic sturgeon detection records (Table 35) were available from a period of January 2006–December 2015. The size of Atlantic sturgeon at tagging ranged from 29.8–268.0 cm TL. Atlantic sturgeon were assigned to a DPS based on genetic information (collected at tagging and analyzed in conjunction with this assessment), if available, or their tagging location. The model was implemented in R and WinBUGS.

The coastwide mean survival estimate was high for all Atlantic sturgeon, at 0.96 (0.84–0.99, 95% credible interval). Adult survival (0.94, 0.71–1.00) was slightly higher than juvenile survival (0.91, 0.63–1.00). Estimates from the best supported model used a single survival estimate, but had varying monthly detection. All models produced similar estimates of survival, suggesting robust results.

Individual DPS mean survival estimates were variable and lower than the coastwide pooled estimates. Estimates from the best supported model used a single survival estimate, but had varying monthly detection. The credible intervals for the DPS-level estimates of survival were wider than the coastwide estimates. These results may be due to low sample size in these size groups and not necessarily low survival. Further tagging studies may be required to improve estimates in these areas.

TOR6: State assumptions made for models and for calculations of indices and other statistics. Explain the likely effects of assumption violations on synthesis of input data and model outputs.

Indices are calculated using specific distributional assumptions to standardize for effects of factors like environmental conditions that are not considered in the survey design. These assumptions are tested through the standardization process to identify the statistically most appropriate distribution, but natural data do not follow a theoretical distribution perfectly. Misspecifying the distribution underlying the GLM standardization approach will result in incorrect estimates of variance and potentially biased indices. In addition, although some indices track abundance of juveniles and can be assigned to an individual DPS, many trawl-based indices are likely sampling fish from other DPS units than the waters in which they operate.

The tagging model explored a number of assumptions about model structure, including time- and DPS-varying survival and detection probabilities. The final model was chosen based on the DIC, so the quality of information in the available data influences the model structure selected. Better quality data, including more tagged fish at the DPS and size class category, might change the structure of the model selected. In addition, the model assumes that all tagged fish disappear from the model due to mortality, not tag loss or failure. If tag failure is a more common event than assumed, estimates of survival will increase.

The EPR analysis uses the traditional equilibrium assumptions about natural mortality, size and fecundity at age, maturity, and selectivity. Current estimates of M, growth, and fecundity need more research, especially at the DPS level, but violating the assumption of time-constant parameters would have a bigger effect on the EPR results. Similarly, the selectivity of bycatch and shipstrike sources of mortality is poorly known and needs more research. Total mortality will be sensitive if selectivity changes on immature individuals.

The DBSRA model was most sensitive to assumptions about the state of the population relative to the unfished state. Estimates of allowable removals were sensitive to a number of assumptions about the shape of the underlying production curve, the status of the population at the end of the time-series, and other parameters, but the estimates of unexploited stock size were robust to these assumptions.

TOR7: Where possible, assess stock status based on biological characteristics, including but not limited to:

a. Trends in age and size structure

Available data on age and size structure were limited temporally or by small sample sizes. For this reason, it was not possible to assess stock status relative to trends in age and size structure on a coastwide, DPS, or population level.

b. Trends in temporal indicators of abundance

Indices of relative abundance, grouped by DPS, were compared to the threshold reference points defined in TOR #3 based on ARIMA modeling (see section 6.9). No statistically significant monotonic trends were identified in the adult or subadult and adult surveys. The Gulf of Maine, New York Bight, Chesapeake Bay, and Carolina DPS areas are above the 25th percentile of their respective time-series. The South Atlantic DPS was unknown because there was no abundance index from that DPS with a long enough time series to use in ARIMA.

TOR8: Characterize uncertainty of model estimates and biological or empirical reference points.

Estimates of bycatch had fairly wide confidence intervals due to the low sample sizes of Atlantic sturgeon in the observer datasets.

The trend analysis and ARIMA model results are influenced by the uncertainty in the indices of abundance. The indices generally had low encounter rates with Atlantic sturgeon and wide confidence intervals around the estimates of CPUE, which reduced the models abilities to detect significant trends.

Estimates of survivorship from the tagging model were more robust for the coastwide model, with the annual estimate of survival having a lower standard deviation and tighter credible intervals than the DPS-level estimates. Similarly, estimates of survival for adults and for juveniles were more uncertain than estimates for the pooled size classes. Sample size is most likely driving these differences, with the most precise estimates coming from the pooled samples.

The uncertainty of the $Z_{50\%EPR}$ estimates was explored by calculating the value over a range of ship strike and bycatch mortalities (see section 6.14). In general, there was little difference among the $Z_{50\%EPR}$ values over the ranges explored for both the coastwide analysis and the northern and southern DPS area analyses (see response to TOR #3).

Estimates of unexploited population size from the DBSRA analysis had reasonable confidence intervals. Uncertainty in this model is driven in part by the uncertainty assumed in the input parameters, so widening the range of parameter values that model draws from will increase uncertainty, but it also is affected by the ability of the model to fit a range of K that results in a trajectory of biomass that did not cause the population to go extinct or recover beyond the assumed terminal year status.

TOR9: Recommend stock status as related to reference points (if available). For example:

a. Is the stock below the biomass threshold?

The SAS was unable to develop estimates of current biomass or abundance at the coastwide or DPS level.

b. Is mortality above the threshold?

At the coastwide level, the estimates of total mortality from the tagging model for all fish age 4 to 21 ($Z_{coast\text{-}2015}$ = 0.04) was below the Z threshold ($Z_{50\%EPR\ coast}$ = 0.09).

The point estimate of Z for the New York Bight DPS ($Z_{NYB\text{-}2015}$ = 0.09) was below the northern region Z threshold ($Z_{50\%EPR\ north}$ = 0.10). The point estimates of Z for the other DPSs were above the region-specific Z thresholds. However, the DPS-level estimates of Z from the tagging model had wide credible intervals which included the Z threshold in all cases, so we cannot say with statistical certainty whether the DPS-level estimates of Z are above or below the thresholds.

c. Is the index above or below a reference index value?

The terminal year values for all indices were all credibly above the 25th percentile of their respective time series.

The situation relative to index values in 1998, the year the coastwide moratorium was implemented, was mixed. The 2015 index from the Gulf of Maine DPS (ME-NH Trawl survey) was not credibly above the index value in 2000 (survey started in 2000). All terminal year indices from surveys in the New York Bight DPS were credibly above their respective 1998 index values. Terminal year index values from surveys in the Chesapeake Bay DPS were not credibly above their respective 1998 index values. Finally, terminal year index values for all fitted indices in the Carolina DPS, save one, were above their respective 1998 index values. The South Atlantic DPS status relative to 1998 is unknown because the one survey developed for that region was not long enough to test.

TOR10: Other potential scientific issues:

a. **Compare reference points derived in this assessment with what is known about the general life history of the population unit. Explain any inconsistencies.**

The $Z_{50\%EPR}$ estimates developed in this assessment are very low, but that is consistent with what we know about the life history of Atlantic sturgeon. They are long-lived, slow-growing, and slow to mature. In addition, they are vulnerable to incidental mortality before they mature, which lowers the amount of anthropogenic mortality they can sustain.

The DBSRA estimate of unexploited stock size is 27,760 mt. Recorded landings of approximately 2,000 - 3,000 mt at the beginning of the historical record (which are most likely an underestimate) would therefore be an exploitation rate of 10%, higher than the total mortality benchmark and consistent with overexploitation that allowed high catches but quickly drove the stock to depleted levels.

TOR11: Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

The Atlantic Sturgeon SAS and Technical Committee (TC) identified a number of research recommendations to improve future stock assessments. High priority research needs include monitoring bycatch and bycatch mortality, establishing regional and coastwide fishery-independent surveys to monitor annual abundance, continuing genetic sampling and refining the baseline, increasing the sample size of acoustically tagged fish, collecting data on regional vessel strike occurrences, and collecting DPS-specific age, growth, fecundity, and maturity information.

TOR12: Recommend timing of next benchmark assessment and intermediate updates, if necessary, relative to biology and current management of the species.

The Atlantic sturgeon SAS and TC recommend that an assessment update be considered in five years, although recognizing the life history and data needs it is unlikely that a significant increase in information will be available by that time. The SAS and TC recommend that a benchmark stock assessment be conducted in ten years if improvements in data have been made. The SAS and the TC also recommend that members stay proactive about monitoring research programs and maintaining current sampling programs.

1 INTRODUCTION

1.1 Brief Overview and History of the Fisheries

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) are one of the largest and longest-lived anadromous fish in North America and can be found along the entire Atlantic coast from Labrador, Canada to St. Johns River, Florida (refer to Appendix B for more information on the types of water bodies and systems where Atlantic sturgeon are known (or expected) to occur within each distinct population segment). These taxonomically primitive fish have been taken for food by humans for at least 3,000-4,000 years (Warner 1972) supporting fisheries of varying magnitude since colonial times—there are reports from Maine and Massachusetts from as early as the 1600s that cite Atlantic sturgeon as an important fishery in those states (Wheeler and Wheeler 1878; Jerome et al. 1965). However, larger scale commercial fisheries for this species did not exist until the mid-1800s (Goode 1887). Sturgeon were primarily harvested for their flesh and eggs (caviar from sturgeon eggs was considered a delicacy in Europe), although other parts had commercial value as well. Sturgeon skin was made into leather for clothes and bookbinding, and a component of the swim bladder was used to make adhesives and a gelatin that served as a clarifying agent in jellies, wine and beer. Swim bladders were also fashioned into windows for carriages (Goode 1887).

Records of Atlantic sturgeon commercial harvest have been kept since 1880 (Figure 1). At that time, Atlantic sturgeon were among the top three species in weight of fish harvested commercially along the Atlantic coast, and considered second in value only to lobster (US Bureau of Fisheries 1907; US Commission of Fish and Fisheries 1884-1905). Although landings data prior to 1967 do include shortnose sturgeon (shortnose sturgeon were listed under the Endangered Species Act in 1967, formerly the Endangered Species Preservation Act) it is likely that the bulk of those landings can be attributed to the much larger Atlantic sturgeon (Secor and Waldman 1999). Atlantic sturgeon landings peaked in 1890 at 3,348 metric tons (mt) and were dominated by the Mid-Atlantic jurisdictions (e.g., the Hudson and Delaware Rivers and the Chesapeake Bay systems), although landings also came from southeastern states of North Carolina, South Carolina and Georgia. By 1901, the fishery collapsed to less than 10% of its peak landings recorded roughly a decade earlier (Secor 2002). Landings continued to decline and remained between 1-4% of its peak from 1910 to 1995. After the collapse of Atlantic sturgeon stocks in the Mid-Atlantic region, landings for North Carolina, South Carolina, and Georgia dominated the coastal harvest. Landings for these states declined by the 1980s and coastwide harvest shifted back to New York and New Jersey. There are no records of a significant recreational fishery for Atlantic sturgeon. Refer to Appendix B for more detail on the history of Atlantic sturgeon fisheries within each Distinct Population Segment (DPS).

1.2 Management History

By the late 1980s, commercial fishing operations (directed and incidental) were still conducted on remnant populations throughout much of the species range. Acknowledging that restoration of the stock would not be realized without immediate management action, the Atlantic States Marine Fisheries Commission (ASMFC or Commission) began development of a Fishery

Management Plan (FMP) for the species which was implemented in 1990. The goal of the FMP is to provide a framework for the restoration of Atlantic sturgeon to fishable abundance throughout its range. For the FMP, fishable abundance was defined as 700,000 pounds, or 10% of 1890 landings of 7 million pounds. Among the management recommendations of that plan was the statement that states should adopt a: 1) minimum size limit of 2.13 m total length (TL) and institute a monitoring program; 2) a moratorium on all harvest; or 3) for states and jurisdictions to submit an alternative management program to the Plan Review Team for determination of conservation equivalency.

The FMP suggested that the dramatic decline in landings was primarily caused by overfishing, although habitat loss and degradation, and impediments to spawning areas (i.e., dams) likely also contributed to the decline. By 1996 (and as early as 1984 in some states), Atlantic sturgeon fishery closures were instituted in ten states and jurisdictions along the Atlantic Coast. Since 1997, all states have enacted bans on harvest and possession of Atlantic sturgeon and sturgeon parts. Despite these closures stocks continued to decline. In response, the Commission's member states and jurisdictions determined that the FMP was insufficient for conservation and restoration of Atlantic sturgeon stocks and initiated development of Amendment 1 which was approved in June 1998. The goal of the Amendment "is to restore Atlantic sturgeon spawning stocks to population levels which will provide for sustainable fisheries, and ensure viable spawning populations." The Amendment strengthens conservation efforts by formalizing the closure of the directed fishery and by banning possession of bycatch and eliminating any incentive to retain Atlantic sturgeon. Under Amendment 1, states must maintain complete closure of any directed fishery for Atlantic sturgeon and prohibit landings from any fishery until stocks exhibit a minimum of 20 protected year classes of spawning females and the FMP is modified to permit harvest and possession.

The Amendment also requires states to monitor, assess, and annually report Atlantic sturgeon bycatch and mortality in other fisheries, although bycatch reporting is widely accepted as being underreported or not reported at all. The Amendment also requires that states annually report habitat protection and enhancement efforts. Finally, each jurisdiction with a reproducing subpopulation should conduct juvenile assessment surveys (including CPUE estimates, tag and release programs, and age analysis). States with rivers that lack a reproducing Atlantic sturgeon subpopulation(s) but support nursery habitat for migrating juveniles should also conduct sampling.

Applicants for exemption to the ban on possession for aquaculture and importation of non-indigenous Atlantic sturgeon (i.e., originating from outside U.S. jurisdiction) must adhere to the terms, limitations, enforcement, and reporting requirements which were approved by the Commission in January 2001 and receive approval from the Board through the adaptive management process. For example, Addendum I (2001) to the Atlantic sturgeon FMP exempts Florida from the possession moratorium for the purposes of developing private aquaculture facilities for cultivation and propagation of the species. Addendum II (2005) exempts a private company in North Carolina from the moratorium on possession, propagation, and sale of Atlantic sturgeon meat and eggs and allows a Canada-based exporter to export Atlantic sturgeon fry and fingerlings into North Carolina. Addendum III (2006) similarly allows a private company in North Carolina to import Atlantic sturgeon from a Canada-based exporter.

Addendum IV to Amendment 1, approved in 2012, updates habitat information for Atlantic sturgeon and identifies areas of concern and research needs.

1.3 Stock Assessment History

Per the 1998 Atlantic sturgeon stock assessment report, Atlantic sturgeon populations throughout the species' range were either extirpated or considered to be at historically low abundances (ASMFC 1998). The report defined the target fishing mortality (F) rate as that level of F that generated an eggs-per-recruit (EPR) equal to 50% of the EPR at F = 0.0 (i.e., a "virgin stock," or a stock that is yet to experience mortality due to fishing). This target rate (F_{50}) equals 0.03 (annual harvest rate of 3%) for a restored population. This target is far below estimates of F prior to enactment of the fishery moratoria, which ranged from 0.01–0.12 for females and 0.15–0.24 for males. It is important to note that while these estimates were determined for the Hudson River stock and may not apply to other specific stocks along the Atlantic coast, they are suggestive of the coastwide population.

Although populations of Atlantic sturgeon have persisted, adult population abundance in some systems may be so low as to significantly impede reproduction success and timely recovery. Recruitment levels have been estimated in only the Hudson and Altamaha Rivers in single year studies. In many systems age-0 and age-1 juveniles remain undetected despite directed efforts to do so. Impediments to recovery largely include historical overfishing, incidental bycatch, ship strikes, and the degradation and loss of essential fish habitat (e.g., spawning and nursery grounds). The 1998 report also suggested that aside from major threats to existing habitat, including climate change, reducing bycatch mortality is of greatest importance to restoring Atlantic sturgeon.

1.3.1 Endangered Species Act

Undertaken concurrently with the Commission's stock assessment in 1998, NOAA Fisheries evaluated the status of the species with regard to listing under the Endangered Species Act (ESA). That Status Review Report concluded that listing was not warranted at the time (NOAA 1998).

In February 2007, a Status Review Team (SRT) finalized its report on the status of U.S. Atlantic sturgeon (ASSRT 2007). The SRT identified five DPSs—discrete population units with distinct physical, genetic, and physiological characteristics—along the Atlantic coast: Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic (Figure 2). The SRT concluded that there was a greater than 50% chance that the Carolina, Chesapeake Bay, and New York Bight DPSs would become endangered within the next 20 years. The biggest threats to the recovery of the DPSs included bycatch mortality, water quality, lack of adequate state or federal regulatory mechanisms, and dredging activities. The SRT did not have enough information to decide on the status of the Gulf of Maine and South Atlantic DPSs at that time.

In 2009, the National Resources Defense Council petitioned NOAA Fisheries to list Atlantic sturgeon under the provisions of the ESA based on the recommendations from the 2007 Status Review. In January 2010, NOAA Fisheries reported that the petition may be warranted, and after further review, NOAA Fisheries published two proposed rules (75 FR 61872 and 75 FR 61904) in October 2010 to list the Gulf of Maine DPS as threatened and the remaining DPSs as endangered. Over 400 public comments were submitted to NOAA Fisheries on the proposed rule.

NOAA Fisheries published two final rules (77 FR 5880 and 77 FR 5914) in February 2012, declaring the Gulf of Maine DPS as threatened and the remaining four DPSs as endangered (effective April 2012). Additionally, pursuant to section 7 of the ESA, NOAA Fisheries released a draft biological opinion in May 2013 stating that seven Northeast fisheries will likely not jeopardize the continued existence of the five Atlantic sturgeon population segments (NOAA Fisheries Consultation No. F/NER/2012/01956). NOAA Fisheries published an Interim Final 4(d) Rule for the threatened Gulf of Maine DPS in December 2013 which essentially provides the same protection as an endangered listing.

In 2013, in response to the ESA listing, the Board initiated the development of a coastwide benchmark stock assessment to evaluate stock status, stock delineation, and bycatch. Data (including bycatch, survey, tagging, and genetic data) have been collected from dozens of state and federal agencies and academic programs throughout the coast. In 2014, the Board evaluated progress on the benchmark assessment and decided to change the completion date to 2017 to allow for the most comprehensive assessment possible.

1.4 Management Unit Definition

The management unit is defined as “Atlantic sturgeon stocks of the east coast of the U.S., from the Canadian border to Cape Canaveral in Florida” (ASMFC 1998). Accordingly, all ASMFC member states and jurisdictions, including the District of Columbia and the Potomac River Fisheries Commission, have a declared interest in the Interstate FMP for Atlantic sturgeon.

2 LIFE HISTORY

Section 2 is intended to be representative of the coastwide metapopulation. See “Appendix B” for additional DPS-specific life history information.

2.1 Stock Definitions

The Atlantic sturgeon is broadly distributed along the Atlantic coast from Florida to the Canadian Maritimes and historically ranged into Europe before its extirpation there (Ludwig et al. 2002). Adults and subadults can range extensively along the coast, and commonly comprise mixed stocks in both estuarine and coastal regions (Dunton et al. 2012; Wirgin et al. 2012). Although the coastal movements of subadults and adults are not well understood, it is generally believed that adults preparing to spawn progress northward from southern winter foraging areas towards their natal rivers (see Hilton et al. 2016 for a thorough review of Atlantic sturgeon life history). These spawning adults are followed by subadults that move into estuaries as well as adults that generally reside at the mouth of bays and nearshore coastal waters over the summer before departing southward in the fall (Welsh et al. 2002; Erickson et al. 2011; Dunton et al. 2012). Spawning takes place over coarse grained materials or bedrock. After hatching, juvenile Atlantic sturgeon reside in the freshwater portion of their natal river for their first year or two before they begin to transition into the estuary (McCord et al. 2007). Ultimately, between ages 3-5 these individuals will enter the coastal migratory stock as outlined above.

Generally speaking, each river supports a unique spawning population. Based on the observed levels of genetic differentiation, populations are expected to be demographically independent among natal rivers. In some rivers (e.g. Edisto and James in Virginia), recent work supports separate spring and fall spawning runs in several systems (Post et al. 2014; Smith et al. 2015; Balazik et al. 2017; Farrae et al. 2017). There is also increasing evidence of adults visiting multiple spawning tributaries during the same spawning season, suggesting a degree of straying particularly between adjacent rivers (C. Stence, MD DNR, pers. comm.).

For the purpose of management, Atlantic sturgeon populations within the United States are divided into DPSs under the Endangered Species Act, reflecting the significance and discreteness of these units (ASSRT 2007). There is minimal contemporary gene flow among the DPS units, and the units represent broad patterns in genetic structure (ASSRT 2007; Fritts et al. 2016; Savoy et al. 2017). Juveniles (<550 mm total length) and adults (≥1,300 mm total length) observed near spawning areas are generally thought to represent the population endemic to the river where they are observed. However, subadults and adults mix extensively and can only be distinguished using molecular approaches.

Contemporary spawning populations within each DPS

The stock assessment subcommittee (SAS) evaluated the spawning populations of Atlantic sturgeon along the U.S. Atlantic coast. The SAS compiled a list of rivers and tributaries by DPS and assigned a level of spawning certainty to each of them (Table 1). This list is based on the 2007 status review with updates from researchers and scientific literature for this stock assessment and likely is not a comprehensive list. In the Gulf of Maine DPS, the Kennebec is the only river with confirmed spawning and other rivers remain unknown or historical sites of spawning that have not been documented as having spawning Atlantic sturgeon in recent decades. The Connecticut, Hudson, and Delaware Rivers have confirmed spawning for the New York Bight DPS and the Tauton River remains unknown although it did have spawning Atlantic sturgeon historically. For the Chesapeake Bay DPS, the James River is the only site of confirmed spawning while four other rivers in that region are highly likely to have a spawning population. The Roanoke River in the Carolina DPS is the only river with confirmed spawning, although several more are categorized as highly likely, suspected, or unknown. The Edisto, Savannah, and Altamaha Rivers in the South Atlantic DPS are all sites of confirmed spawning, while several more rivers in the region are suspected or unknown.

2.2 Migration Patterns

The 1998 Atlantic sturgeon stock assessment relied primarily on conventional tagging data to develop information on Atlantic sturgeon migration patterns (ASMFC 1998). This method, the best at the time, depended solely on adequate tag retention and subsequent capture and reporting of the animal either by commercial fishers or by other sturgeon researchers. With the introduction of a coastwide fishing moratorium for Atlantic sturgeon and closure of fisheries in 1998, commercial fisher interaction was no longer a viable method of collecting recapture information. However, since that assessment, biotelemetry including acoustic tagging has, for the most part, replaced conventional tagging efforts because of its reliability, long lived transmitters, and cooperation among researchers. For the last 10+ years, this method of tracking animals has provided multi-year accounts of individuals and, in some cases, changed institutional knowledge and beliefs.

In northern rivers, Atlantic sturgeon most often spawn in tidal freshwater regions of large estuaries (Hildebrand and Schroeder 1928; Moser and Ross 1995; Bain 1997; Colette and Klein-MacPhee 2002). This pattern is most prevalent in New England and U.S. Mid-Atlantic estuaries where obstructions to migration at the fall line preclude upriver migration. In the south where many rivers remain unblocked, Post et al. 2014 shows that Atlantic Sturgeon used approximately 74% of the river habitats available to them within the Altamaha System below the Fall Line, including the Ocmulgee and Oconee tributaries; one individual fish migrated to RKM 408 in the Ocmulgee River, the longest documented migration of an Atlantic sturgeon within a U.S. spawning river. By comparison, spawning runs in the Roanoke River reached RKM 204, adult spawning runs in the Hudson River only reach RKM 182 and spawning runs in the James River have been documented to reach RKM 155 (Van Eenennaam 1996; Balazik et al. 2012a).

Spawning migrations are cued by temperature, which causes fish in U.S. South Atlantic estuaries to migrate earlier than those in Mid-Atlantic and New England portions of their range (Smith 1985). In Florida, Georgia, and South Carolina, spawning migrations begin in February. Collins et al. (2000) found that in the Edisto River, South Carolina, ripe males were captured as early as March 2nd, and a single ripe female was captured on March 7th. Additionally, the researchers captured spent males as early as late March and spent females as late as mid-May. In contrast, researchers in the Mid-Atlantic region report that spawning migrations for Atlantic sturgeon begin between April and May (Hildebrand and Schroeder 1928; Dovel and Berggren 1983; Secor and Waldman 1999; Bain et al. 2000). In New England and Canada, spawning migrations occur from May through July (Collette and Klein-MacPhee 2002). Furthermore, Hatin et al. (2002) reported that spawning occurred from early June to approximately July 20th in the St. Lawrence River, Québec.

In addition to a spring migration, many studies document the occurrence of a fall migration (Smith et al. 1984; Collins et al. 2000; Laney et al. 2007; Balazik and Musick 2015; Smith et al. 2015). Most fall migrations are movements out of the estuaries into marine habitats. Fall migrations occur from September through December, again, depending on the latitude (Smith 1985). In addition, some researchers have proposed that an alternate fall migration into estuaries may be related to spawning (Smith et al. 1984; Rogers and Weber 1995; Weber and Jennings 1996; Moser et al. 1998; Collins et al. 2000; Laney et al. 2007), which has recently been confirmed for the James River, Roanoke River, and Altamaha (Balazik and Musick 2015; Hilton et al. 2016).

2.2.1 Spawning

2.2.1.1 Northeast

In the Northeast, hereby defined as large coastal river systems north of the Chesapeake Bay, spawning of Atlantic sturgeon is believed to be restricted to a single spawning season in the late spring-early summer months, although recent telemetry evidence and anecdotal reports suggest a second spawning event may take place in the Delaware River (Dewayne Fox, Delaware State University, personal communication). Adults begin entering the Delaware in late April with spawning believed to take place in May and June (Borodin 1925; Simpson and Fox 2007). The timing of river entry and spawning is delayed as one moves north into the Hudson River (late May into July; Van Eenennaam et al. 1996) and further north, begins in late May and into early July while in the Kennebec River spawning is believed to occur in June and July (Wippelhauser et al. 2017). Although the timing of spawning is unknown for the Connecticut River, the length frequency distribution of river-resident juveniles supports a single spawning season (Savoy et al. 2017). Quantitative estimates of inter-basin exchange by spawning adults are not well documented, but genetic evidence suggests that recolonization may occur from distant populations (Savoy et al. 2017) or inadvertent introductions (T. Savoy, CTDEP, personal communication).

2.2.1.2 Southeast

Historically, Atlantic sturgeon in Chesapeake Bay and south were thought to spawn only during spring months however, Smith et al. 2015 identified a fall spawn within the Roanoke River, NC through the collection of eggs utilizing artificial substrates. They were successful in collecting 38 eggs over 21 days of sampling immediately below the first shoals at Weldon (RKM 220). Estimated spawning dates were 17-18 and 18-19 of September when water temperatures were 25 to 24°C and river discharge was 55 to 297 m3/s. Spring spawning fish usually enter the rivers during winter months and initiate spawning migrations in March and April or when water temperatures are between 13 and 19^{o}C (Smith 1985; Collins et al. 2000). Spawning habitat for the spring spawn occurs between RKM 80 and 150 and consists of rocky coble or limestone outcrops (Collins et al. 2000; Post et al. 2014; Balazik and Musick 2015). Collected telemetry data indicates that fall spawns are now evident in all historic Atlantic sturgeon rivers in Virginia, North Carolina, South Carolina, and Georgia (Hager et al. 2014; Post et al. 2014; Smith et al. 2015; Balazik and Musick 2015; Ingram and Peterson 2016). Spawning fish enter the rivers in late summer and begin migrations upriver when water temperatures are between 25 and 28^{o}C. Generally, spawning habitat for fall spawners is higher in estuaries and rivers than spring spawning, occurring between RKM 180-350. Sturgeon remain present on spawning grounds while water temperatures decrease, then they quickly emigrate during late fall. Based on telemetry and genetic data, spawning events (spring and fall) occur in some rivers in South Carolina, but single fall spawns are believed to occur in Georgia rivers and spring spawning remains unknown in the Roanoke River, North Carolina (Post et al. 2014; Smith et al 2015; Farrae et al. 2017).

2.2.2 Coastal Migration

Atlantic sturgeon are believed to reside in their natal rivers for the first couple of years before joining the coastal mixed stock (Dovel and Berggren 1983; Bain 1997; Hatin et al. 2007; McCord et al. 2007). As subadults, Atlantic sturgeon exhibit fidelity to their natal system where they return in the late spring and summer months for foraging, or they remain offshore. Upon reaching maturity they exhibit increased natal site fidelity and are believed to return to their rivers only for spawning with foraging taking place at the mouth of large estuaries and nearshore marine waters (Dunton et al. 2012; Breece et al. 2016). As such, Atlantic sturgeon will spend most of their lives in marine or estuarine waters where the risk of bycatch in fixed and mobile fisheries is enhanced (Collins et al. 1996; Dunton et al. 2015). In coastal Atlantic waters, survey, bycatch, and conventional tagging data support seasonal migrations to the south during winter months and to the north during spring months (Hilton et al. 2016). Perspectives on coastal migrations has been enhanced greatly through telemetry studies. Telemetered adult Atlantic sturgeon tagged off the coast of Delaware have been acoustically detected from Cape Canaveral, Florida, to the Gulf of St. Lawrence, Canada, providing evidence of their dispersal mechanism for their historical European colonization (Ludwig et al. 2002; Wirgin et al 2015). Continuous sampling efforts to tag large adult Atlantic sturgeon (>150 cm fork length (FL)) by researchers coupled with increased hydroacoustic telemetry arrays available to detect and provide information at much greater resolution than historically possible allowing for near continuous detection records for adults. Results from this data indicate, during peak summer temperatures, non-spawning adult Atlantic sturgeon from southeastern rivers begin nearshore (1-12 miles from shore) northerly migrations and are frequently captured or detected during spring and summer months in Delaware and New York (Oliver et al. 2013; Post el al. 2014). Additionally, multi-year tracking of these same fishes in subsequent years show spawning behavior in southeastern rivers.

2.3 Age

2.3.1 Ageing error

Age determination depends on careful and consistent interpretation of optical zonation patterns associated with annuli, which are presumed to form at an annual rate. Validation of annual periodicity of annuli in fin spines has been tested through (1) measurement of seasonal growth of the marginal increment, (2) comparison of estimated age to known age in reared sturgeons up to age 4 years, and (3) through correspondence between optical chemical zonation patterns across annuli (Stevenson and Secor 1999). These approaches provide limited evidence that optical patterns correspond to ages in juveniles and subadults. Despite an attempt to conduct radiometric dating of fin spines (Burton et al. 1999), longevity estimates in adult Atlantic sturgeon remain unverified. Precision in age interpretations have been evaluated through paired comparisons of estimates between two readers. Coefficient of variation (CV) between readers ranged from 1.8-5.6% (1.8% (Balazik et al. 2012), 3.8% (Dunton et al. 2015), 4.8% (Stevenson and Secor 2000), and 5.6% (Stewart et al. 2015)). Minimal bias was detected between different readers, except for Balazik et al. (2012), who reported a strong subjective effect between readers. Age calibrations were exercised between two past studies' first authors: Van Eenennaam and Doroshov (1998) vs. Stevenson and Secor (2000). Still, no reader set exists for training and assessing precision among studies or laboratories. In general CVs of 5-10% are expected for longer lived species such as Atlantic sturgeon (Stevenson and Secor 2000; Campana 2001). On the other hand, an error of one year can convey substantial bias to growth models when assigning ages less than 10 years.

2.3.2 Maximum Size and Age

Longevity is a useful parameter in estimating natural mortality, age at maturity, and life-time reproductive rates, which in turn are used in developing biological reference points. Parameterization of L_∞ is very sensitive to the size distribution of the fitted sample and selective fishing and other sources of mortality, whereby past exploitation and ecosystem changes can shape the demographics and yield of extant populations. For instance, Balazik et al. (2010) analyzed 400-year-old Atlantic sturgeon spines from a Jamestown, Virginia, colonial midden and observed older individuals and slower growth than in the extant population of James River Atlantic sturgeon.

Vladykov and Greely (1963) reference a female taken in the Saint Johns River, New Brunswick, during July 1924 which was 427 cm (14 feet) in length and weighed 369 kg. Bigelow and Shroeder (1953) discounted an observation of an 18-foot long Atlantic sturgeon, but thought 12 feet (366 cm) was "perhaps the greatest length to expect today." Maximum size from the growth study data sets was 277 cm (Van Eenannaam and Doroshov 1998; Stevenson and Secor 2000), or approximately 9 feet. Based on observations of Atlantic sturgeon carcasses during the past two decades, U.S. Fish and Wildlife Service (USFWS) scientist Albert Spells suggested 10 feet (305 cm) might be a reasonable estimate of maximum length during the recent period.

Maximum age was reported in an obscure way in Magnin (1964) as 60 years—"thus we examined an *A. oxyrhynchus* that was 60 years old" (Google translation from French)—without reference to the fish's size or origin. Among the reviewed growth studies, a maximum age of 43 was observed by Van Eenannaam and Doroshov (1998) for the Hudson River. A 250 cm TL Atlantic sturgeon stranded on the western shore of Delaware Bay was estimated to be 47 years old (Secor 1995). Stewart et al. (2015) observed a maximum age of 51 years in their St. John's River sample. Smith (1985) observed a maximum age from commercial samples of 30 years in South Carolina. Given these records, longevity of 60 years seems reasonable for populations in the northern extent of its range. The SAS agreed that longevity of 40 years was reasonable for more southern populations.

2.4 Growth

2.4.1 Methods

Biological data for Atlantic sturgeon were compiled from several past and on-going research programs along the Atlantic Coast. The available biological data were used to model the length-weight and age-length relationships for Atlantic sturgeon at the coastwide and DPS levels. Note that data were not available for all DPS areas. All modeling was done in R (R Core Team 2017).

The traditional length-weight function was used to model the relationship between TL in centimeters and weight in grams:

$$W = aL^b$$

where W is weight in grams, L is TL in centimeters, and a and b are parameters of the length-weight function.

After some preliminary exploration of alternative models, the working group decided to model the age-length relationship using the traditional von Bertalanffy model:

$$L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$$

where L_t is length at age t, L_∞ is the asymptotic average length, K is the Brody growth coefficient, and t_0 is the age when average length is zero. In the fitting procedure, the observations were weighted by the inverse of the sample size at age. Exploratory modeling found that this was necessary to obtain realistic estimates of L_∞. Confidence intervals for the age-length model parameters were constructed based on 1,000 bootstrap samples and was implemented using the nlsBoot() function within the nlstools package in R (Baty 2015).

The assumptions associated with the fit of the von Bertalanffy model were evaluated for the fit to all available data. A plot of the observed data was inspected to identify potential outliers. A plot of the residuals versus fitted values was created to evaluate whether the variability about the model is constant. A histogram of the model residuals and a Q-Q plot were constructed to assess the normality of the errors.

2.4.2 Results

The parameter estimates of the length-weight relationship fit to the Atlantic sturgeon data are summarized in Table 2. Comparison of the predicted length-weight relationships among DPS areas suggests differences (Figure 4 - 7). These differences stem, in part, from differences in the range of lengths and weights observed and available sample sizes.

The von Bertalanffy age-length model appears to provide an adequate fit to the available data, in general (Figure 9). No obvious outliers are apparent. A plot of the residuals versus fitted values suggests that there may be an additional inflection in early growth not accounted for in the von Bertalanffy growth model (Figure 10). Attempts to fit a double von Bertanffy growth model (after Balazik et al. 2012b) did not improve the residual pattern. The histogram of the residuals (Figure 10) and the Q-Q plot (Figure 11) indicate that the residuals are normally distributed.

A summary of the age-length parameter estimates suggests variation in growth among the DPS areas (Table 3). The plots of the observed data and the predicted age-length relationships suggest that Atlantic sturgeon may live longer and grow slower in the north compared to the south (Figure 12 - 12). Note that the very high L_∞ estimate for the Chesapeake DPS was supported by very few adult samples for that analysis and that Balazik et al. (2012b) chose to fit a double von Bertlanffy to that data set. Still, for the combined model (Figure 8), parameter values estimated here are generally within the range of published estimates (Van Eenennaam and Doroshov 1998; Dunton et al. 2015; Stewart et al. 2015).

2.5 Maturity

Reproductive schedules are not well studies for Atlantic sturgeon, with only a single detailed detailed study (Van Eenennaam and Doroshov 1998). In a review article Smith (1985) suggested that maturity at age for coastal Atlantic sturgeon stocks varied by latitude where maturation is reached at an earlier age in southern regions, althought this has not been confirmed. Sex differentiation may begin as early as age 1 but is completed by age 4 (Van Eenennaam and Doroshov 1998). Coastwide estimates for maturity range from five years to 32 years, although maturity is reached earlier on average in males than in females (Smith and Clugston 1997). Fecundity increases with body size and age, although this was dampened in older females (Van Eenennaam and Doroshov 1998). The total length and weight of mature female Atlantic sturgeon is 2-3 m and 100-200 kg, respectively, while mature males range from 1.4-2.1 m and 50-100 kg (Smith 1985; Collins et al. 2000; Dadswell 2006).

2.6 Mortality

2.6.1 Natural Mortality

Atlantic sturgeon are a long-lived species, with a maximum recorded age of 60 years in the northern extent of its range and 40 years in the southern extent, suggesting natural mortality (M) on subadults and adults is low.

Some work has been done to empirically estimate total mortality. For samples collected in the mid-1990s, Kahnle et al. (1998) estimated total mortality (Z) to be the summation of F and M for the harvested stock of Hudson River females ($Z = 0.15$ to $0.20\ yr^{-1}$), and males ($Z = 0.22$ to $0.31\ yr^{-1}$). Stevenson (1997) also estimated Z based on catch curve analysis for the Hudson River during the 1990s. Female and male Z was estimated at 0.04 and 0.18. Fishery samples from coastal New Jersey supported an estimate of $Z = 0.26$.

Hightower et al. (2015) developed estimates of Z from acoustic tagging data for fish tagged in North Carolina, South Carolina, and Georgia. Their estimates ranged from 0.14–0.18, with the estimate for the pooled adults (150–231 cm) equal to 0.15. Petersen et al. (2008) estimated Z from catch curves of adult fish (ages 9–14) in the Altamaha River in 2004 and 2005. They estimated Z at 0.19 for 2004 and 0.24 for 2005.

Schueller and Petersen (2010) developed estimates for age 1–3 fish (30–75+ cm) in the Altamaha River from acoustic tagging data and found much lower estimates of survival, with Z ranging from 1.08–3.51 over three years. However, mortality and emigration are confounded in their study, so their estimates of Z are likely biased high. Their results still suggest that mortality may be higher in the youngest fish.

Although these estimates are post-moratorium, they still include anthropogenic sources of mortality such as bycatch and ship strikes, and therefore are not true estimates of M.

Several age-constant and age-varying ways to estimate natural mortality based on maximum age and life-history parameters were explored (Figure 15). Then et al. (2014) suggested that maximum age-based estimators are more reliable than life-history-based estimators, at least for age-constant estimates. Age-constant estimates of M for a maximum age of 60 years ranged from 0.05–0.115 (Table 6; Figure 15).

Lorenzen's (1996) equation relating M to body weight to estimate natural mortality at age was used (Table 7; Figure 15). These estimates were scaled to a maximum age of 60, meaning that the estimates of natural mortality at age were scaled to ensure the proportion of the population left alive at age 60 would be equivalent to an age-constant estimate of M derived from a maximum age of 60 years. This resulted in estimates of M-at-age that ranged from 0.3 for age 1 down to 0.040–0.034 for ages 25-60+.

Then et al.'s (2014) recommended age-constant estimator produced the highest estimate of M, at M = 0.115, which was higher than the estimates of Z from the tagging models we examined (see section 6.12). Therefore, for age-constant M approaches, Hewitt and Hoenig's (2005) regression method was used which produced an estimate of M=0.07, consistent with what had been used in the last benchmark assessment. For age-varying M approaches, the Lorenzen method scaled to a maximum age of 60 years was used for the coastwide and northern EPR analysis and 40 years was used for the southern EPR analysis.

2.6.2 Bycatch Mortality

While there is no longer a directed fishery, mortality still occurs when Atlantic sturgeon are caught as bycatch in a variety of fisheries throughout the species range. Atlantic sturgeon are caught predominantly in sink gill net gear (Stein et al. 2004; ASMFC 2007), but also pound nets, trawls, and drift and anchored gill nets. During the NMFS review to list Atlantic sturgeon under the ESA in 2012, it was determined that bycatch mortality was one of the primary threats to the species. The need to reduce or eliminate bycatch mortality for Atlantic sturgeon was identified in Amendment 1 to the FMP in 1998. There is limited data on Atlantic sturgeon bycatch, although there are several observer programs in place that provided data and are described in section 4. In 2003, an Atlantic Sturgeon Technical Committee Workshop on the status of Atlantic sturgeon identified several issues regarding bycatch of sturgeon in other fisheries. In 2007, the Sturgeon Technical Committee requested Board support to undertake a focused assessment of the Northeast Fisheries Science Center (NEFSC) Observer database. Findings (ASMFC 2007) indicated similar bycatch levels as a previous analysis (Stein et al. 2004) and indicated bycatch deaths resulting from sink gill nets could be curtailing recovery of some populations. In 2013, ASMFC and NMFS co-hosted a workshop to discuss solutions to reduce Atlantic sturgeon bycatch in southern New England and Mid-Atlantic gillnet fisheries which included some modifications in gear in this fishery as well as reduced soak times (NMFS and ASMFC 2013).

2.6.3 Ship Strike Mortality

Historical accounts of Atlantic sturgeon vessel interactions date back 150 years (Lossing 1866; Ryder 1890) and involved sturgeon jumping out of the water and primarily impacting sailing vessels or slow moving steam ships. In recent years there has been increased attention focused on the mortality of marine megafauna resulting from vessel strikes. Ship related deaths have been linked as a significant source of mortality for a number of taxa including large whales (Knowlton and Kraus 2001; Laist et al. 2001), sea turtles (Hazel et al. 2007), and fishes (Rowate et al. 2007; Simpson and Fox 2009; Brown and Murphy 2010; Balazik et al. 2012c), and was listed as a contributing factor in the 2012 ESA listing decision for Atlantic sturgeon in the New York Bight DPS (NOAA 2012).

In an analysis of vessel interactions with acoustically tagged Atlantic sturgeon, Balazik et al. (2012c) showed that ship strike deaths were due to deep ocean cargo vessels in narrow up-estuary sections of the James River (RKM 102-126), and particularly in an area with an engineered shipping lane, which large sturgeon used as movement corridor. However, the role vessel characteristics (e.g. draft/bottom clearance, speed, and propeller size) play in ship strike events is limited. Atlantic sturgeon appear capable of detecting some vessels and may exhibit avoidance behavior (Barber 2017) although their ability to escape the flows associated with the suction of propellers is likely limited given the levels of ship strikes noted in some systems.

At present we understand that ship strike mortality is a problem in some systems (e.g., important spawning rivers such as the Savannah, James, York, Delaware, and Hudson Rivers), however understanding of the true population level impacts (e.g., the extent and magnitude) remains limited due to our reliance on carcass reports in most system. Reported ship strike deaths in the James River have numbered more than 10 in some years which could represent a significant fraction of the adult population. The rate of carcass reports have increased recently (Figure 16), however it is not known if this is due to increased mortality events or improved carcass reporting. A study of deliberately released sturgeon carcasses estimated 33% reporting of ship-strike carcasses owing to carcasses becoming obscured by vegetation, lack of access, or large drift distances (Balazik, personal communication).

2.7 Feeding Behavior, Competition, and Predation

2.7.1 Egg and larval stage

There are no studies to indicate what larval Atlantic sturgeon prey upon in the wild. However, it is assumed that after they absorb the yolk sac, they feed on small bottom dwelling organisms (Gilbert 1989). Studies of other sturgeon species indicate that larvae in rivers feed on small mobile invertebrates, including cladocerans and copepods (Baranova and Miroshnichenko 1969; Miller et al. 1991). Miller et al. (1991) found that white sturgeon larvae primarily fed on amphipods.

During their lab test, Kynard and Horgan (2002) found that Atlantic sturgeon larvae (30 to 50 days old) preferred illumination and a white substrate. They hypothesize that an illuminated bright substrate may make it easier for young Atlantic sturgeon to locate moving prey. Laboratory rearing of larvae depends principally on *Artemia* sp. as prey, which the Atlantic sturgeon can readily consume (Kynard and Horgan 2002).

Kynard and Horgan (2002) hypothesize that larval and juvenile Atlantic sturgeon have a low predation risk. This hypothesis is based on the theory that migration upon hatching is stimulated by predation risk to embryos. Species that undergo high predation tend to migrate from the area immediately after hatching (Kynard and Horgan 2002). While this hypothesis has not been fully tested, Kynard and Horgan (2002) have determined that shortnose sturgeon embryos have few predators. After sampling predators in a spawning area, they found that only one fish, the fallfish (*Semotilus corporalis*), had sturgeon eggs in its stomach (Kynard and Horgan 2002).

2.7.2 Juvenile stage

Pottle and Dadswell (1979) examined the gut contents of juvenile Atlantic sturgeon in the St. Johns River, Florida. They found that juvenile Atlantic sturgeon fed on diptera and trichoptera, in addition to amphipods. Secor et al. (2000) found that juvenile Atlantic sturgeon in the Chesapeake Bay preyed upon annelid worms, isopods, amphipods, chironomid larvae, and mysids. Moser and Ross (1995) found polycheate worms, isopods, and mollusk shell fragments in the stomachs of juvenile sturgeon in North Carolina. An examination of 12 juvenile Atlantic sturgeon in the Connecticut and Merrimack Rivers showed a mix of amphipods and polychaetes (Kynard et al. 2000). In freshwater, juvenile Atlantic sturgeon ate plant and animal matter, sludgeworms, chironomid larvae, mayfly larvae, isopods, amphipods, and small bivalve mollusks (Scott and Crossman 1973). Scott and Crossman (1973) also noted that sturgeon consumed mud while foraging on the bottom.

Secor et al. (2000) analyzed the gut content of 12 juvenile Atlantic sturgeon in the Chesapeake Bay and found that sand, silt, and detritus accounted for 34% of the gut contents. Annelid worms made up 61% of the prey items, followed by isopods (*Cyathura polita* and *Cyathura* sp.; 23%), amphipods (*Leptocheirus plumulosus* and *Gammarus* sp.; 10%), chironomid larvae (1.6%), and mysids (*Neomysis americana*; 1.5%). One-third of the Atlantic sturgeon had empty guts (Secor et al. 2000). In this small study, Secor et al. (2000) did not find that juvenile Atlantic sturgeon preyed upon mollusks, despite their high biomass in the Chesapeake Bay.

Both juvenile Atlantic sturgeon and shortnose sturgeon occupy the same freshwater/saltwater interface nursery habitat, although shortnose sturgeon tend to be located in freshwater, while Atlantic sturgeon use more saline areas (Dadswell 1979; Dovel and Berggren 1983; Dovel et al. 1992; Kieffer and Kynard 1993; Haley et al. 1996; Bain 1997). Haley et al. (1996) collected the majority of juvenile Atlantic sturgeon in the Hudson River in deeper, mesohaline (3.0 ppt to 16.0 ppt) regions, while juvenile shortnose sturgeon were found most often in the shallower, freshwater (<0.5 ppt) zones of the estuary. Furthermore, bioenergetic comparisons showed that age-1 Atlantic sturgeon demonstrated better growth in brackish water (1 ppt to 10 ppt), than sympatric shortnose sturgeon juveniles (Niklitschek 2001). In contrast, Bain (1997) found that early juvenile Atlantic sturgeon had the same distribution as juvenile shortnose sturgeon in the Hudson River estuary during all seasons. Both species were similar in size, grew at about the same rate, had similar diets, and shared deep channel habitats early in life (Bain 1997). Additionally, Bain (1997) found that the distribution of adult shortnose sturgeon overlapped with the distribution of juvenile Atlantic sturgeon.

Haley et al. (1996) hypothesized that the freshwater/saltwater interface where both sturgeon species concentrate, may serve as a foraging ground, and that Atlantic and shortnose sturgeon may compete for food in this area. However, Pottle and Dadswell (1979) found that juvenile Atlantic and shortnose sturgeon in the St. Johns River preyed on different species. They found that Atlantic sturgeon preyed upon diptera, trichoptera, and some amphipods, while shortnose sturgeon preyed mostly upon cladocerans, amphipods, mollusks, and insect larvae (Pottle and Dadswell 1982). When reared in large outdoor tanks and fed an artificial diet, shortnose sturgeon juveniles fed at higher rates and grew more rapidly than similar sized Atlantic sturgeon (Niklitschek 2001).

In more southern rivers, juvenile Atlantic sturgeon and adult shortnose sturgeon may share parts of the river with similar salinity levels. This has been documented in the Savannah River during the fall and winter, and in the Altamaha River during warm summers (Kieffer and Kynard 1993).

Atlantic sturgeon juveniles would be expected to compete with other demersal feeding fishes in estuaries. In Mid-Atlantic estuaries these demersal feeders include catfishes, white perch, carp, spot, croaker, and hogchoker (Murdy et al. 1997).

2.7.3 Adult stage

It has been hypothesized that Atlantic sturgeon do not feed during spawning migrations. Research is currently being conducted in South Carolina to test this hypothesis (M. Collins, South Carolina Department of Natural Resources, personal communication). Post-spawning adults that remain in freshwater systems have been documented feeding on gastropods and other benthic organisms (Scott and Crossman 1973). In general, adult Atlantic sturgeon feed indiscriminately throughout their lives and are considered to be opportunistic feeders (Vladykov and Greeley 1963; Murawski and Pacheco 1977; Van den Avyle 1983; Bain 1997; Colette and Klein-MacPhee 2002). They feed on mollusks, polychaetes, gastropods, shrimps, isopods, and benthic fish in estuarine areas (Dadswell et al. 1984; Secor et al. 2000b; Colette and Klein-MacPhee 2002). In freshwater, their prey includes aquatic insects, nematodes, amphipods, and oligochaetes (Colette and Klein-MacPhee 2002).

Adult Atlantic sturgeon appear to have few ecological competitors. They spawn later in the season and in different areas than shortnose sturgeon, thus avoiding competition for egg deposition space in areas where their habitat overlaps (Bath et al. 1981; Gilbert 1989; Kynard and Horgan 2002). Other species that might use the same spawning habitat include anadromous species, such as white perch, striped bass, and American shad.

The ASSRT (2007) notes the following information on competition and predation in Atlantic and shortnose sturgeon:

> Atlantic sturgeon are benthic predators and may compete for food with other bottom-feeding fishes and invertebrates including suckers (*Moxotoma* sp.), winter flounder (*Pleuronectes americanus*), tautog (*Tautoga onitis*), cunner (*Tautagolabrus adspersus*), porgies (Sparidae), croakers (Sciaenidae), and stingrays (*Dasyatis* sp.) (Gilbert 1989). Specific information concerning competition between Atlantic sturgeon and other species over habitat and food resources is scarce. There are no known exotic or non-native species that compete directly with Atlantic sturgeon. There is a chance that species such as suckers or other bottom forage fish would compete with Atlantic sturgeon, but these interactions have not been elucidated (from ASSRT 2007).

The relationship between the federally endangered shortnose sturgeon and the Atlantic sturgeon has recently been explored. Shortnose sturgeon are sympatric with Atlantic sturgeon throughout most of their range. Larger, adult shortnose are suspected to compete for food and space with juvenile Atlantic sturgeon in rivers of co-occurrence (Pottle and Dadswell 1979; Bain 1997). Bain (1997) found that while shortnose and Atlantic sturgeon overlap in their use of the lower estuary, the overall distribution of the two species differed by river kilometers, providing evidence that Atlantic and shortnose sturgeon partition space within the Hudson River despite co-occurrence in channel habitats. This finding is consistent with Kieffer and Kynard (1993) who found that subadult Atlantic and adult shortnose sturgeon in the Merrimack River, Massachusetts were spatially separate except for brief use of the same saline reach in the spring. Kahnle and Hattala (1988) conducted late summer-fall bottom trawl collections in the lower Hudson River Estuary from 1981-1986 and found that most shortnose sturgeon occupied RKM 55-60 in water depths of greater than six meters. Even though there was overlap in river miles, there was separation by water depth. In Georgia, the distributions of adult shortnose and juvenile Atlantic sturgeons overlap somewhat, but Atlantic sturgeon tend to use more saline habitats than shortnose sturgeon (G. Roger, formerly Georgia Department of Natural Resources, personal communication; from ASSRT 2007).

Juvenile shortnose sturgeon apparently avoid competition for food with Atlantic sturgeon in the Saint John River, Canada by spatial separation, but adult shortnose may compete for space with similar-sized juvenile Atlantic sturgeon (Dadswell et al. 1984). Bain (1997) analyzed stomach contents of Atlantic and shortnose sturgeon in the Hudson River using gastric lavage and found clear differences in their diets. Polychaetes and isopods were primary foods retrieved from Atlantic sturgeon while amphipods were the dominant prey obtained from shortnose sturgeon (Bain 1997; from ASSRT 2007).

2.7.4 Predation

Very little is known about natural predators of Atlantic sturgeon. The presence of bony scutes are likely effective adaptations for minimizing predation of sturgeon greater than 25 mm TL (Gadomski and Parsley 2005). Documented predators of sturgeon (*Acipenser* sp.) include sea lampreys (*Petromyzon marinus*), gar (*Lepisosteus* sp.), striped bass, common carp (*Cyprinus carpio*), northern pikeminnow (*Ptychocheilus oregonensis*), channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*), grey seal (*Halichoerus grypus*), fallfish (*Semotilus corporalis*), and sea lion (*Zalophus californianus*) (Scott and Crossman 1973; Dadswell et al. 1984; Miller and Beckman 1996; Kynard and Horgan 2002; Gadomski and Parsley 2005; Fernandes 2008; Wurfel and Norman 2006).

Concerns have been raised that invasive species like flathead catfish (*Pylodictus olivaris*) and blue catfish (*Ictalurus furcatus*) are harming the recovery of anadromous species on the Atlantic coast (e.g., Brown et al. 2005, Schmitt et al. 2017). However, the evidence that these species are feeding on young-of-year or juvenile Atlantic sturgeon is inconclusive, and more work needs to be done to determine the extent of these interactions (see also Section 7.3).

There is little information regarding the marine diet of Atlantic sturgeon. Johnson et al. (1997) suggest that this is because of the low population density of Atlantic sturgeon offshore and the fact that most studies have focused on rivers and estuaries. A stomach content study by Johnson et al. (1997) found that Atlantic sturgeon off the coast of New Jersey preyed upon polychaetes, isopods, decapods, and amphipods. They also found that mollusks and fish contributed little to the diet, and that sand and organic debris were major components (Johnson et al. 1997). Scott and Crossman (1973) stated that in marine waters, Atlantic sturgeon fed on mollusks, polychaete worms, gastropods, shrimps, amphipods, isopods, and small fish (particularly sand lances).

Atlantic sturgeon compete with other bottom feeding fish and invertebrates. Gilbert (1989) lists winter flounder (*Pleuronectes americanus*), tautog (*Tautoa onitis*), cunner (*Tautogolabrus adspersus*), porgies (Sparidae), croakers (Sciaenidae), and stingrays (*Dasyatis* sp.) as possible competitors. Scott and Crossman (1973) report that Atlantic sturgeon are killed by sea lampreys, *Petromyzon marinus*; in South Carolina, long nose gar have been reported attacking sturgeon (Smith 1985).

3 HABITAT DESCRIPTION

See "Appendix A – Habitat" for more detail.

Atlantic sturgeon are motile, long lived, and use a wide variety of habitats found in Atlantic coastal waters of the United States, and major river basins from Labrador (Churchill River, George River, and Ungava Bay), to Port Canaveral and Hutchinson Island, Florida (Van den Avyle 1984). Atlantic sturgeon require freshwater habitats for reproduction and early life stages, in addition to hard bottom substrate for spawning (Vladykov and Greeley 1963; Huff 1975; Smith 1985). Coastal migrations and frequent movements between the estuarine and upstream riverine habitats are characteristic of this species (ASMFC 1998). In some systems, Atlantic sturgeon may prefer extensive reaches of silt-free higher gradient boulder, bedrock, cobble-gravel, and coarse sand substrates for spawning habitat (Brownell et al. 2001). Juvenile and adult Atlantic sturgeon frequently congregate in upper estuary habitats around the saltwater interface, and may travel upstream and downstream throughout the summer and fall, and during late winter and spring spawning periods. Adult Atlantic sturgeon may spend many years between spawning periods in marine waters (Brundage and Meadows 1982; Bain 1997; ASMFC 1998; NMFS 1998; Savoy and Pacileo 2003; ASSRT 2007).

3.1 Geographical and temporal patterns of spawning and migration

Atlantic sturgeon most often spawn in tidal freshwater regions of large estuaries (Hildebrand and Schroeder 1928; Moser and Ross 1995; Bain 1997; Colette and Klein-MacPhee 2002). This pattern is prevalent in New England and U.S. mid-Atlantic estuaries, where obstructions to migration at the fall line preclude upriver migration. In the south where some rivers remain unblocked as far as the fall line, Atlantic sturgeon may ascend hundreds of miles upstream into non-tidal rivers to spawn. Spring spawning migrations are cued by temperature, which causes fish in U.S. South Atlantic estuaries to migrate earlier than those in Mid-Atlantic and New England portions of their range (Smith 1985). In Florida, Georgia, and South Carolina, spawning migrations commence in February. In the Mid-Atlantic region spawning migrations commence between April and May (Hildebrand and Schroeder 1928; Dovel and Berggren 1983; Secor and Waldman 1999; Bain et al. 2000). In New England and Canada, spawning migrations occur from May through July (Collette and Klein-MacPhee 2002). In addition to a spring migration, there is recent discovery of a fall spawning migration (Smith et al. 2015; Balazik and Musik 2015). Later fall and winter migrations are movements out of the estuaries into marine habitats, and they generally occur from September through December depending on the latitude (Smith 1985).

3.2 Spawning Habitat Characteristics

Atlantic sturgeon generally spawn in tidal freshwater regions of estuaries, but spawn in inland, nontidal reaches of freshwater rivers in the southeastern part of their range. Most studies report that Atlantic sturgeon spawn in freshwater above the salt wedge in estuaries (Dovel 1979; Smith 1985; Van Eenennaam et al. 1996; Bain et al. 2000). For instance, Dovel (1978, 1979) reported that Atlantic sturgeon in the Hudson River, New York, spawn in freshwater above the salt wedge. Substrate is a key habitat parameter for Atlantic sturgeon, because a hard bottom substrate is required for successful egg attachment and incubation (Vladykov and Greeley 1963; Huff 1975; Smith 1985; Gilbert 1989; Smith and Clugston 1997; Secor et al. 2002; Bushnoe et al. 2005). Within rivers, the areas of cobble-gravel, coarse sand, and bedrock outcrops, which occur in the rapids complex, may be considered prime habitat. In northern rivers, these areas are nearer to the salt-wedge than in southern rivers. Atlantic sturgeon have been documented spawning in water from 3 m to 27 m in depth (Borodin 1925; Dees 1961; Scott and Crossman 1973; Shirey et al. 1999; Bain et al. 2000; Collins et al. 2000; Caron et al. 2002; Hatin et al. 2002); however, spawning depth seems to vary greatly depending upon the available depth range.

3.3 Egg and Larval Habitat

Eggs are deposited into flowing water and disperse following fertilization. After approximately 20 minutes, the demersal eggs become strongly adhesive and attach to hard substrates (Murawski and Pacheco 1977; Van den Avyle 1983). The eggs hatch after 94 to 140 hours. Late-stage larvae settle to demersal habitat following a pelagic yolksac larval period of about 10 days. This will be the principal type of habitat for the remainder of the sturgeon's life (NMFS 1998).

Larval Atlantic sturgeon (<4 weeks old) are < 30 mm (TL) (Van Eenennaam et al. 1996), and are assumed to inhabit the same riverine or estuarine areas where they were spawned (Bain et al. 2000; Kynard and Horgan 2002). Newly hatched larvae are active swimmers and leave the bottom to swim in the water column. Larvae exhibit benthic behavior once the yolk sac is absorbed (Smith et al. 1980, 1981). Bath et al. (1981) caught free embryos by actively netting the bottom near the spawning area, thus demonstrating that early life stages are benthic.

3.4 Juvenile Estuarine Habitat

Juvenile Atlantic sturgeon are thought to remain close to their natal habitats within the freshwater portion of the estuary for at least one year before migrating out to sea (Secor et al. 2000). Migrations to coastal areas occur between two and six years of age (Smith 1985), and are seasonal, with movement occurring north in the late winter, and south in fall and early winter (Dovel 1979; Smith 1985; NMFS 1998). Seasonal migrations of juveniles are regulated by changes in temperature gradients between fresh and brackish waters (Van Den Avyle 1984). Later-stage juveniles often enter and reside in non-natal rivers that lack active spawning sites (Bain 1997). Inter-estuarine migrations have been documented extensively in the literature (Dovel and Berggren 1983; Smith 1985; Welsh et al. 2002; Savoy and Pacileo 2003). These non-natal estuarine habitats serve as nursery areas, providing abundant foraging opportunities and thermal and salinity refuges. Therefore, these areas are very important to the Atlantic sturgeon's survival (Moser and Ross 1995).

3.5 Late Stage Juvenile and Adult Marine Habitat

Juvenile Atlantic sturgeon are known to emigrate out of their natal estuarine habitats and migrate long distances in the marine environment. Little is known about the habitat use of adult Atlantic sturgeon during the non-spawning season, particularly when the sturgeon return to marine waters (Bain 1997; Collins et al. 2000, Erickson et al. 2011). While at sea, adult Atlantic sturgeon have been documented using relatively shallow nearshore habitats (10 to 50 m in depth) (Laney et al. 2007; Stein et al. 2004); however, adult sturgeon have been captured at depths up to 75 m (Colette and Klein-MacPhee 2002). It is possible that individual fish select habitats in the same areas, or even possibly school to some extent (Bain et al. 2000; Stein et al. 2004; Laney et al. 2007). Stein et al. (2004) reported that Atlantic sturgeon were found mostly over sand and gravel substrate, and that they were associated with specific coastal features, such as the mouths of the Chesapeake Bay and Narragansett Bay, and inlets in the North Carolina Outer Banks. Laney et al. (2007) found similar results off the coasts of Virginia and North Carolina.

4 FISHERY-DEPENDENT DATA SOURCES

Historical landings are available for Atlantic sturgeon as well as landings up until the time of the moratorium. Since the moratorium, bycatch of Atlantic sturgeon remains a leading source of mortality. The data sources used in this assessment are described below. The SAS evaluated several sources of fisheries-dependent data for inclusion in the landings and bycatch estimates. Eliminated data sets included Maine's sampling of the commercial gill net fishery and Delaware Ship Strike Mortality Monitoring because of a short time series. Also excluded from analyses were Massachusetts Division of Marine Fisheries bycatch monitoring, USFWS Reward Program, and Delaware Division of Fish and Wildlife Voluntary bycatch logbook program due to low catch rates or reporting or limited access to the fishery after the listing.

4.1 Historical Landings

At the beginning of the 20th century, Atlantic sturgeon were among the top three species in weight of fish harvested commercially along the Atlantic coast (US Bureau of Fisheries 1907; US Commission of Fish and Fisheries 1884-1905). Records of commercial landings were initiated by the Federal government in 1880 through the US Commission of Fish and Fisheries (also known as the US Fish Commission), which collected landings data from fishers and port agents. This dataset represents the best available information on landings from this period, which was the peak of harvest for this species, but there are caveats about the accuracy of the data, including potential issues with species identification and lack of geographical coverage. The time series includes many years with no reported landings interspersed among years of high landings (Figure 1), because the newly formed US Fish Commission did not survey regional fisheries every year (Secor 2002). Further, New England fisheries were first surveyed after the Atlantic sturgeon fishery peaked. Reported landings peaked in 1890 at 3,348 mt. Landings declined precipitously soon after and have remained relatively low through the present.

In the beginning of the 20th century, the Atlantic sturgeon fishery was concentrated in the Delaware River and the Chesapeake systems, although this may also be indicative of concentrated sampling in those regions. Substantive landings also came from the southeastern states of North Carolina, South Carolina, and Georgia (Smith 1985). After the collapse of sturgeon stocks in the Mid-Atlantic States, landings for North Carolina, South Carolina and Georgia dominated the coastal landings. Landings for these states declined by the 1980s and coastwide landings shifted to New York and New Jersey. By this time, most states had implemented some form of dealer reporting, making the landings from the end of the directed time series the most accurate.

Several states closed their sturgeon fisheries in the mid to late 1990s, and a coastwide moratorium was implemented in 1998, ending the directed sturgeon landings time series.

4.2 Northeast Fisheries Observer Program and the At-sea Monitoring Program

The NMFS NEFSC's Fisheries Sampling Branch manages the Northeast Fisheries Observer Program (NEFOP) and the At-Sea Monitoring Program (ASM). NMFS monitors the NEFOP/ASM observer provider companies, provides training and certification, performs data quality assessments, processes pre-trip notification, and manages vessel selection across notification fisheries. Observers have played a vital role in the management of the Northeast and Mid-Atlantic fisheries since NEFOP's inception in 1989 and the establishment of ASM in 2010.

NEFOP/ASM observers collect catch, gear, fishing effort, and biological data over a range of commercial fisheries from Maine to North Carolina. Examples include the groundfish, herring, squid, surf clam and ocean quahog, and lobster fisheries. Observer coverage requirements were established under the Magnuson-Stevens Act and the Standardized Bycatch Reporting Methodology (SBRM) Omnibus Amendment, the Marine Mammal Protection Act and the Endangered Species Act.

Data collected by observers are used to identify key characteristics of commercial fisheries in the Northeast and Mid-Atlantic regions. Catch data and biological information inform stock assessments. Samples from protected species, such as Atlantic sturgeon, provide life history information and data for bycatch estimation.

4.3 North Carolina Estuarine Gill-Net Fisheries

The North Carolina Division of Marine Fisheries (NCDMF) provides at-sea onboard observer coverage for the fall flounder fishery as well as other large and small mesh fisheries throughout the state. Additional large and small mesh trips are observed through the NCDMF alternate platform trips. These trips are conducted from NCDMF-owned vessels where the observers do not ride with the fisherman but observe from a distance.

In addition, the state of North Carolina received an Incidental Take Permit for their anchored estuarine gill-net fishery in July 2014 (Permit number 18102) limiting the number of interactions that can occur through this fishery and making reporting of takes mandatory within 24-48 hours of the take. If take numbers are approached for any Management Unit/season the fishery closes (gear comes out of the water) until the end of that season. The Chowan River is included in that ITP under Management Unit A, the Tar/Pamlico River is included under Management Unit C, the Neuse River is included under Management Unit C, and the Cape Fear River is included under Management Unit E.

4.4 South Carolina American Shad Gill-Net Fishery

Commercial shad fisheries in South Carolina are managed using a combination of seasons, gear restrictions, and catch limits implemented over several management units: Winyah Bay and Tributaries (Waccamaw, Pee Dee, Little Pee Dee, Lynches, Black and Sampit rivers); Santee River; Charleston Harbor (Wando, Cooper & Ashley rivers); Edisto River; Ashepoo River; Combahee River; Coosawhatchie River; Savannah River within South Carolina; Ocean Waters; and Lake Moultrie, Lake Marion, Diversion Canal, Intake Canal of Rediversion Canal and all tributaries and distributaries.

South Carolina DNR collected voluntary landings data by river system since 1979 and instituted mandatory catch and effort reporting in 1998. Beginning in 2000, licensed shad fishermen were also required to account for any sturgeon species captured in their nets. While reporting has not been fully implemented, as many licensed fishermen fish infrequently and provide incomplete, incorrect, or no effort data, SCDNR continues to work successfully with several cooperating commercial American shad gill-net fishermen in order to collect commercial catch and effort data on several river systems. Admittedly, there are likely still some gaps in these data, but they do provide the broadest temporal and spatial view of Atlantic sturgeon bycatch in fisheries for American Shad in South Carolina.

Additionally, in order to address sustainability, further restrictions to South Carolina's shad fishery took place in 2013. These changes in the shad fishery were the first to occur since the closure of the ocean-intercept fishery in 2005. The ASMFC mandated states develop river-specific sustainability plans for American Shad. The plan had to demonstrate that specific shad stocks could support commercial and recreational fisheries that would not diminish potential future stock reproduction and recruitment. Data used, in most cases, are landings that occurred since the 2007 stock assessment (i.e., after 2004). Sustainability for South Carolina Rivers was determined by catch trends (using both fishery-independent and fishery-dependent data), juvenile abundance, and fish passage counts at dams (Post 2012). During the same time, NMFS required South Carolina to account for and reduce the bycatch of Atlantic sturgeon in the shad fishery. To accomplish this, additional statewide gear restrictions (i.e., 50% statewide reduction in allowable gear; 80-90% reduction for high priority rivers) and changes to the legal fishing season were implemented. These two directives far exceeded any changes or restrictions imposed on South Carolina's shad fishery to date. The resulting plan was approved by the ASMFC Shad and River Herring Technical Committee and Management Board in 2013, and led to regulation changes passed into law by the South Carolina General Assembly in late 2013.

5 FISHERY-INDEPENDENT DATA SOURCES

5.1 Stock Assessment Subcommittee Criteria

The SAS established the following set of criteria for evaluating data sets and developing indices of relative abundance for Atlantic sturgeon:

1. Time series: Ideally, the time series should be 40 years long to account for the lifespan of Atlantic sturgeon. Recognizing that would eliminate most surveys, the SAS recommended at least 15 years of data be available in a survey.
2. Survey design: Surveys with statistical designs were preferred, such as surveys with random stratified sampling. Fixed-station surveys were considered if persistence throughout the time series can be demonstrated.
3. Gear: Surveys should operate with gear that is capable of catching Atlantic sturgeon and to which Atlantic sturgeon are available.
4. Temporal and spatial coverage: Only surveys that operate during a time and place where Atlantic sturgeon were available for capture should be considered. Examining the precision or proportion of zero catches of Atlantic sturgeon in a survey can be tools for evaluating this.

5. Methodology: Survey methodology should be consistent throughout the time series or changes should be able to be accounted for in the standardization process.

Fifty surveys were considered by the SAS and nearly half were ruled out for not encountering Atlantic sturgeon (<1% positive tows), or due to incomplete or unavailable data sets (Table 8). The SAS evaluated the remaining 26 data sets and rejected 17 for various reasons as indicated in Table 8 after preliminary data analysis or discussion with the data provider. Abundance indices were developed from the remaining nine surveys. Many of the criteria developed by the SAS had to be relaxed since there are few surveys designed to catch Atlantic sturgeon and many exhibited low occurrence in tows, had limited time series or spatial coverage, or fixed station sampling designs. The list of surveys that were developed into standardized indices of relative abundance of Atlantic sturgeon can be found in Table 9. A length cutoff was used for determining if a survey catches predominantly YOY (<500 mm), juvenile (500-1300 mm), or adult (>1300 mm) Atlantic sturgeon.

5.2 Surveys

5.2.1 Maine-New Hampshire Inshore Groundfish Trawl Survey

5.2.1.1 Survey Design and Methods

The Maine-New Hampshire Inshore Groundfish Trawl (ME-NH Trawl) Survey has been operating since the fall of 2000 and collects samples during the spring (May-June) and fall (October-November) in the coastal waters of Maine and New Hampshire. The survey uses a combination of stratified random sampling and fixed station sampling in five regions and four depth layers. Gear consists of a modified shrimp net with a 2-inch mesh in wings and ½-inch mesh liner in the cod end.

5.2.1.2 Biological Sampling

All catch is identified by species and counted, weighed for aggregate weight, and measured for length including Atlantic sturgeon.

5.2.1.3 Evaluation of Survey Data

Atlantic sturgeon were not caught reliably throughout the time series. When subset to regions 1-3, strata 1-2, and the months of May, October, and November, the amount of positive tows increased to 3%. Based on the lengths provided, this survey catches both juveniles and adults, with an average total length of approximately 1300 mm.

5.2.1.4 Development of Estimates and Index Standardization

An index of relative abundance was developed from the subset of data described above. A full model that predicted catch as a linear function of year, region, depth, and stratum was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial with year, region, and stratum.

5.2.1.5 Abundance Index Trends

Abundance was relatively high in the early time series and then decreased through the mid-2000s. It remained low and then began to increase again in 2014-2015 (Figure 17).

5.2.2 Connecticut Long Island Sound Trawl Survey

5.2.2.1 Survey Design and Methods

The Connecticut Long Island Sound Trawl (CT LIST) Survey is a random stratified survey with 3 bottom types and 4 depth strata that operates from April-December. The survey has been conducted from 1984-present and covers Connecticut and New York waters of Long Island Sound from 5-46 m in depth. The survey uses a 14-m high-rise otter trawl, 102-mm mesh in wings and belly, 76-mm mesh in the tailpiece and 51 mm mesh codend. The net is towed for 30 minutes at 3.5 knots. Catch is sorted by species and starting in 1992 all species are weighed in aggregate.

5.2.2.2 Biological and Environmental Sampling

Atlantic sturgeon are not caught in large numbers in this survey, averaging approximately 14 a year and a total of 458 since the survey began in 1984. Genetic tissue samples and photographs of Atlantic sturgeon collected since 2012 were taken as a condition of the NMFS Biological Opinion under which USFWS funded trawl surveys are operating. Atlantic sturgeon captured since 2009 received a passive integrated transponder (PIT) tag if PIT tag readers and tags were available.

5.2.2.3 Evaluation of Survey Data

The CT LIST survey rarely encounters Atlantic sturgeon, although they are present in the survey seasonally. The survey had 2% positive tows during the spring (May-June) and fall (September-November) months, with more Atlantic sturgeon caught in the fall (n = 311) compared to the spring (n = 111). The average length of sturgeon in these months was 1115 mm (*SD* = 245 mm), indicating that the survey predominantly catches large juveniles.

5.2.2.4 Development of Estimates and Index Standardization

While the survey has been conducted since 1984, environmental data have only been collected since 1992 and not continuously. Standardized indices were developed for the fall months, spring months, and fall and spring months combined. Since the lack of environmental data abbreviated this time series, a nominal index was developed for fall, spring, and fall-spring combined. Index standardization was also completed but did not significantly change the pattern of the index so the nominal index was recommended by the SAS due to its longer time series. Data from 2015 was not included since it was incomplete at the time of the assessment.

5.2.2.5 Abundance Index Trends

For the nominal index developed from the spring and fall months combined (Figure 18), abundance was low through the 1980s and increased through the early 1990s to the highest values in the time series. Abundance decreased again in the mid-1990s and was variable throughout the rest of the time series, with peaks in 1999, 2003, and 2007. Values in 2010-2013 were similar to the low values in the 1980s, with a slight uptick in the terminal year of 2014. Indices specific to the spring or fall months show some seasonal patterns (Figure 19).

5.2.3 New York State Department of Environmental Conservation Juvenile Atlantic sturgeon Abundance Monitoring Program

5.2.3.1 Survey Design and Methods

The New York State Department of Environmental Conservation's (NYSDEC) Juvenile Atlantic sturgeon Abundance Monitoring Program (JASAMP) began in 2006 and takes place in March through early May and targets a specific overwintering area for juvenile ATS, the soft-deep habitats (soft sediments in > 20 ft deep) of Haverstraw Bay (RKM 55-65, RM 35-39). The survey uses anchored gill nets of 7.6-, 10.2-, and 12.7-cm stretch mesh, 61-m long and 2.4-m deep. The three nets, positioned randomly by mesh size, are set perpendicular to shore and fished for approximately two hours through all tide stages (Sweka et al. 2007).

5.2.3.2 Biological and Environmental Sampling

All Atlantic sturgeon collected are measured for TL, FL, weighed, and examined for previous marks. A small piece of flesh is taken from the dorsal fin of each fish for genetic analysis, stored in ethanol, and sent to the genetics repository. Unmarked fish are tagged in the musculature under the dorsal fin with a PIT tag and in the base of the dorsal fin with a USFWS Dart tag. Water quality parameters are measured at all net sets.

5.2.3.3 Evaluation of Survey Data

The time series is too short (2006-2015) in respect to the lifespan of Atlantic sturgeon to be used in this assessment for analyses. The SAS did endorse the development of an index with the intention of using it in future assessments or updates when more years of data become available. Based on the lengths provided, the survey catches small juveniles on average.

5.2.3.4 Development of Estimates and Index Standardization

A full model that predicted catch as a linear function of year, tide, river mile, distance to salt front, bottom salinity, bottom temperature, and bottom dissolved oxygen was compared with nested submodels using AIC. The model with the lowest AIC value was a zero-inflated negative binomial that included year, tide, bottom temperature, distance to salt front, and effort which was included as an offset.

5.2.3.5 Abundance Index Trends

The index of relative abundance of Atlantic sturgeon began in 2006 at its lowest point and gradually increased to its highest value in 2015, with one notable decline in 2013 (Figure 20).

5.2.4 New Jersey Ocean Trawl Survey

5.2.4.1 Survey Design and Methods

The New Jersey (NJ) Ocean Trawl Survey is a multispecies survey that started in August 1988 and samples the nearshore waters from the entrance of New York Harbor south to the entrance of the Delaware Bay five times a year (January, April, June, August, and October). In 1989 there were six cruises (December and February were sampled) and a 20-minute tow duration was adopted. In 1990 the December and January cruises were combined into a single cruise in January. There have been five vessel changes over the course of the survey; the R/V Seawolf has been used since 2002. There are 15 strata with five strata assigned to three different depth regimes; inshore (3 to 5 fathoms), mid-shore (5 to 10 fathoms), and off-shore (10 to 15 fathoms). Station allocation and location is random and stratified by strata size. Approximately 39 tows of 20-minute duration are completed per cruise. The survey extends from Sandy Hook to Cape May, New Jersey, and offshore to the 90' isobath.

The survey net is a two-seam trawl with forward netting of 4.7-inch stretch mesh and rear netting of 3.1-inches stretch mesh. The codend is 3.0-inches stretch mesh and is lined with a 0.25-inch bar mesh liner. Each trawl is 20 minutes long. A series of water quality parameters, such as surface and bottom salinity, temperature, and dissolved oxygen are also recorded at the start of each tow.

5.2.4.2 Biological Sampling

The total weight of each species is measured in kilograms and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest centimeter. Through 2015, a total of 362 Atlantic sturgeon were caught by the trawl survey and all were released alive.

5.2.4.3 Evaluation of Survey Data

The time series is relatively long (1990-2015) and the survey operates in a region that encounters sturgeon, particularly when subset to the inshore and mid-shore strata during the months of January, April, June, and October cruises.

5.2.4.4 Development of Estimates and Index Standardization

A standardized index of relative abundance was developed from the subset to years (1990-2015), months and strata as described above. A full model that predicted catch as a linear function of year, stratum, depth, cruise, bottom salinity, bottom temperature, and bottom dissolved oxygen was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial that included year, stratum, and bottom temperature.

5.2.4.5 Abundance Index Trends

The index of abundance began relatively high in 1990 and decreased to a low by the mid-1990s (Figure 21). The index remained variable through the late-1990s and early-2000s but began to increase in the mid-2000s through the terminal year of 2015 with the exception of the small values in 2011-2012.

5.2.5 Northeast Area Monitoring and Assessment Program Trawl Survey

5.2.5.1 Survey Design and Methods

The Northeast Area Monitoring and Assessment Program (NEAMAP) Trawl Survey began sampling the coastal ocean from Martha's Vineyard, Massachusetts to Cape Hatteras, North Carolina since the fall of 2007. The survey area is stratified by both latitudinal/longitudinal region and depth. A four-seam, three-bridle, 400x12-cm bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.0 kts. The net is outfitted with a 2.54-cm knotless nylon liner to retain the early life stages of the various fishes and invertebrates sampled by the trawl. The survey conducts two cruises a year, one in the spring (April-May) and one in the fall (September-November). A total of 150 sites are sampled per cruise, except 160 sites were sampled in the spring and fall of 2009 as part of an investigation into the adequacy of the program's stratification approach.

5.2.5.2 Biological and Environmental Sampling

For each tow, the catch is sorted by species. Atlantic sturgeon are measured for length, weight, and sex when possible. PIT tags, if present, are also recorded. A number of variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation), atmospheric data, and station identification information are recorded at each sampling site.

5.2.5.3 Evaluation of Survey Data

The time series is too short (2007-2015) in respect to the lifespan of Atlantic sturgeon to be used in this assessment for analyses. The SAS did endorse the development of an index with the intention of using it in future assessments or updates when more years of data become available. The survey encountered Atlantic sturgeon at higher rates when subset for April, May, and October and depth strata 1-3. Based on the lengths provided, the survey predominantly catches juveniles in the spring (April-May average TL = 1175 mm +/- 307 mm; n = 82) and adults in the fall (October average TL = 1324 mm +/- 290 mm; n = 98).

5.2.5.4 Development of Estimates and Index Standardization

The data set was subset to April, May, and October and depth strata 1-3 and a standardized index of relative abundance was developed. In the first year of data (2007), only fall data were available. A full model that predicted catch as a linear function of year, stratum, depth, wind speed, salinity, water temperature, air temperature, barometric pressure, and dissolved oxygen was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial that included year, depth, and dissolved oxygen. Abundance indices were also developed for spring and fall months separately. For the spring months (April-May), the model with the lowest AIC value was a negative binominal that included year, depth, and dissolved oxygen. For the fall month (October), the model included year and water temperature.

5.2.5.5 Abundance Index Trends

The survey of relative abundance of Atlantic sturgeon developed from the NEAMAP survey began with low values in 2007 (although this data point only has fall data) and slowly increased to a high at 2010 (Figure 22). The survey declined again in 2011 until another peak in 2014, although with a large margin of error. Indices were standardized for the spring and fall months separately as well (Figure 23) and seasonal differences can be observed, such a large fall peak in 2014 that is not present in the spring.

5.2.6 Virginia Institute of Marine Science Shad and River Herring Monitoring Survey

5.2.6.1 Survey Design and Methods

The Virginia Institute of Marine Science (VIMS) Shad and River Herring Monitoring Survey began in 1998 and operates in the James, York, and Rappahannock rivers during the months of February-May. Staked gill nets of 900-ft in length are used in the James and York rivers at sites that were identified as traditional shad fishing locations. On the Rappahannock River, the staked gill net is 912 ft long. Each gill net is fished one day a week during the spring spawning run.

5.2.6.2 Biological and Environmental Sampling

While this survey is designed to target shad and river herring, Atlantic sturgeon has been encountered during sampling times. Atlantic sturgeon are counted and released. Air temperature, surface water temperature, and salinity are recorded at every sampling event.

5.2.6.3 Evaluation of Survey Data

Atlantic sturgeon were rarely encountered during the months of February and May, so only the months of March and April were used in consideration of developing an index of relative abundance. During these months, a total of 225 Atlantic sturgeon have been caught since 1998 and on average the survey encounters juveniles (March average TL = 801 ± 138 mm; April average TL = 758 ± 202 mm). Because the survey uses a fixed station design, analyzing for persistence was pursued but not completed due to the lack of multiple sampling events at each station.

5.2.6.4 Development of Estimates and Index Standardization

A standardized index of relative abundance of Atlantic sturgeon was developed from this survey using only the months of March and April. A full model that predicted catch as a linear function of year, river, salinity, water temperature, and air temperature was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial that included year, river, and water temperature.

5.2.6.5 Abundance Index Trends

The index of Atlantic sturgeon abundance began relatively high in 1998 and decreased to the lowest points in the survey from 2001-2004 (Figure 24). The index began increasing in 2005 to a series high in 2006 but declined again from 2008-2012. The last years of the survey, 2013-2015, suggested that the population in this region is increasing and it ends on another high point in the terminal year.

5.2.7 North Carolina Program 135 Survey

5.2.7.1 Survey Design and Methods

The North Carolina Program 135 (NC p135) is designed as a striped bass independent gill-net survey. NC p135 is a random stratified multi-mesh monofilament gill-net survey, used to monitor the Albemarle and Roanoke striped bass populations and collect information on other species. The survey began in October 1990 and the fishing year is divided into three segments: (1) a fall/winter survey period, which begins approximately 1 November and continues through 28 February and has 7 sample zones with 22 grids per zone, (2) a spring survey period which begins 1 March and continues through approximately June 30 and operates only in the western Albemarle Sound zone, and (3) a summer survey period which starts July 1 and continues through October 30 in 6 sample zones. Survey activities are conducted in a portion of Croatan Sound, the Alligator River, Chowan River, and in the Albemarle Sound near the mouths of the Roanoke, Yeopim, Perquimans, and Scuppernong rivers. For the fall/winter survey period two gangs of twelve meshes (2½, 3, 3½, 4, 4½, 5, 5½, 6, 6½, 7, 8, 10 inch stretch) of gill nets are set by each of the two survey crews. Each crew fishes four sets of nets; two floating (large and small meshes separate) and two sinking (large and small meshes separate). The full complement of nets for each crew contains 960 yards of webbing. Nets are hung in 40-yard sections with a hanging coefficient of 0.50 and approximately 9 feet deep. For the fall/winter survey period the soak time for each selected grid is 24 hours. One unit of effort is defined as a sample and sample equals on 40-yard net soaked for 24 hours. Effort for all mesh sizes is equal except when nets are damaged or hampered by debris in rough weather.

The first year (1990) of sampling underwent some changes and therefore was not used in this analysis. Sampling in June and the summer period (July-October) was discontinued after 1994. No other changes could be determined from the program documentation sampling methods since 1991, except the addition of more habitat parameters, and tag and age coding for striped bass. These changes do not impact estimates of abundance for Atlantic sturgeon.

5.2.7.2 Biological and Environmental Sampling

Atlantic sturgeon collected were counted and measured for total length (mm). The date, weather elements, water depth (m), temperature (^{o}C), salinity (ppt), dissolved oxygen (mg/L), and effort parameters are recorded for each mesh/site combination.

5.2.7.3 Evaluation of Survey Data

In the fall (November-February), the survey caught roughly an equal number of juveniles as YOY, but it was variable within years and only two adults were caught in the fall time series. Atlantic sturgeon were predominantly caught in the quadrants 2-7. In the spring, slightly more juveniles were caught than YOY and only one adult was caught in the entire spring time series. There were 1% positive tows in the fall months, slightly less in spring months.

5.2.7.4 Development of Estimates and Index Standardization

Both a fall (November-February) and a spring index were developed from this survey. A full model that predicted catch as a linear function of year, quadrant, depth, and surface temperature was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial that included year, so the spring index was developed as a nominal index. For the fall index, the negative binomial with year, quadrant, and surface temperature had the lowest AIC.

5.2.7.5 Abundance Index Trends

For the spring index, values were low from the first year of 1991 until the early 2000s and then low again through the mid-2000s (Figure 25). The index was variable for the remaining years, with peaks in 2008 and 2013-2014 and low points in 2010-2011. For the fall index, abundance began mid-range in 1990 and decreased through the mid-1990s (Figure 26). The index was variable with high points in 1997, 2000, 2007, and 2012 and low points in 2002-2003 and 2010.

5.2.8 South Carolina Edisto Sturgeon Monitoring Project Survey

5.2.8.1 Survey Design and Methods

Sampling Atlantic sturgeon in the Edisto River is part of a long-term monitoring project funded by NOAA through the Atlantic Coastal Fisheries Cooperative Management Act. This sampling for sturgeon occurred from January-May in 1994 and 1995, from January-December in 1996-2000, from March-December in 2001-2003, and during May-September in 2004-2015. The sampling gear targeted juveniles at or near the salt front, and the primary sampling method was drift gillnets 92 meters long, 7.5 meters deep, and with 12.5 and 14.0 cm stretched-mesh monofilament, although set nets were also used during some years (i.e., 2000, 2001 and 2002). The sampling site was consistent year-to-year (RKM 28.2) as the gear was fished in a snag-free portion of the river and this was the only adequate sampling location in the brackish estuary. Exceptions occurred in low flow years (i.e., 2000, 2001 and 2002) when nets were set further up river in order to increase catches of juveniles. During 1994-2003 project objectives focused solely on length distribution of younger fish and targeted mostly YOY (<500mm). Beginning in 2003, effort was standardized to address overall abundance for all life stages. Catch rates were variable and may be an indicator of varying year class strength or sampling inefficiencies due to environmental factors (e.g., water salinity or river discharge) that fluctuate at the sampling location year-to-year.

5.2.8.2 Biological and Environmental Sampling

Fork length, total length, and weight is measured on captured Atlantic sturgeon and PIT tag information is recorded. Station number and temperature are also collected at each sampling site.

5.2.8.3 Evaluation of Survey Data

Because this was a fixed station survey focused on an area near the salt front, an analysis for persistence was attempted but not completed since there were too few stations for the analysis. Atlantic sturgeon were encountered during this survey but not at the St. Pierre strata. From 1994-2015, over 4,000 Atlantic sturgeon (174-2,102 mm TL) including 2,003 age-1 Atlantic sturgeon (< 525 mm) have been collected.

5.2.8.4 Development of Estimates and Index Standardization

A standardized index of relative abundance for Atlantic sturgeon was developed excluding the St. Pierre strata because no Atlantic sturgeon were caught there. A full model that predicted catch as a linear function of year, station, and temperature was compared with nested submodels using AIC. Because there was no standardized sampling design for effort in years 1994-2003, and was solely focused on targeting juveniles and included multiple gears, the model was applied for years 2004-2015 only when consistent effort and gears were used. Also, in order to account for years with high freshwater input when YOY dominated the catch, fish <550mm were excluded from the time series. This approach allowed for more appropriate abundance estimates across the time series for age 2 and older fish that are able to tolerate a wider range of salinities. The model with the lowest AIC value was a negative binomial that included all variables.

5.2.8.5 Abundance Index Trends

The index of relative abundance developed from the South Carolina Edisto survey data was variable from 2004-2015 (Figure 27), with a declining trend in the last 3 years.

5.2.9 US Fish and Wildlife Cooperative Tagging Cruise

5.2.9.1 Survey Design and Methods

The US Fish and Wildlife Service Cooperative (USFWS Coop) Winter Tagging Cruise began in 1988 and operated from January-February in the overwintering grounds off North Carolina and Virginia (the last USFWS Coop was conducted in 2016). Most of the habitat surveyed during the cruise was within state waters, although some years the survey went beyond state waters. This survey does not have a statistical design and all habitat types are not sampled equally since effort is targeted for striped bass, restricted to depths over approximately eight meters (for safety reasons) and hard-bottom habitats are avoided (to avoid damage to habitat and gear). Although its goals were to capture and tag migratory striped bass, Atlantic sturgeon were encountered on a regular basis and were tagged from 1988 through 2010. Four stern trawlers and one side trawler have been used during this survey and maximum tow duration is 30 minutes in order to reduce bycatch and maximize survival.

5.2.9.2 Biological and Environmental Sampling

When Atlantic sturgeon are captured, they are counted, tagged, measured, and weighed. Tissue from the barbell or caudal fin clip is also removed for genetic analysis and some pectoral fin spine sections have been removed in the past for ageing. Since 1994, all Atlantic sturgeon have been scanned for coded wire tags or PIT tags. All untagged Atlantic sturgeon are tagged prior to release. Environmental variables are collected with each tow including surface temperature, depth, air temperature, and surface salinity.

5.2.9.3 Evaluation of Survey Data

The lack of statistical design for this survey was a concern for the SAS, but Atlantic sturgeon were encountered regularly so an index of relative abundance was developed. There are gaps in the survey (the survey was not conducted on the trawl vessel in 2012 and 2013 due to funding issues) and due to the lack of permits for handling sturgeon in recent years, methodology changed to avoid encountering them. For this reason, only the years of 1988-2010 were considered for index standardization. The survey predominantly catches juveniles (average TL = 992 mm, SD = 196 mm).

5.2.9.4 Development of Estimates and Index Standardization

A standardized index of relative abundance was developed for this survey. A full model that predicted catch as a linear function of year, depth, air temperature, water temperature, salinity (although not complete throughout the time series), and latitude and longitude was compared with nested submodels using AIC. The model with the lowest AIC value was a negative binomial that included year and depth.

5.2.9.5 Abundance Index Trends

The index of relative abundance for Atlantic sturgeon developed from the USFWS Coop cruise was variable throughout the time series (Figure 28). There were some peaks in abundance in 2002 and 2006-2009 but many low points including the terminal year of 2010.

5.3 Summary of Index Data

Nine fishery-independent surveys were developed into indices of relative abundance of Atlantic sturgeon, although NEAMAP, JASAMP, and SC Edisto were not used in modeling approaches due to the short time series. Those surveys may be included in the modeling approaches in future assessment updates when they reach the 15-year minimum standard.

Many of the criteria for survey selection had to be relaxed and therefore many of the surveys developed into indices only encountered sturgeon in 1-3% of the tows. Time series ranged from 9-26 years, none of which reached the goal of a 40-year time series. Two of the nine surveys, VIMS Shad and River Herring Monitoring Survey and SC Edisto, were from fixed station surveys where persistence could not be established due to limited stations in those surveys for the analysis. Index values and associated standard errors vary from survey to survey (Table 10; Figure 29).

6 METHODS AND RESULTS

6.1 Effective Population Size

6.1.1 Background of Analysis

Effective population size is a population genetics metric that provides important information on the genetic welfare of populations (Palstra and Ruzzante 2008; Husemann et al. 2016). This measure describes an idealized population with the same rate of genetic loss as the observed population (Wright 1938). In practice, effective population size is usually much smaller than census population size (Vucetich et al. 1997; Palstra and Fraser 2012). A variety of factors, such as fluctuations in abundance, skewed sex-ratios, non-random mating, and variability in reproductive success can reduce effective population size below the census population size.

Effective population size complements traditional demographic perspectives. This metric is directly linked to the rate of genetic drift, a process through which genetic diversity is lost through random chance (Husemann et al. 2016). Over time, genetic drift leads to allelic fixation and populations may lose their ability to adapt to future change (Lande 1988). Moreover, when effective population sizes are low, genetic drift can override selective pressures and erode fitness. Given the recent demographic bottlenecks (Secor 2002) and limited contemporary gene flow observed in Atlantic sturgeon (Grunwald et al. 2008), estimates of effective population size can help inform managers on the status and recovery of populations.

Estimates of effective population size were generated for 11 rivers and a sound using a genetic baseline developed at the U.S. Geological Survey (USGS) Leetown Science Center in Kearneysville, West Virginia. In addition, the availability of a large amount of genetic data for the Hudson River enabled an examination of changes in effective population size through time (1996-2015) for this population

6.1.2 Methods

Genetic Baseline

Genotypes from 1,658 Atlantic sturgeon representing 50 collections from 11 rivers plus one sound (Albemarle, North Carolina) were used to characterize the effective population size of

Atlantic sturgeon populations (Table 11). All individuals included in the baseline were captured in the riverine environment, except for one collection, Albemarle Sound. The Albemarle Sound samples were collected in tidal waters outside of a known spawning area. This is a known weakness of the current baseline, as it may represent sturgeon from several spawning populations within the Carolina DPS. Leetown Science Center is actively working with another agency to incorporate additional collections from the Carolina DPS, however these samples were not yet available at the time this report was prepared. River-resident juveniles (<500 mm TL; RRJ) and adults (≥1,500 mm TL) were included in the baseline. Individuals outside of this size-criteria were excluded from the genetic baseline due to the extensive dispersal of juvenile and adult Atlantic sturgeon outside of spawning. The only exception is that subadults were used to characterize the St. Lawrence River, as these were the only samples that we have been able to access. All collections within a river were aggregated to maximize the number of samples available to produce each estimate. Estimates were also generated for each collection from the Hudson River to facilitate an examination of trends over time.

Extraction of DNA and Genotyping

Atlantic sturgeon samples were genotyped at the USGS Leetown Science Center. Whole genomic DNA was extracted from tissue samples using the Qiagen Blood and Tissue extraction kit (Qiagen, Valencia, California, USA). All samples were screened for 12 Atlantic sturgeon microsatellite loci (*LS*19, *LS*39, *LS*54, *LS*68, *Aox*12, *Aox*23, *Aox*45, *AoxD*170, *AoxD*188, *AoxD*165, *AoxD*44, *AoxD*241; described in May et al. 1997; King et al. 2001; Henderson-Arzapalo and King 2002).

Estimation of Effective Population Size

Estimates of effective population size (N_e) were generated for each collection in NeEstimator (Do et al. 2014) using a rare allele cutoff of 0.02. Confidence intervals (95%) were produced using the jackknife approach.

6.1.3 Results

Effective population sizes varied considerably across the range of Atlantic sturgeon. Several rivers in the baseline exhibited very low effective population sizes (e.g., York, Albemarle, Ogeechee, and James; Table 11; Figure 30). The Hudson and Altamaha rivers exhibited two of the largest effective population sizes observed across the range of Atlantic sturgeon. This is consistent with earlier reports that these are the largest contemporary populations in the United States (ASSRT 2007; Kahnle et al. 2007; Peterson et al. 2008), and previously published estimates of effective population size (Moyer et al. 2012; O'Leary et al. 2014). The Savannah River also showed large effective population size relative to the other U.S. populations.

The Hudson River collections were the most robust in terms of sample size and length of the time series. Estimates of effective population size for the Hudson River ranged from 74.2 to 479.1 and were similar for adults and juveniles between 2006 and 2015 (Table 12; Figure 31). Confidence intervals were broad and in many instances had upper limits that could not be interpreted (infinite). Still, there may be a trend towards a reduction in effective population size between the early samples (1996-1997) and the more recent samples (2006-2015). Given the uncertainty of estimates in the current time series, future studies may consider the use of genomic approaches to provide more precise estimates of effective population size.

Based on this analysis, many Atlantic sturgeon populations are considered at significant risk of genetic drift, allelic fixation, and loss of genetic diversity (Kimura and Ohta 1969; Allendorf 1986). This is supported by reports by O'Leary et al. (2014) and Farrae et al. (2017), who projected future losses of genetic diversity for several populations. Moreover, many of the populations that were not represented in our genetic baseline are thought to be small and as such likely have very small effective population sizes. These relict populations are likely to be at even greater risk for loss of genetic diversity (Moyer et al. 2012). Since genetic diversity is linked to population fitness and future adaptive potential (Reed and Frankham 2003; Jump et al. 2009), continued monitoring and management consideration of effective population size in Atlantic sturgeon populations is warranted (Moyer et al. 2012).

6.2 Bycatch Estimates

6.2.1 Northeast Fisheries Observer Program and the At-sea Monitoring Program

6.2.1.1 Background of Analysis and Model Description

Analysis subsequent to previous estimates of sturgeon discards (Stein et al. 2004; ASMFC 2007), indicated that ratio estimators used in these early analyses may not be sufficient because Atlantic sturgeon encounters within defined spatial and temporal strata were more heterogeneous than desirable for a ratio estimator. Additionally, an examination of observer data indicated that the species mix within a trip may be a better predictor of Atlantic sturgeon encounter rates than the traditional variables used to describe a stratum such as mesh and gear, and a model-based approach may help to resolve some of the heterogeneity within a stratum. Accordingly, a generalized linear model (GLM) framework was developed to estimate Atlantic sturgeon discards in federal waters (Miller and Shepherd 2011).

This GLM framework was carried forward to estimate Atlantic sturgeon discards for this benchmark assessment. The GLM modeled Atlantic sturgeon takes on each trip as a function of the trip-specific species mix, year, and quarter. In Miller and Shepherd (2011), the species mix considered was comprised of those species currently managed with federal fishery management plans. However, in the approach applied here, the species considered as covariates were those species caught most on observed hauls encountering Atlantic sturgeon. More specifically, the total hail weights were estimated for all individual species on hauls that encountered Atlantic sturgeon and the species included as covariates were those whose cumulative sums represented 95% of the total hail weights on these hauls (Table 13 and Table 14). Depth and mesh were also examined as potential covariates; however, these variables were not included because they were often missing and can change substantially over the course of a trip. The composition of species landed on a trip was thought to be a proxy for differences in mesh size and depth.

Following and Miller and Shepherd (2011), a quasi-Poisson assumption was used for modeling Atlantic sturgeon takes as a function of species landed, year, and quarter factors, permitting the variance to be greater than that associated with a Poisson distribution. Each species was included as a binary predictor variables; runs that included species landed weights as continuous variables had convergence problems. The general model for the log-average take on a trip i was:

$$\ln(\hat{T}_i) = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} + \cdots + \hat{\beta}_p X_{pi}$$

where $X_{1i}, \ldots, X_{pi}$ represent the p species, gear, quarter covariates including any modeled interactions, and $\hat{\beta}_p$ represent estimated parameters.

Candidate models were fit separately to all observed bottom otter trawl and gill-net (sink and drift) trips. Models were fit to an appropriate subset of observer trips between 2000 and 2015. This subset of observed trips included all coastal statistical areas (Figure 32) and those observer programs that encountered Atlantic sturgeon and had a representative geographic range. Model selection was robust to the choice of included areas and observer programs. The species included as covariates for each gear are detailed in Tables 1 and 2 for otter trawls and gill nets, respectively.

Candidate models included the following factors and interactions:

1. No covariates
2. Quarter
3. Year
4. Quarter + Year + Quarter:Year
5. Species
6. Species + Quarter + Species:Quarter
7. Species + Year + Species:Year
8. Species + Year + Quarter + Species:Quarter + Species:Year
9. Species + Year + Quarter + Species:Quarter + Species:Year + Year:Quarter
10. Species + Year + Quarter + Species:Quarter + Species:Year + Year:Quarter + Species:Quarter:Year

For each gear (otter trawl and gill net), the best performing model was selected based on $QAIC_c$; the preferred model was the one with the minimum $QAIC_c$ value.

To predict Atlantic sturgeon take for all commercial landings, landings for each trip between 2000 and 2015 in the vessel trip report (VTR) database were determined for each species covariate. Using the estimated coefficients from the best performing model for each gear, the expected Atlantic sturgeon take was predicted for each VTR trip where information was available on whether the species was landed, and, if necessary, year and quarter. Total annual discard estimates were the sums of all predictions from the best-performing model for trips made in the relevant year.

To estimate dead bycatch, GLMs were fit to data based only on those Atlantic sturgeon encounters where individuals were recorded as dead. These models, however, resulted in nonsensical estimates for the total expected Atlantic sturgeon take when expanded to the VTR trips, presumably due to low sample sizes. As a result, dead discards were estimated by calculating the proportion of observed Atlantic sturgeon recorded as dead and applying this proportion to the total take estimate.

To explore patterns in Atlantic sturgeon bycatch, the distributions of depths and temperatures on observed hauls encountering Atlantic sturgeon were compared to those hauls that did not encounter Atlantic sturgeon using Kolmogorov-Smirnov tests.

6.2.1.2 Results

The best performing model fitted to trip-specific observer bottom otter trawl data was model 6 that allowed quarterly effects of the species mix on Atlantic sturgeon take (Table 15 and Table 16). Model 10 failed to converge. The best performing model fitted to trip-specific observer gillnet data was model 9 that allowed yearly and quarterly effects of the species mix on Atlantic sturgeon take as well as the interaction between year and quarter (Table 17 and Table 18). Model 10 again failed to converge.

The best performing model for each gear type was applied to vessel trip reports to predict Atlantic sturgeon take for all trips. The total bycatch of Atlantic sturgeon from bottom otter trawls ranged between 624–1,518 fish over the time series (Table 19; Figure 33). The proportion of the encountered Atlantic sturgeon recorded as dead ranged between 0–18% and averaged 4%. This resulted in annual dead discards ranging from 0–209 fish. Likewise, the total bycatch of Atlantic sturgeon from sink and drift gill nets ranged from 253–2,715 fish (Table 20; Figure 34). The proportion of Atlantic sturgeon recorded as dead ranged between 12–51% and averaged 30%, resulting in annual dead discards ranging from 110–690 fish.

Otter trawls and gillnets caught similar sizes of Atlantic sturgeon, with most fish in the 100 – 200 cm total length range, although both larger and smaller individuals were encountered (Figure 35).

Over all gears and observer programs that have encountered Atlantic sturgeon, the distribution of haul depths on observed hauls that caught Atlantic sturgeon was significantly different from those that did not encounter Atlantic surgeon (KS test: $D = 0.60$, $p < 0.001$) with Atlantic sturgeon encountered primarily at depths less than 20 m (Figure 36). Likewise, the distribution of surface water temperatures on observed hauls encountering Atlantic sturgeon was significantly different from those not encountering Atlantic sturgeon KS test: $D = 0.14$, $p < 0.001$) with Atlantic sturgeon primarily encountered at water temperatures of approximately 45–60º F (Figure 37). The spatial distribution of Atlantic sturgeon encounters on observed bottom otter trawls and gillnets by semester are depicted in Figure 38-Figure 41.

6.2.2 North Carolina estuarine gill-net fishery Atlantic sturgeon bycatch estimates

6.2.2.1 Background of Analysis and Model Description

Data

The North Carolina Division of Marine Fisheries' (NCDMF) Sea Turtle Bycatch Monitoring Program (Program 466) and Alternative Platform Observation Program (Program 467) are the primary programs by which the NCDMF collects information on bycatch from the state's commercial fisheries. Currently, these programs are limited to observations of North Carolina's estuarine gill-net fishery.

The number of commercial fishery trips observed by Programs 466 and 467 in management unit A has been limited (Figure 42), though most Atlantic sturgeon bycatch occurs in this area. To supplement information on bycatch of Atlantic sturgeon in management unit A for the purposes of model development, data from NCDMF's Striped Bass Independent Gill-Net Survey (Program 135) were used. While this program uses a variety of mesh sizes, only data collected from those mesh sizes that are permitted in the commercial fishery were used in the analysis (small: 3.0 and 3.5 ISM; large: 5.0, 5.5, and 6.0 ISM). Additionally, data collected during times and in areas when and where commercial fisheries are restricted were excluded from the analyses.

An estimate of total effort for North Carolina's estuarine gill-net fishery was needed to predict the bycatch for the entire fishery. Total effort was estimated by combining information from three NCDMF monitoring programs: Sea Turtle Bycatch Monitoring Program (see above), Trip Ticket Program, and Commercial Fish House Sampling Program (Program 461). Effort was measured as soak time (days) multiplied by net length (yards).

Commercial fisheries statistics in North Carolina are collected under a mandatory reporting program, the NCDMF Trip Ticket Program (Lupton and Phalen 1996). Data on individual fishing trips are recorded on trip ticket forms used by state-licensed fish dealers to document all transfers of fish sold from the fishermen to the dealer. Information reported on these forms includes transaction date, area fished, gear used, landed species, and total weights of each individual species, as well as fisherman and dealer information. The Trip Ticket Program is considered a census of all North Carolina landings and fishing trips.

Modeling

A GLM framework was used to predict Atlantic sturgeon interactions in North Carolina's estuarine gill-net fishery based on data collected during 2004 through 2015. Only those variables available in all data sources could be considered as potential covariates in the model. Available variables included year, mesh size, season, and management unit. Mesh sizes were categorized as large (≥5 inches) or small (<5 inches). Seasons were designated as: winter (December–February); spring (March–May); summer (June–August); and fall (September–November). Throughout this section (estimation of incidental takes), the term "year" is based on the season designation such that a year includes the month of December from the previous calendar year and the months January through November from the current calendar year.

Management units are shown in Figure 42. Management units A1, A2, and A3 were combined into a single management unit, unit A, for modeling purposes. Interactions were modeled independent of fish disposition (i.e., live or dead).

The numbers of Atlantic sturgeon occurring as bycatch was modeled by a set of explanatory variables and an offset term for effort. The variables investigated (and available) included year, mesh size, season, and management unit, all of which were treated as categorical variables. Using effort as an offset term in the model assumes that the number of Atlantic sturgeon interactions is proportional to fishing effort (A. Zuur, Highland Statistics Ltd., pers. comm.). Due to the small sample size and to maintain parsimony, no interactions between covariates were considered in the model. Code to compute many of the analyses were adapted from Zuur et al. (2009, 2012) and was implemented in R (R Core Team 2017).

The Poisson distribution is commonly used for modeling count data; however, the Poisson distribution assumes equidispersion—that is, the variance is equal to the mean. Count data are more often characterized by a variance larger than the mean, known as overdispersion. Some causes of overdispersion include missing covariates, missing interactions, outliers, modeling non-linear effects as linear, ignoring hierarchical data structure, ignoring temporal or spatial correlation, excessive number of zeros, and noisy data (Zuur et al. 2009, 2012). A less common situation is underdispersion in which the variance is less than the mean. Underdispersion may be due to the model fitting several outliers too well or inclusion of too many covariates or interactions (Zuur et al. 2009).

Data for each species were first fit with a standard Poisson GLM and the degree of dispersion was then evaluated. If over- or underdispersion was detected, an attempt was made to identify and eliminate the cause of the over- or underdispersion (to the extent allowed by the data) before considering alternative models, as suggested by Zuur et al. (2012). In the case of overdispersion, a negative binomial distribution can be used as it allows for overdispersion relative to the Poisson distribution. Alternatively, one can use a quasi-GLM model to correct the standard errors for overdispersion. If the overdispersion results from an excessive number of zeros (more than expected for a Poisson or negative binomial), then a model designed to account for these excess zeros can be applied. There are two types of models that are commonly used for count data that contain excess zeros. Those models are zero-altered (two-part or hurdle models) and zero-inflated (mixture) models (see Minami et al. 2007 and Zuur et al. 2009 for detailed information regarding the differences of these models). Minami et al. (2007) suggests that zero-inflated models may be more appropriate for catches of rarely encountered species; therefore, zero-inflated models were considered here if deemed appropriate.

All available covariates were included in the initial model and assessed for significance using the appropriate statistical test. Non-significant covariates were removed using backwards selection to find the best-fitting predictive model.

Estimation of Bycatch

Predicted numbers of Atlantic sturgeon bycatch were computed using the best-fitting GLM and assuming effort levels equivalent to those observed in 2004 through 2015. The GLM coefficients were applied to the corresponding predictor variables in the trip-level effort data to predict bycatch numbers. The proportion of fish observed dead was applied to the estimates of total bycatch to obtain estimates of dead discards.

6.2.2.1 Results

The best-fitting GLM was a standard Poisson model (Table 21) and all covariates (e.g., year, season, mesh, units) were found to be significant (Table 22). A Cook's distance plot suggests there were no outliers with a high impact on the regression parameters estimated by the Poisson GLM (i.e., no observations where Cook's distance > 1; Figure 43). There were no obvious patterns in the plots of the residuals (Figure 44-Figure 47). The model was found to provide an overall significant fit to the data (χ^2 = 1,626.2, df = 19, p < 0.0001).

Predicted total bycatch numbers for 2004 to 2015 ranged from a low of 1,286 Atlantic sturgeon in 2011 to a high of 13,668 Atlantic sturgeon in 2008 (Table 23, Figure 48). The percent of observed Atlantic sturgeon recorded as dead ranged from 0 - 20%, with an overall mean of 6%. Estimates of dead discards ranged from 0 – 424 fish (Table 23, Figure 48). Estimates of total bycatch in the most recent years (2010-2015) were generally lower than estimates for the earlier years (2004-2009).

Atlantic sturgeon caught in North Carolina's estuarine gillnet fishery were predominantly juveniles, with most fish less than 100 cm total length (Figure 49).

6.2.3 South Carolina American Shad fishery sturgeon bycatch estimates

The South Carolina Department of Natural Resources (SCDNR) manages American shad populations and collects fishery-independent and fishery-dependent data for the major shad rivers in the state. SCDNR collected voluntary landings data by river system since 1979 and instituted mandatory catch and effort reporting in 1998. Beginning in 2000, licensed shad fishermen were also required to account for any sturgeon species captured in their nets. Annual catch rates for sturgeon can be calculated using this information combined with provided effort data (Table 24 and Table 25). While reporting has not been fully implemented, as many licensed fishermen fish infrequently and provide incomplete, incorrect, or no effort data, SCDNR continues to work successfully with several cooperating commercial American shad gill-net fishermen to collect commercial catch and effort data on several river systems. Admittedly, there are likely still some gaps in these data, but they do provide the broadest temporal and spatial view of Atlantic sturgeon bycatch in fisheries for American shad in South Carolina. Additionally, SCDNR conducted fishery-independent shad studies for many years in several rivers where similar gear to those in the gill-net fisheries are used. In most cases, overlap with the commercial fishery occurs, which allows for more precise estimates of bycaught sturgeon.

Throughout South Carolina, American shad fisheries take place in estuaries and rivers from mid-January-mid April, depending on area. Fishers use either drift or set gill nets with a stretch mesh size of 13.97 cm. Bycatch of sturgeon in shad fisheries has been studied in both South Carolina and Georgia rivers. Collins and Smith (1997) indicated that catch rates for both Atlantic and shortnose sturgeon varied between 0.010–0.013 (fish per 91.4m of gill-net-hour) for the Winyah Bay, South Carolina, and 0.020–0.066 for the lower Savannah River. As part of the elimination of the shad ocean intercept fishery in 2005, areas where sturgeon were collected in the Winyah Bay are now unlawful to fish. Likewise, a study to estimate total by-catch and mortality of shortnose sturgeon in the Altamaha River, Georgia's commercial shad fishery indicated catch rates were highest during January and February (Bahn et al. 2012). As a result of these finding, Georgia's shad fishery was essentially closed to fishing in areas that are in close proximity to sturgeon spawning grounds in the Altamaha River.

Beginning in 2000, SCDNR collected monthly catch reports for all shad fishers throughout the state. Reports indicate pounds of shad caught but also account for when sturgeon were captured during netting events. Between years 2000-2015, a total of 1,479 Atlantic sturgeon were reported in the Winyah Bay and Waccamaw, Pee Dee, and Santee rivers' shad fisheries (Table 24) in the Carolina DPS. Average annual effort during the same time series equaled 4,029,432 net yards per hour with an average annual catch-per-unit-effort (CPUE) of 0.00035 Atlantic sturgeon per net yards per hour. It is important to note, since shad regulation changes in 2013 as part of requirements of South Carolina's Shad Sustainably Plan, reported numbers of Atlantic sturgeon for Carolina DPS river's decreased by 88% and CPUE decreased by 84%. These are significant decreases to already low levels of overall impact.

Between years 2000-2015 a total of 68 Atlantic sturgeon were reported in the Edisto, Combahee, and Savannah rivers' shad fisheries (Table 25) in the South Atlantic DPS. Average annual effort during the same time series equaled 327,842 net yards per hour with an average annual CPUE of 0.000013 Atlantic sturgeon per net yards per hour. It is important to note, since shad regulation changes in 2013 as part of requirements of South Carolina's Shad Sustainably Plan, reported numbers of Atlantic sturgeon for South Atlantic DPS rivers were zero. These are also significant decreases to already low levels of overall impact and relatively high numbers of Atlantic sturgeon catches in the time series compared to relatively low effort suggests Atlantic sturgeon populations in these rivers may be recovering.

6.2.4 Comparison of Bycatch Estimates

It is hard to compare the estimates from the NMFS and North Carolina observer programs to the estimates from the South Carolina logbook program due to the differences in how the data are collected. The South Carolina data are self-reported and are most likely an underestimate, since under-reporting is known to occur, while the NMFS and North Carolina estimates are developed from a sample of fishing trips in these regions and have their own degree of uncertainty.

South Carolina fishers reported an average of 4.25 Atlantic sturgeon caught per year in rivers in the South Atlantic DPS and 92.4 Atlantic sturgeon per year in waters in the Carolina DPS. No information was provided on the percent of those fish that were encountered dead or the size range of fish captured.

Estimates of total bycatch from the NMFS observer programs (gillnets and trawls combined) were lower than estimates from the North Carolina observer programs, but estimates of dead bycatch were similar (Figure 50) because the NMFS observer programs encountered a higher proportion of dead fish on gillnet hauls than North Carolina did. Estimates of bycatch from the NMFS observer program averaged 1,139 Atlantic sturgeon caught per year with 295 dead (25.9% dead) in the gillnet fishery and 1,062 Atlantic sturgeon caught per year with 41 fish dead (3.9% dead) in otter trawl fishery. Estimates of bycatch from the North Carolina observer programs averaged 4,179 Atlantic sturgeon caught per year with 218 dead (5.2% dead).

The NMFS observer program also encountered a different size range of fish than the North Carolina observer programs did. The Atlantic sturgeon observed in the NMFS program were larger, primarily subadults and adults, while the fish observed in the North Carolina programs were smaller, mostly juveniles with few adults observed (Figure 51). This is not surprising given that the NMFS programs mainly observe trips in coastal ocean waters while the North Carolina programs observe trips in estuarine waters, so they are observing fisheries that interact with different components of the Atlantic sturgeon population. This highlights the importance of having observer coverage in coastal, inshore and estuarine fisheries.

6.3 Mann-Kendall

6.3.1 Analysis Description

The Mann-Kendall test was performed to evaluate temporal trends in the indices. The Mann-Kendall test is a non-parametric test for monotonic trend in time-ordered data (Gilbert 1987). A total of 14 indices were evaluated and so the Holm-Bonferroni method was applied to counteract the problem of multiple comparisons. The method is intended to control the familywise error rate (the probability of making one or more false discoveries or type I errors) through adjustment of the p values.

6.3.2 Results

Only one statistically significant temporal trend was detected among the indices evaluated (Table 26). The juvenile index derived from the spring component of North Carolina's Program 135 survey exhibited a significant upward trend over the time series (1990-2015). No other significant trends were detected.

6.4 Power Analysis

6.4.1 Background of Analysis and Model Description

Power analysis was used to calculate the probability of detecting trends in the abundance indices developed from fishery-independent data using the methods of Gerrodette (1987) in R

(RCT 2017). Using this approach, changes in abundance can take place due to constant increments (linear model) or at a constant rate (exponential model). Linear trends were modeled as $A_i=A_1[1+r(i-1)]$ where A_i represents the abundance as a function of an index of time (i) and r is a constant increment of changes as a fraction of the starting abundance index (A_1). Exponential trends were modeled as $A_i=A_1(1+r)^{i-1}$. For a linear change, r=R/(n-1) where R is the overall fraction change in abundance. For an exponential change, $r=(R+1)^{1/(n-1)} – 1$. For each survey, the median CV can be calculated as the median proportional standard error or ($SE(A_i)/A_i$). The SAS established a reference point of a power of 0.80 for surveys to detect an increasing trend.

6.4.2 Model Configuration

All fishery-independent surveys that were developed into abundance indices were tested in the power analysis. Variability in abundance as a function of both linear and exponential change was tested using a one-tailed test. Power was calculated for a change (R) of ±50% over a 20-year time period for both a linear and exponential trend and R = 0.026 for a linear trend and R = 0.022 for an exponential trend. If spring and fall components of a survey were available, both were tested.

6.4.3 Model Results

Coastwide

Median CVs, or proportional standard error, ranged from 0.202–1.108 for the surveys analyzed and power values ranged from 0.13 to 0.98 (Table 27). As expected, surveys with low CVs had higher power and those with high CVs had lower power. Exponential trends indicated slightly higher power than linear trends. For both linear and exponential trends, the ability to detect decreasing trends was higher than that of increasing trends. The surveys with greater than a 0.80 power of being able to detect a 50% increase in abundance were NC p135 (fall only), SC Edisto, and JASAMP. The remaining surveys all fell below the desired power of 0.80 and therefore the ability to detect trends in the past 20 years is limited for many of the surveys used in this assessment.

Gulf of Maine DPS

The only abundance index for Atlantic sturgeon in this region was developed from the ME-NH Trawl Survey. This survey had the highest median CV (1.108) of all the surveys used in this assessment and the lowest power to detect a 50% increase in abundance over 20 years. For linear trends, the power was 0.13 and for exponential trends it was 0.16, well below the desired power of 0.80.

New York Bight DPS

Three surveys that were developed into indices of relative abundance for this region were tested for their power to detect 50% change in abundance for Atlantic sturgeon over 20 years. For the spring-only, fall-only, and spring-fall combined CT LIST survey index, the CVs were high and therefore the power was low (0.18-0.28) to detect an increasing trend over 20 years. JASAMP had a low median CV compared to other surveys tested and had higher power to detect trends. The power to detect an increasing trend in this survey was 0.89, above the desired value of 0.80. The NJ Ocean Trawl survey had a median CV of 0.518 and the power to detect an increasing trend over 20 years was 0.30-0.32.

Chesapeake Bay DPS

Of the surveys used in modeling for Atlantic sturgeon, only the VIMS Shad and River Herring Monitoring survey operates solely in the Chesapeake Bay. This survey had a high median CV (0.443) and low power to detect a 50% increase over 20-years at 0.37 for a linear trend and 0.39 for an exponential trend, well below the desired power of 0.80.

Carolina DPS

Both the fall and spring components of abundance indices for Atlantic sturgeon developed from the NC p135 survey were tested using power analysis. Compared to the surveys in other DPSs, this survey had relatively low median CVs (0.211 for the fall and 0.301 for the spring). For the fall component, the power to detect a 50% increase over 20 years was 0.87, above the desired value of 0.80. For the spring component, the power was much lower at 0.62 and 0.63 for linear and exponential trends, respectively.

South Atlantic DPS

The abundance index developed from the SC Edisto was tested for its power to detect a 50% increase in Atlantic sturgeon abundance over 20 years. This survey had a very low median CV (0.202) and the analysis indicated that the power was 0.89, above the desired power of 0.80. Of all the surveys used in the assessment, this one had the highest power to detect an increasing trend in Atlantic sturgeon abundance.

6.5 Cluster Analysis

6.5.1 Background of Analysis and Model Description

Cluster analysis was used to identify common trends in the fishery-independent survey data. Trends were identified using hierarchical agglomerative cluster analysis with a group average linking method using linear (Pearson) correlations as the measures of similarity. The analysis was used to determine if the abundance indices indicate any spatial or temporal clustering, i.e., spring and fall surveys or surveys within a DPS cluster together.

6.5.2 Model Configuration

Cluster analysis was performed in R (RCT 2017) on five of the six surveys that were developed into abundance indices and had at least 15 years of data, including seasonal components when available. These surveys included ME-NH Trawl, CT LIST (fall index), NJ Ocean Trawl, VIMS Shad and River Herring Monitoring, and NC p135 (spring and fall indices). The analysis requires continuous data sets with no missing values so 2015 data was omitted since it was not available for all surveys, the USFWS Coop was omitted from the analysis due to its terminal year of 2010, and the spring component of the CT LIST survey was omitted because it had missing data in 2010. Two time periods were tested to accommodate as many surveys as possible. The first time period tested, 1991-2014, was the longest but was restricted to four indices (CT LIST-fall, NJ Ocean Trawl, NC p135-spring, and NC p135-fall). The second time period tested, 2000-2014, was shorter but included six indices (ME-NH Trawl, CT LIST-fall, NJ Ocean Trawl, VIMS Shad and River Herring Monitoring, NC p135-spring, and NC p135-fall).

6.5.3 Model Results

For the cluster analysis on the 1991–2014 time period, two clusters were identified in the data with NC p135 spring and fall surveys in one cluster and CT LIST (fall) and NJ Ocean Trawl surveys in a second cluster (Figure 52). The results indicated some spatial structure with the survey components from the Carolina DPS clustering together and two surveys from the New York Bight DPS clustering together.

For the cluster analysis on the 2000–2014 time period, there were two clusters as indicated by the dendrogram (Figure 53). The surveys from CT LIST (fall) and ME-NH Trawl clustered together. While these surveys do not come from the same DPS, they are the two most northern surveys in the analysis and may represent some spatial clustering. The second cluster included the spring and fall component of the NC p135 survey, the NJ Ocean Trawl survey, and the VIMS Shad and River Herring Monitoring survey. Within this cluster there was some sub-structure, with the NC surveys grouping together and the NJ Ocean Trawl and VIMS survey clustering together. While there is no DPS level clustering occurring in this time period and the two surveys in the New York Bight DPS were in different clusters, there is some possible spatial structure between northern and southern surveys.

6.6 Conn Method

6.6.1 Background of Analysis and Model Description

When several population abundance indices provide conflicting signals, hierarchical analysis can be used to estimate a single population trend. The abundance indices for Atlantic sturgeon were combined into a composite index using hierarchical modeling as described in Conn (2010). This method assumes each index samples a relative abundance but that the abundance is subject to sampling and process errors. It can be used on surveys with different time series and selectivities, but it does assume that indices are measuring the same relative abundance.

6.6.2 Model Configuration

All available indices for juveniles and adult Atlantic sturgeon were standardized to their means. This included relative abundance indices from the ME-NH Trawl, CT LIST, NJ Ocean Trawl, VIMS Shad and River Herring Monitoring, NC p135, and the USFWS Coop surveys. If there was a fall or spring component, the fall components of the survey were selected to try to keep the indices during one time period. The indices were combined into one hierarchical index using the methods as described by Conn (2010) and the analysis was performed in R (RCT 2017). Additionally, the Conn method was applied to a subset of indices for an index of surveys that primarily catch juvenile Atlantic sturgeon (CT LIST, VIMS Shad and River Herring Monitoring, and NC p135) and one that catches both adults and juveniles (USFWS Coop, ME-NH Trawl, and NJ Ocean Trawl).

6.6.3 Model Results

The hierarchical model developed from all the available abundance indices predicted a stable abundance from 1984–2015, with peaks in the 1980s and late-1990s as well as in 2006 and 2007 (Figure 54). The index showed an increasing trend in the last three years, although there is a wide confidence interval around most of the estimates. A comparison of the individual indices and the Conn index can be seen in Figure 55.

The estimates of the standard deviation of the process error for each of the indices were also examined. High values suggest that the index may be a poor index for tracking abundance whereas lower values indicate indices that may be better tracking the population or it could suggest that these indices are measuring different populations. The standard deviation of the process errors for the USFWS Coop, ME-NH Trawl, and NJ Ocean Trawl surveys were much higher than those of CT LIST, VIMS Shad and River Herring Monitoring, and NC p135 (Figure 56). This may indicate that the USFWS Coop, ME-NH Trawl, and NJ Ocean Trawl surveys may not be tracking the population or it may be reflecting differences in sampling programs between all of the surveys (see Conn 2010 for a more thorough discussion). In fact, the three indices with the lowest process error variance are classified as catching juveniles while the three indices with higher process error variance catch both juveniles and adults (Table 9). Additionally, the three surveys that catch predominantly juvenile Atlantic sturgeon occur inshore while the three that catch juveniles and adults operate offshore on the mixed population.

The three abundance indices that were classified as juvenile indices (CT LISTS, VIMS Shad and River Herring Monitoring, and NC p135) were combined into a hierarchical index using the Conn method, excluding indices that catch juveniles and adults (Figure 57). The pattern of abundance was similar to the combined index using all six juvenile and adult indices but with smaller confidence intervals. The pattern of juvenile abundance appeared steady throughout the time series, with no large peaks or valleys. Moderate peaks occur in the mid-1980s and late-1990s as well as in 2006-2007, with the lowest values occurring in the late 1980s, 2003, and 2010.

Excluding surveys that caught predominantly juveniles, the three surveys catching both juveniles and adults (USFWS Coop, ME-NH Trawl, and NJ Ocean Trawl) were combined to create a hierarchical index using the Conn method (Figure 58). These three surveys had very large estimates of process error variance, suggesting that they may not be tracking abundance. The plot of abundance shows very large confidence intervals and no discernible pattern through the time series.

6.7 Dynamic Factor Analysis

6.7.1 Background of Analysis and Model Description

Dynamic factor analysis (DFA) can be used to identify a set of underlying trends when there are several time series of abundance indices available. The Multivariate Auto-Regressive State Space (MARSS) model is a package available in R (RCT 2017) that can be used for analyzing time-series data, including performing DFA. The model incorporates both process and observation error and explains variations in the indices using linear combinations of a set of hiding random walks. For a full description of the model see Holmes et al. 2014.

6.7.2 Model Configuration

Using the abundance indices for Atlantic sturgeon, DFA was used to find the number of trends from one (implying a coastwide stock) to four trends (representing 4 DPSs, excluding the South Atlantic DPS since there were no abundance indices representing that area that had >15 years of data). Using the six available abundance indices, DFA was performed on the detrended data by calculating z-scores. If seasonal components of a survey were available, the fall component was chosen for analysis. Several possible models were used to test for underlying trends using four structures for the R matrix, or the observation variance-covariance matrix:

1. Same variances and no covariance (“diagonal and equal”)
2. Different variances and no covariance (“diagonal and unequal”)
3. Same variance and same covariance (“equalvarcov”) and
4. Difference variances and covariances (“unconstrained”)

6.7.3 Model Results

Many parameters would not converge using the full time series (1984-2015), so the time series was shortened to begin in 1990 when more surveys had data. Assuming unequal variances and no covariance for the observation errors (R matrix), many parameters did not converge to the maximum likelihood values despite increasing the number of model iterations, possibly because the amount of data did not support the amount of parameters the model was estimating. The model was rerun assuming equal variances and no covariance and most of the parameters did converge. The results indicate that there is one underlying trend in the data (Table 28) and that this is best model based on the AICc values.

The DFA analysis concluded that there is only one trend in the Atlantic sturgeon abundance index data. This implies that the indices have similar trends, or no trend, and therefore are possibly capturing the coastwide stock rather than DPS-specific trends. This is likely due to having a combination of juvenile and adult indices as well as localized indices and others that sample the mixed offshore population.

6.8 Population Viability Analysis

6.8.1 Background of Analysis and Model Description

Estimates of extinction risk can be important when performing an assessment on a species that is threatened or endangered. The MARSS package in R (Holmes et al. 2014) has developed a population viability analysis (PVA) approach that can be used to calculate extinction risk metrics by fitting a univariate state-space model to population data with observation and process error. This approach uses a density-independent, stochastic exponential growth model in log space. PVA has been shown to produce accurate and reliable predictions and is a good tool for managing threatened or endangered species (Brook et al 2000), although there has been conflicting evidence regarding its application and use (Ellner et al. 2002). The results of the PVA depend on the quality of the data. A long time series as well as surveys that properly and consistently sample the species are necessary (Coulson et al. 2001). This poses a challenge for making predictions about the Atlantic sturgeon population, as most regions lack a survey that would be analogous to census data or a long-term data set of population count estimates. Additionally, the several available abundance indices suffer from low detection rates, often as low as 1% positive tows, because they are not directed for Atlantic sturgeon. During the Atlantic sturgeon status review by NMFS (2007), there were only two populations that had abundance estimates available: the Hudson and Altamaha Rivers (Schueller and Peterson 2006; Kahnle et al. 2007). Currently, there are localized abundance estimate time series available, such as the swept area estimates from NEAMAP for 2008-2012 (Kocik et al. 2013) and juvenile abundance estimates (Farrae 2009; Schueller and Peterson 2010; Hale et al. 2016) and effective population size (Moyer et al. 2012) in 2004-2007 for the Altamaha River in Georgia. Yet there are no long term population estimates to perform a robust PVA at the coastwide or DPS level.

PVA has been performed on a few sturgeon species. Jager et al. (2011) developed a PVA for the endangered shortnose sturgeon in the Ogeechee River system in Georgia. This analysis benefited from population estimates from 1990-2009 since the goals of the Recovery Plan (NMFS 1998) required abundance, age structure, and recruitment be determined for segments of the population. This model was adapted for the lower Columbia white sturgeon but is in development and has not been peer-reviewed so it is currently not used for management (ODFW 2011). The Canadian stock of the Atlantic sturgeon performed a Bayesian belief network analysis (Nantel 2010) to calculate probabilities of threats to the population but this was done for exploratory purposes and not for stock status (COSEWIC 2011).

While the data available for the current Atlantic sturgeon stock assessment does not support a PVA analogous to other sturgeon species, an attempt was made to apply the PVA code in the MARSS package to the available abundance indices. Because of the lack of robust data for this analysis, these should be taken as exploratory and not for management. The MARSS PVA is a model with process and observation variability that estimates the parameters *u* (growth rate), *Q* (Process errors), and *R* (observation errors).

While the MARSS PVA approach estimates the mean population growth rate and process variability under the assumption that the data have observation error, the more classic approach was developed by Dennis et al. (1991). The Dennis model, or method, assumes there is no observation error and thus the variability is all from process error.

6.8.2 Model Configuration

Both the MARSS PVA and the Dennis method were used for Atlantic sturgeon in this report. DFA indicated that there is one underlying trend in the Atlantic sturgeon data, therefore all available abundance indices were combined using the Conn approach (Conn 2010) that was developed as described in this report (see sections 6.6-6.7). PVA was used to evaluate if there has been any population growth for Atlantic sturgeon using the Conn index as well as each individual abundance index and any combination of surveys that represented the same DPS, mainly CT LIST and NJ Ocean Trawl (NY Bight DPS).

6.8.3 Model Results

6.8.3.1 Conn Index

PVA was performed on the Conn index using the 1984-2015 time series. Using the MARSS PVA approach with process and observation errors, the *Q* estimate (process error) was zero which means the maximum-likelihood estimate that the data are generated by is a process with no environment variation and only observation error and the model would not converge on a reasonable estimate for growth (Table 29). Using the Dennis et al. (1991) approach, the growth rate was estimated to be 1.2% (SE = 0.11) with *Q*=0.36, although the growth rate for this model was not significant (*P*=0.91). Therefore, the PVA performed on the coastwide Conn index indicates that no significant growth or decline in the population has taken place over the time series (1984-2015).

While the population has not shown significant growth over the entire time series, the data was shortened to 1998-2015 to see if there has been growth since the moratorium took place in 1998. As opposed to the coastwide analysis, all parameters converged using the MARSS PVA. The population growth rate was -0.01% [CI: -3.3%, 3.2%], although the confidence interval includes zero. The Dennis method was also run and indicated an approximately 1% per year decline and this result was also not significant (*P*=0.95). Therefore, the PVA indicates that no significant growth or decline in the population has taken place since the moratorium. Risk figures are shown in Figure 59.

6.8.3.2 Gulf of Maine DPS

Maine-New Hampshire Inshore Groundfish Trawl Survey
PVA was attempted on the ME-NH Trawl abundance index data for 2000-2015. The MARSS PVA would not converge on a solution and the *Q* parameter estimates for the Dennis method provided values that were outside a reasonable range (Table 29).

6.8.3.3 New York Bight DPS

Connecticut Long Island Sound Trawl
PVA was attempted on the CT LIST fall abundance index data for 1984-2015. The MARSS PVA would not converge on a solution and the *Q* parameter estimates for the Dennis method provided values that were outside a reasonable range (Table 29).

New Jersey Ocean Trawl
PVA was attempted on the NJ Ocean Trawl fall abundance index data for 1990-2015. The MARSS PVA would not converge on a solution and the *Q* parameter estimates for the Dennis method provided values that were outside a reasonable range (Table 29).

Combined Connecticut Long Island Sound Trawl and New Jersey Ocean Trawl
MARSS PVA has a feature where multi-site and subpopulation data can be combined and analyzed. Because CT LIST and NJ Ocean Trawl surveys are both located in the New York Bight DPS, they were combined within the MARSS package (Figure 60) and analyzed to see if the New

York Bight has experienced any significant population growth from 1984-2015. Assuming the CT LIST and NJ Ocean Trawl surveys represent a single population with independent and non-identical errors, results indicate an increase in the population of 4.9% [CI:-10.9%, 20.7%], although the confidence interval includes zero (Table 29). Additionally, the Dennis method also estimated the population growth rate to be 4.9% although these results were not significant (*P*=0.261). Therefore, no significant growth was detected in the New York Bight region using PVA.

6.8.3.4 Chesapeake Bay DPS

VIMS Shad and River Herring Monitoring

The MARSS PVA was run on the VIMS Shad and River Herring Monitoring abundance index data for 1998-2015. The population growth rate of the population was estimated to be -1.8%, although the confidence intervals around that estimate were wide and included zero (Table 29). The Dennis method estimated a similar population growth rate of -1.6% with similarly large errors. The results from the Dennis method were not significant (P=0.953). Therefore, no significant growth was detected in the VIMS index data using PVA.

6.8.3.5 Carolina DPS

North Carolina Program 135 Survey

The MARSS PVA was run on the fall portion of the NC p135 index data from 1990-2015. Using the MARSS PVA, the population growth rate was 3.9 % [CI: 0.1%, 7.8%], indicating that this population is growing (Table 29). Positive growth was not confirmed with the Dennis approach which found the population was decreasing at 1.5%, although these results were not significant (*P*=0.941).

6.8.3.6 US Fish and Wildlife Cooperative Tagging Cruise

PVA was attempted on the USFWS Coop abundance index data for 1988-2010. The MARSS PVA would not converge on a solution and the *Q* parameter estimates for the Dennis method provided values that were outside a reasonable range (Table 29).

6.9 Autoregressive Integrated Moving Average (ARIMA)

6.9.1 Background of Analysis and Model Description

Observed time series of abundance data are variable, reflecting changes in fish populations, within survey sampling variability, and varying catchability over time (Pennington 1986). Autoregressive Integrated Moving Average (ARIMA) models provide a means to filter measurement error from process variability (Box and Jenkins 1976; Helser and Hayes 1995), and hence allow us to more closely track a population than the raw data (Pennington 1986). ARIMA models provide time series estimates of abundance where the variance of the fitted estimates is less than the variance of the observed time series.

6.9.2 Model Configuration

Relative abundance indices used in this analysis are shown in Table 30. ARIMA models were only fit to indices with at least 15 years of data, without any missing data points (exploratory analyses indicated that model results could be sensitive to missing values).

ARIMA models were implemented using the *fishmethods* package in R (Nelson 2017; RCT 2016) and generally followed the approach of Helser and Hayes (1995) who extended Pennington's (1986) approach of *a priori* specification of an ARIMA model in which the population's size follows a random walk process. Helser and Hayes (1995) used bootstrap methods to infer population status relative to an index-based reference point. They used a two-tiered approach for this evaluation, whereby they specified the probability of being above or below a reference point and the associated statistical level of confidence (i.e., 80%) in this specification. Their approach takes into account the uncertainty in both the value of the fitted survey index for a given year and the reference point to which the population level is compared (Helser and Hayes 1995). This report used a parsimonious approach to this end that did not require subjective determination of an associated level of statistical confidence (e.g., 80%, 90% or 95%) by applying the approach used in Shertzer et al. (2008), NEFSC (2013), and ASMFC (2016). For bootstrapping, 1,000 samples were generated.

The terminal year of a given survey was compared to two index-based reference points: 1) the 25th percentile of the fitted time series (ASMFC 2013), and 2) the fitted abundance index from 1998 (implementation of ASMFC moratorium for Atlantic sturgeon). Related to the former reference point, we ran models using a) all available data for a given survey, and b) truncating all datasets to a common set of years (2000-2015) to explore whether the results were sensitive to the specific years over which the 25th percentile was calculated. Surveys that started after 2000 or had fewer than 15 years of data were omitted from this secondary analysis. For the later reference point (i.e., 2, above), for surveys that started after 1998, the terminal year was compared to the first year of the survey. See Table 30 for specifics. Probabilities greater than or equal to 0.50 were considered credible evidence that an index value was greater than a reference point (ASMFC 2013). Index values were log transformed prior to analysis [ln(y+0.01)].

The influence of the first data point on an ARIMA result has been raised as a concern in previous assessments where ARIMAs have been used (e.g., ASMFC 2012). Consequently, the sensitivity of the results to the influence of data points early in the time series was explored by re-running ARIMAs where the first 4 years of data were sequentially removed, one year at a time, in a reverse-retrospective fashion (e.g., run model with all years of data, run model removing the first year of data, run model removing the first two years of data, three years, etc.).

Finally, as a compliment to analyses reported elsewhere in this document, the significance of trends in each fitted index was evaluated by following the Mann-Kendall methods described in Section 6.3.

6.9.3 Model Results

Descriptive statistics from all model runs are provided in Table 32. When adjusted for multiple tests (Holm 1979; RCT 2017), residuals from all model fits were normally distributed (Table 32).

Fitted indices, grouped by DPS, are plotted in Figure 61, Figure 62, and Figure 63. Significant trends (Holm-adjusted p-values ≤ 0.05) are indicated with a + or – (for positive or negative trends, respectively) in Figure 61, Figure 62, and Figure 63, and summarized in Table 30.

6.9.3.1 Gulf of Maine DPS

Maine-New Hampshire trawl survey

Descriptive statistics from the ME-NH Trawl survey ARIMA are provided in Table 32. The fitted index declined from 2000 through the late 2000s before rising through 2015 (Figure 61, Figure 62, and Figure 63). No significant trend was detected in this index (Mann-Kendall τ -0.30, padj = 0.46; Table 30). The index is credibly above the 25th percentile of the time series [P(2015 index > 25th pctl) = 0.73; Table 30)]. Figure 64 suggests little change in this conclusion provided the time series includes at least 15 years of data.

This survey started in 2000, so a comparison against the index in 1998 is not possible; the index is credibly below the index in 2000 [P(2015 index > 2000 index) = 0.28; Table 30)], the first year in the time series. Figure 65 suggests little change in this conclusion provided the time series includes at least 15 years of data.

6.9.3.2 New York Bight DPS

Descriptive statistics from surveys conducted in the New York Bight DPS are provided in Table 32. Fitted indices are provided in Figure 61, Figure 62, and Figure 63. Terminal year fitted indices from all surveys in this DPS were credibly above both the 25th percentile of their respective surveys and their index value in 1998 (not all surveys had index values through 2015). The CT LIST spring nominal index, CT LIST fall nominal index, and the CT LIST combined spring-fall index had significant ($\alpha = 0.05$, Mann Kendall Test) increasing trends (Table 30).

Connecticut Long Island Sound Spring Nominal Index

The CT LIST spring (nominal) index declined through about 1990, increased through the early 2000s, and has been stable since then (Figure 63). Over the entire time series this index showed a significant increasing trend (Mann Kendall $\tau = 0.40$, $p_{adj} = 0.01$). Due to missing data points the model was fit with data only through 2014. The index value in 2014 is credibly above both the index value from 1998 and the 25th percentile of the time series (Table 30). The conclusion regarding status relative to 1998 was sensitive to the starting year of the survey (Figure 65).

Connecticut Long Island Sound Fall Nominal Index

The CT LIST fall (nominal) index shows a significant increasing trend over the time series (Mann Kendall $\tau = 0.86$, $p_{adj} < 0.0001$; Table 30 and Figure 63). Due to missing data points the model was fit with data only through 2009. The index value in 2009 is credibly above both the index value from 1998 and the 25th percentile of the time series. These conclusions are robust to the starting year of the survey (Figure 64 and Figure 65).

Connecticut Long Island Sound Combined Spring and Fall Nominal Index
The combined spring and fall index closely mirrors the CT LIST fall-only index (Figure 61 and Figure 63). This combined index also showed a significant increasing trend over the time series (Mann Kendall $\tau = 0.78$, $p_{adj} < 0.0001$; Table 30). The index in 2009 (terminal year due to missing values) was credibly above both the 25th percentile of the time series and the index value in 1998 (Figure 64 and Figure 65).

New Jersey Ocean Trawl
The New Jersey ocean trawl index declined through the mid-1990s (the time of commercial fishery closure in NJ) after which it increased, peaking in the mid-2000s, before dipping slightly and again rising (Figure 61, Figure 62, and Figure 63). The index in 2015 was credibly above both the 25th percentile of the time series and the index in 1998 (Table 30, Figure 64, and Figure 65).

6.9.3.3 Chesapeake Bay DPS

Virginia Institute of Marine Science (VIMS) Shad and River Herring Monitoring Survey
Two indices were developed from the VIMS Shad and River Herring Monitoring survey: an index including the James, York, and Rappahannock rivers, and an index including only the James River. These indices were very strongly correlated with each other (Figure 66). Both indices show a sinuous pattern with peaks in 1998, 2006, and 2015 (Figure 61, Figure 62, and Figure 63). Fitted indices from this DPS had no significant trend ($\alpha = 0.05$, Mann Kendall Test; Table 30). The indices in 2015 were credibly above the 25th percentile of their respective time series (Figure 64). The indices in 2015 were likely below their respective index values in 1998, though this conclusion is sensitive to survey start year (Figure 65). Descriptive statistics from these surveys are provided in Table 32.

6.9.3.4 Carolina DPS

Descriptive statistics from surveys conducted in the Carolina DPS are provided in Table 32. Fitted indices are provided in Figure 61, Figure 62, and Figure 63. Terminal year indices in this DPS were all credibly above the 25th percentile of their respective survey time series (Table 30). Terminal year indices in this DPS were all credibly above their respective index value in 1998 except for the North Carolina p135fall YOY index. Fitted indices from this DPS had either no significant trend or significantly increasing trends ($\alpha = 0.05$, Mann Kendall Test). The USFWS Coop cruise survey in this DPS was strongly positively correlated with NC p195 spring indices and the NJ Ocean Trawl index and strongly negatively correlated with the ME-NH Trawl index (Figure 66). Fitted NC p135 spring indices tend to be strongly positively correlated with fitted indices in CT LIST and the Conn index. Fitted indices in NC p135 in fall are strongly correlated with fitted indices from NJ Ocean Trawl and the Conn index.

US Fish & Wildlife Service (USFWS) Cooperative Tagging Program Index

The USFWS Coop index declined through about 1995, after which it increased through 2008, before declining through 2010 (this index ends in 2010; Figure 61, Figure 62, and Figure 63). This index had a significant increasing trend over its duration (Mann Kendall $\tau = 0.64$, $p_{adj} = 0.0002$, Table 30). This index is credibly above both the 25th percentile of the time series and the index in 1998 (Figure 64 and Figure 65).

North Carolina Program 135 Spring YOY & Juvenile Index

This index generally increased over its duration, save a large decline between 2000 and 2005 and a smaller decline between 2008 and 2010 (Figure 61, Figure 62, and Figure 63). The increasing trend over the time series was significant (Mann Kendall $\tau = 0.69$, $p < 0.0001$; Table 30). The index in 2015 is credibly above both the 25th percentile of the time series and the index value in 1998 (Figure 64 and Figure 65).

North Carolina Program 135 spring YOY index

The fitted index generally increased from its inception through 2002 before declining through 2012, and subsequently rising (Figure 63). The trend in the fitted index over the time series was not significant (Table 30). The index value in 2015 is credibly above both the 25th percentile of the time series and the index in 1998 (Table 30, Figure 64 and Figure 65).

North Carolina Program 135 Spring Juvenile Index

The fitted index increased from the survey's inception through the early 2000s, and again from the mid-2000s through 2013 (Figure 61, Figure 62, and Figure 63). The increasing trend in the fitted index over the time series was significant (Table 30), and the index in 2015 is credibly above both the 25th percentile of the time series and the index in 1998 (Figure 64 and Figure 65).

North Carolina Program 135 Fall YOY & Juvenile Index

The fitted index declined from inception of the survey through 1994 before generally rising over the duration of the time series (Figure 61, Figure 62, and Figure 63). The trend in the fitted index was significantly increasing (Table 30). The index in 2015 was credibly above both the 25th percentile of the time series and the index in 1998 (Figure 64 and Figure 65).

North Carolina Program 135 Fall YOY Index

The fitted index declined from the survey's inception through 1996 before increasing through 2001 and subsequently declining and stabilizing over the reminder of the time series (Figure 61, Figure 62, and Figure 63). The trend in this index was not significant (Table 30). The index in 2015 is credibly above the 25th percentile of the time series (Figure 64). The index is not credibly above the index in 1998, though the probability of this hovers just below 0.50 (Figure 65). This conclusion is sensitive to the survey start year.

North Carolina Program 135 Fall Juvenile Index

The fitted index from this survey declined through 1994 before increasing through 2012 and stabilizing for the remainder of the time series (Figure 61, Figure 62, and Figure 63). The trend from the fitted index over the time series was significantly increasing (Table 30). The index in 2015 is credibly above both the 25th percentile of the time series and the index in 1998 (Figure 64 and Figure 65).

6.9.3.5 South Atlantic DPS

There were no indices from the South Atlantic DPS that met the SAS's time-series length requirements.

6.9.3.6 Coastwide index

Conn Index
Descriptive statistics from the Conn index are provided in Table 32. This index declined and generally rose between 1984 and 1990; the index declined between 1990 and 1996, after which the index has generally risen (there are two 2-3 year periods of stabilization). By 1996, closures of the Atlantic sturgeon fishery had been instituted in all Atlantic Coast states except for Rhode Island, Connecticut, Delaware, Maryland, and Georgia, all of which adopted a 2.13 m (7-foot) minimum size limit (ASSRT 2007). ASMFC instituted a moratorium in 1998.

The Conn index is credibly above both the 25th percentile of the time series and the index value in 1998 (Figure 64 and Figure 65); this conclusion is insensitive to the survey start year (Figure 64 and Figure 65). Finally, since this index is a composite of all indices, it is not surprisingly strongly correlated with several indices: NC p135 fall juvenile and fall YOY & juvenile indices, NC p135 spring juvenile and spring YOY & juvenile indices, and the NJ Ocean Trawl index (Figure 66).

6.9.4 ARIMA Summary

When using all available years of data for all indices, the terminal year index values were all credibly above the 25th percentile of their respective time series (Table 30). When truncating surveys to a common set of years (2000–2015) the terminal year of only one index, NC p135 spring YOY index, was not credibly above the 25th percentile of the time series (Table 30 and 0), suggesting that the all-year analysis was robust. The situation with respect to index values in 1998 is a little more mixed (Table 30). The 2015 index from the Gulf of Maine DPS (ME-NH Trawl survey) is not credibly above the index value in 2000 (survey started in 2000). All terminal year indices from surveys in the New York Bight DPS are credibly above their respective 1998 index values. Terminal year index values from surveys in the Chesapeake Bay DPS are not credibly above their respective 1998 index values (these indices are very strongly correlated with each other; Table 30, Figure 66). Finally, terminal year index values for all fitted indices in the Carolina DPS, save one, are above their respective 1998 index values (Table 30).

All surveys examined had, over their entire duration, either no significant trend or an increasing trend (Table 30). Similarly, fitted indices exhibited either strong positive correlations among one another (arbitrarily defined as ≥ +0.60), or no strong correlation among each other, except for the ME-NH Trawl index where we saw strong negative (arbitrarily defined as ≤ -0.60) correlations with one fitted index in the Carolina DPS, and one in the New York Bight DPS (Figure 66). Fitted indices from a given survey where ages were split out or combined tended to be strongly positively correlated with each other (e.g., NC p135 spring juvenile index strongly positively correlated with NC p135 spring juvenile and YOY index; Figure 66).

In general, conclusions regarding terminal year status relative to the 25th percentile reference point were insensitive to survey start year provided surveys had at least 15 years of data (Figure 64). Conclusions regarding status relative to 1998 were mixed suggesting some caution when interpreting results where we saw a change in status as a function of survey start year (Figure 65). Removing years of data sometimes increased the probability of the terminal year being above the index in 1998 (e.g., VIMS Shad and River Herring Monitoring survey) and sometimes decreased the probability (CT LIST spring nominal index). We explored alternate methods of time series smoothing (e.g., splines and loess smoothers), but these alternate methods require subjectivity in determining just how much smoothing to apply. The model-based ARIMA approach removes that subjectivity, increases the precision of the index, allows us to quantify the status of a terminal year (or any other year) index accounting for uncertainty in the index and reference point, and filters out measurement error (Pennington 1986; Helser and Hayes 1995).

6.10 Mixed Stock Analysis

Overview

Atlantic sturgeon from different populations and DPSs mix extensively in marine and estuarine waters. One known aggregation occurs near the mouth of the Hudson River in the New York Bight (Dunton et al. 2010). In the early 1990s, an intercept-fishery targeted Atlantic sturgeon off the coast of New York and New Jersey. Spine samples archived from sturgeon harvested by this fishery (provided by Dave Secor, Chesapeake Biological Laboratory; see Stevenson and Secor 1999) presented a unique opportunity to examine changes in stock composition over time when compared against recent mixed stock analyses. In addition, Dewayne Fox (Delaware State University) provided a large number of tissue samples collected from adult Atlantic sturgeon that were captured and tagged off the coast of Delaware during the spring. A series of published mixed stock analyses of Atlantic sturgeon captured in coastal environments allowed for comparisons to be made across space and time (Table 33). One mixed stock analysis (Wirgin et al. 2015a) was not included in comparisons, as most of these fish were included in the current analysis on adults captured off the Delaware coast.

Extraction of DNA and Genotyping

DNA was extracted from samples collected from fish harvested in the Hudson River intercept fishery (1993–1995; *n* = 83) and tagged more recently (2009–2016; *n* = 391) off the coast of Delaware. Samples were genotyped at the USGS Leetown Science Center. Whole genomic DNA was extracted from tissue samples using the Qiagen Blood and Tissue extraction kit (Qiagen, Valencia, California, USA). All samples were screened for 12 Atlantic sturgeon microsatellite loci (*LS*19, *LS*39, *LS*54, *LS*68, *Aox*12, *Aox*23, *Aox*45, *AoxD*170, *AoxD*188, *AoxD*165, *AoxD*44, *AoxD*241; described in May et al. 1997, King et al. 2001, and Henderson-Arzapalo and King 2002). Due to the age of the Hudson River intercept fishery samples, genotypes could not be obtained at all loci for many of the individuals.

Genetic Baseline
Genotypes from 1,658 Atlantic sturgeon representing 50 collections from 11 rivers plus one sound (Albemarle, North Carolina) were used to characterize the genetic signature of potential source populations (Table 34). All individuals included in the baseline were captured in the riverine environment with the exception of one collection, Albemarle Sound. The Albemarle Sound samples were collected in tidal waters outside of a known spawning area. This is a known weakness of the current baseline, as it may represent sturgeon from several spawning populations within the Carolina DPS. Leetown Science Center is actively working with another agency to incorporate additional collections from the Carolina DPS, however these samples were not yet available when these assignments were run. River-resident juveniles (<500 mm TL) and adults (≥1,500 mm TL) were included in the baseline. Individuals outside of this size criterion were excluded from the genetic baseline due to the extensive dispersal of subadult and adult Atlantic sturgeon outside of spawning. The only exception is some subadults were used to characterize the St. John River, as these were the only samples that we have been able to access. This is expected to have minimal influence on the current analysis, given that the St. John River is very far away from the study area. All collections were grouped by river to provide a reference for assignment testing.

Genetic Assignments
Genetic assignment testing was conducted using GeneClass2 (Piry et al. 2004) using the criterion of Rannala and Mountain (1997) with the previously described genetic baseline as a reference. The efficiency of this approach was tested by assigning known samples to rivers within the baseline. Overall, 84.9% of individuals were correctly assigned to their river of origin, and 95.2% of individuals were correctly assigned to their DPS of origin (Table 35).

Next, GeneClass2 was used to assess the origin of genotyped individuals. The river with the highest assignment probability was assumed to be the river of origin. Most assignment probabilities were strong (>90%). However, these results should be interpreted with some caution as the assignments are based solely on allele frequencies, and it is possible that by chance an individual has a genotype that is more common in another population. This is especially true for individuals where fewer than 12 loci were scored, as was common in the historic samples from the intercept fishery (mean = 9.3 scored loci/sample; range: 2-12).

Synthesis of mixed stock analyses
Based on the mixed stock analysis, the New York Bight intercept fishery primarily harvested sturgeon from the Hudson River population (Figure 67). However, the harvested fish were clearly not restricted to the Hudson River population, as many fish from the Delaware River were taken in addition to individuals from more distant sources (Figure 67). In the sample of 83 fish, the presence of four separate DPSs was detected and some Atlantic sturgeon from Canada (Figure 67). This suggests that the fishery impacted populations across the coast, and continued to impact other populations (especially the Delaware River population) after local moratoriums had been enacted. More recent surveys of stock composition (Dunton et al. 2012; Waldman et al. 2013; O'Leary et al. 2015; and the Delaware Coast assignments presented here; Figure 67 and Figure 68) are consistent with this result, and suggest that ongoing bycatch in the New York

Bight may continue to have a coastwide impact on the recovery of Atlantic sturgeon (Dunton et al. 2015). Collectively, these results highlight the importance of this area for many Atlantic sturgeon populations, and the potential for localized mortality to impact populations across the United States.

These results (39.6% Hudson River origin) are not consistent with Waldman et al. (1996) which reported that the overwhelming majority (97.2%) of Atlantic sturgeon captured in the New York Bight were from the Hudson River population. However, Waldman et al. (1996) used a less-resolved genetic approach (mitochondrial DNA and RFLP versus microsatellites; see comparison of assignment accuracy in Waldman et al. 2013) and lacked baseline samples for the Albemarle Sound, as well as the Delaware, James, and York Rivers. Thus, it is likely that Waldman et al. (1996) lacked the power to identify additional stocks in the fishery, and these were likely present in their samples yet undetected.

In general, the relative abundance of each DPS observed in the New York Bight appears to have been relatively consistent over time (Figure 68). However, the small historical proportion of Atlantic sturgeon from the Chesapeake Bay (James and York Rivers), Carolina (Albemarle Sound; entirely absent), and South Atlantic (Edisto, Savannah, Ogeechee, and Altamaha Rivers) DPSs relative to recent observations may suggest that these populations are recovering, at least with respect to the New York Bight DPS (Figure 67, Figure 68). Additionally, recent work by Savoy et al. (2017) suggests that there may be some recovery occurring within the Connecticut River. However, these fish were not represented in any of the genetic baselines and therefore have not been resolved in any of the mixed stock analyses to date.

6.11 Conventional Tagging Model

Conventional tagging data were available through the USFWS Cooperative Coastal Sturgeon Tagging Program Database. The database collects information on the release and recapture of shortnose and Atlantic sturgeon tagged with conventional streamer tags (as opposed to acoustic tags, although some fish are double-tagged) by thirty-three partners from Maine to Georgia, including state agencies, federal agencies, and academic institutions. The program has existed since 1988. Over 20,000 Atlantic sturgeon have been tagged, with a recapture rate of approximately 9%.

Although the conventional tagging database provides a longer time-series of tagged fish than the acoustic tagging dataset, the SAS had concerns about the reliability of the dataset, including the low recapture rate, the uncertainty in the reporting rate, and the potential for incomplete reporting.

6.12 Acoustic Tagging Model

6.12.1 Background of Analysis and Model Description

The Cormack–Jolly–Seber (CJS) model is an open capture–recapture model that provides estimates of detection probability (probability that a tagged fish will be detected by a receiver if present), and apparent survival (a fish's probability of surviving and being in an area covered by receivers; Kéry and Schaub 2012). Each tagged individual in the model has a capture history based on whether it was alive and detected for a given sampling period. Hightower et al. (2015) previously analyzed a subset (from South Atlantic and Carolina DPSs) of this dataset using the CJS model.

6.12.2 Acoustic Tagging Data

Atlantic sturgeon have been implanted with acoustic transmitters by a number of researchers throughout the Atlantic Coast. Data for this analysis were provided by 12 different researchers and state agencies from all five DPSs. A total of 1,331 tagged Atlantic sturgeon detection records (Table 36) were available from a period of January 2006–December 2015 (Figure 69). The size of Atlantic sturgeon at tagging ranged from 298–2,680 mm TL (Figure 70). Atlantic sturgeon were assigned to a "home" DPS via genetic information (collected at tagging and analyzed in conjunction with this assessment) when possible. Otherwise, individuals were assigned to a DPS based on tagging location.

6.12.3 Model Configuration

The model was constructed in Program R and run using WinBUGS. The model code was based on that of Kéry and Schaub (2012) and Hightower et al. (2015). A simulation study was used to evaluate model performance. The model estimates survival and detection probability on monthly data time-steps. Monthly estimates of survival were then converted to annual estimates. A variety of modeling scenarios were evaluated with different temporal and DPS varying estimates of both survival and detection probability. Additionally, tags were analyzed based on three size groups: all combined, adults (>1,300 mm TL), and juveniles (<1,300 mm TL). The best model for each size group was selected using Deviance Information Criterion (DIC).

6.12.4 Model Results

6.12.1.1 Coastwide Results

Overall, the mean survival estimate was high for all Atlantic sturgeon, at 0.96 (0.84–0.99, 95% credible interval; Table 37). Adult survival (0.94, 0.71–1.00) was slightly higher than juvenile survival (0.91, 0.63–1.00). This translates into total mortality (Z) estimates of 0.04 for all Atlantic sturgeon, 0.06 for adults only, and 0.09 for juveniles. Estimates from the best supported model used a single survival estimate, but had varying monthly detection. All models produced similar estimates of survival (~0.90), suggesting robust results. Detection was lower in winter and early spring months (Figure 71), and slightly higher for juveniles. This is consistent with observations of Atlantic sturgeon moving to areas with poor receiver coverage or areas where receivers are pulled seasonally (e.g., coastal Delaware). Juvenile Atlantic sturgeon had a higher detection probability, likely because they tend to remain within inshore areas with generally better receiver coverage.

Estimated annual survival was somewhat higher than estimated by Hightower et al. (2015) for the subset of this data, while Kahnle et al. (2007) estimated annual adult Atlantic sturgeon survival to range between 0.76-0.92. Additionally, for related gulf sturgeon, Pine et al. (2001) estimated subadult and adult survival of 0.84 and Rudd et al. (2014) estimated survival to range from 0.70–0.98 for four different population groups.

6.12.1.2 DPS-Specific Results

Individual DPS mean survival estimates were variable and lower than the coastwide pooled estimates (Table 38). Estimates from the best supported model used a single survival estimate, but had varying monthly detection. Monthly detection estimates were like those of the coastwide estimates. Pooled size estimates for the Carolina and South Atlantic DPSs were like the results of Hightower et al. (2015) for rivers in those same DPSs. Mean survival estimates for adult (Table 39) and juvenile (Table 40) size groups was widely variable among DPSs. Mean survival estimates were lower for individual DPSs than coastwide. The Carolina DPS (0.34, 0.02–0.87) adult and Gulf of Maine DPS (0.35, 0.02–0.91) and South Atlantic DPS (0.62, 0.13–0.96) juvenile estimates were especially low, although the credible intervals were very wide.

Mean survival estimates were lower for individual DPSs than for the coastwide population. This was a result of how mean estimates are derived in the model. The CJS model appeared to be somewhat sensitive to sample size and credible intervals were generally wider in groups with smaller sample sizes (Table 36). The posterior distributions of survival were left skewed and had an upper bound of 1.0, so that greater uncertainty tended to pull mean estimates down. Using the same model, Hightower et al. (2015) also observed a higher pooled than individual survival estimate in all but one of their study rivers and credible intervals were all larger for individual estimates.

Further tagging studies may be required to improve estimates in areas with poor estimates and small sample sizes. If survival is actually high, adding additional years of telemetry data will improve and increase estimates of survival, since there would be additional opportunities to detect tagged sturgeon that may have been unobserved previously, although still alive. The next step for using acoustic tagging data should involve method with a spatial component, such as multi-state modeling (Kéry and Schaub 2012). This would allow for the quantifying of movements and has already been successfully used for sturgeon populations (Rudd et al. 2014).

6.13 Stock Reduction Analysis

Stock reduction analysis attempts to answer the question “given what we know about the life history of a species, how productive would the stock have to have been to sustain the observed catch and end up where it is now?”

The two modeling frameworks explored in this assessment are Depletion-Based Stock Reduction Analysis (DBSRA; Dick and MacCall 2011) and Stochastic Stock Reduction Analysis (SSRA; Walters et al. 2006). The major difference between the two approaches is the population model that underlies the analysis: DBSRA uses a surplus production model and SSRA uses an age-structured model.

6.13.1 Depletion-Based Stock Reduction Analysis

6.13.1.1 Background of Analysis and Model Description

Depletion-based stock reduction analysis (DBSRA) is a technique proposed by Dick and MacCall (2010, 2011) to generate sustainable yield reference points for data-poor groundfish stocks in the Pacific Northwest. It is a variation on stochastic stock reduction analysis (Walters et al., 2006) that uses a production model rather than an age-structured model to describe the underlying population dynamics.

In this approach, a population is described by a model, in this case the Pella–Tomlinson–Fletcher (PTF) surplus production model:

$$B_{t+1} = B_t + \gamma \cdot MSY \cdot \left(\frac{B_t}{K}\right) - \gamma \cdot MSY \cdot \left(\frac{B_t}{K}\right)^n - C_t \tag{1}$$

In this formulation, *n* is the shape parameter that defines where the maximum productivity of the stock occurs relative to *K*, the carrying capacity or virgin biomass:

$$\frac{B_{MSY}}{K} = n^{\frac{1}{(1-n)}}$$

When *n* = 2, the PTF model is equivalent to the Schaefer model, where $B_{MSY} = 0.5K$. When $n < 2$, the maximum productivity of the stock occurs at a biomass less than half of *K*, whereas when $n > 2$, the maximum occurs at greater than half of *K*. The parameter γ is entirely dependent on *n:*

$$\gamma = \frac{n^{\left(\frac{n}{n-1}\right)}}{n-1} \tag{2}$$

MSY represents the maximum sustainable yield of the stock. Dick and MacCall reparametrized *MSY* as a function of the shape of the productivity curve, *K,* and U_{MSY}:

$$MSY = K \cdot \frac{B_{MSY}}{K} \cdot U_{MSY} \tag{3}$$

It has been noted that the PTF model tends to overestimate production at low stock sizes when the production curve is skewed away from the traditional symmetrical Schaefer shape. Therefore, Dick and MacCall implemented a hybrid production function that estimate production using the Schaefer function below a certain biomass and the PTF function above it.

We can select reasonable values for B_{MSY}/K and U_{MSY} based on our knowledge of the life history of this species and meta-analysis of other, similar species, and then ask the question: if the population sustains *y* years of observed catch, what did the virgin population size have to be in order to both sustain those catches without being driven to extinction and end up at some known fraction of *K* at the end of the time series?

Selecting point values for B_{MSY}/K and U_{MSY}, as well as for the final target B_y/K ratio, will give us one solution. By instead drawing values from distributions for those parameters, we can incorporate our uncertainty about those parameters into the final estimates of *K*, and by extension B_{MSY} and the proposed overfishing limit.

The formulation of Dick and MacCall's DBSRA as implemented here includes three extensions: (1) catch is not assumed to be known without error and instead is drawn from a series of annual distributions; (2) the population is not necessarily assumed to start at *K*, but from a proportion of *K* that is drawn from a distribution; and (3) *K* is assumed to have changed over time in stanzas, with *K* in later years being calculated as a proportion of virgin *K*. The proportion of virgin *K* in later years is also drawn from a distribution.

6.13.1.2 Model Configuration

It is not possible to separate historical landings by DPS. The oldest historical fisheries tended to operate on mature individuals returning to spawn, but there have also been significant removals from ocean fisheries, including the directed ocean intercept fisheries off New York and the Carolinas and bycatch from other ocean fisheries. In addition, even in-river fisheries may harvest fish from another DPS that are visiting to feed or shelter in the estuaries. Therefore, this model treats the coastwide meta-complex of Atlantic sturgeon populations as a single stock.

The total removals time series for this model (Table 41) includes US Fish Commission landings data from 1887–1949, state and federal landings data obtained from ACCSP from 1950–2015, and estimates of bycatch from the Northeast Fisheries Pelagic Observer Program (2000–2015; see Section 4.2) and NC's inshore gill-net monitoring program (2004–2015; see section 4.3). The DBSRA requires input in total weight, so for estimates of bycatch in numbers, data on mean weight of observed sturgeon were used to convert numbers into weight.

There are gaps in the earliest years of the historical catch record; these most likely do not represent true years of zero catch, but rather a lack of reporting. A loess smoother was used to interpolate years of missing catch over the first 25 years of the data series (Figure 72).

Removals were assumed to have some degree of uncertainty around them. For each run, a time-series of removals was created by drawing an estimate of catch for each year from independent lognormal distributions with the mean equal to the reported annual value and a CV which varied depending on the time period and the assumed reliability of reporting from that period (Table 41; Figure 73).

The analysis draws values needed to parameterize the hybrid PTF function from distributions specified by life history analysis, meta-analysis of similar species, and expert opinion. The values drawn are natural mortality, the ratio of F_{MSY} to M, the ratio of B_{MSY} to K, and the ratio of biomass in the terminal year to K. In addition, for some runs, the ratio of biomass in the initial year to K and the ratio of K in recent years to virgin K were also drawn from distributions.

The distributions of M, F_{MSY}/M, and B_{MSY}/K were assumed to be informative (lognormal or beta distributions) while the distributions for the other parameters were uniform.

The parameters and their distributions are described in 0 and Figure 74.

6.13.1.3 Model Results

Overall rates of success–runs that ended at the correct B_{2015}/K ratio and did not drive the population extinct–were low. The model preferred runs where the ratio of B_{2015-}/K was higher (Figure 75). The model struggles to reconcile the high catches at the beginning of the time series with the lack of recovery with the low observed catch in recent years. Allowing K to vary over time–suggesting lower productivity in recent years–increased the number of successful runs.

Across different sensitivity runs, estimates of virgin K were very similar (Figure 77), with the base single K model having a median K = 27,988 mt and the base two-stanza K run having a median initial K = 27,724 mt.

For the 2-stanza K model, the model preferred runs with a median K scalar of approximately 0.46 (Figure 78), suggesting the current carrying capacity of the Atlantic coast is K = 12,777 mt. Estimates of current K were similar across sensitivity runs for the 2-stanza model as well (Figure 78).

This model cannot be used to evaluate stock status, since stock status relative to K is one of the inputs (Figure 74). However, trends are similar across runs regardless of final stock status, with the population declining rapidly from the beginning of the time-series to the early 1900s to a low but stable abundance, with the population beginning to increase again from the late 1990s onwards.

ARIMA trend analysis generally suggested either no trends or increasing trends for the indices examined, which is generally consistent with the DBSRA result.

6.13.2 Stochastic Stock Reduction Analysis (SSRA)

6.13.2.1 Background of Analysis and Model Description

Walters *et al.* (2006) developed stochastic stock reduction analysis (SSRA) to answer the question:

> *"If the stock had average unfished recruitment R0 and exhibited recruitment over time that varied around a mean recruitment relationship (around a stock–recruitment curve) in a pattern similar to that observed for other populations, how probable is it that stock size would end up at or near the present estimated size given the observed history of catch?"*

Conceptually, this is very similar to the DBSRA, but SSRA uses an age-structured model to describe the population dynamics instead of a surplus production model. Abundance at age ($N_{a,y}$) is calculated as:

$$N_{a+1,y+1} = N_{a,y} \cdot e^{-M_a}\left(1 - v_a U_y\right) \tag{4}$$

Where M_a is natural mortality at age, v_a is vulnerability to the fishery at age, and U_y is the annual exploitation rate.

Vulnerability is specified as an input to the model (unlike a traditional catch-at-age model where vulnerability/selectivity is estimated by the model). The annual exploitation rate is calculated as:

$$U_y = \frac{C_y}{\sum_a N_a v_a w_a} \tag{5}$$

Where C_y is annual removals in weight, and w_a is individual weight at age.

Age-1 abundance every year is specified as:

$$N_{1,y+1} = \frac{K(\frac{R_0}{SSB_0})SSB_y}{1+[\frac{K-1}{SSB_0}]SSB_y} e^{\vartheta_y} \tag{6}$$

Where R_0 is virgin recruitment, K is the Goodyear recruitment compensation ratio, and ϑ_y are the annual recruitment deviations around the stock-recruitment relationship.

By specifying K and ϑ_y based on life history information and meta-analysis of similar species and then fitting to an estimate of population size in recent years or an index of abundance, we can estimate R_0. By resampling from the recruitment deviations, we can develop a distribution of the probability of being at abundance N in the terminal year, given virgin recruitment R_0.

Like the DBSRA, this is not intended to be a stand-alone stock assessment model but instead to provide information on historical unfished population sizes and productivity. Walters et al. (2006) used white sturgeon as a proof of concept in their original paper, and Ahrens and Pine (2014) used this approach to develop habitat-based recovery targets for Gulf sturgeon.

6.13.2.2 Model Configuration

As with the DBSRA, since we cannot separate landings by DPS for the time-series, this model is applied to the coastwide meta-population of Atlantic sturgeon. The time series of catch is the same as used for the DBSRA (Table 41).

Natural mortality was estimated using the Lorenzen equation as described in section 2.6.1. Weight at age was calculated as described in section 2.4. Maturity at age was taken from Kahnle (2007). Vulnerability was defined in two periods, a directed period from 1887–1997 and a bycatch/incidental period from 1998–2015. The directed selectivity was taken from Kahnle (2007), and the bycatch selectivity was calculated for the Egg-per-Recruit analysis as described in Section 6.14. The Goodyear compensation ratio was set at 5.0, the same value used by Walters et al. (2006) for white sturgeon and by Ahrens and Pine (2014) for Gulf sturgeon.

There are no estimates of absolute abundance for the coastwide Atlantic sturgeon population, so the model was tuned to fisheries-independent indices of abundance. The CT Long Island Sound Trawl Survey, which samples the mixed ocean population and goes back to 1984, was used as the base case index, and the hierarchical coastwide index of adult abundance derived using the Conn method (see Section 6.6) was used as sensitivity run.

The SSRA was implemented in ADMB with estimates of recruitment deviations drawn outside the model in R from a normal distribution with a mean of 0 and a standard deviation of 0.6, following the work of Rose et al. (2001). Attempts were made to estimate recruitment deviations within ADMB, but there was not enough information in the indices to allow the model to converge. Average unfished recruitment, R_0, and index catchability was estimated internally.

6.13.2.3 Model Results

The SSRA was not stable. Without estimates of absolute abundance to scale the population at the end of the time-series, q had to be constrained to prevent the model from allowing the population to recover to levels above the initial conditions, similar to the behavior of the DBSRA. When q was constrained, many of the deterministic runs of the model, with different parameterization of selectivity or other sensitivity runs, would not converge, even without recruitment deviations added in. As a result, the uncertainty in the estimates from the resampled runs is an underestimate the true uncertainty.

The SSRA estimated virgin average recruitment (R_{0+}) at 32,300 age-1 fish (Figure 80). Estimates of recruitment in the Altamaha River in recent years was 1,072–2,033 individuals (Schueller and Peterson 2010); in the Ogeechee River was 450 individuals (Farrae et al. 2009); and in the Delaware River was 3,656 individuals (Hale et al. 2016), suggesting current recruitment, at least within river systems where estimates are available, is below virgin unfished recruitment for the coast.

Trends in spawning stock biomass (SSB) and abundance were similar to trends estimated by the DBSRA and the scale of the initial biomass was similar for both models (0 and Figure 82). The SSRA also suggests that the population has been trending upwards in recent years.
Estimates of exploitation were high at the beginning of the time-series but have declined to very low levels in recent years (Figure 83).

Both the DBSRA and the SSRA, when unconstrained, showed the population recovering rapidly from the mid-1900s onward, to levels at or above virgin conditions. Our current perception of the stock is that this is not true. This suggests that either we are missing a source of mortality that is acting to keep the population at lower levels, or that productivity has changed and the lower levels of removals we see today have a larger impact on the population than they would have at the beginning of the time-series.

6.14 Egg-per-Recruit

6.14.1 Background of Analysis and Model Description

The eggs-per-recruit analysis was applied to data that were considered the best representation of the stock on a coastwide scale. To evaluate the sensitivity of the model to differences in life history parameters among the different DPSs, the analysis was also run assuming life history parameters representative of a northern region (slower growing, longer lived) and life history parameters representative of a southern region (faster growing, shorter lived). Based on data availability, data from the New York Bight DPS were used to represent the northern region and data from the Carolina DPS were used to represent the southern region. The required life history parameters were not currently available from the Gulf of Maine DPS or South Atlantic DPS.

6.14.2 Model Configuration

Growth

The von Bertalanffy age-length function was used to predict length at age. The parameters were those estimated in section 2.4 of this report and those used here are summarized in Table 43.

The length-weight relationship was described in section 2.4 of this report and the parameters used here are summarized in Table 44.

For the coastwide and northern region eggs-per-recruit models, a maximum age of 60 years was assumed. A maximum age of 40 years was assumed for the southern region model.

Spawning

Estimates of age and length at maturity were difficult to identify. One maturity schedule was found in Kahnle et al. (2007) and was applied here to all configurations (Figure 84).

There is limited information available on fecundity parameters for Atlantic sturgeon. The data that are available were collected from South Carolina (Smith et al. 1982) and the Hudson River (van Eenannaan et al. 1996; van Eenannaam and Doroshov 1998; Table 45). After extensive discussion, the SAS felt the linear length-fecundity relationship estimated by van Eenannaam and Doroshov (1998) was the most appropriate to incorporate into the eggs-per-recruit model representing the coastwide stock and was also used for the northern region (Figure 85). The linear weight-fecundity relationship estimated by Smith et al. (1982) was used for the southern region eggs-per-recruit model (Figure 86).

Spawning was initially assumed to occur every three years for the coastwide stock, but preliminary analyses found that changing this assumption had no impact on model results.

Mortality

The eggs-per-recruit model incorporated three sources of mortality: natural, bycatch, and ship strikes. Natural mortality was assumed to vary with age based on the estimates derived in Section 2.6.1 using the Lorenzen method (Figure 87). A range of bycatch and ship strike mortality values was evaluated and is described below.

Selectivity

Age-specific selectivity vectors were derived for bycatch mortality and ship strike mortality. Bycatch selectivity was determined following the methods of Restrepo et al. (2007), which is a simple approach based on equilibrium catch curves. Bycatch lengths for Atlantic sturgeon were available from the NEFOP/ASM data set and Delaware State University (DSU). These lengths were collected from both gill nets and trawls. The lengths were converted to ages based on the von Bertalanffy age-length relationship described earlier. These data were then used to estimate frequency at age (Figure 88). A linear regression is then applied to the $\log_e$-transformed observed proportion at age, p_a, for fully-selected ages (here, ages 12+):

$$log_e(p_a) = b_1 + b_2 \times a$$

The selectivity can then be estimated from the ratio of observed proportions to predicted proportions:

$$\hat{p}_a = e^{\hat{b}_1 + \hat{b}_2 \times a}$$

$$\hat{S}_a = \frac{p_a}{\hat{p}_a}$$

and then re-scaled so the maximum is 1.0 (Figure 89).

Here, the estimation of selectivity was taken several steps further (modified Restrepo approach). Based on the results of the Restrepo approach, the SAS felt selectivity was likely maximum at ages 18 and older (Figure 89). The Restrepo-based selectivity vector was re-scaled so the maximum was 1.0 at age 18, and the selectivity at older ages was fixed at age 18 (Figure 90). A logistic function was fit to this adjusted curve to estimate the final selectivity curve that was assumed for bycatch in the eggs-per-recruit model (Figure 91).

Following Brown and Murphy (2010), Atlantic sturgeon were assumed to be fully vulnerable to ship strikes at age 3 and not vulnerable at all at ages 1 and 2 (knife-edge selectivity; Figure 92).

Eggs-per-Recruit Model

The number of pre-spawners in the model was computed as:

$$PreSpawn_0 = 1 \qquad \text{where } a = 1$$

$$PreSpawn_a = PreSpawn_{a-1} \times e^{-Z_a} \qquad \text{where } a > 1$$

Z_a is the sum of mortality at age (natural + bycatch + ship strike) after accounting for selectivity. Selectivity at age for ship strikes was divided by three for the coastwide and northern region models to account for ship strikes occurring at an assumed rate of every three years. In the southern region model, ship strikes were assumed to occur every five years.

The number of spawners in the population was computed as:

$$Spawn_a = PreSpawn_a \times \frac{m_a}{3}$$

where m_a is maturity at age a. The value of three (3) in the denominator is to account for spawning every third year. Varying this value did not have an impact on model results.

The number of female spawners, $Spawn_{a,fem}$, was estimated by multiplying the number of spawners at age by the assumed sex ratio, 0.50.

For the coastwide and northern region models, the number of eggs laid per female was estimated based on the length-fecundity relationship estimated by van Eenannaam and Doroshov (1998) and described earlier. The linear weight-fecundity relationship estimated by Smith et al. (1982) was used for the southern region model. The total number of eggs laid at age, E_a, was computed as the number of female spawners multiplied by the derived fecundity at age, fec_a:

$$E_a = Spawn_{a,fem} \times fec_a$$

Eggs-per-recruit, EPR, was calculated as:

$$EPR = \frac{\sum_a E_a}{PreSpawn_{a=1}}$$

The EPR analysis was used to find the value of Z that resulted in an EPR that was 50% of the EPR of an unfished stock (i.e., no anthropogenic mortality). This was accomplished based on assumed values for bycatch and ship strike mortality rates. First, ship strike mortality was assumed equal to 0.0 and the value of bycatch mortality that would result in Z at $EPR_{50\%}$ was determined using Excel's solver optimization tool. This value was the maximum bycatch mortality allowed and was used to set the upper limit of the range of bycatch mortality explored. Similarly, bycatch mortality was set equal to 0.0 to find the value of ship strike mortality that would result in Z at $EPR_{50\%}$ and the maximum value of ship strike mortality considered. Starting with values of 0.0, bycatch and ship strike mortality values were incremented by 0.01 (finding Z at $EPR_{50\%}$ at each increment) until the maximum value was reached.

In order to make the results more compatible with those of the tagging model (see Section 6.12.4), the estimated full *Z* values were converted to number-weighted mean values, using the numbers-at-age-per-recruit values of a population with that level of Z. Estimates of number-weighted Z were calculated for all ages, adults (>130 cm), and fish age 4 to 21 (the age range in the tagging model).

6.14.3 Model Results

Coast

For the coastwide analysis, the EPR associated with an unfished stock was 1.7 million eggs per recruit. This results in an $EPR_{50\%}$ of 0.85 million eggs per recruit. Values of $Z_{50\%EPR}$ ranged from 0.12 to 0.13 for all fish, ranged from 0.068 to 0.072 for adult fish, and ranged from 0.085 to 0.094 for tagged fish (aged 4 to 21), depending on the assumed level of input mortality (Table 46). The estimated value of $Z_{50\%EPR}$ (number-weighted) increased for all fish and tagged fish (fish aged 4 to 21) as total *F* increased. For adult fish, values of $Z_{50\%EPR}$ decreased with increasing *F*.

Northern Region

For the northern region model, the EPR associated with an unfished stock was 1.1 million eggs per recruit, which results in an $EPR_{50\%}$ of 0.57 million eggs per recruit. Values of $Z_{50\%EPR}$ ranged from 0.12 to 0.13 for all fish, ranged from 0.086 to 0.090 for adult fish, and ranged from 0.10 to 0.11 for tagged fish (aged 4 to 21), depending on the assumed level of input mortality (Table 47). Like the coastwide model, $Z_{50\%EPR}$ (number-weighted) increased for all fish and tagged fish (aged 4 to 21) with increasing *F* and decreased for adult fish with increasing *F*.

Southern Region

The EPR associated with an unfished stock was 254,249 eggs per recruit for the southern region model. This results in an $EPR_{50\%}$ of 127,125 eggs per recruit. Values of $Z_{50\%EPR}$ ranged from 0.15 to 0.16 for all fish, ranged from 0.12 to 0.13 for adult fish, and ranged from 0.12 to 0.13 for tagged fish (aged 4 to 21), depending on the assumed level of input mortality (Table 48). Similar to the coastwide and northern DPS models, $Z_{50\%EPR}$ (number-weighted) increased for all fish and tagged fish (aged 4 to 21) with increasing *F* and decreased for adult fish with increasing *F*.

Discussion

Estimated values of $Z_{50\%EPR}$ were very low, reflecting the long-lived, slow-growing, slow to mature life history of Atlantic sturgeon. This analysis suggests Atlantic sturgeon cannot sustain high levels of anthropogenic mortality.

The estimated values of $Z_{50\%EPR}$ increased as total *F* increased for all fish and tagged fish (aged 4 to 21). For adult fish, values of $Z_{50\%EPR}$ decreased with increasing *F*. Values of $Z_{50\%EPR}$ were higher for the southern region model as compared to the northern region model over the range of bycatch and ship strike mortalities evaluated; however, the range of $Z_{50\%EPR}$ values was extremely small, with only tiny differences in $Z_{50\%EPR}$ for the bycatch-only scenario and the ship strike-only scenario.

7 DISCUSSION

Atlantic sturgeon are not well monitored by the existing fishery-independent and -dependent data collection programs, and the uncertainty in the data hinders the SAS's ability to make strong quantitative conclusions. Trend analysis of most indices showed either no significant trends or increasing trends, suggesting stable or increasing populations of Atlantic sturgeon. Effective population size estimates were generally small, although highly uncertain in some cases. Low effective population sizes do not necessarily translate into low absolute abundance levels, but they may raise concerns about the potential for the loss of genetic diversity and the resilience of Atlantic sturgeon populations. Estimates of total mortality were very low. Observer coverage was not sufficient to fully characterize coastwide Atlantic sturgeon bycatch and bycatch mortality. Bycatch mortality estimates derived from NMFS data were very similar in magnitude to those derived from NCDMF data. At the coastwide level, Z was estimated at 0.04, below the estimates of $Z_{50\%EPR}$. Z estimates are low but are in the ballpark of other published estimates for Carolina and South Atlantic rivers. At the coastwide level, total mortality appears to be low and sustainable. Estimates of Z from individual DPSs were less reliable (with much wider confidence intervals), reflecting smaller sample sizes at the DPS level.

Qualitatively, Atlantic sturgeon are showing signs of recovery relative to 1998, so it is important to continue management actions that have contributed to this (the moratorium, habitat restoration/protection, better bycatch monitoring) and work on improving them (e.g., identifying bycatch and ship strike hotspots and ways to reduce those interactions).

There has been a tremendous amount of new information about Atlantic sturgeon collected in recent years, which doesn't resolve the issue of the lack of historical data, but puts stock assessment scientists and fisheries managers on a better path going forward to continue to monitor stocks of Atlantic sturgeon and work towards its restoration.

7.1 Stock Status Determination Criteria

Atlantic sturgeon received full protection in its designation as a federally endangered species in 2012 (Federal Register 2012). However, there remains no NOAA Recovery Plan against which to evaluate Atlantic sturgeon status at the coastwide or DPS-level. Also, for a species that has been under a moratorium for nearly twenty years, the traditional "overfished" and "overfishing" status designations are not as meaningful.

For this assessment, quantitative stock status was determined via the probability that the terminal year of the indices for a given DPS was greater than the index values from the start of the moratorium in 1998 (as evaluated by the ARIMA analysis), and by comparing estimates of total mortality from the tagging model to estimates of $Z_{50\%EPR}$.

Because the available indices only cover the most recent time period, long after the height of exploitation, metrics like trends in landings and consideration of anecdotal historical records were used to determine a qualitative biomass or abundance status relative to historical levels. In all DPSs and at the coastwide level, Atlantic sturgeon were determined to be depleted, a term that acknowledges the impact of not just directed fishing mortality, but also bycatch mortality, ship strikes, and reductions in productivity due to habitat loss.

Given the limited data available to establish quantitative metrics to determine stock status, the SAS also considered more qualitative criteria such as the appearance of Atlantic sturgeon in rivers where they had not been documented in recent years (Table 1), discovery of spawning adults in rivers they had not been documented before, and increases in anecdotal interactions such as reports of jumping Atlantic sturgeon by recreational angler and ship strikes. These qualitative metrics come with the caveat that these increases in documented Atlantic sturgeon abundance may in some cases be the result of increased research and attention, not a true increase in abundance. However, this kind of qualitative information is still important in describing the current status of Atlantic sturgeon.

7.2 Stock Status Determination

Coastwide

At the coastwide level, Z was estimated at 0.04 which is below the threshold estimate of $Z_{50\%EPR}$ and each DPS was above the threshold estimate (Table 49 and Table 50, Figure 93). While DBSRA results could not be used to evaluate stock status for the coastwide stock, trends were similar across runs regardless of final stock status, with the population declining rapidly from the beginning of the time-series to the early 1900s to a low but stable abundance and increasing again from the late 1990s onwards (Figure 76). SSRA analyses suggested that trends in SSB and abundance were similar to trends estimated by the DBSRA and the scale of the initial biomass was similar for both models (0 and Figure 82). The SSRA also suggests that the population has been trending upwards in recent years. SSRA suggests that estimates of exploitation were high at the beginning of the time-series but have declined to very low levels in recent years (Figure 83). EPR analyses suggest that Atlantic sturgeon cannot sustain high levels of anthropogenic mortality.

The SAS considers all DPSs of Atlantic sturgeon to be depleted relative to historical levels. In recent years, when using all available years of data for all indices, the terminal year index values were all credibly above the 25th percentile of their respective time series. When comparing index values in 1998 to 2015 using ARIMA, stock status varied. Using this metric for stock status determination, the Gulf of Maine and Chesapeake Bay DPS were below their 1998 values while the New York Bight and Carolina DPS as well as the coastwide stock were above their 1998 values (Table 50, Figure 93). The South Atlantic DPS could not be evaluated using this metric since it did not have a survey in the region that fulfilled the criteria to be used in ARIMA. The Conn index, used as an index of the coastwide meta-population, was credibly above its 1998 value (Table 50, Figure 93). In addition to the quantitative metrics in Table 50, all of the DPSs showed qualitative signs of improving populations such as increased presence of Atlantic sturgeon, including in rivers where species interactions had not been reported in recent years, and the discovery of spawning in rivers where it had not been previously documented.

Gulf of Maine DPS

Trend analysis for the ME-NH Trawl indicated there was no significant trend over the time-series, but that the index in 2015 was likely to be above the 25th percentile of the time-series according to the ARIMA. This index was likely below its value in 2000 (Figure 94); the survey started in the year 2000, and so could not be compared to the reference 1998 year as the other surveys were. Some challenges for using this index as a proxy for the DPS was that the index has relatively wide confidence intervals, even after standardization due to small proportion of tows that were positive for sturgeon. In addition, this index operates in marine waters, so may encounter sturgeon from other DPSs as well as from the Gulf of Maine. Anecdotal evidence suggests that the population is stable or increasing and in the last decade there have been sightings or capture of fish in the Penobscot River, Saco River, and Presumpscot River where sturgeon have not been documented in many years. The mortality estimate for pooled adults and juveniles, Z=0.30, is higher than estimates of $Z_{50\%EPR}$ for both the coast and the northern region from the EPR model, indicating total mortality is too high for the Gulf of Maine DPS (Table 49, Figure 95). However, estimates of total mortality for Gulf of Maine fish from the tagging model had very wide confidence intervals.

New York Bight DPS

There has been documented spawning in the New York Bight DPS in the Connecticut, Hudson, and Delaware Rivers. ARIMA results suggest that the terminal year fitted indices from all surveys in New York Bight DPS were credibly above both the 25th percentile of the surveys and index value in 1998 (not all surveys had index values through 2015) (Figure 96). The CT LIST spring nominal index, CT LIST fall nominal index, and the CT LIST combined spring-fall index had significant ($\alpha = 0.05$, Mann Kendall Test) increasing trends (Table 30); the time series trend in the NJ Ocean Trawl index was not significant ($P > 0.05$). The mortality estimate for pooled adults and juveniles, Z=0.09, is lower than the estimate of $Z_{50\%EPR}$ for the northern region from the EPR model (Table 49, Figure 97). Estimates of total mortality for New York Bight DPS fish from the tagging model had the narrowest credible intervals for any DPS, but they still included the Z-threshold.

Given the results of this assessment the New York Bight DPS of Atlantic sturgeon is considered above the level of abundance reported in 1998. The Hudson River conducts a juvenile abundance survey (NYDEC JASAMP) which did not meet the criteria for time series length for the assessment, but since 2006 it shows a positive trend. This increasing trend is somewhat tempered by a recent study (Kazyak et al. *in preparation*) that estimated the 2014 Hudson River Atlantic sturgeon spawning run was 450 (95% CI = 205-987) individuals. If skipped spawning is taken into consideration (Bain 1997), the annual run estimate appears to be similar to the total adult population ($\widehat{N}$ = 873) reported by Kahnle et al. (2007) for the last decade of the commercial fishery. In the Delaware River, an observed reduction in catch of fishery-independent bottom trawls and a directed gill net survey in the mid-estuary were used in the 1998 assessment to describe a decrease in relative abundance of Atlantic sturgeon. Population estimates based on mark and recapture of subadult Atlantic sturgeon from the gill net survey dropped from 5,600 in 1991 to less than 1,000 in 1995 with no recaptures collected in 1996 or 1997 (ASMFC 1998). Unfortunately, the mid-estuary gill net survey targeting subadults was not continued. However, both bottom trawl surveys suggest an increasing trend in relative abundance of predominately subadults since 1998 (Park 2016) supporting the results of the current assessment.

Chesapeake Bay DPS

In 1998, Atlantic sturgeon were thought not to use Chesapeake Bay tributaries for spawning. It is now known that spawning definitely occurs in the James and York (Pamunkey sub-tributary) Rivers, and likely occurs in the Nanticoke River (Marshyhope sub-tributary). Spawning is suspected to occur in several other tributaries (Rappahannock and other sub-estuaries of the York and Nanticoke Rivers). The fitted index from this DPS had two large oscillations and no significant trend over the duration of their respective time series ($\alpha = 0.05$, Mann Kendall Test; Table 26). ARIMA results indicated that the index in 2015 was credibly above the 25th percentile of its respective time series (Figure 64), but that the 2015 index was likely below the 1998 index (Figure 98). Still, because the index exhibited two large oscillations, this last analysis of status may be less relevant to trends in abundance. The mortality estimate for pooled adults and juveniles, Z=0.13, is higher than estimates of $Z_{50\%EPR}$ for both the coast and the southern region from the EPR model, indicating total mortality is too high for the Chesapeake Bay DPS (Table 49, Figure 99). However, estimates of total mortality for Chesapeake Bay fish from the tagging model had wide confidence intervals.

Carolinas DPS

In the Carolina DPS, Atlantic sturgeon have been verified to spawn in the Roanoke River, and are suspected to spawn in the Tar-Pamlico, Neuse, and Cape Fear Rivers in North Carolina as well as, the Pee Dee and Cooper Rivers in South Carolina based on recent tagging studies and collections of river-resident age-0 and age-1 fish. Many of the spawning populations in the Carolina DPS have not been verified through egg or larval collections, and that there are few long term data on relative sturgeon abundance. However, anecdotal evidence suggests spawning is occurring in more rivers than previously believed but spawning success is likely variable thus emphasizing the importance of protecting spawning and nursery habitats and migration corridors within the Carolina DPS. Based on the results of the ARIMA and trend analysis for the Carolina DPS, terminal year indices were all credibly above the 25th percentile of its respective survey time series. Terminal year indices in the Carolina DPS were all credibly above its respective index value in 1998 except for the North Carolina p135-fall index (Figure 100). Fitted indices from the Carolina DPS had either no significant trend or significantly increasing trends ($\alpha = 0.05$, Mann Kendall Test). The mortality estimate for pooled adults and juveniles, Z=0.25, is higher than estimates of $Z_{50\%EPR}$ for both the coast and the southern region from the EPR model, indicating total mortality is too high for the Carolina DPS (Table 49, Figure 101). However, estimates of total mortality for Carolina DPS fish from the tagging model had very wide credible intervals.

South Atlantic DPS

The SC Edisto survey index time series was not long enough (<15 years) to be included in the ARIMA analysis, so status relative to 1998 is not known. However, trend analysis for this index appear to be stable from 2004-2015. Atlantic sturgeon spawning takes place in the Edisto, Combahee, Savannah, Altamaha, Ogeechee, and Satilla Rivers. Dual spawning events (spring and fall) have also been confirmed in the Edisto River and may occur in other South Carolina Rivers (Post et al. 2014, Farrae et al. 2017). Four Atlantic sturgeon that were at large for up to 16 years were recaptured (originally tagged as YOY, <500mm) in the Edisto River, suggesting that the 1998 moratorium has worked and these fish were not impacted by anthropogenic effects. Repeat annual captures of age 0+ fish indicate successful spawning and recruitment is evident in the Edisto, Savannah, Altamaha, Ogeechee, and Satilla Rivers. Additionally, age 1 population estimates exist for many Georgia Rivers (Bahr and Peterson 2016, Farrae et al. 2009). These estimates along with other qualitative data suggest populations in these South Atlantic DPS rivers appear to be stable, if not increasing.

7.3 Threats and Barriers to Recovery

Primary threats to recovery of Atlantic sturgeon stocks and populations throughout the U.S. Atlantic Coast include fishery and research bycatch (takes) in U.S. and Canadian waters, ship strikes, and habitat loss and degradation including from dredging operations, shoreline modification, water pollution, and dam construction. Other potential emerging threats include invasive species, such as blue and flathead catfish. In regions where sturgeon from different DPSs mix in coastal aggregations, threats to these aggregations (e.g., bycatch mortality and ship strikes) may have disproportionate population effects at the DPS-level.

Bycatch is most likely the primary source of fishing mortality currently and is a primary threat to the recovery of species, particularly where bycatch exists on mixed stock aggregations (e.g., Long Island Sound of New York), because Atlantic sturgeon are long lived, have an older age at maturity, lower maximum fecundity, low natural mortality rates and low abundance, and older ages at which 50% of the egg production is realized. Incidental bycatch of Atlantic sturgeon can occur in most fishery gears including gill nets, pound nets, hoop nets, fyke nets, fish pots, fish traps, crab pots, trawls and hook and line, with gill net and trawl interactions having the highest potential for mortality. Data on bycatch in the ocean is limited due to low to non-existent rates of on-board observer coverage in most fisheries that may encounter sturgeon. Little is known about survival of fish that are captured and released. Total losses from bycatch are unknown and may be hindering recovery of stocks. Though bycatch remains a threat to recovery of Atlantic sturgeon it may not be as severe of a threat as in the past. Since Atlantic sturgeon were listed under the ESA, many fisheries that interact with Atlantic sturgeon have been modified to minimize these interactions through various means such as the requirements of incidental take permits for Atlantic sturgeon and sea turtles, as well as changes to fisheries required by American Shad Sustainability Plans.

In addition to bycatch, poaching of Atlantic sturgeon is also known to occur. Incidents of poaching have been documented by law enforcement in Virginia, South Carolina and New York (ASSRT 2007). In some cases, the fish were killed for personal consumption, and in others, they were intended for the black market. The magnitude of removals due to poaching is unknown, but since the $Z_{50\%EPR}$ rates are so low, even small levels of poaching could hinder stock recovery.

Ship strikes also remain as a source of mortality and a threat to recovery for Atlantic sturgeon. Due to the high volume of large cargo vessel traffic in relatively shallow shipping channels where Atlantic sturgeon pass through to get to and from ocean waters and spawning grounds, ship strike mortality may threaten the recovery of Atlantic sturgeon, particularly in the New York Bight (Hudson and Delaware Rivers), the Chesapeake Bay (James, York and Nanticoke Rivers) and the Carolina (Cape Fear River and Charleston Harbor) DPSs. Due to the highly migratory behavior of Atlantic sturgeon, ship strike impacts in any DPS waterbody may play a role in threats to Atlantic sturgeon throughout its range (e.g., mixed stock aggregations).

For Atlantic sturgeon, habitat loss and degradation, hypoxia, and climate change are also threats and barriers to recovery. Spawning and nursery habitats occur in the highest segments of estuaries just below the fall line where low volumes, depths, and channel widths make them particularly vulnerable to shoreline modifications, dredging, and flow regulation (see Appendix A – Habitat). Since the early-mid 1800s, building of dams has cut off access to historical spawning grounds. Changes to flow regimes caused by dams may also alter the accessibility of the remaining spawning habitat below the dams and interfere with Atlantic sturgeon's ability or willingness to return to their natal spawning grounds. Deposition of dredged materials from major shipping and navigation channels across the Atlantic coast has resulted in the loss of historical Atlantic sturgeon spawning and nursery habitat. Maintenance dredging of shipping channels and for beach renourishment projects also has the potential to affect habitat essential to the recovery of the species. Additional negative impacts to Atlantic sturgeon habitat due to dredging, dam construction, and shoreline operations include reduced water quality, changes in flow rates, nutrient loading which can lead to low dissolved oxygen and hypoxic zones. Some of the impacts of the loss of historical spawning and nursery grounds may be reversed by dam removal projects (e.g., the removal of the Edwards Dam on the Kennebec River in 1999, the Penobscot River Restoration Project), or habitat mitigation and restoration. DO levels below 3 ppm are stressful to sturgeon. Low DO was a historic problem in the Hudson (untreated sewage); DO has increased as a result of improved sewage treatment, however still continue to be an issue in older urban areas (e.g., New York City). Research has shown that the survival, growth, and movement behaviors of young sturgeon (age 0-1) are sensitive to hypoxia; post-juvenile stages show more resilience to hypoxic conditions. Summertime hypoxia remains systemic throughout much of the shallow water Chesapeake Bay and is likely curtailing the amount of available habitat to Atlantic sturgeon. Regional warming and changed seasonality will likely influence how Atlantic sturgeon use habitat throughout its range for foraging, reproduction and nursery grounds (Najjar et al. 2010). Low overall rates of climate warming was predicted to severely decrease summertime carrying capacity for juvenile Atlantic sturgeon (Niklitschek and Secor 2005). Several states and regions have either implemented, developed, or initiated development of regional water plans aimed to meet future water needs for both water quantity and water quality (ground water and surface water) for Atlantic sturgeon and other marine (and freshwater) species (e.g., New York and Georgia).

In addition to degrading habitat, construction projects such as dredging, bridge construction, and underground power line installation may also result in mortality due to ship strikes or other accidental interactions.

Invasive species such as blue catfish and flathead catfish may be another potential threat to Atlantic sturgeon recovery. Blue catfish are generalist piscivores and are present in Atlantic sturgeon nursery and spawning habitats in the Chesapeake Bay, Carolina, and South Atlantic DPSs (Schloesser et al. 2011). Flathead catfish are abundant in the Carolina DPS (south of the Albemarle Sound area) and the South Atlantic DPS, and concerns have been raised that flathead catfish may be harming the recovery of anadromous fish in mid-Atlantic rivers (Brown et al., 2005). Evidence that these species prey upon young-of-year Atlantic sturgeon is inconclusive. Moser et al. 2000 tested whether flathead catfish preyed on shortnose sturgeon (30 cm) in a controlled system, and despite sturgeon being the only prey available, none were consumed. However, a direct observation of an Atlantic sturgeon in the gut contents of a flathead catfish was made by Flowers et al. (2011) from the Satilla River. A recent study found no physical or genetic evidence of Atlantic sturgeon was found in the stomachs of 2,495 blue and flathead catfish collected from the James River (Schmitt et al. (2017), Bob Greenlee, VA Dept. of Fish and Game, personal communication). However, that study was conducted from March-May, and thus may have missed the period when fall-spawned young-of-year were available to the catfish. More research is needed to determine whether these invasive species are a threat to Atlantic sturgeon recovery.

8 RESEARCH RECOMMENDATIONS

The SAS identified several research recommendations that would benefit Atlantic sturgeon and future stock assessments. Research recommendations have been categorized as future research, data collection, and assessment methodology and ranked as high or moderate priority. Recommendations with asterisks (**) indicate improvements that should be made before initiating another benchmark stock assessment. The SAS recommends that an update be considered in 5 years and a benchmark stock assessment considered in 10 years given the life history of Atlantic sturgeon and the need for more data. The SAS and TC recommend that during the years between this assessment and the next, members remain proactive about monitoring research programs, maintaining tagging networks and genetic databases, and continuing to initiate or participate in activities that accomplish some of the research recommendations listed below.

Future Research

High Priority

Identify spawning units along the Atlantic coast at the river or tributary and coastwide level.

**Expand and improve the genetic stock definitions of Atlantic sturgeon, including developing an updated genetic baseline sample collection at the coastwide, DPS, and river-specific level for Atlantic sturgeon, with the consideration of spawning season-specific data collection.

Determine habitat use by life history stage including adult staging, spawning, and early juvenile residency.

Expand the understanding of migratory ingress of spawning adults and egress of adults and juveniles along the coast.

Identify Atlantic sturgeon spawning habit through the collection of eggs or larvae.

Investigate the influence of warming water temperatures on Atlantic sturgeon, including the effects on movement, spawning, and survival.

Moderate Priority
Evaluate the effects of predation on Atlantic sturgeon by invasive species (e.g., blue and flathead catfish).

Data Collection

High Priority
**Establish regional (river or DPS-specific) fishery-independent surveys to monitor Atlantic sturgeon abundance or expand existing regional surveys to include annual Atlantic sturgeon monitoring. Estimates of abundance should be for both spawning adults and early juveniles at age. See Table 8 for a list of surveys considered by the SAS.

**Establish coastwide fishery-independent surveys to monitor Atlantic sturgeon mixed stock abundance or expand existing surveys to include annual Atlantic sturgeon monitoring. See Table 8 for a list of surveys considered by the SAS.

**Continue to collect biological data, PIT tag information, and genetic samples from Atlantic sturgeon encountered on surveys that require it (e.g., NEAMAP). Consider including this level of data collection from surveys that do not require it.

**Encourage data sharing of acoustic tagged fish, particularly in underrepresented DPSs, and support programs that provide a data sharing platform such as The Atlantic Cooperative Telemetry Network. Data sharing would be accelerated if it was required or encouraged by funding agencies.

**Maintain and support current networks of acoustic receivers and acoustic tagging programs to improve the estimates of total mortality. Expand these programs in underrepresented DPSs.

**Collect DPS-specific age, growth, fecundity, and maturity information.

**Collect more information on regional vessel strike occurrences, including mortality estimates. Identify hot spots for vessel strikes and develop strategies to minimize impacts on Atlantic sturgeon.

**Monitor bycatch and bycatch mortality at the coastwide level, including international fisheries where appropriate (i.e., the Canadian weir fishery). Include data on fish size, health condition at capture, and number of fish captured.

Assessment Methodology

High Priority

**Establish recovery goals for Atlantic sturgeon to measure progress of and improvement in the population since the moratorium and ESA listing.

**Expand the acoustic tagging model to obtain abundance estimates and incorporate movement.

Moderate Priority

Evaluate methods of imputation to extend time series with missing values. ARIMA models were applied only to the contiguous years of surveys due to the sensitivity of model results to missing years observed during exploratory analyses.

9 REFERENCES

Ahrens, R. N. M., and W. E. Pine. 2014. Informing recovery goals based on historical population size and extant habitat: a case study of the Gulf Sturgeon. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 6: 274-286.

Allendorf, F. W. 1986. Genetic drift and the loss of alleles versus heterozygosity. Zoo Biology 5:181-190.

Altenritter, M.N., G.B. Zydlewski, M.T. Kinnison, and G.S. Wippelhauser. 2017. Atlantic sturgeon use of the Penobscot River and marine movements within and beyond the Gulf of Maine. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 9:216-230.

ASA Analysis and Communication. 2013. 2013 Year Class Report for the Hudson River Estuary Monitoring Program. Prepared on behalf of Entergy Nuclear Indian Point 2 LLC. Entergy Nuclear Indian Point 3 LLC, Entergy Nuclear Operations Inc. and NRG Bowline LLC., NY.

Atkins, C. G. 1887. The river fisheries of Maine. Pages 673-728 in G. B. Goode, editor. The fisheries and fishing industries of the United States, Section V, Volume 1. Government Printing Office, Washington, D.C.

Atlantic Sturgeon Status Review Team (ASSRT). 2007. Status review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Report to National Marine Fisheries Service, Northeast Regional Office, Gloucester, Massachusetts.

Atlantic States Marine Fisheries Commission (ASMFC). 1998. Atlantic Sturgeon Stock Assessment Peer Review Terms of Reference and Advisory report. Washington, D.C. p.33.

ASMFC. 2007. Special Report to the Atlantic Sturgeon Management Board: Estimation of Atlantic sturgeon bycatch in coastal Atlantic commercial fisheries of New England and the Mid-Atlantic. August 2007. 95 pp.

ASMFC. 2012. Stock Assessment Report No. 12-02 of the Atlantic States Marine Fisheries Commission, River Herring Benchmark Stock Assessment. 342 pp.

ASMFC. 2013. Atlantic States Marine Fisheries Commission, 2013 Horseshoe Crab Stock Assessment Update. 68 pp.

ASMFC. 2016. Atlantic States Marine Fisheries Commission, Atlantic Striped Bass Stock Assessment Update. 100 pp.

Atlantic Sturgeon Status Review Team (ASSRT). 2007. Status review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Report to the National Marine Fisheries Service, Northeast Regional Office, Gloucester, MA, pp 187.

Armstrong, J.L. 1999. Movement, habitat selection, and growth of early-juvenile Atlantic sturgeon in Albemarle Sound, North Carolina. M.S. Thesis, North Carolina State University, Raleigh. 77 p.

Bahn, R. A., J. E. Fleming, and D. L. Peterson. 2012. Bycatch of shortnose sturgeon in the commercial American shad fishery of the Altamaha River, Georgia. North American Journal of Fisheries Management 32(3): 557-562.

Bahr, D.L., and D.L. Peterson. 2016. Recruitment of juvenile Atlantic sturgeon in the Savannah River, Georgia. Transactions of the American Fisheries Society 145:1171-1178.

Bain, M. B. 1997. Atlantic and shortnose sturgeons of the Hudson River: common and divergent life history attributes. In Sturgeon Biodiversity and Conservation (pp. 347-358). Springer Netherlands.

Bain, M., N. Haley, D. Peterson, J. R. Waldman, and K. Arend. 2000. Harvest and habitats of Atlantic sturgeon *Acipenser oxyrinchus* Mitchill, 1815 in the Hudson River estuary: lessons for sturgeon conservation. Boletin-Instituto Espanol De Oceanografia, 16(1/4), 43-54.

Balazik, M. T., G. C. Garman, M. L. Fine, C. H. Hager, and S. P. McIninch. 2010. Changes in age composition and growth characteristics of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) over 400 years. Biology Letters 6:708–710.

Balazik, M. T., G. C. Garman, J. P. Van Eenennaam, J. Mohler, and L. C. Woods III. 2012a. Empirical evidence of fall spawning by Atlantic Sturgeon in the James River, Virginia. Transactions of the American Fisheries Society, 141(6): 1465-1471.

Balazik, M. T., S. P. McIninch, G. C. Garman, and R. J. Latour, R. J. 2012b. Age and growth of Atlantic sturgeon in the James River, Virginia, 1997–2011.Transactions of the American Fisheries Society, 141(4): 1074-1080.

Balazik, M. T. Reine, K. J., Spells, A. J., Fredrickson, C. A., Fine, M. L., Garman, G. C., and McIninch. 2012c. The potential for vessel interactions with adult Atlantic sturgeon in the James River, Virginia. North American Journal of Fisheries Management. 32:1062-1069.

Balazik, M.T., and J. A. Musick. 2015. Dual Annual Spawning Races in Atlantic Sturgeon. PLoS ONE 10(5): e0128234. doi:10.1371/journal.pone.0128234

Balazik M.T., D.J. Farrae, T.L. Darden, and G.C. Garman. 2017. Genetic differentiation of spring-spawning and fall-spawning male Atlantic sturgeon in the James River, Virginia. PLOS ONE 12(7): e0179661

Baranova, V. P., and M. P. Miroshnichenko. 1969. Conditions and prospects for culturing sturgeon fry in the Volgograd sturgeon nursery. Hydrobiology Journal 5: 63-67.

Barber, M. R. 2017. Effects of Hydraulic Dredging and Vessel Operation on Atlantic Sturgeon Behavior in a Large Coastal River. Masters Thesis. Virginia Commonwealth University

Bath, D. W., J. M. O'ConnorJ. B. Alber and L. G. Arvidson. 1981. Development and identification of larval Atlantic sturgeon (*Acipenser oxyrhynchus*) and shortnose sturgeon (*A. brevirostrum*) from the Hudson River estuary, New York. Copeia, 1981(3): 711-717.

Baty, F., C. Ritz, S. Charles, M. Brutsche, J-P. Flandrois, and M-L. Delignette-Muller. 2015. A toolbox for nonlinear regression in R: the package nlstools. Journal of Statistical Software 66(5):1-21.

Bigelow, HB, and WC Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Bull. US Fish Wildl. Service 53(74): 577p.

Borodin, N. 1925. Biological observations on the Atlantic sturgeon (*Acipenser sturio*). Transactions of the American Fisheries Society, 55(1): 184-190.

Box, G. E. P. and G. M. Jenkins. 1976. Time series analysis: forecasting and control, revised Ed. Holden-Day Oakland, CA 375 pp.

Breece, M.W., M.J. Oliver, M.A. Cimino, and D.A. Fox. 2013. Shifting Distributions of adult Atlantic Sturgeon amidst post-industrialization and future impacts in the Delaware River: a maximum entropy approach. PloS one 8(11), p.e81321.

Breece, M.W., D. A. Fox, K. J. Dunton, M. G. Frisk, A. Jordaan, and M. J. Oliver. 2016. Dynamic seascapes predict the marine occurrence of an endangered species: Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus*. Methods in Ecology and Evolution.

Brook, B. W., J. J. O'Grady, A. P. Chapman, M. A. Burgman, H. R. Akçakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. Nature, 404(6776): 385-387.

Brown, J.J., and G.W. Murphy. 2010. Atlantic sturgeon vessel-strike mortalities in the Delaware Estuary. Fisheries 35(2): 72-83. DOI: 10.1577/1548-8446-35.2.72

Brown, J. J., J. Perillo, T. J. Kwak, and R. J. Horwitz. 2005. Implications of *Pylodictis olivaris* (flathead catfish) introduction into the Delaware and Susquehanna drainages. Northeastern Naturalist 12(4): 473-484.

Brownell, P. H., S. Bolden, and B. Kynard. 2001. Spawning habitat suitability index models for shortnose and Atlantic sturgeon. Draft report. National Marine Fisheries Service, Southeast Region.

Brundage, H. M., and R. E. Meadows. 1982. The Atlantic sturgeon in the Delaware River estuary. Fisheries Bulletin 80: 337-343.

Burton, E. J., A. A. Andrews, C. H. Coale, and G. M. Cailliet. 1999. Application of radiometric age determination to three long-lived fishes using 210Pb:226Ra disequilibria in calcified structures: a review. American Fisheries Society Symposium Series 23: 77-88.

Bushnoe, T. M., J. A. Musick, and D. S. Ha. 2005. Essential spawning and nursery habitat of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in Virginia. VIMS Special Scientific Report 145, 44.

Campana, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology 59:197–242.

Caron, F., D. Hatin, and R. Fortin. 2002. Biological characteristics of adult Atlantic sturgeon (*Acipenser oxyrinchus*) in the St Lawrence River estuary and the effectiveness of management rules. Journal of Applied Ichthyology 18(4-6): 580-585.

Collette, B.B., and G. Klein-MacPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine. Smithsonian Institution Press, Washington, D.C.

Collins, M. R., S. G. Rogers, and T. I. J. Smith. 1996. Bycatch of sturgeons along the southern Atlantic coast of the U.S. North American Journal of Fisheries Management 16: 24-29.

Collins, M. R., and T. I. Smith. 1997. Management briefs: Distributions of shortnose and Atlantic sturgeons in South Carolina. North American Journal of Fisheries Management 17(4): 995-1000.

Collins, M. R., T. I. Smith, W. C. Post, and O. Pashuk. 2000. Habitat utilization and biological characteristics of adult Atlantic sturgeon in two South Carolina rivers. Transactions of the American Fisheries Society, 129(4): 982-988.

Conn, P. B. 2010. Hierarchical analysis of multiple noisy abundance indices. Canadian Journal of Fisheries and Aquatic Sciences, 67(1): 108-120.

COSEWIC. 2011. COSEWIC assessment and status report on the Atlantic Sturgeon *Acipenser oxyrinchus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 49 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Coulson, T., G. M. Mace, E. Hudson, and H. Possingham. 2001. The use and abuse of population viability analysis. Trends in Ecology and Evolution, 16(5): 219-221.

Dadswell, M. J. 1979. Biology and population characteristics of the shortnose sturgeon, *Acipenser brevirostrum LeSueur* 1818 (Osteichthyes: Acipenseridae), in the Saint John River estuary, New Brunswick, Canada. Canadian Journal of Zoology 57(11): 2186-2210.

Dadswell, M. J. 2006. A review of the status of Atlantic sturgeon in Canada, with comparisons to populations in the United States and Europe. Fisheries 31(5): 218-229.

Dadswell, M. J., B. D. Taubert, T. S. Squiers, D. Marchette, and J. Buckley. 1984. Synopsis of biological data on shortnose sturgeon, *Acipenser brevirostrum LeSueur* 1818.

Dees, L. 1961. Sturgeons. Fishery Leaflet 526.

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115–143.

Dick, E. J., and A. D. MacCall. 2010. Estimates of sustainable yield for 50 data-poor stocks in the Pacific Coast groundfish fishery management plan. National Oceanic & Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center, Fisheries Ecology Division.

Dick, E. J., and A. D. MacCall. 2011. Depletion-Based Stock Reduction Analysis: A catch-based method for determining sustainable yields for data-poor fish stocks. Fisheries Research 110(2): 331-341.

Dovel, W.L. 1979. The biology and management of shortnose and Atlantic sturgeon of the Hudson River. New York State Department of Environmental Conservation, AFS9-R, Albany.

Dovel, W. L., and T. J. Berggren. 1983. Atlantic sturgeon of the Hudson estuary, New York. New York Fish and Game Journal 30:140–172.

Dovel, W. L., A. W. Pekovitch, and T. J. Berggren. 1992. Biology of the shortnose sturgeon (*Acipenser brevirostrum Lesueur*, 1818) in the Hudson River estuary, New York. Estuarine Research in the 1980s. State University of New York Press, Albany, New York, 187-216.

Duncan, M. S., J. J. Isely, and D. W. Cooke. 2004. Evaluation of shortnose sturgeon spawning in the Pinopolis Dam tailrace, South Carolina. North American Journal of Fisheries Management 24(3): 932-938.

Dunton, K. J., A. Jordaan, K. A. McKown, D. O. Conover, and M. G. Frisk. 2010. Abundance and distribution of Atlantic Sturgeon (*Acipenser oxyrhincus*) within the Northwest Atlantic Ocean, determined from five fishery-independent surveys. Fishery Bulletin 108:450-465.

Dunton, K. J., D. Chapman, A. Jordaan, K. Feldheim, S. J. O'Leary, K. A. McKown, and M. G. Frisk. 2012. Genetic mixed-stock analysis of Atlantic *sturgeon Acipenser oxyrinchus oxyrinchus* in a heavily exploited marine habitat indicates the need for routine genetic monitoring. Journal of Fish Biology 80:207-217.

Dunton, K. J., A. Jordaan, D. O. Conover, K. A. McKown, L. A. Bonacci, and M. G. Frisk. 2015. Marine Distribution and Habitat Use of Atlantic Sturgeon in New York Lead to Fisheries Interactions and Bycatch. Marine and Coastal Fisheries 7:18-32.

Dunton, K.J., A. Jordaan, D. H. Secor, C. Martinez, T. Kehler, K. A. Hattala, J. Van Eenennaam, M. Fisher, K. A. McKown, D. O. Conover, and M. G. Frisk. 2016. Age and growth of Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, in the New York Bight. North American Journal of Fisheries Management 36: 62-73.

Ellner, S. P., J. Fieberg, D. Ludwig, and C. Wilcox. 2002. Precision of population viability analysis. Conservation Biology, 16(1): 258-261.

Erickson, D.L., A. Kahnle, M.J. Millard, E.A. Mora, M. Bryja, A.Higgs, J. Mohler, M. Dufour G. Kenney, J. Sweka, and E.K Pikitch. 2011. Use of satellite archival tags to identify oceanic migratory patterns for adult Atlantic sturgeon *Acipenser oxyrinchus* Mithcell 1815. Journal of Applied Ichthyology 27 pgs 356-365.

Farrae, D. J., Schueller, P. M. and Peterson, D. L. 2009. Abundance of juvenile Atlantic sturgeon in the Ogeechee River, Georgia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies, 63: 172–176.

Farrae, D. J., W.C. Post, and T. L. Darden. 2017. Genetic characterization of Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, in the Edisto River, South Carolina and identification of genetically discrete fall and spring spawning. Conservation Genetics doi:10.1007/s10592-017-0929-7.

Fernandes, S. J. 2008. Population demography, distribution, and movement patterns of Atlantic and shortnose sturgeons in the Penobscot River estuary, Maine (Doctoral dissertation, University of Maine).

Fox, A., E.S. Stowe, and D. Peterson. 2017. Occurrence and Movements of Shortnose and Atlantic Sturgeon in the St. Johns River, Florida. Final Report to the United States Army Corps of Engineers and the United States Navy. 25 pp.

Fox, A., and D. Peterson. 2017. Occurrence and Movements of Atlantic and Shortnose Sturgeon in Cumberland Sound and the St. Marys River, Georgia**.** Final Report to the United States Army Corps of Engineers and the United States Navy. 21 pp.

Fritts, M., and D. Peterson. 2011. Status of Atlantic Sturgeon and Shortnose Sturgeon in the St. Marys and Satilla Rivers, Georgia. Final Report to the National Marine Fisheries Service. 27 pp.

Fritts, M.W., C. Grunwald, I. Wirgin, T.L. King, and D.L. Peterson. 2016. Status and genetic character of Atlantic sturgeon in the Satilla River, Georgia. Transactions of the American Fisheries Society 145: 69-82.

Gadomski, D. M., and M. J. Parsley. 2005. Effects of turbidity, light level, and cover on predation of white sturgeon larvae by prickly sculpins. Transactions of the American Fisheries Society 134(2): 369-374.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology, 68(5): 1364-1372.

Gilbert, C. R. 1989. Species Profiles. Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic). Atlantic and Shortnosed Sturgeons. FLORIDA UNIV GAINESVILLE FLORIDA MUSEUM OF NATURAL HISTORY.

Gilbert, R.O. 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York. 320 p.

Goode, G. B. 1887. The fisheries and the fishery industries of the United States. U.S, Commision of Fish and Fisheries Section V. Vol. 1. U. S. Government Printing Office, Washington D.C., 660 pp.

Grunwald, C., L. Maceda, J. Waldman, J. Stabile, and I. Wirgin. 2008. Conservation of Atlantic Sturgeon *Acipenser oxyrinchus*: delineation of stock structure and distinct population segments. Conservation Genetics 9: 1111-1124.

Hager, C., J. Kahn, C. Watterson, J. Russo, and K. Hartman. 2014. Evidence of Atlantic Sturgeon Spawning in the York River System. Transactions of the American Fisheries Society 143(5): 1217-1219.

Hale, E. A., I. A. Park, M. T. Fisher, R. A. Wong, M. J. Stangl, and J. H. Clark. 2016. Abundance Estimate for and Habitat Use by Early Juvenile Atlantic Sturgeon within the Delaware River Estuary. Transactions of the American Fisheries Society 145(6): 1193-1201.

Haley, N., J. Boreman, and M. Bain. 1996. Juvenile sturgeon habitat use in the Hudson River. Section VIII in JR Waldman, WC Nieder, and EA Blair, editors. Final Report to the Tibor T. Polgar Fellowship Program, 995.

Hatin, D., R. Fortin, and F. Caron. 2002. Movements and aggregation areas of adult Atlantic sturgeon (*Acipenser oxyrinchus*) in the St Lawrence River estuary, Quebec, Canada. Journal of Applied Ichthyology, 18(4-6): 586-594.

Hatin, D., J. Munro, F. Caron, and R. D. Simons. 2007. Movements, home range size, and habitat use and selection of early juvenile Atlantic Sturgeon in the St Lawrence estuarine transition zone. Pages 129 - 155 *in* J. Munro, D. Hatin, J. E. Hightower, K. McKown, K. J. Sulak, A. W. Kahnle, and F. Caron, editors. Anadromous sturgeons: habitats, threats, and management American Fisheries Society, Symposium 56, Bethesda, Maryland.

Hazel, J., Lawler, I. R., Marsh, H., and Robson, S. 2007. Vessel speed increases collision risk for the green turtle *Chelonia mydas*. Endangered Species Research, 3:105-113.

Helser, T. E. and D. B. Hayes. 1995. Providing quantitative management advice from stock abundance indices based on research surveys. Fishery Bulletin 93:290-298.

Henderson-Arzapalo, A., and T. L. King. 2002. Novel microsatellite markers for Atlantic Sturgeon (*Acipenser oxyrhinchus*) population delineation and broodstock management. Molecular Ecology Notes 2:437-439.

Hewitt, D. A., and J. M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin 103(2): 433-437.

Hightower, J. E., M. Loeffler, W. C. Post, and D. L. Peterson. 2015. Estimated survival of subadult and adult Atlantic Sturgeon in four river basins in the southeastern United States. Marine and Coastal Fisheries 7(1): 514-522.

Hildebrand, S.F. and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. U.S. Bureau of Fisheries, Bull 43 (Part I), 366p.

Hilton, E.J., B. Kynard, M.T. Balazik, A.Z. Horodysky, and C.B. Dillman. 2016. Review of the biology, fisheries, and conservation status of the Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus* Mitchell, 1815). Journal of Applied Ichthyology 32(Suppl. 1): 30-66.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82:898-902.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6:65-70.

Holmes, E. E., E. J. Ward, and M. D. Scheuerell. 2014. Analysis of multivariate time-series using the MARSS package, Version 3.9. NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112.

Huff, J. A. 1975. Life history of Gulf of Mexico sturgeon, Acipenser oxrhynchus desotoi, in Suwannee River, Florida.

Husemann, M., F. E. Zachos, R. J. Paxton, and J. C. Habel. 2016. Effective population size in ecology and evolution. Heredity 117:191-192.

Ingram, E.C., and D.L. Peterson. 2016. Annual Spawning Migrations of Adult Atlantic Sturgeon in the Altamaha River, Georgia. Article in Marine and Coastal Fisheries Dynamics Management and Ecosystem Science 8(1): 595-606.

Jager, H. I., M. S. Bevelhimer, and D. L. Peterson. 2011. Population viability analysis of the endangered Shortnose Sturgeon (No. ORNL/TM-2011/48). OAK RIDGE NATIONAL LAB TN ENVIRONMENTAL SCIENCES DIV.

Jerome, W.C. Jr., A. P. Chesmore, C.O. Anderson, Jr. and F. Grice. 1965. A study of the marine resources of the Merrimack River estuary. Massachusetts Division of Marine Fisheries Department of Natural Resources Series 1:90 p.

Johnson, J. H., D. S. Dropkin, B. E. Warkentine, J. W. Rachlin, and W. D. Andrews. 1997. Food habits of Atlantic sturgeon off the central New Jersey coast. Transactions of the American Fisheries Society 126(1): 166-170.

Johnson, J. H., J. E. McKenna Jr., D. S. Dropkin, and W. D. Andrews. 2005. A novel approach to fitting the von Bertalanffy relationship to a mixed stock of Atlantic sturgeon harvested off the New Jersey Coast. Northeastern Naturalist 12(2): 195-202.

Jump, A. S., R. Marchant, and J. Penuelas. 2009. Environmental change and the option value of genetic diversity. Trends in Plant Science 14:51-58.

Kahnle, A., and K. Hattala. 1988. Bottom trawl survey of juvenile fishes in the Hudson River estuary. Summary Report for 1981-1986. New York State Department of Environmental Conservation. Albany, NY, USA.

Kahnle, A. W., K. A. Hattala, K. A. McKown, C. A., Shirey, M. R. Collins, T. S. Squiers Jr, and T. Savoy. 1998. Stock status of Atlantic sturgeon of Atlantic Coast estuaries. Report for the Atlantic States Marine Fisheries Commission. Draft III.

Kahnle, A.W., K. A. Hattala, and K. A. McKown. 2007. Status of Atlantic sturgeon of the Hudson River Estuary, New York, USA. American Fisheries Society, Symposium 56, Bethesda, Maryland.

Kazyak, D. C., A. M. Flowers, J. A. Madsen, M. Breece, A. Higgs, L. M. Brown, and D. A. Fox. *In Preparation*. Integrating side-scan sonar and acoustic telemetry to estimate the annual spawning run size of Atlantic Sturgeon in the Hudson River. Planned Submission to Canadian Journal of Fisheries and Aquatic Sciences.

Kéry, M., and M. Schaub. 2012. Bayesian population analysis using WinBUGS: a hierarchical perspective. Academic Press, Waltham, Massachusetts.

Kieffer, M. C., and B. Kynard. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society, 122(6): 1088-1103.

Kimura, M., and T. Ohto. 1969. The average number of generations until fixation of a mutant gene in a finite population. Genetics 61:763-771.

King, T. L., B. A. Lubinski, and A. P. Spidle. 2001. Microsatellite DNA variation in Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) and cross-species amplification in the Acipenseridae. Conservation Genetics 2:103-119.

Knowlton, A. R., and Kraus, S. D. (2001). Mortality and serious injury of northern right whales (*Eubalaena glacialis*) in the western North Atlantic Ocean. Journal of Cetacean Research and Management (special issue), 2:193-208.

Kocik, J., C. Lipsky, T. Miller, P. Rago, and G. Shepherd. 2013. An Atlantic Sturgeon population index for ESA management analysis. US Dept Commer, Northeast Fisheries Science Center Reference Document 13-06.

Kynard, B., M. Horgan, M. Kieffer and D. Seibel. 2000. Habitats used by shortnose sturgeon in two Massachusetts rivers, with notes on estuarine Atlantic sturgeon: a hierarchical approach. Transactions of the American Fisheries Society 129(2): 487-503.

Kynard, B., and M. Horgan. 2002. Ontogenetic behavior and migration of Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, and shortnose sturgeon, *A. brevirostrum*, with notes on social behavior. Environmental Biology of Fishes 63(2): 137-150.

Laist, D. W., Knowlton, A. R., Mead, J. G., Collet, A. S., and Podesta, M. 2001. Collisions between ships and whales. Marine Mammal Science. 17:35-75.

Lande, R. 1988. Genetics and demography in biological conservation. Science 241: 1455-1460.

Laney, R. W., J. E. Hightower, B. R. Versak, M. F. Mangold, W. W. Cole, and S .E. Winslow. 2007. Distribution, habitat use, and size of Atlantic sturgeon captured during cooperative winter tagging cruises, 1988-2006. In American Fisheries Society Symposium (Vol. 56, p. 167). American Fisheries Society.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of fish biology 49(4): 627-642.

Lossing, B. J. 1866. The Hudson, from the Wilderness to the Sea. Virtue & Yorston.

Ludwig, A., L. Debus, D. Lieckfeldt, I. Wirgin, N. Benecke, I. Jenneckens, P. Williot, J. R. Waldman, and C. Pitra. 2002. When the American sea sturgeon swam east. Nature 419: 447-448. 10.1038/419447a.

Lupton, B. Y., and P.S. Phalen. 1996. Designing and implementing a trip ticket program. North Carolina Department of Environment, Health, and Natural Resources. North Carolina Division of Marine Fisheries.

May, B., C. C. Krueger, and H. L. Kincaid. 1997. Genetic variation at microsatellite loci in sturgeon: primer sequence homology in *Acipenser* and *Scaphirhynchus*. Canadian Journal of Fisheries and Aquatic Sciences 54: 1542-1547.

McCord, J. W., M. R. Collins, W. C. Post, and T. I. J. Smith. 2007. Attempts to develop an index of abundance for age-1 Atlantic Sturgeon in South Carolina, USA. Pages 397–403 in J. Munro, D. Hatin, J. E. Hightower, K. McKown, Kenneth J. Sulak, A.W. Kahnle, and F. Caron, editors. Anadromous sturgeons: habitats, threats, and management. American Fisheries Society, Symposium 56, Bethesda, Maryland.

Miller, A. I., and L. G. Beckman. 1996. First record of predation on white sturgeon eggs by sympatric fishes. Transactions of the American Fisheries Society 125:338–340.

Miller, T. J., and G.R. Shepherd. 2011. Summary of discard estimates for Atlantic sturgeon (White paper). NOAA/NMFS, Woods Hole, MA: Population Dynamics Branch. http://www.nefmc.org/monk/cte mtg docs/120403/Summary of Discard Estimates for Atlantic Sturgeon-v3.pdf

Minami, M., C. E. Lennert-Cody, W. Gao, and M. Roman-Verdesoto. 2007. Modeling shark bycatch: the zero-inflated negative binomial regression model with smoothing. Fisheries Research 84(2): 210-221.

Moser, M.L., M. Bain, M.R. Collins, N. Haley, B. Kynard, J.C. O'Herron, II, G. Rogers and T.S. Squires. 2000. A protocol for use of shortnose and Atlantic sturgeons. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources, Silver Spring, Maryland. NOAA Technical Memorandum NMFS-OPR-18. 18 pp.

Moser, M. L., J. B. Bichey, and S. B. Roberts. 1998. Sturgeon distribution in North Carolina. Center for Marine Science Research, Wilmington, North Carolina. Final Report to U.S. Army Corps of Engineers, Wilmington District.

Moser, M.L. and S. W. Ross. 1995. Habitat use and movement of shortnose and Atlantic sturgeons in the Lower Cape Fear River, North Carolina. Transactions of the American Fisheries Society 124:225-234.

Moyer, G. R., J. A. Sweka, and D. L. Peterson. 2012. Past and present processes influencing genetic diversity and effective population size in a natural population of Atlantic sturgeon. Transactions of the American Fisheries Society 141(1): 56-67.

Murawski, S. A., and A. L. Pacheco. 1977. Biological and fisheries data on Atlantic sturgeon, *Acipenser oxyrhynchus* (Mitchill). NationalMarine Fisheries Service, Technical Series Report 10, Highlands, New Jersey.

Murdy, E.O., R. S. Birdsong, and J. A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press, Washington DC

Najjar, R. G., C. R. Pyke, M. B, Adams, D. Breitburg, C Hershner, M. Kemp, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2010. Potential climate-change impacts on the Chesapeake Bay. Estuarine, Coastal and Shelf Science 86(1): 1-20.

Nantel, P. 2010. A Bayesian belief network for assessing species status under uncertainty. Available from Patrick Nantel, Parks Canada, Ottawa, Ontario.

National Marine Fisheries Services (NMFS) and United States Fish and Wildlife Service (USFWS). 1998. Status review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). U. S. Department of Commerce, National Oceanic and Atomspheric Administration, National Marine Fisheries Service and United States Fish and Wildlife Service. 126 pp.

NMFS Atlantic Sturgeon Status Review Team. 2007. Status Review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Report to National Marine Fisheries Service, Northeast Regional Office. February 23, 2007. 174 pp.

NMFS and ASMFC. 2013. Workshop on Sea Turtle and Atlantic Sturgeon Bycatch Reduction in Gillnet Fisheries. Jan 22-23, 2013, Ocean City, MD. 48 pp.

National Oceanic and Atmospheric Administration (NOAA). 2012. Endangered and threatened wildlife; notice of 90-day finding on a petition to list Atlantic Sturgeon as threatened or endangered under the Endangered Species Act (ESA). Federal Registry 77: 5880–5912.

Nelson, G. A. 2017. fishmethods: Fishery Science Methods and Models in R. R package version 1.10-1. https://CRAN.R-project.org/package=fishmethods

Niklitschek, E. J. 2001. Bioenergetics modeling and assessment of suitable habitat for juvenile Atlantic and shortnose sturgeons in the Chesapeake Bay. Doctoral Diss., University of Maryland, College Park, 158.

Niklitschek, E. J., and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay. Estuarine, Coastal and Shelf Science 64(1): 135-148.

Northeast Fisheries Science Center (NEFSC). 2013. 57th Northeast Regional Stock Assessment Workshop (57th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 13-16; 967 p. https://www.nefsc.noaa.gov/nefsc/saw/

O'Leary, S. J., K. J. Dunton, T. L. King, M. G. Frisk, and D. D. Chapman. 2014. Genetic diversity and effective size of Atlantic sturgeon, *Acipenser oxyrhinchus oxyrhinchus* river spawning populations estimated from the microsatellite genotypes of marine-captured juveniles. Conservation Genetics 15: 1173-1181.

O'Leary, S. J., K. A. Feldheim, A. T. Fields, L. J. Natanson, S. Wintner, N. Hussey, M. S. Shivji, and D. D. Chapman. 2015. Genetic diversity of white sharks, Carcharodon carcharias, in the Northwest Atlantic and southern Africa. Journal of Heredity 106(3): 258-265.

Oliver, M. J., M. W. Breece, D. A. Fox, D. E. Haulsee, J. T. Kohut, J. Manderson, and T. Savoy. 2013. Shrinking the haystack: using an AUV in an integrated ocean observatory to map Atlantic sturgeon in the coastal ocean. Fisheries 38(5): 210-216.

Oregon Department of Fish and Wildlife (ODFW). 2011. Lower Columbia River and Oregon Coast White Sturgeon Conservation Plan. Technical Report. Clackamas, Oregon. http://www.dfw.state.or.us/fish/crp/docs/lower_columbia_sturgeon/LCR_white_sturgeon_conservation_plan.pdf

Palstra, F. P., and D. E. Ruzzante. 2008. Genetic estimates of contemporary effective population size: what can they tell us about the importance of genetic stochasticity for wild population persistence? Molecular Ecology 17: 3428-3447.

Palstra, F. P., and D. J. Fraser. 2012. Effective/census population size ratio estimation: a compendium and appraisal. Ecology and Evolution 2: 2357-2365.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean temperature in 175 fish stocks. Journal du Conseil 39: 175-192.

Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fishery Bulletin 84(3): 519-525.

Peterson, D. L., P. Schueller, R. DeVries, J. Fleming, C. Grunwald, and I. Wirgin. 2008. Annual run size and genetic characteristics of Atlantic sturgeon in the Altamaha River, Georgia. Transactions of the American Fisheries Society, 137(2): 393-401.

Pine, W. E. III, M. S. Allen, and V. J. Dreitz. 2001. Population viability of the Gulf of Mexico Sturgeon: inferences from capture–recapture and age-structured models. Transactions of the American Fisheries Society 130: 1164–1174.

Piry, S., A. Alapetite, J. M. Cornuet, D. Paetkau, L. Baudouin, and A. Estoup. 2004. GeneClass2: a software for genetic assignment and first-generation migrant detection. Journal of Heredity 95:536–539.

Post, W. C., T. Darden, D. L. Peterson, M. Loeffler, and C. Collier. 2014. Research and management of endangered and threatened species in the southeast: riverine movements of Shortnose and Atlantic sturgeon. South Carolina Department of Natural Resources, Project NAIONMF4720036, Final Report, Charleston.

Pottle, R., and M. J. Dadswell. 1979. Studies on larval and juvenile shortnose sturgeon. Report to Northeast Utilities Service Co., Hartford, CT. 87 pp.

Rannala, B., and J. L. Mountain. 1997. Detecting immigration by using multilocus genotypes. Proceedings of the National Academy of Sciences of the United States of America 94: 9197–9201.

R Core Team (RCT). 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Reed, D. H., and R. Frankham. 2003. Correlation between fitness and genetic diversity. Conservation Biology 17: 230-237.

Restrepo, V.R., J.O. de Urbina, J.-M. Fromentin, and H. Arrizabalaga. 2007. Estimates of selectivity for eastern Atlantic bluefin tuna from catch curves. ICCAT Collective Volume of Scientific Papers 60(3): 937-948.

Rogers, S. G., and W. Weber. 1995. Status and restoration of Atlantic and shortnose sturgeons in Georgia. Final report to NMFS for grant NA46FA102-01.

Rose, K.A., Cowan Jr., J.H., Winemiller, K.O., Myers, R.A., and Hilborn, R. 2001. Compensatory density dependence in fish populations: importance, controversy, understanding and prognosis. Fish and Fish. 2: 293–327.

Rowat, D., Meekan, M. G., Engelhardt, U., Pardigon, B., and Vely, M. (2007). Aggregations of juvenile whale sharks (*Rhincodon typus*) in the Gulf of Tadjoura, Djibouti. Environmental Biology of Fishes, 80: 465-472.

Rudd, M. B., R. N. M. Ahrens, W. E. Pine III, and S. K. Bolden. 2014. Empirical, spatially explicit natural mortality and movement rate estimates for the threatened Gulf Sturgeon (Acipenser oxyrinchus desotoi). Canadian Journal of Fisheries and Aquatic Sciences 71: 1407–1417.

Ryder, J. A. 1890. The sturgeons and sturgeon industries of the eastern coast of the United States: with an account of experiments bearing upon sturgeon culture. US Government Printing Office.

Savoy T., L. Maceda, N. K. Roy, D. Peterson, and I. Wirgin. 2017. Evidence of natural reproduction of Atlantic sturgeon in the Connecticut River from unlikely sources. PLOS ONE 12:e0175085

Savoy, T., and D. Pacileo. 2003. Movements and important habitats of subadult Atlantic sturgeon in Connecticut waters. Transactions of the American Fisheries Society 132(1): 1-8.

Schloesser, R. W., M. C. Fabrizio, R. J. Latour, G. C. Garman, B. Greenlee, M. Groves, and J. Gartland. 2011. Ecological role of blue catfish in Chesapeake Bay communities and implications for management. In Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium (Vol. 77, pp. 369-382).

Schmitt, J. D., E. M. Hallerman, A. Bunch, Z. Moran, J. A. Emmel and D. J. Orth. 2017. Predation and Prey Selectivity by Nonnative Catfish on Migrating Alosines in an Atlantic Slope Estuary. Marine and Coastal Fisheries 9(1): 108-125.

Schueller, P., and D. L. Peterson. 2006. Population status and spawning movements of Atlantic sturgeon in the Altamaha River, Georgia. Presentation to the 14th American Fisheries Society Southern Division Meeting, San Antonio, February 8-12th, 2006. Scott, WB and EJ Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin, 184, 966.

Schueller, P., and D. L. Peterson. 2010. Abundance and recruitment of juvenile Atlantic Sturgeon in the Altamaha River, Georgia. Transactions of the American Fisheries Society 139(5): 1526-1535.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada: Fisheries Research Board of Canada Bulletin, Vol. 184. Fisheries Research Board of Canada, Ottawa.

Secor, D. H. 1995. New Longevity Record for Mid-Atlantic Bight Atlantic Sturgeon, p. 5-6 In M. Bain [ed.] Sturgeon Notes Issue #3, June 1995. Cornell Univ. Ithaca.

Secor, D. H., E.J. Niklitschek, J. T. Stevenson, T. E. Gunderson, S. P. Minkkinen, B. Richardson, B. Florence, M. Mangold, J. Skjeveland, and A. Henderson-Arzapalo. 2000. Dispersal and growth of yearling Atlantic sturgeon, Acipenser oxyrinchus, released into Chesapeake Bay. Fishery Bulletin 98(4): 800-800.

Secor, D. H., and J. R. Waldman. 1999. Historical abundance of Delaware Bay Atlantic sturgeon and potential rate of recovery. In American Fisheries Society Symposium (Vol. 23, pp. 203-216).

Secor, D. 2002. Atlantic sturgeon fisheries and stock abundances during the late nineteenth century. Pages 89–97 in W. Van Winkle, P. J. Anders, D.H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Shertzer, K. W., M. H. Prager, and E. H. Williams. 2008. A probability-based approach to setting annual catch levels. Fishery Bulletin 106(3): 225-232.

Shirey, C. A., A. C. Martin, E. J. Stetzar. 1999. Atlantic sturgeon abundance and movement in the lower Delaware River. Final Report. NOAA Project No. AGC-9N. Grant No. A86FA0315. Delaware Division of Fish and Wildlife, Dover

Simpson, P. C., and D. A. Fox. 2007. Atlantic sturgeon in the Delaware River: contemporary population status and identification of spawning areas. National Oceanic and Atmospheric Administration Marine Fisheries Service, Report Award NA05NMF4051093, Gloucester, Massachusetts.

Simpson, P. C., and D. A. Fox. 2009. Contemporary understanding of the Delaware River Atlantic sturgeon: survival in a highly impacted aquatic ecosystem. American Fisheries Society Symposium 69: 867-870.

Smith, T. I. 1985. The fishery, biology, and management of Atlantic sturgeon, *Acipenser oxyrhynchus*, in North America. Environmental Biology of Fishes, 14(1): 61-72.

Smith, T. I. J., D. E. Marchette, and R. A. Smiley. 1982. Life history, ecology, culture and management of Atlantic sturgeon, *Acipenser oxyrhynchus oxyrhynchus*, Mitchill. South Carolina. South Carolina Wildlife Marine Resources. Resources Department, Final Report to US Fish and Wildlife Service Project AFS-9, 75.

Smith, T. I. J., D. E. Marchette, and G. F. Ulrich. 1984. The Atlantic sturgeon fishery in South Carolina. North American Journal of Fisheries Management 4: 164-176.

Smith, T. I., and J. P. Clugston. 1997. Status and management of Atlantic sturgeon, *Acipenser oxyrinchus*, in North America. Environmental Biology of Fishes, 48(1-4): 335-346.

Smith, J. A., H. J. Flowers, and J. E. Hightower. 2015. Fall spawning of Atlantic sturgeon in the Roanoke River, North Carolina. Transactions of the American Fisheries Society 144:48–54.

Stein, A. B., K. D. Friedland, and M. Sutherland. 2004. Atlantic sturgeon marine bycatch and mortality on the continental shelf of the Northeast United States. North American Journal of Fisheries Management 24(1): 171-183.

Stevenson, J. T. 1997. Life History Characteristics of Atlantic sturgeon *Acipenser oxyrinchus* in the Hudson River and a Model for Fisheries Management. M.S. thesis, MEES Program, University of Maryland, College Park. 222 p.

Stevenson, J. T., and D. H. Secor. 1999. Age determination and growth of Hudson River Atlantic sturgeon, Acipenser oxyrinchus. U.S. National Marine Fisheries Service Fishery Bulletin 97: 153–166.

Stevenson, J. T., and D. H. Secor, D. H. 2000. Age determination and growth of Hudson River Atlantic sturgeon, *Acipenser oxyrinchus*. Fishery Bulletin 98(1): 153-166.

Stewart, N. D., M. J. Dadswell, P. Leblanc, R. G. Bradford, C. Ceapa, and M. J. W. Stokesbury. 2015. Age and growth of Atlantic sturgeon from the Saint John River, New Brunswick, Canada. N. Am. J. Fisheries Management 35: 364-371.

Sweka, J.A., J. Mohler, and M.J. Millard. 2006. Relative Abundance Sampling of Juvenile Atlantic Sturgeon in the Hudson River. Final Study Report. U.S. Fish and Wildlife Service – Northeast Fishery Center, Lamar, PA 16848.

Then, A. Y., J. M. Hoenig, N. G. Hall, and D. A. Hewitt. 2014. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science 72(1): 82-92.

US Bureau of Fisheries. 1907. Statistics of the fisheries of the Middle Atlantic States for 1904. Report of Comm. of Fisheries for 1905. Appendix (Doc. 609).

US Commission of Fish and Fisheries. 1884-1905. Reports of the Commissioner, 1882-1905.

Van den Avyle, M. J. 1983. Species Profiles: Life Histories and Environmental Requirements (South Atlantic)-Atlantic Sturgeon. US Fish. Wildl. Ser., Div. Biol. Ser. FWS/OBS-82/11. US Army Corps Eng. TREL-82-4.

Van Eenennaam, J. P., S. I. Doroshov, G. P. Moberg, J. G. Watson, D. S. Moore, and J. Linares. 1996. Reproductive conditions of the Atlantic sturgeon (Acipenser oxyrinchus) in the Hudson River. Estuaries 19(4): 769-777.

Van Eenannaam, J.P., and S.I. Doroshov. 1998. Effects of age and body size on gonadal development of Atlantic sturgeon. Journal of Fish Biology 53(3): 624-637.

Vladykov, V. D., and J. R. Greeley. 1963. Order Acipenseroidei. In Fishes of the Western North Atlantic. Sears Foundation Marine Research. Yale Univ. 1(3): 630 p.

Vucetich, J. A., T. A. Waite, and L. Nunney. 1997. Fluctuating population size and the ratio of effective to census population size. Evolution 51: 2017-2021.

Waldman, J. R., J. T. Hart, and I. I. Wirgin. 1996. Stock composition of the New York Bright Atlantic sturgeon fishery based on analysis of mitochondrial DNA. Transactions of the American Fisheries Society 125: 364-371.

Waldman, J. R., T. King, T. Savoy, L. Maceda, C. Grunwald, and I. Wirgin. 2013. Stock Origins of Subadult and Adult Atlantic Sturgeon, *Acipenser oxyrinchus*, in a Non-natal Estuary, Long Island Sound. Estuaries and Coasts 36: 257-267.

Walters, C. J., S. J. Martell, and J. Korman. 2006. A stochastic approach to stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences 63(1): 212-223.

Warner, F. W. 1972. The foods of the Connecticut Indians. Bull. Arch. Soc. Connecticut 37: 27-47.

Weber, W., and C. A. Jennings. 1996. Endangered species management plan for the shortnose sturgeon, *Acipenser brevirostrum*. Final Report to Fort Stewart Military Reservation, Fort Stewart, Georgia.

Welsh, S. A., S. M. Eyler, M. F. Mangold, and A. J. Spells. 2002. Capture locations and growth rates of Atlantic sturgeon in the Chesapeake Bay. Am. Fish. Soc. Symp. 28:183-194.

Wheeler, G. A. and H. W. Wheeler. 1878. History of Brunswick, Topsham, and Harpswell, Maine. Alfred Mudge & Son Printers, Boston, Massachusetts.

Wippelhauser, G. S., J. Sulikowski, G. B. Zydlewski, M. A. Altenritter, M. Kieffer, and M. T. Kinnison. 2017. Movements of Atlantic Sturgeon of the Gulf of Maine Inside and Outside of the Geographically Defined Distinct Population Segment. Marine and Coastal Fisheries 9(1): 93-107.

Wirgin, I., L. Maceda, J. R. Waldman, S. Wehrell, M. Dadswell, and T. King. 2012. Stock Origin of Migratory Atlantic Sturgeon in Minas Basin, Inner Bay of Fundy, Canada, Determined by Microsatellite and Mitochondrial DNA Analyses. Transactions of the American Fisheries Society 141(5): 1389-1398.

Wirgin, I., M. W. Breece, D. A. Fox, L. Maceda, K. W. Wark, and T. King. 2015a. Origin of Atlantic Sturgeon Collected off the Delaware Coast during Spring Months. North American Journal of Fisheries Management 35: 20-30.

Wirgin, I., L. Maceda, C. Grunwald, and T. L. King. 2015b. Population origin of Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* by-catch in US Atlantic coast fisheries. Journal of Fish Biology 86: 1251-1270.

Worth, S. G. 1904. Report on operations with the striped bass at the Weldon, North Carolina sub-station in May 1904. Department of Commerce and Labor, Bureau of Fisheries, Washington, DC.

Wurfel, B. and G. Norman. 2006. Oregon and Washington to expand sea lion control efforts in the Columbia River. Oregon Department of Fish and Wildlife News Release March 17, 2006. http://www.dfw.state.or.us/news/2006/march/018.asp

Wright, S. 1938. Size of population and breeding structure in relation to evolution. Science 87:430–431.

Yarrow, H. C. 1874. Report of a reconnaissance of the shad—rivers south of the Potomac. Pages 396-402 i/i Report of the Commissioner for 1872 and 1873, part 2. U.S. Commission of Fish and Fisheries, Washingion, D.C.

Zuur, A. F., and E. N. Ieno. 2012. Zero inflated models and generalized linear mixed models with R (No. 574.50182 Z8).

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Zero-truncated and zero-inflated models for count data. In Mixed effects models and extensions in ecology with R (pp. 261-293). Springer New York.

10 TABLES

Table 1. Evidence for spawning tributaries and sub-populations for U.S. Atlantic sturgeon. Level of certainty assigned to spawning sub-populations are, **(1) Confirmed** – Eggs, embryo, larvae, or YOY (<30 cm TL) observed in tributary; **(2) Highly likely** - Large adults physically observed expressing gametes in freshwater tidal reaches of the tributary; discrete genetic composition associated with adults or early life stages within a tributary; **(3) Suspected** - Adults observed (either by telemetry, capture, ship strikes, or 2nd hand accounts) in upper reaches of tributaries; recent historical accounts (last 30 years) of adults observed in upper reaches of tributaries; presence of river-resident juveniles (Age-1, <50cm TL); **(4) Unknown**; and **(5) Suspected historical** - (Yes/No) either confirmed, highly likely or suspected, but no physical observations of such criteria in the last 30 years. PC = personal communication. Note that this is not to be considered a comprehensive list of rivers and tributaries along the U.S. Atlantic coast.

DPS	River System/ Tributary	Spawning Certainty	Evidence	Reference(s)
Gulf of Maine	St. Croix	4	No mention of sturgeon in Atkins 1887; salt wedge almost to the first dam in summer	Larsen and Doggett 1979 (in ASMFC 1998)
	Penobscot	5	Suspected historical, possibly extirpated; current telemetry detections not in freshwater reaches	Altenritter et al. 2017
	Kennebec	1	Larvae captured	Wippelhauser et al. 2017
	Merrimack	4	Subadults and adults captured and tagged since 1990s	ASSRT 2007 (citing Knyard & Keiffer)
New York Bight	Tauton	5	Historical records indicate spawning occurred; sparse observations reported	ASSRT 2007
	Connecticut	1	Collection of river-resident juveniles	Savoy et al. 2017
	Hudson	1	Ripe females captured, YOY and age 1 fish captured, genetics	Amanda Higgs, PC; ASA Analysis and Communication 2013
	Delaware	1	Collection of YOY and age-1 fish, movements of spawning adults (assessed histologically), in-river mortality events of spawning adults (ship strikes)	Breece et al. 2013; Hale et al. 2016

Table 1. *Continued*

DPS	River System/Tributary	Spawning Certainty	Evidence	Reference(s)
Chesapeake Bay	James	1	Ripe females captured and detected; YOY captured; genetics	Balazik et al. 2012a; Hager et al. 2014; Hilton et al. 2016
	York- Pamunkey	2		
	Nanticoke-Marshyhope	2	Ripe females	C. Stence, PC
	Potomac	4	Insufficient evidence of Atlantic sturgeon to make a determination	D. Secor, PC
	Upper Nanticoke	3	Telemetry detections of adults on spawning grounds during fall	M. Balazik, PC; I. Park, PC; D. Secor, PC; J. Kahn, PC
	Rappahannock	2	Telemetry detections of adults on spawning grounds during fall; expression of gametes in tidal freshwater	
	Mattaponi	2	Telemetry detections of adults on spawning grounds during fall, field observations of ripe females and expressing milt from males	
Carolina	Chowan	4	Insufficient evidence of Atlantic sturgeon to make a determination	Post et al. 2014
	Roanoke	1	Embryos collected, spring and fall	Yarrow 1874; Worth 1904; Smith et al. 2015
	Tar/Pamlico	3	Collection of YOY and Age-1 fish	M. Loeffler, PC
	Neuse	2	Age-1, large juveniles, sub-adults and adult fish collected during FI monitoring efforts; historical YOY collections	M. Loeffler, PC; W. Laney, PC
	White Oak	4	Insufficient evidence of Atlantic Sturgeon to make a determination	M. Loeffler, PC

Table 1. *Continued*

DPS	River System/Tributary	Spawning Certainty	Evidence	Reference(s)
Carolina (continued)	New	4	Insufficient evidence of Atlantic Sturgeon to make a determination	M. Loeffler, PC
	Cape Fear	2	Tagged ripe adult during spring spawning season	Post et al. 2014
	Waccamaw	4	No sturgeon detected upriver of the confluence with Big Bull Creek to N.C.	Post et al. 2014
	Great Pee Dee	2	Telemetry detections of adults and collection of YOY and Age-1 fish	Post et al. 2014
	Black	3	Telemetry detections of adults upriver of the highest receiver (RKM 74)	Post et al. 2014
	Santee	2	Capture of Age-1 fish and potential YOY during high flow events	Post et al. 2014
	Cooper	2	Capture of ripe males; capture of juveniles in 1980s	Collins and Smith 1997; Duncan et al. 2004; Post et al. 2014
	Wando	4	No detected Atlantic sturgeon upriver; small coastal river	B. Post, PC
	Stono	4	No detected Atlantic sturgeon upriver; small coastal river	B. Post, PC
South Atlantic	Edisto	1	Capture of ripe females, juveniles and Age-1 fish	Collins and Smith 1997; Post et al. 2014; Farrae et al. 2017
	Combahee	3	Telemetry detections of large adults in the fall	Post et al. 2014
	Coosawhatchie	5	Historical commercial fishery	Post et al. 2014
	Broad	4	No detected Atlantic sturgeon upriver	Post et al. 2014
	Savannah	1	Telemetry detections of adults upstream near New Savannah Bluff Lock and Dam (RKM 301) during fall	Post et al. 2014; Bahr and Peterson 2016

Table 1. *Continued*

DPS	River System/Tributary	Spawning Certainty	Evidence	Reference(s)
South Atlantic (continued)	Ogeechee	3	Mark-recapture study found river-resident juveniles	Farrae et al. 2009
	Altamaha	1	Capture of age-1 and juveniles; genetics	Peterson et al. 2008; Schueller and Peterson 2010; Ingram and Peterson 2016
	Satilla	1	Capture of YOY and age-1 fish; genetics	Fritts et al. 2016
	St. Marys	3	Adults observed	Fritts and Peterson 2011; Fox and Peterson 2017
	St. Johns	5	Genetics and tagging indicate Atlantic sturgeon found in this river are migrants	Fox et al. 2017.

Table 2. Parameters estimates and associated standard errors of the total length (cm)-weight (g) relationship for Atlantic sturgeon by DPS.

DPS	n	a	SE[a]	b	SE[b]
All	6,304	0.00513	0.000286	3.05	0.0107
Gulf of Maine	618	0.0119	0.00211	2.85	0.0354
New York Bight	735	0.0235	0.00428	2.76	0.0345
Chesapeake Bay	190	0.00549	0.00306	3.06	0.109
Carolina	4,761	0.00186	0.000119	3.25	0.0129

Table 3. Parameters estimates and associated standard errors of the von Bertalanffy age-length (total; cm) relationship for Atlantic sturgeon by DPS.

DPS	n	L_∞	SE[L_∞]	K	SE[K]	t_0	SE[t_0]
All	2,539	286	2.08	0.0622	0.00140	-0.340	0.129
New York Bight	2,679	299	2.37	0.0511	0.00104	-1.82	0.102
Chesapeake Bay	239	451	63.4	0.0283	0.00601	-2.80	0.493
Carolina	1,901	182	1.29	0.169	0.00473	-0.759	0.0719

Table 4. Parameter estimates of the von Bertalanffy age-length (cm) relationship from selected papers.

Location	Sex	Length Type	L_∞	K	t_0	Source
Hudson River & Hudson Bight (NY)	female	Fork	259	0.0639	1.02	Van Eenennaam and Doroshov (1998)
Hudson River & Hudson Bight (NY)	male	Fork	201	0.113	0.870	Van Eenennaam and Doroshov (1998)
Hudson River & New York Bight (NY)	female	Total	256	0.07	-3.23	Stevenson and Secor (2000)
Hudson River & New York Bight (NY)	male	Total	180	0.25	2.37	Stevenson and Secor (2000)
Atlantic Ocean (NJ coast)	pooled	Fork	171	0.163	0.7	Johnson et al. (2005)
Atlantic Ocean (NJ coast)	female	Fork	422	0.023	-7.5	Johnson et al. (2005)
Atlantic Ocean (NJ coast)	male	Fork	205	0.080	-4.0	Johnson et al. (2005)
Atlantic Ocean, Hudson River (NY), Delaware River and Bay (DE)	pooled	Total	279	0.057	-1.28	Dunton et al. (2016)
Saint John River (Canada)	female	Total	264	0.04	-0.94	Stewart et al. (2015)
Saint John River (Canada)	male	Total	230	0.06	-0.60	Stewart et al. (2015)
Saint John River (Canada)	pooled	Total	254	0.05	-0.86	Stewart et al. (2015)
Albemarle Sound (NC)	pooled	Fork	269	0.0903	-0.148	Armstrong (1999)
Albemarle Sound (NC)	pooled	Fork	218	0.117	-0.102	Armstrong (1999)

Table 5. Estimates of mortality based on longevity, growth parameters, and catch curve analysis.

M yr^{-1}	Population	Method	Source
0.05	Hudson River	Longevity=95% survival; longevity=60 years	Stevenson 1997
0.07	Hudson River	Hoenig 1983; longevity=60 years	Kahnle et al. 1998
0.13	Hudson River	Pauly 1980; mean T=13 C; HR von B parameters	Stevenson 1997
0.19-0.24	Altamaha River	Catch Curve Analysis	Peterson et al. 2008

Table 6. Age-constant estimators of natural mortality for Atlantic sturgeon.

Reference	Equation	M
Hoenig 1983 (rule-of-thumb)	$M = 3 / t_{max}$	0.050
Hewitt and Hoenig 2005	$M = 4.22 / t_{max}$	0.070
Updated Hoenig 1983 (Then et al. 2014)	$M = \exp[1.717-1.01*\ln(t_{max})]$	0.089
Updated Hoenig Non-linear least squares (Then et al. 2014)	$M = 4.899 * t_{max} -0.916$	0.115
Updated growth-based estimator (Then et al. 2014)	$M = 4.118*K^{0.73} * L_{\infty}^{-0.33}$	0.084

Where t_{max} = maximum age

K and L_{∞} = von Bertalanffy growth coefficients

Table 7. Age-varying estimates of natural mortality for Atlantic sturgeon.

Age	M	Age (cont.)	M
1	0.305	40	0.036
2	0.192	41	0.036
3	0.144	42	0.035
4	0.118	43	0.035
5	0.101	44	0.035
6	0.089	45	0.035
7	0.080	46	0.035
8	0.073	47	0.035
9	0.068	48	0.035
10	0.064	49	0.035
11	0.060	50	0.034
12	0.057	51	0.034
13	0.055	52	0.034
14	0.053	53	0.034
15	0.051	54	0.034
16	0.049	55	0.034
17	0.048	56	0.034
18	0.047	57	0.034
19	0.045	58	0.034
20	0.044	59	0.034
21	0.043	60	0.034
22	0.043		
23	0.042		
24	0.041		
25	0.041		
26	0.040		
27	0.040		
28	0.039		
29	0.039		
30	0.038		
31	0.038		
32	0.038		
33	0.037		
34	0.037		
35	0.037		
36	0.037		
37	0.036		
38	0.036		
39	0.036		

Table 8. Surveys considered, accepted and rejected for developing indices of relative abundance for Atlantic sturgeon. Asterisks in the "Accepted" column indicate a survey that was developed into an index but should not be used in analysis at this time due to the time series being too short. All surveys are fishery-independent unless indicated with "(FD)" (fishery-dependent).

Surveys Considered	Accepted	Rejected	Reason(s) Rejected						
			Time series too short or broken	Rare occurrence of sturgeon	Unusable as suggested by data submitter	Inconsistent methods, gear changes	Limited covariates	Incomplete dataset or unavailable	FD survey concerns
ME Gillnet		X	X			X	X		
ME-NH Trawl	X								
MA FD Investigation Maintenance Sampling		X		X					
MA FI Trawl Survey		X		X					
MA Industry based survey for cod		X		X					
RI Trawl		X		X	X				
CT LIS Trawl	X								
NY Juvenile Gillnet	X*		X						
NY Hudson River shad gillnet fishery (FD)		X	X						X
NY Hudson River power generator monitoring		X			X	X			
NYSDEC bottom trawl for striped bass		X		X	X				
NJ Ocean Trawl	X								
DE DFW ATS juvenile survey		X	X						
DE trawl (16' and 30')		X		X					
DSU inshore juvenile sampling & offshore sampling		X	X		X				
MD Coastal Offshore Trawl Survey		X		X					

Table 8. *Continued*

Surveys Considered	Accepted	Rejected	Reason(s) Rejected						
			Time series too short or broken	Rare occurrence of sturgeon	Unusable as suggested by data submitter	Inconsistent methods, gear changes	Limited covariates	Incomplete dataset or unavailable	FD survey concerns
VIMS Shad Monitoring	X								
NEAMAP	X*		X						
NC Program 120		X		X					
NC Program 135	X								
NC Program 915		X		X					
SC Edisto River Sturgeon Montoring	X*								
UGA Work		X	X						
USFWS Winter Trawl COOP Cruise	X								
NEFOP / ASM (FD)		X			X	X			X
NEFSC trawl		X		X	X	X			
The following surveys were rejected immediately due to extremely low encounter rates, or due to limited geographic coverage and survey design methods:									
NY Fall Shoals Survey		X				X			
VT Trawl Survey		X							
Upper James River Work		X						X	
James River FRG		X				X		X	
NC AR Gillnet -Fall/Winter		X							
NC AR Gillnet - Spring		X							
Historic Altamaha Study		X						X	
NJ Striped Bass Tagging Survey		X		X					
DE Carcass Report		X							
MD Striped Bass Gillnet Survey		X		X					

Table 8. *Continued*

Surveys Considered	Accepted	Rejected	Reason(s) Rejected						
			Time series too short or broken	Rare occurrence of sturgeon	Unusable as suggested by data submitter	Inconsistent methods, gear changes	Limited covariates	Incomplete dataset or unavailable	FD survey concerns
VIMS Juvenile Fish and Blue Crab Survey		X		X		X			
ChesMMAP		X							
Southeast Area Ocean Gillnet		X	X	X					
NC AS Trawl		X		X					
NC South Gillnet		X	X	X					
Cape Fear Gillnet		X	X						
Carolina Power and Light Surveys		X							
GA Brunswick River Sampling		X	X						
Pee Dee River Run Atl. Sturgeon Gillnet		X	X	X					
Pee Dee River Survey		X							
Winyah Bay		X							
Santee River		X		X					
Two South Carolina Rivers Studies		X	X	X					
Savannah River and Selected Tribs		X	X	X					
Georgia Shad Tagging		X							
SEAMAP		X		X					

Table 9. The survey name, time series length, months included in the index, and average size of Atlantic sturgeon in fishery-independent surveys that were used for developing indices of relative abundance. A length cutoff was used for determining if surveys catch predominantly YOY (<500 mm), juveniles (500-1300 mm), or adults (>1300 mm).

Survey	**Years**	**Index Months**	**Average size**
ME-NH Trawl	2000-2015	5,10,11	Juveniles & Adults
CT LIST	1984-2014	5-6,9-11	Juveniles
NYDEC JASAMP	2006-2015	3-5	Small Juveniles
NJ Ocean Trawl	1990-2015	1,4,6,10	Juveniles & Adults
VIMS Shad	1998-2015	3-4	Juveniles
NEAMAP	2007-2015	4-5,10	Juveniles & Adults
NC p135	1991-2015	Spring	Juveniles
NC p135	1990-2015	Fall (11-2)	Juveniles
SC Edisto	2004-2015	1-12	Juveniles & Adults
USFWS Coop	1988-2010	1-2	Juveniles & Adults

Table 10. Index values for fishery-independent surveys and associated standard errors.

Year	ME-NH Trawl		CT LIST		CT LIST (spring only)		CT LIST (fall only)		NYDEC JASAMP	
	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)
1984			0.0458	0.0213	0.0938	0.0690	0.0303	0.0173		
1985			0.0120	0.0085	0.0000	0.0000	0.0167	0.0117		
1986			0.0279	0.0130	0.0000	0.0000	0.0448	0.0208		
1987			0.0200	0.0099	0.0083	0.0083	0.0250	0.0143		
1988			0.0150	0.0112	0.0167	0.0167	0.0083	0.0083		
1989			0.0550	0.0226	0.0083	0.0083	0.0833	0.0366		
1990			0.0439	0.0271	0.0077	0.0077	0.0696	0.0474		
1991			0.0188	0.0108	0.0167	0.0117	0.0125	0.0125		
1992			0.1875	0.1090	0.1000	0.1000	0.2750	0.1940		
1993			0.3000	0.2362	0.0250	0.0143	0.4750	0.3932		
1994			0.3000	0.2324	0.0583	0.0432	0.4417	0.3851		
1995			0.0375	0.0233	0.0250	0.0250	0.0375	0.0278		
1996			0.0163	0.0121	0.0167	0.0167	0.0125	0.0125		
1997			0.0313	0.0164	0.0167	0.0117	0.0375	0.0278		
1998			0.1006	0.0548	0.1167	0.0731	0.0375	0.0375		
1999			0.2438	0.1617	0.2250	0.2085	0.1500	0.0855		
2000	0.0375	0.0463	0.0438	0.0205	0.0333	0.0235	0.0375	0.0214		
2001	0.0666	0.0654	0.1154	0.0568	0.0259	0.0259	0.1875	0.1039		
2002	0.0452	0.0392	0.1125	0.0396	0.0833	0.0366	0.1000	0.0579		
2003	0.0364	0.0370	0.1871	0.1435	0.0000	0.0000	0.3867	0.2959		
2004	0.0061	0.0086	0.0503	0.0444	0.0000	0.0000	0.1000	0.0882		
2005	0.0074	0.0107	0.0545	0.0325	0.0500	0.0424	0.0375	0.0214		
2006	0.0329	0.0310	0.1742	0.0896	0.1000	0.0579	0.3225	0.2429	0.61	0.15
2007	0.0073	0.0102	0.1085	0.0588	0.0408	0.0267	0.1625	0.1145	0.67	0.19
2008	0.0243	0.0265	0.0565	0.0330	0.0167	0.0167	0.1250	0.0891	0.70	0.15
2009	0.0278	0.0273	0.1125	0.0494	0.0083	0.0083	0.2125	0.0969	2.15	0.37
2010	0.0112	0.0133	0.0368	0.0368	0.0179	0.0179			2.02	0.33
2011	0.0096	0.0121	0.0313	0.0164	0.0326	0.0242	0.0250	0.0176	2.75	0.57
2012	0.0240	0.0271	0.0438	0.0185	0.0333	0.0165	0.0375	0.0278	3.29	0.62
2013	0.0072	0.0102	0.0250	0.0152	0.0250	0.0186	0.0125	0.0125	1.44	0.32
2014	0.0295	0.0299	0.0760	0.0653	0.0000	0.0000	0.1646	0.1412	5.35	1.07
2015	0.0503	0.0475							5.64	0.79

Table 10 *continued*.

Year	NJ Ocean Trawl		VIMS Shad		NEAMAP		NEAMAP (spring only)		NEAMAP (fall only)	
	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)
1984										
1985										
1986										
1987										
1988										
1989										
1990	1.8658	0.8904								
1991	1.0721	0.5180								
1992	0.9730	0.4775								
1993	0.3850	0.2522								
1994	0.0000	0.0000								
1995	0.1628	0.1257								
1996	0.2605	0.1822								
1997	0.5043	0.2893								
1998	0.0725	0.0785	1.4772	0.3995						
1999	0.9752	0.4851	0.9316	0.4007						
2000	0.0752	0.0785	1.1127	0.6786						
2001	0.3680	0.2287	0.1390	0.1164						
2002	0.3986	0.2316	0.0588	0.0425						
2003	1.3698	0.6576	0.1515	0.0736						
2004	1.0986	0.5530	0.1317	0.0982						
2005	1.8252	0.8496	1.1565	0.3541						
2006	1.5350	0.7161	1.7627	0.3469						
2007	1.5662	0.7278	1.4030	0.3529	0.0115	0.0090			0.0332	0.0250
2008	1.3874	0.6605	0.4405	0.1951	0.0647	0.0170	0.0640	0.0240	0.0858	0.0296
2009	0.7775	0.4098	0.1774	0.0811	0.0755	0.0204	0.0506	0.0201	0.0681	0.0288
2010	0.9820	0.4996	0.1779	0.0623	0.1358	0.0558	0.0926	0.0303	0.1228	0.0737
2011	0.2641	0.1820	0.3497	0.1548	0.0827	0.0309	0.1328	0.0711	0.0536	0.0213
2012	0.1594	0.1271	0.1573	0.0840	0.0686	0.0281	0.0615	0.0418	0.0818	0.0342
2013	1.0456	0.5253	0.5419	0.1688	0.0488	0.0155	0.0638	0.0248	0.0231	0.0123
2014	0.6278	0.3549	0.9026	0.2012	0.1335	0.0817	0.0567	0.0265	0.3075	0.2750
2015	1.9230	0.8934	1.2113	0.5407	0.0470	0.0159	0.0511	0.0241	0.0276	0.0155

Table 10 *continued*.

Year	NC p135 (spring)		NC p135 (fall)		SC Edisto		USFWS Coop	
	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)	Index	SE (Index)
1984								
1985								
1986								
1987								
1988							0.0433	0.0134
1989							0.0088	0.0064
1990			0.0329	0.0063			0.0251	0.0135
1991	0.0022	0.0011	0.0083	0.0022			0.0075	0.0046
1992	0.0046	0.0015	0.0022	0.0011			0.0625	0.0308
1993	0.0010	0.0007	0.0064	0.0020			0.0000	0.0000
1994	0.0085	0.0023	0.0127	0.0028			0.0278	0.0140
1995	0.0026	0.0012	0.0101	0.0026			0.0000	0.0000
1996	0.0044	0.0017	0.0082	0.0022			0.0597	0.0198
1997	0.0104	0.0032	0.0372	0.0056			0.0289	0.0146
1998	0.0130	0.0029	0.0165	0.0031			0.0127	0.0135
1999	0.0054	0.0016	0.0173	0.0033			0.0136	0.0100
2000	0.0234	0.0051	0.0713	0.0093			0.0488	0.0203
2001	0.0253	0.0042	0.0162	0.0033			0.0319	0.0170
2002	0.0069	0.0022	0.0070	0.0021			0.1050	0.0278
2003	0.0028	0.0011	0.0026	0.0015			0.0265	0.0108
2004	0.0005	0.0005	0.0212	0.0038	3.0755	0.5431	0.0031	0.0031
2005	0.0027	0.0012	0.0232	0.0040	2.0760	0.4904	0.0103	0.0106
2006	0.0082	0.0023	0.0130	0.0029	4.8621	0.7685	0.0823	0.0204
2007	0.0064	0.0024	0.0439	0.0062	0.8852	0.2559	0.0746	0.0245
2008	0.0347	0.0050	0.0157	0.0034	1.7584	0.3796	0.1898	0.0352
2009	0.0180	0.0040	0.0114	0.0026	3.3101	0.6104	0.0752	0.0195
2010	0.0091	0.0026	0.0095	0.0026	0.8877	0.2170	0.0082	0.0083
2011	0.0067	0.0024	0.0256	0.0042	3.3358	0.8870		
2012	0.0175	0.0043	0.0360	0.0059	3.2343	0.5757		
2013	0.0683	0.0089	0.0155	0.0034	3.3711	0.6317		
2014	0.0292	0.0050	0.0206	0.0041	2.5827	0.4271		
2015	0.0215	0.0036	0.0162	0.0031	1.8458	0.4060		

Table 11. Summary of Atlantic sturgeon included in the genetic baseline for calculations of effective population size for 11 rivers and one sound. Sturgeon incorporated into the baseline were either river-resident juveniles (<500 mm TL; RRJ) or adults (≥1,500 mm TL). Effective population size estimates were calculated with NeEstimator and are provided with 95% confidence intervals.

DPS	River	Years	Size Class	Samples	Effective Population Size (N_e)
Gulf of Maine	St. Lawrence	2013	Adult	30	39.0 (24.6-76.1)
Gulf of Maine	St. John	1991-1993	Adult	31	115.0 (51.3-Infinite)
Gulf of Maine	Kennebec	1980-2011	Adult	52	63.4 (47.3-91.1)
New York Bight	Hudson	1996-2015	RRJ and Adult	337	144.2 (82.9-286.6)
New York Bight	Delaware	2009-2015	RRJ and Adult	181	56.7 (42.5-77.0)
Chesapeake	York	2013-2015	Adult	136	7.8 (5.3-10.2)
Chesapeake	James	1998-2015	RRJ and Adult	346	40.9 (35.6-46.9)
Carolina	Albemarle	1998-2008	RRJ and Adult	37	14.2 (11.8-17.1)
South Atlantic	Edisto	1996-2005	RRJ	109	55.4 (36.8-90.6)
South Atlantic	Savannah	2000-2013	RRJ	98	126.5 (88.1-205.0)
South Atlantic	Ogeechee	2003-2015	RRJ	115	32.2 (26.9-38.8)
South Atlantic	Altamaha	2005-2015	RRJ and Adult	186	111.9 (67.5-216.3)

Table 12. Hudson River genetics collections used to evaluate changes in effective population size over time. Effective population size estimates were calculated with NeEstimator and are provided with 95% confidence intervals. Sturgeon incorporated into the baseline were either river-resident juveniles (<500 mm TL; RRJ) or adults (≥1,500 mm TL).

Year	Size Class	Samples	Effective Population Size (N_e)
1996	Adult	28	479.1 (86.9-Infinite)
1997	Adult	25	358.5 (89.1-Infinite)
2006	Adult	31	148.4 (60.2-Infinite)
2008	Adult	20	195.2 (52.4-Infinite)
2008	RRJ	23	93.1 (43.5-124139.6)
2009	Adult	40	75.3 (47.3-154.7)
2010	Adult	48	135.1 (82.7-313.2)
2014	RRJ	38	74.2 (46.4-155.3)
2015	Adult	53	179.8 (85.1-4683.5)
2015	RRJ	31	143.8 (70.3-2064.3)

Table 13. Species that represented 95% of the total landings on otter trawl trips that encountered Atlantic sturgeon. Data source: NEFOP/ASM

Common name	Scientific name	Cumulative proportion
Atlantic Croaker	*Micropogonias undulatus*	0.49
Summer Flounder	*Paralichthys dentatus*	0.59
Atlantic Long-Fin Squid	*Loligo paelei*	0.68
Skate, Unclassified	*Rajidae*	0.75
Little Skate	*Raja eriancea*	0.8
Horseshoe Crab	*Limulus polyphemus*	0.82
Spiny Dogfish	*Squalus acanthias*	0.84
Atlantic Cod	*Gadus morhua*	0.86
Winter Skate	*Raja ocellata*	0.88
Scup	*Stenotomus chrysops*	0.89
Yellowtail Flounder	*Pleuronectes ferrugineus*	0.9
Butterfish	*Peprilus triacanthus*	0.92
Striped Bass	*Morone saxatilis*	0.93
Winter Flounder	*Pleuronectes americanus*	0.94
Clearnose Skate	*Raja eglanteria*	0.95

Table 14. Species that represented 95% of the total landings on sink and drift gillnet trips that encountered Atlantic sturgeon. Data source: NEFOP/ASM

Common name	Scientific name	Cumulative proportion
Monkfish	*Lophius americanus*	0.33
Winter Skate	*Raja ocellata*	0.57
Spiny Dogfish	*Squalus acanthias*	0.76
Smooth Dogfish	*Mustelus canis*	0.83
Atlantic Cod	*Gadus morhua*	0.87
Bluefish	*Pomatomus saltatrix*	0.9
Striped Bass	*Morone saxatilis*	0.92
Skate, Unclassified	*Rajidae*	0.93
Pollock	*Pollachius virens*	0.94
Atlantic Croaker	*Micropogonias undulatus*	0.95

Table 15. QAICc values for each successfully converged candidate model fitted to trip-specific observer otter trawl data from 2000-2015. Data source: NEFOP/ASM

Model	QAICc
1	1760.19
2	1748.92
3	1736.75
4	1738.29
5	1378.03
6	1322.82
7	1528.15
8	1490.34
9	1541.93

Table 16. Estimated parameters for model 6 fitted to trip-specific observer otter trawl data from 2000-2015. Data source: NEFOP/ASM

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-5.063	1.069	-4.735	0.000
but.bTRUE	-0.517	0.598	-0.865	0.387
cl.sk.bTRUE	-15.689	7882.510	-0.002	0.998
cod.bTRUE	-0.774	0.997	-0.776	0.438
croak.bTRUE	3.684	0.621	5.935	0.000
fluke.bTRUE	1.085	0.622	1.743	0.081
hshoe.bTRUE	3.245	1.158	2.803	0.005
lit.sk.bTRUE	1.505	1.585	0.950	0.342
loligo.bTRUE	-0.303	0.553	-0.548	0.584
other.bTRUE	0.751	0.951	0.789	0.430
sbass.bTRUE	-0.400	1.042	-0.384	0.701
scup.bTRUE	-2.149	2.026	-1.061	0.289
sp.dog.bTRUE	0.770	1.507	0.511	0.609
unk.sk.bTRUE	-0.930	2.048	-0.454	0.650
wint.fl.bTRUE	0.201	0.903	0.222	0.824
wint.sk.bTRUE	-2.064	1.364	-1.513	0.130
yt.fl.bTRUE	-0.180	1.160	-0.155	0.877
factor(QTR)2	0.978	1.242	0.788	0.431
factor(QTR)3	-0.782	2.278	-0.343	0.731
factor(QTR)4	1.169	1.273	0.918	0.358
but.bTRUE:factor(QTR)2	0.176	0.736	0.239	0.811
but.bTRUE:factor(QTR)3	0.528	0.756	0.699	0.485
but.bTRUE:factor(QTR)4	1.439	0.719	2.002	0.045
cl.sk.bTRUE:factor(QTR)2	15.087	7882.510	0.002	0.998
cl.sk.bTRUE:factor(QTR)3	17.771	7882.510	0.002	0.998
cl.sk.bTRUE:factor(QTR)4	15.403	7882.510	0.002	0.998
cod.bTRUE:factor(QTR)2	-1.427	1.368	-1.043	0.297
cod.bTRUE:factor(QTR)3	-10.872	572.950	-0.019	0.985
cod.bTRUE:factor(QTR)4	0.347	1.174	0.295	0.768
croak.bTRUE:factor(QTR)2	0.217	0.777	0.279	0.780
croak.bTRUE:factor(QTR)3	-1.164	0.734	-1.586	0.113
croak.bTRUE:factor(QTR)4	-2.001	0.762	-2.625	0.009
fluke.bTRUE:factor(QTR)2	0.209	0.817	0.256	0.798
fluke.bTRUE:factor(QTR)3	2.648	2.106	1.258	0.209
fluke.bTRUE:factor(QTR)4	0.445	0.799	0.557	0.578
hshoe.bTRUE:factor(QTR)2	-3.845	1.550	-2.481	0.013
hshoe.bTRUE:factor(QTR)3	-5.491	1.448	-3.791	0.000
hshoe.bTRUE:factor(QTR)4	-2.886	1.357	-2.126	0.033
lit.sk.bTRUE:factor(QTR)2	-0.884	1.633	-0.542	0.588
lit.sk.bTRUE:factor(QTR)3	-0.911	1.646	-0.553	0.580
lit.sk.bTRUE:factor(QTR)4	-1.927	1.722	-1.119	0.263
loligo.bTRUE:factor(QTR)2	-0.043	0.659	-0.065	0.948
loligo.bTRUE:factor(QTR)3	-0.463	0.698	-0.664	0.507
loligo.bTRUE:factor(QTR)4	-0.593	0.673	-0.880	0.379
other.bTRUE:factor(QTR)2	-0.404	1.057	-0.382	0.702
other.bTRUE:factor(QTR)3	-1.873	1.024	-1.830	0.067
other.bTRUE:factor(QTR)4	-1.064	1.112	-0.957	0.338
sbass.bTRUE:factor(QTR)2	0.132	1.341	0.098	0.922
sbass.bTRUE:factor(QTR)3	0.330	1.583	0.209	0.835

Table 16. *Continued*

	Estimate	Std. Error	t value	Pr(>|t|)
sbass.bTRUE:factor(QTR)4	0.542	1.226	0.442	0.659
scup.bTRUE:factor(QTR)2	2.281	2.056	1.110	0.267
scup.bTRUE:factor(QTR)3	2.256	2.075	1.087	0.277
scup.bTRUE:factor(QTR)4	1.190	2.076	0.573	0.567
sp.dog.bTRUE:factor(QTR)2	-2.512	1.768	-1.421	0.155
sp.dog.bTRUE:factor(QTR)3	-1.700	2.524	-0.674	0.501
sp.dog.bTRUE:factor(QTR)4	-0.038	1.584	-0.024	0.981
unk.sk.bTRUE:factor(QTR)2	1.770	2.091	0.846	0.397
unk.sk.bTRUE:factor(QTR)3	-1.448	2.878	-0.503	0.615
unk.sk.bTRUE:factor(QTR)4	1.907	2.107	0.905	0.366
wint.fl.bTRUE:factor(QTR)2	-0.741	0.980	-0.756	0.450
wint.fl.bTRUE:factor(QTR)3	-0.242	1.496	-0.162	0.871
wint.fl.bTRUE:factor(QTR)4	0.536	1.021	0.525	0.600
wint.sk.bTRUE:factor(QTR)2	2.858	1.402	2.039	0.041
wint.sk.bTRUE:factor(QTR)3	-0.481	1.812	-0.266	0.791
wint.sk.bTRUE:factor(QTR)4	2.338	1.433	1.631	0.103
yt.fl.bTRUE:factor(QTR)2	-0.474	1.353	-0.351	0.726
yt.fl.bTRUE:factor(QTR)3	-12.200	592.393	-0.021	0.984
yt.fl.bTRUE:factor(QTR)4	-1.384	1.348	-1.027	0.305

Table 17. QAICc values for each successfully converged candidate model fitted to trip-specific observer sink and drift gillnet data from 2000-2015. Data source: NEFOP/ASM

Model	QAICc
1	6042.44
2	5665.83
3	5884.50
4	5450.15
5	5260.49
6	4939.70
7	4944.05
8	4666.11
9	4639.77

Table 18. Estimated parameters for model 9 fitted to trip-specific observer gillnet data from 2000-2015. Data source: NEFOP/ASM

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-2.495	0.438	-5.701	0.000
blue.bTRUE	-1.082	0.619	-1.749	0.080
cod.bTRUE	-0.808	0.544	-1.484	0.138
croak.bTRUE	0.170	0.468	0.364	0.716
monk.bTRUE	0.772	0.408	1.894	0.058
other.bTRUE	-0.122	0.335	-0.363	0.716
pol.bTRUE	0.148	0.720	0.206	0.837
sbass.bTRUE	1.468	0.366	4.009	0.000
sm.dog.bTRUE	1.123	0.385	2.915	0.004
sp.dog.bTRUE	1.298	0.360	3.602	0.000
unk.sk.bTRUE	1.076	0.731	1.472	0.141
wint.sk.bTRUE	-1.786	0.572	-3.125	0.002
factor(QTR)2	-0.764	0.522	-1.463	0.143
factor(QTR)3	-3.099	1.022	-3.032	0.002
factor(QTR)4	-0.245	0.506	-0.484	0.628
factor(YEAR)2001	-0.757	0.699	-1.084	0.279
factor(YEAR)2002	-2.214	1.049	-2.110	0.035
factor(YEAR)2003	0.667	0.619	1.077	0.281
factor(YEAR)2004	-0.546	0.595	-0.918	0.359
factor(YEAR)2005	-1.018	0.725	-1.404	0.160
factor(YEAR)2006	0.687	0.584	1.177	0.239
factor(YEAR)2007	-0.053	0.569	-0.094	0.925
factor(YEAR)2008	-0.524	0.698	-0.751	0.453
factor(YEAR)2009	-0.433	0.698	-0.620	0.535
factor(YEAR)2010	-0.645	0.767	-0.841	0.401
factor(YEAR)2011	-1.309	0.661	-1.982	0.048
factor(YEAR)2012	-0.141	0.649	-0.217	0.828
factor(YEAR)2013	-0.254	0.753	-0.337	0.736
factor(YEAR)2014	-0.306	0.614	-0.498	0.618
factor(YEAR)2015	-1.524	0.814	-1.871	0.061
blue.bTRUE:factor(QTR)2	1.359	0.527	2.580	0.010
blue.bTRUE:factor(QTR)3	1.045	0.632	1.653	0.098
blue.bTRUE:factor(QTR)4	1.182	0.542	2.180	0.029
blue.bTRUE:factor(YEAR)2001	0.257	0.607	0.423	0.672
blue.bTRUE:factor(YEAR)2002	-0.311	0.753	-0.413	0.680
blue.bTRUE:factor(YEAR)2003	-1.140	0.696	-1.640	0.101
blue.bTRUE:factor(YEAR)2004	-0.196	0.502	-0.390	0.696
blue.bTRUE:factor(YEAR)2005	0.537	0.574	0.936	0.349
blue.bTRUE:factor(YEAR)2006	0.229	0.548	0.418	0.676
blue.bTRUE:factor(YEAR)2007	0.531	0.565	0.940	0.347
blue.bTRUE:factor(YEAR)2008	0.149	0.720	0.207	0.836
blue.bTRUE:factor(YEAR)2009	-1.634	0.824	-1.983	0.047
blue.bTRUE:factor(YEAR)2010	-0.451	0.755	-0.597	0.550
blue.bTRUE:factor(YEAR)2011	-1.133	0.885	-1.280	0.201
blue.bTRUE:factor(YEAR)2012	0.183	0.842	0.218	0.828
blue.bTRUE:factor(YEAR)2013	0.137	0.579	0.236	0.813
blue.bTRUE:factor(YEAR)2014	0.012	0.629	0.020	0.984
blue.bTRUE:factor(YEAR)2015	-0.300	0.496	-0.605	0.545

Table 18 continued.

	Estimate	Std. Error	t value	Pr(>|t|)
cod.bTRUE:factor(QTR)2	-0.257	0.361	-0.711	0.477
cod.bTRUE:factor(QTR)3	0.931	0.638	1.460	0.144
cod.bTRUE:factor(QTR)4	-0.723	0.367	-1.968	0.049
cod.bTRUE:factor(YEAR)2001	0.221	0.784	0.282	0.778
cod.bTRUE:factor(YEAR)2002	0.663	0.800	0.829	0.407
cod.bTRUE:factor(YEAR)2003	0.018	0.727	0.025	0.980
cod.bTRUE:factor(YEAR)2004	0.737	0.587	1.255	0.209
cod.bTRUE:factor(YEAR)2005	0.709	0.725	0.978	0.328
cod.bTRUE:factor(YEAR)2006	-0.935	1.029	-0.909	0.364
cod.bTRUE:factor(YEAR)2007	-1.320	0.836	-1.579	0.114
cod.bTRUE:factor(YEAR)2008	0.072	1.122	0.064	0.949
cod.bTRUE:factor(YEAR)2009	-0.544	0.917	-0.594	0.553
cod.bTRUE:factor(YEAR)2010	0.535	0.737	0.726	0.468
cod.bTRUE:factor(YEAR)2011	1.856	0.696	2.669	0.008
cod.bTRUE:factor(YEAR)2012	1.010	0.676	1.494	0.135
cod.bTRUE:factor(YEAR)2013	1.832	0.787	2.329	0.020
cod.bTRUE:factor(YEAR)2014	2.080	0.662	3.140	0.002
cod.bTRUE:factor(YEAR)2015	-0.557	0.905	-0.615	0.538
croak.bTRUE:factor(QTR)2	0.490	0.451	1.088	0.276
croak.bTRUE:factor(QTR)3	0.944	0.639	1.478	0.139
croak.bTRUE:factor(QTR)4	0.322	0.478	0.674	0.500
croak.bTRUE:factor(YEAR)2001	-0.141	0.660	-0.214	0.830
croak.bTRUE:factor(YEAR)2002	-0.375	0.872	-0.430	0.668
croak.bTRUE:factor(YEAR)2003	-3.029	1.397	-2.168	0.030
croak.bTRUE:factor(YEAR)2004	-0.666	0.631	-1.056	0.291
croak.bTRUE:factor(YEAR)2005	0.561	0.713	0.786	0.432
croak.bTRUE:factor(YEAR)2006	-1.927	0.657	-2.934	0.003
croak.bTRUE:factor(YEAR)2007	-0.326	0.585	-0.557	0.577
croak.bTRUE:factor(YEAR)2008	-0.082	0.771	-0.107	0.915
croak.bTRUE:factor(YEAR)2009	-2.452	1.422	-1.725	0.085
croak.bTRUE:factor(YEAR)2010	-0.782	1.420	-0.551	0.582
croak.bTRUE:factor(YEAR)2011	-13.867	1074.959	-0.013	0.990
croak.bTRUE:factor(YEAR)2012	-14.993	1122.827	-0.013	0.989
croak.bTRUE:factor(YEAR)2013	-1.617	1.407	-1.150	0.250
croak.bTRUE:factor(YEAR)2014	-15.445	811.831	-0.019	0.985
croak.bTRUE:factor(YEAR)2015	-1.787	0.749	-2.386	0.017
monk.bTRUE:factor(QTR)2	-0.163	0.272	-0.599	0.549
monk.bTRUE:factor(QTR)3	-1.077	0.585	-1.842	0.065
monk.bTRUE:factor(QTR)4	0.445	0.332	1.341	0.180
monk.bTRUE:factor(YEAR)2001	0.817	0.596	1.370	0.171
monk.bTRUE:factor(YEAR)2002	1.472	0.786	1.873	0.061
monk.bTRUE:factor(YEAR)2003	-1.075	0.597	-1.801	0.072
monk.bTRUE:factor(YEAR)2004	-0.274	0.546	-0.502	0.616
monk.bTRUE:factor(YEAR)2005	0.992	0.692	1.433	0.152
monk.bTRUE:factor(YEAR)2006	0.149	0.506	0.295	0.768
monk.bTRUE:factor(YEAR)2007	1.750	0.554	3.162	0.002
monk.bTRUE:factor(YEAR)2008	0.694	0.713	0.974	0.330
monk.bTRUE:factor(YEAR)2009	0.163	0.665	0.245	0.806
monk.bTRUE:factor(YEAR)2010	-0.105	0.702	-0.149	0.881
monk.bTRUE:factor(YEAR)2011	-0.726	0.589	-1.232	0.218

Table 18 continued.

	Estimate	Std. Error	t value	Pr(>|t|)
monk.bTRUE:factor(YEAR)2012	-0.371	0.600	-0.619	0.536
monk.bTRUE:factor(YEAR)2013	-0.376	0.674	-0.558	0.577
monk.bTRUE:factor(YEAR)2014	-1.658	0.595	-2.786	0.005
monk.bTRUE:factor(YEAR)2015	-1.230	0.524	-2.345	0.019
other.bTRUE:factor(QTR)2	-0.264	0.237	-1.113	0.266
other.bTRUE:factor(QTR)3	0.622	0.611	1.017	0.309
other.bTRUE:factor(QTR)4	-0.361	0.256	-1.413	0.158
other.bTRUE:factor(YEAR)2001	0.186	0.491	0.379	0.705
other.bTRUE:factor(YEAR)2002	0.412	0.612	0.674	0.500
other.bTRUE:factor(YEAR)2003	0.575	0.522	1.101	0.271
other.bTRUE:factor(YEAR)2004	0.558	0.416	1.341	0.180
other.bTRUE:factor(YEAR)2005	-0.111	0.476	-0.234	0.815
other.bTRUE:factor(YEAR)2006	1.104	0.455	2.424	0.015
other.bTRUE:factor(YEAR)2007	0.301	0.433	0.696	0.487
other.bTRUE:factor(YEAR)2008	0.490	0.557	0.880	0.379
other.bTRUE:factor(YEAR)2009	0.817	0.422	1.934	0.053
other.bTRUE:factor(YEAR)2010	-0.115	0.478	-0.240	0.810
other.bTRUE:factor(YEAR)2011	-0.098	0.541	-0.180	0.857
other.bTRUE:factor(YEAR)2012	-0.309	0.524	-0.589	0.556
other.bTRUE:factor(YEAR)2013	-0.982	0.497	-1.975	0.048
other.bTRUE:factor(YEAR)2014	0.009	0.494	0.018	0.986
other.bTRUE:factor(YEAR)2015	1.527	0.440	3.473	0.001
pol.bTRUE:factor(QTR)2	-0.518	0.508	-1.019	0.308
pol.bTRUE:factor(QTR)3	-0.559	0.661	-0.846	0.397
pol.bTRUE:factor(QTR)4	-0.319	0.474	-0.672	0.501
pol.bTRUE:factor(YEAR)2001	-0.502	1.139	-0.440	0.660
pol.bTRUE:factor(YEAR)2002	-1.163	1.028	-1.131	0.258
pol.bTRUE:factor(YEAR)2003	0.611	0.954	0.641	0.522
pol.bTRUE:factor(YEAR)2004	-1.748	0.965	-1.812	0.070
pol.bTRUE:factor(YEAR)2005	-0.938	1.017	-0.923	0.356
pol.bTRUE:factor(YEAR)2006	-0.901	1.266	-0.711	0.477
pol.bTRUE:factor(YEAR)2007	0.075	1.039	0.072	0.943
pol.bTRUE:factor(YEAR)2008	-0.087	1.329	-0.066	0.948
pol.bTRUE:factor(YEAR)2009	-1.530	1.633	-0.937	0.349
pol.bTRUE:factor(YEAR)2010	0.006	0.916	0.007	0.995
pol.bTRUE:factor(YEAR)2011	0.260	0.783	0.332	0.740
pol.bTRUE:factor(YEAR)2012	-0.662	0.914	-0.724	0.469
pol.bTRUE:factor(YEAR)2013	-0.901	1.121	-0.804	0.421
pol.bTRUE:factor(YEAR)2014	-1.272	0.914	-1.392	0.164
pol.bTRUE:factor(YEAR)2015	-0.902	1.170	-0.771	0.441
sbass.bTRUE:factor(QTR)2	-0.068	0.460	-0.148	0.882
sbass.bTRUE:factor(QTR)3	0.940	0.675	1.393	0.164
sbass.bTRUE:factor(QTR)4	0.422	0.387	1.089	0.276
sbass.bTRUE:factor(YEAR)2001	0.868	0.597	1.454	0.146
sbass.bTRUE:factor(YEAR)2002	0.508	0.756	0.671	0.502
sbass.bTRUE:factor(YEAR)2003	0.229	0.573	0.400	0.689
sbass.bTRUE:factor(YEAR)2004	-0.712	0.605	-1.176	0.240
sbass.bTRUE:factor(YEAR)2005	-0.506	0.784	-0.646	0.518
sbass.bTRUE:factor(YEAR)2006	-0.961	0.732	-1.314	0.189
sbass.bTRUE:factor(YEAR)2007	0.704	0.550	1.280	0.200

Table 18 continued.

	Estimate	Std. Error	t value	Pr(>|t|)
sbass.bTRUE:factor(YEAR)2008	0.071	0.698	0.102	0.919
sbass.bTRUE:factor(YEAR)2009	1.193	0.702	1.699	0.089
sbass.bTRUE:factor(YEAR)2010	-2.041	1.416	-1.441	0.149
sbass.bTRUE:factor(YEAR)2011	-15.528	1239.222	-0.013	0.990
sbass.bTRUE:factor(YEAR)2012	-16.179	1523.573	-0.011	0.992
sbass.bTRUE:factor(YEAR)2013	-18.302	2002.092	-0.009	0.993
sbass.bTRUE:factor(YEAR)2014	-17.858	3207.901	-0.006	0.996
sbass.bTRUE:factor(YEAR)2015	-2.486	1.375	-1.808	0.071
sm.dog.bTRUE:factor(QTR)2	1.145	0.390	2.936	0.003
sm.dog.bTRUE:factor(QTR)3	2.046	0.573	3.570	0.000
sm.dog.bTRUE:factor(QTR)4	-0.112	0.468	-0.239	0.811
sm.dog.bTRUE:factor(YEAR)2001	-1.857	0.654	-2.840	0.005
sm.dog.bTRUE:factor(YEAR)2002	-1.179	0.832	-1.418	0.156
sm.dog.bTRUE:factor(YEAR)2003	-0.847	0.670	-1.264	0.206
sm.dog.bTRUE:factor(YEAR)2004	-1.430	0.708	-2.019	0.044
sm.dog.bTRUE:factor(YEAR)2005	-2.501	1.048	-2.386	0.017
sm.dog.bTRUE:factor(YEAR)2006	-0.836	0.508	-1.645	0.100
sm.dog.bTRUE:factor(YEAR)2007	-1.867	0.552	-3.382	0.001
sm.dog.bTRUE:factor(YEAR)2008	0.053	0.854	0.062	0.951
sm.dog.bTRUE:factor(YEAR)2009	-1.374	0.592	-2.321	0.020
sm.dog.bTRUE:factor(YEAR)2010	0.061	0.719	0.085	0.932
sm.dog.bTRUE:factor(YEAR)2011	-0.644	1.081	-0.596	0.551
sm.dog.bTRUE:factor(YEAR)2012	-0.919	0.669	-1.375	0.169
sm.dog.bTRUE:factor(YEAR)2013	0.817	0.525	1.555	0.120
sm.dog.bTRUE:factor(YEAR)2014	-0.815	0.660	-1.236	0.217
sm.dog.bTRUE:factor(YEAR)2015	-0.621	0.450	-1.381	0.167
sp.dog.bTRUE:factor(QTR)2	-0.438	0.357	-1.224	0.221
sp.dog.bTRUE:factor(QTR)3	0.414	0.550	0.753	0.452
sp.dog.bTRUE:factor(QTR)4	0.721	0.369	1.957	0.050
sp.dog.bTRUE:factor(YEAR)2001	-1.382	0.883	-1.564	0.118
sp.dog.bTRUE:factor(YEAR)2002	-0.995	0.758	-1.312	0.190
sp.dog.bTRUE:factor(YEAR)2003	-1.923	1.101	-1.746	0.081
sp.dog.bTRUE:factor(YEAR)2004	-2.327	0.561	-4.148	0.000
sp.dog.bTRUE:factor(YEAR)2005	-2.330	0.662	-3.523	0.000
sp.dog.bTRUE:factor(YEAR)2006	-1.747	0.693	-2.520	0.012
sp.dog.bTRUE:factor(YEAR)2007	-0.706	0.487	-1.449	0.147
sp.dog.bTRUE:factor(YEAR)2008	-0.395	0.710	-0.556	0.578
sp.dog.bTRUE:factor(YEAR)2009	-4.387	1.468	-2.988	0.003
sp.dog.bTRUE:factor(YEAR)2010	-0.329	0.506	-0.649	0.516
sp.dog.bTRUE:factor(YEAR)2011	-0.774	0.559	-1.384	0.166
sp.dog.bTRUE:factor(YEAR)2012	-1.414	0.582	-2.430	0.015
sp.dog.bTRUE:factor(YEAR)2013	-1.872	0.502	-3.732	0.000
sp.dog.bTRUE:factor(YEAR)2014	-1.433	0.506	-2.835	0.005
sp.dog.bTRUE:factor(YEAR)2015	-0.546	0.472	-1.158	0.247
unk.sk.bTRUE:factor(QTR)2	-0.004	0.618	-0.007	0.995
unk.sk.bTRUE:factor(QTR)3	-0.019	1.143	-0.017	0.987
unk.sk.bTRUE:factor(QTR)4	-0.336	0.650	-0.518	0.605
unk.sk.bTRUE:factor(YEAR)2001	-0.984	1.460	-0.674	0.501
unk.sk.bTRUE:factor(YEAR)2002	0.541	1.025	0.528	0.598
unk.sk.bTRUE:factor(YEAR)2003	-16.305	1422.874	-0.011	0.991

Table 18 continued.

	Estimate	Std. Error	t value	Pr(>|t|)
unk.sk.bTRUE:factor(YEAR)2004	-0.426	0.736	-0.579	0.563
unk.sk.bTRUE:factor(YEAR)2005	-2.128	1.437	-1.481	0.138
unk.sk.bTRUE:factor(YEAR)2006	-1.546	0.775	-1.994	0.046
unk.sk.bTRUE:factor(YEAR)2007	-2.450	1.108	-2.211	0.027
unk.sk.bTRUE:factor(YEAR)2008	-0.983	1.492	-0.659	0.510
unk.sk.bTRUE:factor(YEAR)2009	-1.766	1.439	-1.227	0.220
unk.sk.bTRUE:factor(YEAR)2010	-15.471	1188.913	-0.013	0.990
unk.sk.bTRUE:factor(YEAR)2011	0.008	1.106	0.007	0.995
unk.sk.bTRUE:factor(YEAR)2012	-16.147	1517.068	-0.011	0.992
unk.sk.bTRUE:factor(YEAR)2013	0.131	0.878	0.149	0.882
unk.sk.bTRUE:factor(YEAR)2014	0.201	0.770	0.261	0.794
unk.sk.bTRUE:factor(YEAR)2015	-16.036	726.732	-0.022	0.982
wint.sk.bTRUE:factor(QTR)2	1.329	0.328	4.048	0.000
wint.sk.bTRUE:factor(QTR)3	1.241	0.543	2.287	0.022
wint.sk.bTRUE:factor(QTR)4	1.685	0.358	4.712	0.000
wint.sk.bTRUE:factor(YEAR)2001	0.921	0.651	1.415	0.157
wint.sk.bTRUE:factor(YEAR)2002	0.698	0.706	0.988	0.323
wint.sk.bTRUE:factor(YEAR)2003	0.576	0.737	0.781	0.435
wint.sk.bTRUE:factor(YEAR)2004	1.377	0.598	2.302	0.021
wint.sk.bTRUE:factor(YEAR)2005	0.674	0.661	1.020	0.308
wint.sk.bTRUE:factor(YEAR)2006	-0.926	0.696	-1.331	0.183
wint.sk.bTRUE:factor(YEAR)2007	-0.515	0.643	-0.802	0.423
wint.sk.bTRUE:factor(YEAR)2008	-0.032	0.827	-0.039	0.969
wint.sk.bTRUE:factor(YEAR)2009	1.777	0.705	2.520	0.012
wint.sk.bTRUE:factor(YEAR)2010	1.476	0.760	1.941	0.052
wint.sk.bTRUE:factor(YEAR)2011	2.386	0.663	3.597	0.000
wint.sk.bTRUE:factor(YEAR)2012	1.584	0.721	2.197	0.028
wint.sk.bTRUE:factor(YEAR)2013	1.815	0.748	2.425	0.015
wint.sk.bTRUE:factor(YEAR)2014	1.281	0.673	1.902	0.057
wint.sk.bTRUE:factor(YEAR)2015	0.546	0.596	0.916	0.359
factor(QTR)2:factor(YEAR)2001	0.657	0.649	1.013	0.311
factor(QTR)3:factor(YEAR)2001	-13.559	461.376	-0.029	0.977
factor(QTR)4:factor(YEAR)2001	-1.321	0.717	-1.843	0.065
factor(QTR)2:factor(YEAR)2002	1.518	0.883	1.720	0.085
factor(QTR)3:factor(YEAR)2002	1.863	1.344	1.386	0.166
factor(QTR)4:factor(YEAR)2002	0.665	0.829	0.803	0.422
factor(QTR)2:factor(YEAR)2003	1.046	0.718	1.458	0.145
factor(QTR)3:factor(YEAR)2003	-1.765	1.756	-1.005	0.315
factor(QTR)4:factor(YEAR)2003	-0.519	0.700	-0.741	0.459
factor(QTR)2:factor(YEAR)2004	1.214	0.621	1.956	0.051
factor(QTR)3:factor(YEAR)2004	1.613	1.042	1.549	0.121
factor(QTR)4:factor(YEAR)2004	0.586	0.605	0.969	0.333
factor(QTR)2:factor(YEAR)2005	0.744	0.722	1.030	0.303
factor(QTR)3:factor(YEAR)2005	0.790	1.143	0.692	0.489
factor(QTR)4:factor(YEAR)2005	0.074	0.665	0.112	0.911
factor(QTR)2:factor(YEAR)2006	0.157	0.561	0.279	0.780
factor(QTR)3:factor(YEAR)2006	-0.056	1.083	-0.052	0.959
factor(QTR)4:factor(YEAR)2006	-1.699	0.726	-2.339	0.019
factor(QTR)2:factor(YEAR)2007	-0.030	0.562	-0.053	0.958
factor(QTR)3:factor(YEAR)2007	0.457	1.015	0.450	0.653

Table 18 continued.

	Estimate	Std. Error	t value	Pr(>|t|)
factor(QTR)4:factor(YEAR)2007	-2.339	0.643	-3.636	0.000
factor(QTR)2:factor(YEAR)2008	-0.412	0.771	-0.534	0.593
factor(QTR)3:factor(YEAR)2008	-14.502	394.859	-0.037	0.971
factor(QTR)4:factor(YEAR)2008	-1.017	0.725	-1.402	0.161
factor(QTR)2:factor(YEAR)2009	1.456	0.626	2.325	0.020
factor(QTR)3:factor(YEAR)2009	2.951	1.192	2.476	0.013
factor(QTR)4:factor(YEAR)2009	-1.019	0.661	-1.542	0.123
factor(QTR)2:factor(YEAR)2010	-0.287	0.779	-0.369	0.712
factor(QTR)3:factor(YEAR)2010	-0.816	1.257	-0.649	0.516
factor(QTR)4:factor(YEAR)2010	-0.532	0.761	-0.699	0.485
factor(QTR)2:factor(YEAR)2011	0.069	0.744	0.093	0.926
factor(QTR)3:factor(YEAR)2011	-0.885	1.193	-0.742	0.458
factor(QTR)4:factor(YEAR)2011	-0.680	0.681	-0.999	0.318
factor(QTR)2:factor(YEAR)2012	0.252	0.664	0.380	0.704
factor(QTR)3:factor(YEAR)2012	-13.205	281.847	-0.047	0.963
factor(QTR)4:factor(YEAR)2012	-1.582	0.838	-1.889	0.059
factor(QTR)2:factor(YEAR)2013	0.383	0.771	0.497	0.620
factor(QTR)3:factor(YEAR)2013	0.732	1.137	0.644	0.520
factor(QTR)4:factor(YEAR)2013	0.078	0.768	0.101	0.919
factor(QTR)2:factor(YEAR)2014	0.954	0.676	1.410	0.159
factor(QTR)3:factor(YEAR)2014	0.107	1.228	0.087	0.930
factor(QTR)4:factor(YEAR)2014	0.092	0.704	0.131	0.896
factor(QTR)2:factor(YEAR)2015	2.176	0.819	2.657	0.008
factor(QTR)3:factor(YEAR)2015	-0.334	1.456	-0.229	0.818
factor(QTR)4:factor(YEAR)2015	1.105	0.836	1.321	0.187

Table 19. Annual Atlantic sturgeon bycatch estimates (number of fish) for bottom otter trawl gear based on application of the best performing model (model 6) to otter trawl vessel trip records. Data source: NEFOP/ASM

	Total bycatch estimate	Standard error	Proportion dead	Dead bycatch estimate
2000	1304	214	0	0
2001	1271	208	0	0
2002	1518	216	0	0
2003	1213	163	0	0
2004	1472	190	0	0
2005	1247	154	0.143	178
2006	1168	148	0.179	209
2007	1083	143	0.086	93
2008	910	160	0.161	147
2009	951	142	0.021	20
2010	968	147	0.009	9
2011	892	148	0	0
2012	760	120	0	0
2013	894	151	0	0
2014	717	105	0	0
2015	624	92	0	0

Table 20. Annual Atlantic sturgeon bycatch estimates (number of fish) for coastal ocean gillnet gear based on application of the best performing model (model 9) to gillnet vessel trip records. Data source: NEFOP/ASM

	Total bycatch estimate	Standard error	Proportion dead	Dead bycatch estimate
2000	2242	664	0.128	288
2001	869	458	0.298	259
2002	2715	1796	0.240	652
2003	1119	232	0.212	237
2004	1416	356	0.487	690
2005	690	227	0.306	211
2006	1580	315	0.124	196
2007	1406	332	0.200	281
2008	783	456	0.279	219
2009	1313	678	0.129	169
2010	289	83	0.507	147
2011	414	199	0.440	182
2012	253	67	0.435	110
2013	1746	666	0.375	655
2014	707	203	0.333	236
2015	685	100	0.277	190

Table 21. Estimated coefficients of predictors and their standard errors for the Poisson GLM fit to the NCDMF Atlantic sturgeon bycatch data.

Covariate	Coefficient	Standard Error
Intercept	-8.82791	0.16587
Year—2005	0.66101	0.19339
Year—2006	1.02861	0.18065
Year—2007	0.74343	0.21307
Year—2008	1.4937	0.17847
Year—2009	0.44644	0.2269
Year—2010	0.12413	0.24404
Year—2011	0.31298	0.23273
Year—2012	0.45897	0.19952
Year—2013	0.36929	0.18239
Year—2014	0.26706	0.18355
Year—2015	0.22751	0.17991
Season—Spring	-0.33727	0.09305
Season—Summer	-1.09516	0.17373
Season—Winter	-0.3263	0.09189
Mesh—Small	0.91453	0.07393
Unit—B	-3.01964	0.15197
Unit—C	-2.59923	0.2708
Unit—D	-2.93475	0.50286
Unit—E	-2.62835	0.41189

Table 22. Results of the model selection for the Poisson GLM fit to the NCDMF Atlantic sturgeon bycatch data.

Dropped Term	df	Deviance	AIC	LRT	Pr(>χ^2)
<none>		6,529.4	8,109.1		
Year	11	6,676	8,233.7	146.61	< 2.2e-16 ***
Season	3	6,583.5	8,157.2	54.04	1.099e-11 ***
Mesh	1	6,679.4	8,257.1	150.01	< 2.2e-16 ***
Unit	4	7,419.2	8,990.9	889.74	< 2.2e-16 ***

Table 23. Estimated numbers of Atlantic sturgeon bycatch from NCDMF Atlantic sturgeon bycatch data.

	Total Bycatch	%Dead	Number Dead
2004	2,937	12.0%	352
2005	5,004	7.1%	357
2006	7,291	5.1%	374
2007	5,730	6.1%*	347
2008	13,668	0.0%	0
2009	4,517	6.1%*	274
2010	1,895	6.1%*	115
2011	1,286	0.0%	0
2012	2,118	20.0%	424
2013	2,571	10.0%	257
2014	1,737	3.4%	60
2015	1,390	4.3%	60

*: For years where no Atlantic sturgeon were encountered in the commercial observer data, the percent observed dead over all years was used.

Table 24. Commercial shad fishery catch rates for Atlantic sturgeon within the Carolina DPS (Waccamaw River, Pee Dee River, Winyah Bay, and Santee River), 2000-2015.

Year	Number of Atlantic Sturgeon Caught	Effort (Net Yds/Hr)	CPUE (#ATS/NetYds/Hr)
2000	40	2,284,770	0.0000175
2001	128	3,339,789	0.0000383
2002	74	4,222,339	0.0000175
2003	16	3,881,793	0.0000041
2004	11	4,094,782	0.0000027
2005	0	3,963,111	0.0000000
2006	226	6,607,328	0.0000342
2007	162	2,562,688	0.0000632
2008	76	4,070,683	0.0000187
2009	186	5,110,128	0.0000364
2010	12	3,357,022	0.0000036
2011	173	5,818,003	0.0000297
2012	194	5,617,356	0.0000345
2013	157	3,457,182	0.0000454
2014	14	2,876,558	0.0000049
2015	10	3,207,376	0.0000031

Table 25. Commercial shad fishery catch rates for Atlantic sturgeon within the South Atlantic DPS (Edisto River, Combahee River, and Savannah River), 2000-2015.

Year	Number of Atlantic Sturgeon Caught	Effort (Net Yds/Hr)	CPUE (#ATS/NetYds/Hr)
2000	5	559,575	0.0000089
2001	20	493,149	0.0000406
2002	5	301,618	0.0000166
2003	3	425,421	0.0000071
2004	0	527,201	0.0000000
2005	1	367,849	0.0000027
2006	2	389,517	0.0000051
2007	6	384,197	0.0000156
2008	0	270,265	0.0000000
2009	3	276,875	0.0000108
2010	3	221,982	0.0000135
2011	8	240,967	0.0000332
2012	11	260,664	0.0000422
2013	1	214,095	0.0000047
2014	0	163,182	0.0000000
2015	0	148,910	0.0000000

Table 26. Results of the Mann-Kendall trend analysis. Trend indicates the direction of trend if a statistically significant temporal trend was detected. ns = not significant.

State	Survey	Subset	Available Years	Trend
na	USFWS Coop		1988-2010	ns
Maine/New Hampshire	ME-NH Trawl		2000-2015	ns
Connecticut	Long Island Sound		1992-2014	ns
Connecticut	Long Island Sound	fall	1992-2015	ns
Connecticut	Long Island Sound	spring	1992-2014	ns
New Jersey	Ocean Trawl		1990-2015	ns
Virginia	Trawl Survey		1998-2015	ns
Virginia	Trawl Survey	James River	1998-2015	ns
North Carolina	Program 135	spring	1991-2015	ns
North Carolina	Program 135	spring; YOY	1991-2015	ns
North Carolina	Program 135	spring; juveniles	1991-2015	↑
North Carolina	Program 135		1990-2015	ns
North Carolina	Program 135	fall; YOY	1990-2015	ns
North Carolina	Program 135	fall; juveniles	1990-2015	ns

Table 27. Results of the power analysis by survey for linear and exponential trends in Atlantic sturgeon abundance indices over a twenty-year period. Power were calculated as the probability of detecting a 50% change following the methods of Gerrodette (1987).

Survey	Years	Season	Life Stage	Median CV	Linear Trend		Exponential Trend	
					+50%	-50%	+50%	-50%
ME-NH Trawl	2000-2015	Year-round	Juvenile & Adult	1.108	0.13	0.17	0.16	0.23
CT LIST	1984-2014	Fall	Juvenile	0.709	0.21	0.28	0.23	0.34
CT LIST	1984-2014	Spring	Juvenile	0.796	0.18	0.24	0.20	0.30
CT LIST	1984-2014	Year-round	Juvenile	0.581	0.26	0.36	0.28	0.42
NYSDEC	2006-2015	Spring	Juvenile	0.204	0.89	0.98	0.89	0.98
NJ Ocean Trawl	1990-2015	Year-round	Juvenile & Adult	0.518	0.30	0.42	0.32	0.48
VIMS Shad Monitoring	1998-2015	Spring	Juvenile	0.443	0.37	0.52	0.39	0.57
NEAMAP	2007-2015	Fall	Adult	0.535	0.29	0.41	0.31	0.46
NEAMAP	2008-2015	Spring	Juvenile	0.432	0.38	0.54	0.40	0.58
NEAMAP	2008-2015	Year-round	Juvenile & Adult	0.374	0.47	0.64	0.48	0.68
USFW Coop	1988-2010	Winter	Juvenile & Adult	0.506	0.31	0.44	0.33	0.49
NC p135	1990-2015	Fall	YOY	0.211	0.87	0.97	0.87	0.98
NC p135	1991-2015	Spring	Juvenile	0.301	0.62	0.80	0.63	0.83
SC Edisto	2004-2015	Year-round	Juvenile & Adult	0.202	0.89	0.98	0.90	0.98

Table 28. Model selection results for different structures for the R matrix and for 1 to 4 trends in the data (m). The log likelihood (logLik), number of parameters (K), and AICc values are shown. The model with the lowest AICc has one trend and a diagonal (no covariance) and equal (same variances) R matrix. * = best model.

R	m	logLik	K	AICc
diagonal and equal*	1	-181.97	7	378.85
diagonal and equal	2	-181.57	12	389.76
diagonal and equal	3	-181.57	16	399.87
diagonal and equal	4	-183.21	19	411.21
diagonal and unequal	1	-180.46	12	387.55
diagonal and unequal	2	-177.87	17	395.10
diagonal and unequal	3	-177.58	21	405.55
diagonal and unequal	4	-177.62	24	414.46
equalvarcov	1	-181.56	8	380.30
equalvarcov	2	-181.53	13	392.15
equalvarcov	3	-182.00	17	403.37
equalvarcov	4	-182.25	20	412.08
unconstrained	1	-173.54	27	415.62
unconstrained	2	-170.87	32	427.08
unconstrained	3	-171.14	36	442.33
unconstrained	4	-171.68	39	455.28

Table 29. Results from the MARSS PVA and Dennis Method PVA approaches. Various Atlantic sturgeon surveys, including combinations of some, were included in the analysis. Process errors (Q), observation errors (R), and the population growth rate (U) are reported unless the model would not converge or Q values were out of a reasonable range, as noted. 95% confidence intervals are included in parenthesis for estimates of U.

Survey(s)	MARSS PVA			Dennis Method	
	Q	R	U	Q	U
Conn 1984-2015	Model would not converge			0.36	1.2% (-19.8, 22.2)
Conn 1998-2015	0.09	0.13	-0.01% (-3.3, 3.2)	0.34	-0.9% (-28.5, 26.7)
ME-NH	Model would not converge			Q values unreasonable	
CT LIST	Model would not converge			Q values unreasonable	
NJ Ocean Trawl	Model would not converge			Q values unreasonable	
VIMS	0.82	0.15	-1.8% (-44.9, 41.3)	1.23	-1.6% (-55.3, 52.1)
NC p135	1.2×10^{-4}	0.55	3.9% (0.1, 7.8)	0.94	-1.5% (-40.2, 37.3)
USFW COOP	Model would not converge			Q values unreasonable	
NY Bight (CT, NJ)	0.18	NJ: 0.57 CT: 0.96	4.9% (-10.9, 20.7)	0.06	4.9% (-3.6, 13.4)

Table 30. ARIMA and trend analysis results for Atlantic sturgeon indices of abundance for (a) all years and (b) only overlapping years of 2000-2015. (a) Shown are the probability that the terminal year of an index is greater than the 25th percentile of a time series and the probability that the terminal year of an index is greater than the index value in 1998 (green shading indicates >50% probability); the Mann-Kendall tau (τ) statistics, the Holm-adjusted probability of the Mann-Kendall time series trend being significant, and whether the trend is increasing (+), decreasing (-), or not significant (n.s.). Terminal years other than 2015 are highlighted in yellow. Light grey font indicates a strong within-survey correlation (e.g., CT LIST spring and fall nominal index is strongly correlated with CT LIST fall nominal index). (b) Same as (a), except here, surveys have been truncated to a common set of years to evaluate the influence of specific survey years on probabilities of being above the 25th percentile of a time series.

(a) All years

									Trend analysis results		
DPS	Survey	Months	Ages	P(2015 index > 25th Pctl)	P(2015 index > 1998 index)	N years	First year	Terminal year	M-K τ	M-K p_adj	Trend
GOM	ME-NH Trawl (w/ May)	5,10,11	Juvenile & Adult	0.73	0.28*	16	2000	2015	-0.30	0.4603	n.s.
NYB	CT LIST spring (nom)	5-6	Juvenile	0.68	0.67	31	1984	2014	0.40	0.0123	+
NYB	CT LIST fall (nom)	9-11	Juvenile	0.95	0.82	26	1984	2009	0.86	0.0000	+
NYB	CT LIST spring & fall (nom)	5-6,9-11	Juvenile	0.92	0.65	26	1984	2009	0.78	0.0000	+
NYB	NJ Ocean Trawl	1, 4, 6, 10	Juvenile & Adult	0.90	0.91	26	1990	2015	0.29	0.2129	n.s.
CB	VIMS Shad Monitoring (3R)	3-4	Juvenile	0.96	0.41	18	1998	2015	0.06	1.0000	n.s.
CB	VIMS Shad James River only	3-4	Juvenile	0.95	0.39	18	1998	2015	-0.02	1.0000	n.s.
C	USFW Coop	1-2	Juvenile & Adult	0.71	0.66	23	1988	2010	0.64	0.0002	+
C	NC p135 (spring YOY + Juv)	Spring	YOY & Juvenile	1.00	0.98	25	1991	2015	0.69	0.0000	+
C	NCp135 (spring YOY)	Spring	YOY	0.81	0.78	25	1991	2015	0.35	0.0969	n.s.
C	NC p135 (spring Juv)	Spring	Juvenile	1.00	1.00	25	1991	2015	0.88	0.0000	+
C	NC p135 (fall YOY + Juv)	Fall (11-2)	YOY & Juvenile	0.57	0.51	26	1990	2015	0.50	0.0028	+
C	NC p135 (fall YOY)	Fall (11-2)	YOY	0.54	0.44	26	1990	2015	-0.03	1.0000	n.s.
C	NC p135 (fall Juv)	Fall (11-2)	Juvenile	0.73	0.71	26	1990	2015	0.61	0.0002	+
Coast	Conn Index	Fall	YOY, Juvenile,& Adult	0.62	0.55	32	1984	2015	0.31	0.1004	n.s.

*: ME-NH Trawl survey starts in 2000, therefore this is probability of the 2015 index being above the 2000 index.

Table 30 continued.

(b) 2000-2015

DPS	Survey	Months	Ages	P(2015 index > 25th Pctl)	N Years	First year	Terminal year
GOM	ME-NH Trawl (w/ May)	5,10,11	Juvenile & Adult	0.71	16	2000	2015
NYB	NJ Ocean Trawl	1, 4, 6, 10	Juvenile & Adult	0.95	16	2000	2015
CB	VIMS Shad James River only	3-4	Juvenile	0.96	16	2000	2015
C	NCp135	Spring	YOY	0.31	16	2000	2015
C	NCp135	Spring	juv	0.58	16	2000	2015
C	NCp135	Fall	YOY	0.85	16	2000	2015
C	NCp135	Fall	Juv	1.00	16	2000	2015
Coast	Conn Index	Fall	All ages	0.89	16	2000	2015

Table 31. Summary of tally and percentage of surveys, by DPS, where terminal year index is greater than the 25th percentile of a given time series and the index value in 1998 for a given index for (a) all years available, and (b) subset to a common set of years (2000-2015).

(a) All Available Years

DPS	P(2015 index > 25th Pctl)	P(2015 index > 1998 index)
GOM	1 of 1	0 of 1*
NYB	3 of 3	1 of 1**
CB	1 of 1	0 of 1
C	5 of 5	4 of 5
Coast	1 of 1	1 of 1

DPS	P(2015 index > 25th Pctl)	P(2015 index > 1998 index)
GOM	100%	0%
NYB	100%	100%
CB	100%	0%
C	100%	80%
Coast	100%	100%

* Survey started in 2000

** 2 additional surveys do not include 2015

(b) Only 2000 - 2015

DPS	P(2015 index > 25th Pctl)
GOM	1 of 1
NYB	1 of 1
CB	1 of 1
C	3 of 4
Coast	1 of 1

DPS	P(2015 index > 25th Pctl)
GOM	100%
NYB	100%
CB	100%
C	75%
Coast	100%

Table 32. Summary statistics for ARIMA model results. N = number of years in time series, W = Shapiro-Wilk statistics for normality, adj p = Holm-adjusted probability of rejecting the null hypothesis regarding normality of model residuals, r1, r2, and r3 = the first three sample autocorrelations for the first differenced logged series, (θ) = moving average parameter, SE = standard error of theta, and σ^2 = variance of index. VIMS Shad Monitoring (J-Y-R) = James, York, and Rappahannock rivers.

DPS	Survey	Years avail.	n	W	adj p	r_1	r_2	r_3	θ	SE	σ^2_c
GOM	ME-NH Trawl (w/ May)	2000-2015	16	0.96	1.00	-0.35	-0.13	0.27	0.6	0.32	0.29
NYB	CT LIST spring (nom)	1984-2014	31	0.96	1.00	-0.08	-0.39	-0.03	1	0.24	0.7
NYB	CT LIST fall (nom)	1984-2009	26	0.98	1.00	-0.32	-0.16	-0.02	0.75	0.19	0.98
NYB	CT LIST spring & fall (nom)	1984-2009	26	0.97	1.00	-0.15	-0.3	-0.19	0.74	0.18	0.64
NYB	NJ Ocean Trawl	1990-2015	26	0.89	0.13	-0.46	0.2	-0.23	0.55	0.24	1.55
CB	VIMS Shad Monitoring (J-Y-R)	1998-2015	18	0.98	1.00	0.1	0.02	-0.21	0.09	0.23	0.88
CB	VIMS Shad James River only	1998-2015	18	0.95	1.00	-0.05	0	-0.07	0.05	0.24	1.07
C	USFW Coop	1988-2010	23	0.96	1.00	-0.48	0.29	-0.46	0.87	0.13	0.69
C	NC p135 (spring YOY + Juv)	1990-2015	25	0.94	1.00	-0.17	-0.26	-0.12	0.51	0.31	0.21
C	NCp135 (spring YOY)	1990-2015	25	0.91	0.44	-0.39	-0.17	0.15	1	0.15	0.08
C	NC p135 (spring Juv)	1990-2015	25	0.88	0.08	-0.29	-0.21	-0.09	0.55	0.17	0.15
C	NC p135 (fall YOY + Juv)	1990-2015	26	0.95	1.00	-0.26	-0.26	0.11	0.97	0.3	0.2
C	NC p135 (fall YOY)	1990-2015	26	0.89	0.11	-0.32	-0.26	0.16	1	0.12	0.14
C	NC p135 (fall Juv)	1990-2015	26	0.98	1.00	-0.23	-0.24	0	0.87	0.12	0.1
Coast	Conn Index	1984-2015	32	0.97	1.00	-0.09	-0.38	0.07	0.93	0.16	0.29

Table 33. Characteristics of current and previous mixed stock analysis on Atlantic sturgeon. Abbreviations for baseline populations are as follows: SL – St Lawrence, SJ – St John, KE – Kennebec, HU – Hudson, DE – Delaware, YO – York, JA – James, ALB – Albemarle, ED – Edisto, CO – Combahee, SAV – Savannah, OG – Ogeechee, ALT – Altamaha, and SAT – Satilla. *Omitted from comparisons since most of these fish were included in the present analysis of adult sturgeon captured off the coast of Delawar.

Study	**Region**	**Sample Years**	**Size/Stage**	***n***	**Methodology (Baseline Populations)**
Hudson intercept	New York Bight	1993-1995	136-229 cm TL	83	Microsatellites (SL, SJ, KE, HU, DE, YO, JA, ALB, ED, SAV, OG, ALT)
Dunton et al. 2012	New York Bight	2005-2009	54-215 cm TL	364	MtDNA control region sequencing (SL, SJ, KE, HU, DE, JA, ALB, ED, CO, SAV, OG, ALT)
Waldman et al. 1996	New York Bight	1993-1994	136-207 cm TL	112	MtDNA RFLP (SL, SJ, HU, ED, SAV, OG, ALT, SAT)
O Leary et al. 2015	New York Bight	2010-2012	71-205 cm TL	460	Microsatellites (SJ, KE, HU, DE, JA, ALB, SAV, OG, ALT)
Waldman et al. 2013	Long Island Sound and Connecticut River	1989-2011 (most 2005-2011)	Adults and subadults	399	MtDNA control region sequencing and microsatellites (SJ, KE, HU, DE, JA, ALB, SAV, OG, ALT)
Wirgin et al. 2012	Bay of Fundy, Canada	2007-2009	46-238 cm TL	181	MtDNA control region sequencing and microsatellites (SJ, KE, HU, DE, JA, ALB, SAV, ALT, OG)
Wirgin et al. 2015a*	Delaware Coast (New York Bight)	2009-2012		261	MtDNA control region sequencing and microsatellites (SJ, KE, HU, DE, JA, ALB, SAV, OG, ALT)
Wirgin et al. 2015b	Mostly in New York Bight and North Carolina coast	2009-2012	122.5 cm TL (mean)	173	MtDNA control region sequencing and microsatellites (SL, SJ, KE, HU, DE, JA, ALB, OG, ED, SAV, ALT)
Delaware coast	New York Bight	2009-2016	Adults	391	Microsatellites (SL, SJ, KE, HU, DE, YO, JA, ALB, ED, SA, OG, ALT)

Table 34. Summary of Atlantic sturgeon collections included in the genetic baseline for assignment to DPS and river of origin. Length data has not yet been recovered for all individuals following the untimely passing of Dr. Tim King. All collections have been classified as including river-resident juvenile (RRJ; <500 mm TL) or adult sturgeon (≥1,500 mm TL) based on his notes. Note that this collection includes seven individuals below 1,500 mm TL (1,370-1,470 mm TL). Length data was not identified for an additional three individuals from the St John River.

DPS	River	Year	Size Class	Samples
Gulf of Maine	St. Lawrence	2013	Adult	30
Gulf of Maine	St. John	1991-1993	Adult*	31
Gulf of Maine	Kennebec	1980	Adult	14
Gulf of Maine	Kennebec	2010-2011	Adult	38
New York Bight	Hudson	1996	Adult	28
New York Bight	Hudson	1997	Adult	25
New York Bight	Hudson	2006	Adult	31
New York Bight	Hudson	2008	Adult	20
New York Bight	Hudson	2008	RRJ	23
New York Bight	Hudson	2009	Adult	40
New York Bight	Hudson	2010	Adult	48
New York Bight	Hudson	2014	RRJ	38
New York Bight	Hudson	2015	RRJ	31
New York Bight	Hudson	2015	Adult	53
New York Bight	Delaware	2009	RRJ	64
New York Bight	Delaware	2011	RRJ and Adult	56
New York Bight	Delaware	2014	RRJ	39
New York Bight	Delaware	2015	RRJ and Adult	22
Chesapeake	York	2013	Adult	18
Chesapeake	York	2014	Adult	54
Chesapeake	York	2015	Adult	64
Chesapeake	James	1998	RRJ	52
Chesapeake	James	2009	Adult	16
Chesapeake	James	2010	Adult	38
Chesapeake	James	2011	Adult	68
Chesapeake	James	2012	Adult	29
Chesapeake	James	2013	Adult	31
Chesapeake	James	2014	Adult	58
Chesapeake	James	2015	Adult	34
Chesapeake	James	2015	Adult	20
Carolina	Albemarle	1998	Adult	11

Table 34. *Continued*

DPS	River	Year	Size Class	Samples
Carolina	Albemarle	2007	RRJ	11
Carolina	Albemarle	2008	RRJ	15
South Atlantic	Edisto	1996	RRJ	14
South Atlantic	Edisto	1998	RRJ	18
South Atlantic	Edisto	2004	RRJ	29
South Atlantic	Edisto	2005	RRJ	48
South Atlantic	Savannah	2000	RRJ	29
South Atlantic	Savannah	2007	RRJ	11
South Atlantic	Savannah	2008	RRJ	14
South Atlantic	Savannah	2013	RRJ	44
South Atlantic	Ogeechee	2003	RRJ	10
South Atlantic	Ogeechee	2007-2009	RRJ	15
South Atlantic	Ogeechee	2014	RRJ	43
South Atlantic	Ogeechee	2015	RRJ	47
South Atlantic	Altamaha	2005	RRJ	49
South Atlantic	Altamaha	2010	RRJ	50
South Atlantic	Altamaha	2011	RRJ and Adult	24
South Atlantic	Altamaha	2011	RRJ	40
South Atlantic	Altamaha	2015	RRJ	23

Table 35. Classification confusion matrix for genetic population assignments to river using the Atlantic sturgeon baseline. Overall, 84.9% of individuals within the baseline were correctly assigned to their river of origin using GeneClass2 (shown in bold). The classification efficiency of individuals to DPSs in these assignments was even higher (95.3%; shown in italics)

	Assigned River												
Collection Location	**St Lawrence**	**St John**	**Kennebec**	**Hudson**	**Delaware**	**York**	**James**	**Albemarle**	**Edisto**	**Savannah**	**Ogeechee**	**Altamaha**	**Grand Total**
St Lawrence	***30***												30
St John		***30***	1										31
Kennebec	1	1	***49***				1						52
Hudson			7	***305***	*23*		2						337
Delaware		1	1	*22*	***149***		8						181
York				1		***125***	*8*	1		1			136
James	1			9	9		***312***		1	4	5	5	346
Albemarle								***30***		5	1	1	37
Edisto									***85***	*9*	*7*	*8*	109
Savannah							1	1	*5*	***64***	*9*	*18*	98
Ogeechee									*12*	*11*	***80***	*12*	115
Altamaha									*7*	*29*	*2*	***148***	186
Grand Total	32	32	58	337	181	125	332	32	110	123	104	192	1658

Table 36. Number of Atlantic sturgeon tags and months available for analysis in the acoustic tagging dataset. The number of tags varied by DPS. DPSs are Gulf of Maine (GM), New York Bight (NY), Chesapeake (CH), Carolina (CA), and South Atlantic (SA).

DPS	Number of tags	Number of Adults	Number of Juveniles	Range of months of data
Gulf of Maine	155	129	26	104
New York Bight	458	268	190	117
Chesapeake Bay	359	241	118	114
Carolina	120	32	88	81
South Atlantic	239	190	49	117
Total	1,331	860	471	--

Table 37. Results for the best Cormack-Jolly-Seber model for all acoustically tagged Atlantic sturgeon. The mean estimate, standard deviation, 50%, and 95 % credible intervals are presented. The best DIC selected model had a single estimate of survival (S) and monthly varying detection probability (p).

Parameter	Mean	sd	2.5 %	25 %	75%	97.5 %
Annual S	0.96	0.05	0.84	0.96	0.99	1.00
Monthly S	1.00	0.01	0.98	1.00	1.00	1.00
Jan p	0.07	0.01	0.06	0.07	0.08	0.08
Feb p	0.06	0.01	0.05	0.06	0.06	0.06
Mar p	0.10	0.01	0.09	0.11	0.11	0.11
Apr p	0.30	0.01	0.28	0.30	0.31	0.32
May p	0.50	0.01	0.49	0.51	0.52	0.52
Jun p	0.51	0.01	0.49	0.50	0.51	0.52
Jul p	0.40	0.01	0.38	0.38	0.39	0.41
Aug p	0.41	0.01	0.39	0.39	0.40	0.42
Sep p	0.48	0.01	0.46	0.46	0.47	0.50
Oct p	0.47	0.01	0.45	0.46	0.47	0.48
Nov p	0.25	0.01	0.24	0.24	0.25	0.26
Dec p	0.09	0.01	0.08	0.09	0.10	0.10

Table 38. Survival estimates for the best Cormack-Jolly-Seber model for all acoustically tagged Atlantic sturgeon in each DPS. The mean estimate, standard deviation, 50% and 95% credible interval are presented. The best DIC selected model had a single estimate of survival and monthly varying detection probability.

DPS	N	TL Range (cm)	Mean	sd	2.5%	25%	50%	75%	97.5%	Monthly p
GM	155	29-237	0.74	0.21	0.15	0.64	0.79	0.90	0.99	0.01-0.39
NY	458	26-268	0.91	0.08	0.71	0.88	0.93	0.96	0.99	0.06-0.58
CH	359	19-240	0.88	0.14	0.46	0.85	0.92	0.96	0.99	0.03-0.56
CA	120	72-204	0.78	0.16	0.39	0.70	0.81	0.90	0.99	0.04-0.53
SA	239	28-267	0.86	0.13	0.54	0.82	0.90	0.95	0.99	0.09-0.62

Table 39. Survival estimates for the best Cormack-Jolly-Seber model for adult acoustically tagged Atlantic sturgeon in each DPS. The mean estimate, standard deviation, 50% and 95 % credible interval are presented. The best DIC selected model had a single estimate of survival and monthly varying detection probability.

DPS	N	TL Range (cm)	Mean	sd	2.5%	25%	50%	75%	97.5%	Monthly p
GM	129	130-237	0.72	0.21	0.16	0.60	0.76	0.88	0.98	0.01-0.36
NY	268	130-268	0.85	0.14	0.49	0.79	0.88	0.94	0.99	0.04-0.65
CH	241	134-240	0.82	0.16	0.42	0.77	0.87	0.93	0.99	0.02-0.53
CA	32	133-204	0.33	0.24	0.02	0.13	0.28	0.48	0.87	0.04-0.77
SA	190	132-267	0.83	0.18	0.29	0.78	0.88	0.94	0.99	0.09-0.62

Table 40. Survival estimates for the best Cormack-Jolly-Seber model for juvenile acoustically tagged Atlantic sturgeon in each DPS. The mean estimate, standard deviation, 50% and 95% credible interval are presented. The best DIC selected model had a single estimate of survival and monthly varying detection probability.

DPS	N	TL Range (cm)	Mean	sd	2.5%	25%	50%	75%	97.5%	Monthly p
GM	26	29-129	0.35	0.26	0.02	0.11	0.29	0.54	0.91	0.05-0.62
NY	190	26-129	0.80	0.19	0.21	0.74	0.86	0.93	0.99	0.01-0.55
CH	118	19-127	0.71	0.20	0.26	0.58	0.75	0.88	0.98	0.17-0.79
CA	88	72-129	0.72	0.20	0.20	0.61	0.76	0.87	0.98	0.05-0.48
SA	49	28-124	0.59	0.24	0.11	0.41	0.62	0.79	0.97	0.10-0.66

Table 41. Total removals (mt) and CV used as input to stock reduction analyses.

Year	Removals	CV
1887	3,094.0	0.3
1888	3,294.0	0.3
1889	2,626.0	0.3
1890	3,270.0	0.3
1891	3,044.0	0.3
1892	2,540.0	0.3
1893	2,104.8	0.3
1894	1,870.8	0.3
1895	1,617.6	0.3
1896	1,369.6	0.3
1897	2,101.0	0.3
1898	1,314.0	0.3
1899	425.9	0.3
1900	308.4	0.3
1901	294.0	0.3
1902	269.0	0.3
1903	146.7	0.3
1904	307.0	0.3
1905	9.0	0.3
1906	76.2	0.3
1907	56.8	0.3
1908	101.0	0.3
1909	3.0	0.3
1910	4.0	0.3
1911	9.0	0.3
1912	9.0	0.3
1913	4.0	0.3
1914	1.0	0.3
1915	0.0	0.3
1916	0.0	0.3
1917	0.0	0.3
1918	78.0	0.3
1919	0.0	0.3
1920	10.0	0.3
1921	41.0	0.3
1922	0.0	0.3
1923	50.0	0.3
1924	4.0	0.3
1925	39.0	0.3
1926	10.0	0.3
1927	23.0	0.3
1928	23.0	0.3
1929	34.0	0.3
1930	30.0	0.3
1931	33.0	0.3
1932	26.0	0.3
1933	20.0	0.3
1934	33.0	0.3
1935	13.0	0.3
1936	60.0	0.3
1937	43.0	0.3
1938	48.0	0.3
1939	22.0	0.3
1940	19.0	0.3
1941	6.0	0.3
1942	22.0	0.3
1943	11.0	0.3
1944	12.0	0.3
1945	41.0	0.3
1946	27.0	0.3
1947	21.0	0.3
1948	41.0	0.3
1949	23.0	0.1
1950	42.1	0.1
1951	30.5	0.1
1952	50.6	0.1
1953	58.6	0.1
1954	54.3	0.1
1955	63.0	0.1
1956	85.7	0.1
1957	68.2	0.1
1958	62.6	0.1
1959	52.3	0.1
1960	64.7	0.1
1961	79.0	0.1
1962	75.8	0.1
1963	79.9	0.1
1964	83.1	0.1
1965	102.7	0.1
1966	87.9	0.1
1967	58.1	0.1
1968	88.1	0.1
1969	108.7	0.1
1970	96.9	0.1
1971	105.5	0.1
1972	122.4	0.1
1973	73.9	0.1
1974	83.5	0.1
1975	69.2	0.1
1976	75.2	0.1
1977	93.9	0.1
1978	81.3	0.1
1979	79.1	0.1
1980	102.2	0.1
1981	82.9	0.1
1982	88.0	0.1
1983	45.1	0.1
1984	81.2	0.1
1985	65.2	0.1
1986	51.6	0.1
1987	42.3	0.1
1988	46.8	0.1
1989	57.8	0.1
1990	92.9	0.1
1991	98.4	0.1
1992	58.8	0.1
1993	31.4	0.1
1994	43.5	0.1
1995	17.4	0.1
1996	3.0	0.2
1997	0.4	0.2
1998	0.2	0.2
1999	0.1	0.2
2000	4.0	0.2
2001	6.7	0.2
2002	15.8	0.2
2003	3.6	0.2
2004	12.5	0.2
2005	8.6	0.2
2006	9.6	0.2
2007	8.1	0.2
2008	6.4	0.2
2009	4.6	0.2
2010	3.3	0.2
2011	4.8	0.2
2012	3.7	0.2
2013	17.6	0.2
2014	5.7	0.2
2015	3.5	0.2

Table 42. Drawn parameters and their distributions for the DBSRA model

Parameter	**Base Distribution**	**Sensitivity Runs**
Natural mortality	Lognormal(0.07, 0.1)	
F_{MSY}/M	Lognormal(0.8, 0.1)	Lognormal(0.45, 0.1)
B_{MSY}/K	Beta(0.4, 0.1)	Beta(0.6, 0.1)
B_{2015}/K	Uniform(0.05, 0.20)	Uniform(0.20, 0.50)
B_{1887}/K	Constant=1	Uniform(0.85, 1.0)
K scalar	Constant=1	Uniform(0.30, 0.75)

Table 43. Estimated von Bertalanffy parameters used in the various analyses of eggs-per-recruit. Length is in centimeters and standard errors are in parentheses.

Region	L_∞	K	t_0
Coast	286 (2.08)	0.0622 (0.00140)	-0.340 (0.129)
New York Bight DPS (northern)	299 (2.37)	0.0511 (0.00104)	-1.82 (0.102)
Carolina DPS (southern)	182 (1.29)	0.169 (0.00473)	-0.759 (0.0719)

Table 44. Parameters of the length (centimeters)-weight (grams) relationship used in the various analyses of eggs-per-recruit. Standard errors are in parentheses.

Region	a	b
Coast	0.00513 (0.000286)	3.05 (0.0107)
New York Bight DPS (northern)	0.0235 (0.00428)	2.76 (0.0345)
Carolina DPS (southern)	0.00186 (0.000119)	3.25 (0.0129)

Table 45. Estimates of the fecundity relationship for Atlantic sturgeon from the literature.

Area	**Relation**	**Equation**	a	b	c	**Source**
South Carolina	weight (kg)-fecundity, linear	$F = a + b * W$	233,064	13,307		Smith et al. 1982
Hudson	length (cm)-fecundity, linear	$F = a + b * L$	-5,888,552	35,560		van Eenannaan et al. 1996
Hudson	length (cm)-fecundity, linear	$F = a + b * L$	-4,678,387	29,182		van Eenannaam and Doroshov 1998
Hudson	age-fecundity, non-linear	$F = a + b * \exp(c * A)$	3,598,025	-6,926,305	-0.05	van Eenannaam and Doroshov 1998

Table 46. Estimated values of $Z_{50\%EPR}$ for the coastwide model for different age groups at various rates of bycatch and ship strike mortality.

F			**N-weighted $Z_{50\%EPR}$**		
Ship Strike	**Bycatch**	**Total**	**All fish**	**Adults**	**Ages 4-21**
0.000	0.030	0.030	0.12	0.072	0.085
0.00042	0.030	0.030	0.12	0.072	0.085
0.010	0.025	0.035	0.12	0.071	0.087
0.020	0.021	0.041	0.12	0.071	0.088
0.022	0.020	0.042	0.12	0.071	0.088
0.030	0.016	0.046	0.12	0.070	0.089
0.040	0.011	0.051	0.12	0.069	0.091
0.043	0.010	0.053	0.12	0.069	0.091
0.050	0.0068	0.057	0.12	0.069	0.092
0.060	0.0021	0.062	0.12	0.068	0.094
0.065	0.000	0.065	0.13	0.068	0.094

Table 47. Estimated values of $Z_{50\%EPR}$ for the northern region model for different age groups at various rates of bycatch and ship strike mortality.

F			**N-weighted $Z_{50\%EPR}$**		
Ship Strike	**Bycatch**	**Total**	**All fish**	**Adults**	**Ages 4-21**
0.000	0.032	0.032	0.12	0.090	0.10
0.0039	0.030	0.034	0.12	0.090	0.10
0.010	0.027	0.037	0.12	0.089	0.10
0.020	0.022	0.042	0.13	0.089	0.11
0.025	0.020	0.045	0.13	0.088	0.11
0.030	0.018	0.048	0.13	0.088	0.11
0.040	0.013	0.053	0.13	0.087	0.11
0.046	0.010	0.056	0.13	0.087	0.11
0.050	0.0080	0.058	0.13	0.087	0.11
0.060	0.0033	0.062	0.13	0.086	0.11
0.067	0.000	0.067	0.13	0.086	0.11

Table 48. Estimated values of $Z_{50\%EPR}$ for the southern region model for different age groups at various rates of bycatch and ship strike mortality.

F			**N-weighted $Z_{50\%EPR}$**		
Ship Strike	**Bycatch**	**Total**	**All fish**	**Adults**	**Ages 4-21**
0.000	0.063	0.063	0.15	0.13	0.12
0.0079	0.060	0.068	0.15	0.13	0.12
0.010	0.059	0.069	0.15	0.13	0.12
0.020	0.055	0.075	0.16	0.13	0.12
0.030	0.052	0.082	0.16	0.13	0.12
0.035	0.050	0.085	0.16	0.13	0.12
0.040	0.048	0.088	0.16	0.12	0.12
0.050	0.044	0.094	0.16	0.12	0.13
0.060	0.041	0.062	0.16	0.12	0.13
0.062	0.040	0.10	0.16	0.12	0.13
0.070	0.037	0.062	0.16	0.12	0.13
0.080	0.033	0.062	0.16	0.12	0.13
0.089	0.030	0.12	0.16	0.12	0.13
0.090	0.030	0.062	0.16	0.12	0.13
0.10	0.026	0.062	0.16	0.12	0.13
0.11	0.023	0.062	0.16	0.12	0.13
0.12	0.020	0.14	0.16	0.12	0.13
0.12	0.019	0.062	0.16	0.12	0.13
0.13	0.015	0.062	0.16	0.12	0.13
0.14	0.012	0.062	0.16	0.12	0.13
0.14	0.010	0.15	0.16	0.12	0.13
0.15	0.0081	0.062	0.16	0.12	0.13
0.16	0.0045	0.062	0.16	0.12	0.13
0.17	0.00093	0.062	0.16	0.12	0.13
0.17	0.000	0.17	0.16	0.11	0.13

Table 49. Estimates of Z relative to $Z_{50\%EPR}$ at the coastwide and DPS-level. Estimates of Z are for all tagged fish from each region/DPS, and $Z_{50\%EPR}$ values are N-weighted values for ages 4-21.

Region	**Z (95% credible interval)**	**$Z_{50\%EPR}$**
Coast	0.04 (0.01 - 0.17)	0.09 (coast)
Gulf of Maine	0.30 (0.01 - 1.90)	0.11 (northern region)
New York Bight	0.09 (0.01 - 0.34)	0.11 (northern region)
Chesapeake Bay	0.13 (0.01 - 0.78)	0.12 (southern region)
Carolina	0.25 (0.01 - 0.94)	0.12 (southern region)
South Atlantic	0.15 (0.01 - 0.87)	0.12 (southern region)

Table 50. Stock status determination for the coastwide stock and DPSs based on morality estimates and biomass/abundance status relative to historic levels and the terminal year of indices relative to the start of the moratorium as determined by the ARIMA analysis. Refer to section 7.2 for a more thorough discussion of stock status in each DPS which includes this quantitative evaluation as well as some qualitative evidence.

		Biomass/Abundance Status	
Population	Mortality Status	Relative to Historical Levels	Terminal year of indices relative to start of Moratorium (1998)
Coastwide	Below Z threshold*	Depleted	Above
Gulf of Maine DPS	*Above Z threshold (highly uncertain)*	Depleted	Below**
New York Bight DPS	*Below Z threshold (highly uncertain)*	Depleted	Above
Chesapeake Bay DPS	*Above Z threshold (highly uncertain)*	Depleted	Below
Carolina DPS	*Above Z threshold (highly uncertain)*	Depleted	Above
South Atlantic DPS	*Above Z threshold (highly uncertain)*	Depleted	Unknown (no available indices)

*: Credible interval of Z includes threshold

**: ME-NH trawl survey index begins in 2000

11 FIGURES

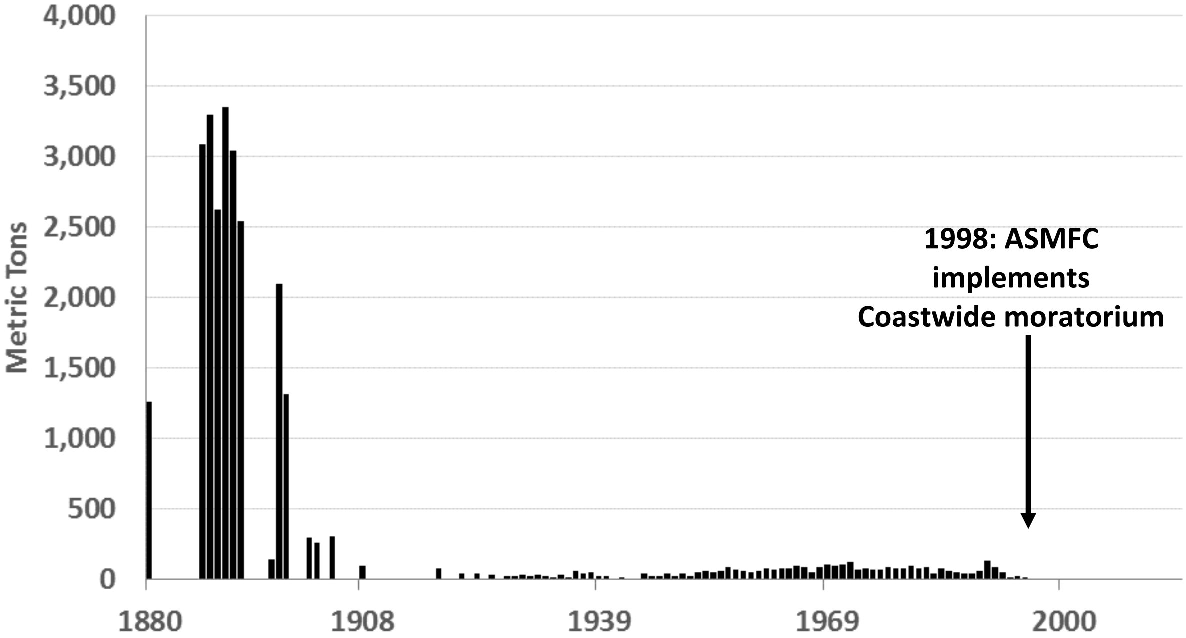


Figure 1. Coastwide commercial landings of Atlantic sturgeon, 1880-2015. ASMFC implemented a coastwide moratorium in 1998.

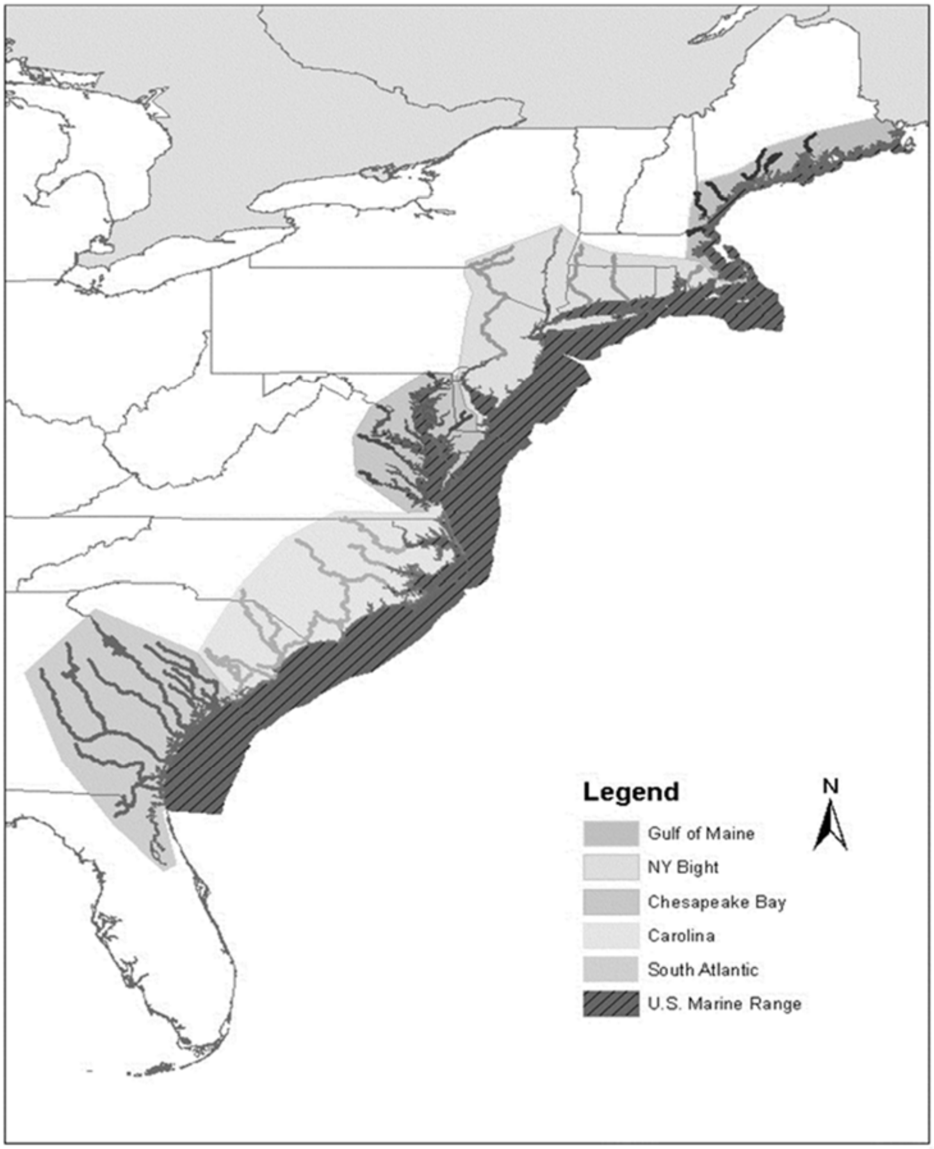


Figure 2. Five Distinct Population Segments (DPS) for the Atlantic sturgeon. Source: NOAA Fisheries Final Rule, 77 FR 5880

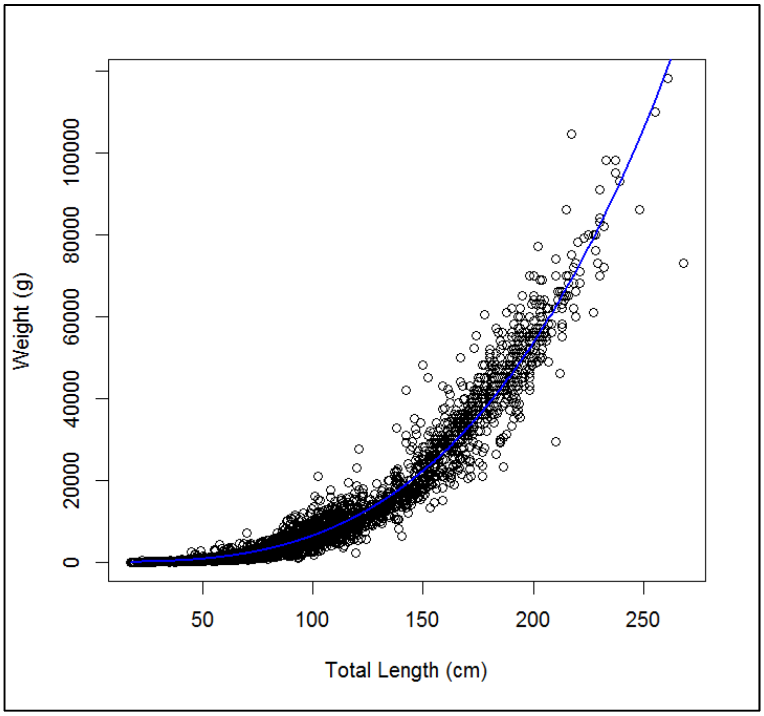


Figure 4. Predicted length-weight (blue line) curve based on all available Atlantic sturgeon observations (open black circles) from along the east coast.

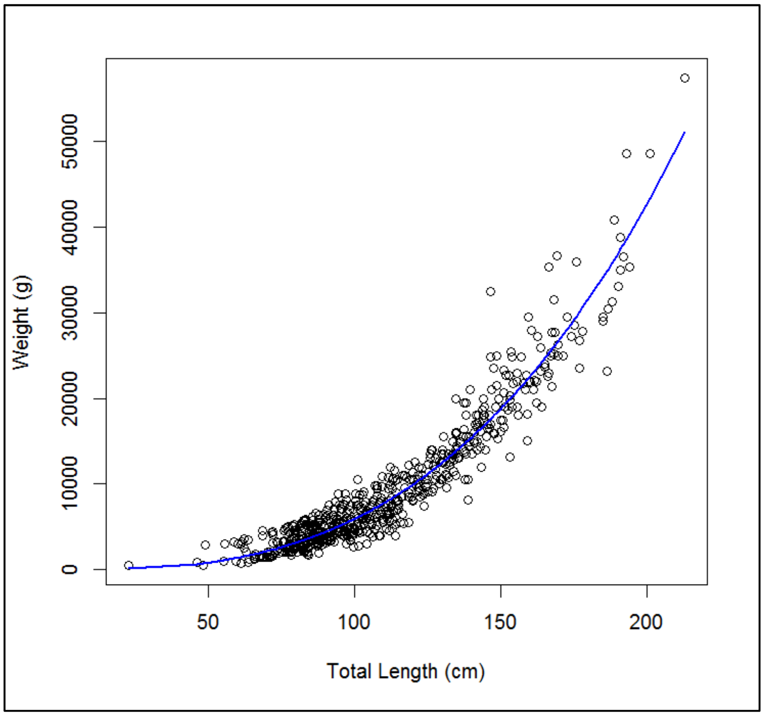


Figure 5. Predicted length-weight (blue line) curve based on available Atlantic sturgeon observations (open black circles) from the Gulf of Maine DPS.

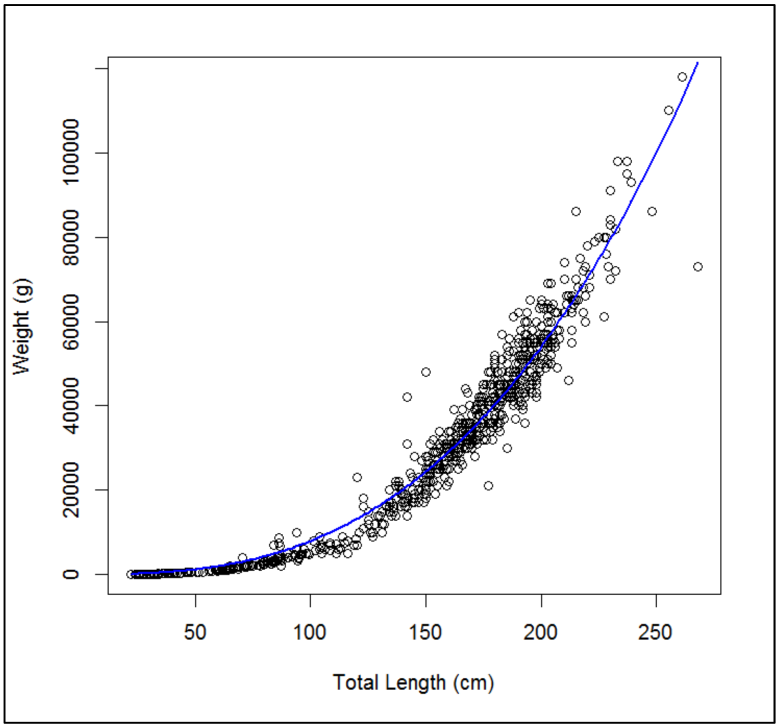


Figure 6. Predicted length-weight (blue line) curve based on available Atlantic sturgeon observations (open black circles) from the New York Bight DPS.

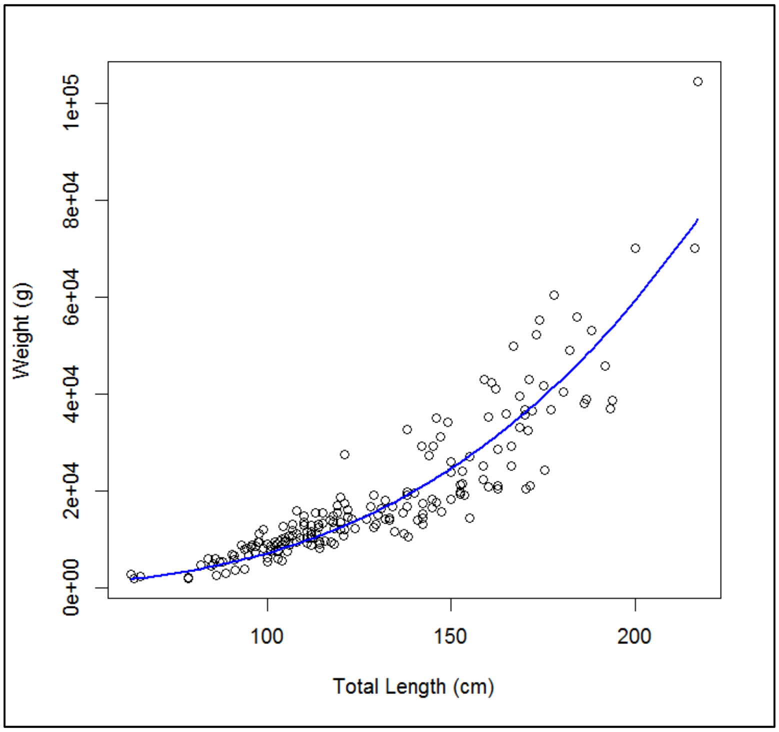


Figure 7. Predicted length-weight (blue line) curve based on available Atlantic sturgeon observations (open black circles) from the Chesapeake Bay DPS.

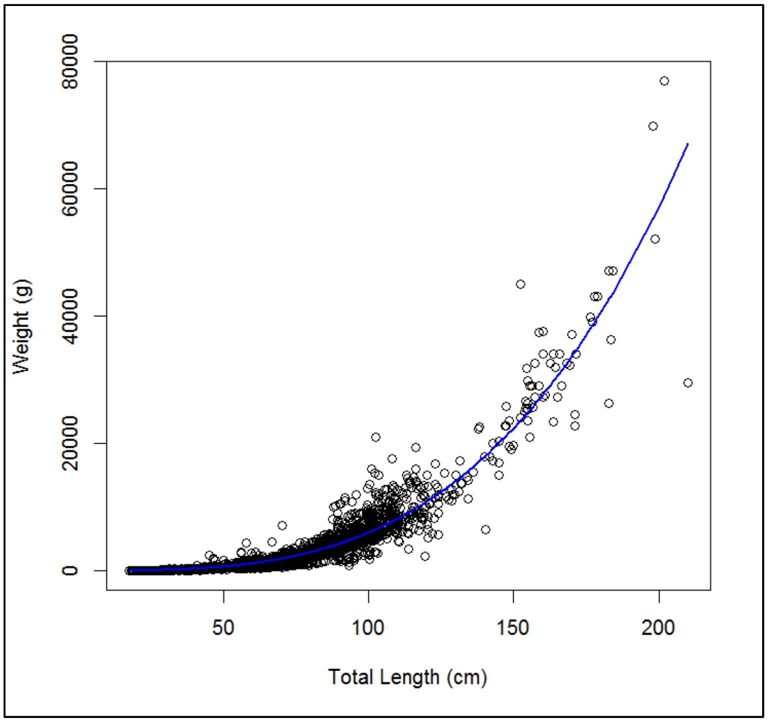


Figure 8. Predicted length-weight (blue line) curve based on available Atlantic sturgeon observations (open black circles) from the Carolina DPS.

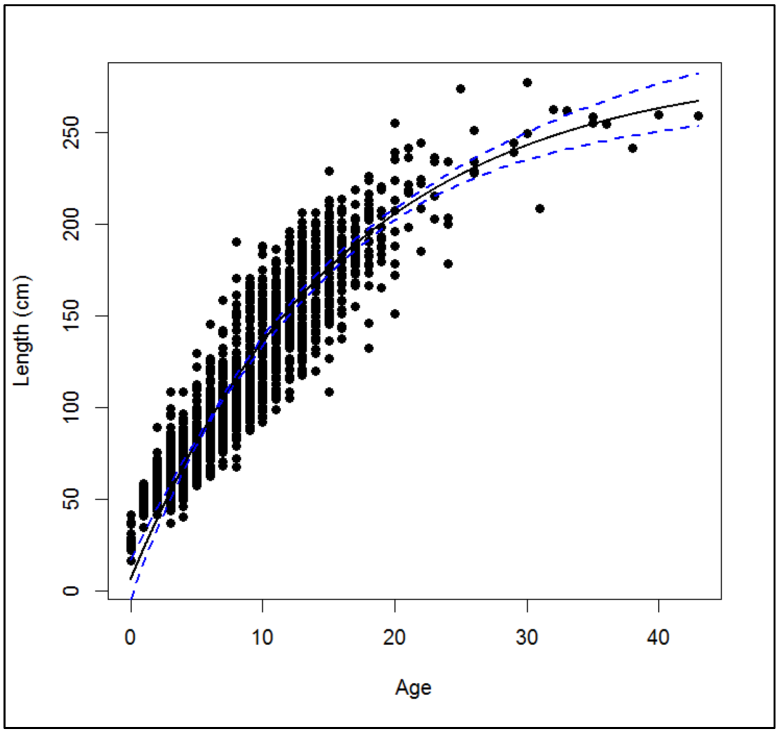


Figure 9. Fitted line plot for the fit of the traditional von Bertalanffy age-length model (with inverse weighting) to all data with approximate 95% bootstrap confidence bounds shown as blue dashed lines.

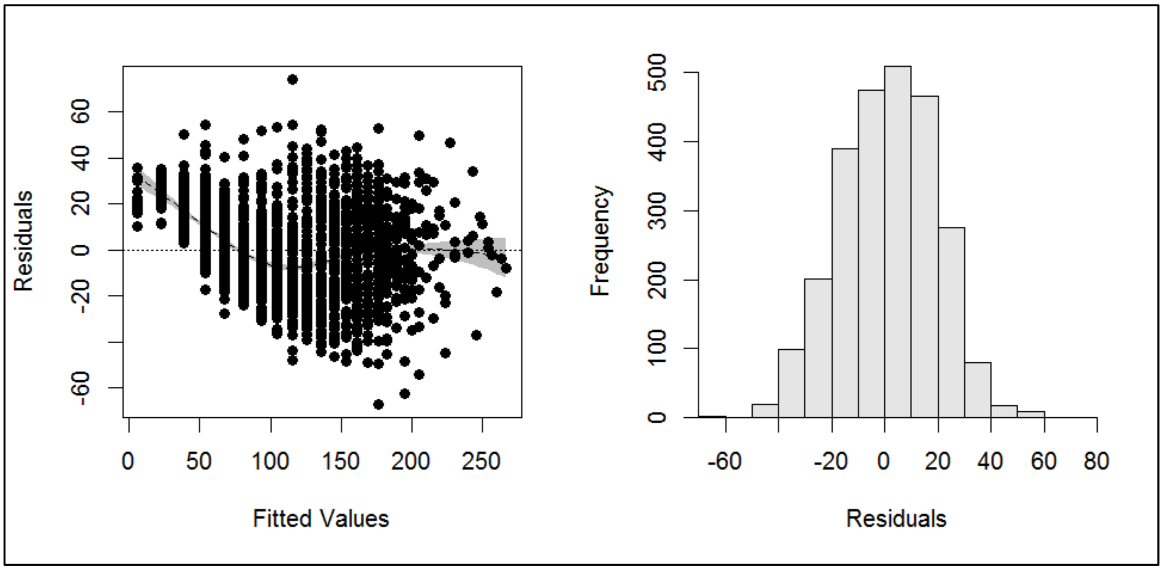


Figure 10. Residual plot (left) and residual histogram (right) from fitting the traditional von Bertalanffy age-length model to all data.

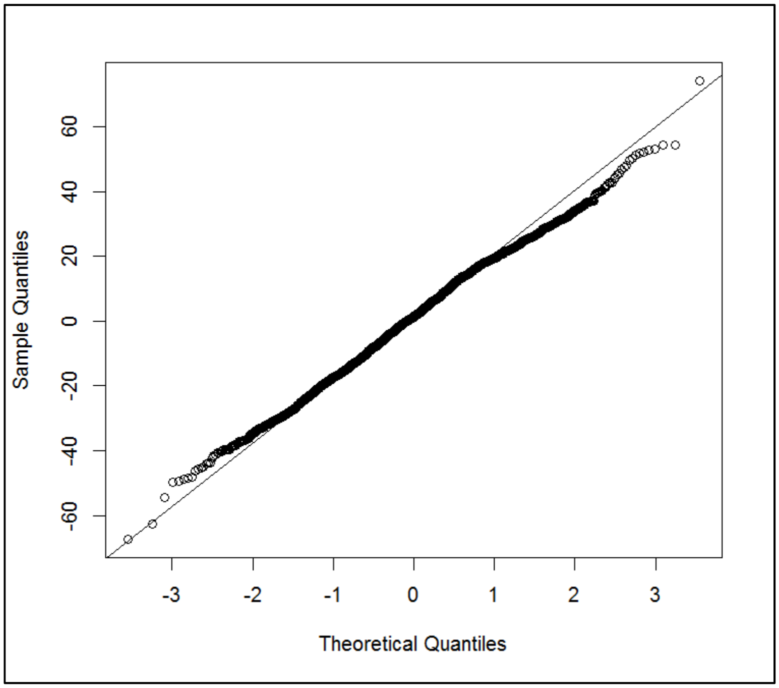


Figure 11. QQ plot of residuals from fitting the traditional von Bertalanffy age-length model to all data.

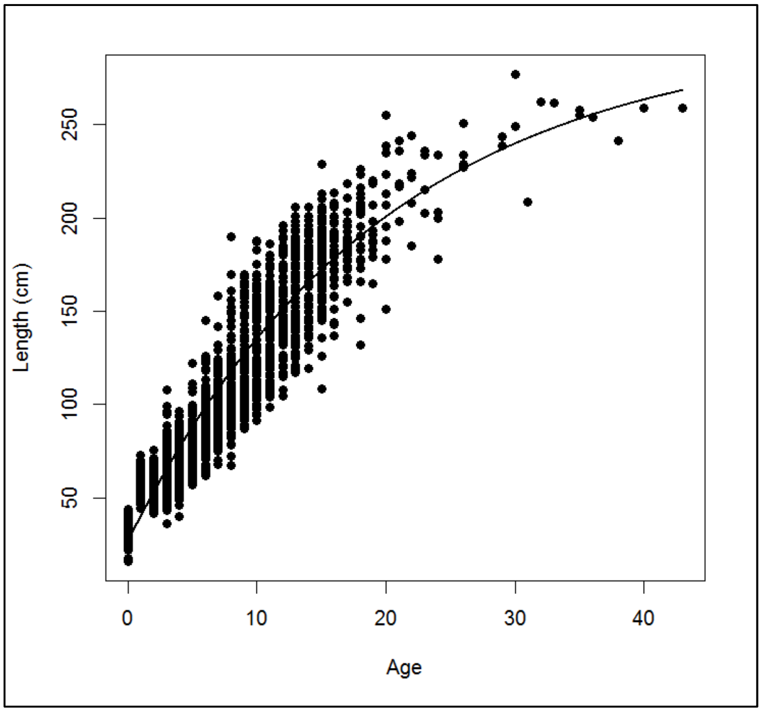


Figure 12. Fitted line plot for the fit of the traditional von Bertalanffy age-length model (with inverse weighting) to available data from the New York Bight DPS.

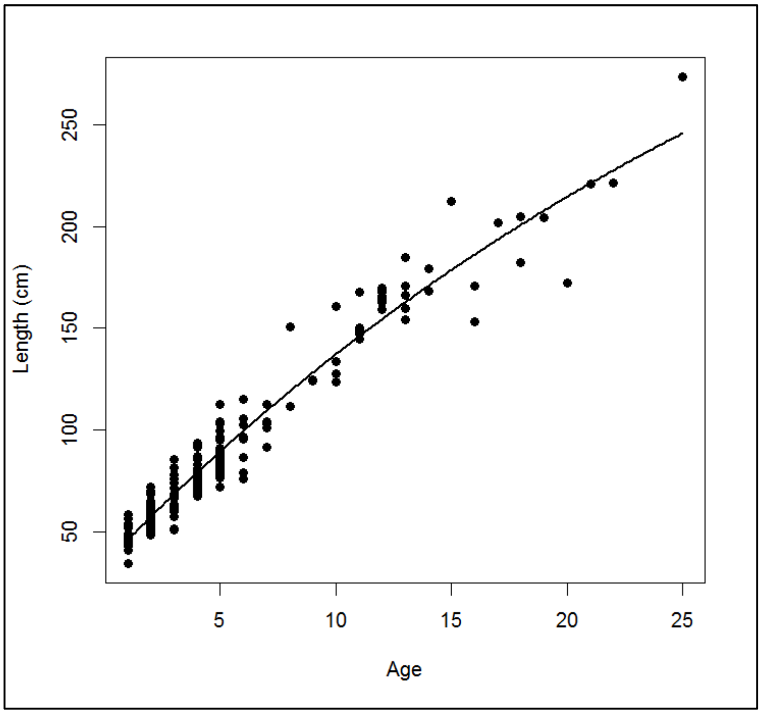


Figure 13. Fitted line plot for the fit of the traditional von Bertalanffy age-length model (with inverse weighting) to available data from the Chesapeake Bay DPS.

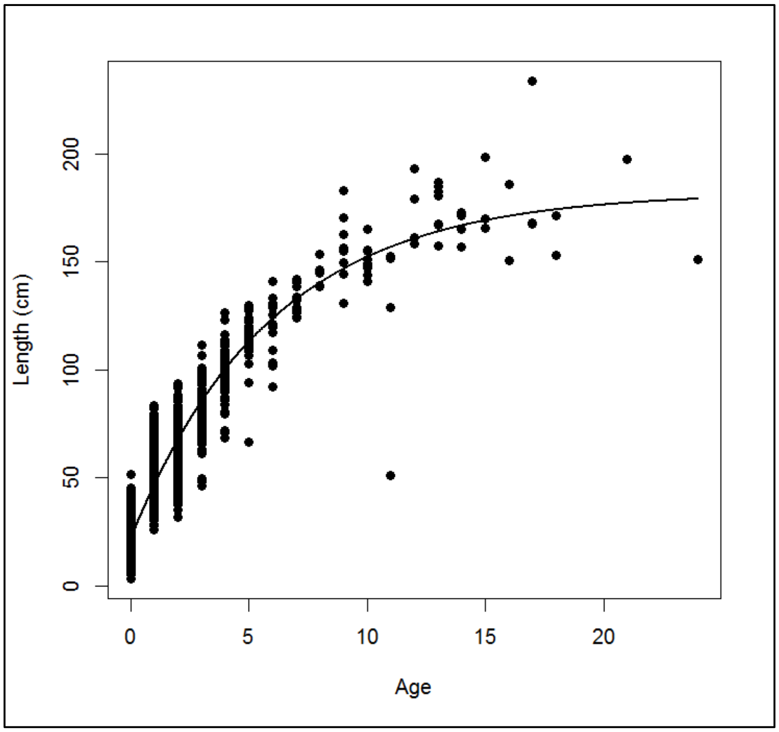


Figure 14. Fitted line plot for the fit of the traditional von Bertalanffy age-length model (with inverse weighting) to available data from the Carolina DPS.

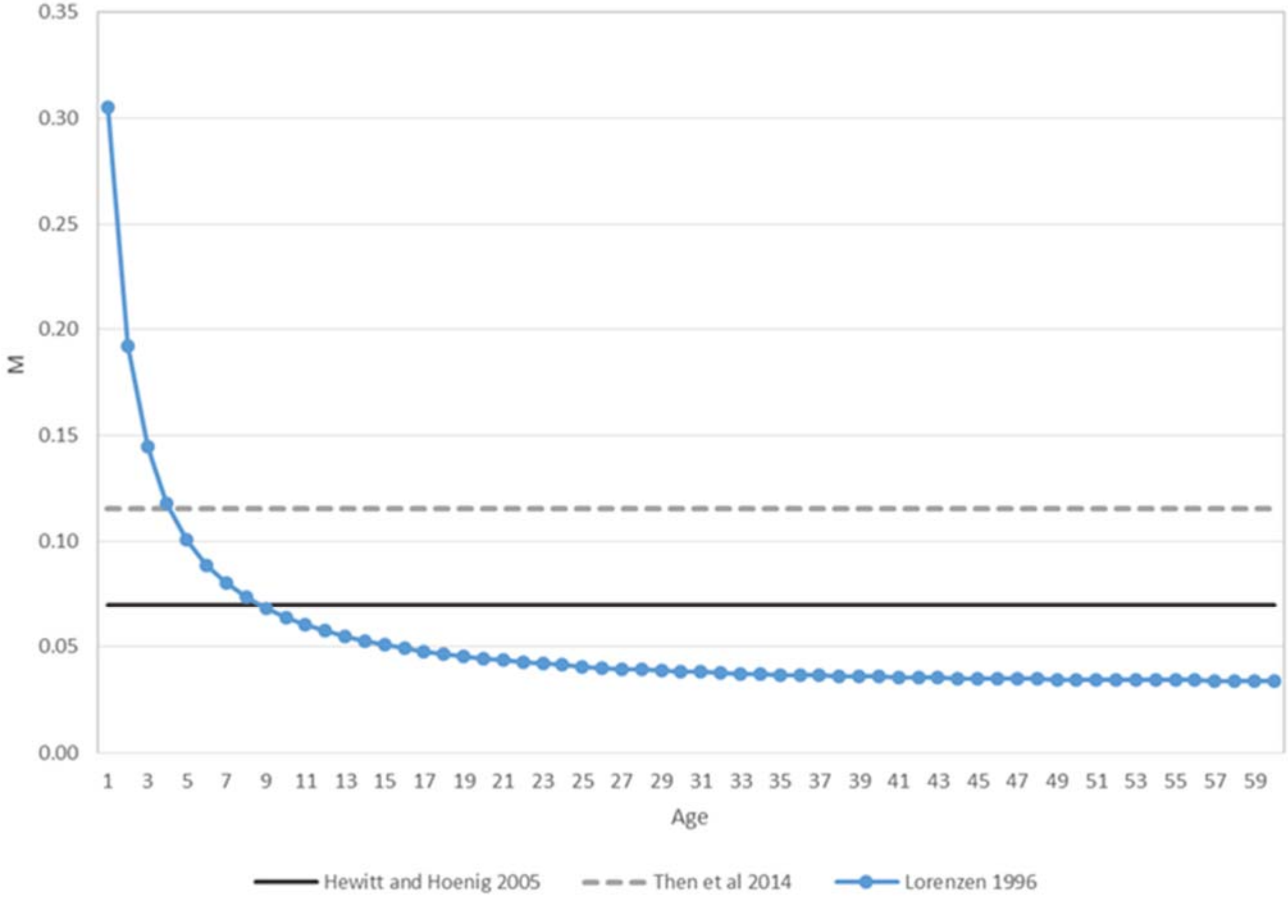


Figure 15. Age-constant and age-varying estimates of natural mortality for Atlantic sturgeon.

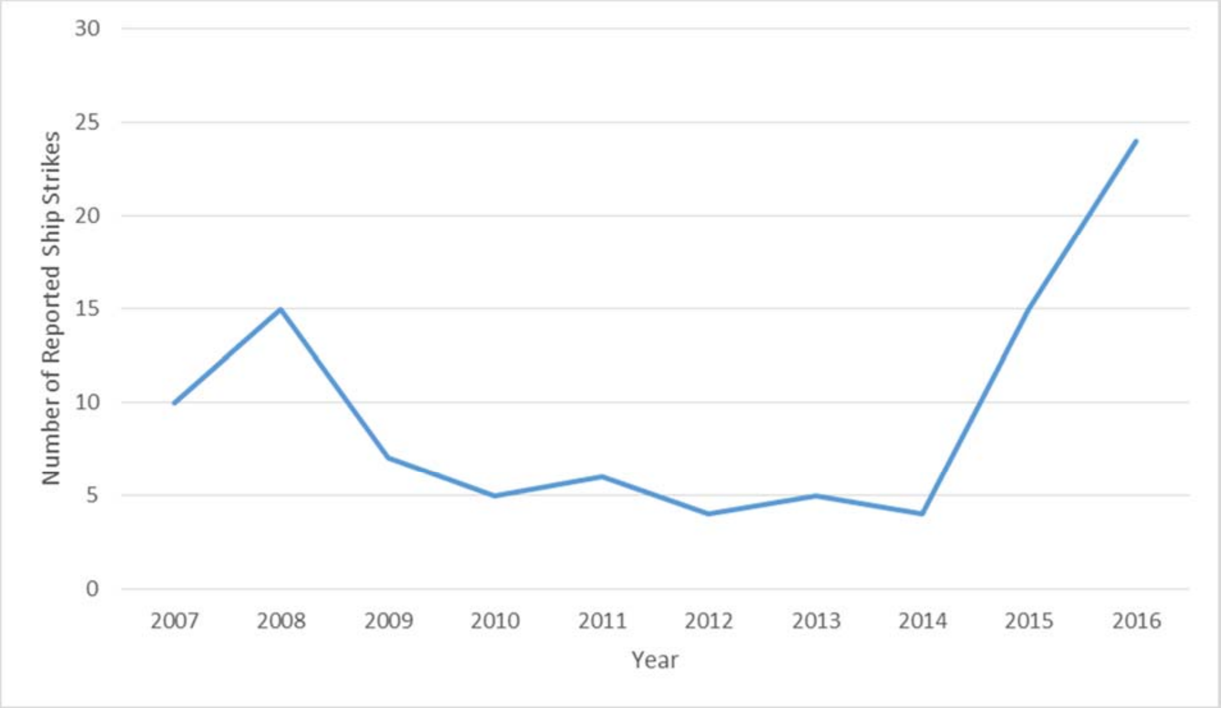


Figure 16. Observed Atlantic sturgeon carcasses attributed to vessel strikes directly observed and recorded in a Virginia Commonwealth database (M. Balazik, personal communication).

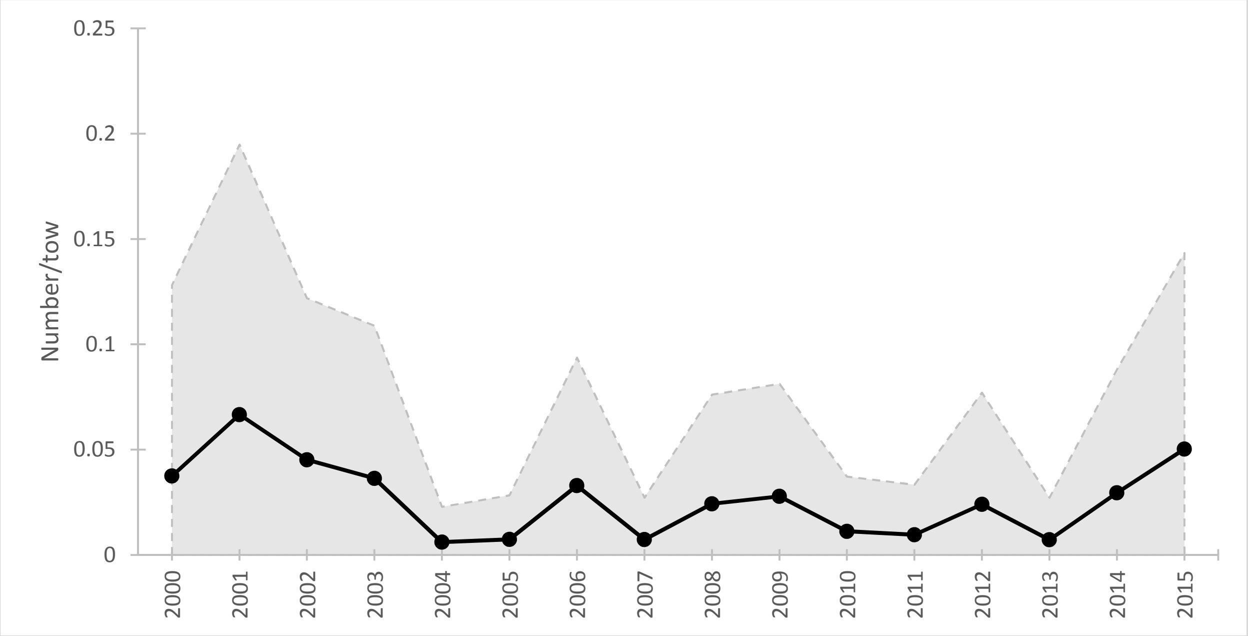


Figure 17. Standardized index of relative abundance of Atlantic sturgeon developed from the Maine-New Hampshire Trawl Survey with 95% confidence intervals.

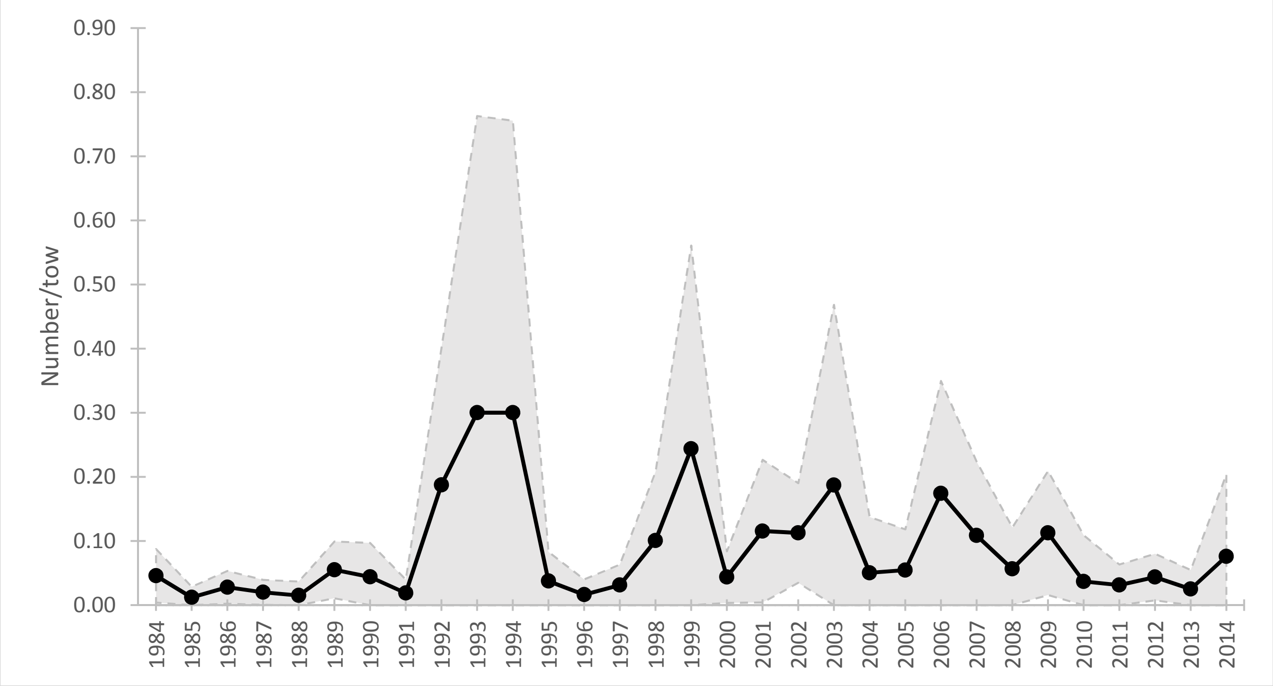


Figure 18. Nominal index of relative abundance of Atlantic sturgeon developed from the Connecticut Long Island Sound Trawl Survey with 95% confidence intervals.

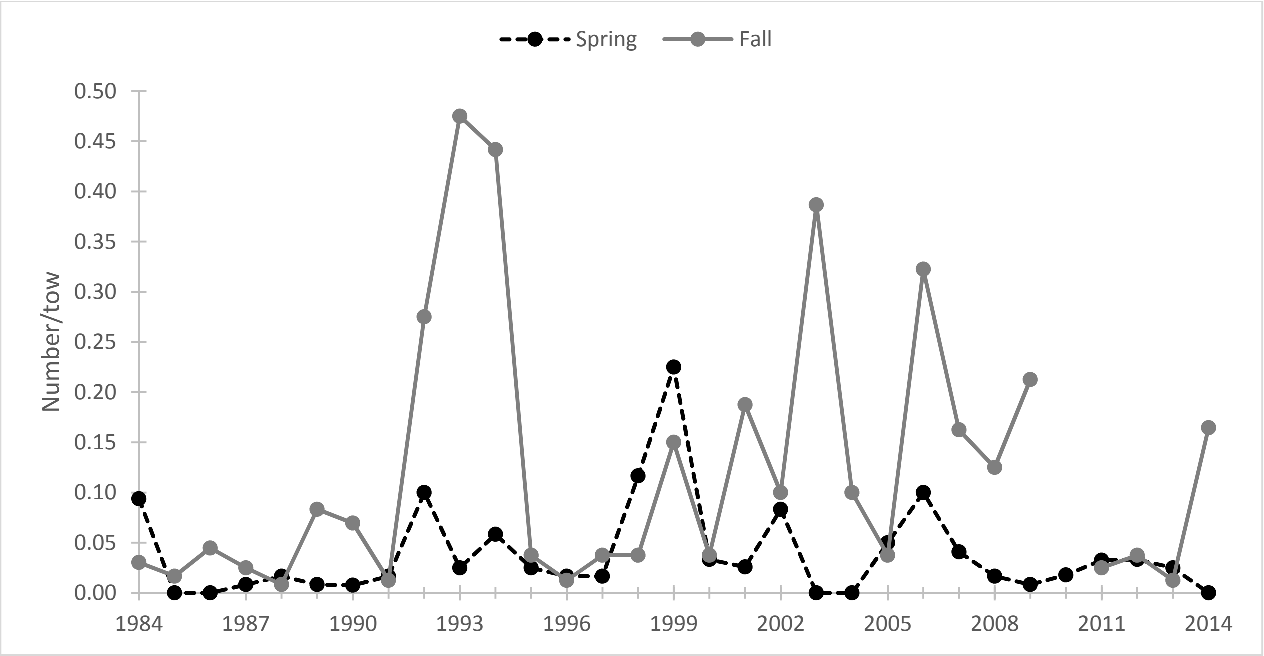


Figure 19. Seasonal nominal indices of relative abundance of Atlantic sturgeon developed from the Connecticut Long Island Sound Trawl Survey. There was no data in the fall 2010.

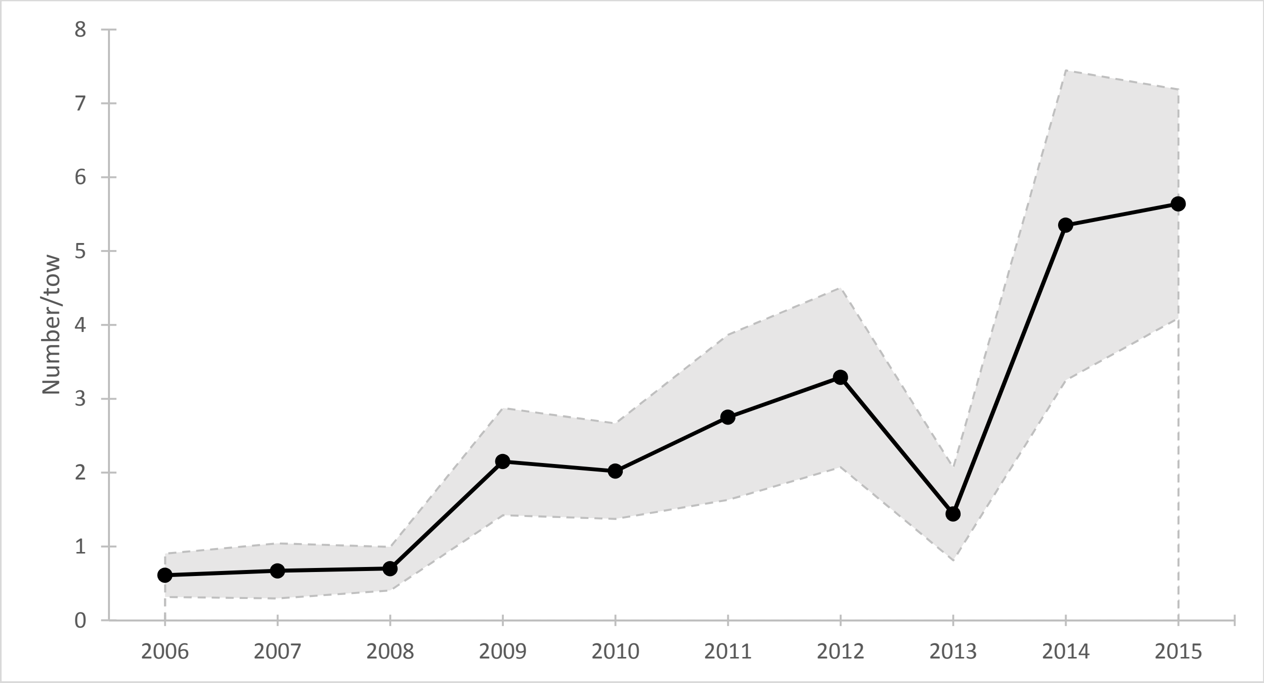


Figure 20. Standardized index of relative abundance of Atlantic sturgeon developed from the NYDEC JASAMP survey with 95% confidence intervals.

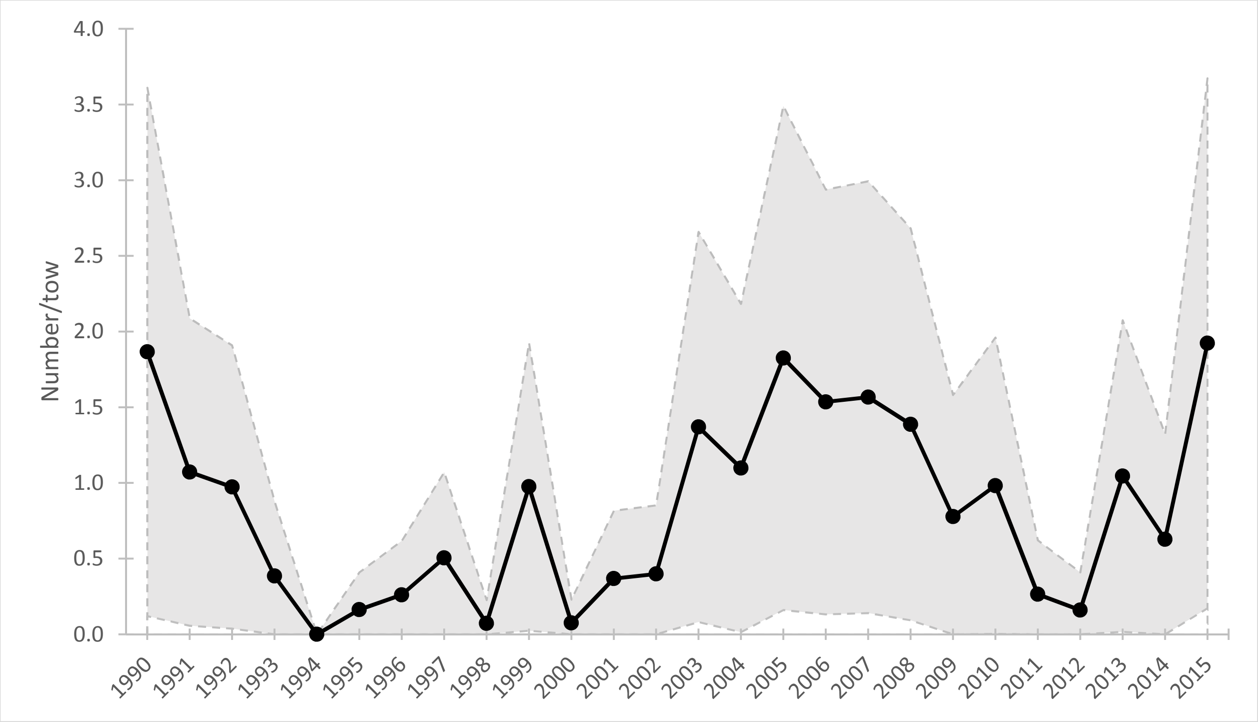


Figure 21. Standardized index of relative abundance of Atlantic sturgeon developed from the NJ Ocean Trawl Survey with 95% confidence intervals.

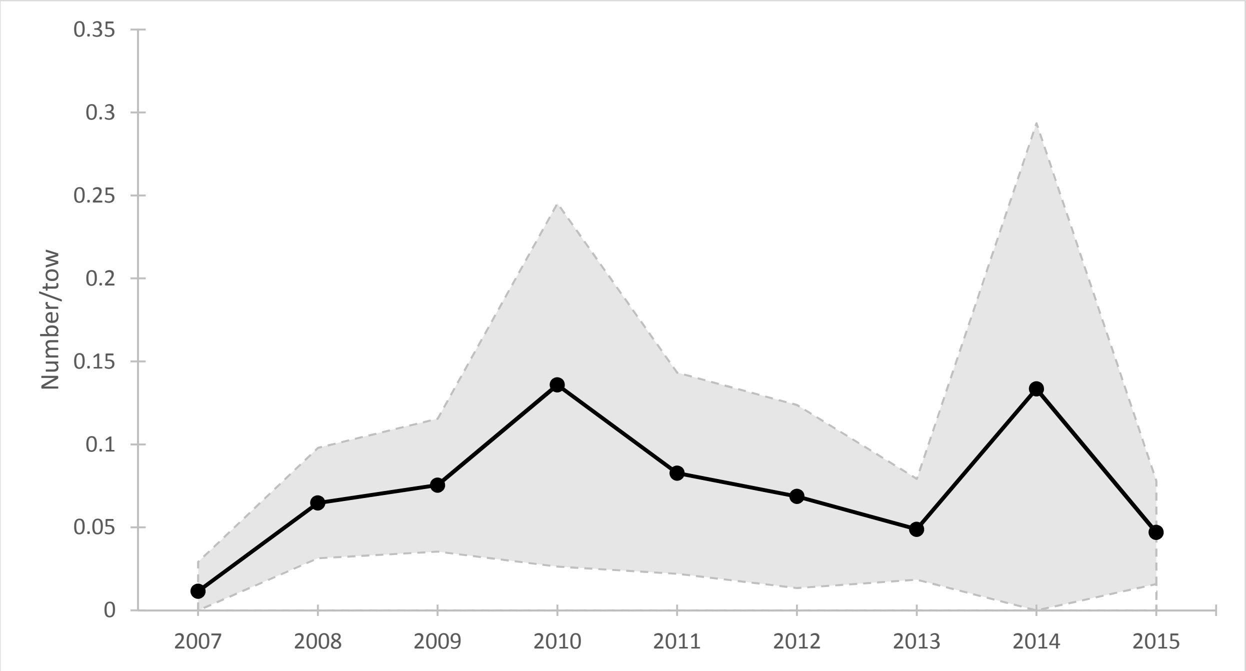


Figure 22. Standardized index of relative abundance of Atlantic sturgeon developed from the NEAMAP Survey with 95% confidence intervals.

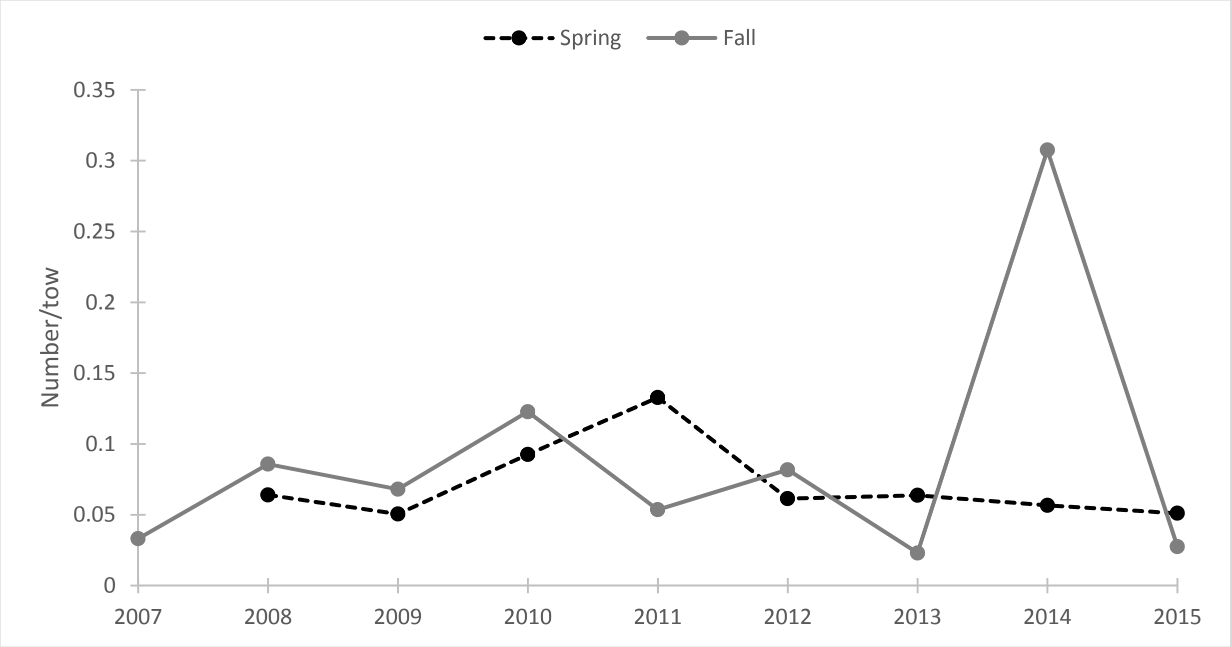


Figure 23. Seasonal standardized indices of relative abundance of Atlantic sturgeon developed from the NEAMAP survey data.

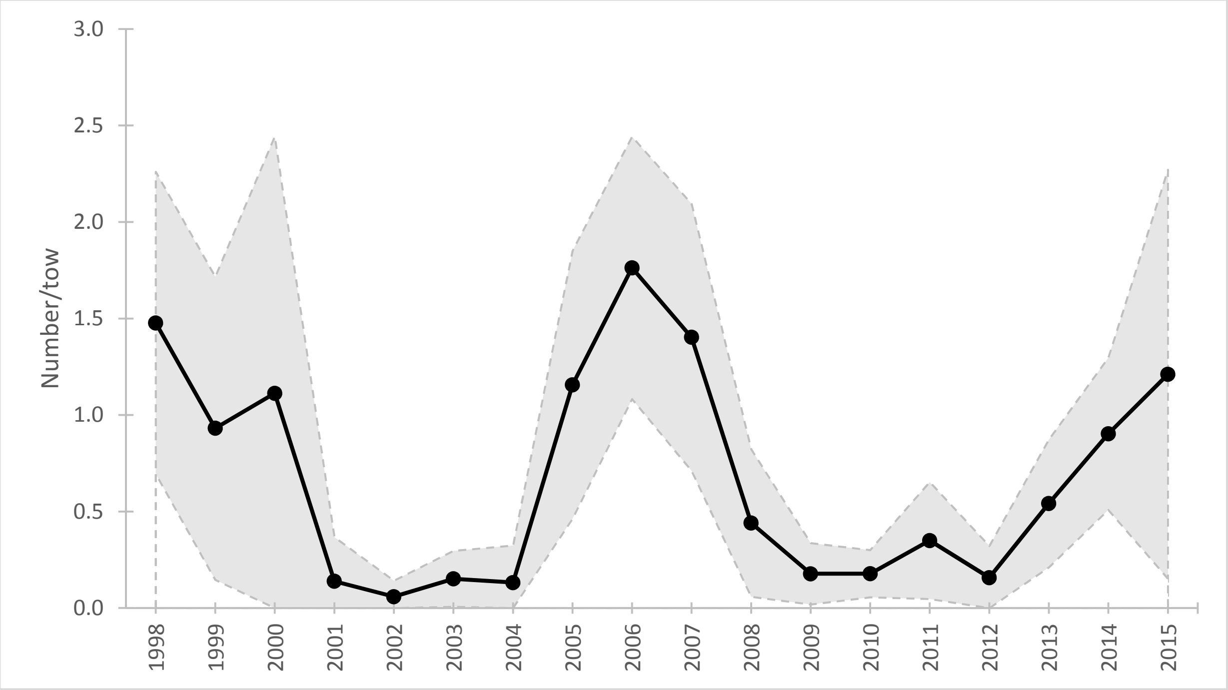


Figure 24. Standardized index of relative abundance of Atlantic sturgeon developed from the VIMS Shad and River Herring Monitoring Survey with 95% confidence intervals.

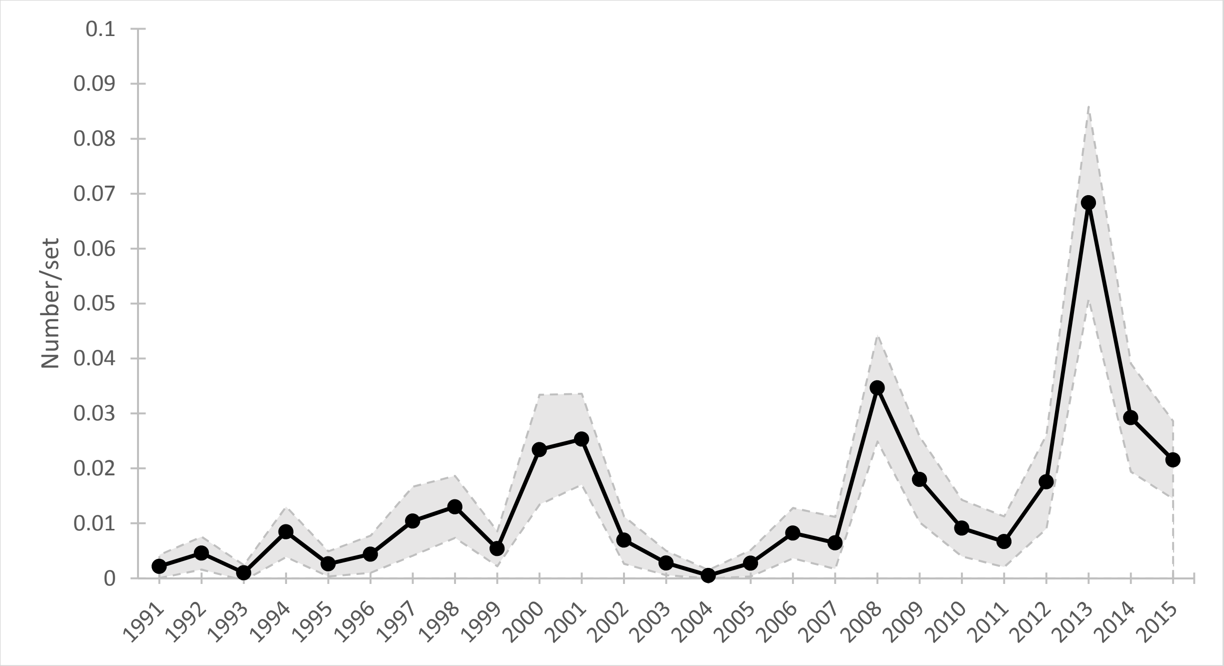


Figure 25. Standardized index of relative abundance of Atlantic sturgeon developed from the spring component of the NC p135 Survey with 95% confidence intervals.

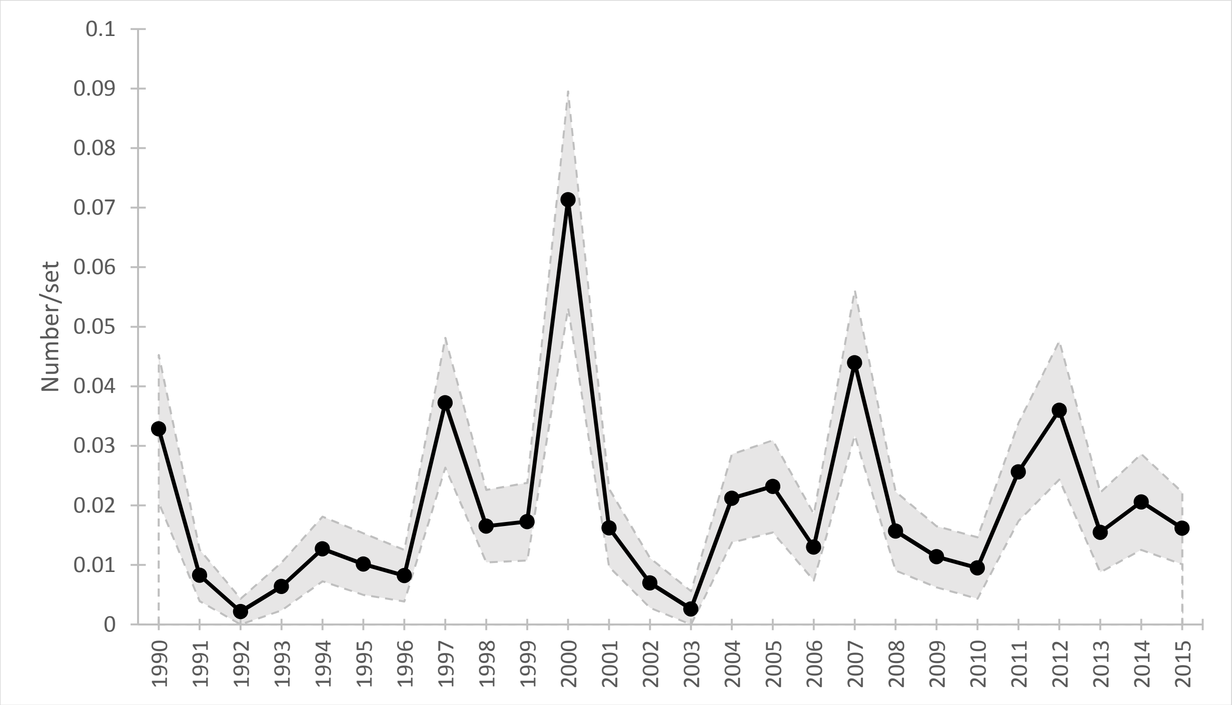


Figure 26. Standardized index of relative abundance of Atlantic sturgeon developed from the fall component of the NC p135 Survey with 95% confidence intervals.

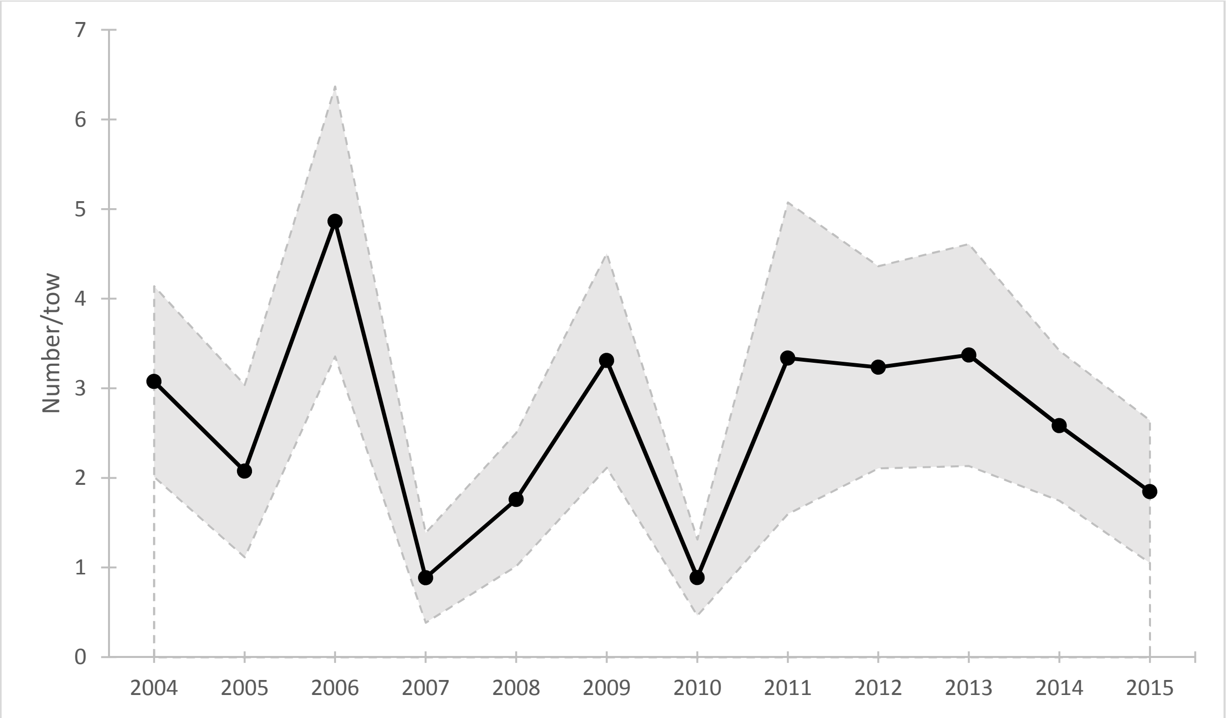


Figure 27. Standardized index of relative abundance of Atlantic sturgeon developed from the SC Edisto Survey with 95% confidence intervals.

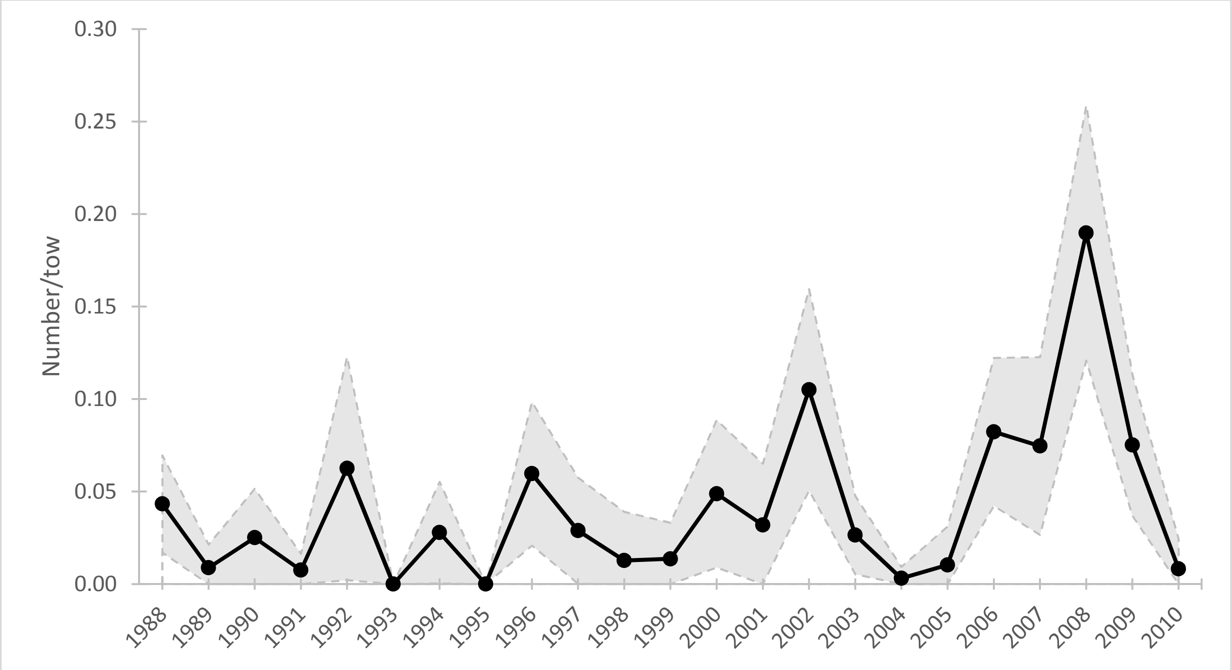


Figure 28. Standardized index of relative abundance of Atlantic sturgeon developed from the USFWS Cooperative Cruise with 95% confidence intervals.

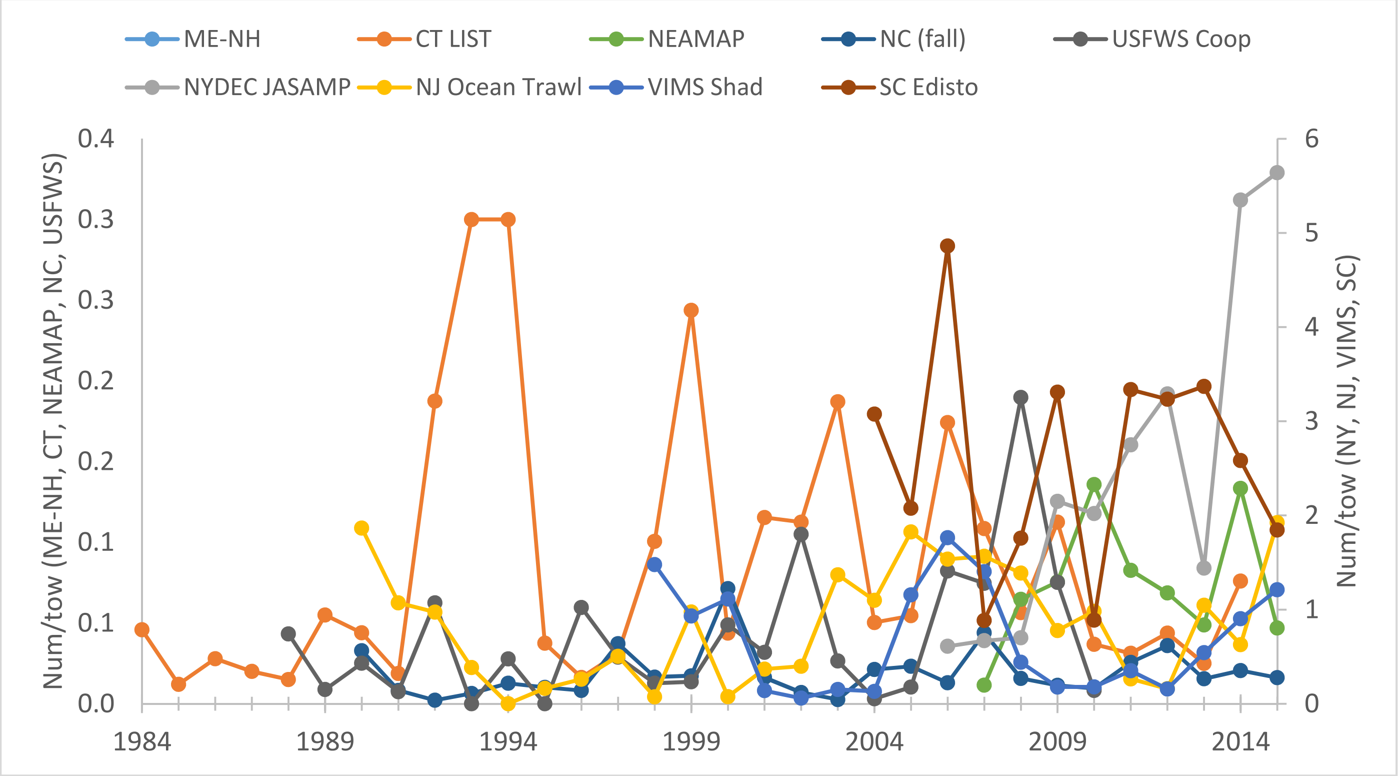


Figure 29. The nine indices of relative abundance developed for Atlantic sturgeon.

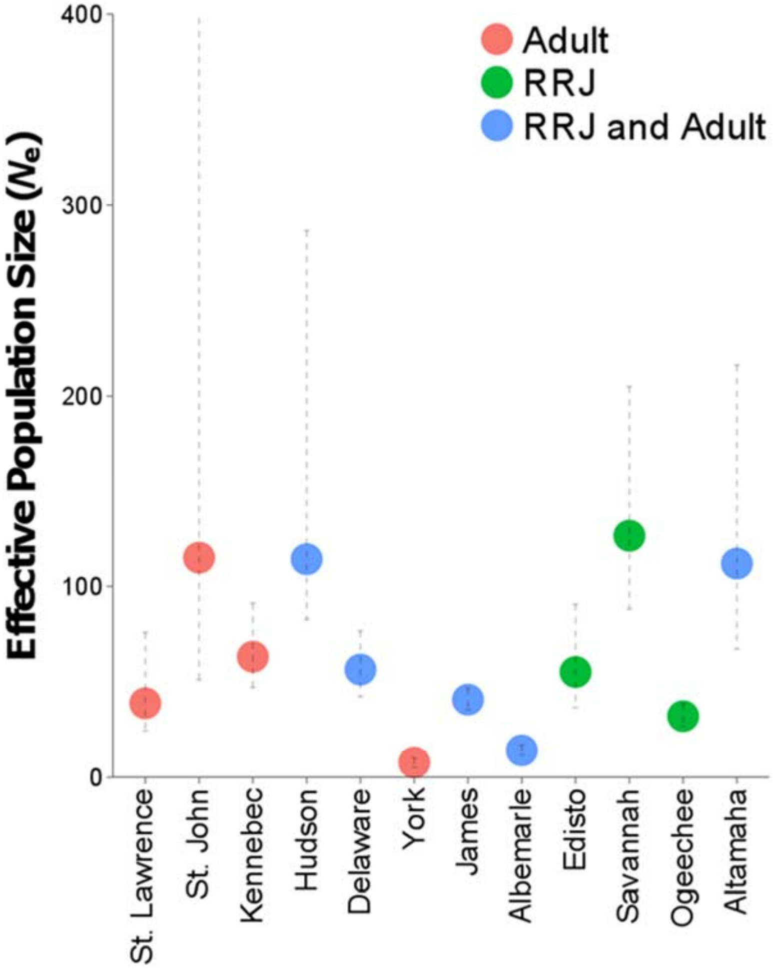


Figure 30. Comparison of effective population size estimates based on Atlantic sturgeon collections from 11 rivers and one sound. Atlantic sturgeon incorporated into the baseline were either river-resident juveniles (<500 mm TL; RRJ) or adults (≥1,500 mm TL). Effective population size estimates were calculated with NeEstimator and are provided with 95% confidence intervals. Values over 400 were truncated for visualization.

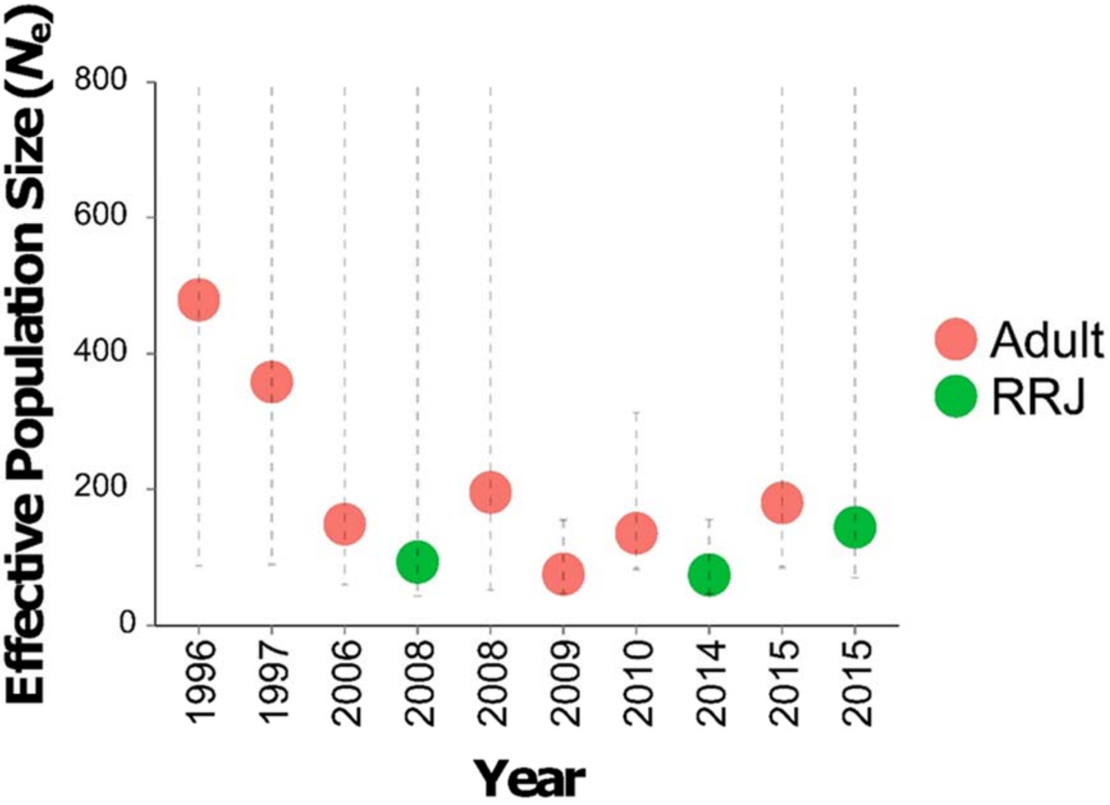


Figure 31. Comparison of effective population size estimates based on Atlantic sturgeon collections from 1996-2015. Sturgeon incorporated into the baseline were either river-resident juveniles (<500 mm TL; RRJ) or adults (≥1,500 mm TL). Effective population size estimates were calculated with NeEstimator and are provided with 95% confidence intervals. Values over 800 were truncated for visualization.

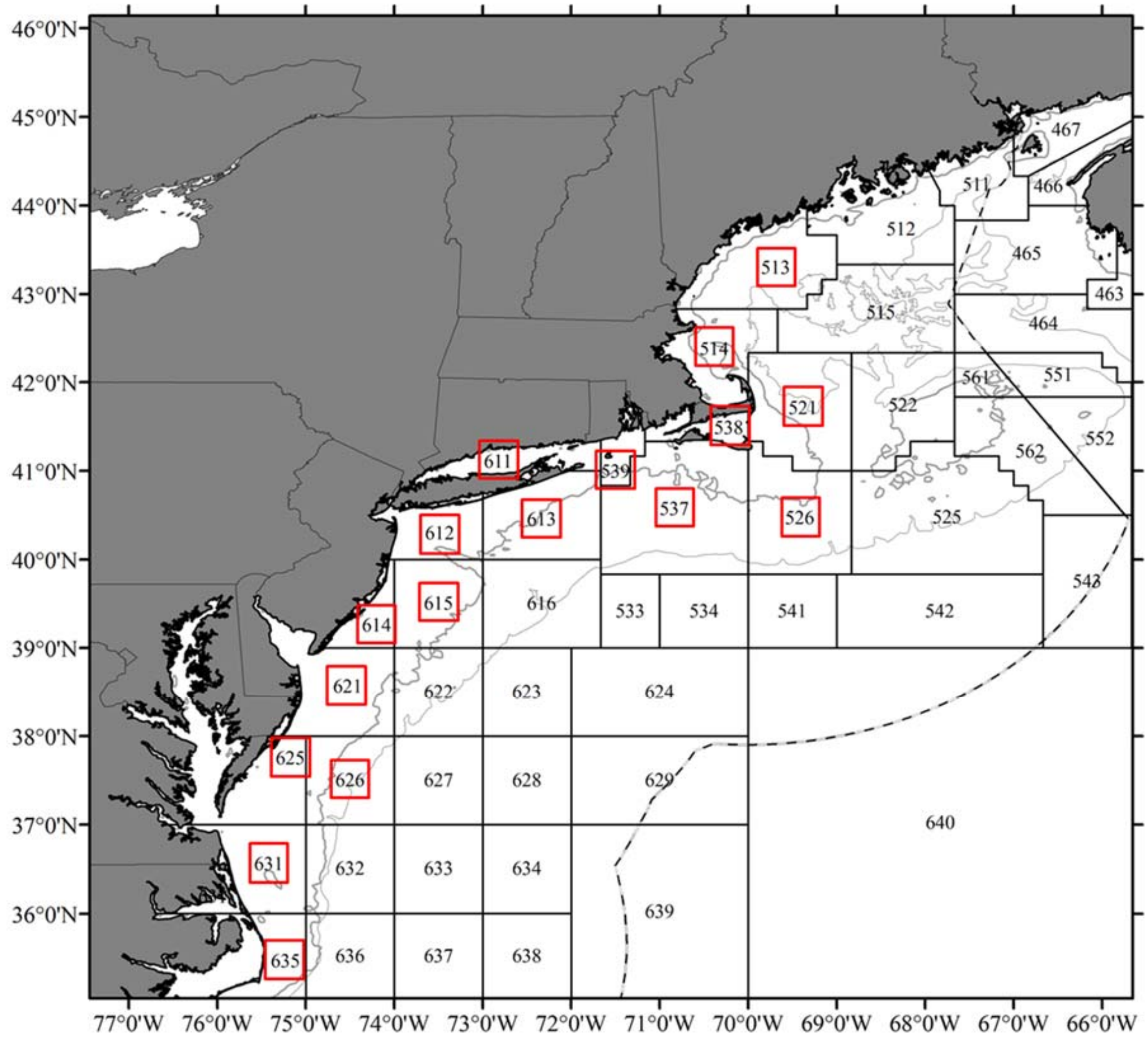


Figure 32. Statistical areas used for commercial fisheries data collection by the National Marine Fisheries Service in the Northeast Region. The 50 and 100 meter bathymetric lines are shown in light gray and the U.S. Exclusive Economic Zone is indicated by the dashed black line. Statistical areas included in the bycatch analysis are highlighted with red boxes.

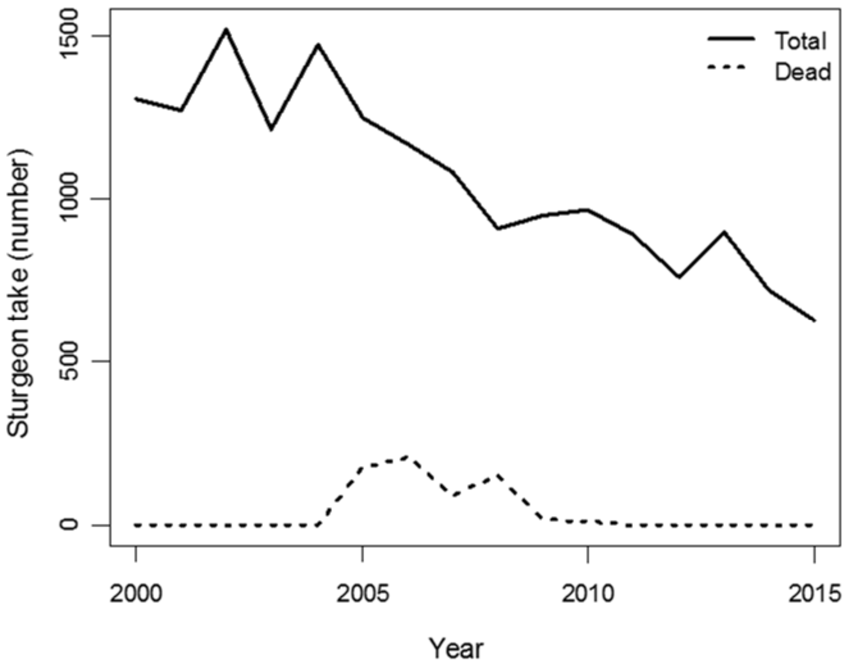


Figure 33. Annual total (solid line) and dead (dotted line) discard estimates from NMFS observer programs for coastal ocean bottom otter trawls from 2000 – 2015.

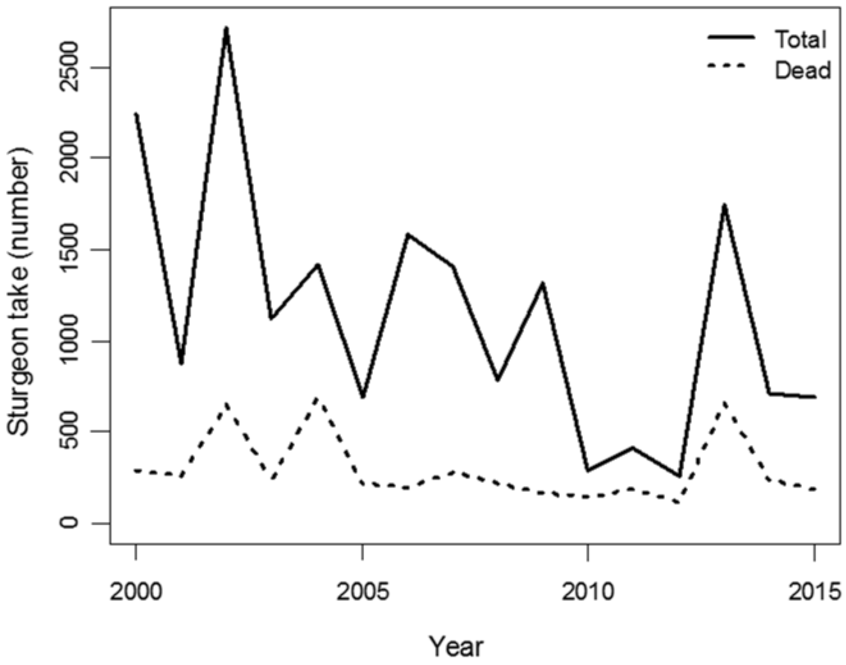


Figure 34. Annual total (solid line) and dead (dotted line) discard estimates from NMFS observer programs for coastal ocean drift and sink gillnets from 2000 – 2015.

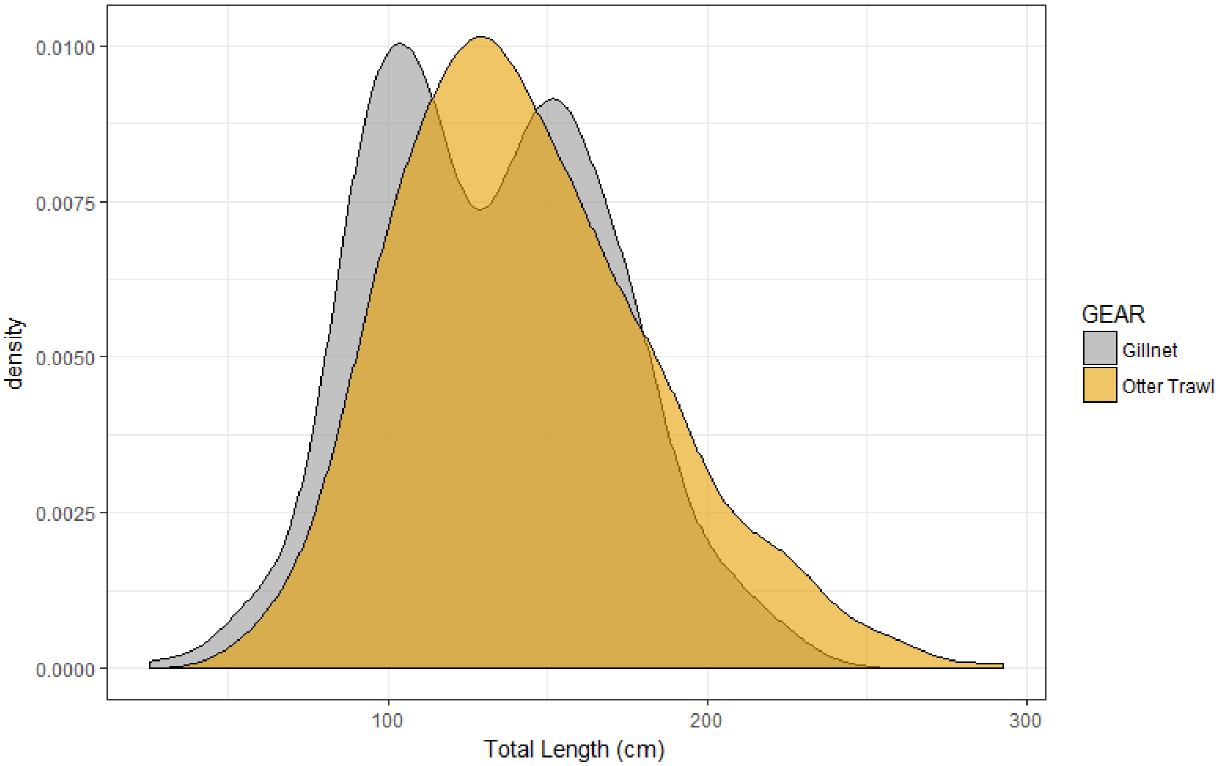


Figure 35. Length frequency distribution of Atlantic sturgeon encountered in the NMFS observer programs by gear.

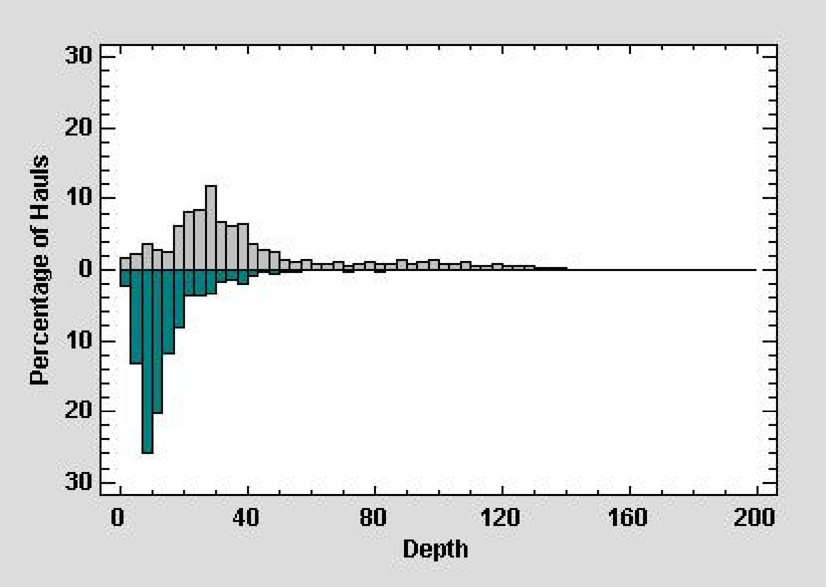


Figure 36. Distribution of haul depths (m) on NMFS-observed hauls encountering sturgeon (teal bars, n=2,773) compared to those that did not encounter sturgeon (gray bars, n=453,799).

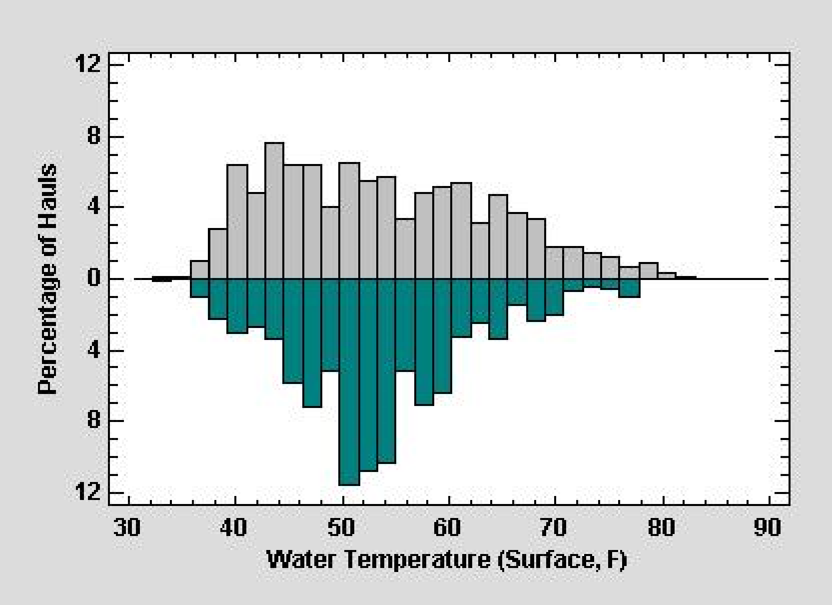


Figure 37. Distribution of surface water temperature on NMFS-observed hauls encountering sturgeon (teal bars, n=2,343) compared to those that did not encounter sturgeon (gray bars, n=352,450).

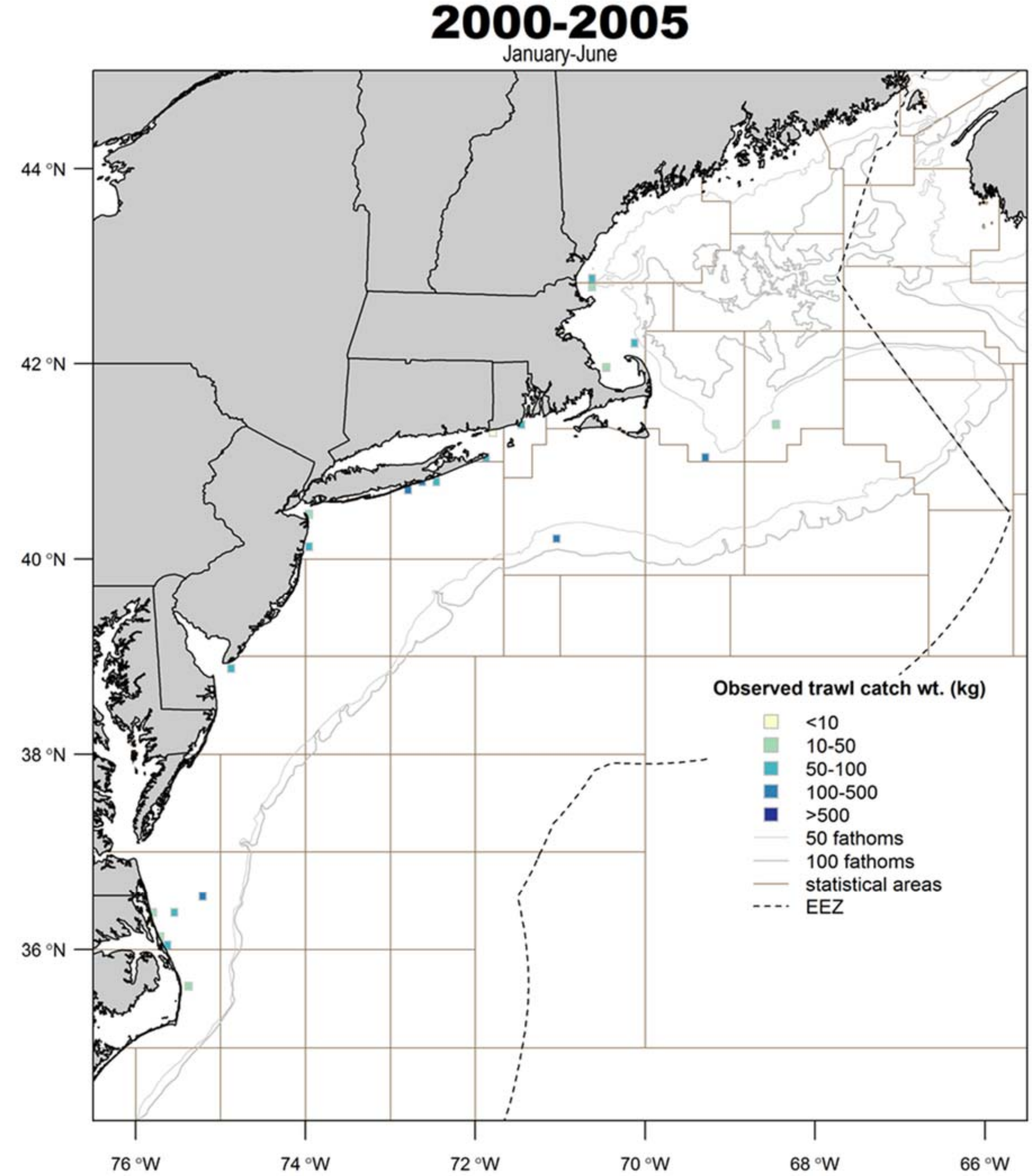


Figure 38. Total weight of encountered Atlantic sturgeon by five-year bins in bottom otter trawls during the first semester by from all federal observer programs included in the bycatch estimation.

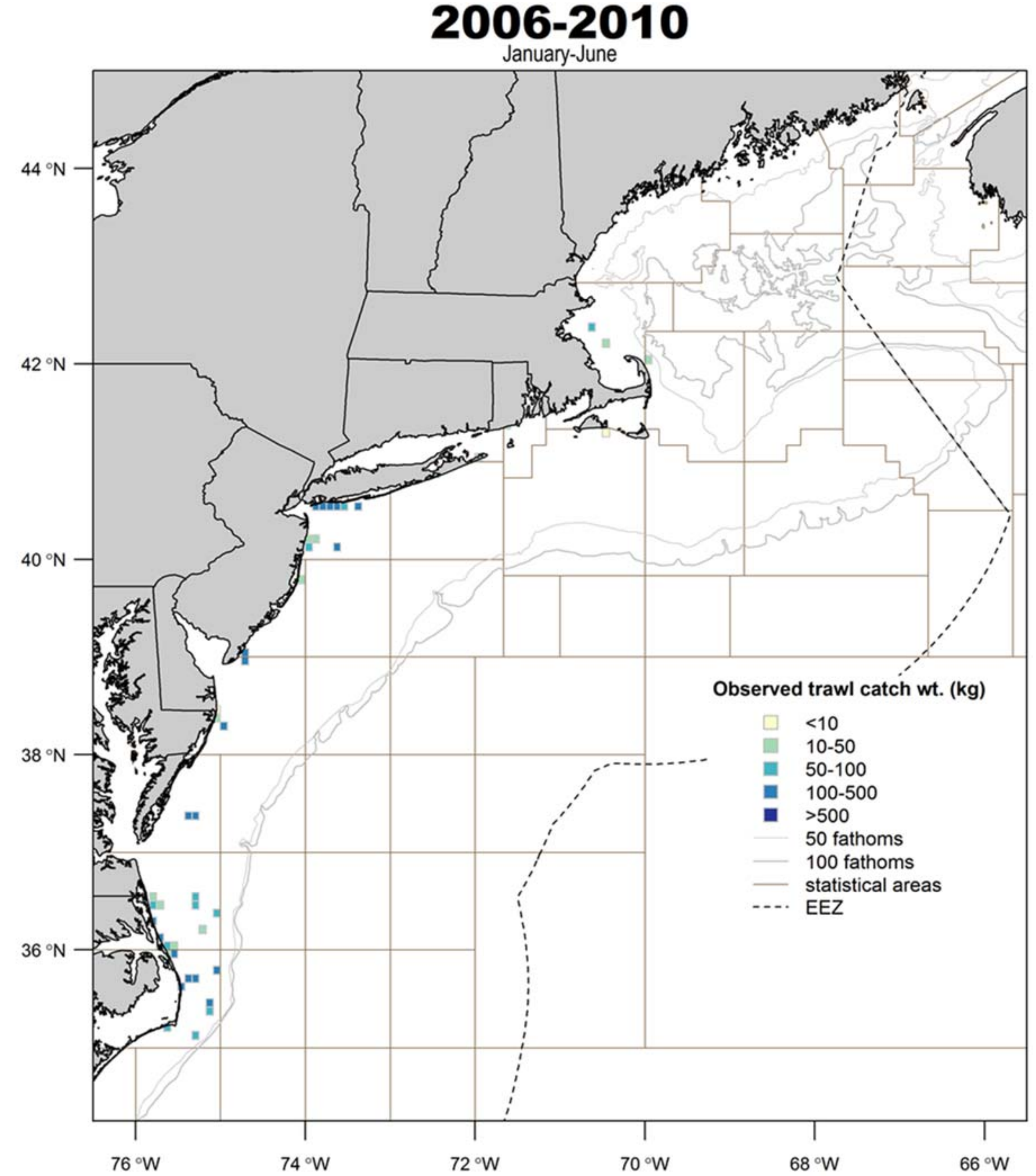


Figure 38 (*continued*)

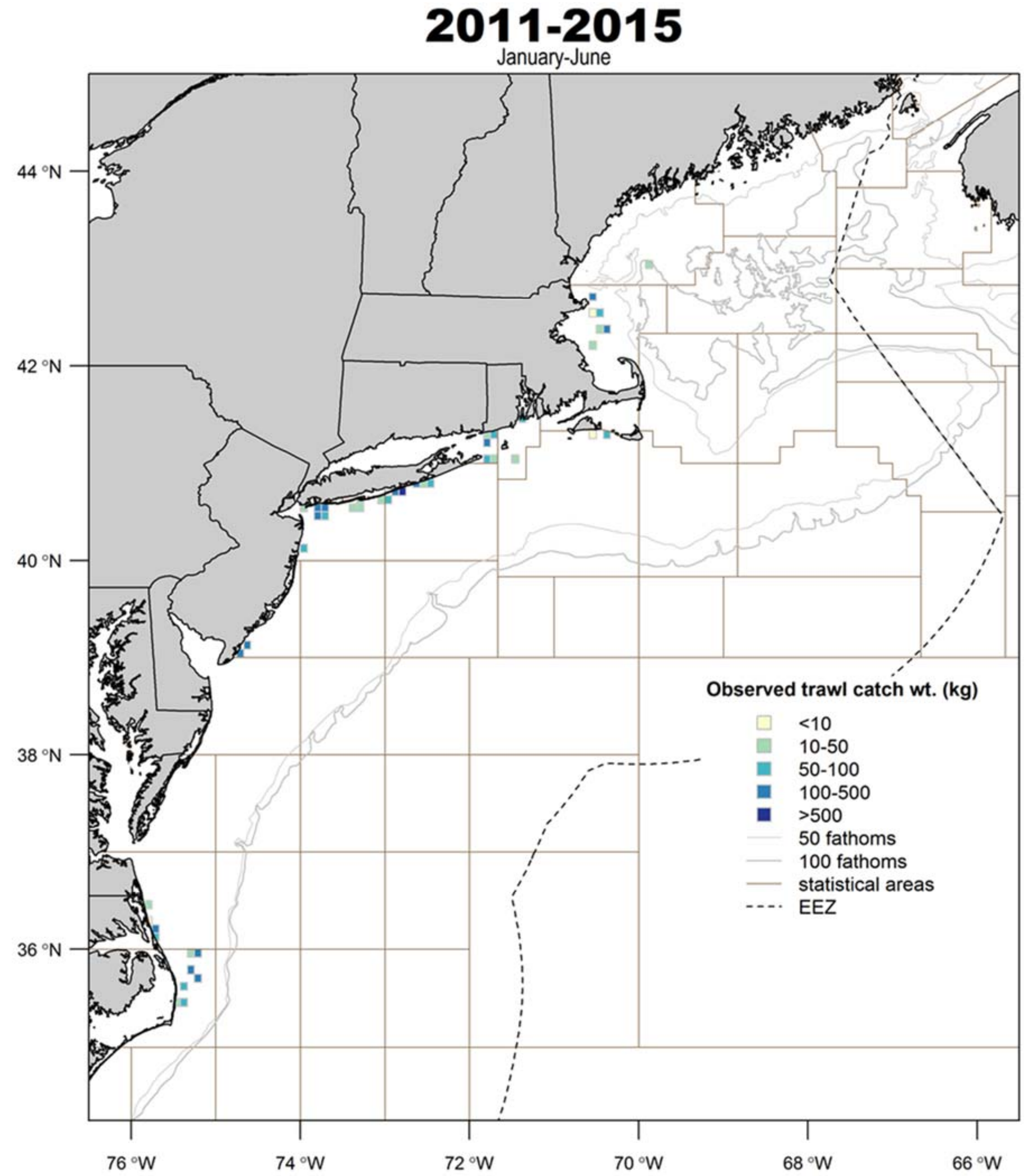


Figure 38 (*continued*)

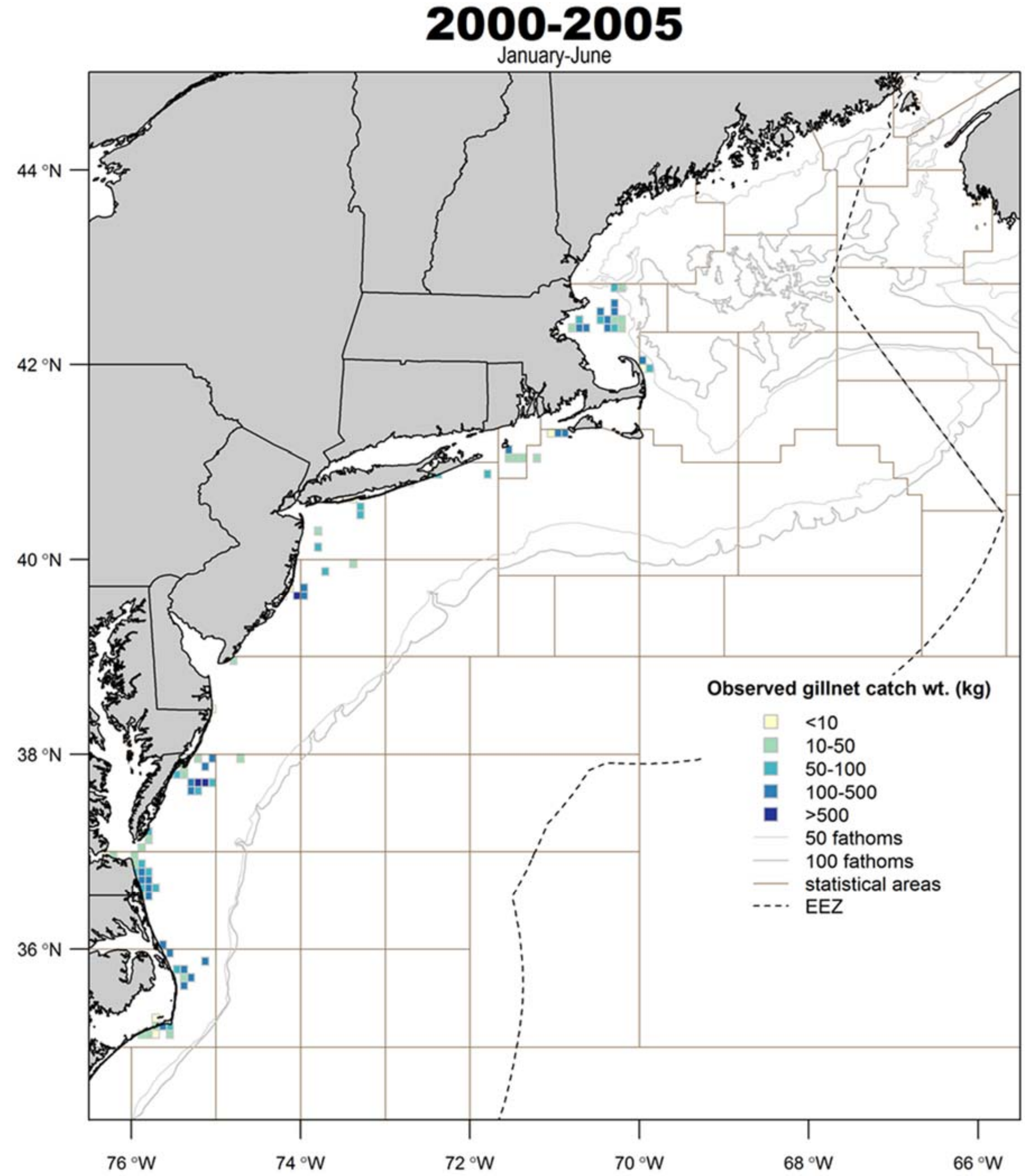
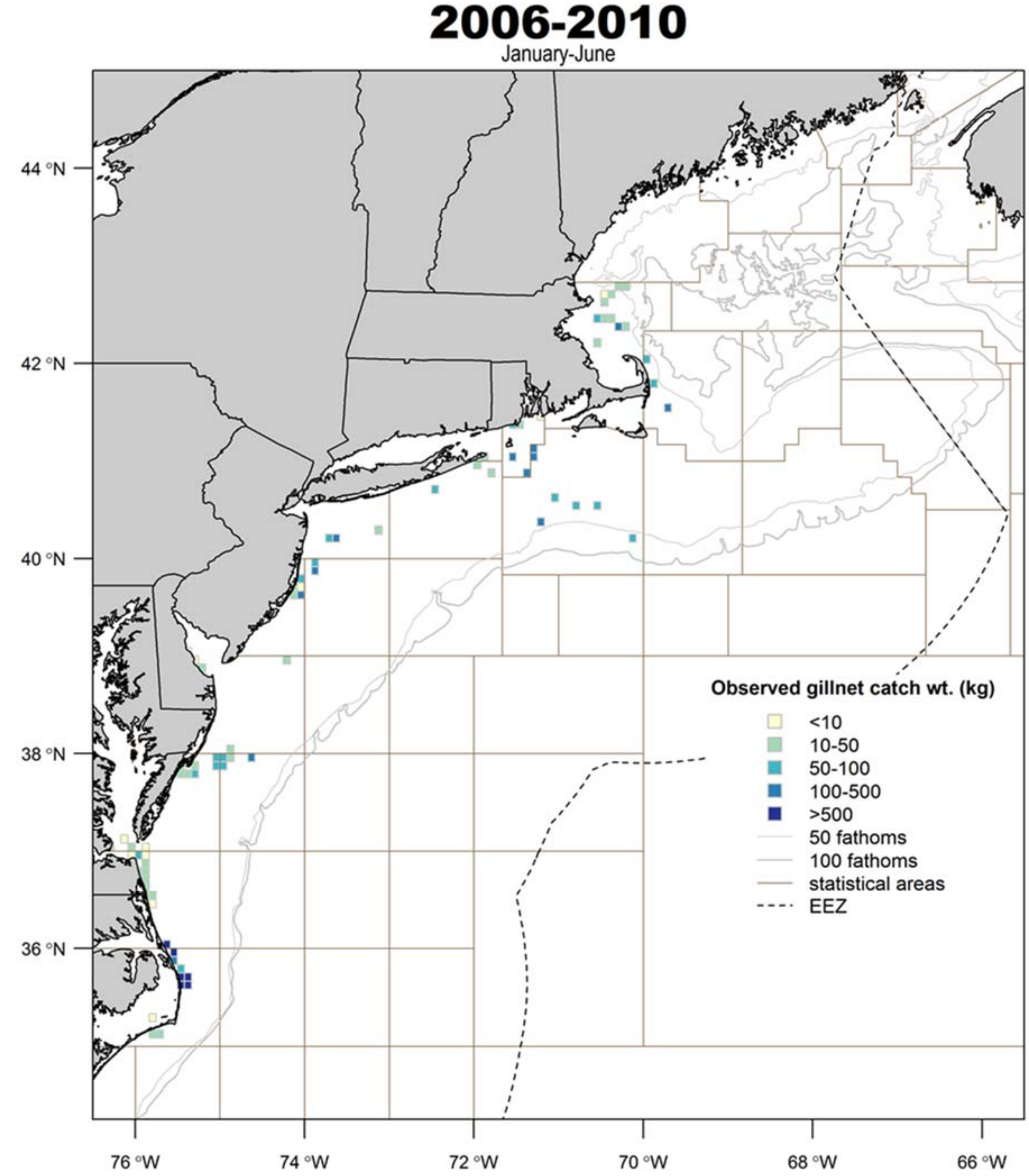


Figure 39. Total weight of encountered Atlantic sturgeon by five-year bins in sink and drift gillnets during the first semester by from all federal observer programs included in the bycatch estimation.



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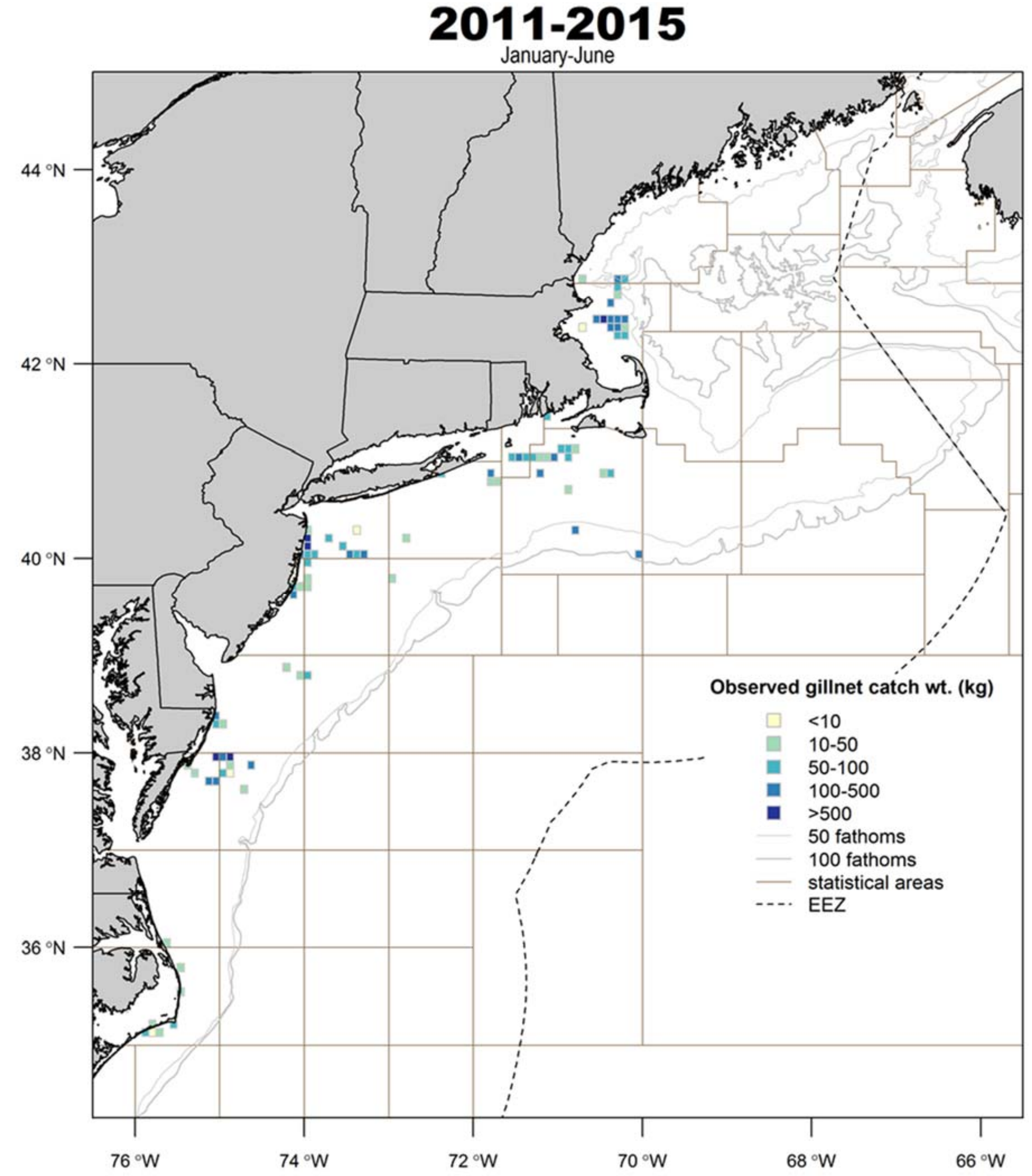


Figure 39 (*continued*)

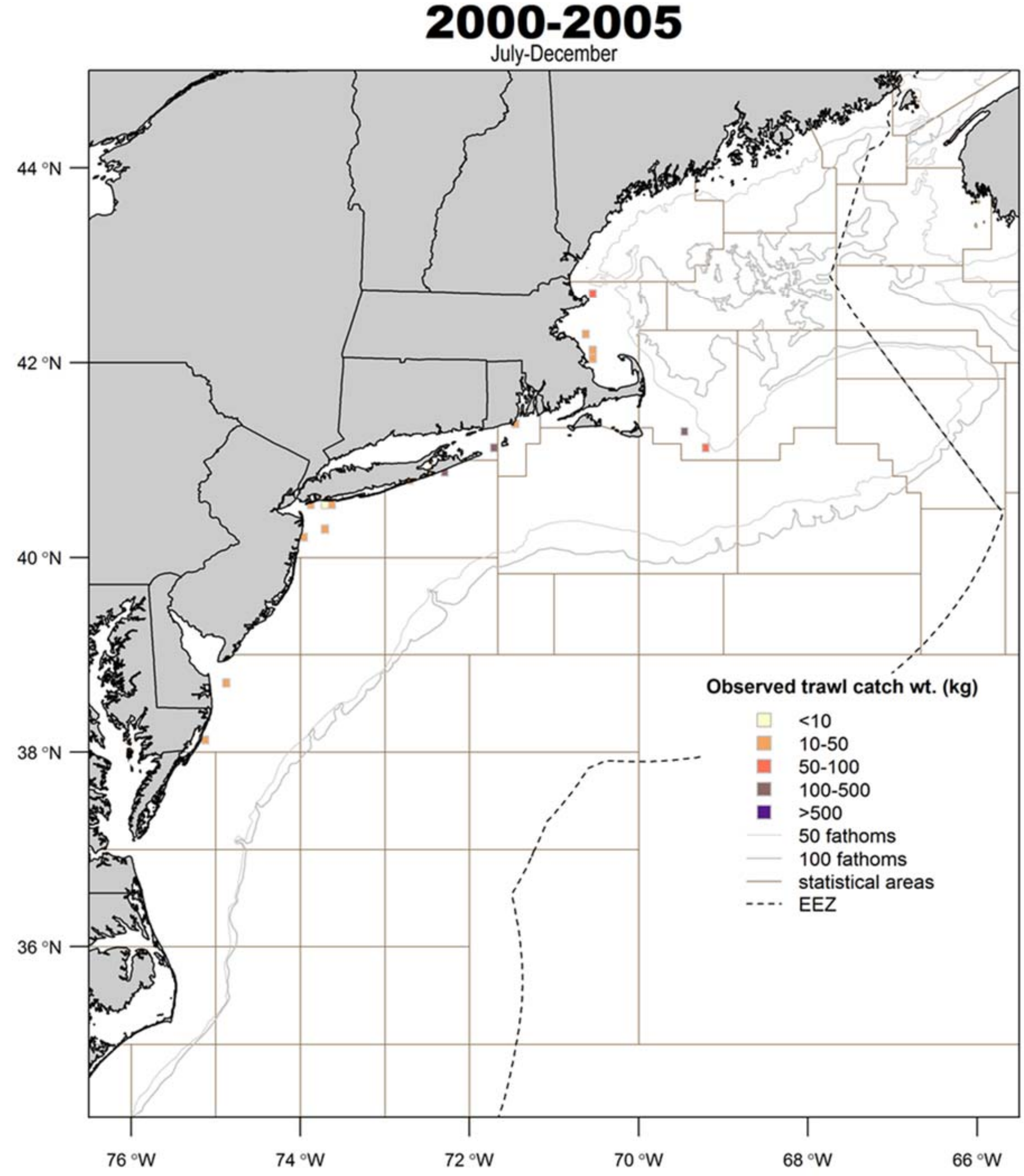
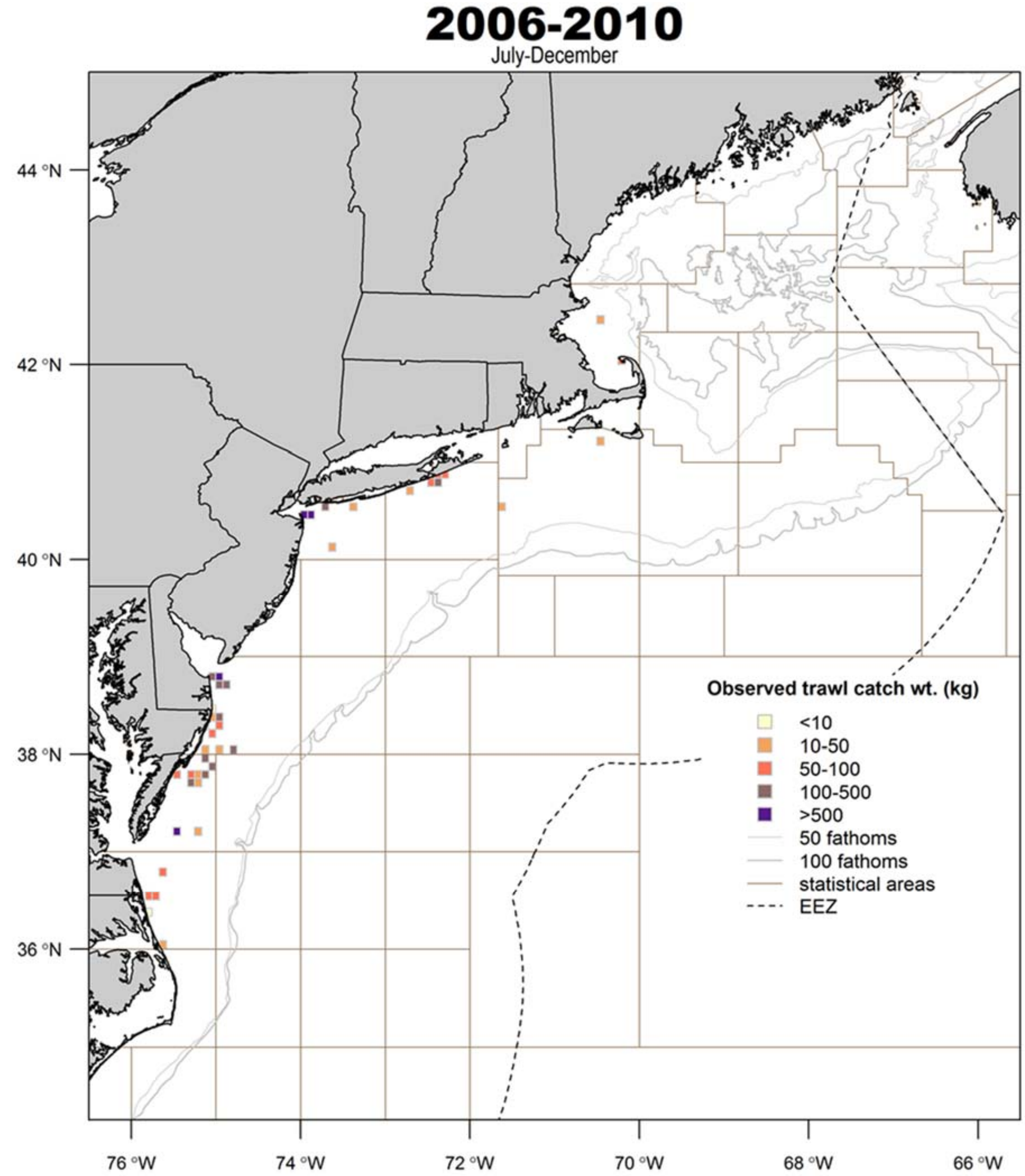


Figure 40. Total weight of encountered Atlantic sturgeon by five-year bins in bottom otter trawls during the second semester by from all federal observer programs included in the bycatch estimation.



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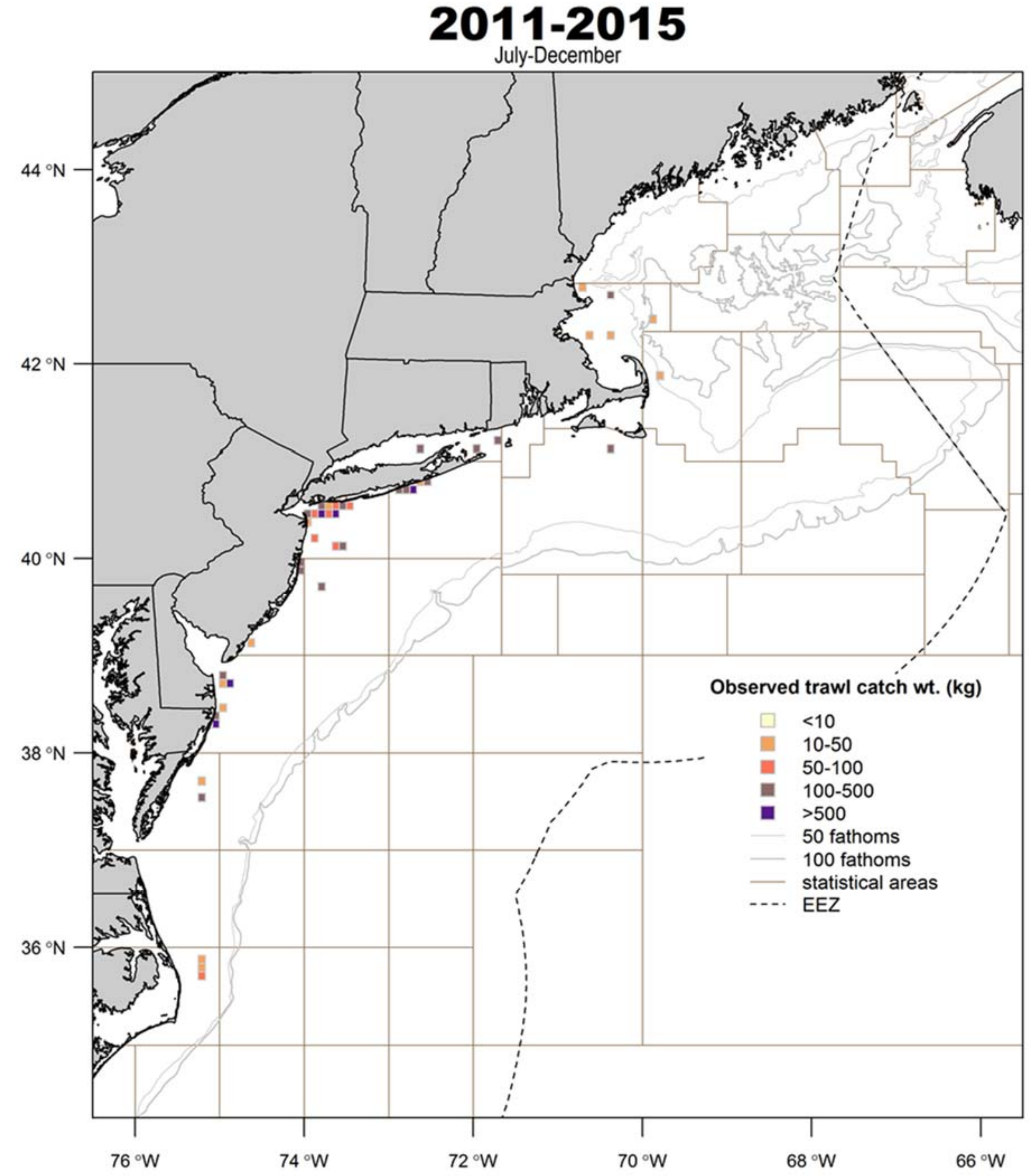


Figure 40 (*continued*)

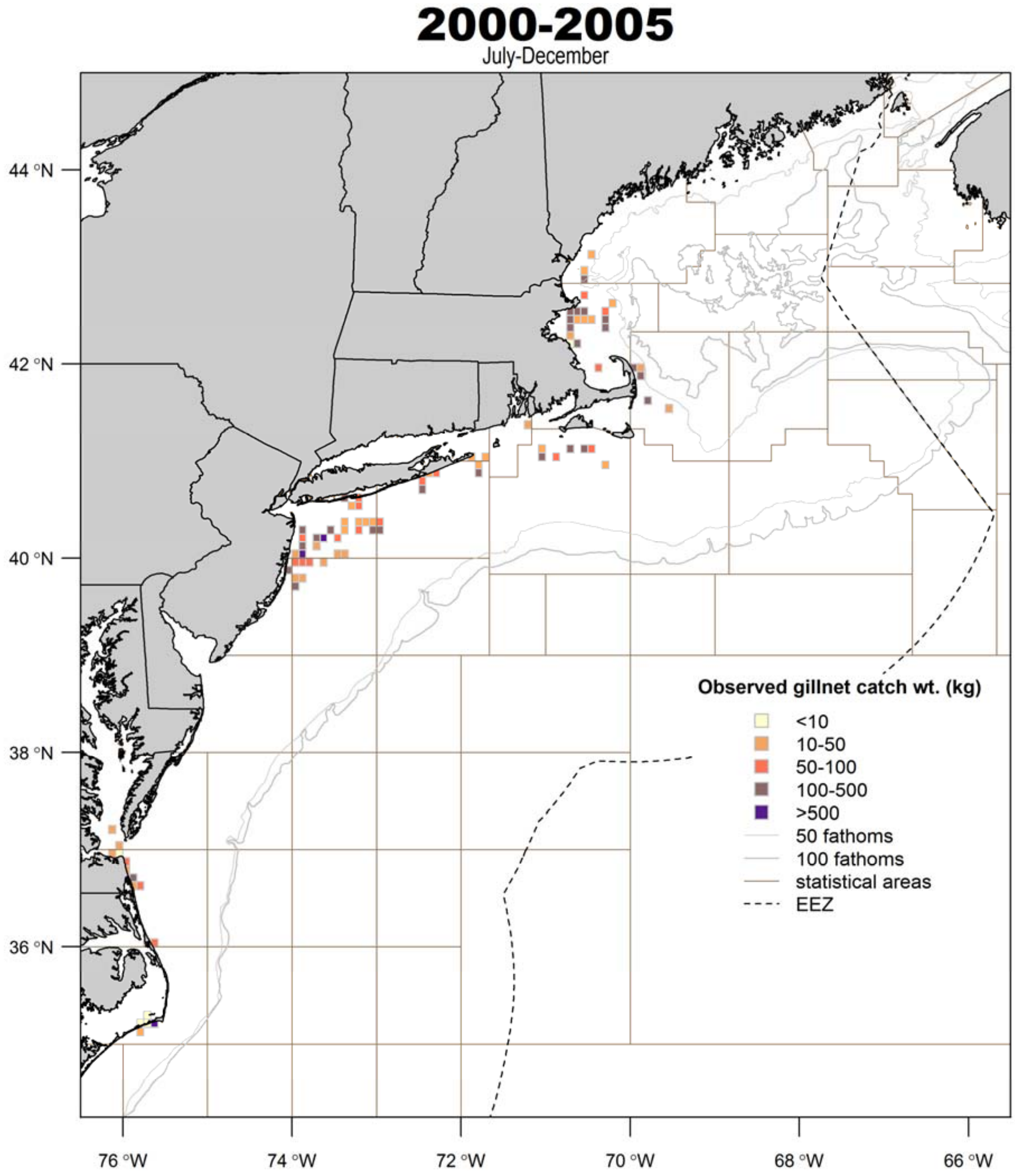
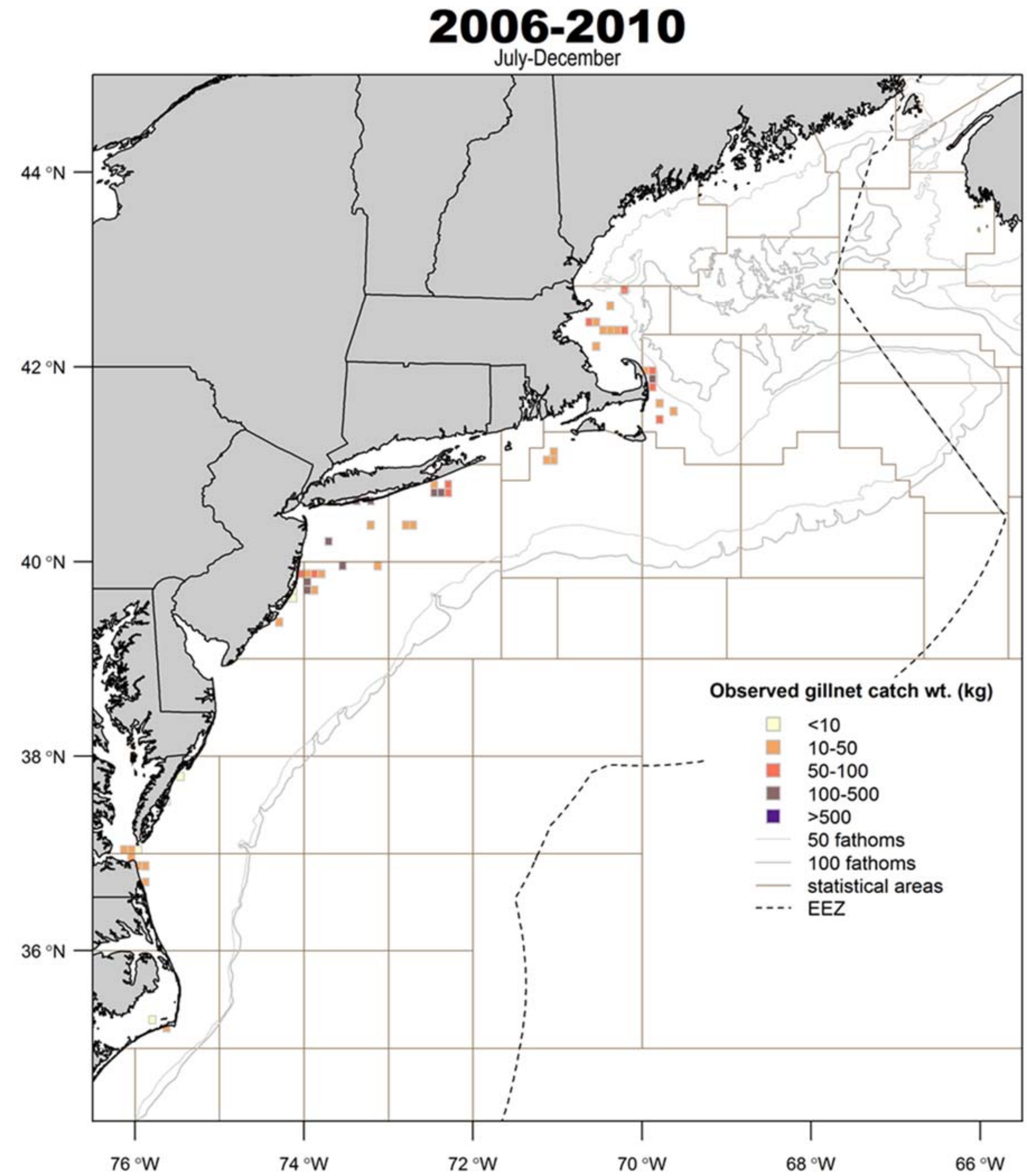


Figure 41. Total weight of encountered Atlantic sturgeon by five-year bins in sink and drift gillnets during the second semester by from all federal observer programs included in the bycatch estimation.



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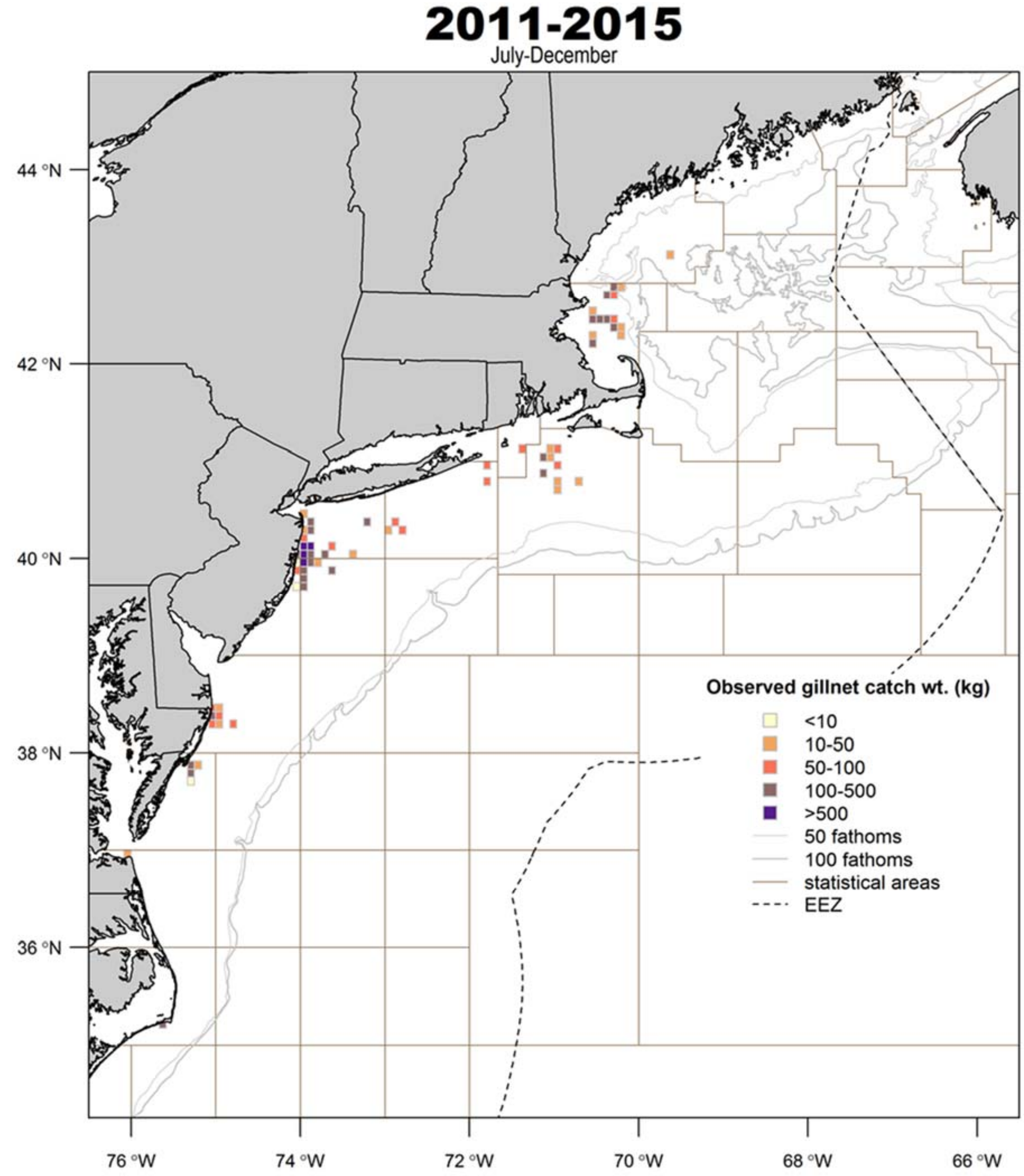


Figure 41 (*continued*)

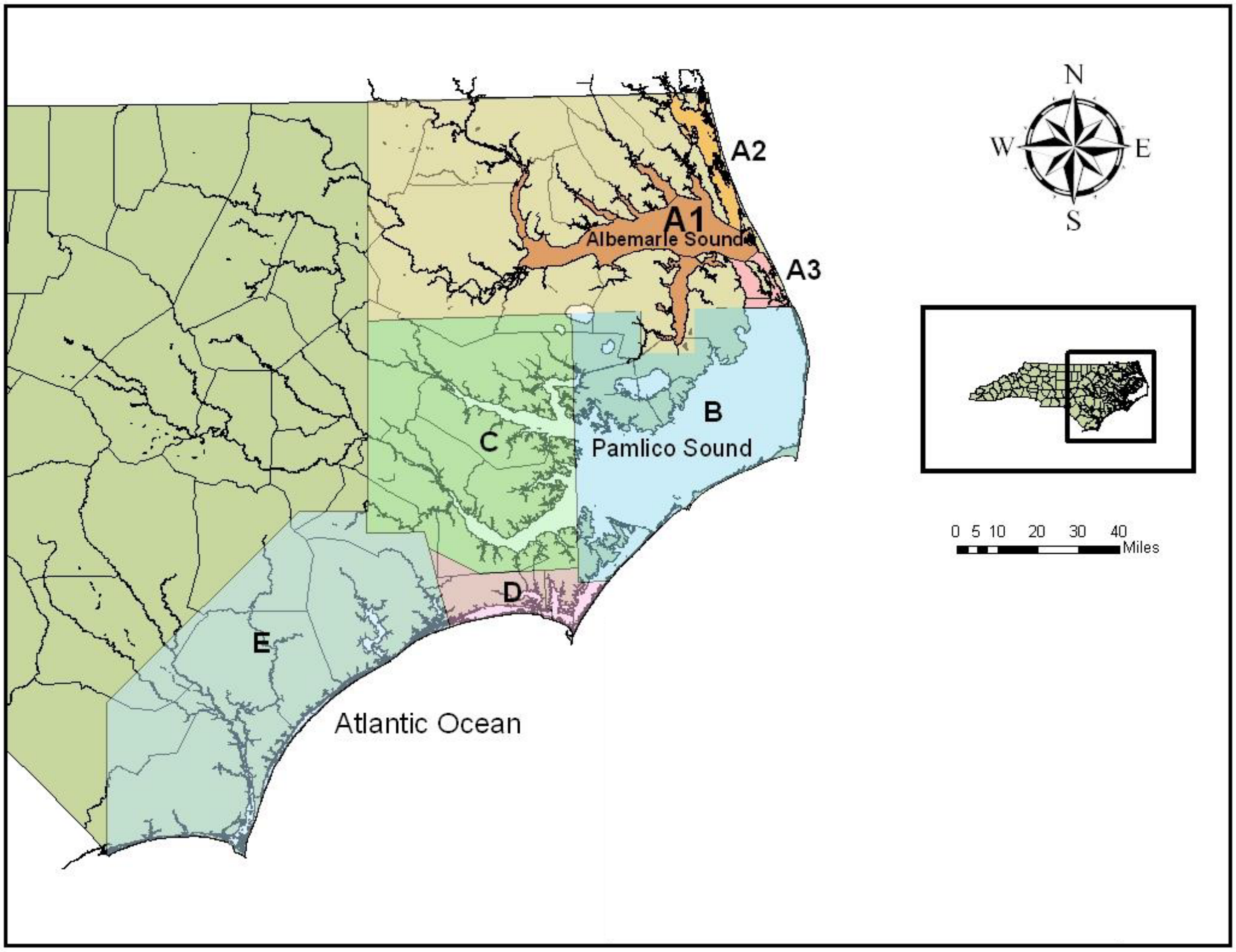


Figure 42. Management unit areas used by the NCDMF's observer programs.

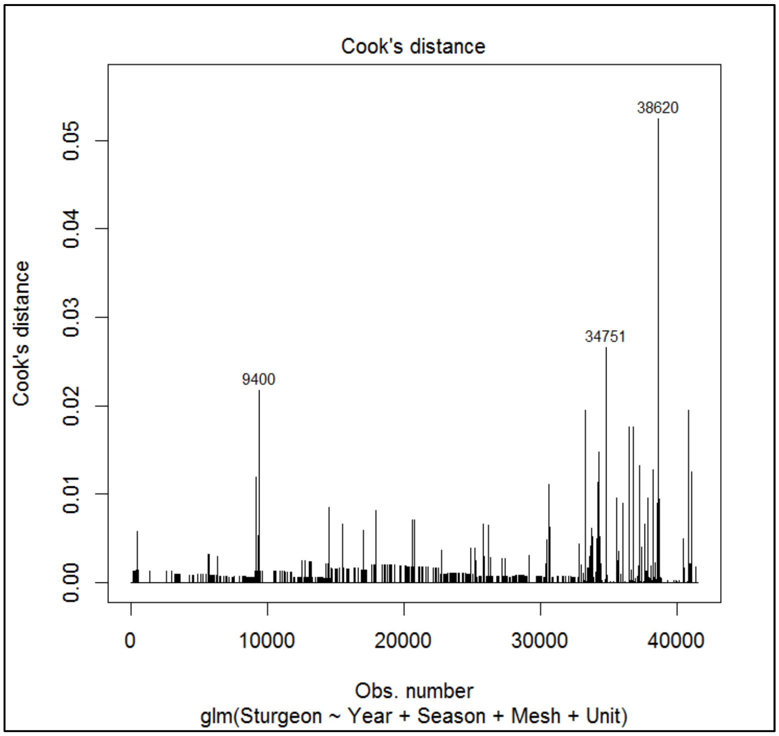


Figure 43. Cook's distance values of the Poisson GLM fit to the NCDMF Atlantic sturgeon bycatch data.

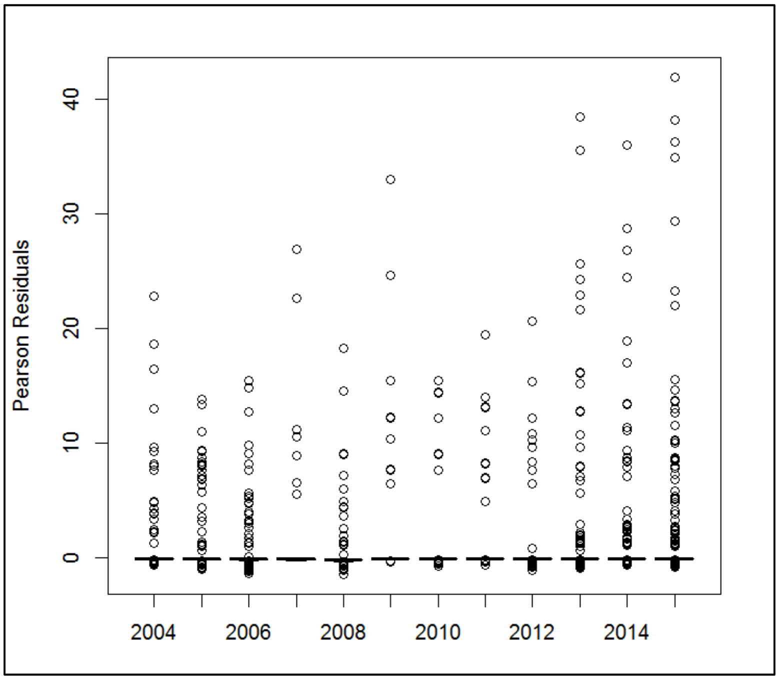


Figure 44. Pearson residuals by year for the Poisson GLM fit to the NCDMF Atlantic sturgeon bycatch data.

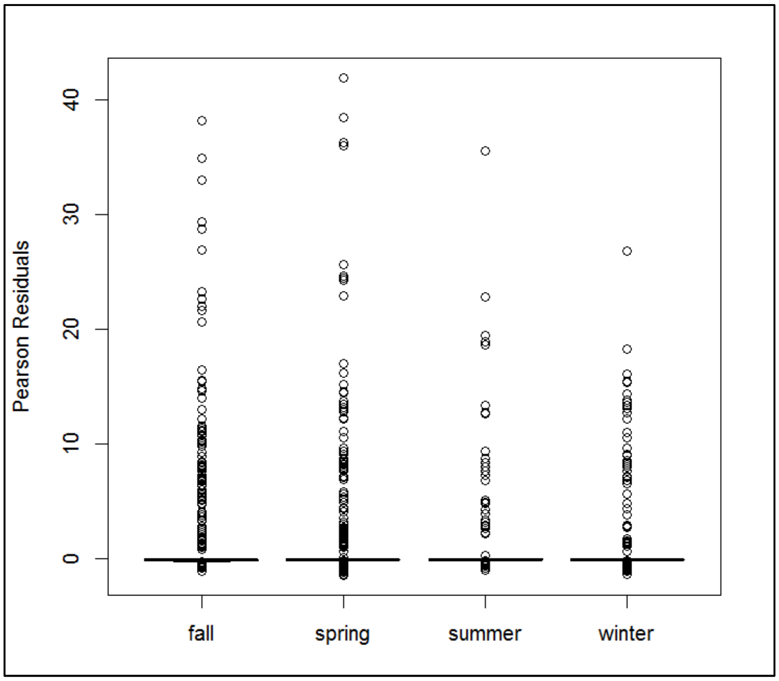


Figure 45. Pearson residuals by season for the Poisson GLM fit to the NCDMF Atlantic sturgeon bycatch data.

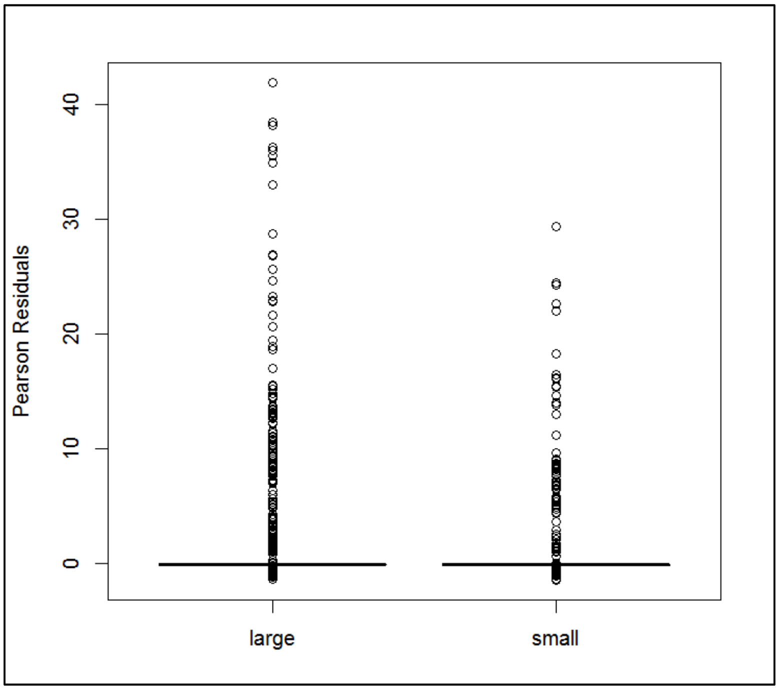


Figure 46. Pearson residuals by mesh size for the Poisson GLM fit to the NCDMF Atlantic sturgeon bycatch data.

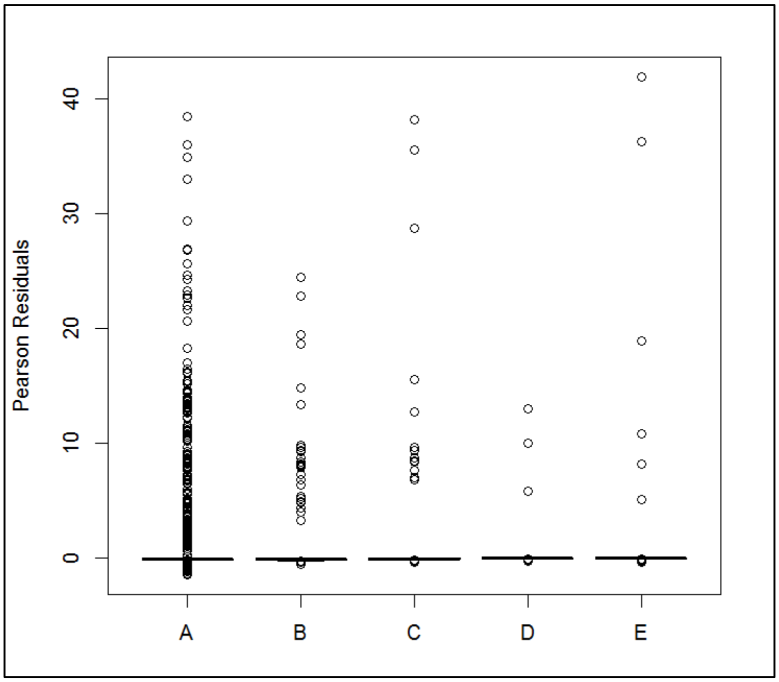


Figure 47. Pearson residuals by management unit for the Poisson GLM fit to the NCDMF Atlantic sturgeon bycatch data.

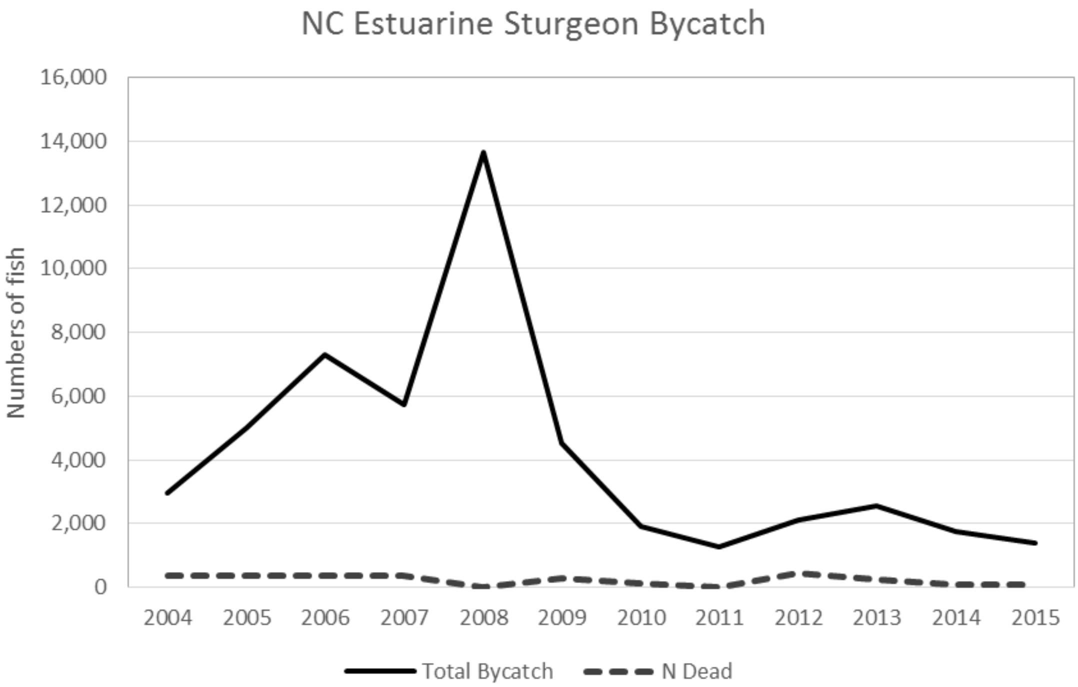


Figure 48. Estimates of total numbers and numbers of dead Atlantic sturgeon caught as bycatch from the North Carolina monitoring programs.

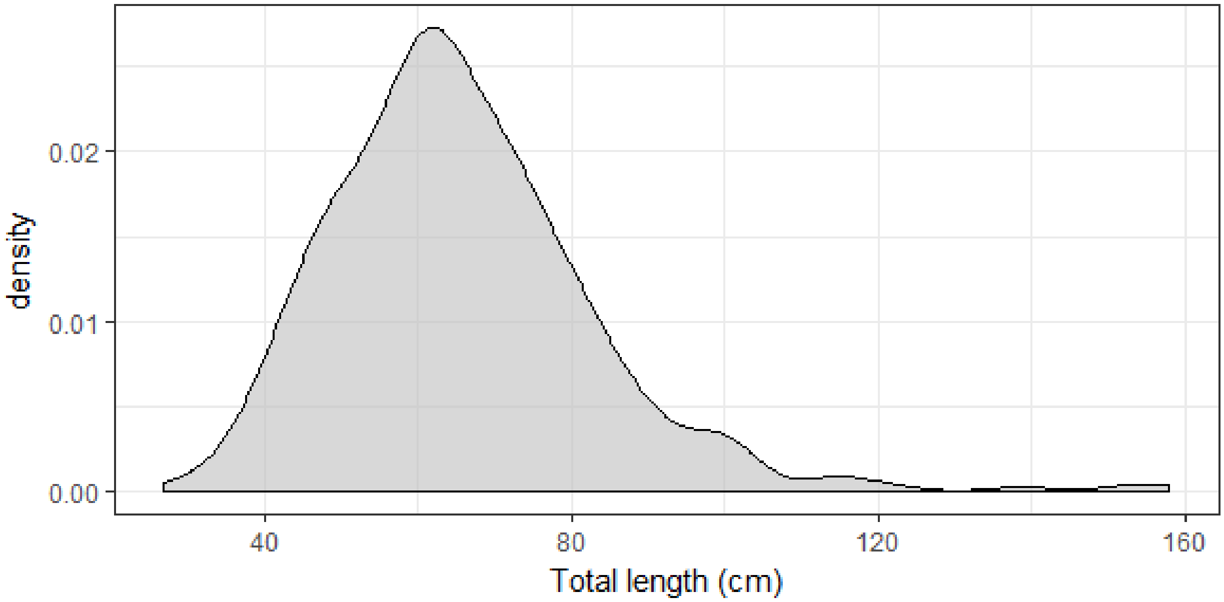


Figure 49. Length frequency distribution of Atlantic sturgeon encountered in the North Carolina gillnet observer programs.

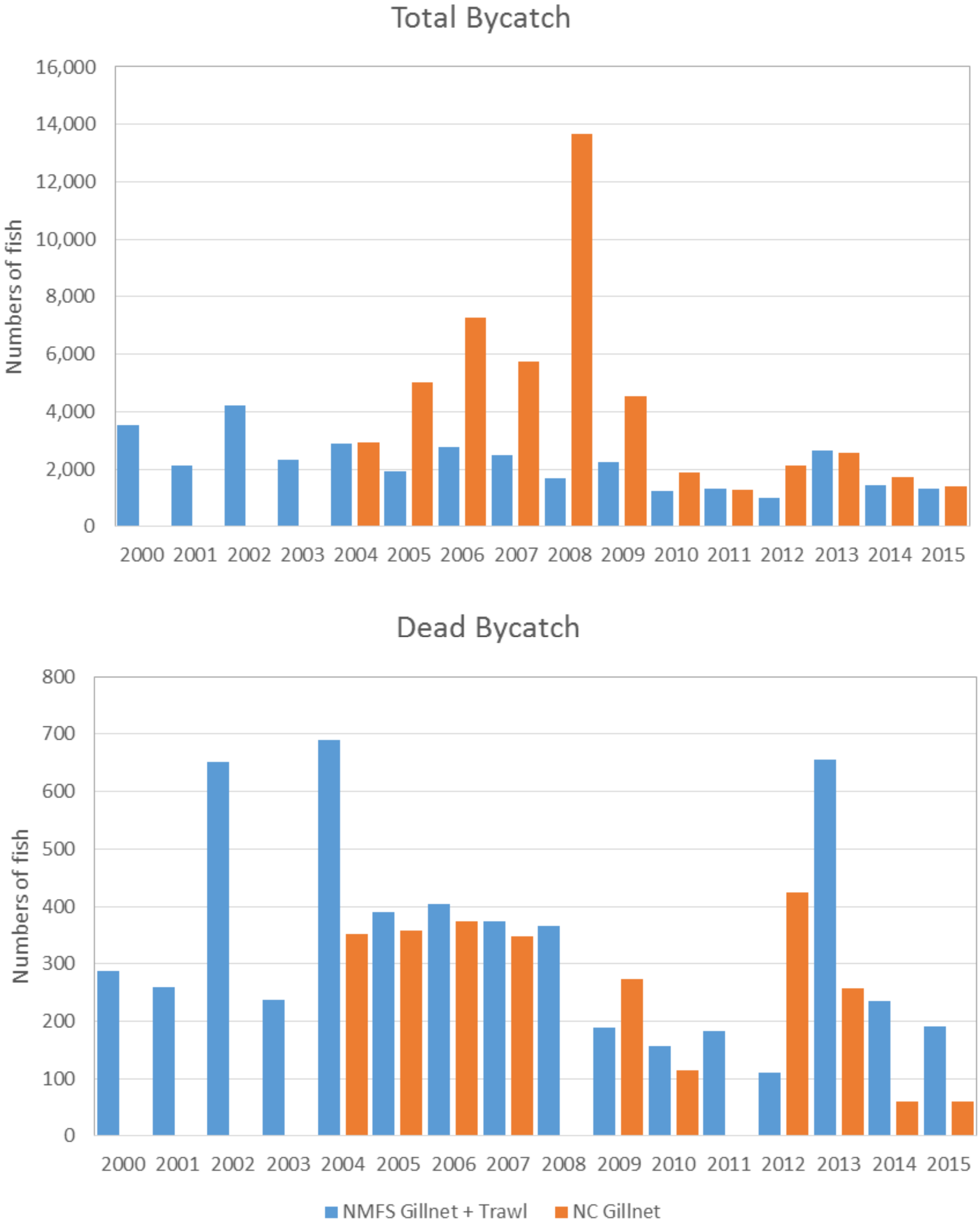


Figure 50. Comparison of total bycatch estimates (top) and dead bycatch estimates (bottom) from the NMFS and North Carolina observer programs.

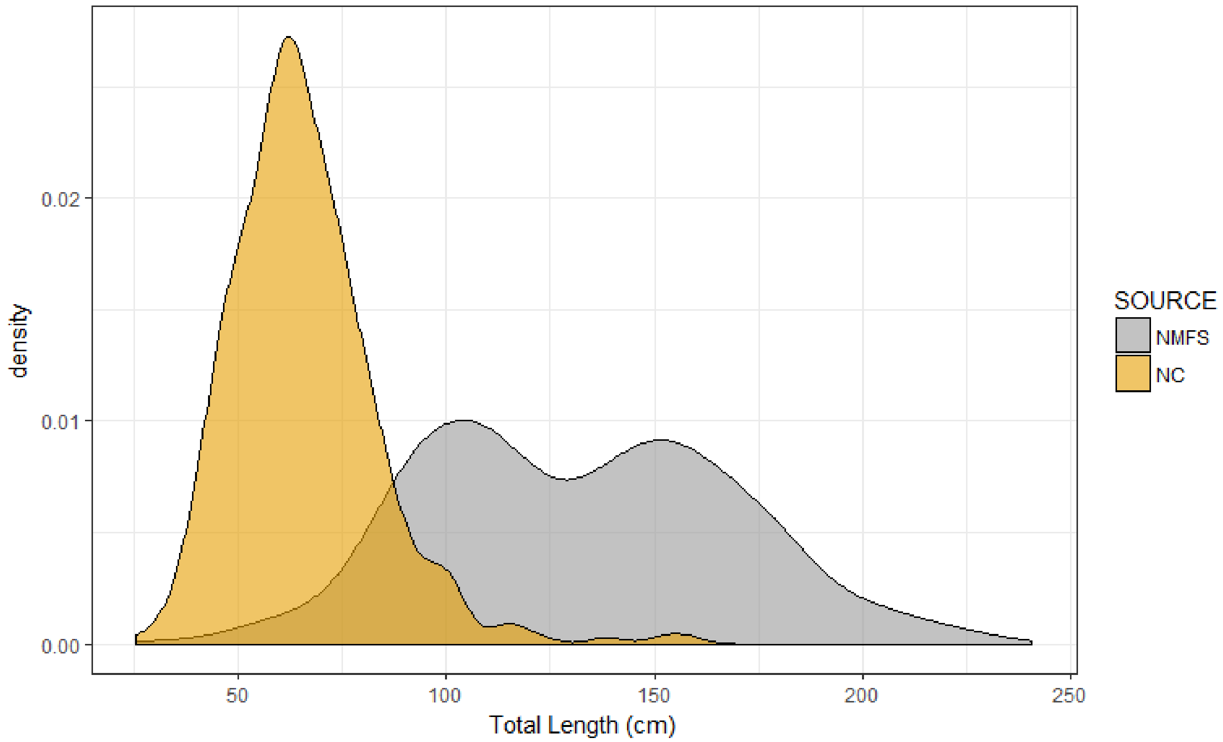


Figure 51. Comparison of size distributions of Atlantic sturgeon caught in gillnets from the NMFS and North Carolina observer programs.

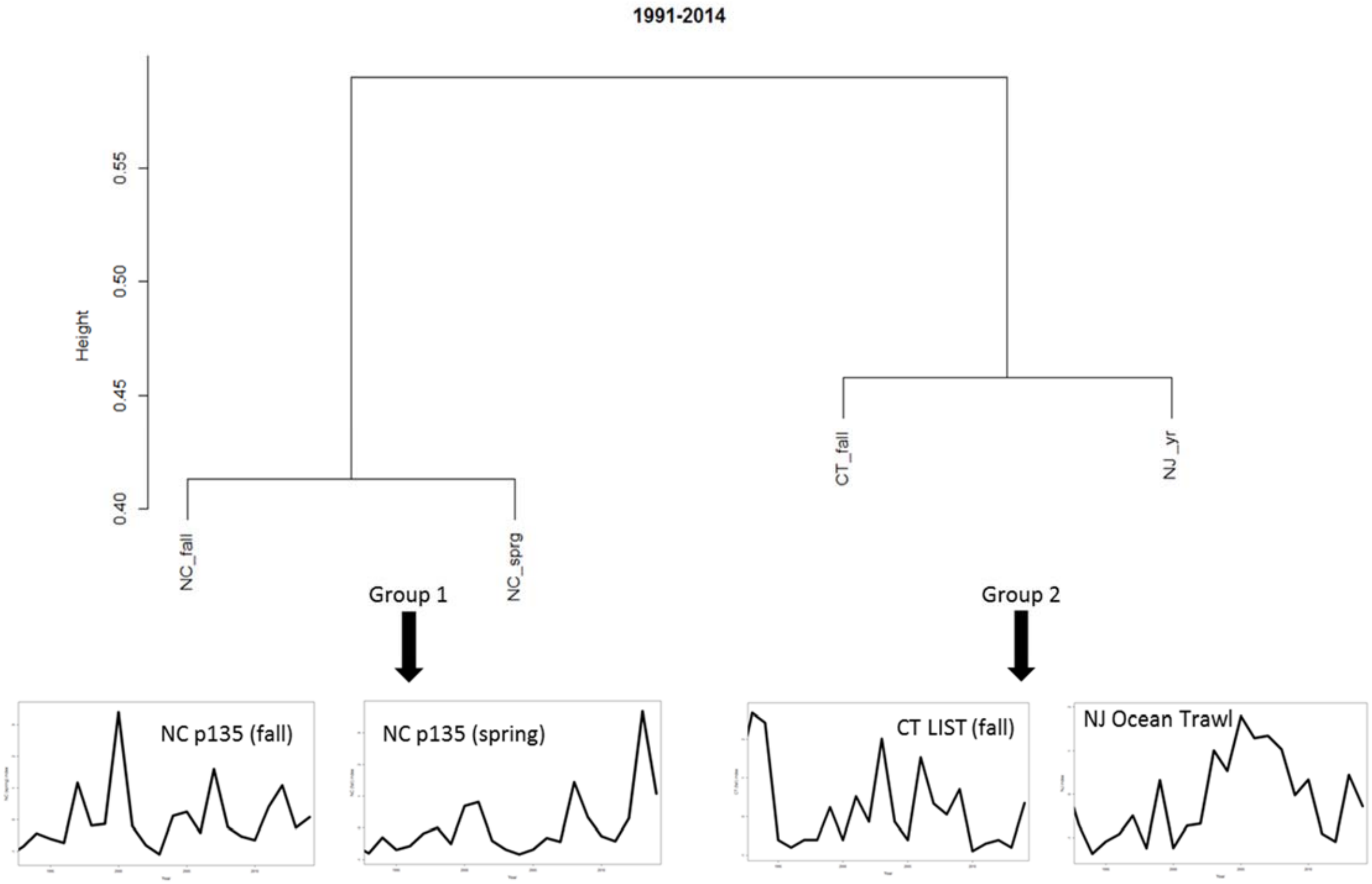


Figure 52. Cluster dendrogram and plots of the normalized index for each fishery-independent survey trend included in the cluster analysis for 1991-2014. If a survey was restricted to season it is specified as fall or spring, otherwise they are considered year-round surveys or "_yr."

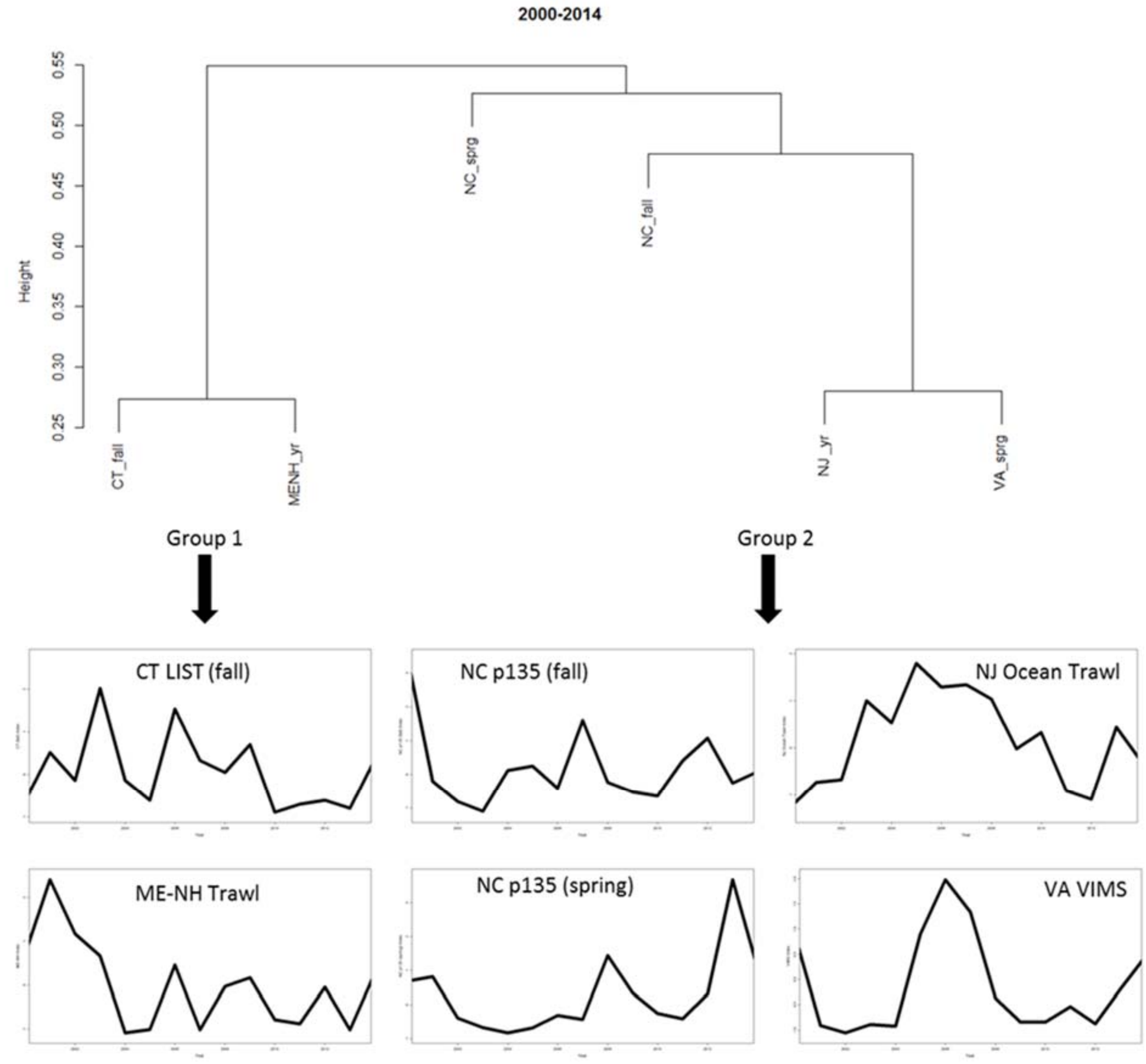


Figure 53. Cluster dendrogram and plots of the normalized index for each fishery-independent survey trend included in the cluster analysis for 2000-2014. If a survey was restricted to season it is specified as fall or spring, otherwise they are considered year-round surveys or "_yr."

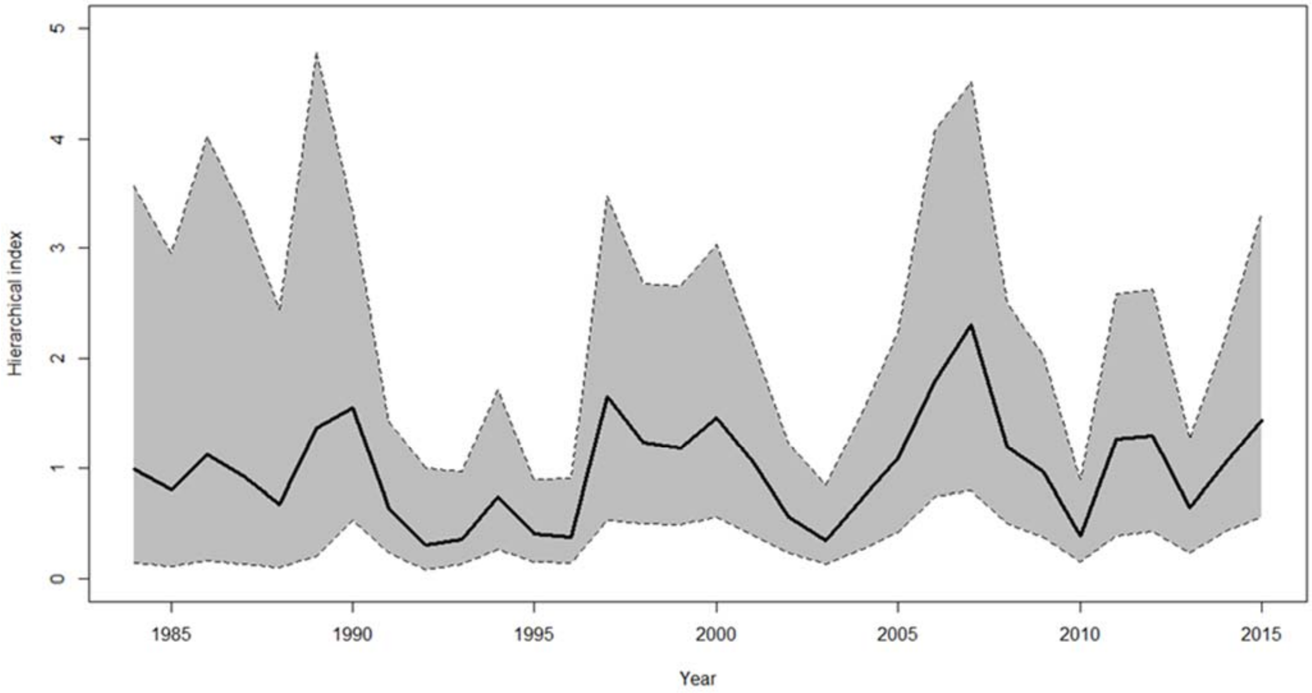


Figure 54. Time series of coastwide juvenile and adult Atlantic sturgeon relative abundance as estimated from hierarchical analysis. The black line gives the posterior mean and the grey, shaded area represents a 95% credible interval about the time series.

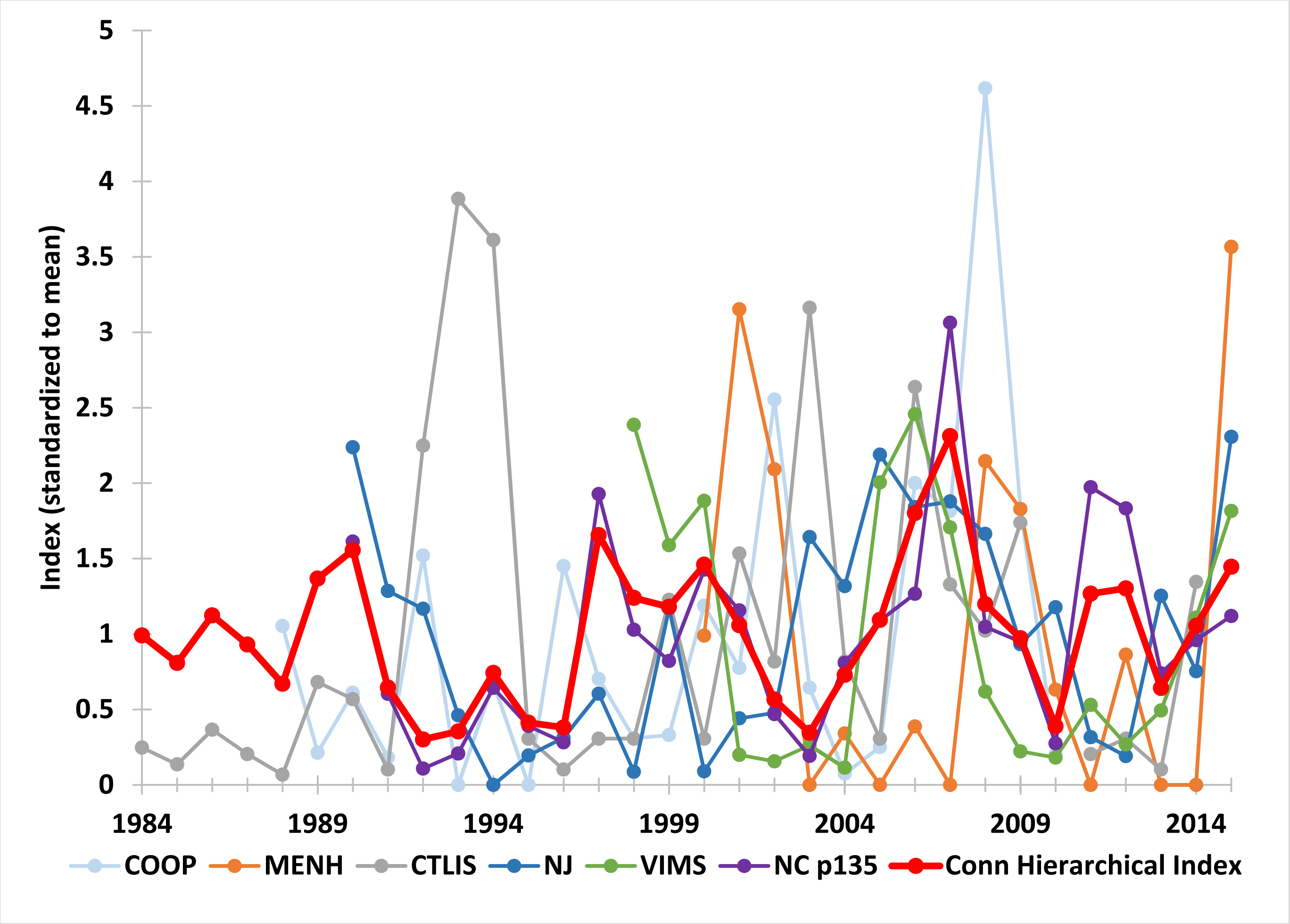


Figure 55. The hierarchical index developed using the Conn method (bold red line) shown with the six abundance indices which have been standardized to their mean.

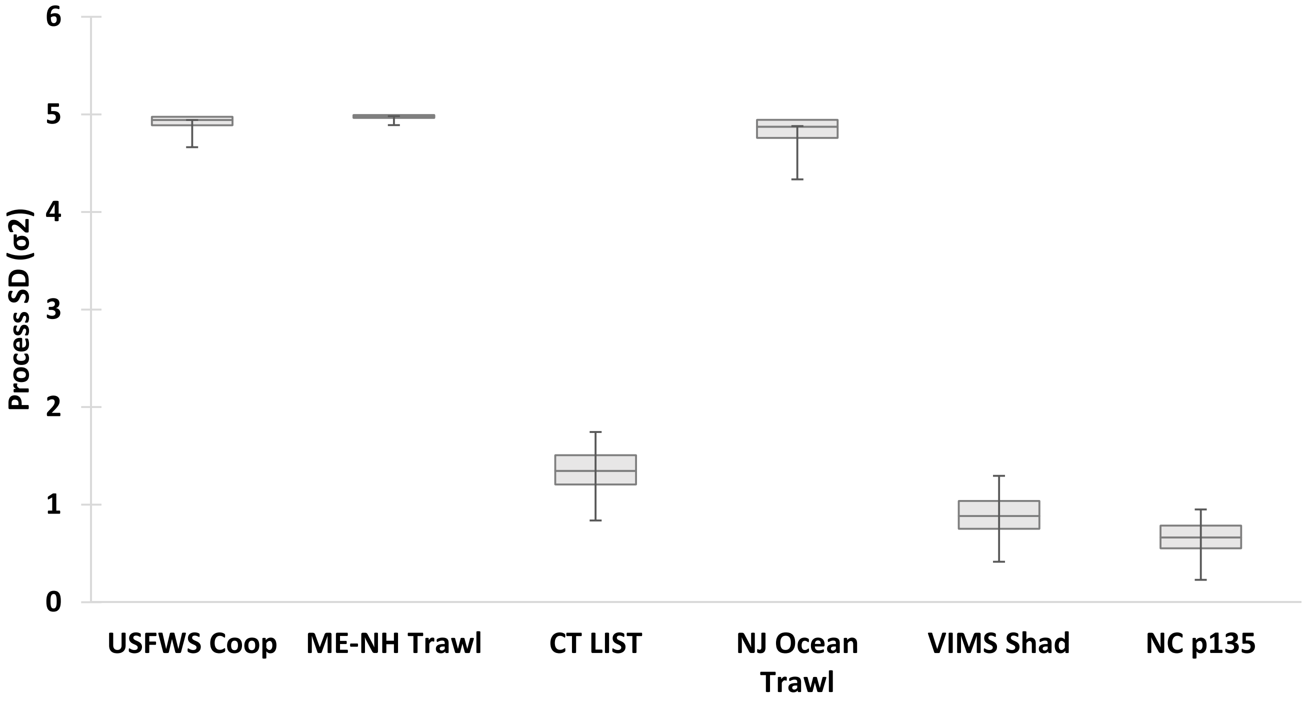


Figure 56. Posterior means and 95% credible intervals for the standard deviation of process error (σ^P) for the six indices of Atlantic sturgeon abundance.

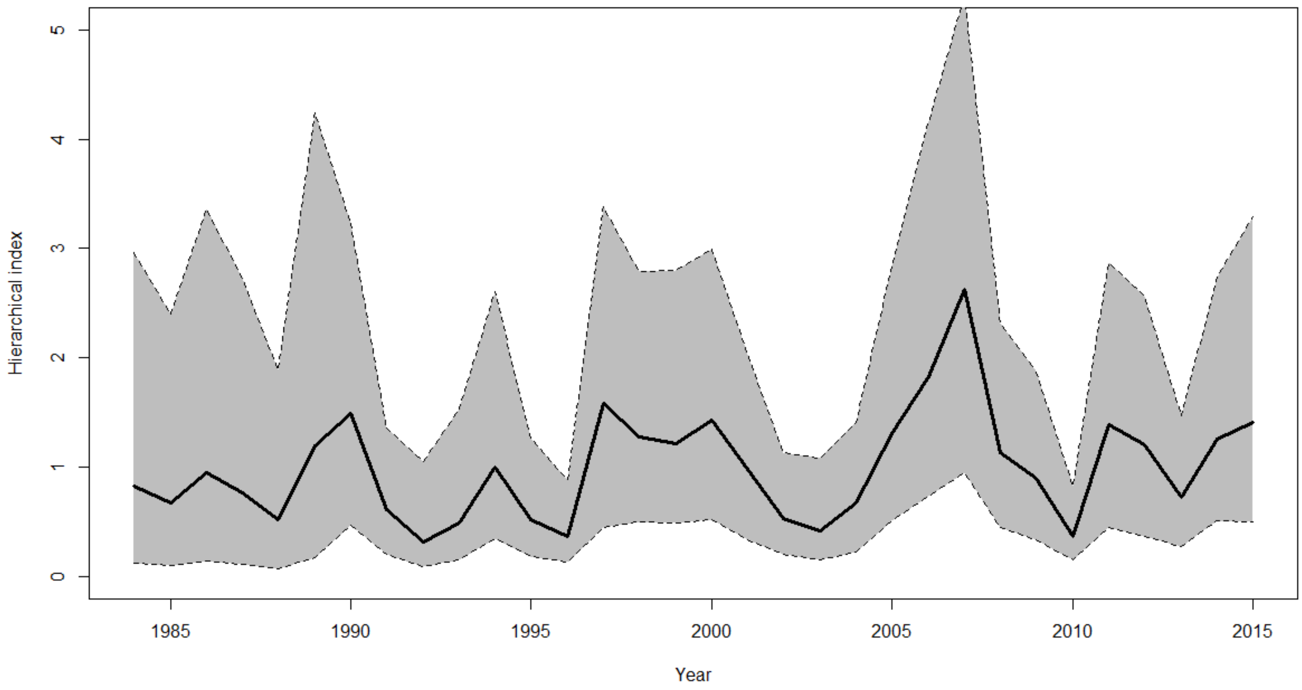


Figure 57. Time series of coastwide juvenile Atlantic sturgeon relative abundance as estimated from hierarchical analysis. The black line gives the posterior mean and the grey, shaded area represents a 95% credible interval about the time series.

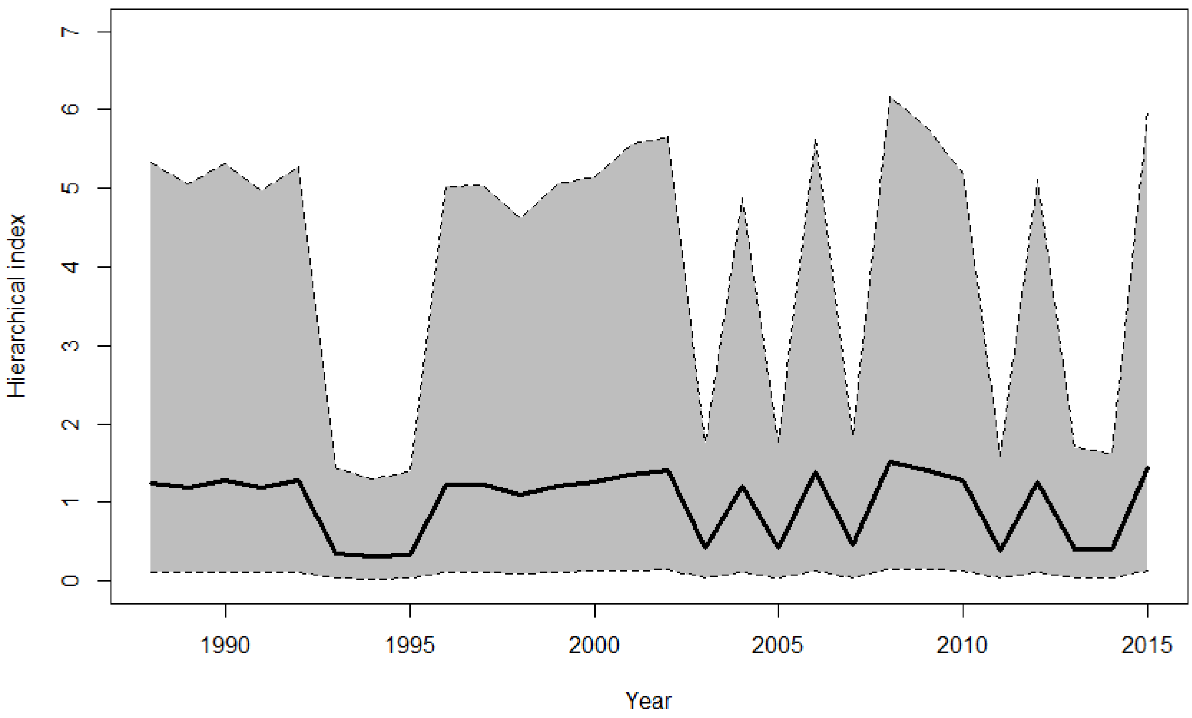


Figure 58. Time series of coastwide juvenile and adult (excluding juvenile-only surveys) Atlantic sturgeon relative abundance as estimated from hierarchical analysis. The black line gives the posterior mean and the grey, shaded area represents a 95% credible interval about the time series.

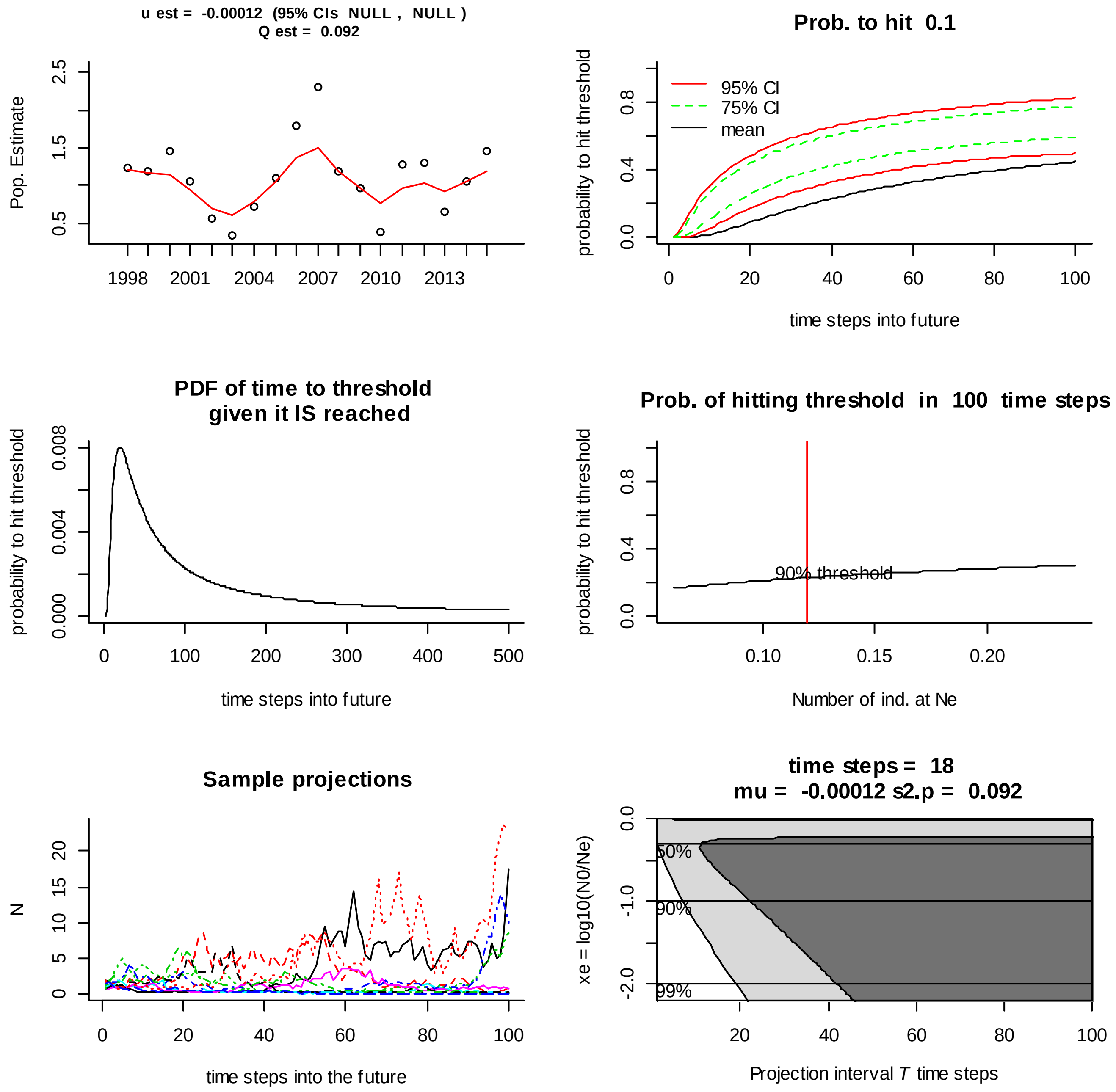


Figure 59. Risk figures using the Conn index for the coast wide population of Atlantic sturgeon from 1998-2015 representing the time period after the moratorium was put in place. Panel 1: Time-series plot of the data. Panel 2: CDF of extinction risk. Panel 3: PDF of time to reach threshold. Panel 4: Probability of reaching different thresholds during forecast period. Panel 5: Sample projections. Panel 6: TMU plot (uncertainty as a function of the forecast).

Figure 60. Plot of the estimate of log abundance index for CT LIST (1) and NJ Ocean Trawl (2) indices representing the NY Bight DPS. The estimate has been scaled relative to the first time series. The 95% confidence intervals are represented by the dashed lines.

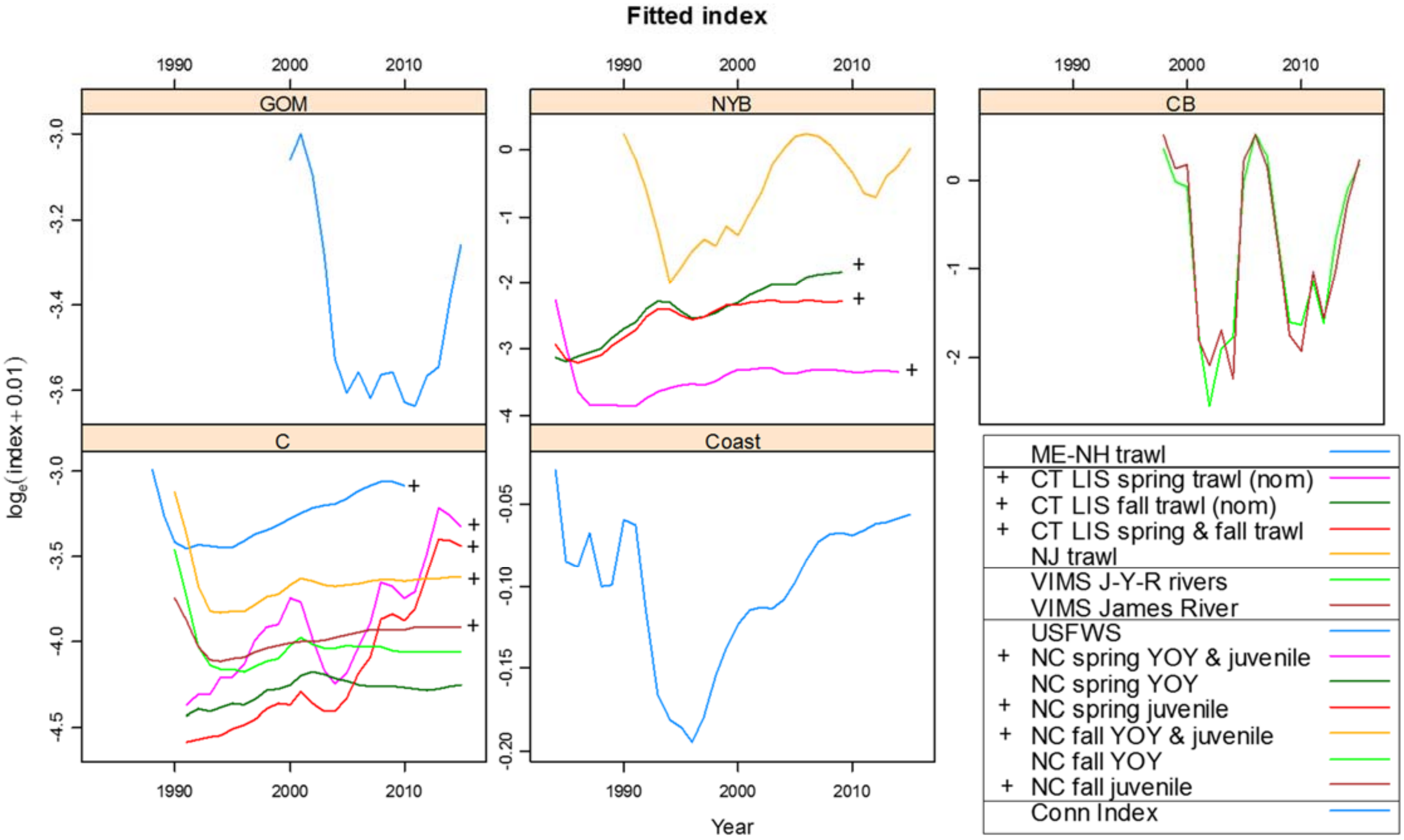


Figure 61. ARIMA fitted indices grouped by DPS. Note that y-axes differ among DPSs (all share a common x-axis). In legend, boxes are drawn around surveys within DPSs. Plus/minus signs have been added to indices with significant increasing or decreasing trends (alpha = 0.05, Mann-Kendall test), respectively.

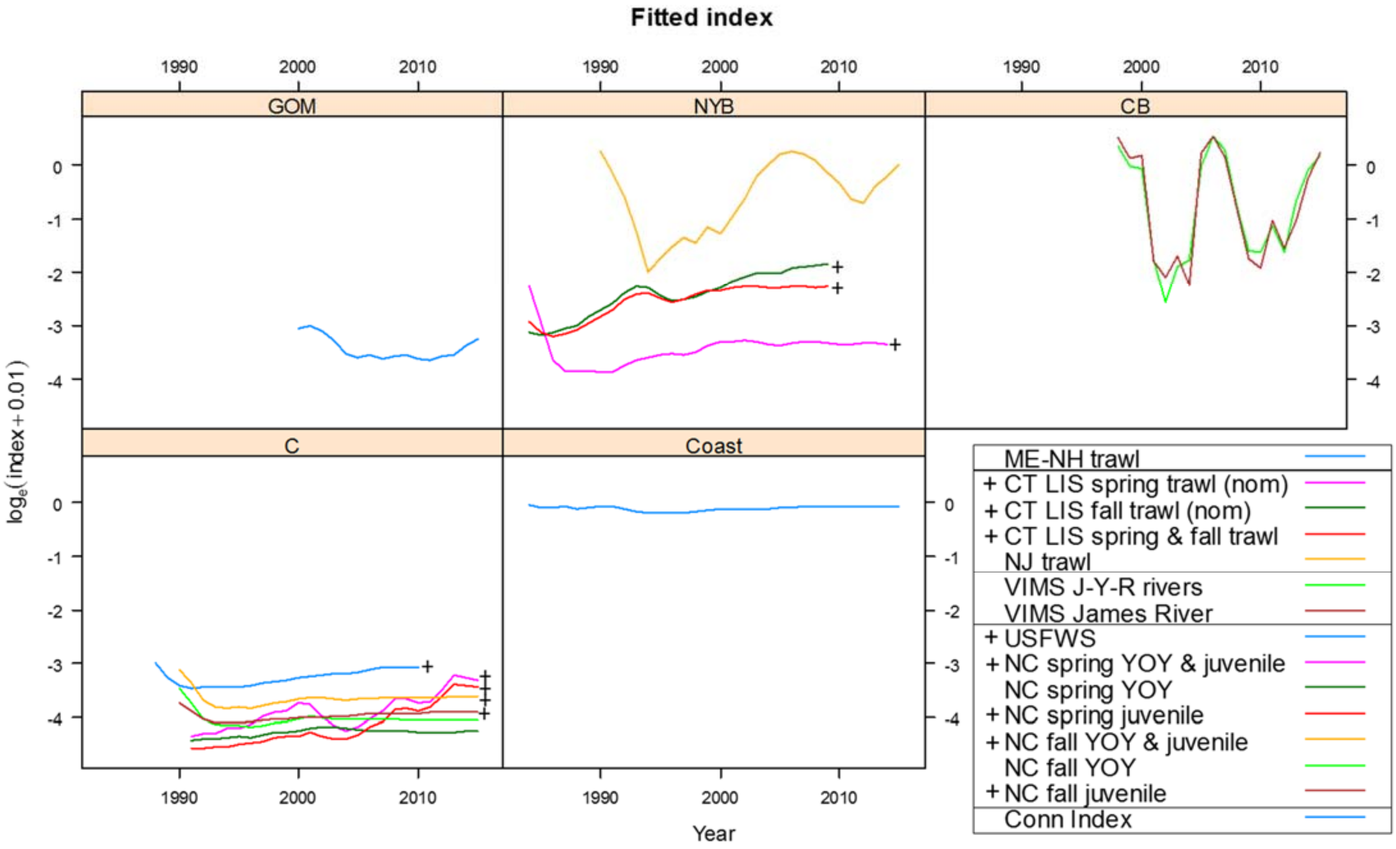


Figure 62. ARIMA fitted indices grouped by DPS plotted on the same scale. Note that x- and y-axes are identical among DPSs. On legend boxes are drawn around surveys within DPSs. Plus/minus signs have been added to indices with significant increasing or decreasing trends (alpha = 0.05, Mann-Kendall test), respectively.

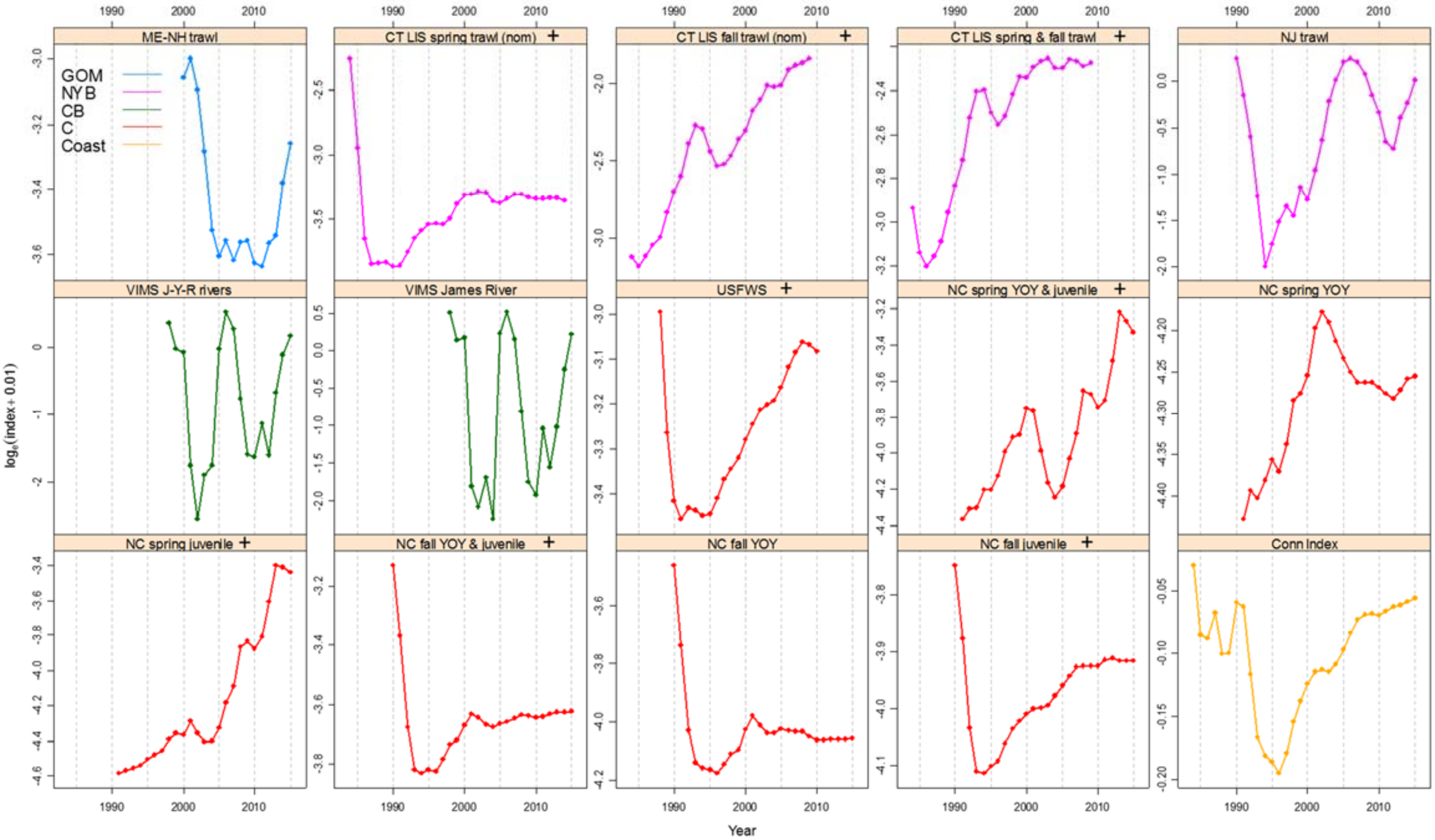


Figure 63. ARIMA fitted indices plotted separately. Note that y-axes differ among all indices and that only a single survey is plotted in each panel. Legend is overlaid on ME-NH Trawl survey. Plus/minus signs have been added to indices with significant increasing or decreasing trends (alpha = 0.05, Mann-Kendall test), respectively.

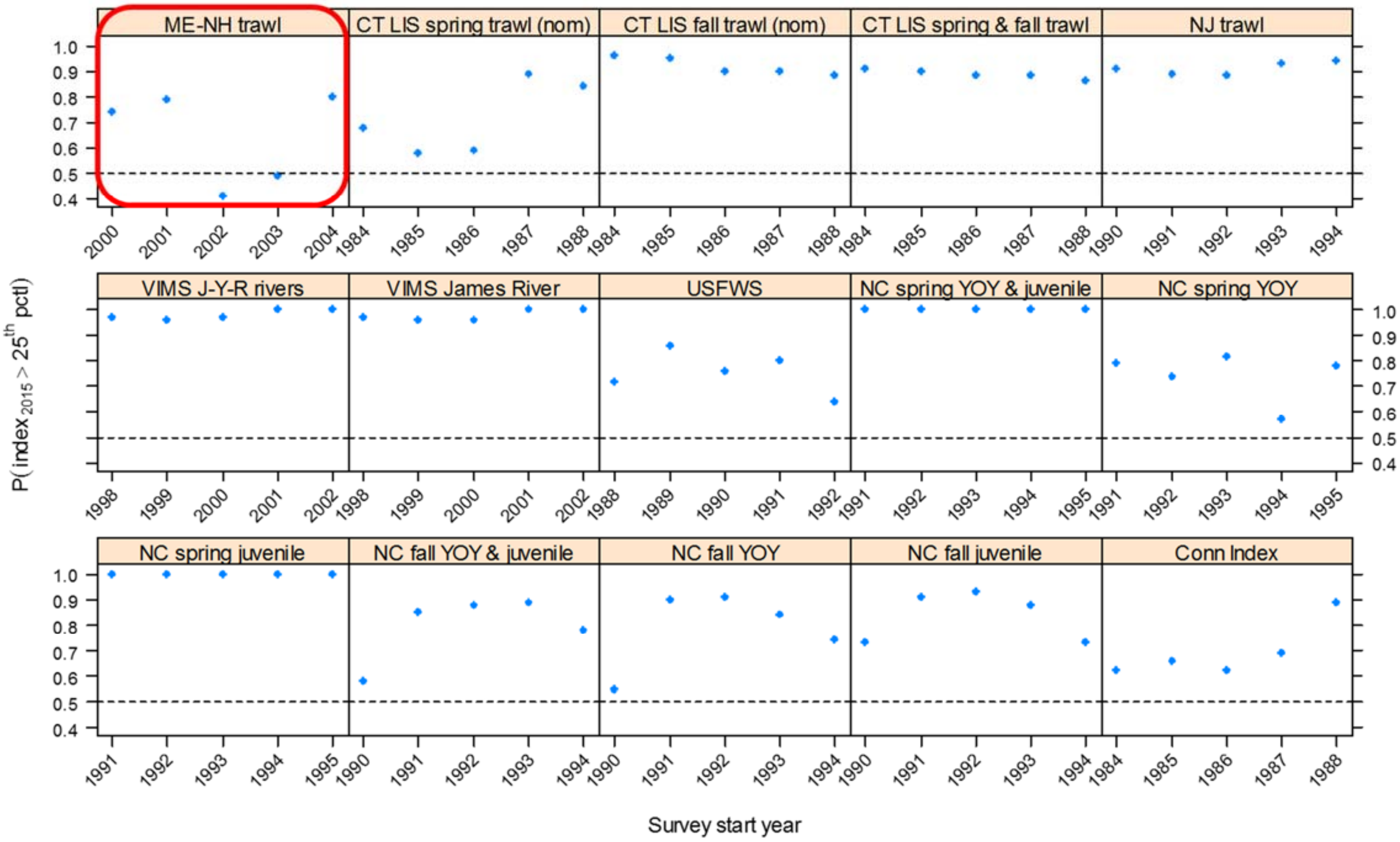


Figure 64. Probabilities that the terminal year of a given index is greater than the 25th percentile of its time series. All terminal years = 2015 except: CT LIS spring= 2014, CT LIS fall and spring & fall combined = 2009, and USFWS = 2010. A dotted horizontal line is added at probability = 0.50. A red box is drawn around indices where credibility of terminal year being above the 25th percentile of a given time series changes with survey start year.

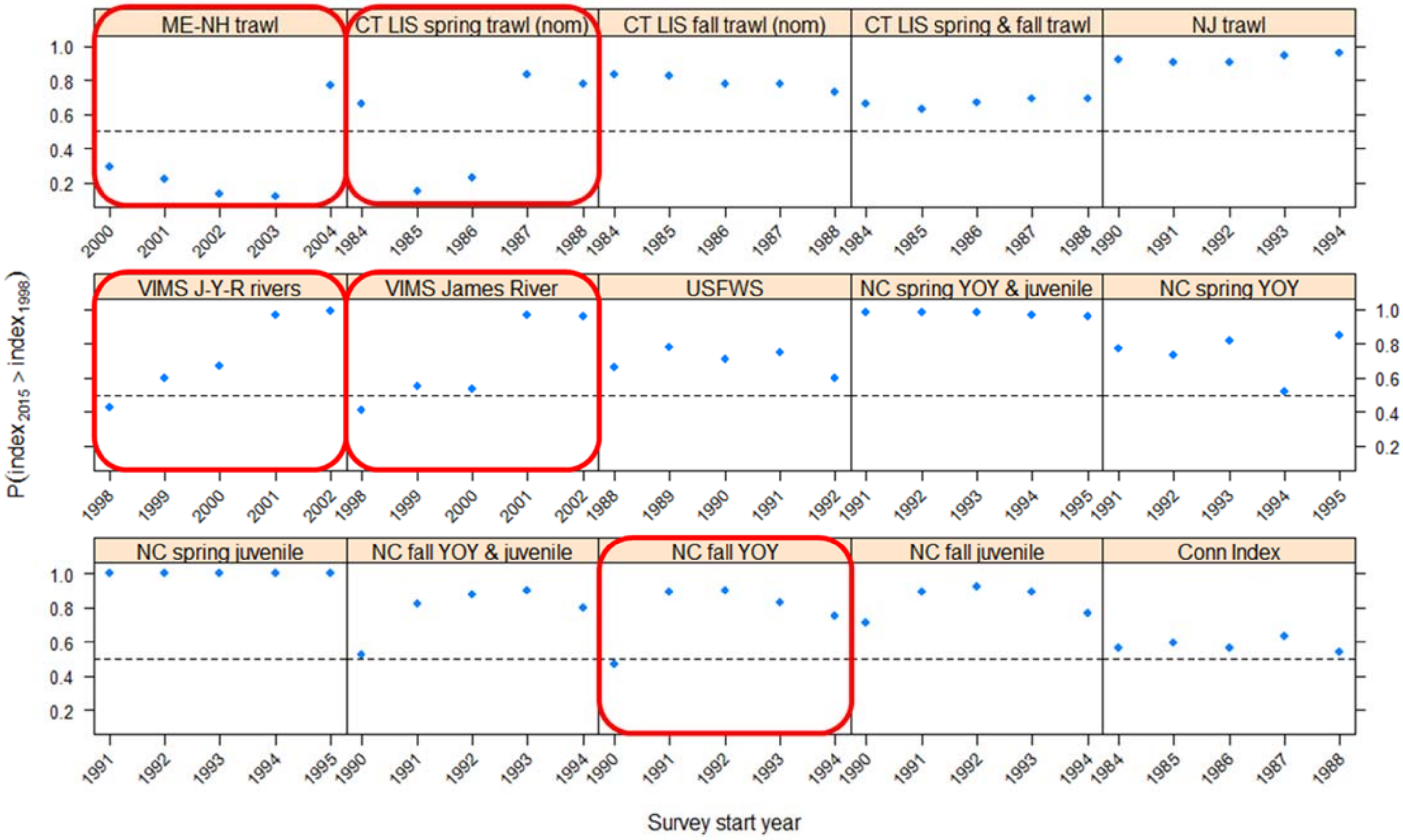


Figure 65. Probabilities that the terminal year of a given index is greater than the index value in 1998. All comparisons are against 1998 except for the ME-NH Trawl, which started in 2000 (and hence, comparison is against 2000). A dotted horizontal line is added at probability = 0.50. A red box is drawn around indices where credibility of terminal year being above the survey's 1998 index value changes with survey start year.

Figure 66. Correlation matrix of surveys. Spearman correlations below diagonal, notable correlations (>=0.60 or <=-0.60) are indicated in green or red, respectively. Lowess smoother added to scatterplots above diagonal. Abbreviated index names are along the diagonal. Black boxes drawn around surveys within single DPSs (save ME-NH Trawl and the Conn index)

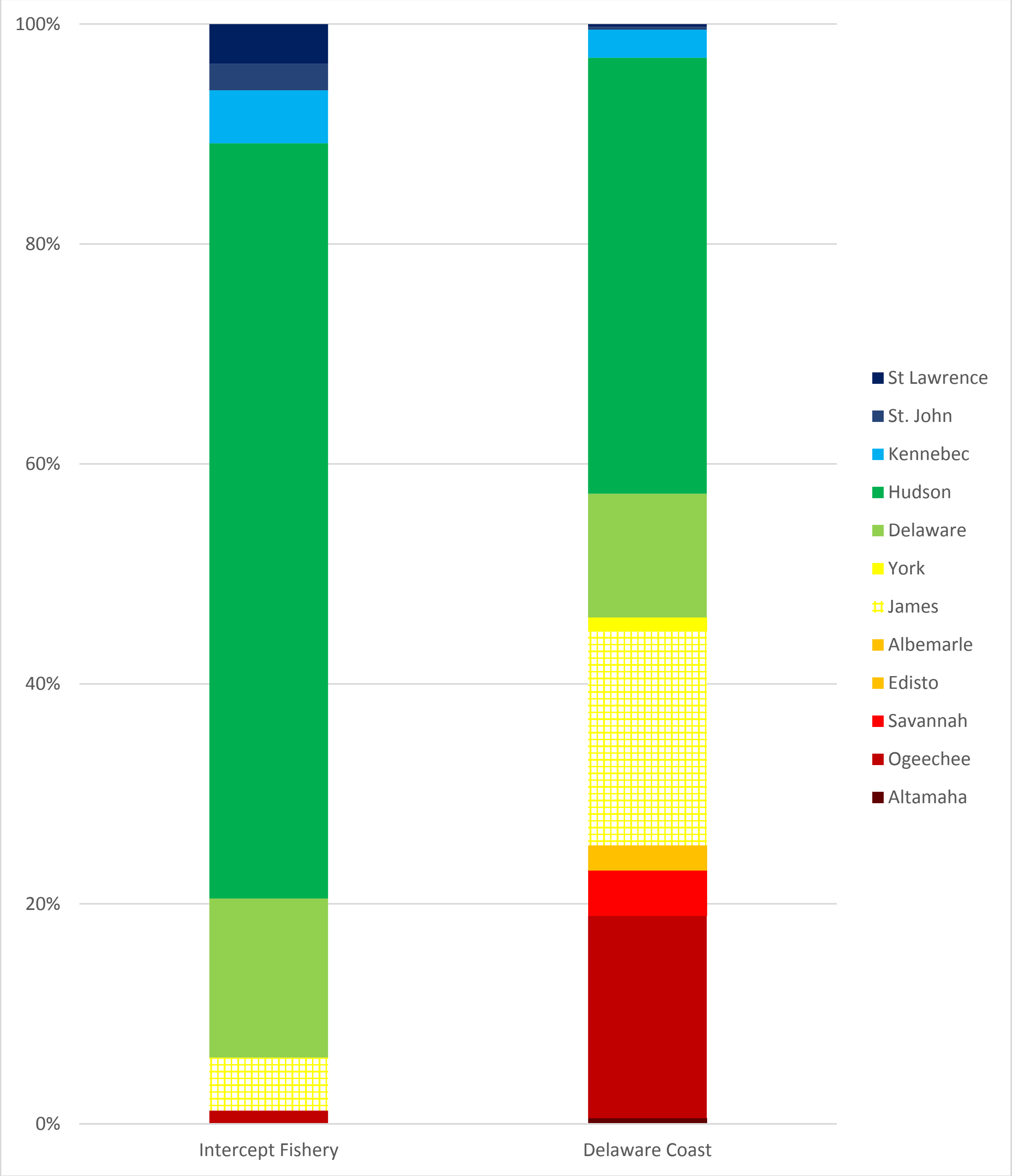


Figure 67. Assigned river of origin for Atlantic sturgeon collected in the New York Bight intercept fishery (n = 83; 1993-1995) and off the coast of Delaware (n = 391; 2009-2016)

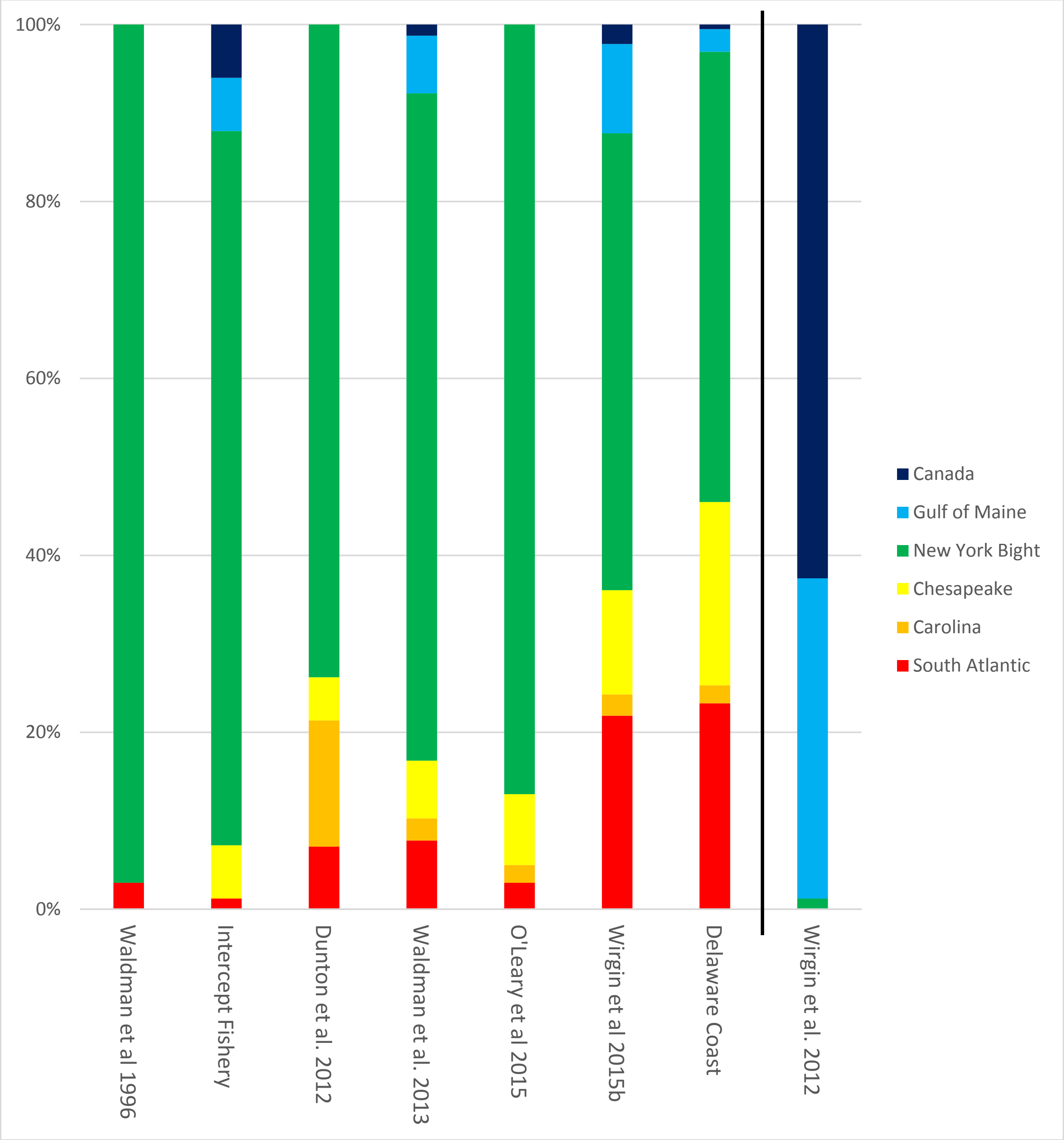


Figure 68. Comparison of new mixed stock analysis for the Intercept Fishery and Delaware Coast with previously published analyses. The New York Bight intercept fishery (*n* = 83; 1993-1995) and the Delaware Coast (*n* = 391; 2009-2016) were analyzed for this assessment. Wirgin et al. (2012; far right) used samples from the Bay of Fundy (outside of the New York Bight) and is shown for contrast.

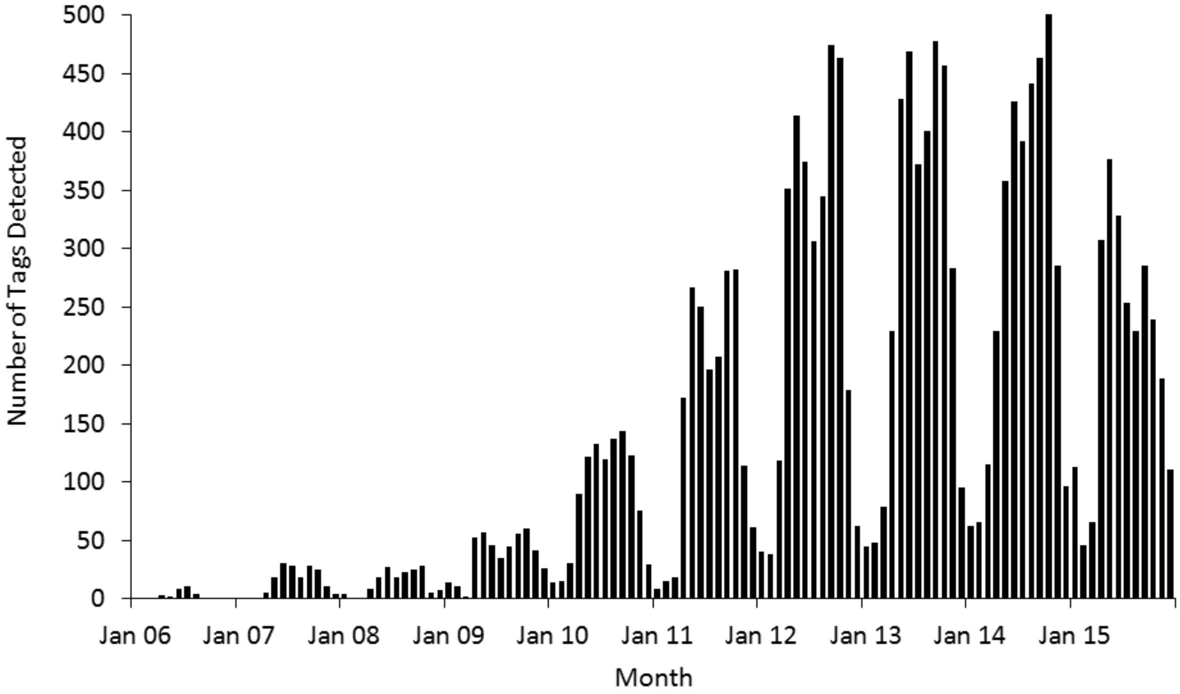


Figure 69. Atlantic sturgeon tag detections by month for the entire data range. The number of tags detected was generally lower in winter and early spring months. Both the number of receivers and tags increased over time.

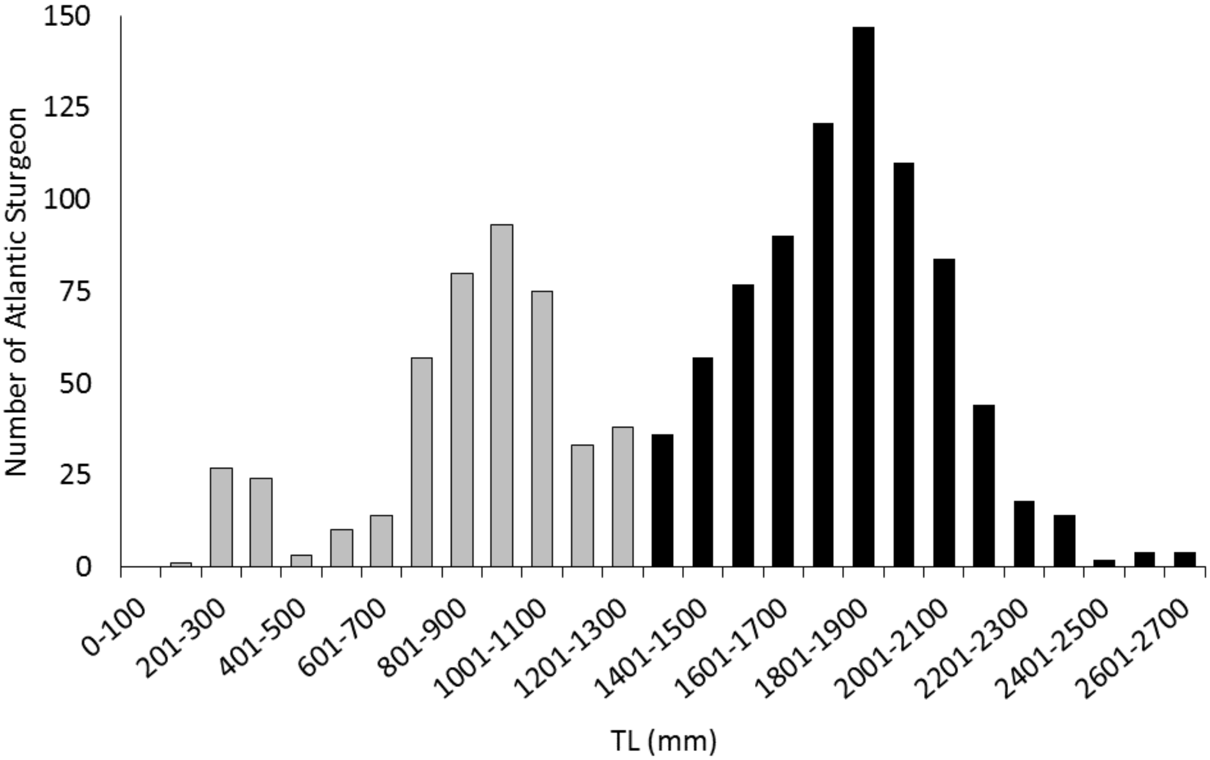


Figure 70. Histogram of tagged Atlantic sturgeon total lengths (TL). Grey bars represent Atlantic sturgeon grouped into the juvenile category, while black bars are adults.

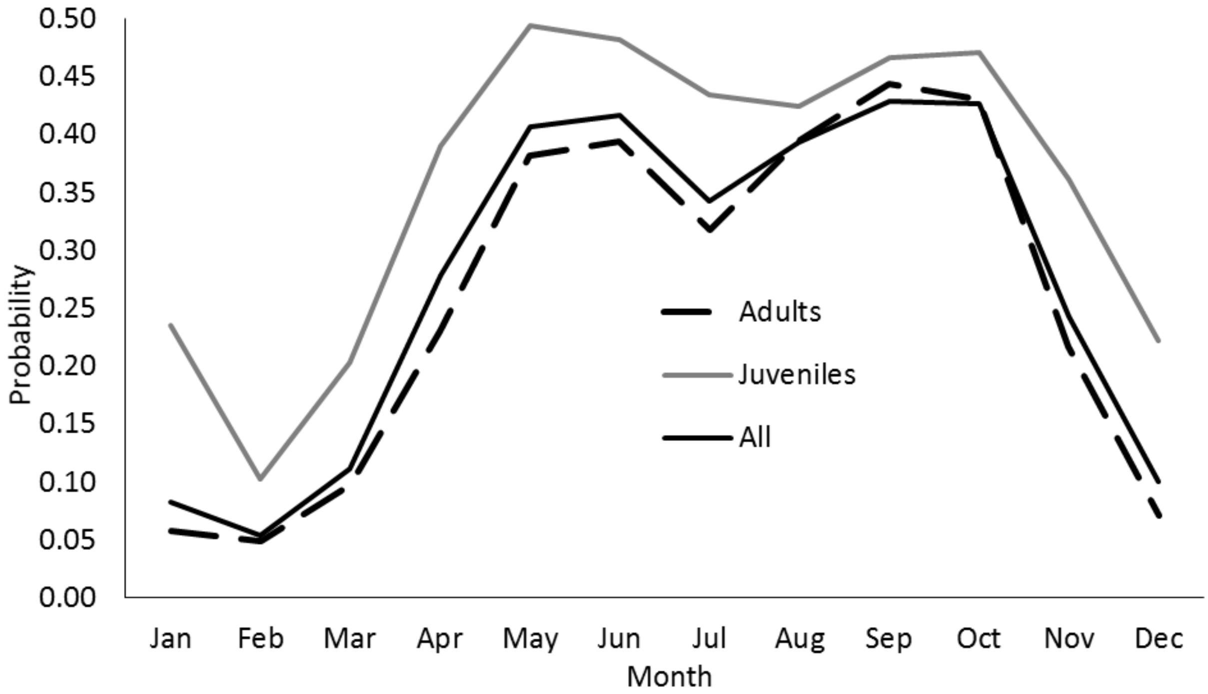


Figure 71. Monthly mean detection probability for Atlantic sturgeon. Detection was generally lower in winter and early spring months. Juvenile detection was somewhat higher than adult detection.

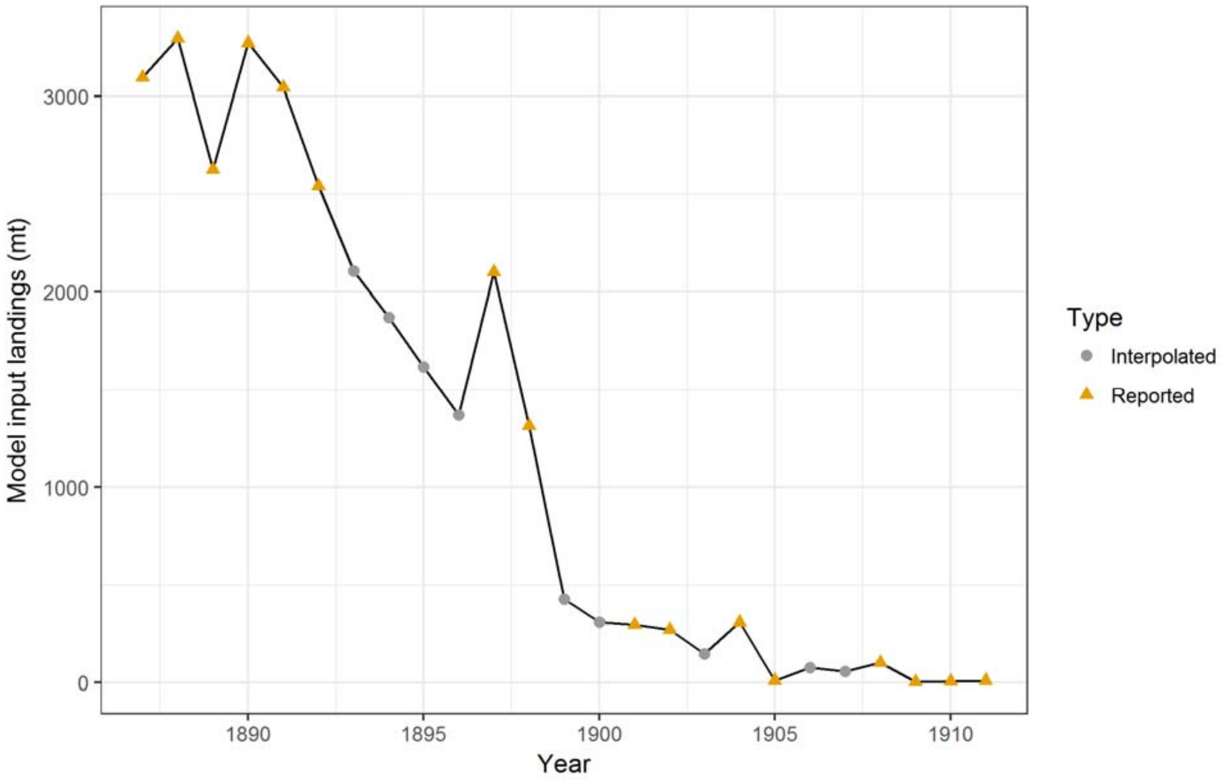


Figure 72. Observed and interpolated historical landings used as input in the stock reduction analyses.

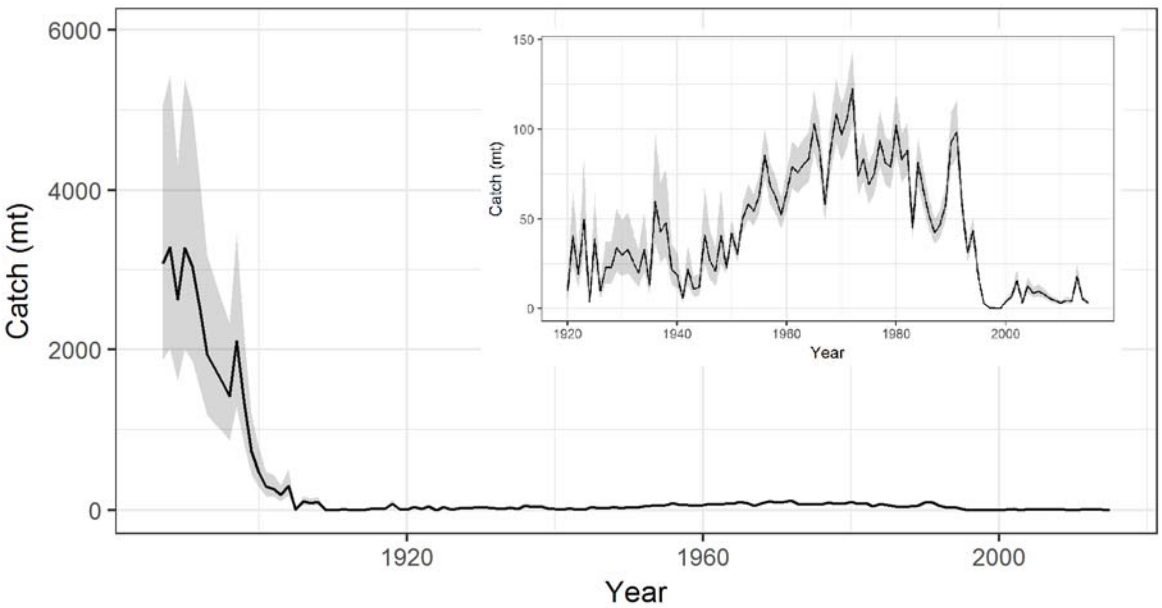


Figure 73. Median time-series of removals with 5th and 95th percentiles of drawn values used as input for the DBSRA. Inset is years 1920-2015 with the y-axis scaled down to show detail.

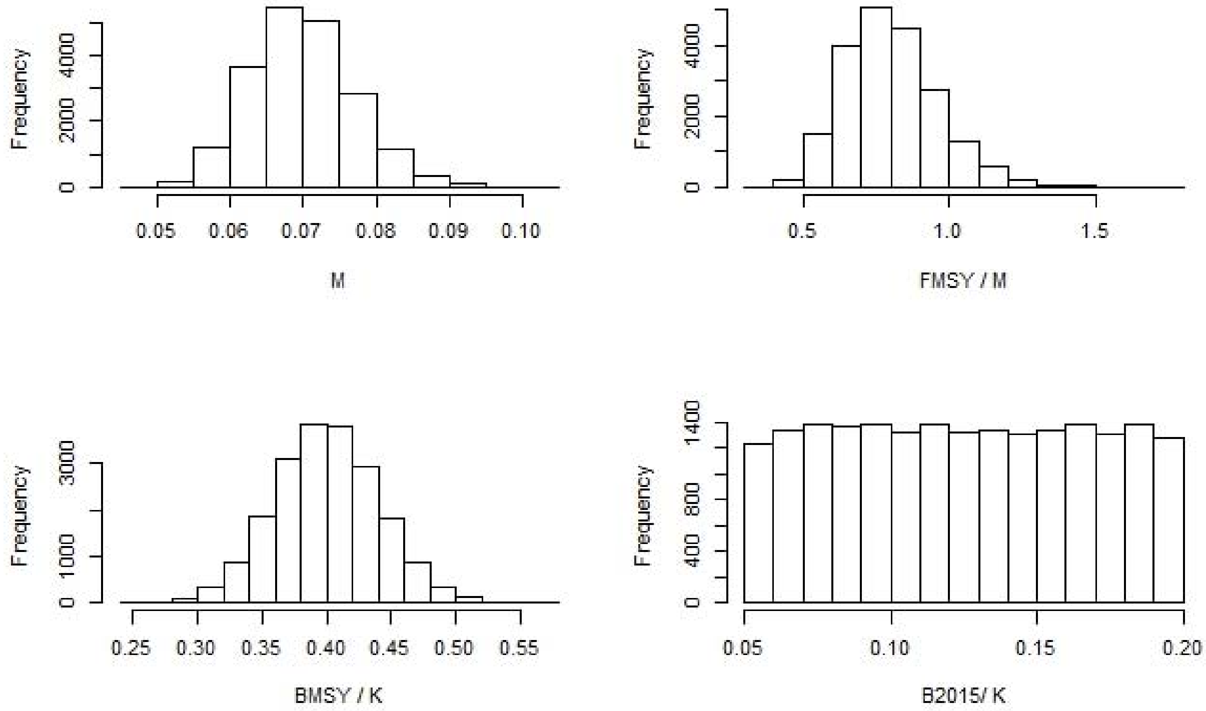


Figure 74. Distributions of drawn parameters used in the base run of the DBSRA model.

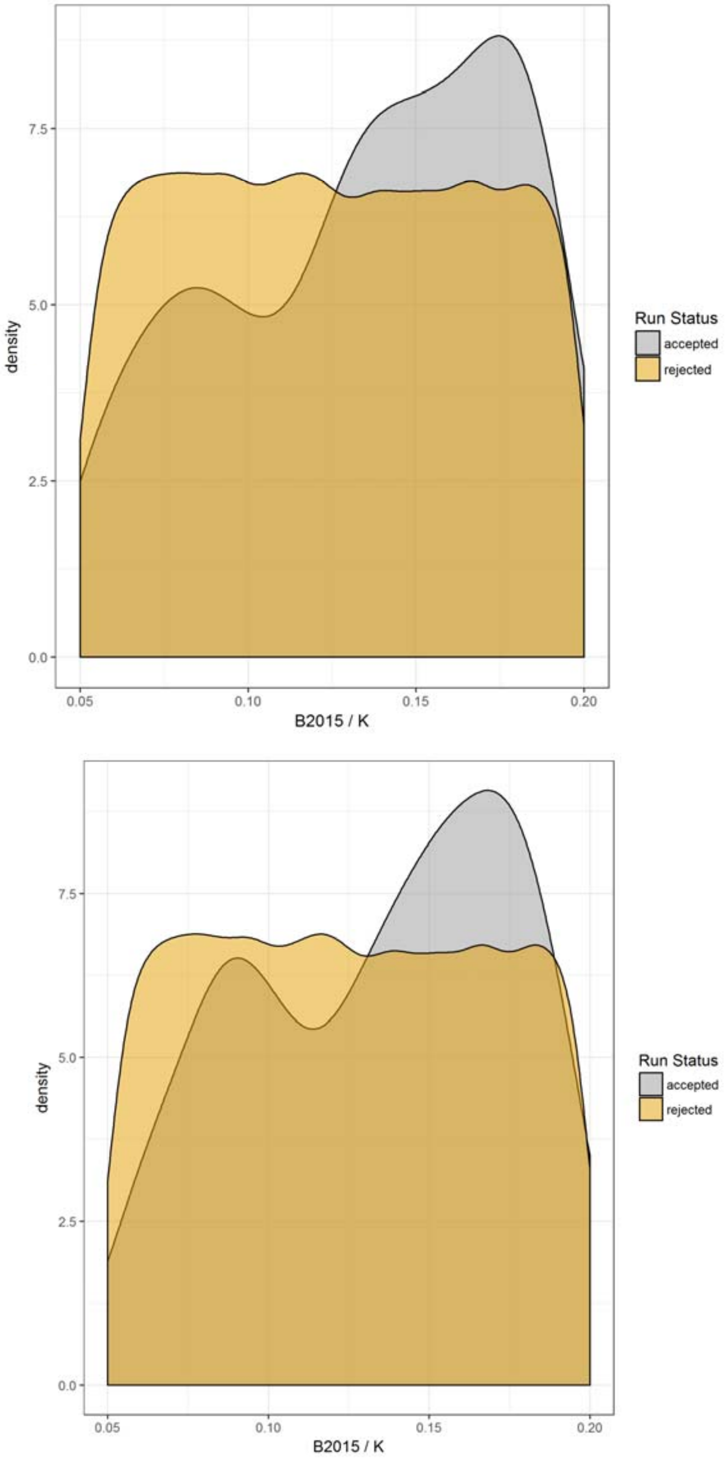


Figure 75. Comparison of B_{2015}/K ratios for accepted and rejected DBSRA runs for the single K scenario (top) and the 2-stanza K scenario (bottom).

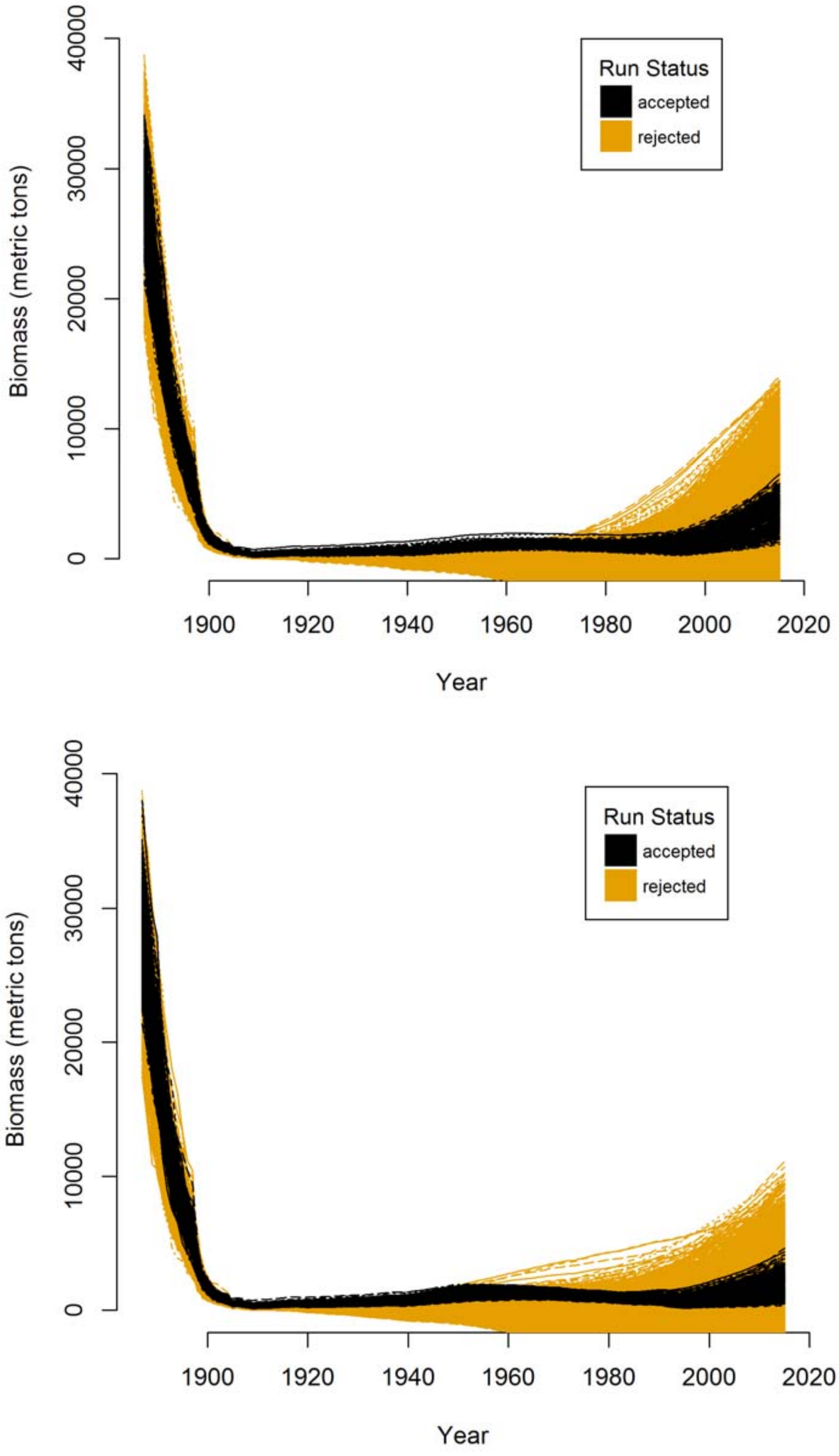
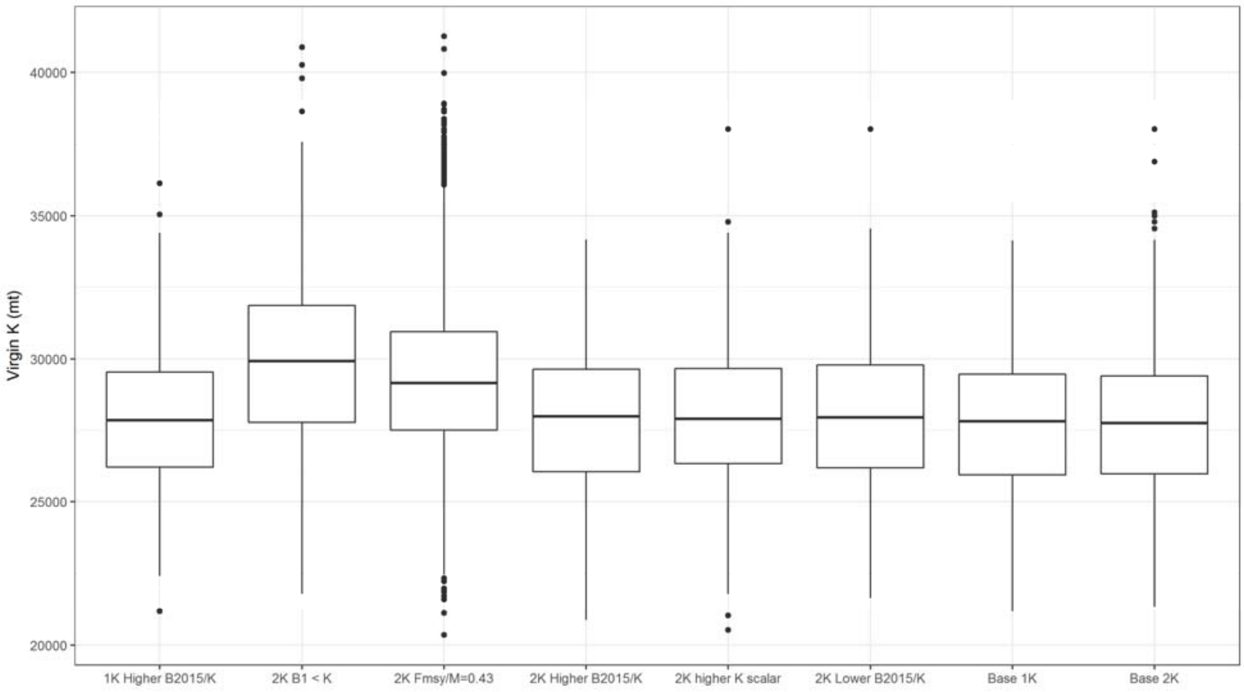


Figure 76. Biomass trajectories for accepted and rejected runs of the DBSRA for the single K model (top) and 2-stanza K model (bottom).



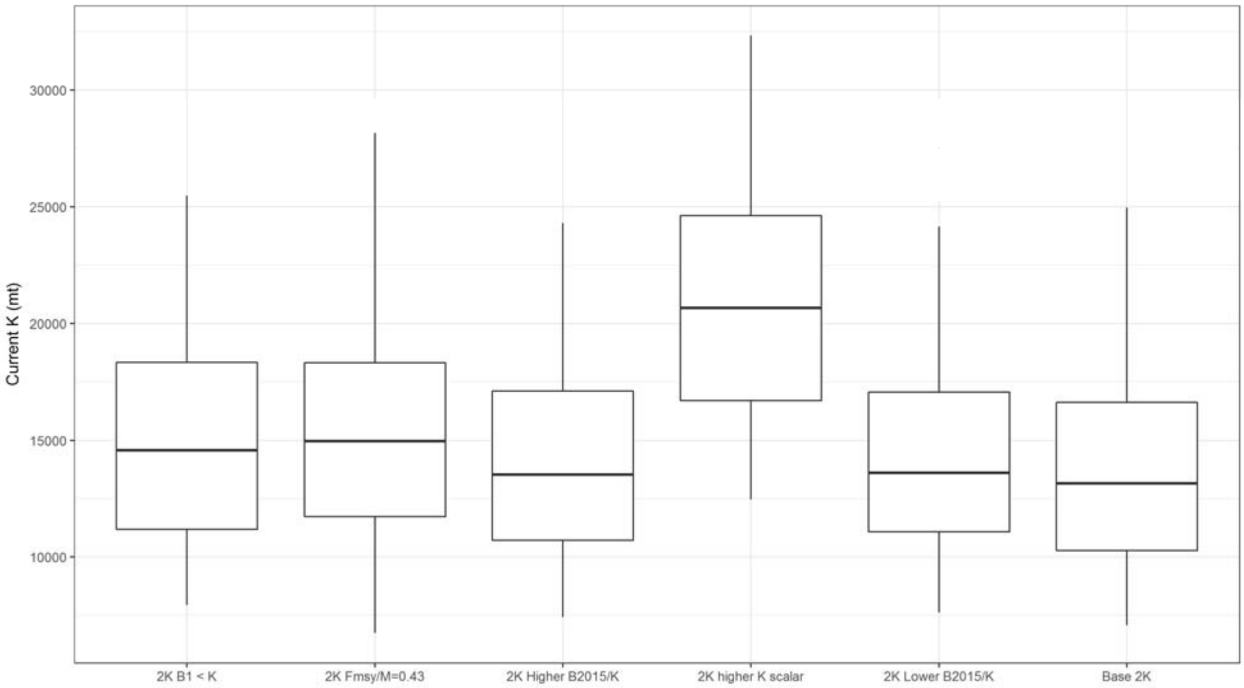


Figure 77. Distributions of virgin K estimates (top) and current K estimates (bottom) for different sensitivity runs of the DBSRA model.

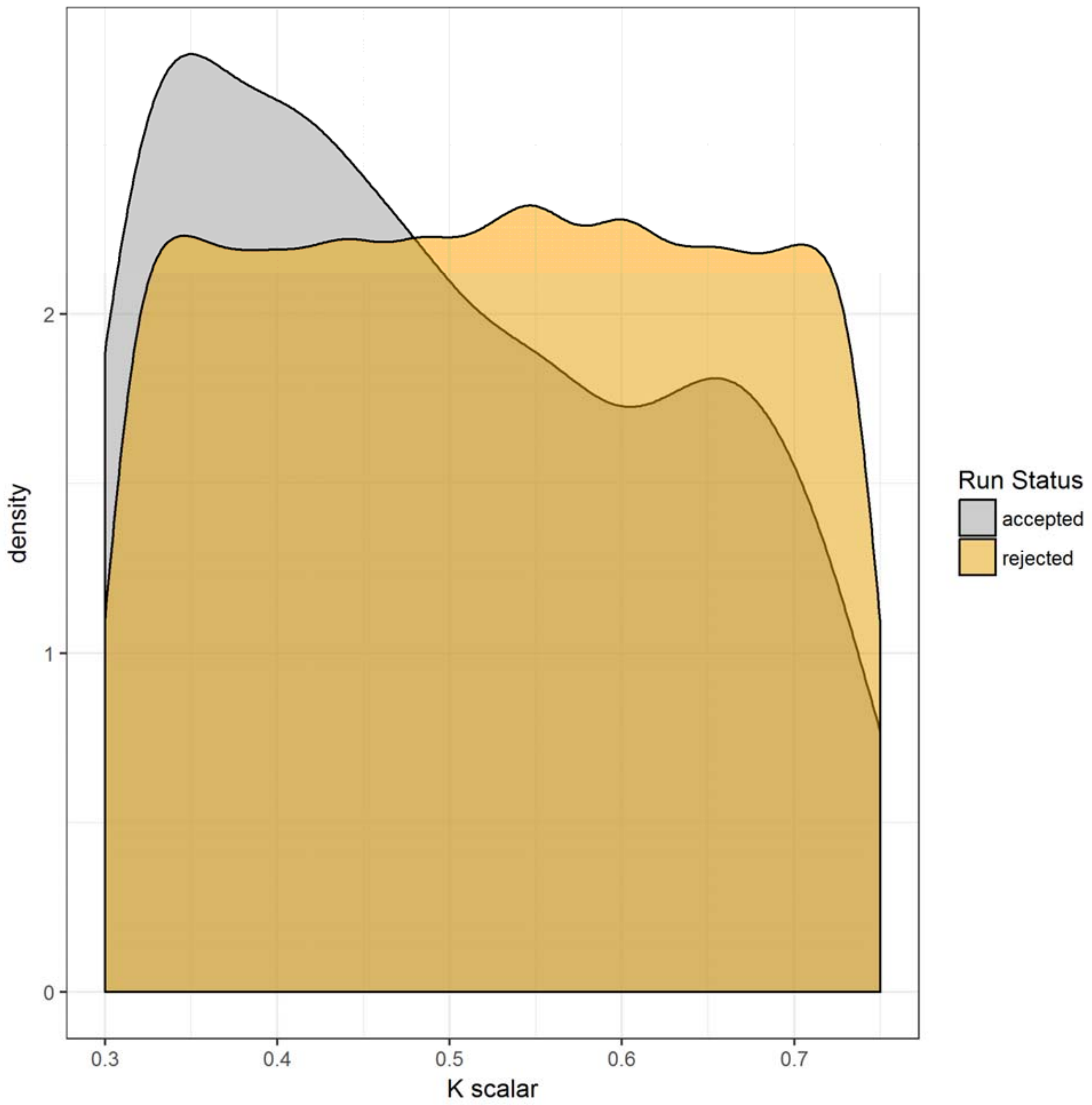


Figure 78. Distribution of K scalar for accepted and rejected runs of the 2-stanza K DBSRA model.

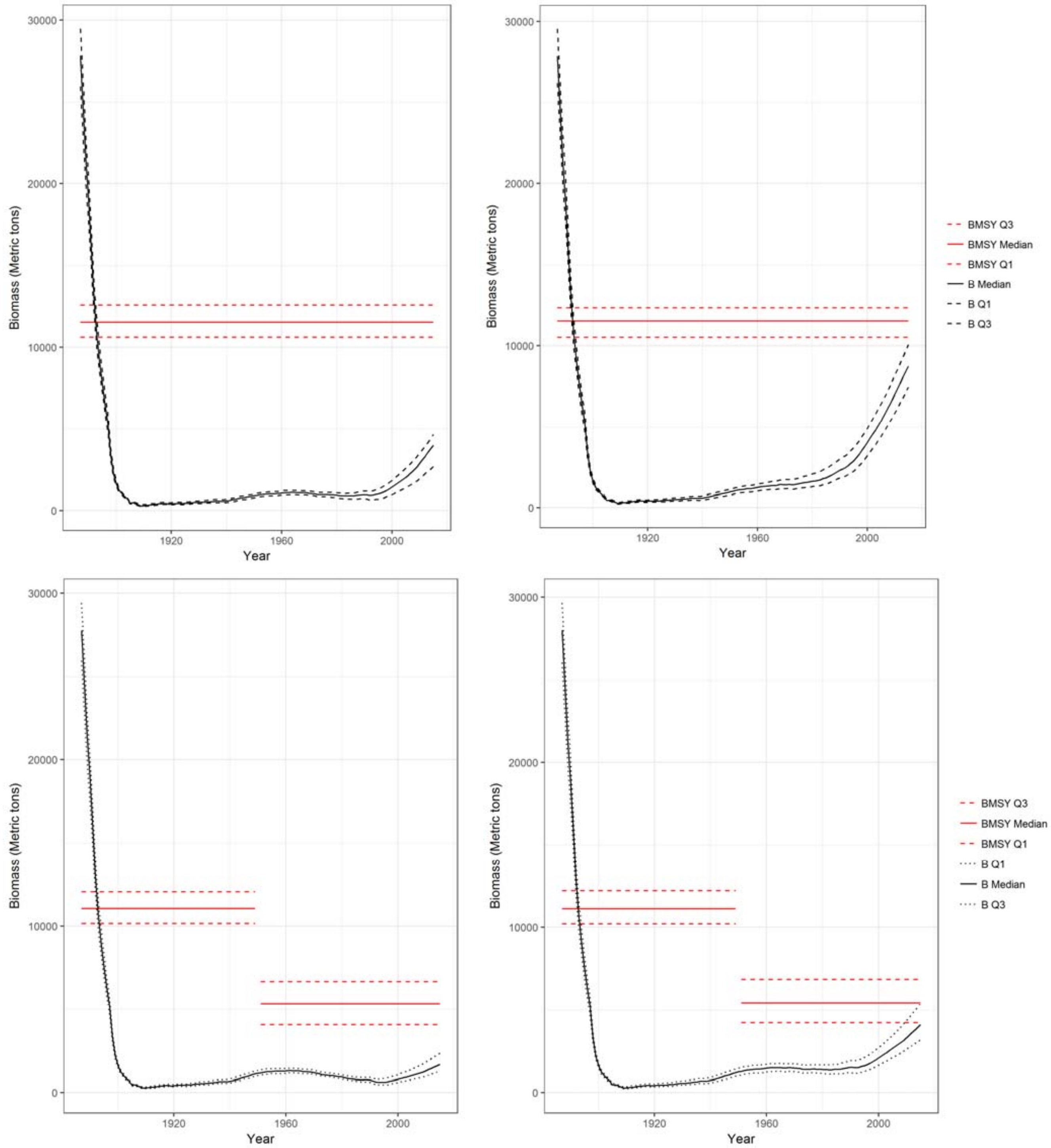


Figure 79. Biomass trajectories relative to B_{MSY} for the single K (top) and 2-stanza K (bottom) runs of the DBSRA. Panels on the left are the base model runs with B_{2015}/K assumed to be 0.05-0.20, while panels on the right are from a sensitivity run with B_{2015}/K assumed to be higher.

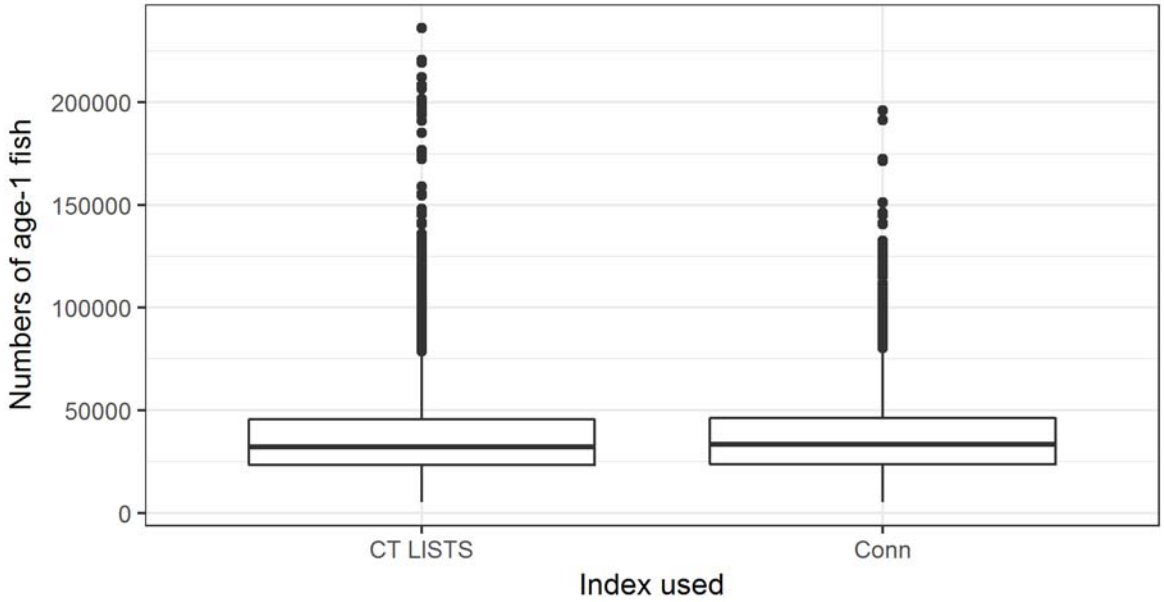


Figure 80. Estimates of virgin, unfished recruitment in from the SSRA model for runs using different indices.

Figure 81.

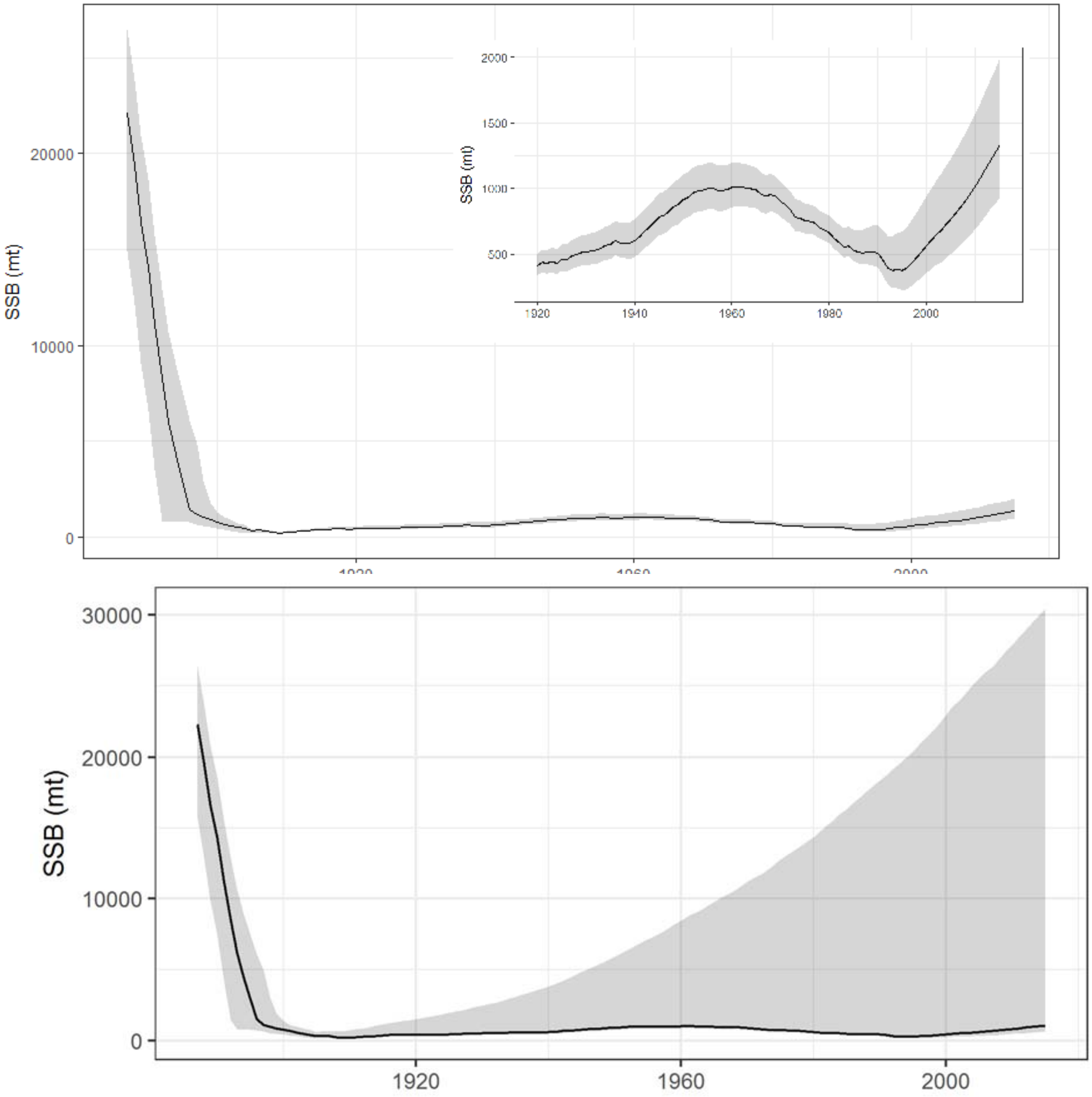


Figure 81. Trends in SSB estimated by the SSRA model for the base model with the CT LISTS index (top) and the Conn index (bottom). The inset figure on the top graph shows the most recent years with a scaled-down y-axis to show detail.

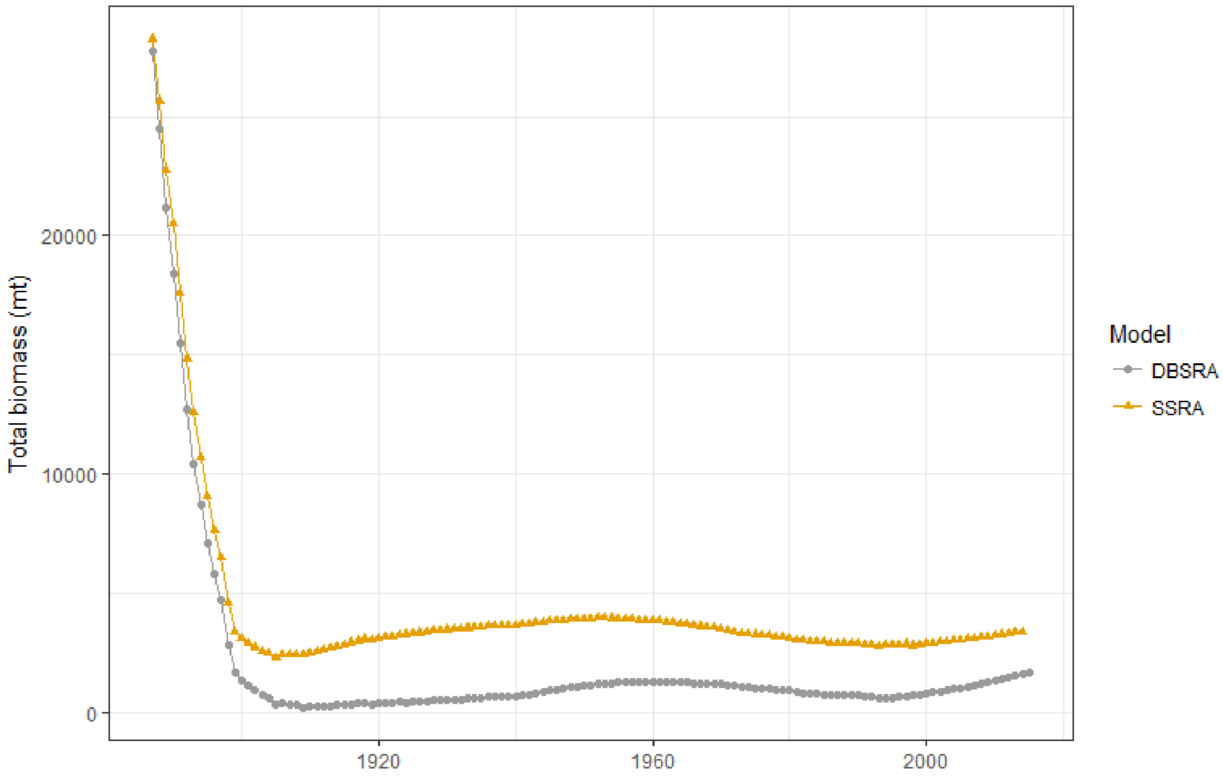
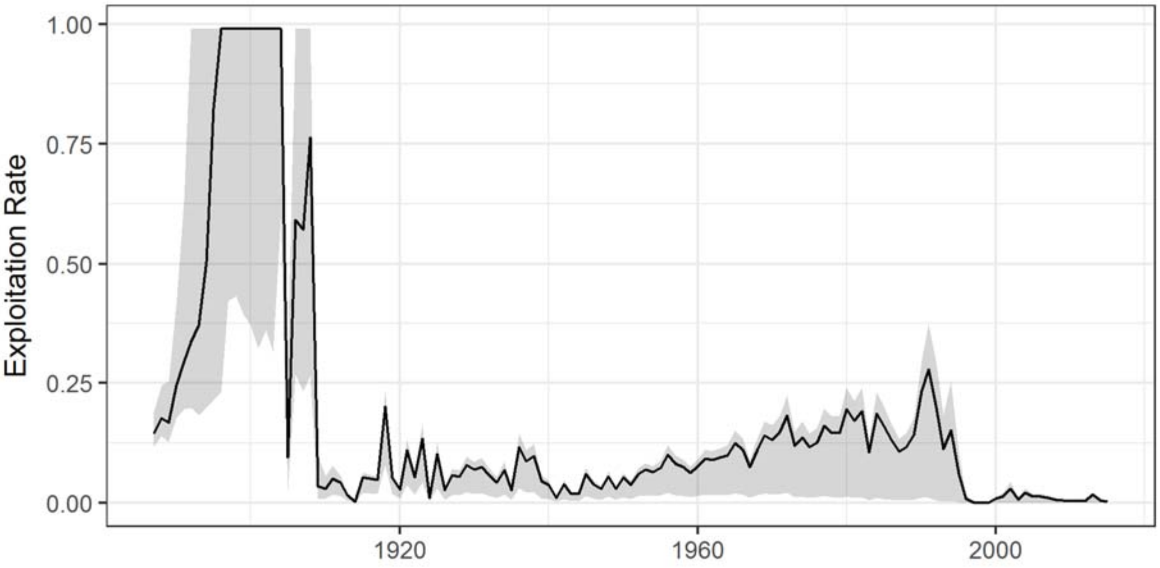


Figure 82. Comparison of biomass estimates from DBSRA and SSRA models.



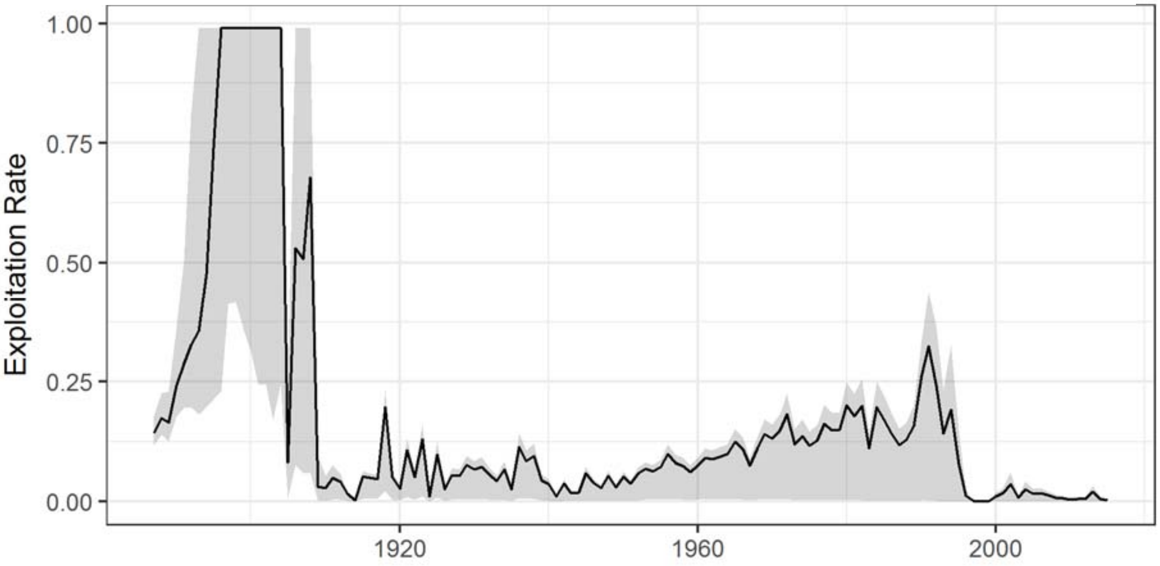


Figure 83. Estimates of exploitation rate from the SSRA model for the base model with the CT LISTS index (top) and the Conn index (bottom).

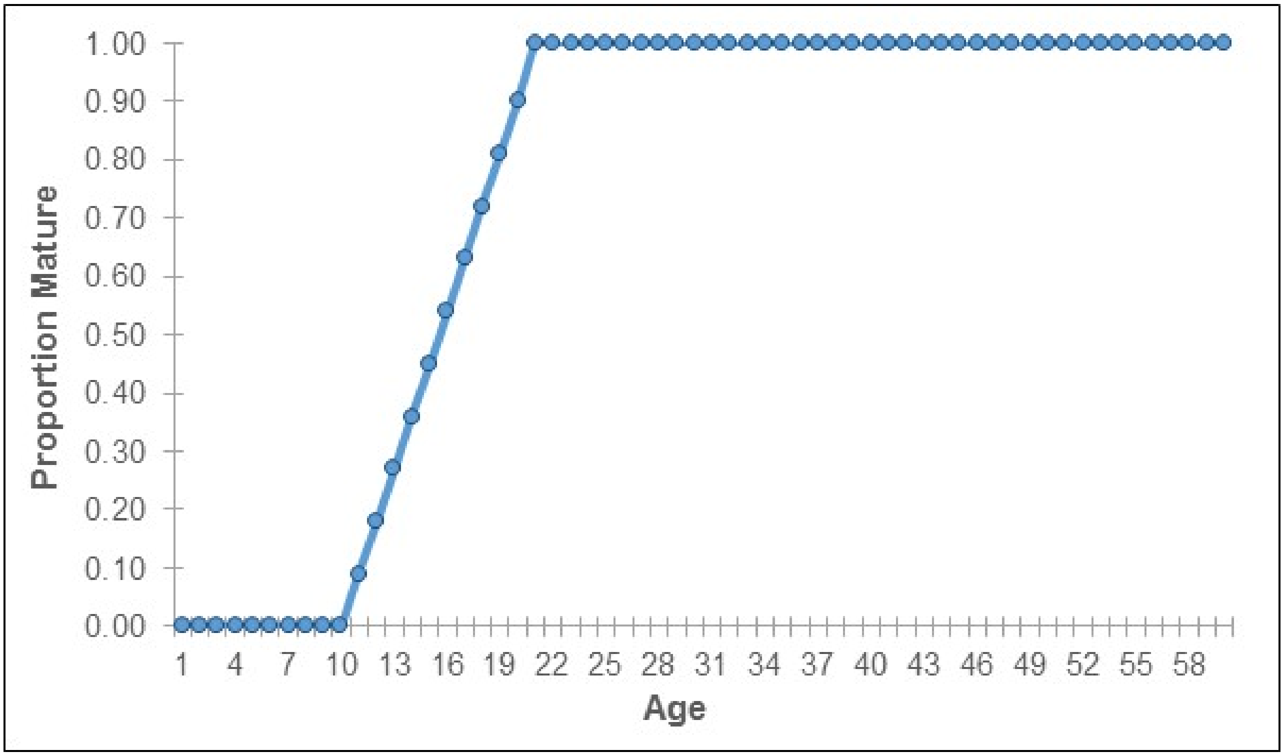


Figure 84. Maturity schedule of Atlantic sturgeon assumed in the eggs-per-recruit model. (Source: Kahnle et al. 2007)

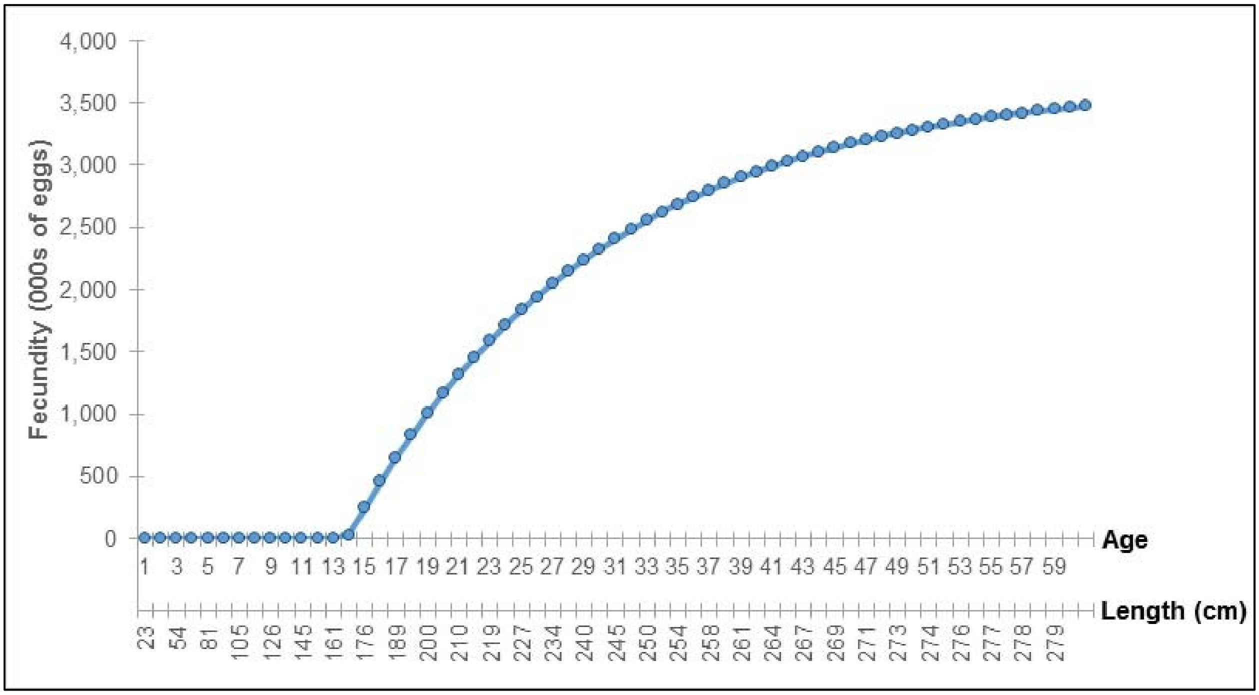


Figure 85. Age-fecundity relationship assumed in the eggs-per-recruit model representing the coastwide stock and northern region. Relationship derived from length-fecundity relationship estimated by Van Eenannaam and Doroshov (1998).

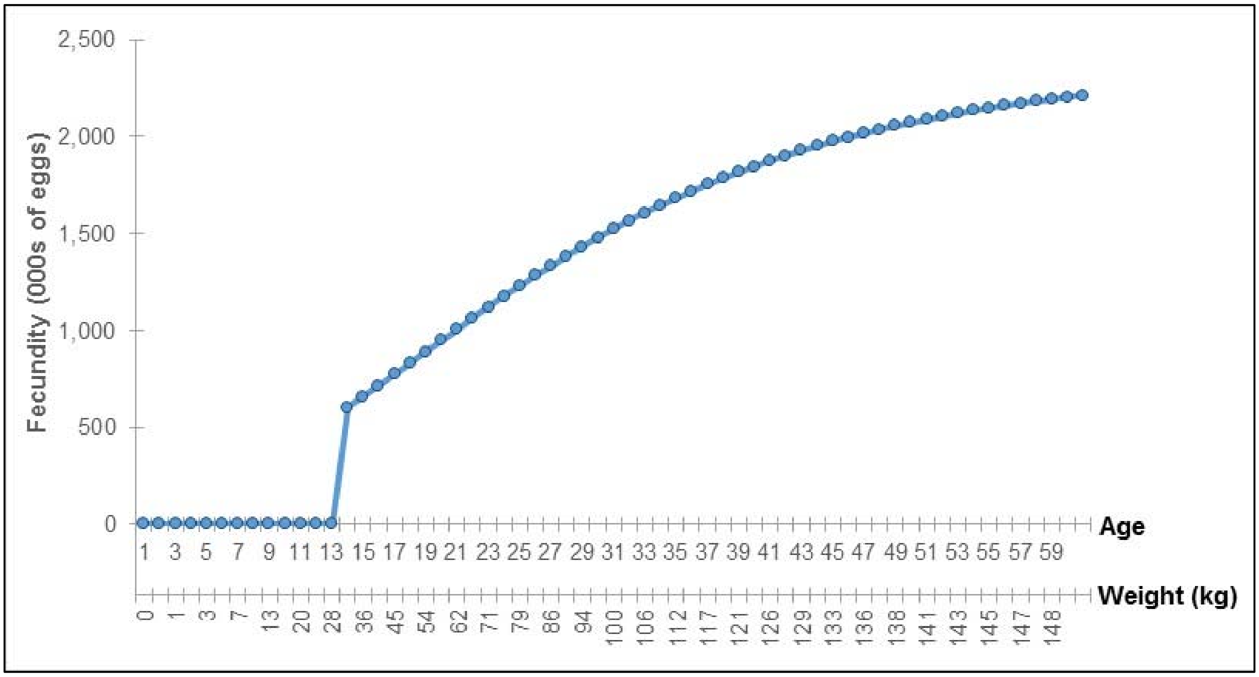


Figure 86. Age-fecundity relationship assumed in the eggs-per-recruit model representing the southern region. Relationship derived from weight-fecundity relationship estimated by van Smith et al. (1982).

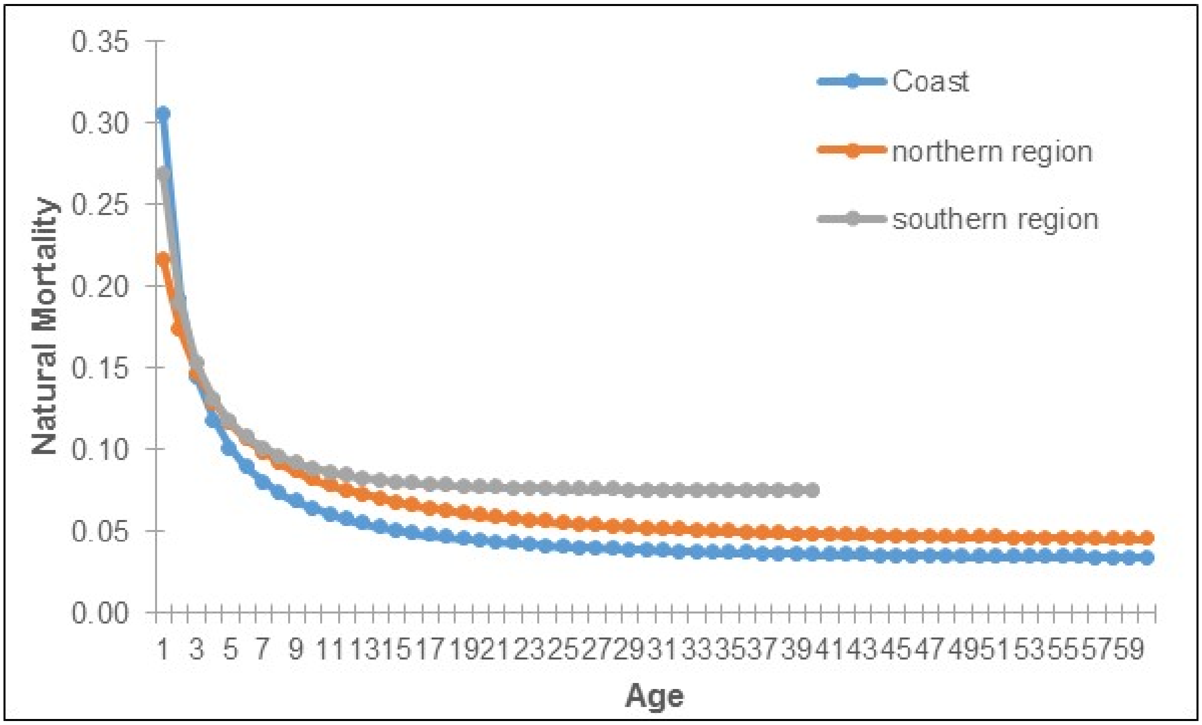


Figure 87. Estimates of age-specific natural mortality assumed for the different eggs-per-recruit models.

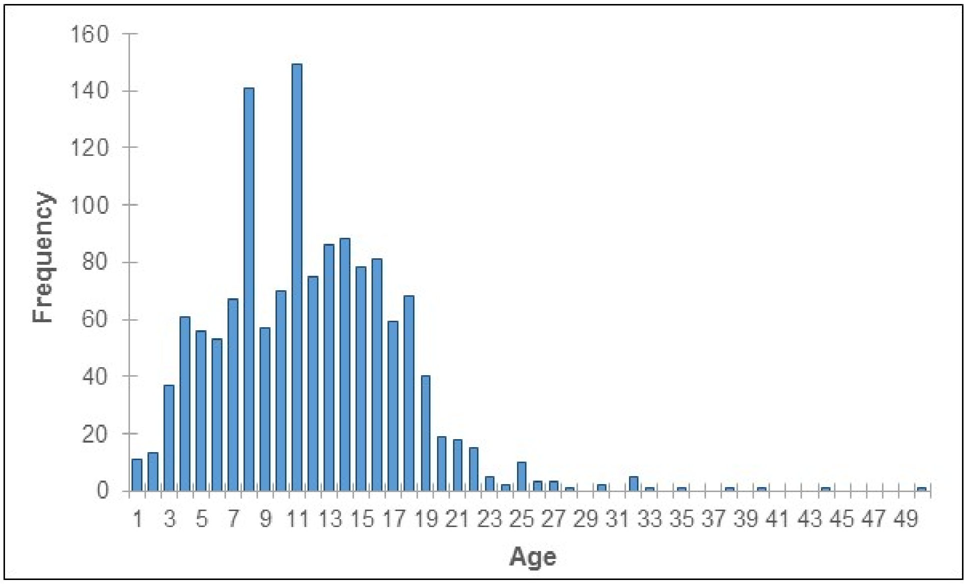


Figure 88. Estimated frequency of Atlantic sturgeon observed in the bycatch of trawls and gill nets. Data collected by the NEFOP/ASM and DSU were combined for analysis.

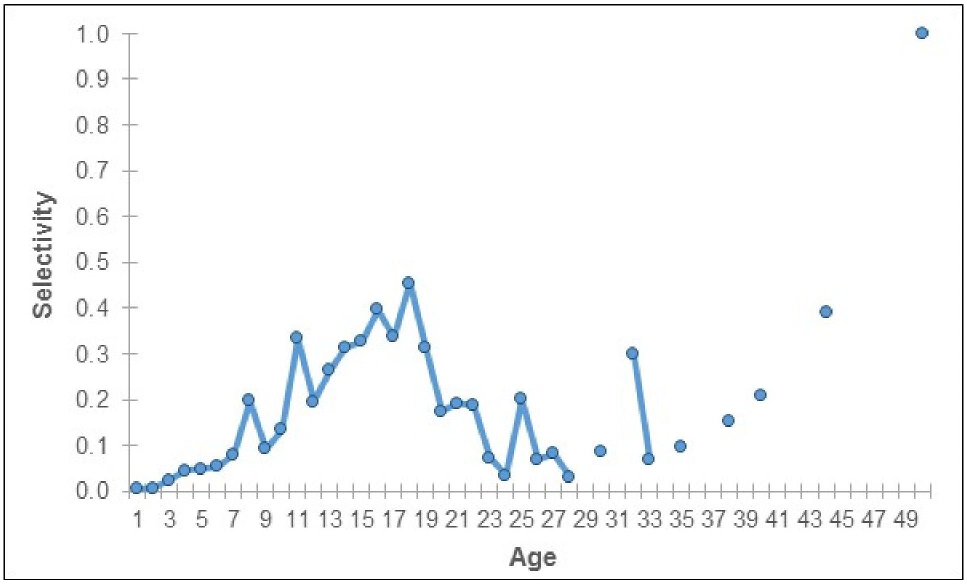


Figure 89. Bycatch selectivity estimated using the Restrepo et al. (2007) approach.

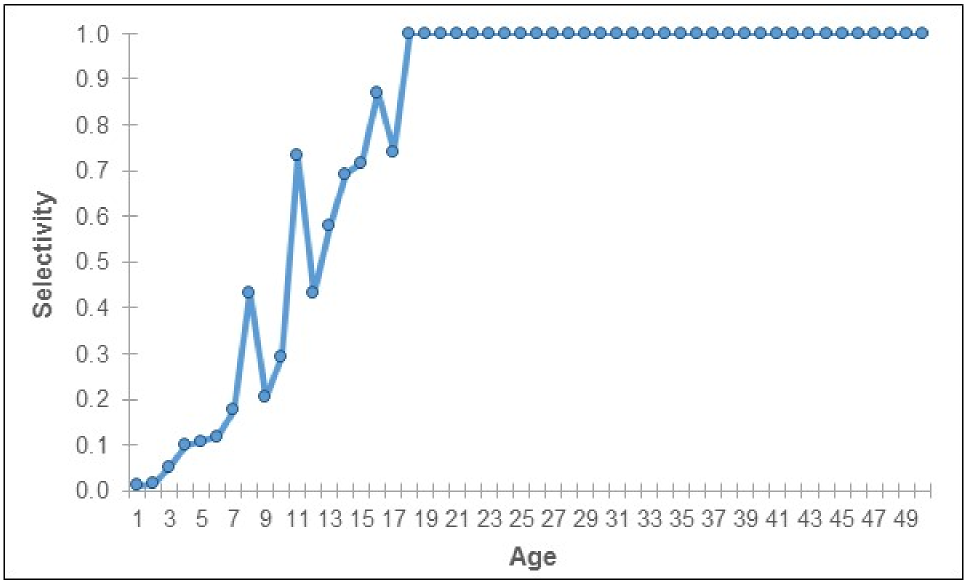


Figure 90. Adjusted version of the Restrepo-derived selectivity such that maximum selectivity occurs at ages 18 and older.

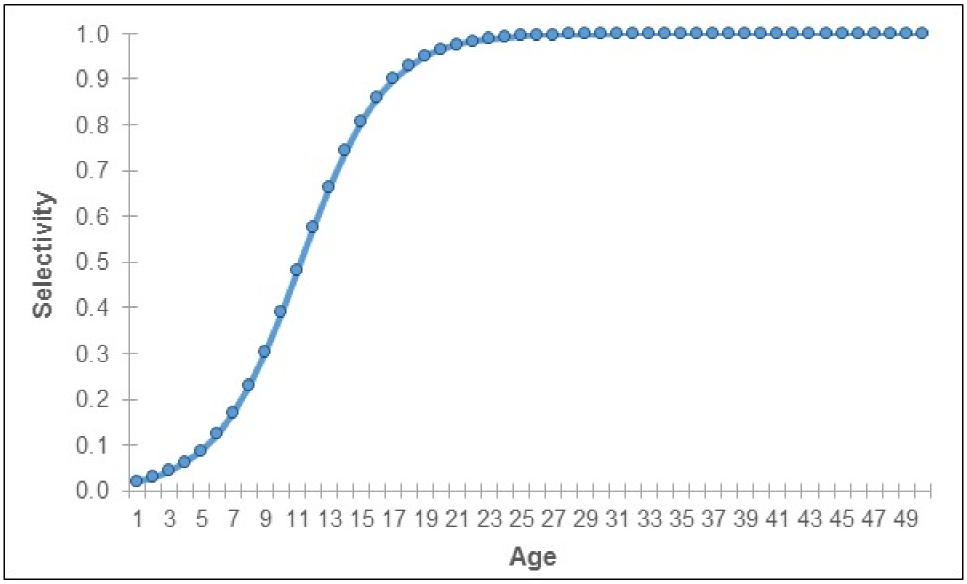


Figure 91. Final selectivity curve assumed for bycatch and incorporated into the eggs-per-recruit model.

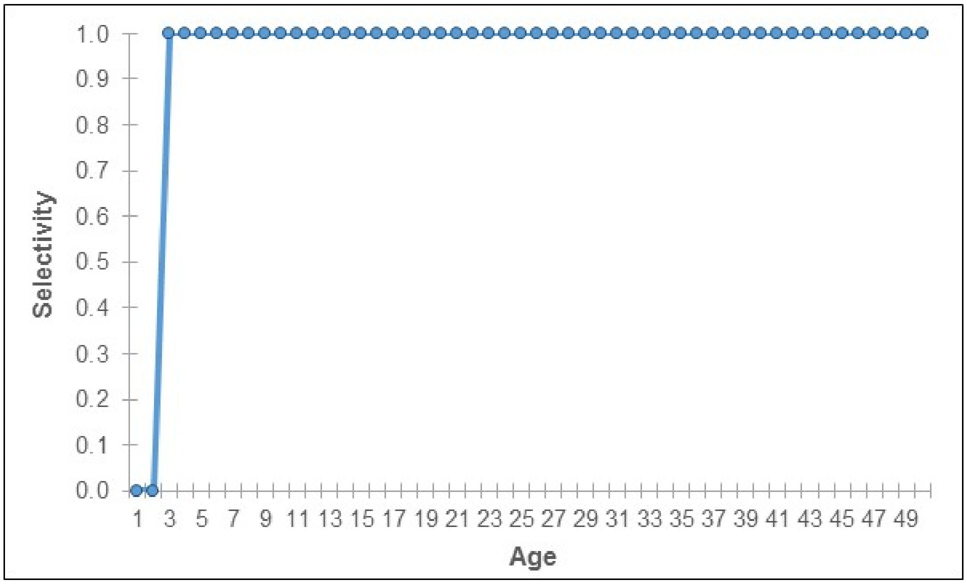


Figure 92. Final selectivity curve assumed for ship strikes and incorporated into the eggs-per-recruit model.

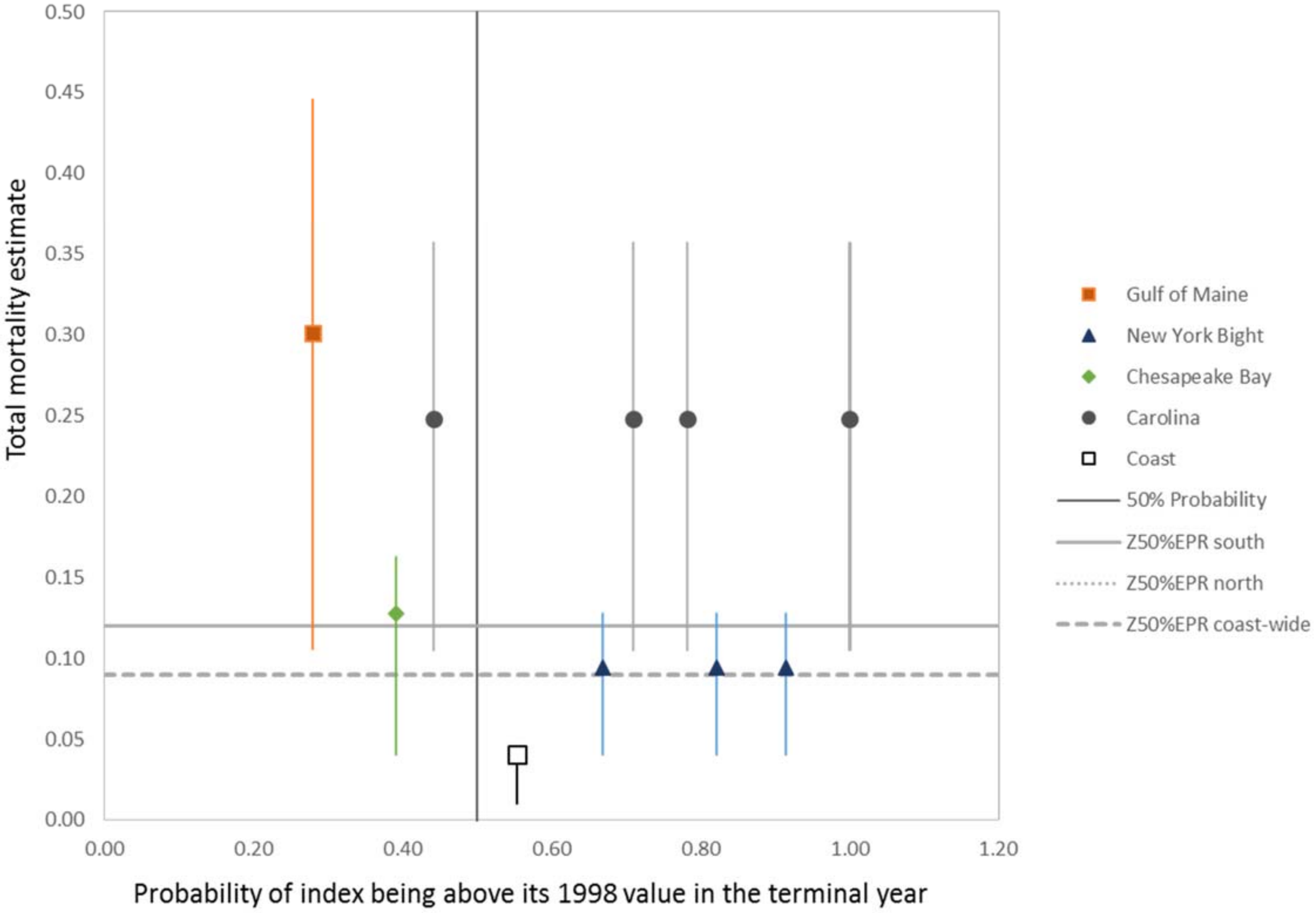


Figure 93. Control rule plot of estimates of tagging mortality plotted against the probability of the index being above its 1998 value in the terminal year for all DPSs and the coast plotted together. The solid vertical lines around each index point represent the 50% credible intervals around the *Z* estimates from the tagging model.

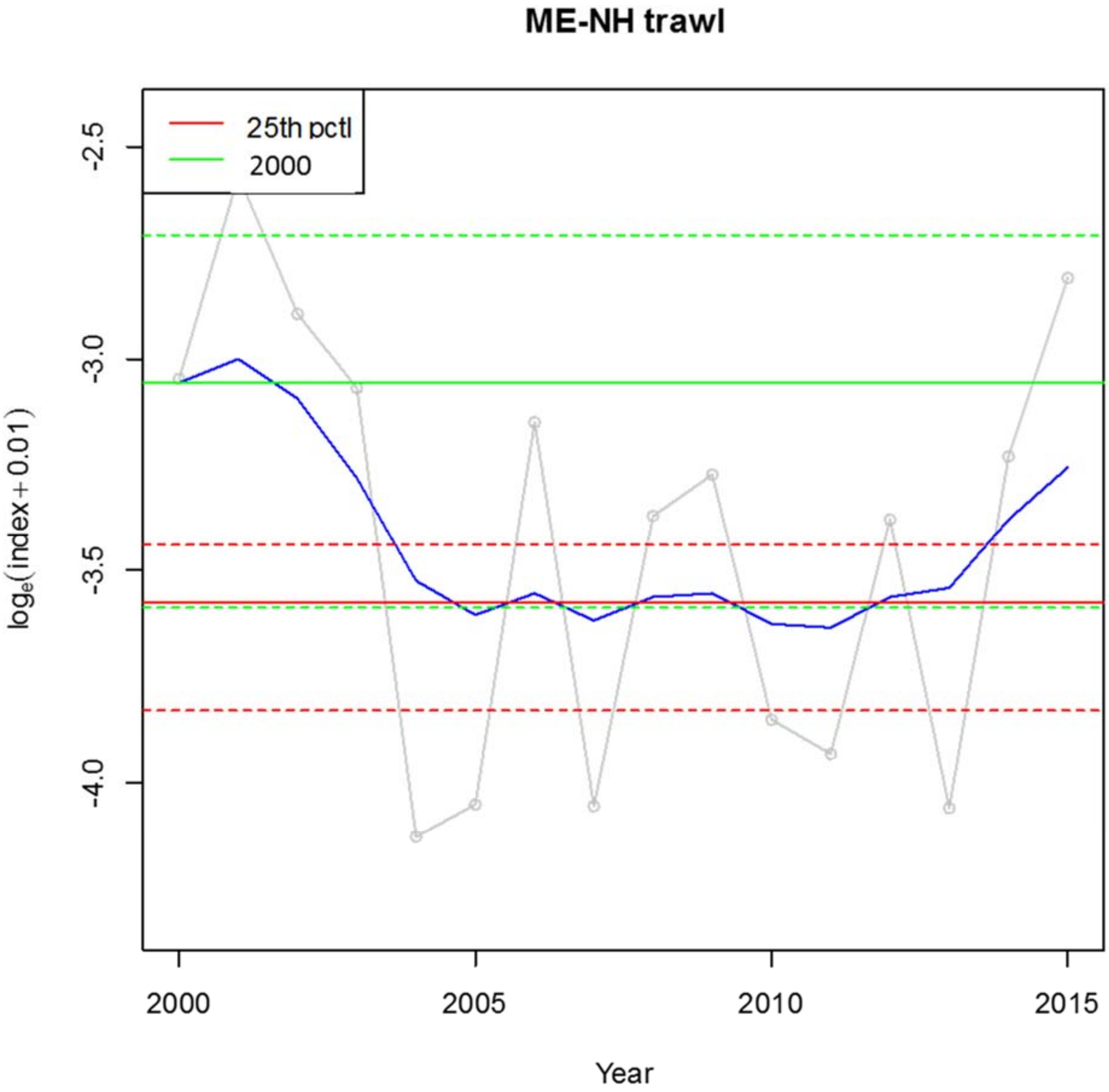


Figure 94. ARIMA fitted index for the Gulf of Maine DPS survey used to establish stock status (solid blue line) plotted with the reference values. The dashed red and green lines represent the 80% confidence intervals around the reference values. The grey line with circles is the raw index input to ARIMA. Note for that this survey, the reference year is 2000 instead of 1998, since this survey did not start until then.

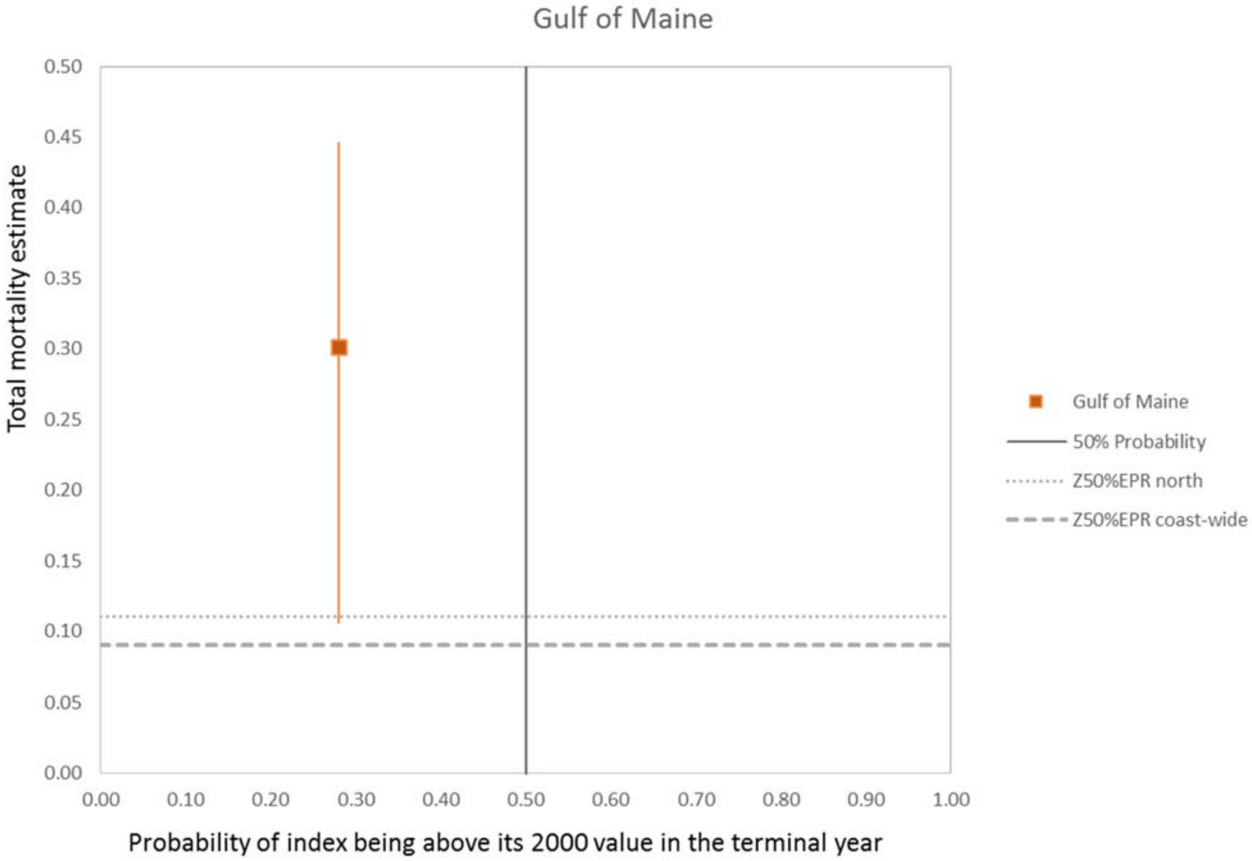


Figure 95. Control rule plot of estimates of tagging mortality plotted against the probability of the index being above its 2000 value in the terminal year for the Gulf of Maine DPS. The solid vertical lines around each index point represent the 50% credible intervals around the Z estimates from the tagging model. The year 2000 was used as a reference year for this index instead of 1998 because the survey had not started in 1998.

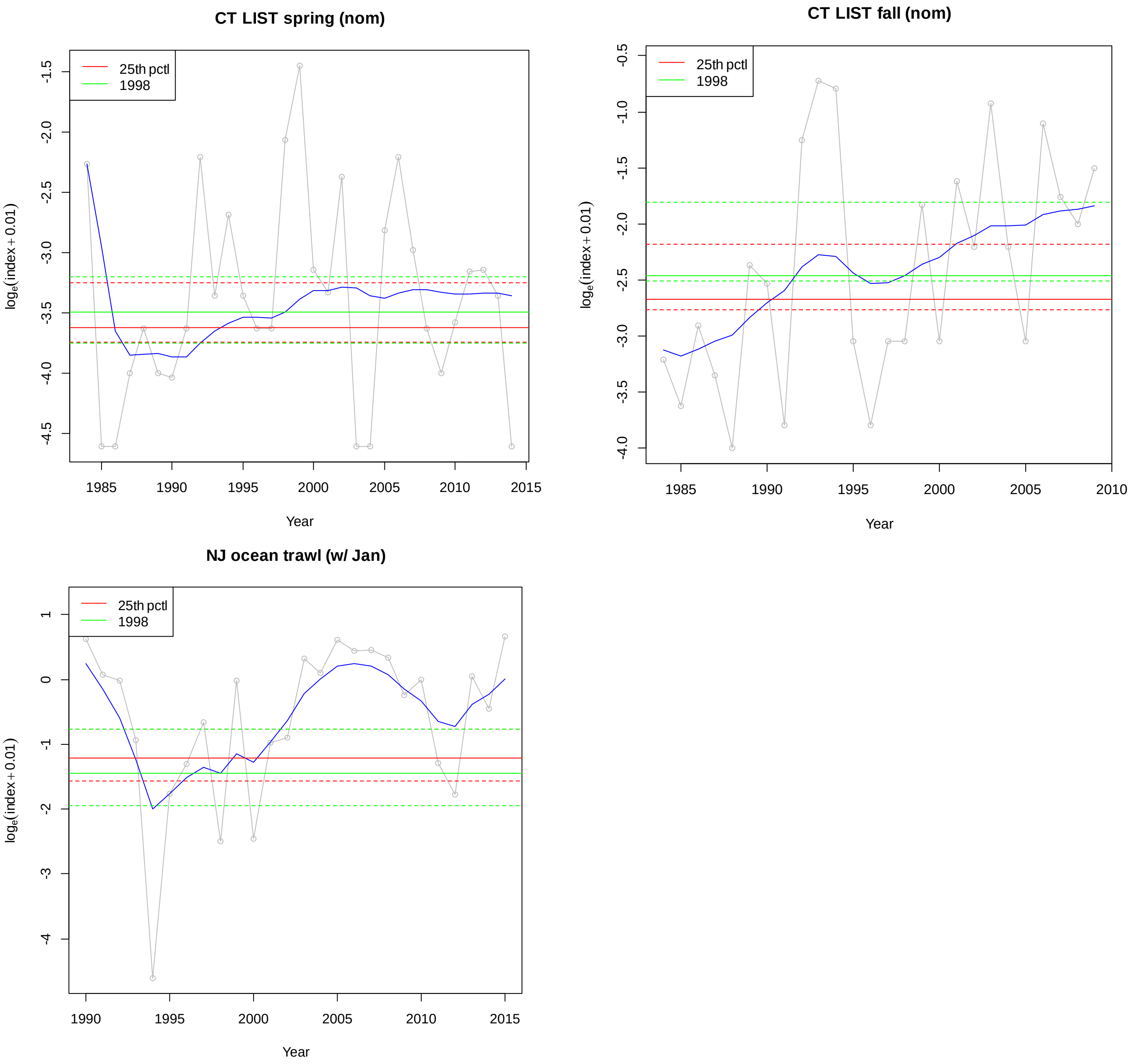


Figure 96. ARIMA fitted indices for the New York Bight DPS surveys used to establish stock status (solid blue lines) plotted with the reference values. The dashed red and green lines represent the 80% confidence intervals around the reference values. The grey line with circles is the raw index input to ARIMA.

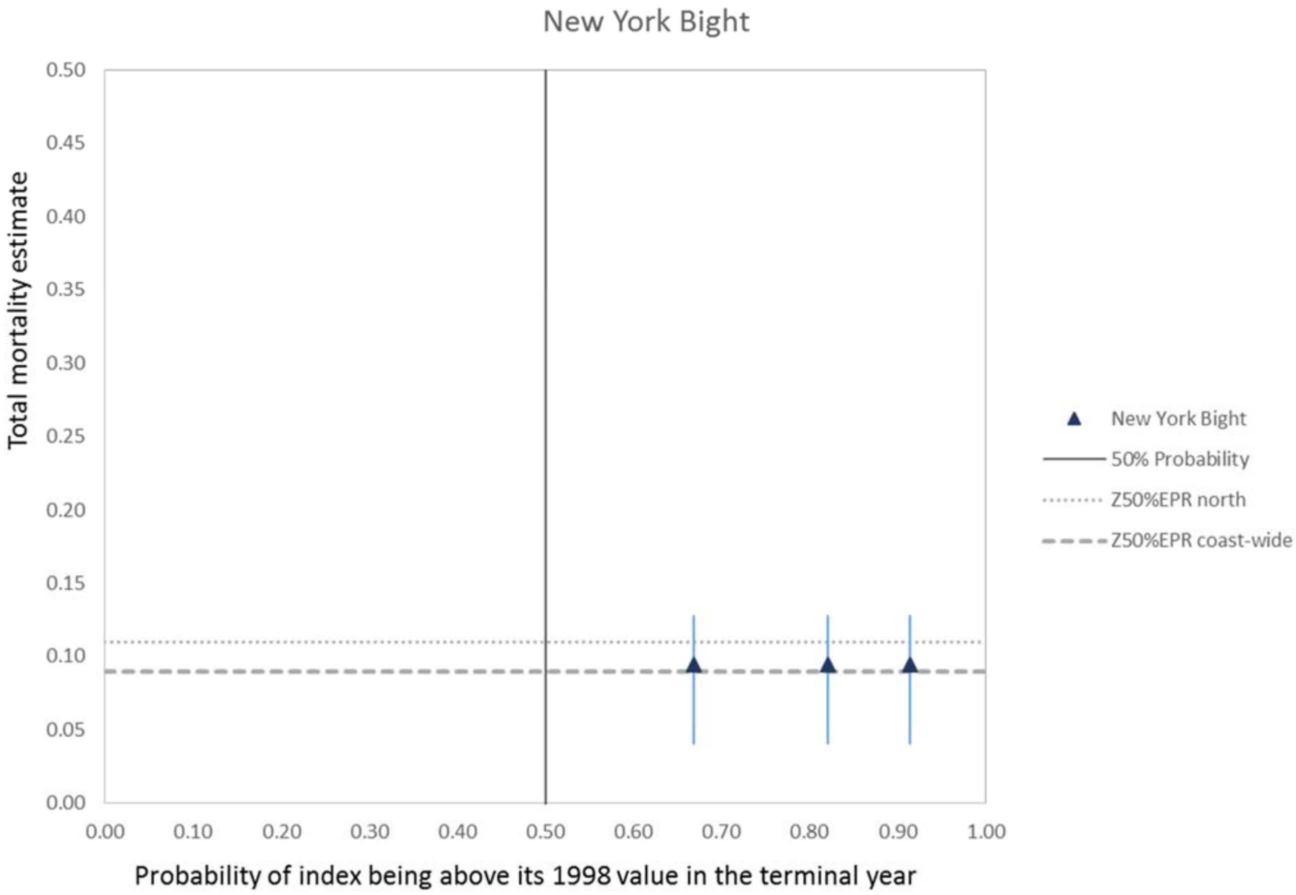


Figure 97. Control rule plot of estimates of tagging mortality plotted against the probability of the index being above its 1998 value in the terminal year for the New York Bight DPS. The solid vertical lines around each index point represent the 50% credible intervals around the *Z* estimates from the tagging model.

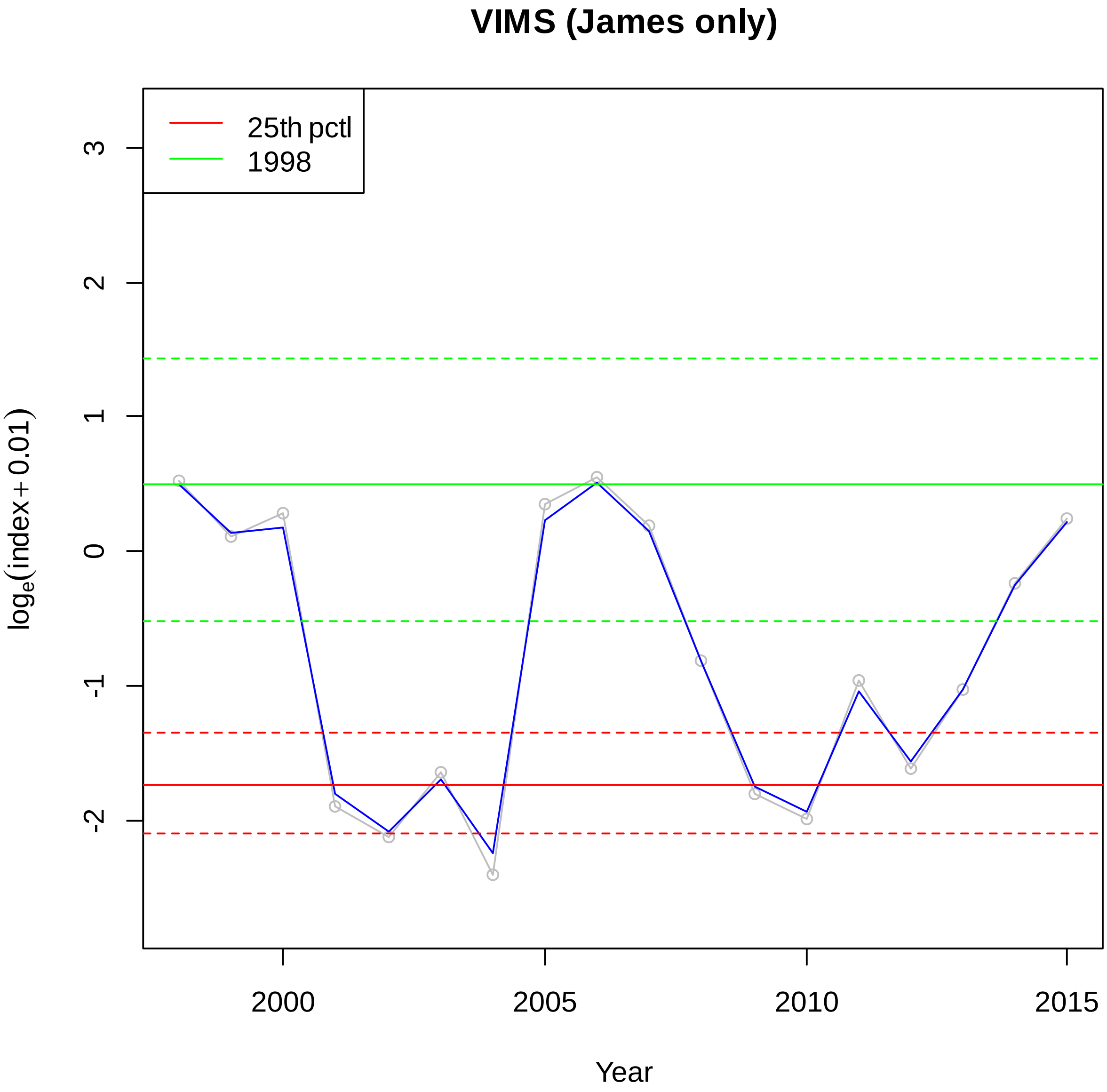


Figure 98. ARIMA-fitted index for the Chesapeake Bay DPS survey used to establish stock status (solid blue line) plotted with the reference values. The dashed red and green lines represent the 80% confidence intervals around the reference values. The grey line with circles is the raw index input to ARIMA.

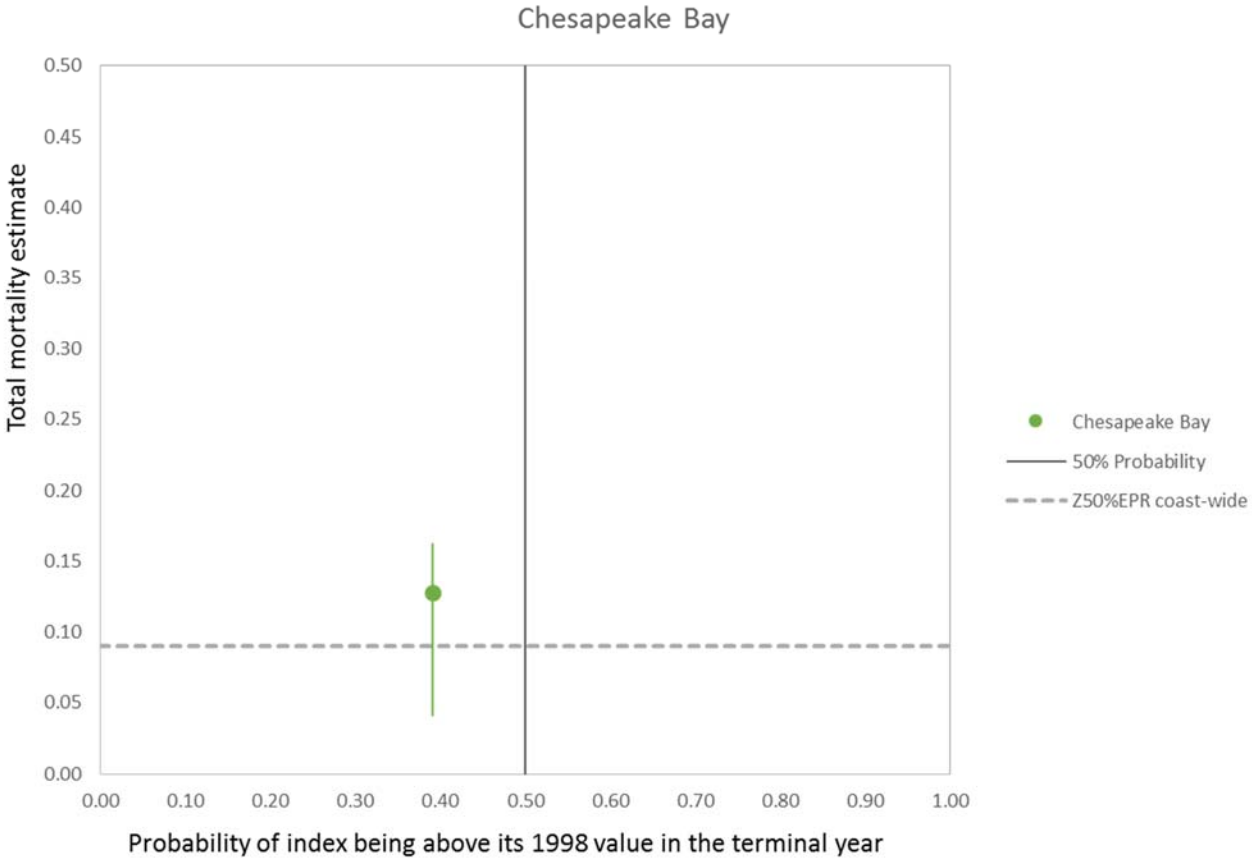


Figure 99. Control rule plot of estimates of tagging mortality plotted against the probability of the index being above its 1998 value in the terminal year for the Chesapeake Bay DPS. The solid vertical lines around each index point represent the 50% credible intervals around the Z estimates from the tagging model.

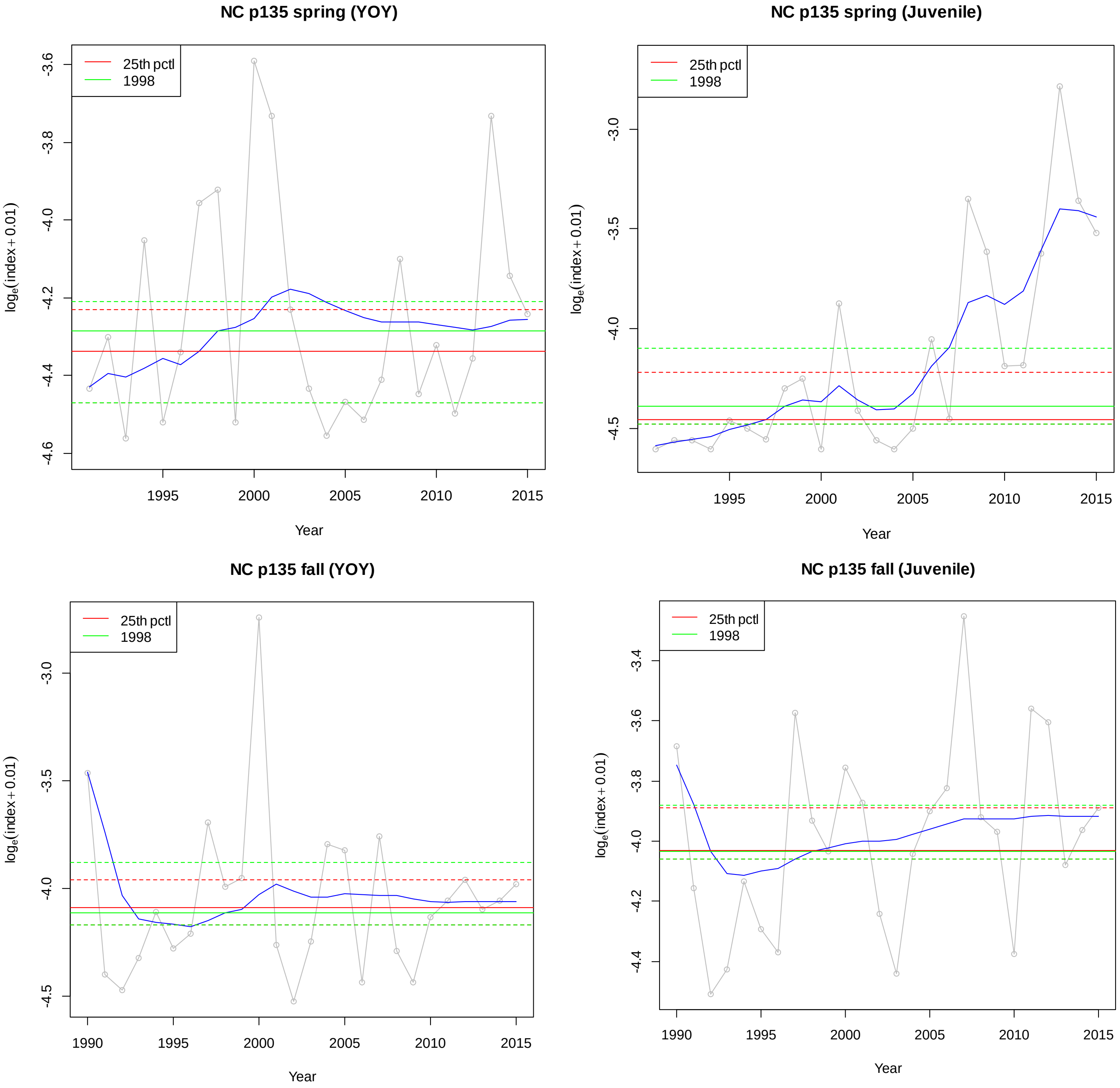


Figure 100. ARIMA-fitted index for the Carolina DPS survey used to establish stock status (solid blue line) plotted with the reference values. The dashed red and green lines represent the 80% confidence intervals around the reference values. The grey line with circles is the raw index input to ARIMA.

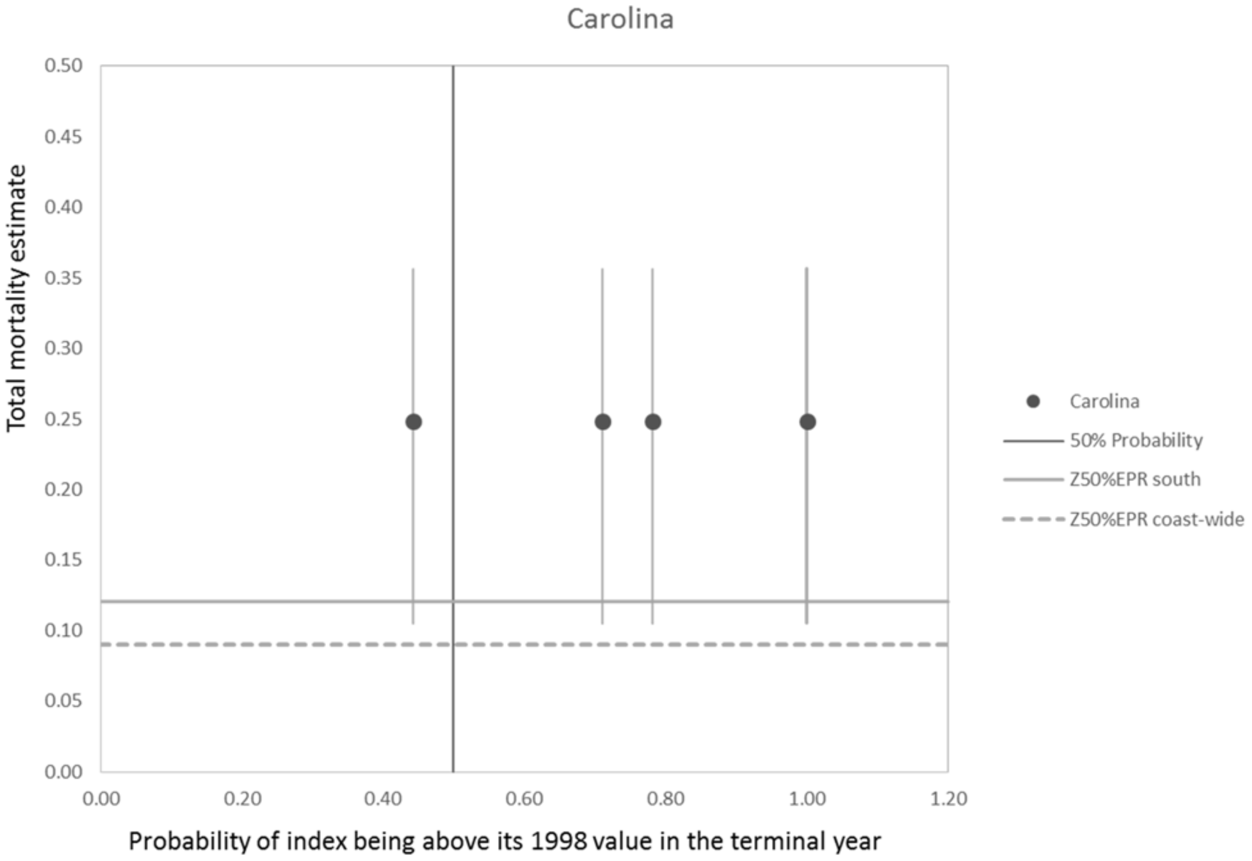


Figure 101. Control rule plot of estimates of tagging mortality plotted against the probability of the index being above its 1998 value in the terminal year for the Carolina DPS. The solid vertical lines around each index point represent the 50% credible intervals around the *Z* estimates from the tagging model.

Atlantic States Marine Fisheries Commission

Appendices to the Atlantic Sturgeon Benchmark Stock Assessment

Table of Contents

APPENDICES

1.0 APPENDIX A – HABITAT

1.1 Brief Overview of Habitat Requirements

The Atlantic sturgeon is an anadromous species found in Atlantic Coastal waters of the United States, and major river basins from Labrador (Churchill River, George River, and Ungava Bay), to Port Canaveral and Hutchinson Island, Florida (Van den Avyle 1984). Historically, Atlantic sturgeon once inhabited northern Europe as well, but since have become extinct (ASSRT 2007). According to historical records, important sturgeon fisheries existed in nearly all Piedmont river basins on the Atlantic Coast at some point in time (Goode 1887). Early accounts of sturgeon fishery landings did not distinguish between Atlantic sturgeon and the smaller shortnose sturgeon (*Acipenser brevirostrum*). However, it is likely that the accounts referred to the larger and more valuable Atlantic sturgeon. Following intense exploitation for food, and construction of mainstem river dams during the 19th and early 20th centuries, sturgeon populations were drastically reduced throughout their range and extirpated in some rivers (ASMFC 1998; USFWS-NMFS 1998; ASSRT 2007). Scientists believe that spawning populations of Atlantic sturgeon were extirpated from the St. Marys River in Georgia, the Housatonic River in Connecticut, the Connecticut River, the Taunton River in Massachusetts and Rhode Island, and all Maryland and Pennsylvania tributaries of the Chesapeake Bay (Burkett and Kynard 1993; Rogers and Weber 1995; ASMFC 1998; USFWS-NMFS 1998; ASSRT 2007).

Atlantic sturgeon are motile, long lived, and use a wide variety of habitats. Atlantic sturgeon require freshwater habitats for reproduction and early life stages, in addition to hard bottom substrate for spawning (Vladykov and Greeley 1963; Huff 1975; Smith 1985b). Coastal migrations and frequent movements between the estuarine and upstream riverine habitats are characteristic of this species (ASMFC 1998). In some systems, Atlantic sturgeon may prefer extensive reaches of silt-free higher gradient boulder, bedrock, cobble-gravel, and coarse sand substrates for spawning habitat (Brownell et al. 2001). Juvenile and adult Atlantic sturgeon frequently congregate in upper estuary habitats around the saltwater interface, and may travel upstream and downstream throughout the summer and fall, and during late winter and spring spawning periods. Adult Atlantic sturgeon may spend many years between spawning periods in marine waters (Brundage and Meadows 1982; Bain 1997; ASMFC 1998; USFWS-NMFS 1998; Savoy and Pacileo 2003; ASSRT 2007).

Much of the habitat information on Atlantic sturgeon remains incomplete. Due to the relatively low numbers of fish in many river basins, habitat utilization patterns have been difficult to establish with certainty (Collins et al. 2000a). Below is a discussion of some of the general habitat requirements for the Atlantic sturgeon. More detailed habitat-related information on the river and estuarine systems contained in each DPS is included within the pertinent DPS section of this report.

1.2 Spawning habitat

Since adult Atlantic sturgeon migrate through rivers and estuaries during their spawning migration, the discussion of adult Atlantic sturgeon estuarine and spawning habitat utilization patterns will be combined in this section. For the purposes of this report, female spawning adults are at least 15 years of age and are a minimum of 1800 mm fork length (FL) or 2000 mm TL. Male adult Atlantic sturgeon are 12 to 20 years of age and between 1350 and 1900 mm FL or 1500 and 2100 mm TL (Bain 1997). See 0 for information on length-at-age.

Spawning location (ecological)

A study by Collins et al. (2000b) indicated that adult Atlantic sturgeon in South Carolina use a wide variety of habitats during the summer. They found sturgeon in the upper fresh/brackish interface zone, the lower interface zone, and in the high salinity portions of the estuary in the Edisto River, South Carolina. Atlantic sturgeon were present in this river from March to October. During the winter, southern Atlantic sturgeon resided in the ocean (Collins et al. 2000b). Adult Atlantic sturgeon in southern rivers exhibit behavior much like gulf sturgeon (*Acipenser oxyrinxhus desotoi*) in that they spend nine months within the river system and three winter months in marine waters (Post et al. 2014).

Most studies indicate that after spawning, Atlantic sturgeon migrate to salt water (Vladykov and Greeley 1963); these down-estuary migrations may occur over several months (Bain 1997) or several weeks (Smith et al. 2015, Ingram and Peterson 2016). In the St. Lawrence River, migrations downstream have been reported from September through November (Scott and Crossman 1973). Hatin et al. (2002) found that many Atlantic sturgeon were gone from the upper St. Lawrence River by late September in some years, while in other years, the sturgeon remained in the upper river through early December. In the Hudson River, females migrate back to salt water immediately following spawning, while males remain until the onset of cold temperatures in the fall (Smith 1985a). Additionally, Bain et al. (2000) reported post-spawn adult sturgeon and older juveniles congregating in deep-water habitat during the summer in the Hudson River, New York.

Spawning and the saltwater interface

Atlantic sturgeon generally spawn in tidal freshwater regions of estuaries but may spawn in nontidal freshwater rivers in the southeastern part of their range. Most studies report that Atlantic sturgeon spawn in freshwater above the salt wedge in estuaries (Dovel 1978, 1979; Smith 1985b; Van Eenennaam et al. 1996; Bain et al. 2000). For instance, Dovel (1978, 1979) reported that Atlantic sturgeon in the Hudson River, New York, spawn in freshwater above the salt wedge. Smith (1985a) suggested that spawning fish may migrate seasonally, following the salt front upriver as the season progresses. Dovel and Berggren (1983) reported that most spawning occurred between rkm 56 and 132 in the Hudson River. However, Van Eenennaam et al. (1996) suggest that these results might be questionable because the salt wedge extends to rkm 98. Atlantic sturgeon eggs cannot tolerate high salinity; thus it is more likely that sturgeon spawn above the salt wedge and not in brackish waters (Van Eenennaam et al. 1996). In addition, Van Eenennaam et al. (1996) found ovulating sturgeon around rkm 136 in the Hudson River system.

Spawning substrate associations

Substrate is a key habitat parameter for Atlantic sturgeon because a hard bottom substrate is required for successful egg attachment and incubation (Vladykov and Greeley 1963; Huff 1975; Smith 1985b; Gilbert 1989; Smith and Clugston 1997; Secor et al. 2002; Bushnoe et al. 2005). Within rivers, the areas of cobble-gravel, coarse sand, and bedrock outcrops, which occur in the rapids complex, may be considered prime habitat (0). In northern rivers, these areas are nearer to the salt-wedge than in southern rivers. South of the Chesapeake Bay, nearly all rivers have extensive rapid-complex habitats in and/or near the fall line zone; these areas are generally at least 100 km upstream from the saltwater interface (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication). This habitat provides Atlantic sturgeon with well-oxygenated water, clean substrates for egg adhesion, crevices that serve as shelter for post-hatch larvae, and macroinvertebrates for food (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Some researchers have attempted to identify likely spawning areas for Atlantic sturgeon using modeling techniques. Brownell et al. (2001) developed a Habitat Suitability Index (HSI) model for spawning Atlantic sturgeon and early egg development, and found that cobble/gravel (64 mm to 250 mm) was the optimal spawning substrate for Atlantic sturgeon. Boulder (250 mm to 4000 mm) scored the second highest in the model, and silt/sand (<2.0mm) and mud/soft clay/fines scored the lowest. The curve and the data values were based on the shortnose sturgeon model, and factors such as oxygenation, substrate embeddedness, available egg attachment sites, protection of eggs from predators, light intensity, and solar warming were all hypothesized to be available in cobble/gravel and boulder substrates (Brownell et al. 2001).

Bushnoe et al. (2005) identified potential spawning areas for Atlantic sturgeon in Virginia based on the location of suitable hard substrate and a variety of other water quality parameters, including temperature, dissolved oxygen, pH, salinity, hardness, and conductivity. They concluded that Turkey Island oxbow and the James Neck oxbow in the James River, the Appomattox River, the Mattaponi, and Pamunkey River in the York River system, and the Rappahannock River all represented potential spawning habitat (Bushnoe et al. 2005).

Smith et al. 2015 identified spawning locations in the Roanoke River by deploying artificial spawning substrate and collecting eggs. The locations were just below the rapids in Weldon, NC where the substrate is bedrock outcrops and gravel.

Spawning depth associations

Atlantic sturgeon have been documented spawning in water from 2.4-60 meters in depth (0) (Borodin 1925; Dees 1961; Scott and Crossman 1973; Shirey et al. 1999; Bain et al. 2000; Collins et al. 2000b; Caron et al. 2002; Hatin et al. 2002). Spawning depth seems to vary greatly depending upon the available depth range.

A recent HSI model developed by Brownell et al. (2001) showed that the optimal depth range in the south for spawning Atlantic sturgeon and egg incubation ranged from 2.4-8 meters. It should be noted that depth in this model had a maximum range of eight meters because areas where spawning is likely to occur (areas above the fall zone) in the South are not much deeper than eight meters (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication). Smith et al. described water depths at their artificial substrate locations as less than five meters during low flow.

Spawning water temperature

Atlantic sturgeon reportedly spawn in waters where temperatures range from 13-26°C (0; Borodin 1925; Huff 1975; Smith 1985b; Bain et al. 2000; Caron et al. 2002; Hatin et al. 2002). Temperature appears to be a universal determining factor in spawning migration times. Migration temperatures seem to be uniform across the Atlantic Coast, with southern fish migrating earlier in the spring and northern fish following a few weeks later once the waters reach the appropriate temperature. Generally, for spring migrations, male Atlantic sturgeon commence upstream migration when waters reach around 6^oC (Smith et al. 1982; Dovel and Berggren 1983; Smith 1985a). Females usually follow a few weeks later when temperatures are closer to 12-13^oC (Dovel and Berggren 1983; Smith 1985a, 1985b; Collins et al. 2000b). Spawning has been found to occur most often in waters 13-21^oC (Ryder 1888; Scott and Crossman 1973; Bain et al. 2000; Caron et al. 2002). In addition, Mohler (2003) stated in the "Culture Manual for Atlantic sturgeon" that the preferred temperature for induced spawning in cultured sturgeons is between 20^oC and 21°C. However, with respect to fall spawn fish, recent work in the Roanoke River show spawning occurring when water temperatures were 24-25°C and the onset of spawning migrations beginning at water temperatures were near 28°C. Once spawning was complete outgoing migrations occurred when water temperatures were near 20°C (Smith et al. 2015)

Spawning water velocity/flow

Atlantic sturgeon lay their eggs in flowing water (Vladykov and Greeley 1963; Van den Avyle 1983). Modeling studies suggest that the optimal water velocities for Atlantic sturgeon spawning range from 0.46-0.76 meters per second. Furthermore, velocities lower than 0.06 meters per second and higher than 1.07 centimeters per second are unsuitable for spawning (Crance 1987). Eggs from fall spawn Roanoke River fish were collected during discharge flows of 55-297 cubic meters per second (Smith et al. 2015). A recent HSI developed for spawning Atlantic sturgeon showed that optimal water velocity for spawning and egg incubation ranged from 0.2-0.76 meters per second (Brownell et al. 2001).

Spawning and other water parameters

Reports of gulf sturgeon (*Acipenser oxyrinchus desotoi*) indicate that other important habitat factors include hardness and conductivity. Sulak and Clugston (1999) and Fox et al. (2000) describe the spawning sites of gulf sturgeon on the Suwannee River, Florida, as having a moderate Ca++ ion concentration and conductivity ranging from 10 µS to 110µS. Bushnoe et al. (2005) used these criteria to identify Atlantic sturgeon spawning habitat in rivers in Virginia. More research will be needed to clarify the importance of these parameters.

1.3 Egg and larval habitat

Geographical and temporal movement patterns

Due to a low tolerance for saline environments, Atlantic sturgeon eggs must be spawned upstream of the salt front (Van Eenennaam et al. 1996). On the other hand, research on the conspecific *A. o. desotoi* (Gulf sturgeon) indicates that Atlantic sturgeon probably select regions with high conductivity, above the salt wedge, but below fall line regions containing freshwater with low conductivity (Sulak and Clugston 1999; Fox et al. 2000).

Eggs are deposited into flowing water and disperse following fertilization. After approximately twenty minutes, the demersal eggs become strongly adhesive and attach to hard substrates (Murawski and Pacheco 1977; Van den Avyle 1983). The eggs hatch after 94 to 140 hours; after a pelagic yolksac larval period of about 10 days, late-stage larvae settle in the demersal habitat. This will be the principal type of habitat for the remainder of the sturgeon's life (USFWS-NMFS 1998).

Little is known about the habitat of larval Atlantic sturgeon. Larval Atlantic sturgeon are less than 4 weeks old, with lengths less than 30 mm TL (Van Eenennaam et al. 1996); they are assumed to inhabit the same riverine or estuarine areas where they were spawned (Bain et al. 2000; Kynard and Horgan 2002). Newly hatched larvae are active swimmers and leave the bottom to swim in the water column. Once the yolk sac is absorbed, the larvae exhibit benthic behavior (Smith et al. 1980, 1981). Bath et al. (1981) caught free embryos by actively netting the bottom near the spawning area, demonstrating that early life stages are benthic.

For a more controlled experiment, Kynard and Horgan (2002) raised captive Atlantic sturgeon in chambers. They found that upon hatching, the embryos sought cover where they remained for a few days. The fish left cover and began to migrate around day 8. Following the passage of a few more days, the larvae stopped migrating and exhibited foraging behavior. Downstream migration resumed during the juvenile period when the temperature dropped. Atlantic sturgeon larvae are capable of dispersing long distances. Movement occurs at night during the first half of the larval migration; eventually, the fish become active during both the day and night (Kynard and Horgan 2002). Kynard and Horgan (2002) hypothesize that this foraging behavior is a way to reduce daytime predation while the larvae are still developing, yet still enable them to forage when there is daylight to aid in the visual detection of prey.

Mohler (2003) found similar results. Cultured Atlantic sturgeon were mostly pelagic after hatching and exhibited a "swim up and drift down" behavior. After three to four days, fry began to exhibit benthic clumping behavior and swam against the direction of water flow in the tank. Fry remained benthic for approximately four days, before moving around the tank in search of food. At this stage, the larval Atlantic sturgeon were noted to be pelagic, until live brine shrimp were thrown into the tank and the fry moved to the bottom of the tank to feed. Atlantic sturgeon fry did not actively seek out a food source, but rather waited until the currents brought food to them (Mohler 2003).

The ASSRT (2007) notes that downstream dispersal patterns may be different among watersheds:

> Differences in the innate dispersal patterns of sturgeon species in early life stages also suggest that there are markedly separated differences in behavior between subpopulations of sturgeon (B. Kynard, USGS Conte Anadromous Fish Research Center, personal communication). Boyd Kynard, a researcher at the USGS Conte Anadromous Fish Research Center (Turner Falls, Massachusetts), has noted major differences in innate dispersal patterns of early life stage sturgeon species including *Acipenser fulvescens* (Wolf and Menominee rivers), *A. brevirostrum* (Connecticut and Savannah rivers), *A. transmontanus* (Sacremento and Kootenai rivers), and Atlantic/Gulf sturgeon subpopulations (Hudson and Suwannee rivers). This research suggests that Atlantic sturgeon are likely adapted to unique features of their watershed, considering their genetic discreteness and differing migration behaviors. These findings are similar to research conducted on striped bass (*Morone saxatilis*), an anadromous fish like Atlantic sturgeon, which correlated egg characteristics (e.g., egg diameter, egg density, etc.) with watershed type (e.g., low, medium, high energy) (Bergey et al. 2003). Differences in egg characteristics likely are the result of subpopulation adaptations to the watershed, but the manner in which these adaptations were produced was not determined. The ASSRT concluded that unique behavioral and physiological traits likely exist for each extant subpopulation of Atlantic sturgeon – except those that share a drainage basin (similar adaptations) (from ASSRT 2007).

Eggs, larvae, and the saltwater interface

Salinity is very important to the survival of sturgeon eggs (McEnroe and Chech 1985; Jenkins et al. 1993; Van Eenennaam et al. 1996). Eggs are spawned in regions between the salt front and the fall-line of large rivers or estuarine tributaries (Borodin 1925; Leland 1968; Scott and Crossman 1973; Crance 1987; Bain et al. 2000). Bath et al. (1981) collected larval sturgeon in salinities of 0-22 parts per thousand (ppt) in the Hudson River, New York. Dovel and Berggren (1983) recorded sturgeon embryos from river kilometer (rkm) 60 to rkm 148, which includes some brackish water. However, Van Eenennaam et al. (1996) report that Atlantic sturgeon embryo habitat must be well above the salt wedge, due to their low tolerance to salinity. Other species of sturgeon show this same salt intolerance. For example, free embryos, larvae, and age-0 juveniles of white sturgeon and shortnose sturgeon also exhibit low salt tolerance. Mortality has been documented at salinities as low as 5-10 ppt (McEnroe and Chech 1985; Jenkins et al. 1993).

Egg and larval substrate associations

Atlantic sturgeon deposit their eggs on benthic hard substrate (Gilbert 1989; Smith and Clugston 1997). The eggs contain adhesive strings that attach to stones, shells, sticks, and weeds (Vladykov and Greeley 1963; Colette and MacPhee 2002). Hard substrate is also important to larval Atlantic sturgeon, as it provides refuge from predators (Kieffer and Kynard 1996; Fox et al. 2000). A study by Kynard and Horgan (2002) showed that after hatching, embryos immediately sought cover. Some scientists hypothesize that rapid-complex habitats might serve as hatcheries for Atlantic sturgeon because they provide cover, well-oxygenated hiding places, and a food source of microinvertebrates (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Egg and larval depth associations

The importance of depth to embryonic and larval Atlantic sturgeon has not been thoroughly discussed in the literature, but it is likely not as important to this species as benthic substrate characteristics (P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication). However, depth of migrating larvae would be an important issue to address for a project inserting intake structures into a river near nursery grounds (W. Patrick, NOAA Fisheries Service, personal communication). Additionally, Bain (1997) found that embryos remain on the bottom of deep channel habitats, and Bath et al. (1981) collected larval samples from 9.1-19.8 meters.

Egg and larval water temperature

Smith et al. (1980) found that Atlantic sturgeon eggs optimally hatch at temperatures ranging from 18°C to 20°C. Hatching occurs approximately 94 to 140 hours after egg deposition at temperatures of 20°C and 18°C, respectively, and larvae assume a demersal existence (Smith et al. 1980). Similarly, Mohler (2003) states that in a culture setting, a temperature range of 20°C to 21°C is favorable for the incubation of Atlantic sturgeon eggs. Temperatures below 18°C prolong hatching and increase the risk of fungal infestation to dead eggs, which in turn can kill the viable individuals. Hatching occurs in 60 hours at this temperature range (Mohler 2003). Bath et al. (1981) collected larval sturgeon in the Hudson Bay, New York, in temperatures of 15.0°C to 24.5°C. Researchers recommend that first-feeding cultured Atlantic sturgeon fry be kept in water temperatures of 15°C to 19°C, and that a temperature of 19°C yields higher growth rates (Kelly and Arnold 1999; Mohler 2003).

1.4 Juvenile habitats

Geographical and temporal movement patterns

For the purposes of this report, a sturgeon will be considered juvenile according to the guidelines found in the ASSRT (2007), which broke juveniles down as such:

1) Young-of-the-year (YOY; age-0): Thought to be natal to the river they were captured in and used as evidence in identifying extant populations
2) Juveniles or subadults (age-1 to age-15): Considered possible migrants from other systems though the older individuals could be reproducing (maybe in more northern waters)
3) Mature adults (age-15) or 150 cm TL: Generally considered mature, and if they were captured in a river during the spawning season it was assumed that they were going to spawn in that river (used to identify extant populations) (ASSRT 2007)

Most researchers have found that growth rates and sizes of Atlantic sturgeon vary by latitude, with rapid growth occurring in the southern latitudes and larger maximum sizes occurring in the north (Vladykov and Greeley 1963; Dovel and Berggren 1983; Smith 1985a, 1985b; Collins et al. 1996; Stevenson and Secor 1999). However, Johnson et al. (2005), working off the New Jersey coast, found that their data did not fit this pattern. They suggested that this might have been due to a mixed sample composed of Atlantic sturgeon from different populations that had different growth rates (Johnson et al. 2005). These findings are partially supported by genetic studies performed by Waldman et al. (1996a) who showed that approximately 90% of the Atlantic sturgeon catch in the New York Bight was of Hudson River origin.

The ASSRT (2007) notes the following information on juvenile Atlantic sturgeon migrations:

> Upon reaching a size of approximately 76 to 92 cm, the sub-adults may move to coastal waters (Murawski and Pacheco 1977; Smith 1985b), where populations may undertake long-range migrations (Dovel and Berggren 1983; Bain 1997; T. King, USGS Leetown Science Center, Aquatic Ecology Laboratory, Kearneysville, West Virginia, supplemental data). Tagging and genetic data indicate that sub-adult and adult Atlantic sturgeon may travel widely once they emigrate from rivers. Sub-adult Atlantic sturgeon wander among coastal and estuarine habitats, undergoing rapid growth (Dovel and Berggren 1983; Stevenson 1997). These migratory sub-adults, as well as adult sturgeon, are normally captured in shallow (10 to 50m) near shore areas dominated by gravel and sand substrate (Stein et al. 2004; from ASSRT 2007).

Juvenile Atlantic sturgeon are thought to remain close to their natal habitats within the freshwater portion of the estuary for at least one year before commencing migration out to sea (Secor et al. 2000b). Migrations out to coastal areas occur between two and six years of age (Smith 1985b), and are seasonal, with movement occurring north in the late winter, and south in fall and early winter (Dovel 1978; Smith 1985b; USFWS-NMFS 1998). Seasonal migrations of juveniles are regulated by changes in temperature gradients between fresh and brackish waters (Van Den Avyle 1984). For example, hatchery-reared juveniles released in the Chesapeake Bay used brackish waters close to the estuary mouth during colder months, and moved upriver during warmer months (Secor et al. 2000b).

Similar behavior has been seen in several river systems, including the Delaware River, Hudson River, and the Winyah Bay system (South Carolina; Brundage and Meadows 1982; Smith et al. 1982; Dovel and Berggren 1983; Gilbert 1989). Dovel and Berggren (1983) reported a mass down-estuary migration of juvenile Atlantic sturgeon in the Hudson Estuary, New York, when the temperature dropped below 20°C. Down-river/down-estuary migrations peak at the end of October in the Hudson system. At this time, many juveniles overwinter in deep holes, while others leave the Hudson River and move south along the Atlantic coast (Dovel and Berggren 1983). In contrast, Moser and Ross (1995) found that juvenile sturgeon in the Cape Fear River, North Carolina, kept the same center of distribution near the saltwater-freshwater interface year round. However, these fish were unable to move upriver because of the location of the Cape Fear Lock and Dam No. 1, just above the estuary (0.5 ppt interface; P. Brownell, NOAA Fisheries, Southeast Regional Office, personal communication).

Coastal features or shorelines where migratory Atlantic sturgeon commonly aggregate include the Bay of Fundy, Massachusetts Bay, Rhode Island, New Jersey, Delaware, Delaware Bay, Chesapeake Bay, and North Carolina, which presumably provide better foraging opportunities (Dovel and Berggren 1983; Johnson et al. 1997; Rochard et al. 1997; Kynard et al. 2000; Eyler et al. 2004; Stein et al. 2004; Dadswell 2006). Smith (1985b) stated that fish tagged off South Carolina migrated as far north as Pamlico Sound and Chesapeake Bay. Most data indicate that Atlantic sturgeon in the northern rivers travel more extensively than those in the southern rivers (ASMFC 1998). However, fish from the southern region have been observed to travel from Florida to New York via acoustic telemetry (Post et al. 2014).

Later-stage juveniles often enter and reside in non-natal rivers that lack active spawning sites (Bain 1997). Inter-estuarine migrations have been documented extensively in the literature (Dovel and Berggren 1983; Smith 1985b; Welsh et al. 2002; Savoy and Pacileo 2003). These non-natal estuarine habitats serve as nursery areas, providing abundant foraging opportunities and thermal and salinity refuges. Therefore, these areas are very important to the Atlantic sturgeon's survival (Moser and Ross 1995).

Juveniles and the saltwater interface

There is a large amount of variation in the salinity tolerance of juvenile Atlantic sturgeon (0). Some Atlantic sturgeon may occupy freshwater habitats for two or more years, while others move downstream to brackish waters when the water temperature drops (Scott and Crossman 1973; Dovel 1978; Hoff 1980; Lazzari et al. 1986). Additionally, bioenergetic studies on YOY juveniles indicate poor survival at salinities greater than 8 ppt, but euryhaline behaviors are exhibited by juveniles age-1 and 2 (Niklitschek 2001).

Juvenile substrate associations

Kynard et al. (2000) reported that juvenile Atlantic sturgeon in Massachusetts were found mostly over sand substrates, but other associated substrates included rock, cobble, and mud (Kynard et al. 2000). Savoy and Pacileo (2003) found that 85% of the juvenile Atlantic sturgeon caught in Long Island Sound were in mud or transitional bottom habitats. Correspondingly, Bain et al. (2000) found juveniles off Long Island Sound over mud substrates. In the Hudson River, Haley et al. (1996) collected juvenile Atlantic sturgeon at sites that had silt substrates. However, the researchers state that it is unclear whether this represents habitat preference or habitat use, as the majority of sites sampled was composed of this substrate (Haley et al. 1996). In the same system, Bain et al. (2000) documented juveniles over clay, silt, and sand substrates. Stein et al. (2004) found migratory subadults, as well as adult Atlantic sturgeon, generally in areas dominated by gravel and sand substrate. Armstrong 1999 captured 66.2% of fish over organic rich mud, 7.0% over sand and 26.8% over mixed organic rich mud and sand within the Albemarle Sound, North Carolina.

Juvenile depth associations

Many researchers have found that juvenile Atlantic sturgeon tend to congregate in deep waters (**Error! Reference source not found.**; Moser and Ross 1995; Bain et al. 2000; Savoy and Pacileo

2003). Moser and Ross (1995) report that juvenile Atlantic sturgeon in North Carolina use deep and cool areas as thermal refuges, particularly in the summertime.
Juvenile Atlantic sturgeon farther north also seem to prefer deeper areas. Bain et al. (2000) stated that those juveniles that did not migrate out to sea during the winter occupied deep-water habitat in the Hudson River, New York. Further north, Savoy and Pacileo (2003) found that juvenile Atlantic sturgeon in Long Island Sound preferred the deep-water areas within the central basin of the Sound. They reported that 71% of the Atlantic sturgeon were caught in areas of the deepest stratum (deeper than 27 m). This area comprised only 26% of the available habitat (Savoy and Pacileo 2003). Savoy and Pacileo (2003) also reported that Atlantic sturgeon were rarely caught in the shallow areas (5-9 meters), and that the 20 fish caught in the shallow stratum were fish migrating in and out of Long Island Sound. Contrary to this, Armstrong 1999 found juveniles in Albemarle Sound preferred depths of 3.6-5.4 meters, however sample size was limited.

While the majority of juvenile Atlantic sturgeon have been collected at the deepest depths available, some have also been collected in shallower waters (**Error! Reference source not found.**). A telemetry study on hatchery-released age-1 juveniles showed that most Atlantic sturgeon used depths less than 6 meters (Secor et al. 2000b).

Juvenile water temperature
Temperature is a key habitat parameter for the structuring of juvenile Atlantic sturgeon summer habitat (0; Niklitschek and Secor 2005). Temperatures more than 28ºC are judged to have sublethal effects on Atlantic sturgeon. An increase in temperature coupled with low dissolved oxygen and high salinity can cause loss of juvenile Atlantic sturgeon nursery habitat. Their low tolerance to temperature and low oxygen is of concern during the first two summers of life when juveniles are restricted to lower saline waters and are unable to seek out thermal refuge in deeper waters (Secor and Gunderson 1998; Niklitschek 2001; Niklitschek and Secor 2005). Armstrong 1999 identified the Albemarle Sound as a relatively shallow system with a lack of cool oxygenated refugia during summer. However, the July collections occurred along the southern shore in waters less than three meters and temperatures approached 30°C. Armstrong 1999 suggests that given its long history of association with the Albemarle Sound, sturgeons may be especially adapted to withstand these summer water quality constraints.

Temperature may also be an important habitat parameter regarding migration patterns, since juvenile Atlantic sturgeon appear to migrate in response to certain temperature thresholds. Dovel and Berggren (1983) stated that downstream migrations in the Hudson River began when temperatures reached 20°C and peaked between 12°C and 18°C. By the time the temperature was 9°C, juvenile Atlantic sturgeon had congregated for the winter in deep holes (Dovel and Berggren 1983) where water temperatures can approach 0°C (Bain et al. 2000). Similar migration patterns were noted by Dovel (1979) in the Hudson River and by Brundage and Meadows (1982) in the Delaware River. However, Lazzari et al. (1986) reported that juvenile Atlantic sturgeon in the Delaware River used the tidal portion of the bay for a longer period and at lower temperatures than reported by other researchers. They found Atlantic sturgeon in these areas through December when temperatures approached 0.5°C.

During their biotelemetry studies, Kieffer and Kynard (1993) found that juvenile Atlantic sturgeon in the Connecticut and Merrimack Rivers, Massachusetts, did not enter the river until mid-May when the temperatures were 14.8°C to 19.0°C. The fish left the river by September or October when river temperatures were 13°C to 18.4°C (Kieffer and Kynard 1993).

Temperature may also affect juvenile Atlantic sturgeon feeding behavior. Mohler (2003) found that in cultured juvenile Atlantic sturgeons, a noticeable decrease in feeding occurred when temperatures dropped to 10°C. However, minimum weight gains were noticed at temperatures as low as 5.4°C, with weight loss occurring at lower water temperatures (Mohler 2003).

Juvenile dissolved oxygen associations

Dissolved oxygen is a very important habitat parameter for juvenile Atlantic sturgeon. A large proportion of Atlantic sturgeon nursery habitat has been degraded because of persistent low levels of dissolved oxygen. Secor and Niklitschek (2001) report that in habitats with less than 60% oxygen saturation (4.3 mg/L to 4.7 mg/L at 22°C to 27°C), YOY fish aged 30 to 200 days, will experience a loss in growth. Mortality of juvenile Atlantic sturgeon has been observed for summer temperatures at levels of less than or equal to 3.3 mg/L (Secor and Niklitschek 2001). Recently, the Chesapeake Bay Program adopted dissolved oxygen guidelines based upon levels that would protect Atlantic and shortnose sturgeon, which show unusually high sensitivity to low oxygen concentrations among estuarine living resources (Secor and Niklitschek 2002; EPA 2003).

1.5 Late Stage Juvenile and Adult Marine Habitat

All estuarine habitats for adult and juvenile Atlantic sturgeon are discussed under previous sections. This section focuses entirely on juvenile and adult Atlantic sturgeon habitat in marine waters.

Geographical and temporal patterns at sea

Juvenile Atlantic sturgeon are known to emigrate out of their natal estuarine habitats and migrate long distances in the marine environment (Murawski and Pacheco 1977); the longest oceanic journey recorded was 1,450 km (Magnin and Beaulieu 1963). Tag returns (n = 120) of juvenile Atlantic sturgeon that were originally tagged in the Delaware River provide insight into the coastal migration of this life stage that encompasses a broad size range (C. Shirey, Delaware Department of Fish and Wildlife, unpublished data). After leaving the Delaware River estuary during the fall, juvenile Atlantic sturgeon were recaptured by commercial fishermen in nearshore waters along the Atlantic coast as far south as Cape Hatteras, North Carolina, where they were recaptured from November through early March. Juvenile Atlantic sturgeon repeatedly crossed the mouth of the Chesapeake Bay and traveled around the Delmarva Peninsula in March and April, with a portion of the tagged fish re-entering the Delaware River estuary. However, many fish continued this northerly coastal migration through the Mid-

Atlantic and into Southern New England waters where they were recovered throughout the summer months, primarily in the waters of Massachusetts, Rhode Island, and Long Island, New York. Movements as far north as Maine were documented. A southerly coastal migration was apparent from tag returns reported in the fall. The majority of these tag returns were reported from relatively shallow nearshore fisheries with few fish reported from waters in excess of 25 meters (C. Shirey, Delaware Department of Fish and Wildlife, unpublished data).

Little is known about the habitat use of adult Atlantic sturgeon during the non-spawning season, particularly when the sturgeon return to marine waters (Bain 1997; Collins et al. 2000b). While at sea, adult Atlantic sturgeon have been documented using relatively shallow nearshore habitats (10-50 meters; Stein et al. 2004; Laney et al. 2007; Erickson et al. 2017). It is possible that individual fish select habitats in the same areas, or even possibly school to some extent (Bain et al. 2000; Stein et al. 2004; Laney et al. 2007).

Substrate associations at sea

Stein et al. (2004) reported that Atlantic sturgeon were found mostly over sand and gravel substrate and that they were associated with specific coastal features, such as the mouths of the Chesapeake Bay and Narragansett Bay, and inlets in the North Carolina Outer Banks. Laney et al. (2007) found similar results off the coasts of Virginia and North Carolina. The researchers used GIS layers to analyze data from the Cooperative Winter Tagging Cruise and found that Atlantic sturgeon were located primarily in sandy substrates. However, the authors state that GIS does not depict small-scale sediment distribution, thus only a broad overview of sediment types was used. In addition, sediment sampling done along the North Carolina coast shows that gravel substrates are found a little farther offshore from where the sturgeon were found.

Depth associations at sea

The greatest depth in the ocean at which Atlantic sturgeon have been reported caught was 75 meters (Colette and Klein-MacPhee 2002). Collins and Smith (1997) report that Atlantic sturgeon were captured at depths of 40 meters in marine waters off South Carolina. Stein et al. (2004) investigated data collected by on-board fishery observers from 1989-2000 to determine habitat preferences of Atlantic sturgeon. They found that Atlantic sturgeon were caught in shallow (<60 m) inshore areas of the Continental Shelf. Sturgeon were captured in depths less than 25 meters along the Mid-Atlantic Bight and in deeper waters in the Gulf of Maine (Stein et al. 2004).

The Northeast Fisheries Science Center bottom trawl survey caught 139 Atlantic sturgeon from 1972-1996 in waters from Canada to South Carolina. They found the fish in depths of 7-75 meters, with a mean depth of 17.3 meters. Of the fish caught, 40% were collected at 15 meters, 13% at 13 m, and less than 5% at all the depth strata (NEFC, unpublished data, reviewed in Savoy and Pacileo 2003).

Upon entering the marine habitat, Atlantic sturgeon have been documented near the shore in shallow waters where the depths measure less than 20 meters (Gilbert 1989; Johnson et al. 1997). During their tagging cruise off the coasts of Virginia and North Carolina, Laney et al.

(2007) captured Atlantic sturgeon at depths up to approximately 6 m. Vladykov and Greeley (1963) record a maximum depth of at least 18 m. Additionally, Johnson et al. (2005) reported that Atlantic sturgeon were caught within 5 km of the coast of New Jersey in waters approximately 15-m deep.

For a summary of significant environmental, temporal, and spatial factors that affect the distribution of Atlantic sturgeon at all stages, see 0.

1.6 APPENDIX A - Tables and Figures

Life stage length and age cut-offs for Atlantic sturgeon.

Life Interval	Age Range (years)	Fork Length (mm)	Total Length (mm)
Larvae	<0.08		≤ 30
Juvenile	0.08-11	~20-1340	~30-1490
Non-spawning adults	≥ 12	≥ 1350	≥ 1500
Female spawners	≥ 15	≥ 1800	≥ 2000
Male spawners	12-20	≥ 1350-1900	≥ 1500-2100

Spawning (and post-spawn) substrate type for Atlantic sturgeon along the Atlantic coast.

Substrate	Activity	Location	Citation
Rock and bedrock	spawning	St. Lawrence River, Québec	Hatin et al. 2002
Rock, clay, & sand	spawning	St. Lawrence River, Québec	Caron et al. 2002
Irregular bedrock, silt, & clay	spawning	Hudson River, NY	Bain et al. 2000
Clay/silt with rocky shoreline	post-spawning	Hudson River, NY	Bain et al. 2000
Hard clay	spawning	Delaware River	Borodin 1925
Small rubble & gravel	spawning	Delaware River	Dees 1961
Clay	spawning	Delaware River	Scott & Crossman 1973
Limestone	spawning	Edisto River, SC	Collins et al. 2000b
Fine mud, sand, pebbles, & shell	post-spawning	Edisto River, SC	Collins et al. 2000b
Cobble/gravel	spawning	HSI Model	Brownell et al. 2001
Bed Rock, fine gravel, course sand	spawning	Roanoke River, NC	Smith et al. 2015

Spawning (and non-spawn) depth ranges for Atlantic sturgeon along the Atlantic coast.

Depth Range (m)	Status	Location	Citation
10 - 22	Spawning	St. Lawrence River, Québec	Caron et al. 2002
17 - 21	Non-spawning	St. Lawrence River, Québec	Caron et al. 2002
15 - 27 (mean)	All	St. Lawrence River, Québec	Hatin et al. 2002
6 - 60	Spawning	St. Lawrence River, Québec	Hatin et al. 2002
>7.6	Migrating	Hudson River, NY	Dovel and Berggren 1983
12 - 27	Spawning	Hudson River, NY	Bain et al. 2000
11 - 13	Spawning	Delaware River	Borodin 1925; Scott & Crossman 1973
1.5 - 13	All	Edisto River, SC	Collins et al. 2000b
2.4 - 8	Spawning	HSI Model	Brownell et al. 2001
<5 (low flow)	Spawning	Roanoke River, NC	Smith et al. 2015

Spawning and migration temperatures for Atlantic sturgeon along the Atlantic coast.

Sex	Activity	Month	Temperature Range (°C)	Location	Citation
M/F	Spawning	N/A	14.5 - 23.4	St. Lawrence River, Québec	Caron et al. 2002; Hatin et al. 2002
M	Migration Up	N/A	5.6 - 6.1	Hudson River, NY	Smith 1985a
F	Migration Up	♂+ few weeks	12.2 - 12.8	Hudson River, NY	Smith 1985a
M	Migration Up	April	6	Hudson River, NY	Dovel and Berggren 1983
F	Migration Up	♂+ few weeks	13	Hudson River, NY	Dovel and Berggren 1983
M/F	Spawning	N/A	14 - 26	Hudson River, NY	Bain et al. 2000
M/F	Spawning	April - June	12.8 - 18.3	Delaware River	Ryder 1888
M/F	Spawning	N/A	13.3 - 17.8	Delaware River	Scott and Crossman 1973
M	Migration Up	N/A	13 - 19	South Carolina	Smith 1985b
F	Spent	Sept. - Oct.	17 - 18	Edisto River, SC	Collins et al. 2000b
M/F	Migration Up	March	13.6	Edisto River, SC	Collins et al. 2000b
M/F	Present	Summer	up to 33.1	Edisto & Combahee Rivers, SC	Collins et al. 2000b
M/F	Spawning	N/A	20 - 21	Aquaculture facility	Mohler 2003
M/F	Spawning	N/A	16 - 21	HSI Model	Brownell et al. 2001
M/F	Spawning	September	22-27	Roanoke River, NC	Smith et al. 2015
M	Migration up/down	August-October	20-28	Roanoke River, NC	Smith et al. 2015
M/F	Migration up/down	August October	19-30	James River, VA	Balazik et al. 2012
M/F	Migration up	August	21-22.8	York River, VA	Hager et al. 2014

Salinity tolerance ranges for young juvenile Atlantic sturgeon along the Atlantic coast.

Salinity Range (ppt)	Location	Citation
>3	Hudson River, New York	Appy and Dadswell 1978
3 - 16	Hudson River, New York	Dadswell 1979
3 - 16	Hudson River, New York	Brundage and Meadows 1982
0 - 6	Hudson River, New York	Dovel and Berggren 1983
3 - 16	Hudson River, New York	Smith 1985b

Depth ranges for young juvenile Atlantic sturgeon along the Atlantic coast

Depth Range (m)	Location	Citation
2 - 12	Massachusetts	Kynard et al. 2000
30 - 40	Long Island Sound, Connecticut	Bain et al. 2000
27 - 37	Long Island Sound, Connecticut	Savoy and Pacileo 2003
Mean = 22.7	Hudson River, New York	Haley et al. 1996
10 – 25 (<700 mm TL)	Hudson River, New York	Bain et al. 2000
16 – 26 (>700 mm TL)	Hudson River, New York	Bain et al. 2000
7 - 16	Delaware River, Pennsylvania	Lazzari et al. 1986
5.5 - 11	Delaware River, Delaware	Shirey et al. 1999
<20	Chesapeake Bay, Virginia	Musick et al. 1994
<7	Brunswick River, North Carolina	Moser and Ross 1995
>10	Cape Fear River, North Carolina	Moser and Ross 1995
1.8 - 5.4	Albemarle Sound, North Carolina	Armstrong and Hightower 2002
3 - 16	Hudson River, New York	Haley et al. 1996
>3	Hudson River, New York	Bain et al. 2000
0 - 12	Delaware River	Shirey et al. 1999
<10	Brunswick River, North Carolina	Moser and Ross 1995

Summer temperature ranges for juvenile Atlantic sturgeon along the Atlantic coast.

Temperature Range (°C)	Location	Citation
13.2 – 26.7	Merrimack River,	Kieffer and Kynard
24.2 – 24.7	Hudson River, New York	Dovel and Berggren
27	Hudson River, New York	Haley et al. 1996
24 – 28	Hudson River, New York	Bain et al. 2000
>26	Satilla River, GA	Fritts et al. 2016
>30	Albemarle Sound, NC	Armstrong 1999
21.3-30.2	Savannah River, GA	Bahr and Peterson
Near 30	Altamaha River, GA	Schueller and
24.7-31.4	Ogeechee River, Ga	Farrae and Perterson

Significant environmental, temporal, and spatial factors affecting distribution of Atlantic sturgeon. This table summarized the current literature on Atlantic sturgeon habitat associations. For most categories, optimal and tolerable ranges have not been identified, and the summarized habitat parameters are listed under the category reported. In some cases, unsuitable habitat parameters are defined. NIF = No Information Found. N/A = Not Applicable.

Life Stage	**Time of Year and Location**	**Depth (m)**	**Temperature (°C)**	**Salinity (ppt)**	**Substrate**	**Current Velocity (m/sec)**	**Dissolved Oxygen (mg/L)**
Adult (Spawning)	Freshwater rivers and possibly tidal freshwater regions of large estuaries (in the north) Feb – Southern states April-May – Mid-Atlantic May-July – Northern States and Canada Sept-Dec – Second spawning documented in Southern regions	**Tolerable:** NIF **Optimal:** 2.4-8+ (HSI model for Southern Regions) **Reported:** 3-27 Roanoke River was >5 (low flow)	**Tolerable:** NIF **Optimal:** 16-21 (HSI model for Southern Regions); 20-21 for cultured sturgeon **Reported:** Male migrations 5.6-6.1; Female migrations 12.2-13; Spawning 13-23.4 Roanoke River migrations 22-28 spawning 24-25	**Tolerable:** NIF **Optimal:** NIF **Reported:** Above the salt wedge in fresh water.	**Tolerable:** 2 NIF **3 Optimal:** Cobble/gravel >64mm-250mm (HSI model for Southern Regions) **Reported:** Hard substrate, including rubble, gravel, clay, rock, bedrock, slag from old steel mills and limestone	**Tolerable:** NIF **Optimal:** 0.2 - 0.76 **Reported:** 0.46 – 0.76 okay; unsuitable if ≤0.06, or ≥ 1.07 Roanoke was 55-297 m3/s	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF Roanoke was 8.0 mg/L

Life Stage	Time of Year and Location	Depth (m)	Temperature (°C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Adult (Estuarine)	Sturgeon do not spawn every year, yet may participate in an upstream migration. After spawning, some sturgeon remain in the rivers through the summer, while others migrate to sea. Downstream migrations occur Sept – Nov in Canada. Present in South March – Oct. Overwinter in the ocean.	**Tolerable:** NIF **Optimal:** NIF **Reported:** 1.5-60	**Tolerable:** NIF **Optimal:** NIF **Reported:** Adult sturgeon documented in waters with temperatures as high as 33.1 in SC.	**Tolerable:** NIF **Optimal:** NIF **Reported:** Documented summer habitat in upper/fresh/ brackish interface, lower interface, and high salinity portions of estuaries in SC. Salinity ranged from 0-28.6	**Tolerable:** NIF **Optimal:** NIF **Reported:** Found over fine mud, sand, pebbles, and shell substrate	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF
Egg and Larval	Eggs are laid in flowing water in rivers along the Atlantic coast. Larval sturgeon are found in same habitat where spawned and are benthic.	**Tolerable:** NIF **Optimal:** 2.4-8+ for egg incubation (HSI model for Southern Regions) **Reported:** Embryos remain in deep channels. Larval collected at 9.1-19.8	**Tolerable:** NIF **Optimal:** 20-21 Cultured sturgeon **Reported:** Eggs hatch in 94-140 hours ranging from 15.0 – 24.5 24-25 for Roanoke River	**Tolerable:** NIF **Optimal:** NIF **Reported:** Found upstream of salt front; have a low tolerance to salinity; mortality reported in 5-10 for some sturgeon species Roanoke River would be 0 at spawning location	**Tolerable:** 4 NIF **5 Optimal:** Cobble/gravel >64mm-250mm (HSI model for Southern Regions) **Reported:** After 20 minutes, eggs become adhesive and attach to hard substrate. Larvae also use hard substrate as refuge	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF

Life Stage	Time of Year and Location	Depth (m)	Temperature (°C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Juvenile (Estuarine)	Remain in natal habitats within estuary for up to a year before migrating out to sea. Migrations to other estuaries are common. Use brackish water near month of estuary during winter and move up-estuary during warmer months	**Tolerable:** 6 NIF 7 **Optimal:** Deep water and holes serve as thermal refuge 8 **Reported:** 2-37	9 **Tolerable:** 10 3-28 11 **Optimal:** ~20 **Unsuitable:** Temperatures >28 are sub-lethal Temps in south are commonly 30 in summer with sturgeon present **Reported:** Downstream migration begins when water reaches 20°C and peaks between 12-18°C. Documented range of 0.5-27	**Tolerable:** 12 NIF 13 **Optimal:** ~10 **Reported:** Large juveniles found mostly where salinity is >3; found in 0-27.5	14 **Tolerable:** 15 NIF 16 **Optimal:** NIF **Reported:** Found mostly over sand substrate and mud or transitional habitats. Also found over rocks and cobble	**Tolerable:** 17 NIF 18 **Optimal:** NIF **Reported:** NIF	**Tolerable:** 19 NIF 20 **Optimal:** >5 mg/L **Reported:** Mortality at summer temperatures (26°C) observed at levels <3.3mg/L maybe not the case for southern populations
Juvenile and adult (At-sea)	Use marine waters during non-spawning seasons. Nearshore areas off the Atlantic coast from the Gulf of Maine to St Johns river Florida. Little is known about this part of their lives	**Tolerable:** 21 NIF 22 **Optimal:** NIF **Reported:** Most found in shallow waters; greatest depth recorded = 75; depth range 7-43	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** Marine waters off the continental shelf	**Tolerable:** NIF **Optimal:** NIF **Reported:** Sand, gravel, silt and clay. Suggested that they will use any substrate that supports their food resource	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF

1.7 APPENDIX A – Literature Cited

Anoushian, W. 2004. Point Judith, Rhode Island fishing activity. Fathom's Report, June 11, 2004.

Appy, R. G., and M. J. Dadswell. 1978. Parasites of *Acipenser brevirostrum* LeSueur and *Acipenser oxyrhynchus* Mitchill (Osteichthyes: Acipenseridae) in the Saint John River Estuary, N.B. with a description of *Caballeronema pseudoargumentosus* sp.n. (Nematoda: Spirurida). Canadian Journal of Zoology 56: 1382-1391.

Armstrong, J. L., and J. E. Hightower. 2002. Potential for restoration of the Roanoke River population of Atlantic sturgeon. Journal of Applied Ichthyology 18: 475-480.

ASMFC (Atlantic States Marine Fisheries Commission). 1998. Amendment 1 to the Interstate Fishery Management Plan for Atlantic Sturgeon. Atlantic States Marine Fisheries Commission, Atlantic Sturgeon Plan Development Team, Washington, D.C.

Atlantic Sturgeon Status Review Team (ASSRT). 2007. Status review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Report to National Marine Fisheries Service, Northeast Regional Office on February 23, 2007.

Atkins, C. G. 1887. The river fisheries of Maine. In: The fisheries of fishery industries of the United States, Section V, Vol. 1. United States Government Printing Office, Washington, D.C.

Bain, M. B. 1997. Atlantic and shortnose sturgeons of the Hudson River: Common and divergent life history attributes. Environmental Biology of Fishes 48: 347-358.

Bain, M. B., N. Haley, D. Peterson, J. R. Waldman, and K. Arend. 2000. Harvest and habitats of Atlantic sturgeon *Acipenser oxyrinchus* Mitchill, 1815, in the Hudson River estuary: Lessons for sturgeon conservation. Instituto Espanol de Oceanografia. Boletin 16: 43-53.

Bangor Daily News. 2005. Brewer angler hooks five-foot sturgeon during lunch break. Bangor Daily News, Saturday, July 9, 2005. Bangor, Maine.

Baranova, B. P., and M. P. Miroshnichenko. 1969. Conditions and prospects for culturing sturgeon in the Volgograd sturgeon nursery. Journal of Hydrobiology 5: 63-67.

Bath, D. W., J. M. O'Connor, J. B. Alber, and L. G. Arvidson. 1981. Development and identification of larval Atlantic sturgeon (*Acipenser oxyrhynchus*) and shortnose sturgeon (*A. brevirostrum*) from the Hudson River estuary, New York. Copeia 3: 711-717.

Beamesderfer, R. C. P., and R. A. Farr. 1997. Alternatives for the protection and restoration of sturgeons and their habitat. Environmental Biology of Fishes 48: 407-417.

Belton, T. J., B. E. Ruppel, and K. Lockwood. 1982. PCBs (Arochlor 1254) in fish tissues throughout the state of New Jersey: A comprehensive survey. Technical Report, New Jersey Department of Environmental Protection, Trenton, New Jersey.

Bergey, L. L., R. A. Rulifson, M. L. Gallagher, and A. S. Overton. 2003. Variability of Atlantic coast striped bass egg characteristics. North American Journal of Fisheries Management 23: 558-572.

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fisheries Bulletin, U.S. Fish and Wildlife Service 53, Washington, D.C.

Borodin, N. 1925. Biological observations on the Atlantic sturgeon, (*Acipenser sturio*). Transactions of the American Fisheries Society 55: 184-190.

Brown, J. J., J. Perillo, T. J. Kwak, and R. J. Horwitz. 2005. Implications of *Plyodictis olivaris* (flathead catfish) introduction into the Delaware and Susquehanna drainages. Northeastern Naturalist 12: 473-484.

Brownell, P. H., S. Bolden, and B. Kynard. 2001. Spawning habitat suitability index models for shortnose and Atlantic sturgeon. Draft report. National Marine Fisheries Service, Southeast Region.

Brundage, H. M., III, and R. E. Meadows. 1982. The Atlantic sturgeon, *Acipenser oxyrhynchus*, in the Delaware River and Bay. U.S. Fish and Wildlife Service. Fisheries Bulletin 80: 337-343.

Budavari, S., M. J. O'Neil, A. Smith, and P. E. Heckelman. 1989. The Merck Index, 11th edition. Merck and Company, Inc. Whitehouse Station, New Jersey.

Burkett, C., and B. Kynard. 1993. Sturgeons of the Taunton River and Mt. Hope Bay: Distribution, habitats and movements. Final Report for Project AFC-24-1, Massachusetts Division of Marine Fisheries, Boston, Massachusetts.

Bushnoe, T. M., J. A. Musick, and D. S. Ha. 2005 (Draft). Essential spawning and nursery habitat of Atlantic sturgeon (*Acipenser oxyrinchus*) in Virginia. Provided by Jack Musick, Virginia Institute of Marine Science, Gloucester Point, Virginia.

Caron, F., D. Hatin, and R. Fortin. 2002. Biological characteristics of adult Atlantic sturgeon (*Acipenser oxyrinchus*) in the St. Lawrence River estuary and the effectiveness of management rules. Journal of Applied Ichthyology 18: 580-585.

Coffin, C. 1947. Ancient fish weirs along the Housatonic River. Bulletin Archives of Society Connecticut 21: 35-38.

Collins, M. R., S. G. Rogers, T. I. J. Smith, and M. L. Moser. 2000a. Primary factors affecting sturgeon populations in the southeastern United States: Fishing mortality and degradation of essential habitats. Bulletin of Marine Science 66: 917-928.

Collins, M. R., and T. I. J. Smith. 1997. Distribution of shortnose and Atlantic sturgeons in South Carolina. North American Journal of Fisheries Management 17: 995-1000.

Collins, M. R,. S. G. Smith, and M. L. Moser. 1996. Bycatch of sturgeons along the southern Atlantic coast of the USA. North American Journal of Fisheries Management 16: 24-29.

Collins, M. R., T. I. J. Smith, W. C. Post, and O. Pashuk. 2000b. Habitat utilization and biological characteristics of adult Atlantic sturgeon in two South Carolina rivers. Transactions of the American Fisheries Society 129: 982-988.

CONED (Consolidated Edison). 1997. Year class report for the Hudson River estuary monitoring program. Jointly funded by Central Hudson Electric and Gas Corp., Consolidated Edison

Company of New York, Inc., New York Power Authority, Niagara Mohawk Power Corporation, Orange and Rockland Utilities, Inc. CONED, New York, New York.

Cooper, S. R., and G. S. Brush. 1993. A 2,500 year history of anoxia and eutrophication in the Chesapeake Bay. Estuaries 16: 617-626.

Crance, J. H. 1987. Habitat suitability index curves for anadromous fishes. Page 554 in M. J. Dadswell, editor. Common Strategies of Anadromous and Catadromous Fishes. American Fisheries Society, Symposium 1, Bethesda, Maryland.

Dadswell, M. J. 1979. Biology and population characteristics of the shortnose sturgeon, *Acipenser brevirostrum* Lesueur 1818 (Osteichthyes: Acipenseridae), in the Saint John River Estuary, New Brunswick, Canada. Canadian Journal of Zoology 57: 2186-2210.

Dadswell, M. J. 2006. A review of the status of Atlantic sturgeon in Canada, with comparisons to populations in the United States and Europe. Fisheries 31: 218-229.

Dadswell, M. J., and R. A. Rulifson. 1994. Macrotidal estuaries: a region of collision between migratory marine animals and tidal power development. Biological Journal of the Linnean Society 51: 93-113.

Dadswell, M. J., B. D. Taubert, T. S. Squires, D. Marchette, and J. Buckley. 1984. Synopsis of biological data on shortnose sturgeon, *Acipenser brevirostrum*, LeSueur 1818. United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service Technical Report No. NMFS 14, Silver Spring, Maryland.

Dees, L. T. 1961. Sturgeons. United States Department of the Interior Fish and Wildlife Service, Bureau of Commercial Fisheries, Washington, D.C.

Dovel, W. L. 1978. Biology and management of shortnose and Atlantic sturgeon of the Hudson River. Performance Report to the New York State Department of Environmental Conservation, Albany, New York.

Dovel, W. L. 1979. The biology and management of shortnose and Atlantic sturgeon of the Hudson River. Final Report to the New York State Department of Environmental Conservation, Albany, New York.

Dovel, W. L., and T. J. Berggren. 1983. Atlantic sturgeon of the Hudson estuary, New York. New York Fish and Game Journal 30: 140-172.

Dovel, W. L., A. W. Pekovitch, and T. J. Berggren. 1992. Biology of the shortnose sturgeon (*Acipenser brevirostrum* LeSueur, 1818) in the Hudson River estuary, New York. Pages 187-216 in C. L. Smith, editor. Estuarine research in the 1980's. State University of New York Press, Albany, New York.

EPA (United States Environmental Protection Agency). 2003. Chapter 3: Dissolved oxygen criteria. Pages 7-100 in Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its tributaries. U.S. Environmental Protection Agency Region III Chesapeake Bay Program Office (Annapolis, Maryland) and Region III Water Protection Division (Philadelphia, Pennsylvania), in coordination with Office of Water Office of Science and Technology, Washington, D.C. US EPA Report No. 903-R-03-002.

Erickson, D.L., A. Kahnle, M.J. Millard, E.A. Mora, M. Bryja, A. Higgs, J. Mohler, M. Dufour G. Kenney, J. Sweka and E.K Pikitch. 2011 Use of satellite archival tags to identify oceanic migratory patterns for adult Atlantic sturgeon *Acipenser oxyrinchus* Mithcell 1815. Journal of Applied Ichthyology 27 pgs 356-365.

Eyler, S., M. Mangold, and S. Minkkinen. 2004. Atlantic Coast sturgeon tagging database. Summary Report prepared by US Fish and Wildlife Service, Maryland Fishery Resource Office, Annapolis, Maryland.

Fernandes, S. 2006. Memo to NMFS-PRD noting the occurrence and observation of seal predation on shortnose sturgeon in the Penobscot River. August 28, 2006.

Florida Museum of Natural History. 2004. Tiny sturgeon snagged in James revives reproductive hopes. Ichthyology at the Florida Museum of Natural History in the News, March 28, 2004.

Folz, D. J., and L. S. Meyers. 1985. Management of the lake sturgeon, *Acipenser fulvescens*, population in the Lake Winnebago system, Wisconsin. Developments in Environmental Biology of Fishes 6: 135-146.

Fox, D. A., J. E. Hightower, and F. M. Parauka. 2000. Gulf sturgeon spawning migration and habitat in the Choctawhatchee River system, Alabama-Florida. Transactions of the American Fisheries Society 129: 811-826.

Gadomski , D. M., and M. J. Parsley. 2005. Laboratory studies on the vulnerability of young white sturgeon to predation. North American Journal of Fisheries Management 25: 667-674.

Gilbert, C. R. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic Bight) – Atlantic and shortnose sturgeons. United States Fish and Wildlife Service Office of Biological Services Report No. FWS/OBS-82/11.122.

Goode, G. B. 1887. The fisheries and the fishery industries of the United States. United States Department of Commerce 109, Fish and Fisheries Section V, volume 1. United States Government Printing Office, Washington D.C.

Gross, M. R., J. Repka, C. T. Robertson, D. H. Secor, and W. Van Winkle. 2002. Sturgeon conservation: Insights from elasticity analysis. Pages 13-30 in W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society Symposium 28, Bethesda, Maryland.

Greene, K. E., J. L. Zimmerman, R. W. Laney, and J. C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: A review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9, Washington, D.C.

Haley, N., and M. Bain. 1997. Habitat and food partitioning between two co-occurring sturgeons in the Hudson River estuary. Presentation at the Estuarine Research Federation Meeting, Providence, Rhode Island, October 14, 1997.

Haley, N., J. Boreman, and M. Bain. 1996. Juvenile sturgeon habitat use in the Hudson River. Pages 1-20 in Final reports of the Tibor T. Polgar Fellowship Program. Hudson River Foundation, New York.

Hatin, D., R. Fortin, and F. Caron. 2002. Movements and aggregation areas of adult Atlantic sturgeon (*Acipenser oxyrinchus*) in the St. Lawrence River estuary, Québec, Canada. Journal of Applied Ichthyology 18: 586-594.

Hildebrand, S. F., and W. C. Schroeder. 1928. Fishes of the Chesapeake Bay. United States Bureau of Fisheries Bulletin 53, Washington, D.C.

Hill, J. 1996. Environmental considerations in licensing hydropower projects: Policies and practices at the Federal Energy Regulatory Commission. Pages 190-199 in L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society Symposium 16, Bethesda, Maryland.

Hoff, J. G. 1980. Review of the present status of the stocks of Atlantic sturgeon *Acipenser oxyrhynchus*, Mitchill. Prepared for the National Marine Fisheries Service, Northeast Region, Gloucester, Massachusetts.

Hoover, E. E. 1938. Biological survey of the Merrimack watershed. New Hampshire Fish and Game Commission, Concord, New Hampshire.

Huff, J. A. 1975. Life history of Gulf of Mexico sturgeon, *Acipenser oxyrhinchus desotoi*, in Suwannee River, Florida. Florida Marine Research Publications 16: 32.

IAN (Integration and Application Network). 1999. Science & Site 104: Long-term options for dredged sediment placement. University of Maryland Center for Environmental Science, Cambridge, Maryland.

Jenkins, W. E., T. I. J. Smith, L. D. Heyward, and M. D. Knott. 1993. Tolerance of shortnose sturgeon, *Acipenser brevirostrum*, juveniles to different salinity and dissolved oxygen concentrations. Proceedings from the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47: 476-484.

Johnson, J. H., D. S. Dropkin, B. E. Warkentine, J. W. Rachlin, and W. D. Andrews. 1997. Food habits of Atlantic sturgeon off the central New Jersey coast. Transactions of the American Fisheries Society 126: 166-170.

Johnson, J. H, J. E. McKenna, Jr., D. S. Dropkin, and W. D. Andrews. 2005. A novel approach to fitting the von Bertalanffy relationship to a mixed stock of Atlantic sturgeon harvested off the New Jersey coast. Northeastern Naturalist 12: 195-202.

Jordan, S., C. Stenger, M. Olson, R. Batiuk, and K. Mountford. 1992. Chesapeake Bay dissolved oxygen goal for restoration of living resource habitats. Maryland Department of Natural Resources, Annapolis, Maryland.

Judd, S. 1905. History of Hadley including the Early of Hatfield, South Hadley, Amherst and Granby, Massachusetts. H. R. Hunting and Company, Springfield, Massachusetts.

Kahnle, A., and K. Hattala. 1988. Bottom trawl survey of juvenile fishes in the Hudson River estuary: Summary report for 1981-1986. New York State Department of Environmental Conservation, Albany, New York.

Kahnle, A. W., K. A. Hattala, and K. McKown. In Press. Status of Atlantic sturgeon of the Hudson River estuary, New York, USA. In J. Munro, D. Hatin, K. McKown, J. Hightower, K. Sulak, A. Kahnle, and F. Caron, editors. Proceedings of the symposium on anadromous sturgeon: Status and trends, anthropogenic impacts, and essential habitats. American Fisheries Society, Bethesda, Maryland.

Kahnle, A. W., K. A. Hattala, K. A. McKown, C. A. Shirey, M. R. Collins, T. S. Squiers, Jr., and T. Savoy. 1998. Stock status of Atlantic sturgeon of Atlantic coast estuaries. Report for the Atlantic States Marine Fisheries Commission: Draft III, Washington, D.C.

Kahnle, A. W., R. W. Laney, and B. J. Spear. 2005. Proceedings of the workshop on status and management of Atlantic Sturgeon Raleigh, NC, 3-4 November 2003. Special Report No. 84 of the Atlantic States Marine Fisheries Commission, Washington, D.C.

Kelly, J. L., and D. E. Arnold. 1999. Effects of ration and temperature on growth of age-0 Atlantic sturgeon. North American Journal of Aquaculture 62: 60-65.

Kemp, W. M., P. A. Sampou, J. Garber, J. Tuttle, and W. R. Boynton. 1992. Seasonal depletion of oxygen from bottom waters of Chesapeake Bay: Roles of benthic and planktonic respiration and physical exchange processes. Marine Ecology Progress Series 85: 137-152.

Kennebec River Resource Management Plan. 1993. Kennebec River resource management plan: Balancing hydropower generation and other uses. Final Report to the Maine State Planning Office, Augusta, Maine.

Kennish, M. J., T. J. Belton, P. Hauge, K. Lockwood, and B. E. Ruppert. 1992. Polychlorinated biphenyls in estuarine and coastal marine waters of New Jersey: A review of contamination problems. Reviews in Aquatic Sciences 6: 275-293.

Khoroshko, P. N., and A. D. Vlasenko. 1970. Artificial spawning grounds of sturgeon. Journal of Ichthyology 10(3): 286-292.

Kieffer, M. C., and B. Kynard. 1993. Annual Movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society 122: 1088-1103.

Kieffer, M. C., and B. Kynard. 1996. Spawning of the shortnose sturgeon in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society 125: 179-186.

King, T. L., B. A. Lubinski, and A. P. Spidle. 2001. Microsatellite DNA variation in Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) and cross-species amplification in the Acipenseridae. Conservation Genetics 2: 103-119.

Kirk, J. P., T. D. Bryce, and J. E. Fleming. 1999. Annual report to the National Marine Fisheries Service describing shortnose studies during 1999 on the Ogeechee River, Georgia under permit 1189.

Kirk, J. P., T. D. Bryce, and J. E. Fleming. 2000. Annual report to the National Marine Fisheries Service describing shortnose studies during 2000 on the Ogeechee River, Georgia under permit 1189.

Kirk, J. P., T. D. Bryce, and J. E. Fleming. 2001. Annual report to the National Marine Fisheries Service describing shortnose studies during 2001 on the Ogeechee River, Georgia under permit 1189.

Kirk, J. P., T. D. Bryce, and J. E. Fleming. 2002. Annual report to the National Marine Fisheries Service describing shortnose studies during 2002 on the Ogeechee River, Georgia under permit 1189.

Kirk, J. P., T. D. Bryce, and J. E. Fleming. 2003. Annual report to the National Marine Fisheries Service describing shortnose studies during 2003 on the Ogeechee River, Georgia under permit 1189.

Kynard, B., and M. Horgan. 2002. Otogenetic behavior and migration of Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, and shortnose sturgeon, *Acipenser brevirostrum*, with notes on social behavior. Environmental Biology of Fishes 63: 137-150.

Kynard, B., M. Horgan, M. Kieffer, and D. Seibel. 2000. Habitat used by shortnose sturgeon in two Massachusetts rivers, with notes on estuarine Atlantic sturgeon: A hierarchical approach. Transactions of the American Fisheries Society 129: 487-503.

Laney, R. W., J. E. Hightower, B. R. Versak, M. F. Mangold, W. W. Cole, Jr., and S. E. Winslow. 2007. Distribution, habitat use and size of Atlantic sturgeon captured during Cooperative Winter Tagging Cruises, 1988-2006. Pages 167-182 in J. Munro, D. Hatin, J. E. Hightower, K. McKown, K. J. Sulak, A. W. Kahnle, and F. Caron, editors. Anadromous sturgeons: Habitats, threats, and management. American Fisheries Society Symposium 56, Bethesda, Maryland.

Lawson, J. 1709. A new voyage to Carolina; Containing the exact description and natural history of that country: Together with the present state thereof, and a journal of a thousand miles, travel'd thro' several Nations of Indians, giving a particular account of their customs, manners and c. London.

Lazzari, M. A., J. C. O'Herron II, and R. W. Hastings. 1986. Occurrence of juvenile Atlantic sturgeon, *Acipenser oxyrhynchus*, in the upper tidal Delaware River. Estuaries 9: 356-361.

Leathery, S. 1998. Euthrophication primary nonpoint pollution problem. Fisheries 23: 38.

Longwell, A. C., S. Chang, A. Herbert, J. Hughes, and D. Perry. 1992. Pollution and developmental abnormalities of Atlantic fishes. Environmental Biology of Fishes 35: 1-21.

Leland, J. G., III. 1968. A survey of the sturgeon fishery of South Carolina. Bears Bluff Laboratories Report No. 47, Wadmalaw Island, South Carolina.

Mac, M. J., and C. C. Edsall. 1991. Environmental contaminants and the reproductive success of lake trout in the Great Lakes: An epidemiological approach. Journal of Toxicology and Environmental Health 33: 375-394.

Mackiernan, G. B. 1987. Dissolved oxygen in the Chesapeake Bay: Processes and effects. Maryland Sea Grant, College Park, Maryland.

Mallin, M. A., M. H. Posey, M. L. Moser, G. C. Shank, M. R. McIver, T. D. Alphin, S. H. Ensign, and J. F. Merritt. 1997. Environmental assessment of the lower Cape Fear River system, 1996-

1997. University of North Carolina at Wilmington, Center for Marine Science Research Report No. 97-01. Wilmington, North Carolina.

Mangin, E., and G. Beaulieu. 1963. Etude morphometrique comparee de l'Acipenser oxyrhynchus Mitchell du Saint-Laurent et de l'Acipenser sturio Linne de la Gironde. Naturaliste Canadien 90: 5-38.

McBride, M. M. 2004. A fisheries ecosystem plan for the Chesapeake Bay. Proceedings of the 14th Biennial Coastal Zone Conference, New Orleans, Louisiana. United States Department of Commerce, NOAA Chesapeake Bay Office.

McEnroe, M., and J. J. Chech, Jr. 1985. Osmoregulation in juvenile and adult white sturgeon. Pages 23-30 in F. P. Binkoswski and S. I. Doroshov, editors. North American sturgeons: Biology and aquaculture potential. Dr. W. Junk Publishers, Dordrecht, Holland.

McCord, J. W. 2004. Atlantic States Marine Fisheries Commission Atlantic sturgeon plan – amendment 1 South Carolina annual report for calendar year 2003. Compliance report submitted to Atlantic States Marine Fisheries Commission, October 19, 2004, Washington, D.C.

Miller, A. I., P. J. Anders, M. J. Parsley, C. R. Spraque, J. J. Warren, and L. G. Beckman. 1991. Reproduction and early life history characteristics of white sturgeons in the Columbia River between Bonneville and McNary dams. Pages 82-144 in A. A. Nigro, editor. Status and habitat requirements of the white sturgeon populations in the Columbia River downstream from McNary Dam. United States Department of Energy, Bonneville Power Administration Division of Fish and Wildlife, Portland, Oregon.

Miller, A. I., and L. G. Beckman. 1996. First record of predation on white sturgeon eggs by sympatric fishes. Transactions of the American Fisheries Society 125: 338-340.

Minta, P. 1992. A preliminary plan for the restoration of anadromous fish to the Thames River Basin. Connecticut Department of Environmental Protection. Unpublished report.

Mohler, J. W. 2003. Culture manual for the Atlantic sturgeon. United States Fish and Wildlife Service Publication, Hadley, Massachusetts.

Moser, M. L., J. B. Bichy, and S. B. Roberts. 1998. Distribution of sturgeon in North Carolina. Final Report to the U.S. Army Corps of Engineers, Wilmington District, Wilmington, North Carolina.

Moser, M. L., J. Conway, T. Thorpe, and J. Robin Hall. 2000. Effects of recreational electrofishing on sturgeon habitat in the Cape Fear river drainage. Final Report to North Carolina Sea Grant, Fishery Resource Grant Program, Raleigh, North Carolina.

Moser, M. L., and S. W. Ross. 1995. Habitat use and movements of shortnose and Atlantic sturgeons in the lower Cape Fear River, North Carolina. Transactions of the American Fisheries Society 124: 225-234.

Murawski, S. A., and A. L. Pacheco. 1977. Biological and fisheries data on Atlantic sturgeon, *Acipenser oxyrhinchus* (Mitchill). National Marine Fisheries Service Technical Series Report 10: 1-69.

Murdy, E. O., R. S. Birdsong, and J. A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institute Press, Washington, D.C.

Murphy, G. 2005. State of Delaware annual compliance report for Atlantic sturgeon. Submitted to the Atlantic States Marine Fisheries Commission Atlantic Sturgeon Plan Review Team, September 2005, Washington, D.C.

Musick, J. A., R. E. Jenkins, and N. M. Burkhead. 1994. Sturgeons: Family Acipenseridae. Pages 183-190 in R. E. Jenkins and N. M. Burkhead. Freshwater fishes of Virginia. American Fisheries Society. Bethesda, Maryland.

NHFG (New Hampshire Fish and Game). 1981. Inventory of the natural resources of the Great Bay estuarine system, volume one. New Hampshire Fish and Game Department, Concord, New Hampshire.

Niklitschek, E. J. 2001. Bioenergetics modeling and assessment of suitable habitat for juvenile Atlantic and shortnose sturgeons (*Acipenser oxyrinchus* and *A. brevirostrum*) in the Chesapeake Bay. Doctoral dissertation. University of Maryland at College Park, Solomons, Maryland.

Niklitschek, E. J., and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay. Estuarine and Coastal Shelf Science 64: 135-148.

NRC (National Research Council). 1996. Upstream: Salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C.

Oakley, N. C. 2003. Status of shortnose sturgeon, *Acipenser brevirostrum*, in the Neuse River, North Carolina. Masters thesis. Department of Fisheries and Wildlife Science, North Carolina State University, Raleigh, North Carolina.

Officer, C. B., R. B. Biggs, J. L. Taft, L. E.. Cronin, M. A. Tyler, and W. R. Boynton. 1984. Chesapeake Bay anoxia: Origin, development, and significance. Science 223: 22-27.

Ong, T. L., J. Stabile, I. I. Wirgin, and J. R. Waldman. 1996. Genetic divergence between *Acipenser oxyrinchus oxyrinchus* and *A. o. desotoi* as assessed by mitochondrial DNA sequencing analysis. Copeia: 464-469.

Parsley, M. J., L. G. Beckman, and G. T. McCabe, Jr. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream from McNary Dam. Transactions of the American Fisheries Society 122: 217-228.

Pennsylvania Commission of Fisheries. 1897. Annual report of the state commissioners of fisheries for the year 1897. Commonwealth of Pennsylvania, Harrisburg, Pennsylvania.

Peterson, D. L. 2004. Annual Report to the National Fish and Wildlife Federation. Washington, D.C.

Peterson, D. L., M. Bain, and N. Haley. 2000. Evidence of declining recruitment of Atlantic sturgeon in the Hudson River. North American Journal of Fisheries Management 20: 231-238.

Pottle, R., and M. J. Dadswell. 1979. Studies on larval and juvenile shortnose sturgeon. Report to Northeast Utilities, Hartford, Connecticut. (MS report available from M. J. Dadswell).

Pottle, R., and M. J. Dadswell. 1982. Studies on larval and juvenile shortnose sturgeon (*Acipenser brevirostrum*). Final report to the Northeast Utilities Service Company, Hartford, Connecticut.

Post, W. C., T. Darden, D. L. Peterson, M. Loeffler, and C. Collier. 2014. Research and management of endangered and threatened species in the southeast: riverine movements of Shortnose and Atlantic sturgeon. South Carolina Department of Natural Resources, Project NAIONMF4720036, Final Report, Charleston.

Rehwoldt, R. E., W. Mastrianni, E. Kelley, and J. Stall. 1978. Historical and current heavy metal residues in Hudson River fish. Bulletin of Environmental Contamination and Toxicology 19: 335-339.

Rehwoldt, R. E., W. Mastrianni, E. Kelley, and J. Stall. 1978. Historical and current heavy metal residues in Hudson River fish. Bulletin of Environmental Toxicology 19: 335-339.

Rochard, E., M. Lepage, and L. Meauze. 1997. Identification and characterization of the marine distribution of the European sturgeon, *Acipenser sturio*. Aquatic Living Resources 10: 101-109.

Rogers, S. G., P. H. Flournoy, and W. Weber. 1994. Status and restoration of Atlantic sturgeon in Georgia. Final report to NMFS for grant No. NA16FA0098-01, -02, and -03.

Rogers, S. G., and W. Weber. 1995. Status and restoration of Atlantic and shortnose sturgeons in Georgia: Final report. National Marine Fisheries Service, Southeast Region, St. Petersburg, Florida.

Ryder, J. A. 1888. The sturgeon and sturgeon industries of the Eastern Coast of the United States, with an account of experiments bearing on sturgeon culture. Bulletin of the United States Fish Commission 8: 231-328.

Safe, S. 1990. Polychlorinated biphenyls (PCBs), dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and related compounds: Environmental and mechanistic considerations which support the development of toxic equivalency factors. Critical Reviews in Toxicology 21: 51-88.

Savoy, T. 1996. Anadromous fish studies in Connecticut waters. Completion Report AFC-22-3. Connecticut Department of Environmental Protection, Hartford, Connecticut.

Savoy, T., and D. Pacileo. 2003. Movements and important habitats of subadult Atlantic sturgeon in Connecticut waters. Transactions of the American Fisheries Society. 132: 1-8.

Savoy, T., and D. Shake. 1993. Anadromous fish studies in Connecticut waters. Progress Report AFC-21-1. Connecticut Department of Environmental Protection, Hartford, Connecticut.

Schuller, P., and D. L. Peterson. 2006. Population status and spawning movements of Atlantic sturgeon in the Altamaha River, Georgia. Presentation to the 14th American Fisheries Society Southern Division Meeting, San Antonio, February 8-12th, 2006.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184, Ottawa, Canada.

Secor, D. H. 2002. Atlantic sturgeon fisheries and stock abundances during the late nineteenth century. Pages 89-98 in W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society Symposium 28, Bethesda, Maryland.

Secor, D. H., P. J. Anders, W. Van Winkle, and D. A. Dixon. 2002. Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. Pages 3-10 in W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society Symposium 28, Bethesda, Maryland.

Secor, D. H., V. Arefjev, A. Nikolaev and A. Sharov. 2000a. Restoration of sturgeons: Lessons from the Caspian Sea Sturgeon Ranching Programme. Fish and Fisheries 1: 215-230.

Secor, D. H., and T. E. Gunderson. 1998. Effects of hypoxia and temperature on survival, growth, and respiration of juvenile Atlantic sturgeon, *Acipenser oxyrinchus*. Fishery Bulletin 96: 603-613.

Secor, D. H., and E. J. Niklitschek. 2001. Hypoxia and sturgeons: Report to the Chesapeake Bay Program Dissolved Oxygen Criteria Team. Technical Report Series No. TS-314-01-CBL. Chesapeake Biological Laboratory, Solomons, Maryland.

Secor, D. H., and E. Niklitschek. 2002. Sensitivity of sturgeons to environmental hypoxia: A review of the physiological and ecological evidence. Pages 61-78 in R. V. Thurston, editor. Fish Physiology, Toxicology, and Water Quality. Proceedings of the Sixth International Symposium, La Paz, Mexico. U.S. Environmental Protection Agency Office of Research and Development, Ecosystems Research Division Report No. EPA/600/R-02/097, Athens, Georgia.

Secor, D. H., E. J. Niklitschek., J. T. Stevenson, T. E. Gunderson, S. P. Minkkinen, B. Richardson, B. Florence, M. Mangold, J. Skjeveland, and A. Henderson Arzapalo. 2000b. Dispersal and growth of yearling Atlantic sturgeon, *Acipenser oxyrinchus*, released into Chesapeake Bay. Fishery Bulletin 98: 800-810.

Secor, D. H., and J. R. Waldman. 1999. Historical abundance of Delaware Bay Atlantic sturgeon and potential rate of recovery. American Fisheries Society Symposium 23: 203-216.

Shirey, C. A., C. C. Martin, and E. J. Stetzar. 1999. Atlantic sturgeon abundance and movement in the lower Delaware River. Grant #A86FAO315 to NMFS. Delaware Division of Fish and Wildlife, Smyrna, Delaware.

Smith, C. L. 1985a. The inland fishes of New York State. New York State Department of Environmental Conservation, Albany, New York.

Smith, T. I. J. 1985b. The fishery, biology, and management of Atlantic sturgeon, *Acipenser oxyrinchus*, in North America. Environmental Biology of Fishes 14: 61-72.

Smith, T. I. J., and J. P Clugston. 1997. Status and management of Atlantic sturgeon, *Acipenser oxyrhinchus*, in North America. Environmental Biology of Fishes 48: 335-346.

Smith, T. I. J., and E. K. Dingley. 1984. Review of biology and culture of Atlantic (*Acipenser oxyrhynchus*) and shortnose sturgeon (*A. brevirostrum*). Journal of World Mariculture Society 15: 210-218.

Smith, T. I. J., E. K. Dingley, and D. E. Marchette. 1980. Induced spawning and culture of Atlantic sturgeon. Progressive Fish-Culturist 42: 147-151.

Smith, T. I. J., E. K. Dingley, and E. E. Marchette. 1981. Culture trials with Atlantic sturgeon, *Acipenser oxyrinchus*, in the U.S.A. Journal of the World Mariculture Society 12: 78-87.

Smith, T. I. J., D. E. Marchette, and R. A. Smiley. 1982. Life history, ecology, culture and management of Atlantic sturgeon, *Acipenser oxyrinchus*, Mitchill, in South Carolina: Final report to the United States Fish and Wildlife Service. South Carolina Wildlife and Marine Resources Department, Columbia, South Carolina.

Smith, T. I. J., D. E. Marchette, and G. F. Ulrich. 1984. The Atlantic sturgeon fishery in South Carolina. North American Journal of Fisheries Management 4: 167-176.

Spagnoli, L. L., and L. C. Skinner. 1977. PCB's in fish from selected waters of New York State. Pesticide Monitoring Journal 11: 69-87.

Spells, A. 1998. Atlantic sturgeon population evaluation utilizing a fishery dependent reward program in Virginia's major western shore tributaries to the Chesapeake Bay. U.S. Fish and Wildlife Service, Charles City, Virginia.

Squiers, T. S. 2001. State of Maine 2001 Atlantic sturgeon compliance report to the Atlantic States Marine Fisheries Commission, Washington, D.C.

Squiers, T. 2003. State of Maine 2003 Atlantic sturgeon compliance report to the Atlantic States Marine Fisheries Commission. Report submitted to Atlantic States Marine Fisheries Commission, October 31, 2003, Washington, D.C.

Squiers, T. 2004. State of Maine 2004 Atlantic sturgeon compliance report to the Atlantic States Marine Fisheries Commission. Report submitted to Atlantic States Marine Fisheries Commission, December 22, 2004, Washington, D.C.

Squiers, T. 2005. State of Maine 2005 Atlantic sturgeon compliance report to the Atlantic States Marine Fisheries Commission. Report submitted to Atlantic States Marine Fisheries Commission, September 30, 2005, Washington, D.C.

Stein, A. B., K. D. Friedland, and M. Sutherland. 2004. Sturgeon marine distribution and habitat use along the northeast coast of the United States. Transactions of the American Fisheries Society 133: 527-537.

Stevenson, J. T., and D. H. Secor. 1999. Age determination and growth of Hudson River Atlantic sturgeon, *Acipenser oxyrinchus*. Fishery Bulletin 97: 153-166.

Sulak, K. J., and J. P. Clugston. 1999. Recent advances in life history of Gulf of Mexico sturgeon, *Acipenser oxyrinchus desotoi*, in the Suwannee river, Florida, USA: A synopsis. Journal of Applied Ichthyology 15: 116-128.

Sweka, J. A., J. Mohler, and M. J. Millard. 2006. Relative abundance sampling of juvenile Atlantic sturgeon in the Hudson River. Final study report for the New York Department of Environmental Conservation, Hudson River Fisheries Unit, New Paltz, New York.

Tracy, H. C. 1905. A list of the fishes of Rhode Island. In: 36th Annual Committee of Inland Fisheries, Providence, Rhode Island.

USFWS-NMFS (United States Fish and Wildlife Service and National Marine Fisheries Service). 1998. Status review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Special report submitted in response to a petition to list the species under the Endangered Species Act. Hadley and Gloucester, Massachusetts.

Van Den Avyle, M. J. 1984. Species profile: Life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic): Atlantic sturgeon. U.S. Fish and Wildlife Service Report No. FWS/OBS-82/11.25, and U. S. Army Corps of Engineers Report No. TR EL-82-4, Washington, D.C.

Van Eenennaam, J. P., S. I. Doroshov, G. P. Moberg, J. G. Watson, D. S. Moore, and J. Linares. 1996. Reproductive conditions of the Atlantic sturgeon (*Acipenser oxyrhinchus*) in the Hudson River. Estuaries 19: 769-777.

Veshchev, P. V. 1981. Effect of dredging operations in the Volga River on migration of sturgeon larvae. Journal of Ichthyology 21: 108-112.

Vladykov, V. D., and J. R. Greeley. 1963. Order Acipenseriformes. Pages 46-56 in H. B. Bigelow, editor. Fishes of the western North Atlantic: Part three soft-rayed bony fishes. Sears Foundation for Marine Research, Yale University, New Haven, Connecticut.

Waldman, J. R., J. T. Hart, and I. I. Wirgin. 1996a. Stock composition of the New York Bight Atlantic sturgeon fishery based on analysis of mitochondrial DNA. Transactions of the American Fisheries Society 125: 364-371.

Waldman, J. R., K. Nolan, J. Hart, and I. I. Wirgin. 1996b. Genetic differentiation of three key anadromous fish populations of the Hudson River. Estuaries 19: 759-768.

Weber, W., and C. A. Jennings. 1996. Endangered species management plan for the shortnose sturgeon, *Acipenser brevirostrum*. Final Report to Port Stewart Military Reservation, Fort Stewart, Georgia.

Welsh, S. A., S. M. Eyler, M. F. Mangold, and A. J. Spells. 2002. Capture locations and growth rates of Atlantic sturgeon in the Chesapeake Bay. Pages 183-194 in W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society Symposium 28, Bethesda, Maryland.

Wharton, J. 1957. The bounty of the Chesapeake, fishing in colonial Virginia. University Press, Charlottesville, Virginia.

Whitworth, W. 1996. Freshwater fishes of Connecticut. State Geological and Natural History Survey of Connecticut, Connecticut Department Bulletin 114, Hartford, Connecticut.

Williams, M. S., and T. E. Lankford. 2003. Fisheries studies in the lower Cape Fear River system, June 2002 – 2003. Pages 116 – 169 in M. M. Mallin, M. R. McIver, H. A. Wells, M. S. Williams, T. E. Lankford, and J. F. Merritt, editors. Environmental Assessment of the Lower Cape Fear River System 2002- 2003. Center for Marine Science Report No. 03-03, University of North Carolina at Wilmington.

Wirgin, I. 2006. Use of DNA approaches in the management of Atlantic sturgeon populations. Presentation given to the Atlantic States Marine Fisheries Commission Atlantic Sturgeon Technical Committee By-catch Workshop, held February 1-3, 2006, Norfolk, Virginia.

Wurfel, B., and G. Norman. 2006. Oregon and Washington to expand sea lion control efforts in the Columbia River. Oregon Department of Fish and Wildlife News Release March 17, 2006. Available: http://www.dfw.state.or.us/news/2006/march/018.asp.

Young, J. R., T. B. Hoff, W. P. Dey, and J. G. Hoff. 1988. Management recommendations for a Hudson River Atlantic sturgeon fishery based on an age-structured population model: Fisheries Research in the Hudson River. State of University of New York Press, Albany, New York.

2.0 APPENDIX B – DPS-SPECIFIC BACKGROUND AND LIFE HISTORY

2.1 GULF OF MAINE DPS

Life History

Maturity

For far northern stocks in the St. Lawrence River in Canada, age at maturity is older than the coastwide averages, with maturity being reached around ages 27 to 28 for females and ages 16 to 24 for males (Scott and Crossman 1973). Spawning migrations begin in May through July in rivers in New England and Canada (Bigelow and Schroeder 1953; Hatin et al 2002; Dadswell 2006). A tagging study in the Penobscot River in Maine found that Atlantic sturgeon entered the estuary as early as late May, concentrated within a small area of the estuary, and moved out to the ocean by October, some traveling between the Penobscot and Kennebec rivers (Fernandes et al 2010).

Growth

No age data are available for the Gulf of Maine DPS, but lengths have been collected through fishery-independent sampling. Gillnet sampling in the Merrimack, Kennebec, and Saco Rivers caught both sub-adults (50-150 cm total length) and adults (>150 cm TL) (Figure 2.2.1). Fish caught by the inshore trawl survey exhibited a similar size range (76-193 cm) (Figure 2.2.2).

2.2 NEW YORK BIGHT DPS

Range and History of Fisheries

New York Bight Atlantic sturgeon refers to individuals originating from four separate river systems including the Taunton, Connecticut, Hudson and Delaware Rivers. The Taunton River is the longest undammed coastal river in New England at approximately 64 km. However, because of the low dissolved oxygen and excessive nutrient loads, the Taunton River is not believed to currently support nursery habitat for juvenile Atlantic sturgeon (Taunton Journal 2006, ASSRT 2007). The Connecticut River is the longest river in New England and extends 660 km from the Canadian border to the Long Island Sound with 86 % of historic habitat available to Atlantic sturgeon above Hadley, MA (ASSRT 2007). The Hudson River extends 507 km from the Adirondack Mountains to the Atlantic Ocean adjacent to New York City. Presently, 245 km of historic habitat is available to Atlantic sturgeon from Manhattan to the Federal Dam in Albany, NY in the Hudson River. The Delaware Estuary extends for 531 kilometers from Hancock, NY down to Lewes, DE. Since no dams are located on the main stem of the Delaware River, 100 % of the historic habitat is available to Atlantic sturgeon (ASSRT 2007).

Atlantic sturgeon of the New York Bight Distinct Population Segment (NYB DPS) have supported subsistence fishers prior to colonization although large scale commercial harvest started in the latter part of the 19th century. Reported commercial landings of Atlantic sturgeon are available for NY State from 1880 through 1996. Until about 1980, most of the NY landings came from the Hudson River. Highest annual landings of the time series (231,000 kg) occurred in 1898.

Landings quickly dropped to 15,000 kg or less per year and remained at low levels through the early 1980's. Market demand remained high and effort and harvest increased substantially in NY and NJ. The greatest increase in landings was in the nearshore ocean waters along Long Island and the NJ coast (ASMFC 1998). In 1990, the Atlantic States Marine Fisheries Commission adopted an interstate Fishery Management Plan (FMP) for Atlantic sturgeon (ASMFC 1990). However, because of the population declines of Atlantic sturgeon associated with harvest, the coast wide fishery was closed in 1998 with Amendment I to the FMP.

Historic levels of abundance within the NYB DPS of Atlantic sturgeon sharply declined by the early 1900s as a result of a sharp increase in harvest. Based on harvest from 1880-1901, Secor (2002) estimated 180,000 adult females were supported by the Delaware River prior to 1890. More recently, however, the estimated number of adults in the Delaware River was believed to have declined to less than 300 individuals in 2007 (ASSRT 2007). Based on 1880-1901 harvest rates from NY, abundance was estimated at 6,000 spawning females in the Hudson River (Secor 2002; Kahnle 2007). In 2007, Kahnle et al. estimated an abundance (using fishery dependent data (1985-1995 for females and 1968-1995 for males) and sex-specific exploitation) of approximately 863 spawning adults in the Hudson River (267 mature females and 596 mature males).

More recent estimates of recruitment have focused on river specific (i.e. natal) populations to examine how populations have responded to the significant decline in biomass associated with directed harvest, bycatch, and habitat degradation/loss. Previous population estimates of age-1 Atlantic sturgeon in the Hudson River estimated the 1976 cohort at 25,647 individuals (Dovel and Berggren 1983) and 4,314 individuals in 1995 (Petersen et al. 2000); which suggested a decline in recruitment (Sweka et al. 2006). Hale et al. (2016) estimated the abundance of Delaware River age 0-1 Atlantic sturgeon at 3,656 individuals in 2014 which is similar in magnitude to the age-1 estimates in the Hudson River suggested by Petersen et al. (2000) in the Hudson River for 1995. However, ages were pooled in Hale et al. (2016) and are not directly relatable to the estimates of age-1 fish in the Hudson River as mortality at age-0 was unknown.

Life History

Migration

Spawning migrations of Atlantic sturgeon are thought to occur from late March or April into May and June in the NYB DPS (Murawski and Pacheco 1977; Smith 1985; Bain 1997; Smith and Clungston 1997; Caron et al. 2002; ASSRT 2007) with individuals returning to their natal rivers to spawn after extensive periods in coastal waters (Grunwald et al. 2008). However, a secondary spawning event may occur in the late summer months for the Delaware River (D. Fox unpublished data) as has been documented for DPSs to the south (Collins et al. 2000, Hager et al. 2014, Post et al. 2014, Balazik and Musick 2015, Smith et al. 2015, Ingram and Peterson 2016. Older research suggested that females did not spawn annually and may spawn at intervals from two to five years (Vladykov and Greeley 1963; Van Eenennaam et al. 1996; Stevenson and Secor 1999). However, recent research using acoustically tagged fish, suggests that the intervals may be as short as every year for females returning to the Hudson River (D. Fox, personal communication).

In the Hudson River, females enter the estuary beginning in mid-May and spawn in the deep channel or off-channel habitats above the salt wedge (Dovel and Berggren 1983). The females leave soon after spawning and the season is typically over by July (Dovel and Berggren 1983; Van Eenennaam et al. 1996). Males enter the river beginning in April and some stay as late as November (Dovel & Berggren 1983). In Delaware, the spawning migration is believed to begin between April and May (Borodin 1925; Simpson 2007).

Erickson et al. (2011) examined 23 adult Atlantic sturgeon tagged with pop-off satellite archival tags (PSAT) in the Hudson River from 2006-2008. The PSAT tags were programmed to release within a few months to a year of deployment. The results showed that time spent in the river after tagging ranged from 6 to 132 days (mean = 55 days). Mean daily depths once in the ocean ranged from 5 to 35 meters and never exceeded 40 meters. Fish occupied the deepest depths in the winter and early spring (December-March) and the shallowest depths during late spring to early fall (May-September). The deepest water occupied by a fish was 92 meters in December. Water temperatures ranged from 8.3°C to 21.6°C. Ten of the PSAT tags released on the programmed date and transmitted the data to a satellite. Five of the PSAT tags transmitted outside the Chesapeake Bay, two popped off near Delaware Bay, two popped off in the river and one in the Bay of Fundy (Cobequid Bay), Nova Scotia. The migratory corridor for the majority of the PSAT tagged Atlantic sturgeon ranged from Long Island to Chesapeake Bay at depths < 40 meters. Areas were Atlantic sturgeon aggregated included the southwest shore of Long Island, along the New Jersey coast, off of Delaware Bay and off of Chesapeake Bay.

Oceanic habitat use of juvenile marine migrant Atlantic sturgeon was examine by Dunton et al. (2010) by identifying their spatial distribution using five fishery-independent surveys. They found areas near the mouths of large bays (Chesapeake and Delaware) and estuaries (Hudson and Kennebec rivers) had higher concentrations of individuals during the spring and fall. During these seasonal aggregations, Atlantic sturgeon may experience higher levels of bycatch mortality (Dunton et al. 2015).

Maturity

Age at maturity remains poorly documented for Atlantic sturgeon in the Hudson River Estuary and poorly understood or undocumented within the other estuarine systems of the NYB. In the Hudson River Estuary, the youngest mature male observed by Dovel and Berggren (1983) was 12 years old. The youngest female was 18 or 19 years old. In another study by Van Eenennaam et al. (1996), the youngest mature female observed was 14 years old. However, if ages are estimated using growth curves for fish harvested in the river results suggest that females as young as age 10 enter the river (ASMFC 1998). Van Eenennaam et al. (1996) reported that males in the spawning population in 1992 and 1993 averaged 15 years old while the average age of females was 20 years.

Dovel and Berggren (1983) reported that most mature males were 1.2-2.0 meters total length and 5.4-47.6 kg in weight. Most females were 1.8-2.4 meters long and 40-116 kg. Van Eenennaam et al. (1996) reported that mean total length of males in the spawning population was 182 cm; that of females was 218 cm. Mean weight of males was 37.3 kg; that of females was 72.7 kg. Information on the reproductive cycle of Atlantic sturgeon of the Hudson River Estuary is incomplete. Van Eenennaam et al. (1996) suggested that males spawn annually, but that the ovarian cycle of females might be greater than a year. However, more recent research, suggests that mature individuals may be larger than reported by Van Eenennaam et al. (1996) in the Hudson River (D. Fox, personal communication).

For the Hudson River stock, females mature at age 15 or older and are greater than 200 cm TL and 34 kg in weight. Males mature at age 12-19 and are greater than 150-210 cm TL. Maturity schedules in this region were based on a gonadal development (histology) study (Van Eenennaam et al. 1996; Van Eenennaam and Doroshov 1998).

Age and Growth

Two earlier studies have provided estimates of length at age for Atlantic sturgeon in the Hudson River Estuary. Both used cross sections of fin rays for estimates of age. Dovel and Berggren (1983) reported on data collected from 1976 through 1978. Sturgeon collected in this study ranged from 0 through 29 years old with sample sizes ranging from one to 40 fish per age. The largest sample sizes were from ages two through four. Van Eenennaam (personal communication) shared data from Atlantic sturgeon sampled in 1992-1994. Sturgeon collected in the study ranged from 5-40 years old. Sample sizes ranged from one to 31 fish per age. The largest sample sizes were from ages 12-18. Van Eenennaam's data were reported by sex and were from fish in the Hudson River and the near shore ocean of the New York Bight. Mean length at age and maximum age for older fish differed by sex. Length at age was similar for males and females for younger fish. Data from Dovel and Berggren (1983) were from fish from the Hudson River only with sexes combined.

Stevenson and Secor (1999) examined 634 pectoral-spines collected from the Hudson River and the New York Bight. Otoliths were also examined from severed heads (n=114). The otoliths were irregularly shaped and difficult to interpret and they suggest to use spines for aging. Stevenson and Secor (1999) found that males grew quicker and reached a smaller asymptotic length at a younger age than females. Females grew more slowly and reached a larger maximum length. They stated that the fishery in the Hudson River and along the coast and the samples used from the fishery probably biased their results from the growth estimates. The oldest females was 42 years old and the oldest male was 35 years old (which was not the largest length fish).

Dunton et al (2016) examined 742 fish, collected from a coastal trawl survey to evaluate the current age structure of the New York Bight DPS. The lengths of fish ranged from 54-248 cm total length, with a mean of 109.3 cm (SD = 22.67). They estimated 21 age classes that ranged from 2-35 years old, with a mean of 8.89 years old (SD = 3.027). These data were combined with other age estimate data to estimate the von Bertalanffy growth function for Atlantic sturgeon in the NYB.

Fecundity

Recent estimates of fecundity have ranged from 0.49 million eggs (ages 15-17) to 1.67 million eggs (ages 24-29), varying as a function of size and age, peaking at 2.6 million eggs (J. Van Eenennaam, personal communication) in the Hudson River (ASMFC 1998). In 2017, the DE DFW documented a fresh vessel strike in which the female that was struck was estimated to possess 2.1 million eggs. Similar to more recent estimates, historical estimates suggested fecundity ranged from .800 to 2.40 million eggs (Ryder 1890).

2.3 CHESAPEAKE BAY DPS

Range and History of Fisheries

Atlantic sturgeon range widely and can occur in most segments of the tidal Chesapeake Bay depending on season, depth, and water quality characteristics. Highest incidence of occurrence is during spring and fall months when sub-adults range widely foraging in sub-estuaries and the mainstem (Welsh et al. 2002; E. Markin, University of Maryland Center for Environmental Science [UMCES], unpublished research). Pre-spawning and spawning adults also occur during summer and fall months (Balazik et al. 2012a). Some adults enter the Chesapeake during winter and spawn during spring months (M. Balazik, personal communication as referenced in Hilton et al. 2016).

Sturgeon was an important source of sustenance for original Jamestown pioneers, with accounts emphasizing their seasonal abundance and availability (Tower et al. 2018; Wharton 1957). Nineteenth century fisheries developed in the Chesapeake Bay much as they did in Delaware as a result of improved processing and shipment capabilities to export caviar principally to German and Russian markets (Cobb 1900; Secor 2002). Fisheries in the Potomac and James River are well described and county-specific reports suggest that sturgeon were taken throughout the Chesapeake Bay for caviar and meat (Secor 2002; Hilton et al. 2016). Interestingly seasonal harvest records indicated that only a spring spawning run was targeted (Hildebrand and Schroeder 1927; Secor 2002). Atlantic sturgeon fisheries were not effectively regulated and by the 1920s very few Atlantic sturgeon were still harvested from the Chesapeake Bay (Hilton et al. 2016). As opposed to other DPSs, the Chesapeake Bay saw no apparent recovery in landings during the 20th Century (Secor et al. 2000). In 1976 and 1996, Virginia and then Maryland and the Potomac River Fisheries Commission instituted harvest moratoria on Atlantic sturgeon. In 1998, the ASMFC harvest ban was implemented (ASMFC 1998) followed by federal protection of the Chesapeake Bay DPS under the Endangered Species Act in 2012. Within the Chesapeake Bay, these new federal protections caused the prohibition of a USFWS-led reward program, initially implemented in 1996 (Mangold et al. 2007). This program had yielded over 2400 capture records in the Chesapeake Bay (Figure 1; E. Markin, UMCES, unpublished data) and provided substantial information on the distribution, demographics, and ecology of Atlantic sturgeon (Secor 2000; Welsh et al. 2002; Chesapeake Bay Program 2003; Hilton et al. 2016). ESA listing for the Chesapeake Bay DPS has also provided Section 6 support for studies that have greatly contributed to studies of habitat characterization and migration, and improved documentation of threats (e.g. Balazik et al. 2012a,b; Hager et al. 2014; Kahn et al. 2014; Balazik 2017).

The incidence of Chesapeake Bay shortnose sturgeon, which is sympatric with Atlantic sturgeon throughout most of its range, has been a controversial topic (Balazik 2017). Rare incidences of shortnose sturgeon in spawning tributaries have been reported (Dadswell et al. 1984; Kynard et al. 2009; Balazik 2017), but genetic studies have yet to confirm whether these constitute a separate population(s) or emigrants from elsewhere (e.g., the Delaware Estuary) (Wirgin et al. 2010).

Life History

Balazik et al. (2012b) has undertaken systemic studies of size and age structure within the James River population. They observed a slightly lower maximum size (L-infinite) and growth rate than that reported for the Hudson River (NY DPS), but substantially higher growth rate than that reported for the northern St. John's River population (see Age and Growth section). Only a single confirmed female was included in the study. Maximum age and size recorded in their study was 25 years and 250 cm FL, although larger individuals have been observed as dead carcasses (e.g., ship strikes) on shore. A. Spells (USFWS, pers. communication) measured one individual carcass ~ 270 cm Fork Length. Historical age structure was reconstructed from fin spines collected from 17th Century Jamestown and indicated an older, slower growing population occurred then in comparison to the extant James River population. Juvenile growth rates were estimated for recaptured individuals released into the Nanticoke River in 1996. Mean summertime lengths at age 1 and age 2 were 26.2 and 55.5 cm FL, respectively (Secor et al. 2000). Most growth occurred during summer and fall months. Annual growth rates in weight ranged 0.6-1.8% per day and were consistent with growth rates observed for other systems (Secor et al. 2000; Welsh et al. 2002).

Reproductive schedules are not well studied in the Chesapeake Bay DPS. Balazik reported a single confirmed single ripe females ranging, which was 201 cm FL and 21 years old (Balazik et al. 2012a). Kahn et al. (2014) reported a single confirmed female in the Pamunkey, which measured 192 cm FL. Three ripe females (188-200 FL) have been captured in the Marshyhope Creek during 2014-2016 (C. Stence, MD DNR pers. comm.). Based on observed sizes and ages in the James River, Balazik et al. (2012b) suggested that males mature at age 10 and females mature at age 15, slightly lower than ages at maturation for the Hudson River population (Van Eenennaam and Doroshov 1998). In the James River, telemetry studies indicate more frequent spawning by males (annual) than females (every 2-3 years) (M. Balazik, VCU, unpublished data as referenced in Hilton et al. 2016). Similarly, acoustically-tagged males in the Marshyhope Creek have been observed to return each year (C. Stence ,MD DNR pers. comm.).

A remarkable discovery is the dominance of a fall spawning run of Atlantic sturgeon within the Chesapeake Bay DPS (Balazik et al. 2012a). Studies in other systems and the 19th Century caviar fishery accounts indicated that Atlantic sturgeon only spawned in spring (Hildebrand and Schroeder 1927; Secor 2002). Fall spawning has been documented in the James River (Balazik et al. 2012a), the Pamunkey River (Hager et al. 2014), the Marshyhope Creek (C. Stence, Maryland

DNR, unpublished data), and in other DPS s (Balazik and Musick 2015; Smith et al. 2015). A less abundant spring spawning run may also exist as a separate race within the James River (M. Balazik, VCU, unpublished data as referenced in Hilton et al. 2016). In a review of spawning seasonality Balazik and Musick (2015) proposed a latitudinal gradient associated with fall spawning runs, which are more predominant in the southern part of the range and less so in the northern part of their range. Still, historical 19th Century fisheries were clearly focused on the spring run, which could suggest that the relative dominance of spring versus fall runs may have shifted in the past owing to fishing pressure or ecosystem change.

Spawning phenology, embryo and larval vital rates, and associated environmental dependence have not been studied within the Chesapeake Bay owing to the failure to sample early life history stages.

Factors affecting distribution and production

Improved riverbed mapping through acoustics has shown areas of salinity, flow, depth and substrate in up-estuary tidal freshwater portions of Chesapeake tributaries that offer potential spawning habitat for Atlantic sturgeon (Bruce et al. 2016). Where such mapping has occurred, there are potentially kilometers of potentially suitable spawning habitat in the James, Nanticoke, and Marshyhope Creek. Still such habitats grade fairly abruptly into substrates of sand and sediment which are not suitable for egg deposition (Bruce et al. 2016). Temperature, pH, and other water quality conditions associated with presence of ripe adults in areas of presumed spawning are now under study but suggest temperatures cue their presence and departure from these areas (C. Stence, MD DNR, unpublished data; M. Balazik, VCU, unpublished data). As indicated above, definitive studies on spawning habitats will require successful sampling of early life history stages.

Nursery habitats for larvae and age-0 juveniles include predation refuges, perhaps related to bottom structure (Hilton et al. 2016) or regions of lower water clarity. Laboratory studies on these stages indicate they are structure-oriented and sedentary (Kynard and Horgan 2002). As age-0 juveniles increase size they are expected to forage more widely in Chesapeake Bay tributaries (Secor et al. 2000). The few sampled age-0 juveniles were captured in freshwater and oligohaline portions of the James and York Rivers (Table 1). Small juveniles released into the Nanticoke River persisted in up-estuary brackish regions during the first two months following their early summer release (Secor et al. 2000).

Laboratory studies and bioenergetics models strongly indicate that age-0 to age-2 fish are sensitive to thermal and DO conditions in the Chesapeake Bay (Secor and Gunderson 1998; Niklitschek and Secor 2009a,b). Niklitschek and Secor (2015) suggested a three-way “habitat squeeze” for age-0 juveniles, which were curtailed to up-estuary regions and then sought to avoid super-optimal temperatures occurring in higher sections of estuaries and lower DO, which tended to occur in down-estuarine regions, particularly for Maryland tributaries. In some years, this habitat curtailment was predicted to nearly extinguish all potential summertime habitats within the Chesapeake Bay (Niklitschek and Secor 2005). Behavioral choice studies indicated that age-1 sturgeon selected temperature and DO levels in accord with bioenergetics model predictions (Niklitschek and Secor 2010). Larger juveniles and sub-adults are not as sensitive to temperature, DO, and salinity interactions. By age-2, laboratory studies indicated no response to salinity in growth rates (Niklitschek and Secor 2009a,b). Information from the past USFWS Reward Program indicates relatively frequent incidence of sub-adults occurs at dissolved oxygen levels <50% and temperatures > 25 C, conditions considered stressful for young juveniles (E. Markin, UMCES, unpublished data).

Forage and predation

In the Chesapeake Bay, diet information only exists for those Atlantic sturgeon juveniles released into the Nanticoke River in 1996, and indicated a diet of annelid worms, isopods and amphipods (Secor et al. 2000) – similar to principal diets observed elsewhere (Johnson et al. 1997; Hilton et al. 2016). Growth rates estimated for these released fish and from the USFWS reward program (Welsh et al. 2002) indicated that suitable forage occurred in the Chesapeake Bay. Further, the frequency of sub-adults visiting from other systems suggests that the Chesapeake Bay estuary supports important forage habitats for several DPS units (Mangold et al. 2007).

Predation has not received much study in the Chesapeake Bay. A controversial topic is the role of invasive catfish – piscivorous blue catfish and flathead catfish – in shaping early mortality of juvenile Atlantic sturgeon (Flowers et al. 2011; Hilton et al. 2016). Particularly in the James River blue catfish numbers have grown exponentially during the past decade and now occur at extremely high numbers in tidal freshwater habitats (Schloesser et al. 2011). Although no sturgeon have been observed in diet studies of invasive catfishes, the rarity of sturgeon in comparison to other fish prey is likely quite high suggesting it may take a very large sample of diet samples to be able to quantify predation effects. Predation trials in laboratory tanks suggested that striped bass and channel catfish will consume small juvenile Atlantic sturgeon if available (E. Markin, UMCES, unpublished data).

Dams within the tributaries of the Chesapeake Bay occur high in tributaries at or above head of tide, and therefore are unlikely to substantially interfere with spawning runs (ASSRT 2007; Hilton et al. 2016). Still, St. Pierre documented incidences, albeit rare of Atlantic sturgeon occurring in the Susquehanna, above the region now impounded by Conowingo Dam (R. St. Pierre, USFWS, as referenced by Horton 1994). An important consideration on dam effects is the discovery that large adult Atlantic sturgeon occur in the highest sections of tidal freshwater estuaries, sometimes at depths < 2 meters and in tidal creek sub-tributaries. Although not impounded directly by dams, these areas can be restricted due to bridges, navigation modifications, and shoreline hardening. Further, upstream dams used for hydroelectricity and flow regulation will strongly modify flow, which is expected to strongly influence spawning cues and spawning and nursery habitat conditions in these low volume tidal freshwater reaches.

The C&D Canal is likely an important movement corridor of migration for Atlantic and shortnose sturgeons between the Chesapeake and Delaware Bays (Dadswell et al. 1984; Wirgin et al. 2010).

2.4 CAROLINA DPS

Range and History of Fisheries

Albemarle Sound Basin, NC

The Albemarle Sound area includes Albemarle Sound, its tributaries, Currituck, Roanoke, and Croatan sounds, and all of their tributaries. Albemarle Sound, located in the northeastern portion of North Carolina, is a shallow estuary extending 88.5 km in an east-west direction averaging 11.3 km wide and .9–6.1 m deep. Ten rivers drain into Albemarle Sound, which joins Pamlico Sound through Croatan and Roanoke sounds, and in turn, empties into the Atlantic Ocean via Oregon Inlet. Currituck Sound joins Albemarle Sound from the northeast. Although the headwaters of the Roanoke River are located in the Appalachian foothills of Virginia, most of the tributaries to the Sound originate in extensive coastal swamps. The Roanoke and Chowan Rivers are the principal tributaries (Street *et al*. 1975; Johnson *et al*. 1981; Winslow *et al*. 1983; Winslow *et al*. 1985; Hightower and Sparks 2003).

Chowan River, NC

The Chowan River forms at the confluence of the Blackwater and Nottoway rivers approximately 9 miles south of the City of Franklin, Virginia. The Chowan River flows from the NC/VA border south for 50 miles where it empties into Albemarle Sound, draining 803 miles of streams over 1,378 sq. miles. There are 19 municipalities within the Chowan Basin, including Edenton, Ahoski, and Murfreesboro.

Roanoke River, NC

The Roanoke River is a relatively narrow stream that follows a winding course to its mouth below Plymouth, where it enters western Albemarle Sound. The Roanoke River watershed arises in the mountains of Virginia and covers 25,035 square km (8,893 square miles); only 9,081 square km (3,506 square miles) of the basin lies within North Carolina (NCDWQ 2001). Fifteen counties and 42 large municipalities (e.g., Greensboro, Winston-Salem, High Point, Roanoke Rapids, Williamston, and Plymouth) are represented within the North Carolina portion of the basin. Near the North Carolina-Virginia border, John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake impound the Roanoke River. The U.S. Army Corps of Engineers (USACE) and Dominion/NC Power Company operate these reservoirs for flood control and hydropower generation. A dam was constructed in 1955 on the River at Roanoke Rapids, North Carolina, 220.6 km (137 miles) from the mouth (Carnes 1965).

Pamlico Sound Basin, NC

The Pamlico Sound area extends from Oregon Inlet south to Core Sound, covering about 1,350,000 acres. Salinity varies from 30 ppt near the three inlets to zero in the upper tributaries. The Neuse and Tar-Pamlico rivers are the two main river systems that provide major fresh water inputs. The average depth of the sound is 16 feet, whereas the Neuse and Tar-Pamlico rivers average 8-11 feet in depth. Both rivers begin in the lower part of the Piedmont Plateau (Copeland and Gray 1991).

Tar-Pamlico River, NC

The Tar-Pamlico watershed is the fourth largest in North Carolina encompassing 14,090 square km (5,440 square miles). From its headwaters in Person County, the Tar-Pamlico watershed is drained by 3,790 km (2,355 miles) of tributaries along its 290 km (180 mile) main-channel length to Pamlico Sound near the confluence of the Pungo River (NCDWQ 1999). River reaches upstream of the City of Washington are designated as the Tar River and are primarily freshwater, while the reach below Washington, referred to as the Pamlico River, has characteristics of an upper estuary. Sixteen counties and six large municipalities (Greenville, Henderson, Oxford, Rocky Mount, Tarboro, and Washington) are represented within the basin. Major tributaries to the river include Fishing, Swift, and Tranters creeks, Cokey Swamp, and the Pungo River. Main stem headwater reaches and tributaries are located within the outer piedmont physiographic region and are characterized by low flows during dry seasons due to minimal groundwater discharge (NCDWQ 1999). However, since the majority of the basin is located within the coastal plain, these waters are largely characterized by slow flowing, low gradient, brown and blackwater streams with extensive floodplains often comprised of bottomland hardwood forests and marshes.

Neuse River, NC

The Neuse River is formed by the confluence of the Eno and Flat Rivers in the Piedmont region of North Carolina and flows in a southeasterly direction through the coastal lowlands discharging into Pamlico Sound 430 km (267 miles) from its origin (Hawkins 1980b; McMahon and Lloyd 1995). Through the Piedmont, the Neuse River has a relatively high gradient, and substrates tend to be rocky (McMahon and Lloyd 1995). As the river passes through the fall line into the coastal lowlands, it widens and slows with the reduced gradient. Downstream of the fall line, substrate is dominated by sand and silt (McMahon and Lloyd 1995). The Neuse River resides entirely within North Carolina and drains approximately 14,500 square km (5,598 square miles) of land, which is composed of approximately 48% forest, 30% agriculture, 9% wetlands, 6% developed lands, and 5% water (Hawkins 1980b; McMahon and Lloyd 1995). Flow regimes in the Neuse River downstream of Raleigh, North Carolina are controlled by Falls Lake Dam (river km 370; river mile 230), which was built in 1983 by the USACOE to create an impoundment for flood control, water supply, water quality, and recreational purposes.

White Oak River Basin, NC

The White Oak River Basin sits between the Pamlico Sound Basin and the Cape Fear River Basin and lies completely within the southern coastal plain. The White Oak Basin contains four river systems (New River, White Oak River, Newport River, and North River) that empty into Bogue, and Core sounds. The Basin consists of 267 miles of fresh water streams and rivers and 192 square miles of saltwater. There are four counties and 14 municipalities within the basin including, Jacksonville and Camp Lejune, Morehead City, and Beaufort (NCDWQ 1997).

White Oak River, NC

The White Oak River is the second largest river in the White Oak River Basin and is directly east of the New River. The river is approximately 48 miles long passing through the Croatan National

Forest and Swansboro. The River flows into western Bogue Sound then to the Atlantic Ocean through Bogue Inlet (NCDWQ 1997).

New River, NC

The New River is the western most river within the White Oak Basin. It is the largest river in the basin and includes the City of Jacksonville and the Marine Core Base Camp Lejune. The river is a coastal blackwater river and is contained entirely within Onlsow County. The upper portion of the river system is characterized by gum-cypress swamps with some upland agricultural and forested lands. The river above the Highway 17 bridge is a narrow free flowing river while the portion below the 17 bridge widens and becomes a slow moving tidal system emptying directly into the Atlantic Ocean through New River Inlet (NCDWQ 1997).

Cape Fear River System, NC

The Cape Fear River, the largest river system in the state, forms at the confluence of the Deep and Haw rivers in the Piedmont region of North Carolina and flows southeasterly for approximately 274 km where it discharges into the Atlantic Ocean at Cape Fear, near Southport, North Carolina. The basin lies entirely within the state, includes portions of 27 counties and 114 municipalities, and encompasses 9,984 km of freshwater streams and rivers, 36 lakes and reservoirs, and 15,864 ha of estuarine waters (NCDWQ 1996). Major tributaries include the Upper and Lower Little Rivers in Harnett County, the Black River in Bladen, Pender, and Sampson counties, and the Northeast Cape Fear River in Duplin, Pender, and New Hanover counties.

Little River, SC

The Little River is a tidal river and flows in both directions according to the tides. The Atlantic Intracoastal Waterway (AIWW) flows across the North Carolina state line in the “Little River Neck” area and merges with the Little River to flow south toward North Myrtle Beach or flow out of the Little River Inlet to the Atlantic Ocean.

Winyah Bay System, SC

The Winyah Bay and its tributaries comprises the northern most watershed in South Carolina and Atlantic sturgeon (ATS) from this basin are included in the Carolina DPS management zone (NOAA 2012a). The Winyah Bay is an 18,158 hectare (ha) estuary that extends nearly 24 kilometers (km) inland and has six tributaries (Sampit, Lynches, Little Pee Dee, Pee Dee, Black, and Waccamaw Rivers). The Sampit is a small, tidal river that becomes unnavigable inland near river kilometer (RKM) 15. The Black River forms in the Pocotaligo and Black River Swamps and courses through the coastal plain for 243 RKM before emptying into the Pee Dee River. The Lynches River begins near the fall line and continues 225 RKM to its confluence with the Pee Dee River. The Little Pee Dee River begins in the coastal plain in North Carolina and continues 187 RKM to its confluence with the Pee Dee River. The Pee Dee River begins at the confluence of the Yadkin and Uwharrie Rivers in North Carolina and flows 90 km in North Carolina and 280 km in South Carolina where it merges with the Waccamaw River and forms Winyah Bay. The Waccamaw River begins in the coastal plain in North Carolina and parallels the Atlantic Coastline for 225 RKM where it merges with the Pee Dee River and forms Winyah Bay.

The upstream limit of the salt wedge varies seasonally and over a tidal cycle. During periods of high streamflow in the watershed freshwater extends to the Atlantic Ocean. During periods of low flow the salt wedge extends approximately 45 km upstream.

All tributaries of the Winyah Bay System flow unimpeded in South Carolina. The first dam on the Pee Dee River is in North Carolina at RKM 302, Blewett Falls Dam. The Pee Dee River is the major river in the Winyah Bay System, and sturgeon are present in the Black, Waccamaw, Pee Dee, and Sampit Rivers (Post et al. 2014, and Collins and Smith 1997).

Historically, ATS were commercially harvested in the Winyah Bay System as it was the primary fishing grounds in South Carolina. Commercial exploitation of the fishery began in the 1870's when Swedish immigrants from Delaware began fishing each spring in Winyah Bay, Georgetown. Declining catch in Delaware Bay was partially responsible for these immigrants and their arrival, coupled with development of rail service from South Carolina to the northern market centers (Baltimore, Philadelphia, New York), and resulted in the commercial exploitation of the sturgeon (Smith et al. 1984). Recorded landings peaked at 218,200 kg in 1897 and just 5 years later, the fishery rapidly declined and in 1902 the recorded landings for South Carolina were 42,600 kg (Smith et al. 1984). South Carolina fishermen, the majority of which fished in the Winyah Bay System, accounted for a significant portion of the U.S. landings of ATS from 1900-1984 (Smith et al. 1984); and South Carolina reported annual landings of 45,000 kg from 1978-1982 (Smith 1985). The ATS gillnet fishery was closed in 1985 throughout South Carolina including the Winyah Bay System and has remained closed to date.

Santee-Cooper System, SC

The Santee and Cooper River Basins originate on the eastern slopes of the Blue Ridge Mountains in western North Carolina (Mathews et al. 1980) and is second only to the Susquehanna on the U.S. East Coast in terms of drainage area and volume of flow (Hughes 1994) and covers 21,700 square miles (Conrads et al. 2002). Atlantic sturgeon (ATS) from this system are included in the Carolina DPS management zone (NOAA 2012a).

In 1938, the South Carolina Public Service Authority (SCPSA) initiated the Santee-Cooper Diversion Project to move water from the Santee River to the Cooper River. This project included the construction of the Santee Dam, locally known as Wilson Dam, for flood control on Santee River at RKM 143, which created Lake Marion, and the construction of Pinopolis Dam at RKM 77 on the Cooper River, a hydroelectric facility and navigation lock, which formed Lake Moultrie (Cooke and Leach 2002). Flows diverted from Lake Marion on the Santee River to Lake Moultrie on the Cooper River. Mean annual flows in the Cooper River increased to 15-20,000 cfs daily and annual flows in the Santee River declined from 525 to 63 cubic meters per second.

Over time, increased flows and sediment loads from the Cooper River led to shoaling in Charleston Harbor. To alleviate this issue, the Cooper River Rediversion Project reduced shoaling in the Harbor by diverting water back to the Santee River through a 15 km Rediversion Canal. The St. Stephen Dam was constructed 7 km up the Rediversion Canal to control the flow from Lake Moultrie to the Canal and has a hydroelectric facility and a fish-lift. The Rediversion

Canal was completed in 1985 and approximately 75 percent of the Cooper River's flow was returned to the Santee River, increasing its flow from 63 to 295 cubic meters per second (Cooke and Leach 2002).

The Cooper River, was historically a small tidal River. While historic data are lacking for the Cooper River it likely supported small stocks of anadromous fish, however it is unknown if sturgeon were present. Presently, the Cooper River is formed by the confluence of the West and East Branches at RKM 48. The East Branch is a tidal slough throughout its 8-mile reach. The upper West Branch is characterized by meandering natural channels bordered by extensive tidal marshes and abandoned rice fields. In the lower West Branch, industrial complexes dominate the river and the east bank contains numerous dredge-material disposal areas. Saltwater in the Cooper River extends from Charleston Harbor upstream to approximately RKM 26. The Cooper River is tidally affected throughout its entire reach (Conrads and Roehl 1999; Conrads et al. 2002). Although water quality is generally good, sediments in some areas are still contaminated due to previous industrial operations and military facilities. The river channel is maintained by dredging all the way to the dam.

The Santee River, formed by the Wateree and Congaree Rivers, was historically one of the longest river systems on the Atlantic coast and supported spawning runs of anadromous fish as far as 438 km inland to Great Falls on the Wateree River and up to 602 km up the Congaree River (Walburg and Nichols 1967). Presently, the Santee River system consists of the North Santee River, North Santee Bay, South Santee River, South Santee Bay and the Rediversion Canal. Throughout the year flows fluctuate drastically depending on discharge from the dam (which is dependent on precipitation and electrical power demand). When not in flood, the Santee River is a shallow, slow moving, meandering river that flows through hardwood swamps (Bulak and Curtis 1977).

Historical landings of Atlantic sturgeon (ATS) in the Santee-Cooper system have been reported, however the nearby Winyah Bay System was the primary fishing grounds in South Carolina. The presence of several dams has resulted in the loss of access to over 62 percent of the historical sturgeon habitat in the complex Santee-Cooper system. This has resulted in the loss of important spawning and juvenile developmental habitat and has reduced the quality of the remaining habitat by affecting water quality parameters (such as depth, temperature, velocity, and DO) that are important to sturgeon (ASMFC 2007; NOAA 2012a).

Charleston Harbor Rivers, SC

Included in the Carolina DPS, the Cooper River system consists of Charleston Harbor, West branch of the Cooper River, East branch of the Cooper River, and the Wando River. Historically, all tributaries to Charleston Harbor were small coastal plain rivers with minimal freshwater flows, which were tidally influenced for their entire lengths. The completion of the Santee Cooper project in the 1940s dramatically changed river discharge in the Cooper River. From the 1940s into the 1980s, nearly all river discharge of the Santee River was diverted through the Santee Cooper project, run through the hydroelectric units in Pinopolis Dam, and discharged down the Tailrace Canal and into the Cooper River. In the 1980s the Rediversion Project diverted part of the Santee River discharge back to the Santee River, however a significant discharge of freshwater still flows into the Cooper River. The Cooper River provides the dominant freshwater input for the Charleston Harbor and provides 77 RKM of riverine habitat (Post et al 2014).

Wando River, SC

The Wando River is a tidal slough that tapers from a width of about ½ mile at its mouth to a narrow tidal creek 34 km upstream from the confluence with the Cooper River. Saltwater extends throughout the Wando River. The banks of the river are dominated by extensive *Spartina alterniflora* salt marshes. The Wando River is tidally affected throughout its entire reach (Conrads and Roehl 1999) with varying levels of urban development (Yassuda et al. 2000).

Cooper River, SC

The Cooper River is mainly a tidal river. Along its course, it merges with Mepkin Creek to form the West Branch of the Cooper River, which converges with the East Branch Cooper River (this area is known as the “T”). The river is then is joined by the Back River, Goose Creek and the Wando River before finally joining the Ashley at the Harbor to flow into the estuary (X).

Life History

Chowan River, NC

Limited information exists to describe the life history of Atlantic sturgeon within the Chowan River. Commercial fisherman have reported collections of various sizes of sturgeon collected from gill nets and pound nets. Sizes reported range from small juveniles to large adults, though the adults have been few. Telemetry data collected during Post et al. (2015) provides additional data on movements of Atlantic sturgeon within the river. Detection data show sturgeon heavily use the lower portion of the Chowan River near the Highway 17 bridge. Adults, sub adults, and juveniles have been detected within the arrays in the Chowan River. Detection data show adults use the mouth of the Chowan as a staging area prior to ascending the Roanoke River in the fall. Data also show young juveniles use the mouth of the Chowan as habitat during all months of the year, sub adults use this habitat during the spring through fall, and fish that have been tagged in other DPSs have frequented this area during their coastal migrations (Post et al. 2014). Spawning of Atlantic sturgeon is not known to occur within the Chowan River.

Roanoke River, NC

Historical reports of Atlantic sturgeon spawning within the Roanoke River suggest a primary spawning in the spring coinciding with the striped bass spawning run (Yarrow 1874; Worth 1904). An alternate spawning time was documented by Worth (1904) who described collections of Sturgeon with various roe conditions during August and September. Additionally, Smith et al (2015) detected a fall spawn occurring in the Roanoke River through the use of acoustic telemetry and artificial substrates. Smith et al (2015) used detection data to identify locations for deploying artificial substrates (spawning pads) to collect released eggs. They were successful in collecting 38 eggs over 21 days of sampling immediately below the first shoals at Weldon. Estimated spawning dates were 17-18 and 18-19 of September when water temperatures were 25 to 24°C and river discharge was 55 to 297 m3/s. These telemetered fish arrived in Weldon typically in August when water temperatures were near 28°C, remained for an average of 40 days then departed late September or early October when water temperatures were near 20° (Smith et. al. 2015).

Tar River, NC

Limited information exists on the life history of Atlantic sturgeon within the Tar/Pam River. Unpublished data from the NCDMF Independent Gill Net Survey and Observer Program show collections of possible young of year (less than 500 mm TL) and juveniles within the Tar/Pam River. Based on collections of Atlantic sturgeon less than 500 mm TL and that early juvenile Atlantic sturgeon reside in their natal system, reproduction may be occurring with the river system (Smith 1985; Secor et al. 2000; Armstrong and Hightower 2002).

Neuse River, NC

Limited information exists on the life history of Atlantic sturgeon with in the Neuse River. Unpublished data from the NCDMF Independent Gill Net Survey and Observer Program show collections of adult size fish (up to 2,300 mm TL), young of year size fish (less than 500 mm TL), and large juvenile and sub adult collections. Though these collections have not been genotyped to a specific DPS the collection of small juveniles or YOY would suggest spawning does occur within this system, however collections of these sizes of fish do not occur every year.

Cape Fear River System, NC

A comprehensive survey of anadromous, estuarine, and resident fishes in the tidal freshwater portion of the lower Cape Fear River drainage was initiated by the NCDMF in January 2002. A total of 145 Atlantic sturgeon was tagged with T-bar tags for the US Fish and Wildlife Service and three were recaptured (2.1% recapture rate [Shelia Eyler, USFWS, personal communication]). One fish emigrated and two fish remained within the Cape Fear. The migrating sturgeon was tagged in the Cape Fear River and recaptured in the Waccamaw River in South Carolina 59 days later. The fish that remained in the Cape Fear did not show any movement based on location of recapture. One fish tagged and subsequently recaptured was at large only one day at the same site. The other recapture was at large for 201 days and recaptured at the same site (NCDMF 2007).

Based on data collected through telemetry tagging, sub-adult sturgeon movement and distribution in the Cape Fear River followed seasonal patterns likely driven by physical conditions within the system. During the summer months (June- August) when temperatures are reaching their maximum, sturgeon distribution was compressed and shifted upriver, and large-scale movements were limited. This shift in distribution and tendency of individual fish to remain in one location during this time period suggest fish are possibly seeking thermal refuge in areas upstream of the salt wedge. During the coldest time of the year (January – February) tagged sub-adult sturgeon are primarily absent from the system, having migrated to the ocean (Post et. al. 2014).

High inter-annual return rates of acoustic tagged sub-adult Atlantic sturgeon to the Cape Fear River demonstrates fish have fidelity to this system. This implies the Cape Fear basin may be the natal system of these fish, or is at least a highly important foraging area (Post et. al. 2014).

Three of the smallest individual Atlantic sturgeon caught, and not implanted with acoustic tags are of particular interest due to their small size. These fish were between 410 and 458 mm FL and were captured during the months of January and February, when nearly all of the larger tagged fish had emigrated and prior to the spring immigration of fish. The size and time of capture of these fish would indicate possible age-1 fish within the Cape Fear River, also suggesting this system may be their natal drainage (Post et. al. 2014).

The observed directed upstream movements of a tagged individual ripe and running mature adult Atlantic sturgeon during the spring spawning season of 2012, and its subsequent behavior in the following years does suggest this fish made a spawning migration. Interestingly, this fish migrated to both the freshwater tidal reaches of the main stem and Northeast Cape Fear Rivers, and has returned each year subsequent to tagging. The area where the fish concentrated its spring movements was well below the accepted historical spawning areas around the fall line on the main stem of the Cape Fear River. If there is successful spawning occurring within the Cape Fear basin, movement data from this single adult fish would suggest it is occurring between RKM 131 and 65 on the Northeast, or between RKM 95 (Lock and Dam #1) and RKM 64 on the main stem of the Cape Fear River. Possible available spawning substrates include cobble fill at the base of the dam or exposed limestone bedrock outcroppings within the freshwater tidal reaches of river (Post et. al. 2014).

Winyah Bay System, SC

Historic commercial landings suggest robust populations of spring spawning fish were once very abundant in the Winyah Bay System. However, since the closure of the commercial fishery in 1985, data on returning adults in the watershed was limited. In 2001-2002 and 2007-2009 telemetry studies were conducted that were primarily focused on Shortnose Sturgeon, however, many Atlantic sturgeon were captured at every netting station in a 30 mile stretch of river, indicating a healthy juvenile population. Additionally, in 2010 funding for a multi-state telemetry study that was focused primarily on adult Atlantic sturgeon provided much more information. Results from this study indicated that fall spawning was also occurring. In September and October adults were located well inland, 150-290 river kilometers (RKM) on suspected spawning migrations. One of these fish was detected spawning in consecutive years, 2012 and 2013. Also of note, two ATS transmitted in other areas (New York and Delaware) were also spawning. In addition to detecting spawning movements in fall and spring, this study also reinforced previous hypotheses on the highly migratory nature of ATS, as 41 fish transmitted in other locations (Connecticut, New York, Delaware, North Carolina, Virginia, and the Edisto and Savannah Rivers, South Carolina) were detected in the Pee Dee and Waccamaw Rivers. In summary, presumed spawning movements were detected in the spring and fall and telemetry as well as sampling results indicate there is a population of ATS in the Winyah Bay System. Although successful spawning has not been confirmed via egg collection, telemetry evidence as well as captures of ATS <500mm TL (Gibbons and Post 2009; Post et al. 2014) point to a successfully reproducing population of ATS.

Santee River, SC
Limited information exists on the life history of Atlantic sturgeon in the Santee River. Results from a multi-state telemetry survey show three fish tagged in the Santee River left the river and were not detected in the Santee River throughout the study. During this study, only one ATS, originally tagged in North Carolina, was detected in the lower Santee River (RKM 16). Additional sturgeon were detected at the mouth of the Santee River but were not detected further upstream and include ATS that were tagged in New York, Delaware, Virginia, North Carolina and the Great Pee Dee, Edisto, and Savannah Rivers, South Carolina (Post et. al. 2014).

In 2014, a study evaluating the status, distribution, and population structure of sturgeon in the Santee River. Receiver data increased tagged ATS detections in the Santee River to 41 fish nine locations from the Altamaha River, GA to the Hudson River, NY. Continued netting efforts have resulted in the capture of 48 Atlantic sturgeon, ranging in size from 286 – 1,880 mm TL. The capture of ten potential young of the year (YOY) fish (286 – 376 mm TL) suggests successful spawning may occur in the Santee River. However, these results must be interpreted with caution since, in 2015, South Carolina experienced historical flooding and it is possible that these YOY fish were transported to the Santee by flood waters from the Pee Dee or Waccamaw River via Winyah Bay and the Intracoastal Waterway (ICW).

Cooper River, SC
Limited information exists on the life history of Atlantic sturgeon in the Cooper River. In 2015, a more comprehensive study of the Cooper River in order to fill in data gaps with objectives to evaluate the status, distribution, and population structure of sturgeon in the Cooper River, and potential reproduction and recruitment of SNS and ATS sturgeon in the Cooper River. To date, this study has captured eight Atlantic sturgeon, ranging in size from 684 – 1638 mm TL . Four of these fish (684 – 1,232 mm), were captured mid-river (RKM 26 – 40) above the saltwater/freshwater interface. The other four fish (1,173 – 1,638 mm TL) were all running ripe males captured at the known SNS sturgeon spawning grounds immediately below Pinopolis Dam (RKM 77). All fish were implanted with Vemco transmitters with an estimated battery life of 1,741 days. After insertion, receiver data detected subsequent downstream migrations indicative of post-spawning behavior. This recent catch data, in conjunction with the capture of juveniles (490 – 610 mm) in the Cooper River in the late 1980's (Collins and Smith 1997), suggests ATS spawning activity occurred and still may occur below Pinopolis Dam.

The well-documented population of SNS sturgeon spawning in the Cooper River at the base of the Pinopolis Dam (Duncan et al. 2004) provided evidence that sturgeon rarely pass through the lock even though they are congregated at the base of the dam, since passage would require swimming upward along a vertical wall approximately 50 ft. high (Cooke et al. 2002). Though SNS sturgeon spawning upstream of Pinopolis dam has been documented there is scant information to support existence of a land-locked subpopulation of Atlantic sturgeon in Lakes Marion and Moultrie. However, in 2007, an Atlantic sturgeon was captured in the fish lift at St.

Stephen Dam; it was removed and released into the Santee River downstream from the dam. (A. Crosby, SCDNR, pers. comm.). It could not be determined whether this animal entered the fish lift from the exit leading to Lake Moultrie or from the downstream entrance in the Rediversion Canal, only that it was in the fish lift.

Wando River, SC

There is no documented evidence that a resident population of sturgeon exists, or ever existed, in the Wando River, however both sturgeon species have been observed. Five ATS sturgeon have been detected by a receiver at RM 3.5, although none spent any substantial amount of time in the river. These fish were tagged in multiple areas: NY, NC, SC, and GA. No netting effort has directly targeted sturgeon in the Wando River.

Maturity

South Carolina fish mature between ages 7- 19 for females and 5-13 years for males (Smith et al 1982). Spawning migration begins in February in South Carolina (Smith 1985) and Atlantic sturgeon leave the system by October to November (Collins et al 2000). Tidal freshwater, river, and lower and upper estuaries were used during the summer months and both fall and spring spawning runs were documented in the Combahee and Edisto rivers in South Carolina (Collins et al. 2000).

2.5 SOUTH ATLANTIC DPS

Range and History of Fisheries

As described in NOAA 77 FR 5914 the definition of the South Atlantic DPS is “South Atlantic’’ population segment, which includes Atlantic sturgeon originating from the ACE basin (Ashepoo, Combahee, and Edisto rivers), Savannah, Ogeechee, Altamaha, and Satilla Rivers.

Ashley River, SC

Included in the South Atlantic DPS, The Ashley River is a tidally influenced, Coastal Plain river that extends approximately 30 miles from Cypress Swamp in Dorchester County to its mouth at Charleston Harbor on the Atlantic Ocean. The entire drainage of the Ashley River system, including its headwaters in Cypress and Wassamassaw swamps, extends approximately 60 river miles. Along its winding course, the river passes through a varied natural and cultural landscape of forested swamps and uplands, tidal marshlands, residential and commercial developments, historic sites and structures, and major urban development at the City of Charleston (SCDNR 2003).

Stono River, SC

No information is available for Atlantic sturgeon in the Stono River.

North Edisto River, SC

No information is available for Atlantic sturgeon in the North Edisto River.

ACE Basin Rivers, SC

The ACE Basin is comprised of the Edisto, Ashepoo, and Combahee Rivers. These three rivers flow unimpeded for their entire lengths and are classified as coastal plain blackwater rivers. The ACE Basin consists of roughly 350,000 acres of marshlands, cypress swamps, beaches, and maritime forests, and the rivers drain into the St. Helena Sound which is located between Charleston and Beaufort, S.C. (Post et al 2014). The lower Edisto and Combahee rivers supported a directed commercial fishery for Atlantic sturgeon prior to the fishery closure in 1985.

Edisto River, SC

The Edisto River is the largest river in the ACE Basin, and begins in the transition zone between piedmont and coastal plain. It is the longest free flowing blackwater river in South Carolina, and during excessive rainy seasons will inundate lowlands and swamps and the flow basin increases to a mile wide or more.

Port Royal Sound Rivers, SC

The Port Royal Sound system consists of the Beaufort, Broad, Colleton, Chechessee, Coosawhatchie, Pocotaligo Rivers, and Whale Branch. The Coosawhatchie River is the largest of the tributary rivers and extends inland 80 RKM. Port Royal Sound receives minimal freshwater input from tributary rivers due to the small watershed it drains, and all of the tributary rivers are characterized as coastal plain blackwater rivers. There are no barriers to upstream migration in the Port Royal Sound system (Post et al 2014).

Calibogue Sound Rivers, SC

No information is available for Atlantic sturgeon in the Caliboge Sound area.

Savannah River, SC-GA

The Savannah River System is comprised of the mainstem Savannah River and the Front, Middle, and Back River. The Savannah River begins in the foothills of Appalachian Mountains in Georgia, and South Carolina and flows 506 km across the piedmont and coastal plain before emptying into the Atlantic Ocean. The river serves as the border between Georgian and South Carolina throughout its entire length. The first barrier to upstream migration is the New Savannah Bluff Lock and Dam (NSBL&D) located at RKM301 near Augusta, Georgia. The lock was designed for navigation and initially provided very limited fish passage. In the late 1980s, identification and documentation of more efficient passage methodologies were completed at NSBL&D and have since been implemented annually. The first true barrier with no dedicated fish passage is the Augusta Diversion Dam located at RKM333 (Post et al 2014).

Wassaw Sound Rivers, GA

No information is available for Atlantic sturgeon in the Wassaw Sound Rivers

Ossabaw Sound Rivers, GA

Ogeechee River, GA

The Ogeechee River begins in the east central piedmont at the confluence of the North and South forks and flows for 564 km uninterrupted into Ossabaw Sound then to the Atlantic Ocean. The River is a blackwater river with only one major tributary, the Canoochee River that joins the Ogeechee near RKM55 (Flemming et al. 2003).

St. Catherines Sound Rivers, GA

No information is available for Atlantic sturgeon in the Catherines Sound Rivers.

Sapelo Sound Rivers, GA

No information is available for Atlantic sturgeon in the Sapelo Sound Rivers.

Deboy Sound Rivers, GA

No information is available for Atlantic sturgeon in the Deboy Sound Rivers.

Altamaha River System, GA

The Altamaha River System is located entirely within the State of Georgia and is formed by the confluence of the Oconee and Ocmulgee rivers. The mainstem flows across the Atlantic coastal plain in a southeasterly direction for 207 km to the coast where it empties into the Atlantic Ocean near Darien, Georgia. Depths average 2–3 m, with a maximum of 18 m in Altamaha Sound (Heidt and Gilbert 1978). The lower Altamaha estuary is characterized by a tidally flooded salt marsh that gradually gives way upstream to cypress swamp. The location of the freshwater–saltwater interface is highly variable (Rogers and Weber 1995). Most of the Altamaha's discharge originates in the Ocmulgee (40%) and Oconee (36%) tributaries (Rogers and Weber 1995). Isolated rocky shoal habitats are found above RKM 80 and throughout the lower reaches of both the Ocmulgee and the Oconee (Flournoy et al. 1992). Both major tributaries have but they are located above the fall line and the biological effects of these dams are considered to be moderate (Dynesius and Nilsson 1994).

St. Simons Sound Rivers, GA

No information is available for Atlantic sturgeon in the St. Simon Sound Rivers.

St. Andrew Sound Rivers, GA

Satilla River

The Satilla River begins in Ben Hill County Ga and flows unimpeded for approximately 378 km before emptying into St. Andrews Sound and the Atlantic Ocean. The saltwater/freshwater interface is around RKM 32 and the tidal influence of the river can be seen as far up stream as RKM 93 (Georgia Shad Plan).

St. Marys River, GA-FL

The St. Marys River begins in the Okenokee Swamp flows for 203 unimpeded km before emptying into the Atlantic Ocean through Cumberland Sound. This river forms the eastern portion of the border between the states of Georgia and Florida. The watershed encompasses

3,350 km2, 59% in Georgia and 41% in Florida. The saltwater/freshwater interface is typically at RKM 33 while the tidal influence extends up to RKM 88. Additional information on Atlantic sturgeon interactions within the St. Marys River have been identified but are not yet available as they are being prepared for publication.

Nassau River, FL
No information is available for Atlantic sturgeon in the Nassau River.

St. Johns River, FL
No information is available for Atlantic sturgeon in the St. Johns River.

DPS-Specific Life History

Current and historical abundance of Atlantic sturgeon is relatively unknown for many of the river systems within the South Atlantic DPS. Much of the available data are from short term studies in a select few rivers. However, some data describing growth, age distribution, abundance, movement, and survival are available for the Edisto River, Combahee, Port Royal Sound, Savannah River, Altamaha River system, the Ogeechee River, and the Satilla River.

Ashley River, SC
There is no documented evidence that a population of Atlantic sturgeon exists, or ever existed, in the Ashley River (ASMFC 1998).

Edisto River, SC
Since 1995 thousands of Atlantic sturgeon juveniles, including 500 age 1 sturgeon have been captured in the Edisto River near the confluence of the Edisto, Ashepoo, and Combahee rivers (Collins and Smith 1997). In March of 1997, four adult Atlantic sturgeon were captured in the Edisto River, one being a gravid female that measured 234 cm total length. A ripe male originally captured in the Combahee River was recaptured a week later in the Edisto suggesting a single reproducing population that spawns in at least two of the rivers.

The Edisto River was also included in the 2011-2014 multi-state study (Post et al 2014). In 2011-2014, most ATS entered the Edisto River between April – June and were detected in the saltwater tidal zone until water temperature decreased below 25°C. They then would enter the freshwater tidal and some fish would make presumed spawning runs around September - October. ATS were detected undertaking upstream migrations in the fall to presumed spawning areas (RKM 146, 183, and 205) each of the 4 years. Post et. al. 2014. Collins et. al. (2000) presumed these spawning locations to be at RKM 105 and 190 in the Edisto River. However Collins et. al. (2000) collected a potentially actively spawning female at RKM 56 and a very recently spawned female at the same location, both in the spring.

Additionally, ATS less than 120 mm, presumably young-of-year, have been observed in the Edisto River during July and August (Post et. al. 2014).

Limited information on ageing of Atlantic sturgeon from the Edisto River exist. Although ages of Atlantic sturgeon collected from the Edisto River were determined from 38 fin spines. Ages were from 7 – 20 years with a modal age of 9 and a mean age of 10.8. When identified to sex, males were aged from 7-15 years and females from 15-20 years (Collins et. al. 2000).

Limited information on sex ratios or maturity exist for the Edisto River as well. Collins et al 2000 collected information on 28 sturgeon, 21 males and 7 females during 1998 and 1999. The males ranged in length from 139-192 cm TL and the females from 180-234 cm TL. Ripe males were collected as early as March 2 and females as early as March 7 when water temperature was 13.68°C (Collins. Et. al. 2000). Spent males were captured as early as late March and spent females as late as mid May. Ripe males began reappearing in sampling during the end of August, only one of seven males captured in October were not running ripe. A late developing female was collected in June and this female moved up stream to RKM 105 in late September. Spent females were collected during September and October when water temperatures were 17-18.8°C (Collins et. al. 2000). Smith (1985) reported males mature as early as age five in South Carolina and Collins et al (2000) reported males mature at age 7.

One estimate of abundance is available for the Edisto River. This was for ATS greater than 1 m in TL from work Flowers and Hightower (2015). They estimated abundance of ATS greater than 1 m at 343.5 individuals with a (150-788 confidence interval).

Potential fall spawning movements for the Edisto River occurred in the late summer through fall as water temperatures began too cool. The typical movement pattern for a spawning fish was to arrive at a river mouth in late spring, remain in the saltwater tidal area through the summer, migrate upstream to freshwater riverine environments (when water temperatures approached 25°C) and remain upstream 2-6 weeks in the fall (when water temperature was between 14 and 25°C), and migrate downstream and exit the river system in late fall/early winter as water temperatures continued to cool (Post et al 2014).

Combahee

The Combahee River was also included in the 2011-2014 multi-state study (Post et al 2014). ATS that were tagged in the Combahee River were absent from the system for the majority of the study period. An ATS that was tagged in June of 2011 left the system in the fall of 2011, returned in July 2012 and left the system again in the fall of 2012. This fish was detected the farthest upstream of any tagged ATS in the Combahee River (RKM 56). Another ATS was identified as a running ripe male at capture in the Combahee River in March 2011, was relocated exhibiting spawning behavior in the North East Cape Fear River, NC in March, 2012, and in 2014 was detected from February – April in the Winyah Bay System (Post et al 2014).

Mortality or survival estimates are limited from the ACE Basin. Hightower et al. (2016) produced an estimate of annual apparent survival rate of 0.871 (95% CI 0.796-0.928) from the ACE Basin. These estimates were calculated from acoustic telemetry tagging data collected during a multi-state tagging project. This estimate is probably low due in part that nine fish that were not detected during the final study have since been detected.

Port Royal Sound System

The Port Royal Sound system is not traditionally known to have a considerable sturgeon population. However, it is situated between two systems that historically and currently have sturgeon populations, the Savannah River and the ACE Basin (Post et. al. 2015). Little to no scientific sampling has been conducted in the Port Royal Sound and Rivers (Smith et. al. 1984). The Port Royal Sound system was included in the 2011-2014 multi-state study (Post et al 2014). With the funding of the Multi State Telemetry work, and array was deployed throughout the waterbody and ATS were detected using the system. There were a total of 18 ATS sturgeon detected during the course of the study. These include ATS transmitted in Delaware, North Carolina, Georgia, and the Edisto, Combahee, and Savannah Rivers, S.C (post et. al. 2014). There were no major upstream migrations or seasonal sturgeon movement patterns of note detected (Post et al 2014).

Savannah River, SC-GA

Estimates of abundance have been determined for age 1 Atlantic sturgeon in the Savannah River by Bahr and Peterson (2016). Barh and Peterson (2016) set gill net and trammel nets within the Savannah River to capture juvenile Atlantic sturgeon. These sturgeon had ages estimated based on length frequency. Estimates of age-1 Atlantic sturgeon were 528 in 2013, 589 in 2014, and 597 in 2015 (Bahr and Peterson 2016).

The Savannah River was also included in the 2011-2014 multi-state study (Post et al 2014). Detection data collected from the Four ATS entered the Savannah River and migrated upstream during the late summer and fall months. Two ATS previously tagged in the Savannah River made upstream spawning movements; this was the second year (2011) one of these fish was detected making similar upstream movements. These two fish were also detected immediately upstream of the New Savannah Bluff Lock and Dam, RKM 301. It is unknown if they passed through the lock or swam over the dam during high flows. Based on detection data, there is a strong possibility that one fish may have been detected by the receiver directly upstream while still remaining downstream of the dam while flow control gates were in a full open position. One ATS tagged in the Savannah River made similar movements in 2011. The other two detected ATS were tagged outside the boundaries of the South Atlantic (SA) DPS (Post et al 2014).

Many sturgeon tagged outside of the Savannah River were detected in the Savannah River throughout the study, and two ATS from DPS's outside of the South Atlantic were detected making presumed spawning migrations in the Savannah River. These two ATS, one tagged in the James River, VA (Chesapeake Bay DPS) on May 13, 2009, was 995mm FL and weighed 9.3kg; and the other one was tagged off the coast of Delaware on May 3, 2011, had eggs present at the time of capture and was 1950mm FL and weighed 72kg. As mentioned previously the ATS transmitted off the Delaware Coast made back-to-back migrations in the Savannah River in 2012 and 2013. It must be noted at this point, efforts were made to contact original taggers of these fish in order to obtain information, if available, concerning genetic assignments based on

DPSs. Through this process, ATS #20473 was confirmed to be a SA DPS fish (Personal Communication Dr. Dewayne Fox, Wirgin et al. *In press*). The genetic sample for the James River, VA fish has not yet been analyzed. Post et al 2014

Twelve sturgeon (eleven ATS and one SNS) originally captured and tagged in the Cape Fear River, NC were detected in the Savannah River. Eight sturgeon originally captured and tagged in the Altamaha River, G.A. were detected in the Savannah River. Five ATS that were tagged in the Edisto River, S.C. were detected in the Savannah River. Two ATS that were tagged in the Great Pee Dee River, S.C. were detected in the lower portion of the Savannah River. Post et al 2014

ATS were detected near upstream spawning grounds in the fall. Most upstream movements began in August, however one fish began ascending the Savannah River in late May. ATS were detected near presumed spawning grounds in August and September at temperatures between 24-29°C. At the conclusion of the spawning event all ATS rapidly returned downstream and exited the system. Post et al 2014

Ogeechee River, GA
In an attempt to provide population estimates for the Ogeechee River Ferrae et. al. (2009) conducted a study in the tidally influenced portion of the river. Gill nets and trammel nets were set in the river 25-90 minutes per set. All Atlantic sturgeon captured were tagged and released, subsequent mark recapture data were analyzed using Huggins closed capture model to estimate abundance. In total 58 juvenile Atlantic sturgeon were collected, including 4 recaptures. Age samples from the collections confirmed age-1 fish were 242-361 mm TL and age-2 and age3 fish measure 606-1015 mm TL (Ferrae et al. 2009). According to Ferrae et al (2009) the most plausible model estimated abundance of juveniles at 450 individuals with a 95% confidence interval of 203-1125 individuals.

The Ogeechee River was also included in the 2011-2014 multi-state study (Post et al 2014). the multi state telemetry study conducted within the Ogeechee River detected Atlantic sturgeon tagged in Coastal Delaware, James River, VA, Cape Fear River, NC, Altamaha River, GA, Edisto, Combahee, Savannah rivers, SC, Long Island Sound, CT, and the NY/NJ Coast.

Altamaha River, GA
Juvenile Atlantic sturgeon were studied extensively during 1991-1994 by Rogers et al (1995). During this study over 2,000 juveniles were collected using trammel nets, 800 of which were nominally age-1.

The Altamaha River was also included in the 2011-2014 multi-state study (Post et al 2014). During three years of the study, 45 adult Atlantic sturgeon were captured and tagged with acoustic transmitters. Size of tagged fish ranged from 1,255 to 2,030 mm FL. Data from acoustic telemetry indicated that the tagged fish were present in the Altamaha River system from April–December. The maximum extent of upriver migrations was documented at RKM 408 on the Ocmulgee River and RKM 356 on the Oconee River (Post et al 2014). Post et al. (2014) described two different migratory patterns for fish in the Altamaha, those that were direct migrants to the spawning areas and those that staged in a location prior to final migration to spawning areas. The two step migrants began in April–May with fish remaining at mid-river locations during the summer months before continuing upstream in the fall. The late-year migrations initiated in August or September and were generally non-stop. All fish exhibited a one-step pattern of migrating downstream in December and early January as water temperatures reached their annual minimums. After leaving the Altamaha River in late winter, 15 (36%) of the tagged fish were subsequently documented in other river systems in Georgia, South Carolina, and Florida (Post el al 2014).

The potential spawning migrations documented in Post et al. (2014) showed that Atlantic sturgeon used approximately 74% of the river habitats available to them within the Altamaha System below the Fall Line, including the Ocmulgee and Oconee tributaries. No individuals migrated all the way to the Fall Line in either tributary. Additionally one individual fish migrated to RKM 408 in the Ocmulgee River, the longest documented migration of an Atlantic sturgeon within a U.S. spawning river. By comparison, adult spawning runs in the Hudson River only reach RKM 182 and spawning runs in the James River have been documented to reach RKM 155 (Van Eenennaam 1996, Balazik et al. 2012).

The presence of adult Atlantic sturgeon within the Altamaha, Oconee, and the Ocmulgee indicate that the estuarine and riverine habitats found within the Altamaha system were used for spawning runs during the late fall as water temperatures decline. Telemetry data indicated the Oconee was used to a lesser extent than the Ocmulgee.

Limited age and growth data are available for the Altamaha River basin from work conducted by Peterson et al. (2008) and Schueller and Peterson (2010). Peterson et al. (2008) aged Atlantic sturgeon collected during 2004 and 2005. These fish ranged in age from 4-14 years (mean 10 years) in 2004 and from 5-17 years (mean 10 years) from 2005. Schueller and Peterson (2010) identified distinct modal distributions of juveniles. Length frequency analysis combined with age data identified age- individuals with lengths ranging from 350-550 mm TL, age-2 individuals ranged from 550-800 mm TL, and age-3 individuals ranged from 800-1,050 mm TL. Schueller and Peterson (2010) did find slight variation in length at age during 2007 when the boundary between age-2 and age-3 fish was identified as 750 mm TL.

Estimates of mortality are available for the Altamaha River through work conducted by Perterson et al. (2008). Peterson et al. (2008) mean estimates of mortality for 2004 was 17.3% and 21.3% for 2005. Estimates of survival are available from three studies completed on the Altamaha River. Peterson et al. (2008) identified annual survival estimates of 0.79 – 0.83 through catch curve analysis for adult Atlantic sturgeon in the Altamaha. Schueller and Peterson (2010) estimated annual survival of Atlantic sturgeon males (0.66) and females (0.88), similar to Peterson et al. (2008). Estimated apparent annual survival of juvenile Atlantic sturgeon was low (0.03-.34) (Schueller and Peterson 2010). These low estimates of apparent survival are most likely attributed to emigration from the system and not true mortality. Hightower et al. (2016), through tagging returns conducted using acoustic telemetry obtained annual apparent survival estimates of 0.842 (95%CI 0.722 – 0.932) for the Altamaha River basin, a size effect (TL covariate) was not evident for the Altamaha River basin.

Schueller and Peterson (2010) also identified estimates of age-1recruitment. The estimates of recruitment ranged from 0.82 to 1.38, indicating recruitment that was slightly less than to more than the previous years' age-1 population. These estimates also indicated that recruitment was time varying and significantly influence by fall discharge with in the river system (Schueller 2010).

Schnabel adult population estimates for the Altamaha River were 324 individuals (CI 143-667) in 2004 and 386 (CI 216-787) in 2005 (Peterson 2008).

Satilla River

Rogers and Weber (1995) indicated that sampling in the Satilla River indicated a highly stressed Atlantic sturgeon population. However, Fritts et al. (2016) targeted Atlantic sturgeon within the Satilla River during 2008-2010. A total of 218 Atlantic sturgeon were captured including 22 in river recaptures. Like in the Ferrae (2009) study on the Ogeechee, fin rays were collected to verify age of Atlantic sturgeon collected during 2010. Results showed age-1 sturgeon were 340-540 mm Tl, similar to those found in the Altamaha River (Fritts et al 2016). After ages were assigned and models estimated an age-1 cohort of 154 fish, with a 95% confidence interval of 108-231 individuals (Fritts et al 2016). These results also indicate that spawning is likely occurring within the Satilla River, based on collections of age-0 and age-1 fish. Genetic collections indicated the juvenile fish collected most closely related populations from other South Atlantic DPS, however results could not positively identify if these fish were from Satilla ancestry (Fritts et. al. 2016). Interesting to note, Fritts et al. (2016) found a high prevalence of Haplotype D among genetic samples collected form the Satilla that proved the Satilla fish were genetically distinct from other collections coastwide based on genetic distance index analysis.

St. Marys River

Hamlen (1884) indicated abundances of Atlantic sturgeon in the St Marys river that were an impediment to the commercial shad fishery. Sampling conducted within the St Marys River yielded zero catch of Atlantic sturgeon (Rogers and Weber 1995).

Nassau River, FL

According to the 2013 Florida Draft Action Plan there has been one interaction with a sturgeon in the Nassau River during the last decade. However, one Atlantic sturgeon tagged within the Altamaha River, GA during a multi-state telemetry study was detected on an array in the Nassau River (Post et. al. 2014).

St. Johns River, FL

Information on Atlantic sturgeon in the St Johns River is lacking. Hamlen (1884) discussed abundances of Atlantic sturgeon in the St Johns River that were an impediment to the shad fishery. More recently, in the last decade there have been 3 reported recreationally caught Atlantic sturgeon from the St. Johns River. According to the 2016 ASMFC Florida Sturgeon

Compliance Report a single Atlantic sturgeon was collected in the St. Johns River, Fla in an experimental gill net. The fish measured 920 mm TL, was tagged, and a genetic sample collected.

Maturity

In the Altamaha River in Georgia, males begin to mature at age 5 and are fully mature by age 9 while females begin to mature at age 11 and are fully mature by age 13 (Peterson et al. 2008). Spawning migration begins in February in Florida and Georgia (Smith 1985).

2.6 APPENDIX B - Tables and Figures

Table 1. Incidence of age-0 Atlantic sturgeon (<50 cm FL) in Chesapeake Tributaries

Year	Number	Source
1972	3	James River, VIMS Trawl Survey
1975	1	James River, VIMS Trawl Survey
1978	2	James River, VIMS Trawl Survey
1979	1	James River, VIMS Trawl Survey
?		York River, VIMS Trawl Survey
2004	1	James River, VIMS Trawl Survey
2012	3	Pamunkey River, VIMS Trawl Survey
2015	2?	James River, power plant?
2016	1	James River, research gill nets (M. Balazik, VCU)

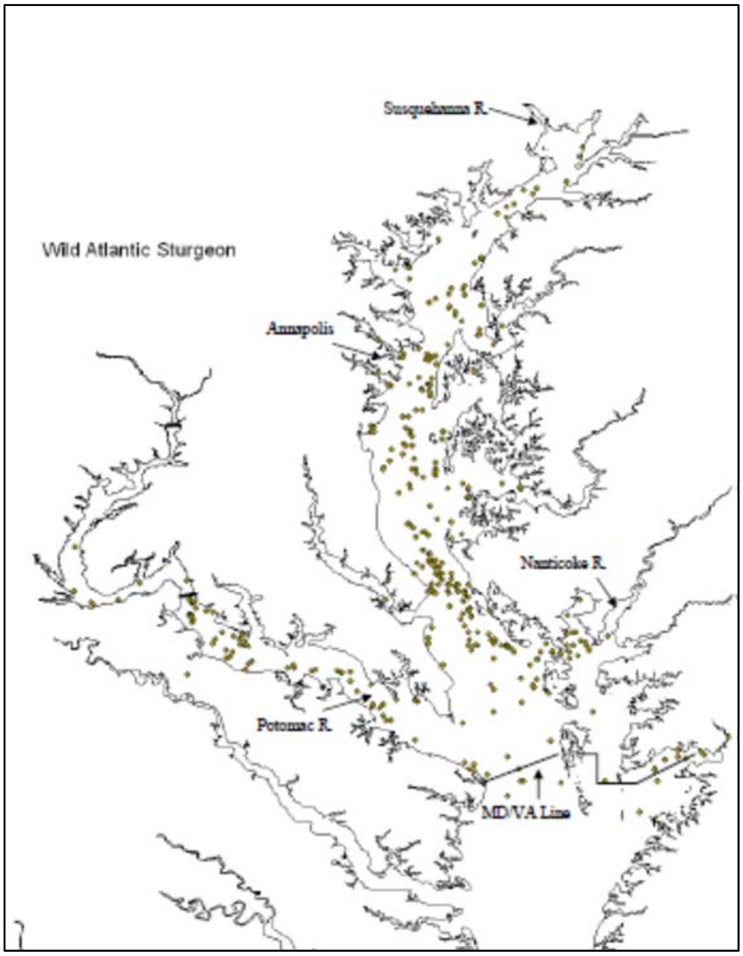


Figure 1. Map of sturgeon captures throughout the Chesapeake Bay during the period 1996-2010. Data from the USFWS Atlantic sturgeon reward program. Placeholder from Mangold et al. 2007. Revised figure will show entire Chesapeake with symbols indicating spawning sub-estuaries.

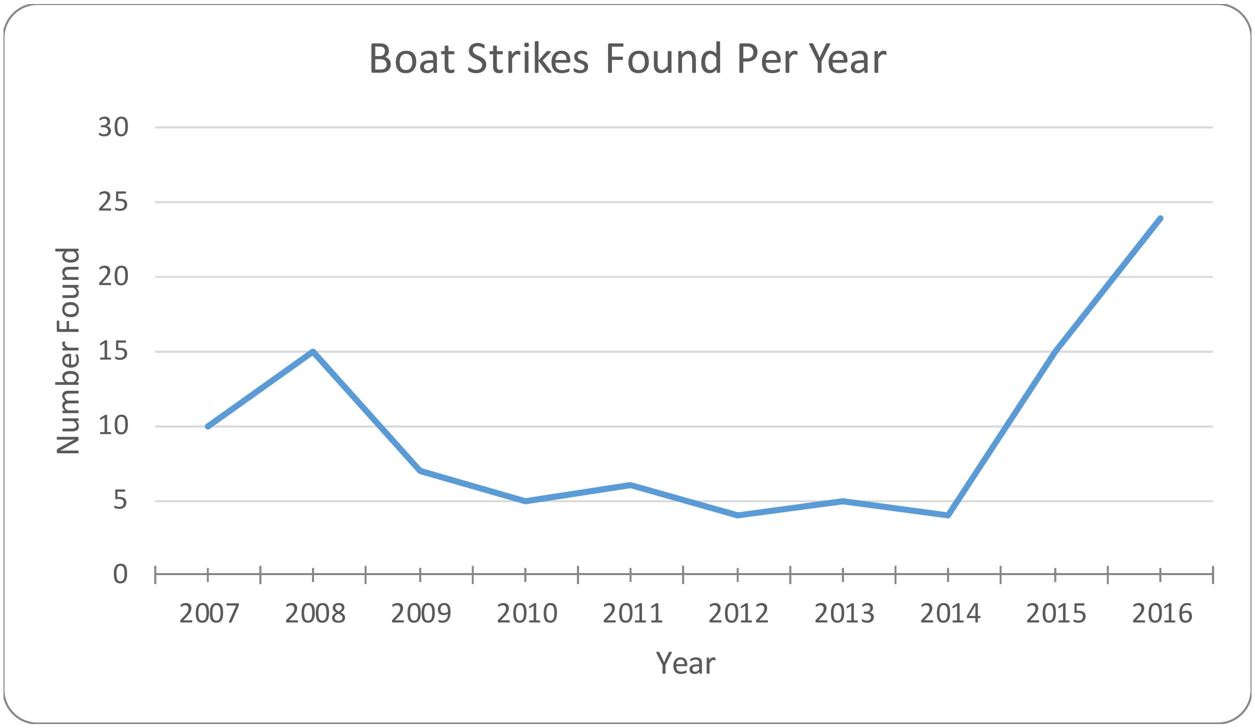


Figure 2. Annual vessel strike Atlantic sturgeon carcasses observed in the James River and its approaches. Data and graphic from M. Balazik, VCU.

2.7 APPENDIX B – Literature Cited

Gulf of Maine

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine, 53: 588. Washington, DC: US Government Printing Office.

Dadswell, M. J. 2006. A review of the status of Atlantic sturgeon in Canada, with comparisons to populations in the United States and Europe. Fisheries, 31(5): 218-229.

Fernandes, S. J., G. B. Zydlewski, J. D. Zydlewski, G. S. Wippelhauser, and M. T. Kinnison. 2010. Seasonal distribution and movements of shortnose sturgeon and Atlantic sturgeon in the Penobscot River estuary, Maine. Transactions of the American Fisheries Society, 139(5): 1436-1449.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology, 68(5): 1364-1372.

Hatin, D., R. Fortin, and F. Caron. 2002. Movements and aggregation areas of adult Atlantic sturgeon (Acipenser oxyrinchus) in the St Lawrence River estuary, Quebec, Canada. Journal of Applied Ichthyology, 18(4-6): 586-594.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin, 184. 966 pp.

New York Bight

ASA Analysis and Communication. 2012. 2012 Year Class Report for the Hudson River Estuary Monitoring Program. Prepared on behalf of Entergy Nuclear Indian Point 2 LLC. Entergy Nuclear Indian Point 3 LLC, Entergy Nuclear Operations Inc. and NRG Bowline LLC., NY.

ASA Analysis and Communication. 2013. 2013 Year Class Report for the Hudson River Estuary Monitoring Program. Prepared on behalf of Entergy Nuclear Indian Point 2 LLC. Entergy Nuclear Indian Point 3 LLC, Entergy Nuclear Operations Inc. and NRG Bowline LLC., NY.

Balazik M.T., Musick J.A. 2015. Dual Annual Spawning Races in Atlantic sturgeon. PLoS ONE 10(5): e0128234. doi:10.1371/journal.pone.0128234

Blevins, D.W. 2011. Water quality requirements, tolerances, and preferences of Pallid Sturgeon (Scaphirhynchus albus) in the Lower Missouri River, in cooperation with USACE. Scientific Investigations Report 2011-5186. http://pubs.usgs.gov/sir/2011/5186/pdf/sir2011-5186.pdf.

Borodin, N. 1925. Biological observations on the Atlantic sturgeon (Acipenser sturio). Transactions of the American Fisheries Society, 55(1): 184-190.

Brown, J. J., and G. W. Murphy. 2010. Atlantic sturgeon vessel-strike mortalities in the Delaware Estuary. Fisheries 35:72–83.

Collins, M.R., T.I.J. Smith, W.C. Post, and O. Pashuk. 2000. Habitat utilizations and biological characteristics of adult Atlantic sturgeon in two South Carolina Rivers. Transactions of the American Fisheries Society 129:982-988.

Damon-Randall, K., R. Bohl, S. Bolden, D. Fox, C. Hager, B. Hickson, E. Hilton, J. Mohler, E. Robbins, T. Savoy, and A. Spells. 2010. Atlantic sturgeon research techniques. NOAA Technical Memorandum NMFS-NE-215.

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115–143.

Dovel, W. L., and T. J. Berggren. 1983. Atlantic sturgeon of the Hudson estuary, New York. New York Fish and Game Journal, 30(2): 140-172.

Erickson, D.L., A. Kahnle, M.J. Millard, E.A. Mora, M. Bryja, A.Higgs, J. Mohler, M. Dufour G. Kenney, J. Sweka and E.K. Pikitch. 2011. Use of satellite archival tags to identify oceanic migratory patterns for adult Atlantic sturgeon *Acipenser oxyrinchus* Mithcell 1815. Journal of Applied Ichthyology 27 pgs 356-365.

Fisher, M. 2013. State of Delaware Annual Compliance Report for Atlantic sturgeon: Submitted to the Atlantic States Marine Fisheries Commission Atlantic sturgeon Plan Review Team.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology, 68(5): 1364-1372.

Hager, Christian, Jason Kahn, Carter Watterson, Jay Russo & Kyle Hartman (2014) Evidence of Atlantic sturgeon Spawning in the York River System, Transactions of the American Fisheries Society, 143:5, 1217-1219

Hale, E. A., Park, I.A., Fisher, M.T., Wong, R.A., Stangl, M.J. and J. F. Clark. 2016. Abundance Estimate for and Habitat Use by Early Juvenile Atlantic sturgeon within the Delaware River Estuary. Transactions of the American Fisheries Society 145 (6): 1193-1201.

Holmes, E. E., E. J. Ward, and M. D. Scheuerell. 2014. Analysis of multivariate time-series using the MARSS package, Version 3.9. NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112.

Ingram, E.C., D.L. Peterson. 2016. Annual Spawning Migrations of Adult Atlantic sturgeon in the Altamaha River, Georgia. Marine and Coastal Fisheries Dynamics Management and Ecosystem Science 8:595-606

McCord, J. W., M. R. Collins, W.C. Post, and T.I.J. Smith. 2007. Attempts to develop an index of abundance for age-1 Atlantic sturgeon in South Carolina, USA. Pages 397–403 in J. Munro, D. Hatin, J. E. Hightower, K. McKown, Kenneth J. Sulak, A.W. Kahnle, and F. Caron, editors. Anadromous sturgeons: habitats, threats, and management. American Fisheries Society, Symposium 56, Bethesda, Maryland.

Miller, Daniel E., 2013. *Hudson River Estuary Habitat Restoration Plan*. New York State Department of Environmental Conservation, Hudson River Estuary Program. http://www.dec.ny.gov/lands/5082.html

Moser, M.L., Bain, M., Collins, M.R., Haley, N., Kynard, B., O'Herron II, J.C., Rogers, G., Squiers, T.S. 2000. A protocol for use of shortnose and Atlantic sturgeons. NOAA Technical Memorandum NMFS-OPR-18. http://www.nmfs.noaa.gov/pr/pdfs/species/Sturgeon_protocols.pdf

Murawski, S.A., and A. L. Pacheco. 1977. Biological and fisheries data on Atlantic sturgeon, Acipenser oxyrhynchus (Mitchill). National Marine Fisheries Service, Northeast Fisheries Center, Sandy Hook Laboratory, Technical Series Report 10, Highlands, New Jersey.

Post, W. C., T. Darden, D. L. Peterson, M. Loeffler, and C. Collier. 2014. Research and management of endangered and threatened species in the southeast: riverine movements of Shortnose and Atlantic sturgeon. South Carolina Department of Natural Resources, Project NAIONMF4720036, Final Report, Charleston.

Ryder, J.A. 1890. The Sturgeon and sturgeon industries of the eastern coast of the United States, with an account of experiments bearing upon sturgeon culture. Bulletin of the U.S. Fish Commission (1888) 8: 231-328.

Secor, D. H. 2002. Atlantic sturgeon fisheries and stock abundances during the late nineteenth century. American Fisheries Society Symposium 28: 89-98.

Simpson, P.C. 2008. Movements and habitat use of Delaware River Atlantic sturgeon. Masters Thesis. Delaware State University, Dover, Delaware. 137pp.

Simpson, P. C., and D. A. Fox. 2009. Contemporary understanding of the Delaware River Atlantic sturgeon: survival in a highly impacted aquatic ecosystem. Pages 867–870 in A. J. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

Smith, J.A., Flowers H.J., Hightower J.E. 2015. Fall spawning of Atlantic sturgeon in the Roanoke River, North Carolina. Transactions of the American Fisheries Society 144:48–54

Stanne, S.P., Panetta, R.G., Forist, B. E. 2007. The Hudson, An Illustrated Guide to the Living River, Second Edition. Hudson River Sloop Clearwater.

Taunton River Journal. 2006. Historical review of Taunton River water quality issues related to American shad. http://www.glooskapandthefrog.org/A%20Shad.htm

Wirgin, I., Breece, M.W., Fox, D. A., Maceda, L, Wark, K.W. & T. King (2015) Origin of Atlantic sturgeon Collected off the Delaware Coast during Spring Months, North American Journal of Fisheries Management, 35:1, 20-30.

Van Eenennaam, J. P., and S. I. Doroshov. 1998. Effects of age and body size on gonadal development of Atlantic sturgeon. Journal of Fish Biology, 53(3): 624-637.

Van Eenennaam, J. P., S. I. Doroshov, G. P. Moberg, J. G. Watson, D. S. Moore, and J. Linares. 1996. Reproductive conditions of the Atlantic sturgeon (Acipenser oxyrinchus) in the Hudson River. Estuaries, 19(4): 769-777.

Chesapeake Bay

Aguilar, R., M. Ogburn, A.C. Driskell, L.A. Weigt, M.C. Groves, and A.H. Hines. 2016. Gutsy genetics: identification of digested piscine prey items in the stomach contents of sympatric native and introduced warmwater catfishes via DNA barcoding. Environmental Biology of Fishes 100(4):325-336.

Atlantic States Marine Fisheries Commission (ASMFC), 1998. Amendment 1 to the Interstate Fisheries Management Plan for Atlantic sturgeon. Fisheries Management Plan Report Number 31 of the ASMFC, July 1998, pp. 1–42

ASMFC. 2007. Estimation of Atlantic sturgeon bycatch in coastal Atlantic commercial fisheries of New England and the Mid-Atlantic. Special Report to the ASMFC Atlantic sturgeon Management Board, August 2007, pp. 1–95.

ASMFC. 2012. Habitat addendum IV to Amendment 1 to the Interstate Fishery Management Plan for Atlantic sturgeon, September 2012, Arlington, VA, USA, pp. 1–15.

Atlantic Sturgeon Status Review Team (ASSRT), 2007. Status review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Prepared by the ASSRT for the National Marine Fisheries Service, National Oceanic and Atmospheric Administration Report, July 27, 2007, pp. 1–174.

Bain, M. B., Haley, N., Peterson, D.L., Arend, K., Mills, K.E., Sullivan, P. J. 2007. Recovery of a US Endangered Fish. PloS One January 2007:1-9.

Balazik, M. 2017. First verified occurrence of the shortnose sturgeon (*Acipenser brevirostrum*) in the James River, Virginia. Fishery Bulletin 115(2):196-200.

Balazik, M. T.; Musick, J. A., 2015. Dual spawning races in Atlantic sturgeon. PLoS One 10, e0128234.

Balazik, M. T.; Garman, G. C.; Fine, M. L.; Hager, C. H.; McIninch, S. P., 2010. Changes in age composition and growth characteristics of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) over 400 years. Biol. Lett. 6, 708–710.

Balazik, M. T., K. J. Reine, A. J. Spells, C. A. Fredrickson, M. L. Fine, G.C. Garman, and S. P. McIninch. 2012. The potential for vessel interactions with adult Atlantic sturgeon in the James River, Virginia. North American Journal of Fisheries Management 32.

Balazik, M. T.; McIninch, S. P.; Garman, G. C.; Latour, R. J., 2012a. Age and growth of Atlantic sturgeon in the James River, Virginia. Trans. Am. Fish. Soc. 140, 1074–1080.

Balazik, M. T.; Garman, G. C.; Van Eenennaam, J. C.; Mohler, J.; Woods, L. C., III, 2012b. Empirical evidence of fall spawning by Atlantic sturgeon in the James River, Virginia, USA. Trans. Am. Fish. Soc. 141, 1465–1471.

Bruce, D., J. Lazar, and A. McGowan. Atlantic sturgeon riverbed habitat mapping in Broad Creek, Marshyhope Cree, and the Nanticoke River. Project Report. NOAA Chesapeake Bay Office. 20 p.

Chesapeake Bay Program (CBP) 2003. Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tributaries. 343 p.

Cobb, J. N., 1900. The sturgeon fishery of the Delaware River and Bay. Rep. U. S. Commission Fish Fisheries 25, 369–381.

Dadswell, M. J., B. D. Taubert, T. S. Squiers, D. Marchette and J. Buckley.1984. Synopsis of biological data on shortnose sturgeon, *Acipenser brevirostrum* LeSueur 1818. NOAA Tech Rep.NMFS14, 45 p.

Damon-Randall, K.; Bohl, R.; Bolden, S.; Fox, D.; Hager, C.; Hickson, B.; Hilton, E.; Mohler, M.; Robbins, E.; Savoy, T.; Spells, A., 2010. Atlantic sturgeon research techniques. NOAA Technical Memorandum NMFS-NE-215, pp. 1–64.

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115–143.

Federal Register, 2012b. Endangered and threatened wildlife and plants; final listing determinations for two distinct population segments of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the Southeast. Fed. Reg. 77, 5914–5982.

Flowers, H. J.; Bonvechio, T. F.; Peterson, D. L., 2011. Observation of Atlantic sturgeon predation by a flathead catfish. Trans. Am. Fish. Soc. 140, 250–252.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology, 68(5): 1364-1372.

Hager, C.; Kahn, J.; Watterson, C.; Russo, J.; Hartman, K., 2014. Evidence of Atlantic sturgeon spawning in the York River system. Trans. Am. Fish. Soc. 143, 1217–1219.

Hildebrand, S. F.; Schroeder, W. C., 1927. Fishes of Chesapeake Bay. Bull. U. S. Bur. Fish. 43, 1–388.

Hilton, E.J., B. Kynard, M.T. Balazik, A.Z. Horodysky, and C.B. Dillman. 2016. Review of the biology, fisheries, and conservation status of the Atlantic sturgeon, (*Acipenser oxyrinchus* Mitcheill, 1815). J. Appl. Icthyol. 32 (Suppl. 1): 30-66.

Holmes, E. E., E. J. Ward, and M. D. Scheuerell. 2014. Analysis of multivariate time-series using the MARSS package, Version 3.9. NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112.

Horton, T. 1994. Chessi & Co.: We miss the big guys when they go. Baltimore Sun. Oct. 1.

Johnson, J. H.; Dropin, D. S.; Warkentine, B. E.; Rachlin, J. W.; Andrews, W. D., 1997. Food habits of Atlantic sturgeon off central New Jersey coast. Trans. Am. Fish. Soc. 126, 166–170.

Kahn, J.; Mohead, M. 2010. A protocol for use of shortnose, Atlantic, Gulf and green sturgeons. NOAA Tech. Memo. No. NMFS-OPR-45. March 2010, 62 pp.

Kahn, J. E.; Hager, C.; Watterson, J. C.; Russo, J.; Moore, K.; Hartman, K., 2014. Atlantic sturgeon annual spawning run estimate in the Pamunkey River, Virginia. Trans. Am. Fish. Soc. 143, 1508–1514.

Kynard, B., and M. Horgan. 2002. Ontogenetic behavior and migration of Atlantic sturgeon, *Acipenser oxyrinchus* oxyrinchus, and shortnose sturgeon, *A. brevirostrum*, with notes on social behavior. Environmental Biology of Fishes 63(2):137-150.

Mangold, M., S. Eyler, S. Minkkinen, B. Richardson. 2007. Atlantic sturgeon reward program for Maryland waters of the Chesapeake Bay and tributaries 1996-2006. USFWS, Annapolis. 26 p.

Musick, J.A. 2005. Essential Fish Habitat of Atlantic sturgeon *Acipenser oxyrinchus* in the Southern Chesapeake Bay. Virginia Institute of Marine Science Scientific Report #145. 48 p.

Najjar, R., C.R. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M.R. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2010. Potential climate-change impacts on the Chesapeake Bay. Estuarine, Coastal and Shelf Science 86: 1-20.

Niklitschek, E.; Secor, D. H., 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay. Estuary. Coast. Shelf Sci. 64, 135–148.

Niklitschek, E.; Secor, D. H., 2009a. Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters. I. Laboratory results. J. Exp. Mar. Biol. Ecol. 381, S150–S160.

Niklitschek, E.; Secor, D. H., 2009b. Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters. II. Model development and testing. J. Exp. Mar. Biol. Ecol. 381, S161–S172.

Niklitschek, E.; Secor, D. H., 2010. Experimental and field evidence of behavioral habitat selection by juvenile Atlantic *Acipenser oxyrinchus oxyrinchus* and shortnose *Acipenser brevirostrum* sturgeons. J. Fish Biol. 77, 1293–1308.

Peterson, D. L.; Schueller, P.; De Vries, R.; Fleming, J.; Gunwald, C.; Wirgin, I., 2008. Annual run size and genetic characteristics of Atlantic sturgeon in the Altamaha River, Georgia. Trans. Am. Fish. Soc. 137, 393–401.

Ricker, W. E. 1958. Maximum sustained yields from fluctuating environments and mixed stocks. Journal of the Fisheries Research Board of Canada 15(5):991-1006.

Robson, D. S., and H. A. Regier. 1964. Sample size in Petersen mark–recapture experiments. Transactions of the American Fisheries Society 93:215–226.

Schlenger, A.J., E. North, Y. Li, K.A. Smith, and D.H. Secor. 2013. Modeling the influence of hypoxia on the potential habitat of Atlantic sturgeon (*Acipenser oxyrinchus*): a comparison of two methods. Marine Ecology Progress Series 483: 257-272.

Schloesser, R. W. Fabrizio, M. C., Latour, R. J., Garman, G. C., Greenlee, B., Groves, M., Gartland, J. 2011. Ecological Role of Blue Catfish in Chesapeake Bay Communities and Implications for Management. Pages 369-382 *in* P. H. Michaletz, and V. H. Travnichek, editors. Conservation, Ecology, and Management of Catfish: The Second International Symposium, 2010, volume 77.

Secor, D.H. 2014. The Unit Stock Concept: Bounded Fish and Fisheries. In S. Cadrin, L. Kerr, and S. Mariani (eds) Stock Identification Methods. Elsevier Press.

Secor, D. H. 2002. Atlantic sturgeon fisheries and stock abundances during the late 19th century. Pages 89–98 in W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Secor, D. 1996. Chesapeake Bay Atlantic sturgeon: current status and future recovery. Chesapeake Biological Laboratory, Solomons, Maryland.

Secor, D. H.; Gunderson, T. E., 1998. Effects of hypoxia and temperature on survival, growth, and respiration of juvenile Atlantic sturgeon *Acipenser oxyrinchus*. Fish. Bull. 96, 603–613.

Secor, D. H.; Niklitschek, E. J.; Stevenson, J. T.; Gunderson, T. E.; Minkkinen, S. P.; Richardson, B.; Florence, B.; Mangold, M.; Skjeveland, J.; Henderson-Arzapalo, A., 2000. Dispersal and growth of yearling Atlantic sturgeon, *Acipenser oxyrinchus*, released into Chesapeake Bay. Fish. Bull. 98, 800–810.

Smith, J. A.; Flowers, H. J.; Hightower, J. E., 2015. Fall spawning of Atlantic sturgeon in the Roanoke River, North Carolina. Trans. Am. Fish. Soc. 144, 48–54.

Speir, H., and T. O'Connell. 1996. Status of Atlantic sturgeon in Maryland's Chesapeake Bay watershed. Maryland Department of Natural Resources, Technical Report 17, Annapolis.

Van Eenennaam, J. P.; Doroshov, S. I., 1998. Effects of age and body size on gonadal development of Atlantic sturgeon. J. Fish Biol. 53, 624–637.

Sulak, K. J., and M. Randall. 2002. Understanding sturgeon life history: enigmas, myths, and insights from scientific studies. Journal of Applied Ichthyology 18:519–528.

Tower, W. S. 1908. The passing of the sturgeon: a case of unparalleled extermination of a species. Popular Science Monthly October:361-371.

Welsh, S. A.; Eyler, S. M.; Mangold, M. F.; Spells, A. J., 2002. Capture locations and growth rates of Atlantic sturgeon in the Chesapeake Bay. Am. Fish. Soc. Symp. 28, 183–194.

Wharton, J. 1957. The Bounty of the Chesapeake, Fishing in Colonial Virginia. Univ. Press, Virginia, Charlottesville.

Wirgin, I., C. Grunwald, J. Stabile, and J. R. Waldman. 2010. Delineation of discrete population segments of shortnose sturgeon Acipenser brevirostrum based on mitochondrial DNA control region sequence analysis. Conservation Genetics 11(3):689-708.

Carolinas

Armstrong, J. L. 1999. Movement, Habitat Selection and Growth of Early-Juvenile Atlantic sturgeon in the Albemarle Sound, North Carolina. Masters Thesis, North Carolina State University, Raleigh, NC.

Armstrong, J. L., J. E. Hightower. 2002. Potential for Restoration of the Roanoke River Population of Atlantic sturgeon. J. Appl. Ichthyol. 18, 475-480.

ASMFC. 1998. Atlantic sturgeon stock assessment. ASMFC Peer Review Report. ASMFC, Washington, D.C., March 1998.

ASMFC. Stock Assessment Report No. 12-02 of the Atlantic States Marine Fisheries Commission, River Herring Benchmark Stock Assessment. 342 pp.

ASMFC. 2013. Atlantic States Marine Fisheries Commission, 2013 Horseshoe Crab Stock Assessment Update. 68 pp.

ASMFC. 2016. Atlantic States Marine Fisheries Commission, Atlantic Striped Bass Stock Assessment Update. 100 pp.

Beardsall, J.W., M.F. McLean, S.J. Cooke, B.C. Wilson, M.J. Dadswell, A.M. Redden & M.J.W. Stokesbury (2013) Consequences of Incidental Otter Trawl Capture on Survival and Physiological Condition of Threatened Atlantic sturgeon, Transactions of the American Fisheries Society, 142:5, 1202-1214.

Box, G. E. P. and G. M. Jenkins. 1976. Time series analysis: forecasting and control, revised Ed. Holden-Day Oakland, CA 375 pp.

Bulak, J. S. and T. A. Curtis. 1977. Santee-Cooper rediversion project. South Carolina Wildlife and Marine Resources Department, Columbia, SC, USA. SCR1-1.

Brook, B. W., J. J. O'Grady, A.P. Chapman, M. A. Burgman, H. R. Akçakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. Nature, 404(6776): 385-387.

Carnes, W. C., 1965: Appendices to the survey and classification of the Roanoke River and tributaries, North Carolina. North Carolina Wildl. Res. Comm. Final Rep., Federal Aid in Fish Restoration, Job I-Q, Proj. F-14-R.

Collins, M.R., S.G. Rogers & T.I.J. Smith (1996) Bycatch of Sturgeons along the Southern Atlantic Coast of the USA, North American Journal of Fisheries Management, 16:1, 24-29.

Collins, M.R., and T.I.J. Smith. 1997. Distribution of shortnose and Atlantic sturgeons in South Carolina. North American Journal of Fisheries Management 17:995-1000.

Collins, M. R., T. I. Smith, W. C. Post, and O. Pashuk. 2000. Habitat utilization and biological characteristics of adult Atlantic sturgeon in two South Carolina rivers. Transactions of the American Fisheries Society, 129(4): 982-988.

Conn, P. B. 2010. Hierarchical analysis of multiple noisy abundance indices. Canadian Journal of Fisheries and Aquatic Sciences, 67(1): 108-120.

Conrads, P.A., and Roehl, E.A. 1999, Comparing Physics-Based and Neural Network Models for Predicting Salinity, Water Temperature, and Dissolved-Oxygen Concentration in a complex Tidally Affected River Basin, South Carolina Environmental Conference, Myrtle Beach, March 15-16.

Cooke, D. W., S. D. Leach, and J. J. Isely. 2002. Behavior and lack of upstream passage of shortnose sturgeon at a hydroelectric facility and navigation lock complex. Pp 101–110. *In*

Van Winkle, W., P. J. Anders, D. H. Secor, and D. A. Dixon, editors. (Eds.). American Fisheries Society Symposium 28. Oshkosh, WI.

Copeland, B. J. and J. Gray. 1991. Status and Trends of the Albemarle-Pamlico Estuaries, Albemarle-Pamlico Estuarine Study Report 90-01 (Department of Environment, Health and Natural Resources, Raleigh, NC).

COSEWIC. 2011. COSEWIC assessment and status report on the Atlantic sturgeon Acipenser oxyrinchus in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 49 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Coulson, T., G. M. Mace, E. Hudson, and H. Possingham. 2001. The use and abuse of population viability analysis. Trends in Ecology & Evolution, 16(5): 219-221.

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115–143.

Duncan, M.S., J.J. Isely, and D.W. Cooke. 2004. Evaluation of shortnose sturgeon spawning in the Pinopolis Dam Tailrace, South Carolina. North American Journal of Fisheries Management 24:932-938.

Ellner, S. P., J. Fieberg, D. Ludwig, and C. Wilcox. 2002. Precision of population viability analysis. Conservation Biology, 16(1): 258-261

Endangered and Threatened Wildlife and Plants; Final Listing Determinations for Two Distinct Population Segments of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the Southeast. February 6, 2012. Federal Register Vol. 77, No. 24.

Flowers, H. J., T. F. Bonvechio, D. L. Peterson. 2011. Observation of Atlantic sturgeon Predation by a Flathead Catfish, Transactions of the American Fisheries Society, 140: 2, 250 — 252.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology, 68(5): 1364-1372.

Gibbons, J. and W.C. Post. 2009. Inter-basin transfer, migration, and habitat use by shortnose sturgeon in the lower Santee River and Winyah Bay System, South Carolina. Final Report to NMFS #NA06NMF4720044. 49pp.

Hawkins, J. H. 1980. Investigations of anadromous fishes of the Neuse River, North Carolina. DMF, Morehead City, NC, Special Science Report No. 34, 111p.

Helser, T. E. and D. B, Hayes. 1995. Providing quantitative management advice from stock abundance indices based on research surveys. Fishery Bulletin 93:290-298.

Hightower, J. E., and K. L. Sparks. 2003. Migration and spawning habitat of American shad in the Roanoke River, North Carolina. Pages 193 –199 in K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world’s shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6:65-70.

Holmes, E. E., E. J. Ward, and M. D. Scheuerell. 2014. Analysis of multivariate time-series using the MARSS package, Version 3.9. NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112.

Hughes, W.B. 1994. National water quality assessment program – the Santee Basin and coastal drainage, NC and SC. USGS, Rep. No. FS94-010.

Jager, H. I., M. S. Bevelhimer, and D. L. Peterson. 2011. Population viability analysis of the endangered Shortnose Sturgeon (No. ORNL/TM-2011/48). OAK RIDGE NATIONAL LAB TN ENVIRONMENTAL SCIENCES DIV.

Johnson, H.B., S.E. Winslow, D.W. Crocker, B,F, Holland, Jr. J.W. Gillikin, and D.L. Taylor and J.G. Loesch, W.H. Kriete, Jr. J.G. Travelstead, E.J. Foell and M.A. Hennigar. 1981. Biology and management of mid-Atlantic anadromous fishes under extended jurisdiction. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries and Virginia Institute of Marine Science, Spec. Sci. Rep. No. 36, 204 p

Kocik, J., C. Lipsky, T. Miller, P. Rago, and G. Shepherd. 2013. An Atlantic sturgeon population index for ESA management analysis. US Dept Commer, Northeast Fish Sci Cent Ref Doc, 13-06.

Leland, J. G., III. 1968. A survey of the sturgeon fishery of South Carolina. Contributed by Bears Bluff Labs. No. 47: 27 pp.

Mathews, Thomas D. et al. 1980 Ecological Characterization of the Sea Island Coastal Region of South Carolina and Georgia, vol. 1. Office of Biological Services, Fish and Wildlife Service, Washington D.C

McMahon, G., and Lloyd, O.B., Jr., 1995, Water-quality assessment of the Albemarle-Pamlico Drainage Basin, North Carolina and Virginia--Environmental setting and water-quality issues: U.S. Geological Survey Open-File Report 95-136, 72 p.

Moser, M. L., S. W. Ross. 1995. Habitat Use and Movements of Shortnose and Atlantic sturgeons in the Lower Cape Fear River, North Carolina. Tans of Am Fish Soc., 124:225-234.

Moyer, G. R., J. A. Sweka and D. L. Peterson. 2012. Past and present processes influencing genetic diversity and effective population size in a natural population of Atlantic sturgeon. Transactions of the American Fisheries Society, 141(1): 56-67.

Nantel, P. 2010. A Bayesian belief network for assessing species status under uncertainty. Available from Patrick Nantel, Parks Canada, Ottawa, Ontario.

North Carolina Division of Marine Fisheries (NCDMF). 2007. Assessment of Fish Populations in the Lower Cape Fear River, 2002-2007. N.C. Department of Environment and Natural Resources, Division of Marine Fisheries, Raleigh, NC.

North Carolina Division of Water Quality (NCDWQ). 1996. Cape Fear River basin-wide water quality plan. N.C. Department of Environment and Natural Resources, Division of Water Quality, Raleigh, NC

NCDWQ. 1997. White Oak River basin wide water quality plan. N.C. Department of Environment and Natural Resources, Division of Water Quality, Raleigh, NC.

NCDWQ. 1999. Tar-Pamlico River Basin wide Water Quality Plan. N.C. Department of Environment and Natural Resources, Raleigh, NC.

NCDWQ. 2001. Roanoke River basin wide water quality plan. N.C. Department of Environment and Natural Resources, Division of Water Quality, Raleigh, NC.

NCDWQ. 1997. White Oak River Basin wide Water Quality Management Plan. Prepared by the North Carolina Division of Water Quality Water Quality Section, Raleigh, North Carolina. 369 pages.

Northeast Fisheries Science Center (NEFSC). 2013. 57th Northeast Regional Stock Assessment Workshop (57th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 13-16; 967 p. https://www.nefsc.noaa.gov/nefsc/saw/

Nelson, G. A. 2017. fishmethods: Fishery Science Methods and Models in R. R package version 1.10-1. https://CRAN.R-project.org/package=fishmethods

National Marine Fisheries Services (NMFS) Atlantic sturgeon Status Review Team. 2007. Status Review of Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus). Report to National Marine Fisheries Service, Northeast Regional Office. February 23, 2007. 174 pp.

National Oceanic and Atmospheric Administration (NOAA). 2012a. Endangered and threatened wildlife and plants; final listing determination for two distinct population segments of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the Southeast. Federal Register 77:24(6 February 2012):5914-5982. Available: http://www.nmfs.noaa.gov/pr/pdfs/fr/fr77-5914.pdf. (August 2014).

NOAA. 2014. Environmental Assessment on the Effects of Issuing an Incidental Take Permit (No. 18102) to the North Carolina Division of Marine Fisheries for Incidental Take of Atlantic sturgeon Distinct Population Segments in the North Carolina Inshore Gill Net Fishery. NOAA Silver Spring, MD.

Oregon Department of Fish and Wildlife (ODFW). 2011. Lower Columbia River and Oregon Coast White Sturgeon Conservation Plan. Technical Report. Clackamas, Oregon. http://www.dfw.state.or.us/fish/crp/docs/lower_columbia_sturgeon/LCR_white_sturgeon_conservation_plan.pdf

Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fishery Bulletin 84(3):519-525.

Post, W. C., T. Darden, D. L. Peterson, M. Loeffler, and C. Collier. 2014. Research and management of endangered and threatened species in the southeast: riverine movements of Shortnose and Atlantic sturgeon. South Carolina Department of Natural Resources, Project NAIONMF4720036, Final Report, Charleston.

R Core Team (RCT). 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

SCDHEC. Waterswheds: Santatee River Basin - Ashley/Cooper Rivers. http://www.scdhec.gov/environment/water/shed/acooper.htm (July 11, 2012).

South Carolina Department of Natural Resources (SCDNR). 2003. Ashley Scenic River Management Plan. Prepared by the Ashley Scenic River Advisory Council in partnership with S. C. Dept. of Natural Resources. Report 25. 81 pages.

Schertzer, K. W., M. H. Prager, and E. H. Williams. 2008. A probability-based approach to setting annual catch levels. Fisheries Bulletin 106:225-232.

Schueller, P., and D. L. Peterson. 2010. Abundance and recruitment of juvenile Atlantic sturgeon in the Altamaha River, Georgia. Transactions of the American Fisheries Society, 139(5): 1526-1535.

Smith, J.A., H.J. Flowers, and J.E. Hightower. 2015. Fall spawning of Atlantic sturgeon in the Roanoke River, North Carolina. Transactions of the American Fisheries Society 144:48-54.

Smith, T. L. J., D. E. Marchette, G. F. Ulrich. 1984. The Atlantic sturgeon Fishery in South Carolina, North American Journal of Fisheries Management, 4:2, 164-176.

Smith, T.I.J., 1985. The fishery, biology, and management of Atlantic sturgeon, *Acipenser oxyrynchus*, in North America. Environmental Biology of Fishes 14: 61-72.

Smith, T. I. 1985. The fishery, biology, and management of Atlantic sturgeon, *Acipenser oxyrhynchus*, in North America. Environmental Biology of Fishes, 14(1): 61-72.

Smith, T. I. J., D. E. Marchette, and R. A. Smiley. 1982. Life history, ecology, culture and management of Atlantic sturgeon, *Acipenser oxyrhynchus oxyrhynchus*, Mitchill. South Carolina. South Carolina Wildlife Marine Resources. Resources Department, Final Report to US Fish and Wildlife Service Project AFS-9, 75.

Street, M. W., P.P. Pate, B.F. Holland Jr., and A.B. Powell. 1975. Anadromous Fisheries Research Program, Northern Coastal Region. NC Division of Marine Fisheries, AFCS-8, 262p.

Walburg, C.H. and P.R. Nichols. 1967. Biology and management of the American shad and status of fisheries, Atlantic coast of the United States, 1960. USFWS Special Report – Fish 550. Washington, DC. 105 pp.

Wirgin, L.M., C. Grunwald & T.L. King (2015) Population Origin of Atlantic sturgeon, *Acipenser oxyrinchus,* by-catch in U.S. Atlantic Coast fisheries. Journal of Fish Biology 86:4.

Winslow, S. E., N. S. Sanderlin, G. W. Judy, J. H. Hawkins, B. F. Holland Jr., C. A. Fischer, and R. A. Rulifson. 1983. North Carolina anadromous fisheries management program. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Anadromous Fish Conservation Act, Completion Report AFCS-16, Morehead City.

Winslow, S.E., S.C. Mozley, and R.A. Rulifson. 1985. North Carolina anadromous fisheries management program. Compliance Report. AFCS-22, North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, 207 p.

Worth, S. G., 1904: Report on operations with the striped bass at the Weldon North Carolina sub-station in May 1904. US. Dept. Commerce and Labor, Bureau of Fisheries, Beaufort, NC.

Yarrow, H. C., 1874: Report of a reconnaissance of the shad-rivers south of the Potomac. Report of the Commissioner for 1872 and 1873, part 2.

South Atlantic

ASMFC. 2012. Stock Assessment Report No. 12-02 of the Atlantic States Marine Fisheries Commission, River Herring Benchmark Stock Assessment. 342 pp.

ASMFC. 2013. Atlantic States Marine Fisheries Commission, 2013 Horseshoe Crab Stock Assessment Update. 68 pp.

ASMFC. 2016. Atlantic States Marine Fisheries Commission, Atlantic Striped Bass Stock Assessment Update. 100 pp.

Balazik, M. T., G. C. Garman, J. P. Eenennaam, J. Mohler, and L. C. Woods III. 2012. Empirical evidence of fall spawning by Atlantic sturgeon in the James River, Virginia. Transactions of the American Fisheries Society 141:1465–1471.

Box, G. E. P. and G. M. Jenkins. 1976. Time series analysis: forecasting and control, revised Ed. Holden-Day Oakland, CA 375 pp.

Brook, B. W., J. J. O'Grady, A.P. Chapman, M. A. Burgman, H. R. Akçakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. Nature, 404(6776): 385-387.

Collins, M.R., T. I. J. Smith, W.C. Post & O. Pashuk (2000) Habitat Utilization and Biological Characteristics of Adult Atlantic sturgeon in Two South Carolina Rivers, Transactions of the American Fisheries Society, 129:4, 982-988.

Collins, M.R., S.G. Rogers, T. I. J. Smith & M.L. Moser (2000) Primary Factors Affecting Sturgeon Populations in the Southeastern United States: Fishing Mortality and Degradation of Essential Habitats. BULLETIN OF MARINE SCIENCE, 66(3): 917–928.

Conn, P. B. 2010. Hierarchical analysis of multiple noisy abundance indices. Canadian Journal of Fisheries and Aquatic Sciences, 67(1): 108-120.

COSEWIC. 2011. COSEWIC assessment and status report on the Atlantic sturgeon Acipenser oxyrinchus in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 49 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Coulson, T., G. M. Mace, E. Hudson, and H. Possingham. 2001. The use and abuse of population viability analysis. Trends in Ecology & Evolution, 16(5): 219-221.

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115–143.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Science 266:753–762.

Ellner, S. P., J. Fieberg, D. Ludwig, and C. Wilcox. 2002. Precision of population viability analysis. Conservation Biology, 16(1): 258-261

Farrae, D. J., P. M. Schueller, D. L. Peterson. 2009. Abundance of Juvenile Atlantic sturgeon in the Ogeechee River, Georgia. Proc. Annu. Conf. SEAFWA.

Florida Fish and Wild Life Conservation Commission (FFWCC). 2016. State of Florida Annual Compliance Report for Atlantic sturgeon. Division of Habitat and Species Conservation. Florida Fish and Wild Life Conservation Commission, Tallahassee, Fla.

Fleming, J. E., T. D. Bryce, and J. P. Kirk. 2003. Age, growth, and status of shortnose sturgeon in the lower Ogeechee River, Georgia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 57:80–91.

Flowers, H.J. & J.E. Hightower (2015) Estimating Sturgeon Abundance in the Carolinas Using Side-Scan Sonar, Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 7:1, 1-9.

Flournoy, P. H., S. G. Rogers, and P. S. Crawford. 1992. Restoration of Shortnose Sturgeon in the Altamaha River, Georgia. Final Report to the U.S. Fish and Wildlife Service, Atlanta, Georgia.

Fritts, M.W., C. Grunwald, I. Wirgin, T. L. King & D.L. Peterson (2016) Status and Genetic Character of Atlantic sturgeon in the Satilla River, Georgia, Transactions of the American Fisheries Society, 145:1, 69-82.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology, 68(5): 1364-1372.

Hamlen, Wm. 1884. 109. Reconnaissance of the Florida Rivers with a View to Shad Hatching. Bulletin of the United States Fish Commission. Washington, DC.

Hightower, J.E., M. Loeffler, W.C. Post & D.L. Peterson (2015) Estimated Survival of Subadult and Adult Atlantic sturgeon in Four River Basins in the Southeastern United States, Marine and Coastal Fisheries, 7:1, 514-522

Heidt, A. R., and R. J. Gilbert. 1978. The shortnose sturgeon in the Altamaha River drainage, Georgia. Pages 54–60 in R. R. Odum and L. Landers, editors. Proceedings of the rare and endangered wildlife symposium. Georgia Department of Natural Resources, Game and Fish Division, Technical Bulletin of Wildlife 4, Athens.

Helser, T. E. and D. B, Hayes. 1995. Providing quantitative management advice from stock abundance indices based on research surveys. Fishery Bulletin 93:290-298.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6:65-70.

Holmes, E. E., E. J. Ward, and M. D. Scheuerell. 2014. Analysis of multivariate time-series using the MARSS package, Version 3.9. NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112.

Jager, H. I., M. S. Bevelhimer, and D. L. Peterson. 2011. Population viability analysis of the endangered Shortnose Sturgeon (No. ORNL/TM-2011/48). OAK RIDGE NATIONAL LAB TN ENVIRONMENTAL SCIENCES DIV.

Kocik, J., C. Lipsky, T. Miller, P. Rago, and G. Shepherd. 2013. An Atlantic sturgeon population index for ESA management analysis. US Dept Commerce, Northeast Fish Sci Cent Ref Doc, 13-06.

Moyer, G. R., J. A. Sweka and D. L. Peterson. 2012. Past and present processes influencing genetic diversity and effective population size in a natural population of Atlantic sturgeon. Transactions of the American Fisheries Society, 141(1): 56-67.

Nantel, P. 2010. A Bayesian belief network for assessing species status under uncertainty. Available from Patrick Nantel, Parks Canada, Ottawa, Ontario.

National Marine Fisheries Services (NMFS) Atlantic sturgeon Status Review Team. 2007. Status Review of Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus). Report to National Marine Fisheries Service, Northeast Regional Office. February 23, 2007. 174 pp.

Northeast Fisheries Science Center (NEFSC). 2013. 57th Northeast Regional Stock Assessment Workshop (57th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 13-16; 967 p. https://www.nefsc.noaa.gov/nefsc/saw/

Nelson, G. A. 2017. fishmethods: Fishery Science Methods and Models in R. R package version 1.10-1. https://CRAN.R-project.org/package=fishmethods

Oregon Department of Fish and Wildlife (ODFW). 2011. Lower Columbia River and Oregon Coast White Sturgeon Conservation Plan. Technical Report. Clackamas, Oregon. http://www.dfw.state.or.us/fish/crp/docs/lower_columbia_sturgeon/LCR_white_sturgeon_conservation_plan.pdf

Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fishery Bulletin 84(3):519-525.

Peterson, D. L., P. Schueller, R. DeVries, J. Fleming, C. Grunwald, and I. Wirgin. 2008. Annual run size and genetic characteristics of Atlantic sturgeon in the Altamaha River, Georgia. Transactions of the American Fisheries Society, 137(2): 393-401.

Post, B.C., T. Darden, D. L. Peterson, M. Loeffler, C. Collier (2014) Research and Management of Endangered and Threatened Species in the Southeast: Riverine Movements of Shortnose and Atlantic sturgeon, 274 pp.

R Core Team (RCT). 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rogers, S. G. and W. Weber. 1994. Occurrence of shortnose sturgeon (*Acipenser brevirostrum*) in the Ogeechee-Canoochee river system, Georgia during the summer of 1993. Final Report of the United States Army to the Nature Conservancy of Georgia.

Rogers, S.G. and W. Weber, 1995. Movements of shortnose sturgeon in the Altamaha River system, Georgia. Contribution Series No. 57, Coastal Resources Division, Georgia Department of Natural Resources, Brunswick, GA, 78 p.

Schertzer, K. W., M. H. Prager, and E. H. Williams. 2008. A probability-based approach to setting annual catch levels. Fisheries Bulletin 106:225-232.

Schueller, P., and D. L. Peterson. 2010. Abundance and recruitment of juvenile Atlantic sturgeon in the Altamaha River, Georgia. Transactions of the American Fisheries Society, 139(5): 1526-1535.

Smith, T.I.J., D.E. Marchette & G.F. Ulrich (1984) The Atlantic sturgeon Fishery in South Carolina, North American Journal of Fisheries Management, 4:2, 164-176

Smith, T. I. 1985. The fishery, biology, and management of Atlantic sturgeon, *Acipenser oxyrhynchus*, in North America. Environmental Biology of Fishes, 14(1): 61-72.

Van Eenennaam, J. P., S. I. Doroshov, G. P. Moberg, J. G. Watson, D. S. Moore, and J. Linares. 1996. Reproductive conditions of the Atlantic sturgeon (*Acipenser oxyrinchus*) in the Hudson River. Estuaries 19:769–777.