

Stock Assessment Report No. 12-01  
of the

## **Atlantic States Marine Fisheries Commission**

*American Eel Benchmark Stock Assessment*



**Accepted for Management Use May 2012**



*Working towards healthy, self-sustaining populations for all Atlantic coast fish species  
or successful restoration well in progress by the year 2015*



## Preface

The 2012 Benchmark Stock Assessment of American Eel occurred through an Atlantic States Marine Fisheries Commission (ASMFC) external peer review process. ASMFC organized and held Data Workshops on September 14-16, 2009 and June 21-24, 2010. Assessment Workshops were held on May 23-26, 2011 and August 22-25, 2011. Participants of the Data and Assessment Workshops included the ASMFC American Eel Stock Assessment Subcommittee and Technical Committee, as well as invited individuals from state and federal partners. ASMFC coordinated a Peer Review Workshop from March 16 – 17, 2012. Participants included members of the American Eel Stock Assessment Subcommittee and a Review Panel consisting of four reviewers appointed by ASMFC.

### **Terms of Reference and Advisory Report of the Peer Review Panel (PDF Pages 3-35)**

The Terms of Reference Report provides a detailed evaluation of how each Terms of Reference was addressed by the Stock Assessment Subcommittee, including the Panel's findings on stock status and future research recommendations. The Advisory Report provides an summary of the stock assessment results supported by the Review Panel.

### **American Eel Stock Assessment Report for Peer Review (PDF Pages 36-338)**

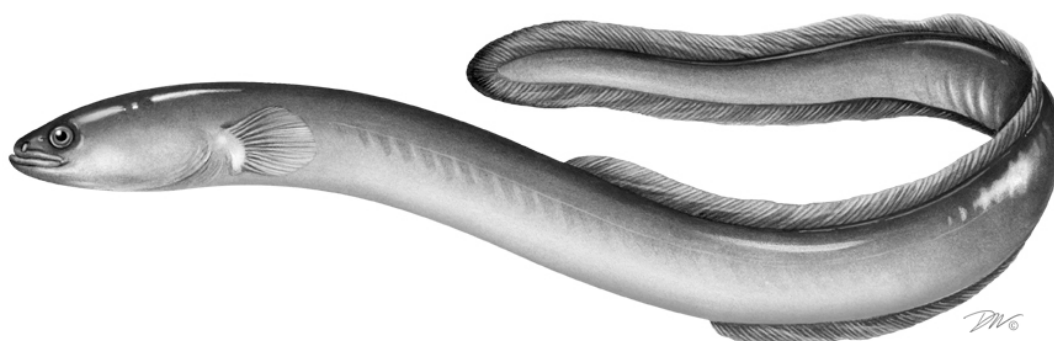
This report describes the background information, data used, and analysis for the assessment submitted by the Technical Committee to the Review Panel. It contains a coastwide and regional analysis and comparison of American eel populations.

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA10NMF4740016





# **Terms of Reference & Advisory Report of the American Eel Stock Assessment Peer Review**



Conducted on  
March 12-13, 2012  
Raleigh, North Carolina

Prepared by the  
ASMFC American Eel Stock Assessment Peer Review Panel

Dr. Karin Limburg, Panel Chair, State University of New York

Dr. Ken Oliveira, University of Massachusetts-Dartmouth

Dr. John Wiedenmann, Rutgers University

Dr. Bob O'Boyle, Beta Scientific Consulting

**Atlantic States Marine Fisheries Commission**

*Working towards healthy, self-sustaining populations for all Atlantic coast fish species  
or successful restoration well in progress by the year 2015*

## Table of Contents

<b>PREFACE</b> .....	<b>1</b>
<b>ACKNOWLEDGEMENTS</b> .....	<b>3</b>
<b>INTRODUCTION</b> .....	<b>4</b>
<b>TERMS OF REFERENCE FOR THE AMERICAN EEL STOCK ASSESSMENT PEER REVIEW</b> .....	<b>4</b>
1. EVALUATE THE THOROUGHNESS OF DATA COLLECTION AND THE PRESENTATION AND TREATMENT OF FISHERY-DEPENDENT AND FISHERY-INDEPENDENT DATA IN THE ASSESSMENT.....	5
2. EVALUATE THE METHODS AND MODELS USED TO ESTIMATE POPULATION PARAMETERS (E.G., <i>F</i> , BIOMASS, ABUNDANCE) .....	7
3. EVALUATE THE DIAGNOSTIC ANALYSES PERFORMED.....	10
4. EVALUATE THE ASSESSMENT’S BEST ESTIMATES OF STOCK BIOMASS, ABUNDANCE, AND EXPLOITATION FOR USE IN MANAGEMENT, IF POSSIBLE, OR SPECIFY ALTERNATIVE ESTIMATION METHODS. ....	12
5. EVALUATE THE CHOICE OF REFERENCE POINTS AND THE METHODS USED TO ESTIMATE REFERENCE POINTS. EVALUATE THE STOCK STATUS DETERMINATION FROM THE ASSESSMENT. IF APPROPRIATE, SPECIFY ALTERNATIVE METHODS/MEASURES. ....	12
6. REVIEW THE RESEARCH, DATA COLLECTION, AND ASSESSMENT METHODOLOGY RECOMMENDATIONS PROVIDED BY THE TECHNICAL COMMITTEE AND MAKE ANY ADDITIONAL RECOMMENDATIONS WARRANTED. CLEARLY PRIORITIZE THE ACTIVITIES NEEDED TO INFORM AND MAINTAIN THE CURRENT ASSESSMENT, AND PROVIDE ADDITIONAL RECOMMENDATIONS THAT MAY IMPROVE THE RELIABILITY OF FUTURE ASSESSMENTS.....	13
7. RECOMMEND TIMING OF THE NEXT BENCHMARK ASSESSMENT AND UPDATES RELATIVE TO THE LIFE HISTORY AND CURRENT MANAGEMENT OF THE SPECIES. ....	14
<b>ADVISORY REPORT</b> .....	<b>15</b>
A. STATUS OF STOCKS: CURRENT AND PROJECTED, WHERE APPLICABLE .....	15
B. STOCK IDENTIFICATION AND DISTRIBUTION .....	15
C. MANAGEMENT UNIT .....	15
D. LANDINGS.....	16
E. DATA AND ASSESSMENT .....	17
F. BIOLOGICAL REFERENCE POINTS .....	17
G. FISHING MORTALITY .....	17
H. RECRUITMENT .....	18
I. SPAWNING STOCK BIOMASS.....	18
J. BYCATCH .....	18
K. OTHER COMMENTS .....	18
L. SOURCES OF INFORMATION (LITERATURE CITED) .....	19

## Preface

### *Summary of the ASMFC Peer Review Process*

The Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2002 and 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; (2) improve the quality of Commission stock assessments; (3) improve the credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments. The Commission stock assessment review process includes an evaluation of input data, model development, model assumptions, scientific advice, and a review of broad scientific issues, where appropriate.

The Benchmark Stock Assessments: Data and Assessment Workshop and Peer Review Process report outlines options for conducting an external peer review of Commission managed species. These options are:

1. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).
2. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).
3. The Transboundary Resources Assessment Committee (TRAC) reviews stock assessments for the shared resources across the USA-Canada boundary and is conducted jointly through the National Marine Fisheries Service and the Canada Department of Fisheries and Oceans (DFO).
4. A Commission stock assessment Peer Review Panel conducted by 3-5 stock assessment biologists (state, federal, university). The Commission Review Panel will include scientists from outside the range of the species to improve objectivity.
5. A formal review using the structure of existing organizations (i.e. American Fisheries Society, International Council for Exploration of the Sea, or the National Academy of Sciences).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes all Commission managed species based on species management board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In March 2012, the Commission convened a Stock Assessment Peer Review Panel comprised of scientists with expertise in stock assessment methods and/or diadromous species and their life history. The review of the American eel stock assessment was conducted at the Doubletree Brownstone Hotel in Raleigh, North Carolina from March 12-13, 2012. Prior to

the Review Panel meeting, the Commission provided the Review Panel Members with an electronic copy of the 2012 American Eel Stock Assessment Report.

The review process consisted of an introductory presentation of the completed 2012 stock assessment. Each presentation was followed by general questions from the Panel. The second day involved a closed-door meeting of the Review Panel during which the documents and presentations were reviewed and a report prepared.

The report of the Review Panel is structured to closely follow the terms of reference provided to the stock assessment team.



## Acknowledgements

The Review Panel thanks members of the American Eel Stock Assessment Subcommittee and Technical Committee, as well as staff of the Atlantic States Marine Fisheries Commission, particularly Patrick Campfield, for support during the review process.



*Photo: Travis Elsdon*

## Introduction

The American eel *Anguilla rostrata* is one of 15 species in the family Anguillidae. All are characterized by great adaptability to a wide range of aquatic ecosystems, and consequently are found around the globe. All reproduce at sea and are at least facultatively catadromous, meaning they use inland habitats. Their complex life history is documented well in the 2012 American Eel Stock Assessment report. Of note is the fact that the American eel, from its northern limit in Greenland down to its southern limit in French Guiana, is one population.

In New Zealand, anguillid eels are revered as spirits as much as they are prized as food (Prosek 2010). In traditional North American Indian cultures, the same is true. The Iroquois Confederacy in New York State has an Eel Clan; many of the governing leaders are recruited from this clan. However, today, the American eel is all but extirpated from Lake Ontario drainages, and most members of the Eel Clan have never seen a live eel (J. Shenandoah, Onondaga Nation elder, personal communication).

Eels were formerly extremely abundant in inland waters of eastern North America, colonizing lakes, rivers, streams, and estuaries. In Onondaga Lake in New York State, 17th century Jesuit missionaries noted with wonder that "...the eel is so abundant that a thousand are sometimes speared by a single fisherman in a night..." (Clark 1849). American eels penetrated the major Atlantic waterways of North America, reaching the Great Lakes via the St. Lawrence River and the mid-western American states via the Mississippi as far as Minnesota (Eddy and Underhill 1974). Coastal eel abundances were very high, and during the spring, runs of recruiting glass eels would form "walls of glass" as they ascended barriers. Eel fisheries flourished well into the early 20th century.

Eels were once an important food fish in the U.S., but today are mainly sold as bait or exported to Europe and Asia, where demand continues to be high. Declines in European and Asian eels drive the export fishery, and in particular, the export market for glass eels has commanded prices exceeding \$2000/lb this year.

*The American eel stock status is depleted.* The seeds of the current depletion lay in part in a fishing up/fishing down' episode that occurred on American eels in the 1970s into the 1980s as export demand rose. Roughly during the same period, river damming intensified and hydroelectric facilities on dams caused additional mortality. A suite of stressors including habitat loss from dams or urbanization, turbine mortality, the non-native swim-bladder parasite *Anguillicola*, toxic pollutants, and climate change are all factors that act in concert with fishing mortality on American eel. Through a series of data analyses and modeling, the SASC has documented this depletion. The following Peer Review Report discusses the SASC stock assessment findings, comments on strengths and weaknesses, and makes recommendations for additional data needs and future assessments.

## Terms of Reference for the American Eel Stock Assessment Peer Review

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

- 1. Consideration of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, ageing accuracy, sample size),**
- 2. Presentation of data source variance (e.g., standard errors),**
- 3. Justification for inclusion or elimination of available data sources,**
- 4. Calculation and/or standardization of abundance indices.**

In accordance with recommendations from the 2005 stock assessment peer review (ASMFC 2006), more up-to-date information was included as regards biology, life history, and habitat use in continental waters. Updated information was also provided on fishing regulations (commercial and recreational), as well as on an ongoing review by the U.S. Fish and Wildlife Service for possible listing under the Endangered Species Act.

Trends in catch and value of catch were included. Of special note is the current market price of glass eels, which rose to over \$2000/lb this spring (NYT 2012). This fishery is regulated in the state of Maine, but the SASC noted that poaching (unlicensed fishing) is a serious concern in many states, including Maine. In other fisheries, which are largely for bait (domestic usage) or export, there are uncertainties in catches particularly for recreational fishing and for data prior to the standardized record-keeping of the 1950s. *Nevertheless, the Panel felt the data collection and data quality analyses conducted were adequate.*

The American eel Stock Assessment Subcommittee (SASC) canvassed and assessed all available and known data sets (the Panel noted there were some that were unknown to the SASC). Over 100 data sets, comprising fishery-independent and dependent studies, were found and assessed (Appendix A of the stock assessment report). Fishery-dependent data were examined for trends but not included in the analyses due to problems with series standardization. Fishery-independent data sets were excluded if they were less than 10 years in length, if eels were sparsely reported, if there was bias due to catchability, or if sampling protocols or sites were inconsistent. *Given what was available, the Panel felt the data were sufficient to perform the necessary assessments.*

However, some potentially useful data sets were unavailable to the assessment due to data processing lags, unknown errors, or legal issues. One such data set that would have been of particular utility is a 30+ year Juvenile Fish and Blue Crab Trawl Survey conducted by the Virginia Institute of Marine Science (VIMS). Raw survey data were requested but not provided by VIMS. Index values were provided, although there was apparently a processing error in the data base, such that all size classes (pre-recruits, recruits, and post-recruits) appeared to have identical indices of abundance. The Panel judged index values to be erroneous based on length-frequency data provided for selected

years of the survey. *The Panel recommends additional effort be made to obtain raw data, and/or reconcile the size-based abundance data with length frequency data in the VIMS Trawl Survey, so that this valuable data set can be used in future assessments.*

The data sets were analyzed for trends by grouping them into six regions, loosely defined as hydrologic units. This approach worked better in data-rich regions of the north and mid-Atlantic, but North Carolina, South Carolina, Georgia, and Florida were grouped as a single unit, due to data paucity, making it difficult to discern trends in this region.

The assessment considered length-weight relationships, age-length relationships, sex ratios, and growth models (6 in total, evaluated with AIC). Length-weight relationships varied by region, with the highest weight per length in the southeastern region and lowest in the Hudson River. As is the case for European eel, age at length shows great variation, but there are significant regional trends: higher lengths at age in the north and lower lengths at age in the South Atlantic. These are likely affected by habitat and environment, as is also the case with sex ratio. As for growth, no single model stood out as “best,” due in part to the data sets available. Notwithstanding this, these analyses confirmed that there is only a weak relationship of age with length in American eel.

As recommended in the 2005 peer review (ASMFC 2006), trend analyses were performed after first standardizing the data sets by generalized linear modeling (GLM; protocols documented in Appendix B of stock assessment report). The Panel noted that while this is a reasonable approach, the variance in the indices is likely understated. GLMs were applied to individual datasets to standardize the indices of abundance, and then those estimates were input into another GLM to produce regional or coastwide estimates of abundance. Datasets from individual surveys could not be combined into a single GLM due to the different covariates measured in the individual surveys. The Panel felt that doing a trend analysis on a regional or coastwide GLM estimate of abundance (which is based on GLM estimates of abundance of individual surveys) masked the uncertainty in these trends. It was suggested that hierarchical GLM may be used in future assessments to explore relationships across regions where covariate data exist. This may allow for determination of the level of unquantified uncertainty in the current approach.

Regional and coast-wide abundance indices (GLM-standardized) of young-of-year (YOY) and older eels were developed by combining individual data sets. Trends were shown with standard error bars about the estimates. Region to region, some areas exhibited clear declines (Hudson, southern states) while others exhibited little or no trend (e.g., Delaware and Mid-Atlantic coastal bays). However, to some extent this was confounded by the length of the time series and the availability of the regional data sets.

Power analysis, Mann-Kendall tests, meta-analyses, and ARIMA models were used to examine trends in the data and were useful as exploratory tools. The Panel was concerned that the ARIMA approach depended heavily on the first data point in any given time series, as this often defined the resulting observed trend even when immediately adjacent data points showed the opposite trend. Caution should therefore be

taken with interpreting ARIMA-based indices. Nevertheless, taken in the aggregate, a number of these analyses showed evidence of a long-term decline in eel abundance.

The ‘traffic light approach’ (TLA; cf. Caddy 1998, 1999) was also used to explore trends in the various data sets. The TLA provides a framework to communicate trends in disparate data sets to stakeholders and the general public. The SASC used the TLA to summarize the trends in abundance indices, color coding them by region and year as ‘green’ (metric above 75<sup>th</sup> percentile), ‘yellow’ (between 25<sup>th</sup> and 75<sup>th</sup> percentile), and ‘red’ (below the 25<sup>th</sup> percentile of the data). This yielded complex spatial and temporal patterns in the indices that were difficult to interpret. The Panel noted the TLA could be used to put the abundance indices in the broader context of trends in the environment (e.g. regional temperatures and salinities), the eel’s biology (e.g. growth, condition, and early life history) and loss of its habitat (e.g. dam construction).

As required by ASMFC mandate, states must now monitor YOY eels. Data sets were analyzed but few trends were found, likely because the monitoring programs were only relatively recently implemented. Other, longer term ichthyoplankton data (Little Egg Inlet, NJ and Beaufort Inlet, NC) could be of interest. These data are of leptocephali just encountering the coast, and hence may be more a measure of inter-annual variability in offshore recruitment from the Sargasso. Although Sullivan et al. (2006) found little concordance in these data, the GLM normalized data (presented in Figures 5.35 and 5.36 of the stock assessment report) showed a high degree of temporal concordance (Figure 1). Although the Beaufort data are truncated to 2003 (due to lack of resources to process the samples), the strong concordance suggests the Beaufort site might show trends similar to Little Egg Inlet in recent years (a marked decline in abundance after 2008).

In summary, following the recommendations of the 2005 stock assessment peer review, many data sets and ancillary information were gathered; uncertainties quantified; trends examined in multiple ways; and strengths and weaknesses of data and approaches were pointed out. *The Panel considers that a credible analysis of the available data was undertaken by the SASC.*

**2. Evaluate the methods and models used to estimate population parameters (e.g.,  $F$ , biomass, abundance), including but not limited to:**

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

The SASC considered a range of potential population models, most of which have been designed for use in data-poor situations. These included Catch Curve Analysis, Depletion-Corrected Average Catch (DCAC), Depletion-Based Stock Reduction Analysis (DB-SRA), Surplus Production Models (SPM; both age-structured and catch-free), An Index Method (AIM), Collie-Sissenwine, Survival Estimation in Non-Equilibrium situations (SEINE), and a suite of models used by ICES (Study Leading to Informed Management of Eels or SLIME). A number of these models were not pursued due to the lack of appropriate input information. Other models were considered inappropriate to the eel management needs of the ASMFC. For instance, the SLIME suite of models is generally designed to meet Northeast Atlantic-specific management requirements (i.e., provide estimates of escapement). The remaining models were pursued at some level. Surplus production models were attempted using the various regional and coast-wide yellow-stage indices of abundance but stable solutions could not be found. An AIM model was attempted for the Delaware Bay/Mid-Atlantic Coastal Bays and Chesapeake Bay regions but only one of the survey indices exhibited a correlation with the catch, and thus the method was not pursued. The SEINE model relies on a time series of data of sufficient length (greater than 10 years), which is generally lacking.

The DB-SRA, which is an evolution of the DCAC, was thus pursued for application to American eels. The eel DB-SRA assumes that stock dynamics follow a hybrid of a Schaefer and Pella-Tomlinson-Fletcher surplus production functions (Dick and MacCall, 2011). It was noted that the Pacific Fishery Management Council requested a formal review of the DB-SRA model, along with others, and determined that it generally performs well in data-poor situations (Dorn, 2011). The model is applicable to a stock which has a time series of catch and for which productivity is not dominated by recruitment variability. Dorn (2011) noted that the performance (in terms of the federal Overfishing Limit or OFL estimation) was robust across a wide range of scenarios explored in simulation studies. In addition, the OFLs estimated by the model were generally lower than the “true” estimates, suggesting they are biased towards lower risk. The model has a number of advantages – it has minimal input data requirements, has a means to explore uncertainties, and allows determination of stock status in relation to derived reference points.

*The Panel endorsed the SASC’s selection of the DB-SRA model for use in the American eel stock assessment but had a number of concerns.* The model’s production function is designed for Pacific finfish and may not be appropriate for east coast American eel. In its current configuration, the model is restricted to describing eel stock dynamics during the freshwater / estuarine life history stages, with no consideration of the marine stage. Thus, it cannot respond to the dynamics of eel stock components that reside elsewhere (e.g. in Canadian and Caribbean waters, or in offshore marine waters). The assumption is made that the dynamics of non-US eel stock components follow those modeled for the US component. This assumption is violated in Canadian waters as some eel fisheries (e.g. Ontario) are currently closed (DFO, 2010). The model makes the assumption that there is negligible error in the catch. The SASC noted a number of issues with the historical catch which puts this assumption in doubt. In order to compensate for a lack of data, the DB-SRA requires a number of assumptions on stock dynamics, including natural mortality

(M), the  $F_{MSY}/M$  ratio, the  $B_{MSY}/K$  ratio, and finally the  $B_{CURRENT}/K$  (or depletion) ratio. Input estimates of the carrying capacity (K) are varied to determine the K which provides the desired current depletion ratio. Virtually all the parameters of the stock's production dynamics are defined based upon an expert judgment process. Therefore, careful consideration needs to be given to the selection of these inputs. The Panel was satisfied that the SASC chose appropriate estimates of input parameters, based upon knowledge of eel life history and analogy to other finfish stocks.

The DB-SRA model of Dick and MacCall (2011) does not incorporate observation on abundance indices either through a least squares or likelihood function to optimize the search of the input parameters. Thus, issues of effective sample size, likelihood weighting schemes, and so on, are not relevant to the current model. Subsequent to the review meeting, one of the panelists (J. Wiedenmann) was informed by the co-creator of DB-SRA (E. Dick) that the PFMC does not use the model to assess stock status and that it is only used to estimate yield under an assumed estimate of current depletion. This usage may be due to the lack of an optimization function in the model. However, in a form of optimization (see below), the SASC used the 1990–2010 coastwide eel biomass indices to help inform the input distribution of  $B_{CURRENT}/K$ . The Panel felt this was an important innovation to the DB-SRA formulation introduced by the SASC, and represents a step toward more formal model fitting.

Another innovation introduced by the SASC was the incorporation of M in two time periods (1880–1969 and 1970–2010) to model the effects of habitat loss on stock productivity. Dam construction on the US east coast was considerable prior to 1970 which limited habitat availability to eels. The Panel considered that while adjustment of the model's production function due to habitat loss was necessary, it may be more appropriate to do this through a change to K. During the review meeting, a model change was made in which K varied between two time stanzas, with it being 75% of the historical K since 1970. Preliminary runs indicated the M and K adjusted models provided similar outputs. While the Panel accepted these adjustments to address the impact of habitat loss on the eel production function, it encouraged further explorations of these relationships.

The average age of maturity was assumed to be 8, which was used as the time lag between stock production and fishery exploitation. The Panel noted this may be too short a period: 4 is the age of recruitment to the fishery, the larval stage is 1-½ years duration and it takes about 4 years for a larva to grow to the silver (exploited) stage. Further analyses are encouraged to explore the sensitivity of the estimated reference points and stock status to changes in the age of maturity.

Notwithstanding the issues with the DB-SRA model, the Panel considered that the SASC undertook an appropriate selection process, adequately derived the range of input parameters and undertook innovative model adjustments to addresses issues specific to American eels.

### **3. Evaluate the diagnostic analyses performed, including but not limited to:**

- a. Sensitivity analyses to determine model stability and potential consequences of major model assumptions**
- b. Evaluate the methods used to characterize uncertainty in estimated parameters. Ensure the implications of uncertainty in technical conclusions are clearly stated.**

For the DB-SRA, a number of sensitivity analyses were conducted to explore model stability and the impacts of different model assumptions. A thorough exploration of the sensitivity of results to model inputs and assumptions was conducted. In total, 14 sensitivity runs were reported within the assessment, although additional runs were explored at the stock assessment review meeting.

A thorough explanation of DB-SRA is provided in response to ToR 2. For all of the input distributions ( $M$ ,  $F_{MSY}/M$ ,  $B_{MSY}/K$ , and  $B_{CURRENT}/K$ ), the SASC assumed uniform distributions. Different ranges were explored for  $B_{CURRENT}/K$ , but not for  $M$ ,  $F_{MSY}/M$ ,  $B_{MSY}/K$ . While the Panel agreed with the general ranges for the  $M$ ,  $F_{MSY}/M$ , and  $B_{MSY}/K$ , it felt that an exploration of broader ranges, at least during initial runs, could better describe plausible values.

The sensitivity runs can be grouped into 2 broad categories: runs with a single  $M$ -stanza, and runs with a double- $M$  stanza. DB-SRA assumes productivity (in relation to biomass) is constant through time, and the single  $M$ -stanza run assumes no change in productivity. Within the single  $M$ -stanza runs, model sensitivity to the magnitude and duration of early catches (pre-1900), as well as the effect of starting the model at different time periods (1880, 1925, 1970) was explored. It was acknowledged in the assessment that productivity has likely declined for American eels, largely due to the loss of eel habitat from dams. To account for this potential decline in eel productivity through time, a double- $M$  stanza model was run whereby  $M$  was increased and  $F_{MSY}/M$  was decreased (thus assuming total mortality that produces  $MSY$  ( $Z_{MSY}$ ) is constant). The sensitivity of the timing and magnitude of this increase in  $M$  was explored.

The double  $M$ -stanza approach was deemed the preferred approach. Allowing for changes in productivity through time is a novel modification to DB-SRA. The Panel agreed this modification has the potential to be very useful, allowing for the application of DB-SRA to a wider range of species believed to have historical changes in productivity. The Panel discussed additional ways of characterizing a loss of productivity in the model. For example, given the loss of eel habitat through the damming of waterways, one might expect that the carrying capacity ( $K$ ) of the population has been greatly reduced. Therefore, decreasing  $K$  through time could also account for the loss in productivity in the DB-SRA model, and doing so avoids using the assumption that as  $M$  increases  $F_{MSY}$  decreases (see also ToR 2). The Panel recommended that a sensitivity run with a lower  $K$  in recent years be explored. This run was conducted and showed promise, but the limited time for this analysis prevented full consideration of the analysis.



In DB-SRA, a single parameter,  $K$ , is estimated, and important management quantities ( $MSY$ ,  $B_{MSY}$ ,  $B_{CURRENT} / B_{MSY}$ ,  $F_{CURRENT} / F_{MSY}$ ) are determined using this estimate along with the input parameters (note that  $F_{MSY}$  is determined solely by the input parameters). In general, model estimates of  $K$  and  $MSY$  were robust across a wide range of parameter values and across sensitivity runs. However, at higher levels of  $B_{MSY} / K$ ,  $M$ , and  $F_{MSY} / M$ , unreasonably high estimates of  $K$  resulted, suggesting such values might not be plausible for eels. In addition, estimates of  $K$  were similar across runs that started at different years (1880, 1925, and 1970). The Panel noted, however, that regardless of the starting year for model runs, biomass initially declined very rapidly. For example, in the preferred model run, biomass declined by about 90% in the first 10 years; the Panel wondered whether such a rapid decline was possible. Runs that explored earlier start years with a gradual increase in catches (up to 1880) showed a more gradual decline, but again, biomass still reached near historical lows by 1890. The Panel wondered if there was any evidence (anecdotal or otherwise) to support such a low population in the 1890s.

Estimates of current biomass from the DB-SRA model are dependent upon the input value of  $B_{CURRENT} / K$ . In addition, current biomass estimates combined with catch levels determine the current exploitation rate. Thus, although some of the derived management quantities were robust across runs, the estimates of current stock status relative to management reference points are extremely sensitive to the range of  $B_{CURRENT} / K$ . The assumed range of  $B_{CURRENT} / K$  in the preferred model run was between 0.05 and 0.15. The motivation for use of this range is that a  $B_{CURRENT} / K$  value of 0.1 tended to match recent trends in biomass in the 20-30 year coast wide indices. Between 1991 and 2010, both the 20 and 30 year indices showed a roughly 10% increase in biomass, and a  $B_{CURRENT} / K$  of 0.1 in a number of model runs resulted in a similar increase across a range of other parameters. Use of trends in the available indices is a potentially productive way to help parameterize the model, particularly the values for  $B_{CURRENT} / K$ . However, the Panel was concerned about the model estimates of current stock status and harvest rates being entirely dependent upon the average increase of 10% based on two coast wide indices of abundance (see ToR 4 for uncertainty about the strength of the trend in these indices). The Panel agreed a wider range of  $B_{CURRENT} / K$  should be explored, perhaps between 0.05 and 0.3, with the distribution being centered at different values within this range.

Along with additional explorations of the range of  $B_{CURRENT} / K$ , there was consensus amongst the Panel that later ages at maturity should be explored. In addition, the DB-SRA exploration would benefit from incorporating uncertainty into the catch series, either based on empirical estimates of uncertainty or on some ad-hoc approach.

*Overall, the Panel was impressed with the development of the DB-SRA model for American eels. The SASC explored a wide range of possible models, and used a few novel approaches to overcome some of the model assumptions (i.e. 2 productivity stanzas) and to better inform model parameterization (i.e. using an index trend to select  $B_{CURRENT} / K$ ). However, the Panel was not comfortable relying entirely on the trend in this index to center the  $B_{CURRENT} / K$  distribution at 0.1, as doing so automatically resulted in the estimated eel population being overfished in the final year.*

**4. Evaluate the assessment's best estimates of stock biomass, abundance, and exploitation for use in management, if possible, or specify alternative estimation methods.**

There is uncertainty in the magnitude of biomass and fishing mortality estimates from the DB-SRA model, particularly in recent years. However, general patterns in the estimates can be discerned from the model runs. Estimated biomass declined rapidly between 1880 and 1890, and reached historical lows in the early 1900s. Biomass increased gradually starting around 1910, reaching a peak in the early 1970s (but below the biomass in the beginning of the time series). The very high catches in the late 1970s and early 1980s resulted in a rapid decline in biomass until the mid 1990s. It is unclear what the biomass trend in recent years is because this trend depends on the assumed level of  $B_{CURRENT} / K$ .

Exploitation rates fluctuated greatly over time, but there were 3 periods of high to very high exploitation rates (approximately between 1890-1910, 1930-1936, and 1978-1995). The highest exploitation rates occurred in the early 1900s, and these values may have been over 5 times higher than the estimated FMSY. Trends in recent exploitation rates are uncertain as they are sensitive to  $B_{CURRENT} / K$ .

Abundance indices were not available for most of the time period and thus could not be used to support the DB-SRA trends in biomass in the early years. Trend analyses of abundance indices for more recent years suggested declining or stable abundance of eels in recent decades. The 30-year GLM-estimated index of coast wide abundance showed a decline in biomass in the early to mid-1980s until about 1990. The DB-SRA estimates of biomass showed a decline a few years earlier, but the general trends were in agreement. However, the 40-year GLM index only used indices of abundance from the Chesapeake, and did not match the trends in estimated biomass since the 1970s.

In summary, the estimates of biomass showed two periods of high biomass: during the early 1880s, and from about 1965-1980. As referenced in ToR 3, the Panel questioned whether such a rapid decline in biomass could have occurred in the 1880s, and if eel biomass could have been at such low levels starting around 1890. In addition, current estimates of coast wide biomass could not be determined due to the sensitivity of this estimate to the assumed distribution for  $B_{CURRENT} / K$ .

**5. Evaluate the choice of reference points and the methods used to estimate reference points. Evaluate the stock status determination from the assessment. If appropriate, specify alternative methods/measures.**

The SASC determined three sets of reference points (RPs) – the first based on an ARIMA analysis of the 20 year (or more) coast wide yellow eel survey index, the second using the Traffic Light Approach (TLA) and the third based on the results of the DB-SRA model. The ARIMA derived RPs were proposed as the lower 25<sup>th</sup> percentile of the fitted abundance index. It was further suggested that a high probability (i.e. 80%) of the

current year's index being below this level would provide strong evidence that the stock biomass is below the RP. The Panel considers the utility of this RP as limited. It is not clear what management action should be taken if and when an RP is met or exceeded as the RP is not derived from stock dynamics which could be used to inform a desired management response.

The TLA was applied to all individual, regional, and coast wide indices of relative abundance by the SASC. After scaling, each annual index was assigned to one of three color categories - white (good), gray (intermediate), or black (bad) - based on the 25th and 75th percentiles of each index series (see also ToR 1). The results were complex and difficult to interpret. Nonetheless, empirically-based RPs of this nature have been used in stocks (e.g. Hardie et al., 2011) for which population models are not available. As part of a TLA, they are one metric in a suite of many to inform managers of stock status. Pre-agreed upon decisions on management actions are made if and when RPs are met. The TLA is not without its problems but can allow management actions to ensure stock sustainability in data-poor situations (Halliday et al., 2001). Further, the TLA allows consideration of a wider suite of information than can normally be incorporated into a model (e.g. environmental indicators), thus allowing interpretation of model results in a broader context. *The Panel suggests that a TLA be explored which would incorporate a wide array of data related to American eel stock dynamics. This may be used to assist in coast wide and regional management decision-making while modeling efforts continue.*

The two *M* stanza DB-SRA provided American eel stock RPs which were relatively robust to input assumptions. The carrying capacity (*K*) ranged from 16,274 - 23,595 t (median of 18,274t).  $B_{MSY}$  ranged from 5,085 - 8,912t (median of 6,823t) while *MSY* ranged from 827 - 1510t (median of 1,060t). The associated  $F_{MSY}$  ranged 0.14 - 0.26 (median of 0.19). The Panel considered, however, that while these RPs were generally representative of optimal stock dynamics, the uncertainties in the DB-SRA model did not permit statements on current stock status in relation to these RPs.

*In summary, the Panel is very encouraged by the modeling efforts of the SASC and finds they are a significant advance since the 2006 assessment (see also ToR 3).*

*Notwithstanding this, while it is highly likely that the American Eel stock is depleted, the overfishing and overfished status in relation to the biomass and fishing mortality reference points cannot be stated with confidence.*

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

The recommendations provided by the SASC were fairly comprehensive and the Panel feels these covered the primary areas needed to improve future assessments. The Review Panel has incorporated these recommendations into Table 1, with prioritization and comments explaining the priority provided.

**7. Recommend timing of the next benchmark assessment and updates relative to the life history and current management of the species.**

*The Panel recommends timing the next benchmark to permit the collection of additional data and assess progress with regard to the Panel's recommendations. This would be at a minimum 5 years from the current benchmark. This is also in keeping with the long generation time for eels (3-5 years in south, 10-20 years in north).*

*The Panel also concurs with the SASC's suggestion that the next benchmark assessment be conducted together with the corresponding Canadian team. To this end, it was suggested that a planning meeting be convened at the 2014 AFS meeting, which will be held in Quebec City.*

## Advisory Report

### A. Status of stocks: Current and projected, where applicable

The Panel review concluded the American eel population is *depleted* in U.S. waters. The stock is at or near historically low levels. This is likely due to a combination of historical overfishing, habitat loss due to damming mainstems and tributaries of rivers, mortality from passing through hydroelectric turbines, pollution, possibly parasites and disease, and unexplained factors at sea.

A depletion-based stock reduction analysis (DB-SRA) was conducted by the Stock Assessment Subcommittee (SASC); results suggested overfishing has been occurring since the 1980s. However, while it is highly likely the American eel stock is depleted, the overfishing and overfished status in relation to the biomass and fishing mortality reference points cannot be stated with confidence (see ToRs 2, 3 and 5).

### B. Stock Identification and Distribution

The American eel is a panmictic species, that is, a single, genetically homogeneous population. This is due to having a single spawning region in the Sargasso Sea. After hatch, American eel leptocephali (the larvae) drift with currents in a generally westward direction, but encounter both the North and South American continents. Consequently, the distribution of American eel ranges from northern South America, into the Gulf of Mexico, and along the North American east coast as far as Labrador and Greenland. As a partially catadromous species (Daverat et al. 2006), American eel colonized a wide range of inland waters, penetrating as far inland as Lake Ontario and its drainages, and the Mississippi River as far as Iowa (Tesch 2003). There is overlap on the spawning grounds with the European eel, *Anguilla anguilla*, and a hybrid zone is found in Iceland (Albert et al. 2006).

Although panmictic, there are distinct, habitat-related trends in size and sex ratio in anguillid eels (e.g., Oliveira 1999, Davey and Jellyman 2006). Sex determination is at least to some extent environmentally determined and appears to be a function of density and growth rate, with males arising at higher local population densities. These differences appear to produce females that are larger and therefore more fecund (but take longer to mature) and males that mature as quickly as possible (Davey and Jellyman 2006). Therefore, loss of larger, older females in the female-dominated Laurentian Great Lakes drainage, and possibly other areas where females are produced, is cause for concern.

### C. Management Unit

From the draft stock assessment Executive Summary, p. iv:

“The management unit for American eel under the jurisdiction of ASMFC includes that portion of the American eel population occurring in the territorial seas and inland waters

along the Atlantic coast from Maine to Florida. The goal of the American Eel Fishery Management Plan (approved November 1999) is to conserve and protect the American eel resource to ensure ecological stability while providing for sustainable fisheries.”

As noted in the last stock assessment peer review (ASMFC 2006), because of the wide range (over 50 degrees of latitude) and geographic biological differences in this panmictic species (see above), management of eels in U.S. waters must also consider status of eels beyond U.S. territory. This would at a minimum include coordination with Canada and Caribbean countries.

#### **D. Landings**

Earliest Federal records of eel fishing date from the late 19<sup>th</sup> century, but eel fishing has been documented back to the 17<sup>th</sup> century. Gear ranges from traditional spears to pots, pound nets, and weirs. During the 20<sup>th</sup> century, heaviest fishing pressure occurred in response to demand from Europe beginning in the 1960s, and decline began to occur in the early 1980s (Figure 2). Harvests have been more or less constant since the previous stock assessment.

From the current stock assessment Executive Summary, p. iv:

“During 1950 to 2010, American eel landings from the U.S. Atlantic Coast ranged between approximately 664,000 pounds (301.2 MT) in 1962 and 3.67 million pounds (1664.7 MT) in 1979. After a decline in the 1950s, landings increased to a peak in the 1970s and 1980s before declining again in the 2000s. The value of U.S. commercial American eel landings as estimated by NMFS has varied between a few hundred thousand dollars (prior to the 1980s) and a peak of \$6.4 million in 1997. Total landings value increased through the 1980s and 1990s, dropped in the late 1990s, and increased again in the 2000s.

“Since 1950, the majority (>76%) of American eel commercial landings were caught in pots and traps. Fixed nets (e.g., weirs, pound nets) accounted for about 8% of the landings. Approximately 4% of landings were caught using other gears (non-pot/trap or fixed net). About 12% of landings are reported with unknown gear type. Over the last two decades, pots and traps have become the dominant gear reported for most eel landings.”

A glass eel fishery arose in the 1970s in response to demand from Japan. High prices for glass eels periodically drove up effort in this fishery; currently demand is at a record high, due to a shortage of Japanese eels in the wake of the 2011 tsunami and its impacts. Prices currently top \$2000/pound (NYT 2012). The glass eel fishery is legal only in the states of Maine and South Carolina, but the high market prices are an encouragement to poaching in many states.

## **E. Data and Assessment**

Data sets were canvassed from as many sources as possible and trends were examined. Fishery-dependent data were examined, but not used in the actual assessment. Fishery-independent data sets were standardized with generalized linear models (GLMs), then analyzed for the ability to detect trends (power analysis), monotonic trends (Mann-Kendall tests), coherence of trends over space (via meta-analysis), and general temporal and geographic trends (geographically based time series (ARIMA) modeling, traffic light analysis). The results indicated variable responses, but most of the data sets indicated decline. See ToR 1 for further elaboration, as well as discussion of data sets.

## **F. Biological Reference Points**

Three approaches were used to create biological reference points. The first was to use ARIMA models with standardized abundance index data sets of at least 20 years' length, to estimate the probability that the abundance in any given year (particularly later years) was less than the 25<sup>th</sup> percentile of the data in the time series. The ARIMA analysis yielded low probabilities of decline, except for the Hudson River, western Long Island, and the North Carolina estuarine trawl survey. The Panel noted some difficulties with undue weight given to the first datum of the time series (see ToR 1), and interpreting the utility of this as a reference point (see ToR 5).

The second approach was to undertake a 'Traffic Light Approach' by grouping different assessments within geographic regions and years, coding them as indicating 'good', 'intermediate', and 'bad' in terms of percentiles of ranges. The results were complex and difficult to interpret. Nevertheless, the Panel felt the TLA approach could be refined to include more indices – including environmental and habitat indices – related to eel population dynamics.

The third approach was to use depletion-based stock reduction analysis (DB-SRA; Dick and MacCall 2011). Details of the model are found in the stock assessment report and are further discussed in ToRs 2-4 above. As noted in ToR 5, the analysis that assumed two different temporal stanzas of natural mortality ("two  $M$  stanza DB-SRA"), where  $M$  increased after 1970 to reflect the increased impacts of dams on eel mortality, was robust to different input assumptions, and produced a range of estimates of carrying capacity ( $K$ ), biomass at MSY ( $B_{MSY}$ ), and fishing mortality at MSY ( $F_{MSY}$ ). However, due to uncertainties discussed above, the Panel felt it was not possible to determine current stock status in relation to these reference points.

## **G. Fishing Mortality**

The SASC has made progress in assessing fishing mortality ( $F$ ) through development of the DB-SRA. While trends in  $F$  can be discerned from the model, estimates from recent years are uncertain, as they depend on the assumed level of current depletion. Therefore, the results are tentative, and more analysis is needed.

## **H. Recruitment**

As noted in ToR 1, the young-of-year (YOY) indices that began in 2000 or later show few trends; a longer Hudson River YOY index showed a declining trend; and the ichthyoplankton indices may show a recent, sharp decline (see ToR 1 for discussion). The 2005 stock assessment review noted the value of long term trawl data sets, such as that from VIMS, but trends were difficult to discern because age and size data were not available. The SASC attempted to obtain size data for the VIMS survey, but there were issues in the data that require further exploration.

The Panel strongly supports the recommendation of the SASC to continue the YOY monitoring programs, to encourage all states to participate with comparable, standardized data collection and reporting protocols, and to obtain size- or age-based trend data from VIMS and other long term sources, if possible.

## **I. Spawning Stock Biomass**

The magnitude of spawning stock biomass (SSB) is difficult to assess due to uncertainties in abundance estimates, growth rates (which are variable in eels) and population productivity. And, an unknown fraction of the spawning stock is outside U.S waters. The DB-SRA calculated SSB values that would produce the observed abundance trends, but these are as yet unvalidated.

## **J. Bycatch**

Eel bycatch is not considered to be a major problem. Eels are caught incidentally by recreational fishers, and the Marine Recreational Information Program (MRIP) does list American eel as a bycatch species. The stock assessment report notes that bycatch reported by MRFSS has declined from an average of ca. 22 MT/year in the 1980s to 4 MT/year in the 2000s, but even steeper declines have occurred in the North Atlantic region (see the American Eel Stock Assessment Report, pp. 47-48).

Some eel bycatch information (e.g., from rainbow smelt fisheries in Massachusetts) may be of value as indices of abundance or catch per unit effort (e.g. Figure 5.37 of Stock Assessment report). However, eel capture efficiencies in these fisheries are unknown and would need to be determined.

## **K. Other Comments**

In general, the Panel was satisfied with the progress made by the SASC and encourages them to continue working on the new approaches developed for this stock assessment. The Panel also agreed with the research recommendations of the SASC for further improvements to the stock assessment (Table 1).

Given the unique life history and biology of anguillid eels, which defy national boundaries, it is important to devise means to manage the American eel to account for the contributions of and threats to the portion of the population outside the U.S. Ideally,



there would be an ‘International Northwest Atlantic Eel Council’; the American Eel Technical Committee has approached their counterparts in Canada, which is a good start.

As data accumulate and models improve, the SASC is encouraged to further integrate the data and models. In addition, models that explore the stochastic variability of eel growth and its implications for fisheries could integrate such environmental variables as climate, dams, turbines, pollution, and habitat alterations. These or other models would ideally explore the marine phases for recruitment and reproduction, both of which are critical but largely unknown.

#### **L. Sources of Information (Literature Cited)**

- Albert, V., B. Jonsson, and L. Bernatchez. 2006. Natural hybrids in Atlantic eels (*Anguilla anguilla*, *A. rostrata*): evidence for successful reproduction and fluctuating abundance in space and time. *Molecular Ecology* 15: 1903-1916.
- ASMFC. 2006. Terms of Reference & Advisory Report to the American Eel Stock Assessment Peer Review. Secor, D., G. Chaput, J. Collie, and J. Hightower. Atlantic States Marine Fisheries Commission Stock Assessment Report No. 06-01. Arlington, VA.
- Caddy, J.F. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. *FAO Fisheries Technical Paper* No. 379. 30 pp.
- Caddy, J.F. 1999. Deciding on precautionary management measures for a stock based on a suite of limit reference points (LRPs) as a basis for a multi-LRP harvest law. *NAFO Scientific Council Studies* 32:55–68.
- Clark, Joshua H.V. 1849. *Onondaga: or Reminiscences of Earlier & Later Times*. Stoddard and Babcock. Syracuse, NY.
- Daverat, F., K.E. Limburg, I. Thibault, J.-C. Shiao, J.J. Dodson, F. Caron, W.-N. Tzeng, Y. Iizuka, and H. Wickström. 2006. Phenotypic plasticity of habitat use by three temperate eel species: *Anguilla anguilla*, *A. japonica* and *A. rostrata*. *Marine Ecology Progress Series* 308: 231-241.
- Davey, A.J.H., and D.J. Jellyman. 2006. Sex determination in freshwater eels and management options for manipulation of sex. *Reviews in Fish Biology and Fisheries* 15: 37-52.
- Department of Fisheries and Oceans Canada (DFO). 2010. Status of American eel and progress on achieving management goals. DFO Canada Science Advisory Secretariat. Science Advisory Report 2010/062.
- 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.
- Dorn, M. 2011. Assessment methods for data-poor stocks. Report of the Review Panel meeting. SWFSC, NMFS report. 24 pp.

- Eddy, S., and J.C. Underhill. 1974. Northern fishes; with special reference to the upper Mississippi Valley. University of Minnesota Press, Minneapolis, Minnesota. 414 pp.
- Halliday, R.G., L.P. Fanning, and R.K. Mohn. 2001. Use of the traffic light method in fishery management planning. Canadian Science Advisory Secretariat Research Document 2001/108. 41 pp.
- Hardie, D., M. Covey, M. King and B. Zisserson. 2001. Scotian Shelf Shrimp 2010 – 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/102.
- New York Times (NYT). 2012. Netting Tiny Eels and Big Profits. March 29, 2012.
- Oliveira, K., J.D. McCleave, and G.S. Wippelhauser. 2001. Regional variation and the effect of habitat on sex distribution of American eels, *Anguilla rostrata*. Journal of Fish Biology. 58: 943-952.
- Prosek, J. 2010. Eels: An Exploration, from New Zealand to the Sargasso, of the World's Most Mysterious Fish. Harper, New York.
- Sullivan, M.C., K.W. Able, J.A. Hare, and H.J. Walsh. 2006. *Anguilla rostrata* glass eel ingress into two, U.S. east coast estuaries: patterns, processes and implications for adult abundance. Journal of Fish Biology 69:1081-1101.
- Tesch, F.-W. 2003. The Eel. 3<sup>rd</sup> edition. Blackwell Science, Oxford.

## M. Tables

Table 1. Review Panel evaluation and prioritization of American eel research recommendations. Red text indicates recommendations the Technical Committee and SASC presented as improvements needed for the next benchmark assessment.

Research Recommendation	Time Period	Priority	Review Panel Comments
<b>Data Collection</b>			
<b>Fisheries Catch and Effort</b>			
<b>Improve accuracy of commercial catch and effort data</b>			
Compare buyer reports to reported state landings.	Short term	Moderate to high	The Panel agrees these measures could provide a more reliable measure of ‘actual’ landings.
Improve compliance with landings and effort reporting requirements as outlined in the ASMFC FMP for American eel (see ASMFC 2000a for specific requirements).	Short term		
Require standardized reporting of trip-level landings and effort data for all states in inland waters; data should be collected using the ACCSP standards for collection of catch and effort data (ACCSP 2004).	Short term		
<b>Estimate catch and effort in personal-use and bait fisheries</b>			
Monitor catch and effort in personal-use fisheries that are not currently covered by MRIP or commercial fisheries monitoring programs.	Short term	High	The recommendations would provide for a better understanding of this apparent major source of eel exploitation in U.S. waters.
Implement a special-use permit for use of commercial fixed gear (e.g., pots and traps) to harvest American eels for personal use; special-use permit holders should be subject to the same reporting requirements for landings and effort as the commercial fishery.	Long term	High	
Improve monitoring of catch and effort in bait fisheries (commercial and personal-use).	Short term	High	
<b>Estimated non-directed fishery losses</b>			
Recommend monitoring of discards in targeted and non-targeted fisheries.	Short term	Low to Moderate	Bycatch of American eel is considered minor and MRIP data show it declining since the 1980s.

Table 1 (Cont'd).

Research Recommendation	Time period	Priority	Review Panel Comments
<b>Data Collection (cont'd)</b>			
<b>Fisheries Catch and Effort</b>			
Continue to require states to report non-harvest losses in their annual compliance reports.	Short term	Moderate	If sources of non-harvest losses can be distinguished from passage issues (hydropower; below)
<b>Characterize the length, weight, age, and sex structure of commercially harvested American eels along the Atlantic Coast over time</b>			
Require that states collect biological information by life stage (potentially through collaborative monitoring and research programs with dealers) including length, weight, age, and sex through fishery-dependent sampling programs; biological samples should be collected from gear types that target each life stage; at a minimum, length samples should be routinely collected from commercial fisheries.	Short term	High	Data on age and sex (< 400mm) require sacrificing the eel; not be a feasible undertaking without the collaboration of fishers and dealers. Length and weight should be more readily available.
Finish protocol for sampling fisheries; SASC has draft protocol in development.	Short term	High	See above.
<b>Improve estimates of recreational catch and effort</b>			
Collect site-specific information on the recreational harvest of American eels in inland waters; this could be addressed by expanding the MRIP to riverine/inland areas.	Long term	Low-moderate	The recreational fishery appears to a great extent to be coupled with the bait fishery. The recommendations above should fulfill this need.
Improve knowledge of fisheries occurring south of the U.S. and within the species' range that may affect the U.S. portion of the stock (i.e., West Indies, Mexico, Central America, and South America).	Long term	Moderate-High	This region is an unknown contributor to the American eel spawning population. Its proximity to the spawning area makes this a worthwhile undertaking.

Table 1 (Cont'd).

Research Recommendation	Time period	Priority	Review Panel Comments
<b>Data Collection (cont'd)</b>			
<b>Socioeconomic Considerations</b>			
Perform economic studies to determine the value of the fishery and the impact of regulatory management.	Long term	Moderate	The extent of eel-specific fishers to the proportion of supplemental fishers is needed.
<b>Improve knowledge regarding subsistence fisheries</b>			
Review the historical participation level of subsistence fishers and relevant issues brought forth with respect to those subsistence fishers involved with American eel.	Long term	Low to moderate	The Panel agrees these recommendations may provide some insight into changing exploitation of the species.
Investigate American eel harvest and resource by subsistence harvesters (e.g., Native American tribes, Asian and European ethnic groups).	Long term	Low to moderate	
<b>Distribution, Abundance, &amp; Growth</b>			
<b>Improve understanding of the distribution and frequency of occurrence of American eels along the Atlantic coast over time</b>			
Maintain and update the list of fisheries-independent surveys that have caught American eels and note the appropriate contact person for each survey.	Short term	High	A potentially valuable source of information; however, differing methodologies (i.e sampling gear and ageing) may complicate interpretation.
Request that states record the number of eels caught by fishery-independent surveys; recommend states collect biological information by life stage including length, weight, age, and sex of eels caught in fishery-independent sampling programs; at a minimum, length samples should be routinely collected from fishery-independent surveys.	Short term	High	Length data can be obtained fairly easily. See preceding caution.

Table 1 (Cont'd).

<b>Research Recommendation</b>	<b>Time period</b>	<b>Priority</b>	<b>Review Panel Comments</b>
<b>Data Collection (cont'd)</b>			
Encourage states to implement surveys that directly target and measure abundance of yellow- and silver-stage American eels, especially in states where few targeted eel surveys are conducted.	Long term	High	State implemented surveys may be the best way to control sampling bias and coordinate methods for the collection of all relevant biological data.
A coast wide sampling program for yellow and silver American eels should be developed using standardized and statistically robust methodologies.	Long term	High	See comments from previous three recommendations.
<b>Improve understanding of coast wide recruitment trends</b>			
Continue the ASMFC-mandated YOY surveys; these surveys could be particularly valuable as an early warning signal of recruitment failure.	Short term	High	The Panel agrees the YOY surveys present a valuable warning system for recruitment success or failure. However, a standardized sampling regime would enhance the value of these data.
Develop proceedings document for the 2006 ASMFC YOY Survey Workshop; follow-up on decisions and recommendations made at the workshop.			
Examine age at entry of glass eel into estuaries and freshwater.	Long Term	Moderate	Allows for better estimation of the time lag between spawner escapement and glass eel recruitment. Currently eel ages are only based on years in freshwater (or near freshwater).
Develop monitoring framework to provide information for future modeling on the influence of environmental factors and climate change on recruitment.	Long term	Moderate	A systematic method of gathering environmental and climate change data that can be linked to recruitment could provide the foundation for a working coast wide model.
Improve knowledge and understanding of the portion of the American eel population occurring south of the U.S. (i.e., West Indies, Mexico, Central America, and South America).	Long term	Moderate to high	As previously noted, the proximity of these regions to the spawning area may make their contribution of spawning valuable.

Table 1 (Cont'd).

Research Recommendation	Time period	Priority	Review Panel Comments
<b>Future Research</b>			
<b>Biology</b>			
<b>Improve understanding of the leptocephalus stage of American eel</b>			
Examine the mechanisms for exit from the Sargasso Sea and transport across the continental shelf.	Long term	Moderate	The understanding of larval migration and energetics could provide insight to declines in recruitment due to oceanic causes.
Examine the mode of nutrition for leptocephalus in the ocean.	Long term	Moderate	
Improve understanding of impact of contaminants as sources of mortality and non-lethal population stressors.	Short term	Moderate-high	Unfortunately, the biology of American eels (long lived, lipid rich, benthic) make them ideal for bioaccumulation of contaminants. USFWS currently has a project examining maternal transfer of contaminants in American eel.
Investigate the effects of environmental contaminants on fecundity, natural mortality, and overall health.	Long term	Moderate-high	
Research the effects of bioaccumulation with respect to impacts on survival and growth (by age) and effect on maturation and reproductive success.	Short term	Moderate-high	
<b>Improve understanding of impact of <i>Anguillicoloides crassus</i> on American eel</b>			
Investigate the prevalence and incidence of infection by the nematode parasite <i>A. crassus</i> across the species range.	Short term	Low-moderate	The parasite has already been documented throughout most of US Coast and the Canadian Maritime provinces. In 2011, it was found in Lake Ontario. However, the effect of the parasite on American eels and especially the spawning migration has yet to be established.
Research the effects of the swim bladder parasite <i>A. crassus</i> on American eel growth and maturation, migration to the Sargasso Sea, and spawning potential.	Short term	Moderate to high	
Investigate the impact of the introduction of <i>A. crassus</i> into areas that are presently free of the parasite.	Long term	Low to moderate	

Table 1 (Cont'd).

Research Recommendation	Time period	Priority	Review Panel Comments
<b>Future Research (cont'd)</b>			
<b>Biology</b>			
<b>Improve understanding of spawning and maturation</b>			
Investigate relation between fecundity and length and fecundity and weight for females throughout their range.	Long term	Low to moderate	Eel size-fecundity relationships have already been established. Effort would be better spent understanding the size variation in females.
Identify triggering mechanism for metamorphosis to mature adult, silver eel life stage, with specific emphasis on the size and age of the onset of maturity, by sex; a maturity schedule (proportion mature by size or age) would be extremely useful in combination with migration rates.	Long term	Moderate to high	As indicated above, these are valuable data. Important to conduct on a latitudinal and habitat level to allow for use in management.
Research mechanisms of recognition of the spawning area by silver eel, mate location in the Sargasso Sea, spawning behavior, and gonadal development in maturation.	Long term	Moderate	As previously noted for larval stages, an understanding of oceanic conditions (Gulf Stream shifts, etc.) may explain non-anthropogenic declines in recruitment.
Examine migratory routes and guidance mechanisms for silver eel in the ocean.	Long term	Moderate	
Improve understanding of predator-prey relationships.	Long term	Moderate	The Panel agrees. Smaller eels are readily preyed upon in all habitats. Larger females may have a size refuge during the freshwater phase.
Investigating the mechanisms driving sexual determination and the potential management implications.	Long term	High	Eels have sex specific life history strategies. The causes of sex determination would be of major importance to management.



Table 1 (Cont'd.)

Research recommendation	Time period	Priority	Review Panel Comments
<b>Future Research (cont'd)</b>			
<b>Passage &amp; Habitat</b>			
<b>Improve upstream and downstream passage for all life stages of American eels</b>			
Develop design standards for upstream passage devices for eels; this will be a product (at least partial design guidelines) from the ASMFC 2011 Eel Passage Workshop; i.e., the research need may be partially met in the near term.	Short term	High	These are all a high priority recommendations but the Panel would like to emphasize the need to separate upstream and downstream passage. Upstream passage contributes primarily to habitat availability of yellow stage eels while downstream has a more direct and readily measured mortality effect on migrating silver stage eels.
Investigate, develop, and improve technologies for American eel passage upstream and downstream at various barriers for each life stage; in particular, investigate low-cost alternatives to traditional fishway designs for passage of eel.	Long term	High	
<b>Improve understanding of the impact of barriers on upstream and downstream movement</b>			
Evaluate the impact, both upstream and downstream, of barriers to eel movement with respect to population and distribution effects; determine relative contribution of historic loss of habitat to potential eel population and reproductive capacity.	Long term	High	As noted above, it may be more effective to focus on upstream passage and the effects on movement and habitat losses of yellow phase eels. Silver eel downstream access is not significantly reduced but rather impacted by factors such as turbine mortality.
Recommend monitoring of upstream and downstream movement at migratory barriers that are efficient at passing eels (e.g., fish ladder/lift counts); data that should be collected include presence/absence, abundance, and biological information; provide standardized protocols for monitoring eels at passage facilities; coordinate compilation of these data; provide guidance on the need and purpose of site-specific monitoring.	Long term	Moderate	

Table 1 (Cont'd.)

<b>Research recommendation</b>	<b>Time period</b>	<b>Priority</b>	<b>Review Panel Comments</b>
<b>Future Research (cont'd)</b>			
<b>Passage &amp; Habitat</b>			
<b>Improve understanding of habitat needs and availability</b>			
Assess characteristics and distribution of American eel habitat and value of habitat with respect to growth and sex determination; develop GIS of American eel habitat in U.S.	Long term	Moderate	This will have to be a habitat-specific analysis. Past studies show high habitat-specific variability in sex ratios within a drainage system.
<b>Improve understanding of habitat needs and availability</b>			
Assess available drainage area over time to account for temporal changes in carrying capacity; develop GIS of major passage barriers.	Long term	Low-moderate	Following possible changes (GIS) in carrying capacity could also provide an understanding of sex ratio changes.
Improve understanding of within-drainage behavior and movement and the exchange between freshwater and estuarine systems.	Long term	Moderate	Allows for better understanding of habitat use and movement between habitats. May also provide needed data for regions where fisheries are either estuarine or freshwater based.
<b>Improve estimates of mortality associated with upstream and downstream passage</b>			
Monitor non-harvest losses such as impingement, entrainment, spill, and hydropower turbine mortality.	Short term	High	In river systems with hydropower, it is essential to have these data; a substantial source of mortality that must be accounted for.
Evaluate eel impingement and entrainment at facilities with NPDES authorization for large water withdrawals; quantify regional mortality and determine if indices of abundance could be established as specific facilities.	Long term	Moderate	See above.

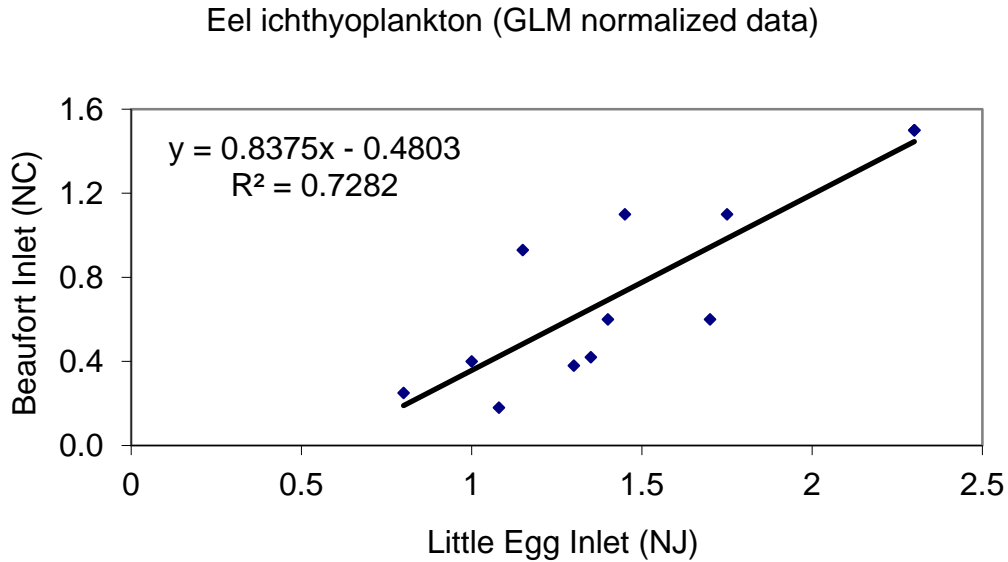
Table 1 (Cont'd.)

Research Recommendation	Time period	Priority	Review Panel Comments
<b>Future Research (cont'd)</b>			
<b>Assessment Methodology &amp; Management Support</b>			
Coordinate monitoring, assessment, and management among agencies that have jurisdiction within the species' range (e.g., ASMFC, GLFC, Canada DFO).	Short term	High	The Panel gives this recommendation a very high priority. The Panmictic nature of eel and the amount of the species' range within Canadian waters makes any solely U.S. based assessment incomplete.
Perform a joint U.S.-Canadian stock assessment.	Short term	High	
Perform periodic stock assessments (every 5-7 years) and establish sustainable reference points for American eel; required to develop a sustainable harvest rate in addition to determining whether the population is stable, decreasing, or increasing.	Short term	Moderate to high	Periodic assessment is needed but a longer time interval (8-10 years) may better estimate population trends. This longer time period may better reflect the eels generation time.
Develop new assessment models (e.g., delay-difference model) specific to eel life history and fit to available indices.	Long term	Moderate to High	Alternate models that do not rely on tracking ages may prove useful but the complex life history makes this difficult.
<b>Conduct intensive age and growth studies at regional index sites to support development of reference points and estimates of exploitation.</b>	Short term	Moderate to high	In order for these data to be of use, standardization of sampling gear, habitat, and ageing methods must first be completed.

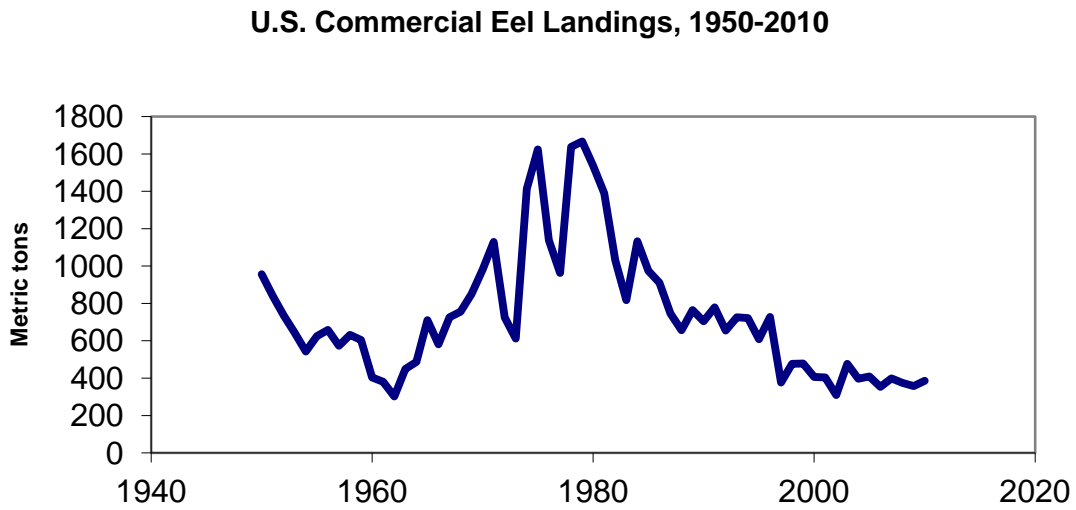
Table 1 (Cont'd.)

Research Recommendation	Time Period	Priority	Review Panel Comments
<b>Future Research (cont'd)</b>			
Develop GIS-type model incorporating habitat type, abundance, contamination, and other environmental factors.	Long term	Low to Moderate	The models would be useful if all factors influencing abundance are included (i.e dams and all fisheries).
Develop population targets based on habitat availability at the regional and local level.	Long term	Low to Moderate	Population targets would be most useful if developed at the local (habitat) level. Regional variation is typically very large.
Implement large-scale (coast-wide or regional) tagging studies of eels at different life stages; tagging studies could address a number of issues including: <ul style="list-style-type: none"> <li>– Growth</li> <li>– Passage mortality</li> <li>– Movement, migration, and residency</li> <li>– Validation of ageing methods</li> <li>– Reporting rates</li> <li>– Tag shedding or tag attrition rates</li> </ul>	Long term	Moderate to-high	A far-reaching recommendation that the Panel feels has good potential. Current long term tagging studies in the St. Lawrence River System have begun to provide data on several of these questions. Some regions would require a long time lag (10 plus years) to address questions.

N. Figures



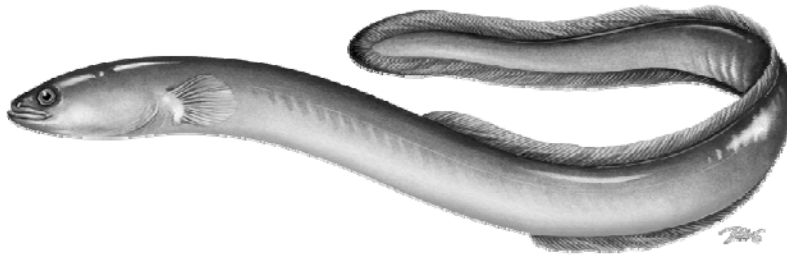
**Figure 1.** Regression of eel leptoccephali indices from Beaufort Inlet, NC on Little Egg Inlet, NJ. The high leverage point consists of two superimposed points.



**Figure 2.** Commercial landings of American eel. Data source: NOAA Fisheries.



# American Eel Stock Assessment for Peer Review



Prepared by the  
ASMFC American Eel Stock Assessment Subcommittee:

Ms. Laura Lee (Chair), North Carolina Division of Marine Fisheries  
Mr. Jeffrey Brust, New Jersey Division of Fish and Wildlife  
Mr. Bradford Chase, Massachusetts Division of Marine Fisheries  
Mr. John Clark, Delaware Division of Fish and Wildlife  
Ms. Sheila Eyler, U.S. Fish & Wildlife Service  
Dr. Geneviève Nesslage, Atlantic States Marine Fisheries Commission  
Dr. John Sweka, U.S. Fish & Wildlife Service  
Ms. Kate Taylor, Atlantic States Marine Fisheries Commission  
Mr. Keith Whiteford, Maryland Department of Natural Resources



**Atlantic States Marine Fisheries Commission**

*Working towards healthy, self-sustaining populations for all Atlantic coast fish species  
or successful restoration well in progress by the year 2015*

# Atlantic States Marine Fisheries Commission

## *American Eel Stock Assessment for Peer Review*

### Preface

An External Peer Review Panel of independent experts met in March 2012 to review the American Eel Stock Assessment and concluded, based on the data and analyses performed in the assessment that the American eel stock was depleted. However, the Panel recommended that the Depletion-Based Stock Reduction Analysis (DB-SRA), initially recommended by the ASMFC American Eel Technical Committee (TC) for use in setting overfished and overfishing stock status determinations, undergo additional testing and development before it is used to generate reference points for management. Following the Peer Review Workshop, the TC and American Eel Stock Assessment Subcommittee (SAS) reviewed the Peer Review Panel's Terms of Reference and Advisory Report and agreed that further development of the DB-SRA is needed.

The Peer Review Panel also suggested the term 'depleted' is more appropriate for describing American eel stock status given the combination of causes for decline, including significant levels of harvest in the 1970s, habitat loss, passage impediments and mortality, disease, and potentially shifting oceanographic conditions. All three trend analysis methods (Mann-Kendall, Manly, and ARIMA) detected significant downward trends in numerous indices over the time period examined. Also, the DB-SRA indicated that the stock is at low biomass compared to previously high levels observed in the 1970s. The TC and SAS agreed with the Peer Review Panel that the stock assessment indicated ***the stock is depleted. No overfishing determination can be made at this time*** based solely on the trend analyses performed (i.e., without finalized DB-SRA results). However, the TC and SAS caution that although commercial fishery landings and effort in recent times have declined in most regions (with the possible exception of the glass eel fishery), ***current levels of fishing effort may still be too high given the additional anthropogenic and environmental stressors affecting the stock.*** Fishing on all life stages of eels, particularly YOY and out-migrating silver eels, could be particularly detrimental to the stock, especially if other sources of mortality (e.g., turbine mortality, changing oceanographic conditions) cannot be readily controlled. ***Management efforts to reduce mortality on American eels in the U.S. are warranted.***

Note that **statements highlighted in yellow** below have been modified by the TC following the Peer Review Workshop and are accompanied by a footnote explaining the wording change made by the TC with regards to stock status.



## **DEDICATION**

To the eel from the River Neuse....

## ACKNOWLEDGEMENTS

The ASMFC American Eel Technical Committee: Keith Whiteford (MD, Chair), Brad Chase (MA, Vice Chair), Jennifer Pyle (NJ), Michael Kaufmann (PA), Jessica Fischer (NH), Tim Wildman (CT), John Whitehead (Appalachian State University), Gail Wippelhauser (ME), Eric Thadey (DC), Richard Maney (NOAA Fisheries), Katy West (NC), Carl Hoffman (NY), Alex Haro (USGS), Allan Hazel (SC), Patrick Geer (GA), Phil Edwards (RI), Shelia Eyer (USFWS), John Clark (DE), Ellen Cosby (PRFC), Theodore Bestor (Harvard University), and Kimberly Bonvechio (FL).

For their assistance with the stock assessment, the committee would like to thank: Ken Able (Rutgers University), Robert Adams (HREP), John Archambault (SC DNR), Donna Bellais (GSMFC), Peter Bourque (ME IFW), Heidi Bray (ME DMR), Eric Brittle (VA DGIF), David Cairns Canada DFO), Floyd Campfield, A.C. Carpenter (PRFC), Mike Celestino (NJ DFW), Bryan Chikotas (PAFB), Joe Cimino (VMRC), Peter Clarke (NJ DFW), Jennifer Cudney (ECU), Julie Defilippi (ACCSP), Mari Beth Delucia (The Nature Conservancy), E. J. Dick (NOAA Fisheries), EPRI American Eel Interest Group, Mary Fabrizio (VIMS), Kari Fenske (SEDAR), Dewayne Fox (DSU), Lewis Gillingham (VMRC), Bob Graham (Dominion Environmental Biology), Don Hamilton (NPS), Kathy Hattala (NYS DEC), Paul Jacobson (EPRI), Bud LaRoche (VA DGIF), Steven Leach (Normandeau Assoc., Inc.), Alan Lowther (NOAA Fisheries), Leonard Machut (VIMS), Stephanie McNerny (NC DMF), Kris McShane (NYSDEC), Wendy Morrison (UMCES CBL), Scott Newlin (DNREC), Mary Savage (USITC), David Secor (UMCES CBL), Chris Schiralli (NYS DEC), Kenneth Strait (PSEG), Chris Taylor (NOAA Fisheries), Jackie Toth (Rutgers University), Troy Tuckey (VIMS), Vic Vecchio (NOAA Fisheries), Geoff Veinott (Canada DFO), Alan Weaver (VA DGIF), Michael Wilberg (UMCES CBL), and Renee Zobel (NHFG).

## EXECUTIVE SUMMARY

The management unit for American eel under the jurisdiction of ASMFC includes that portion of the American eel population occurring in the territorial seas and inland waters along the Atlantic coast from Maine to Florida. The goal of the American Eel Fishery Management Plan (approved November 1999) is to conserve and protect the American eel resource to ensure ecological stability while providing for sustainable fisheries.

In the U.S., all life stages are subject to fishing pressure, and the degree of fishing also varies through time and space. Glass eel fisheries are permitted in Maine and South Carolina. Yellow and silver eel fisheries exist in all Atlantic Coast states with the exception of Pennsylvania. Eels are harvested for food, bait, and export markets.

During 1950 to 2010, American eel landings from the U.S. Atlantic Coast ranged between approximately 664,000 pounds in 1962 and 3.67 million pounds in 1979. After a decline in the 1950s, landings increased to a peak in the 1970s and 1980s before declining again in the 2000s. The value of U.S. commercial American eel landings as estimated by NMFS has varied between a few hundred thousand dollars (prior to the 1980s) and a peak of \$6.4 million in 1997. Total landings value increased through the 1980s and 1990s, dropped in the late 1990s, and increased again in the 2000s.

Since 1950, the majority (>76%) of American eel commercial landings were caught in pots and traps. Fixed nets (e.g., weirs, pound nets) accounted for about 8% of the landings. Approximately 4% of landings were caught using other gears (non-pot/trap or fixed net). About 12% of landings are reported with unknown gear type. Over the last two decades, pots and traps have become the dominant gear reported for most eel landings.

A new set of watershed-based geographic regions were created for this assessment—the Gulf of Maine, Southern New England, Hudson River, Delaware Bay/Mid-Atlantic Coastal Bays, Chesapeake Bay, and the South Atlantic. The South Atlantic and Chesapeake Bay regions showed distinct large peaks in commercial landings in the early 1980s. Landings in all regions declined throughout the 1990s. Most regions remained stable throughout the 2000s except for Southern New England and Delaware Bay/Mid-Atlantic Coastal Bays where landings declined.

For this assessment, the committee evaluated nearly 100 fishery-dependent and independent U.S. data sources representing several life stages and geographical and temporal scales. Fifty-two fishery-dependent and independent data sources were selected for use in this assessment because they were considered adequate for describing life history characteristics and abundance trends of eels on either a coast-wide or regional basis. Trends in fishery-dependent CPUE were used to describe the fisheries but were not included in analyses because they were not thought to represent trends in eel abundance over time due to either poor participation in the fishery (i.e., few fishers), major unquantified changes in the fishery over time, or insufficient time series. Reasons for exclusion of a fishery-independent survey or sampling program included:

- Lacked sufficient time series to identify trends (<10 years)
- Reported inconsistent sampling methodology (i.e., frequent changes in survey methodology) that could not be accounted for via standardization techniques
- Intermittent or rare catches of eels

- Operated during a time of the year when or in an area where eel are not typically available to sampling gear
- Used survey gear with rare, uncertain, or biased catchability for eel

Very few fishery-independent surveys target American eels (with the exception of the state-mandated young-of-year surveys and a few surveys in Maryland). All fishery-independent surveys used in this assessment were evaluated using a standard set of criteria that resulted in data-based decisions to inform the analytical framework (primary assumptions regarding the error structure) for each survey independently. Application of these criteria resulted in nearly all surveys being standardized (unless otherwise noted) using a generalized linear model to account for changes in catchability of eels.

Trend analyses of abundance indices provided evidence of declining or, at least, neutral abundance of American eels in the U.S in recent decades. All three trend analysis methods (Mann-Kendall, Manly, and ARIMA) detected significant downward trends in numerous indices over the time period examined. The Mann-Kendall test detected a significant trend in the 30-year index of coast-wide yellow-phase abundance. The Manly meta-analysis showed a decline in at least one of the indices for both yellow and YOY life stages. Also, there was consensus for a decline for both life stages through time. Both the ARIMA and Mann-Kendall analyses indicate decreasing trends in the Hudson River and South Atlantic regions. In contrast, survey indices from the Chesapeake Bay and Delaware Bay/Mid-Atlantic Coastal Bays regions showed no consistent increasing or decreasing trends. Overall, however, the prevalence of significant downward trends in multiple surveys across the coast is cause for concern.

In addition to trend analyses, historical and recent commercial landings data were used to perform a Depletion-Based Stock Reduction Analysis (DB-SRA). The DB-SRA showed a coast-wide decline in stock biomass since the 1980s. ~~Based on DB-SRA results, the American eel resource in the U.S. is below the overfished threshold and above the overfishing threshold. Therefore, the stock is overfished and overfishing is occurring relative to MSY-based reference points, given the assumptions made (particularly the depletion level and  $B_{MSY/K}$ ).~~ The Technical Committee agrees with the DB-SRA model conclusion that overfishing is occurring and that current biomass is below the estimated biomass threshold; however, while the term “overfished” is used to define this condition in terms of the model,<sup>1</sup> it is important to recognize that multiple sources of mortality have been contributing to the reduced biomass levels. Significant levels of harvest in the 1970s, loss of habitat, and predation are some of the major contributing factors to the overfished status in the DB-SRA base model results.

Although commercial fishery landings and effort in recent times have declined in most regions (with the possible exception of the glass eel fishery), current levels of fishing effort may still be too high given the additional stressors affecting the stock such as habitat loss, passage mortality, and disease as well as climate change leading to shifting oceanographic conditions. Fishing on all life stages of eels, particularly YOY and out-migrating silver eels, could be particularly detrimental to the stock, especially if other sources of mortality (e.g., turbine mortality, changing

---

<sup>1</sup> In accordance with the findings of the Peer Review Panel regarding the need for further development of the DB-SRA, the Technical Committee does not recommend using DB-SRA-derived reference points at this time. Based on the results of the trend analyses and the biomass trends predicted by the DB-SRA, *the stock is declared depleted*. No overfishing declaration can be made at this time.

oceanographic conditions) cannot be readily controlled. Management efforts to reduce mortality on American eels in the U.S. are warranted. Collaboration with Canada to cooperatively monitor, assess, and manage American eels should provide a more complete and accurate picture of the resource.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	iii
EXECUTIVE SUMMARY .....	iv
LIST OF TABLES .....	x
LIST OF FIGURES .....	xiv
TERMS OF REFERENCE .....	21
1 INTRODUCTION .....	22
1.1 Fisheries Management .....	22
1.1.1 Management Unit Definition .....	22
1.1.2 Regulations & Management .....	22
1.2 Stock Assessment History .....	24
1.3 Petitions for ESA Listing .....	24
2 LIFE HISTORY .....	25
2.1 Stock Definitions .....	26
2.2 Migration Patterns .....	26
2.3 Life Cycle .....	27
2.4 Life Stages .....	27
2.4.1 Egg .....	27
2.4.2 Leptocephali .....	27
2.4.3 Glass Eel .....	28
2.4.4 Elver .....	28
2.4.5 Yellow Eel .....	29
2.4.6 Silver Eel .....	30
2.5 Life History Characteristics .....	31
2.5.1 Age .....	31
2.5.2 Growth .....	32
2.5.3 Reproduction .....	33
2.5.4 Food Habits .....	34
2.5.5 Natural Mortality .....	35
2.5.6 Incidental Mortality .....	37
3 HABITAT DESCRIPTION .....	38
3.1 Brief Overview .....	38
3.2 Habitat Description by Life History Stage .....	38
3.2.1 Spawning Habitat .....	38
3.2.2 Glass Eel and Elver Habitat .....	38
3.2.3 Yellow and Silver Eel Habitat .....	39
3.3 Habitat Areas of Particular Concern .....	40
4 FISHERIES DESCRIPTION .....	40
4.1 Commercial Fisheries .....	40
4.1.1 Glass Eel Fishery .....	41
4.1.2 Yellow Eel Fishery .....	42
4.1.3 Silver Eel Fishery .....	43
4.1.4 Bait Fishery .....	43
4.1.5 Exports .....	43
4.2 Commercial Catch-Per-Unit-Effort .....	44
4.3 Recreational Fisheries .....	48

4.4 Subsistence Fisheries .....	49
4.5 Gulf of Mexico.....	49
4.6 Fisheries Outside the United States .....	49
4.6.1 Commercial Fisheries in Canada .....	49
4.6.2 Commercial Fisheries in Central and South America.....	50
5 DATA SOURCES .....	51
5.1 Fishery-Dependent.....	51
5.1.1 Commercial Fisheries .....	51
5.1.2 Recreational Fisheries.....	62
5.2 Fishery-Independent Surveys and Studies.....	64
5.2.1 Annual Young-of-Year Abundance Surveys.....	65
5.2.2 Southern New England .....	69
5.2.3 Hudson River .....	71
5.2.4 Delaware Bay Bay/Mid-Atlantic Coastal Bays .....	75
5.2.5 Chesapeake Bay .....	83
5.2.6 South Atlantic .....	95
6 ASSESSMENT .....	100
6.1 Coast-wide Abundance Indices.....	100
6.1.1 Data Collection .....	101
6.1.2 Development of Estimates .....	101
6.1.3 Estimates .....	102
6.2 Regional Abundance Indices .....	102
6.2.1 Data Collection .....	103
6.2.2 Development of Estimates .....	103
6.2.3 Estimates.....	103
6.3 Analyses of Life History Data .....	104
6.3.1 Growth Meta-Analysis.....	104
6.3.2 SLYME (Sequential Life-table and Yield-per-Recruit Model for the American Eel)	
.....	106
6.4 Trend Analyses .....	106
6.4.1 Power Analysis .....	106
6.4.2 Mann-Kendall Analysis .....	107
6.4.3 Manly Analysis .....	108
6.4.4 ARIMA .....	109
6.4.5 Traffic Light Method .....	110
6.5 SEINE (Survival Estimation In Non-Equilibrium Situations).....	111
6.6 DB-SRA (Depletion-Based Stock Reduction Analysis).....	112
6.6.1 Methods.....	112
6.6.2 Results.....	117
6.7 Age-structured Production Model.....	118
6.7.1 Methods.....	118
6.7.2 Results.....	119
7 STOCK STATUS DETERMINATION .....	119
7.1 Status Determination Criteria .....	119
7.2 Current Stock Status .....	120
8 DISCUSSION & CONCLUSIONS.....	120

9 INTEGRATED PEER REVIEW RECOMMENDATIONS .....	123
10 RESEARCH RECOMMENDATIONS .....	124
11 LITERATURE CITED .....	129
12 TABLES .....	149
13 FIGURES .....	192
APPENDIX 1A. Summary of data sources included in assessment .....	267
APPENDIX 1A. <i>Continued</i> .....	268
APPENDIX 1B. Summary of reviewed data sources deemed inadequate for assessment. ....	269
APPENDIX 1B. <i>Continued</i> .....	270
APPENDIX 1B. <i>Continued</i> .....	271
APPENDIX 2. Description of index standardization methodology.....	272
APPENDIX 3. Copy of report on SLYME model. ....	274



## LIST OF TABLES

Table 1.1.	Commercial fishery regulations for American eels as of 2012, by state. For specifics on licenses, gear restrictions, and area restrictions, please contact the individual state. ....	149
Table 1.2.	Recreational fishery regulations for American eels as of 2012, by state. For specifics on licenses, gear restrictions, and area restrictions, please contact the individual state. ....	150
Table 2.1.	Timing and average length reported for glass-stage American eel upstream migrants in various locations. ....	151
Table 2.2.	Average length, age, and timing reported for migrating silver-phase American eels in various locations, by sex. Length and age ranges are in parentheses. ....	152
Table 2.3.	Average length and age reported for yellow-phase American eels in various locations, by salinity and sex. Length and age ranges are in parentheses. ....	153
Table 2.4.	Average growth rate (mm/year) reported for American eels in various locations, by estimation method and salinity. ....	154
Table 2.5.	Average length (mm) at age reported for American eels in various locations. Age includes only years spent inland (i.e., does not include first oceanic year). ...	155
Table 2.6.	Parameter estimates for the linear regression of length in millimeters on age in years reported for American eel in previous studies. An asterisk (*) denotes studies for which the biological data were available for inclusion in the current assessment. ....	156
Table 2.7.	Parameter estimates of the allometric relation of length in millimeters to weight in grams reported for American eel in previous studies. An asterisk (*) denotes studies for which the biological data were available for inclusion in the current assessment. ....	157
Table 2.8.	Percentage of females reported for American eels in various locations, by salinity. ....	158
Table 2.9.	Parameters of the allometric fecundity (F)-length (L) and fecundity-weight (W) relationship for American eels estimated by studies in various locations. The length range of individual eels used in the study and estimated fecundity values are also given. These parameter values apply to length measured in millimeters and weight measured in grams. The unit for fecundity is millions of eggs. ....	159
Table 5.1.	Summary of (A) length (mm) and (B) weight (g) data from New Jersey commercial biosamples. ....	160
Table 5.2.	Length-weight parameters from New Jersey commercial biosamples. ....	160
Table 5.3.	Numbers of American eels available for sampling in the VMRC’s Biological Sampling Program, by gear, 1989–2010. Other gears include fyke net, crab pot, and gill net. ....	161
Table 5.4.	Numbers of American eel samples reported by the MRFSS angler-intercept survey and at-sea headboat survey, by catch type, 1981–2010. ....	162
Table 5.5.	Numbers of American eels that available for biological sampling in the MRFSS angler-intercept survey and at-sea headboat survey, by survey component, 1981–2010. ....	163

Table 5.6.	Estimates of recreational fishery harvest and released alive for American eels along the Atlantic coast, 1981–2010. The precision of each estimate, measured as proportional standard error (PSE), is also given. ....	164
Table 5.7.	Currently active sampling sites for the ASMFC-mandated annual American eel YOY abundance survey. Sites formatted in <b>bold</b> font have been sampled for at least 10 years as of 2010.....	165
Table 5.8.	Summary of GLM analyses used to standardize YOY indices developed from the ASMFC-mandated recruitment surveys. Phi is the overdispersion parameter.....	166
Table 5.9.	Spearman's rank correlation between YOY indices developed from the ASMFC-mandated recruitment surveys. Values formatted in <b>bold</b> font are statistically significant at $\alpha < 0.10$ .....	167
Table 5.10.	Summary of GLM analyses used to standardize fisheries-independent indices developed from non-ASMFC-mandated surveys. Phi is the overdispersion parameter.....	168
Table 5.11.	Summary (A) length and (B) weight information by year from the Upper Delaware, all locations combined.....	169
Table 6.1.	Summary of surveys used in development of region-specific indices of American eel relative abundance. Asterisks (*) denote the ASMFC-mandated recruitment surveys.....	170
Table 6.2.	Spearman's rank correlation between regional YOY indices for American eel. Values formatted in <b>bold</b> font are statistically significant at $\alpha < 0.10$ .....	171
Table 6.3.	Spearman's rank correlation between regional yellow-phase indices for American eel. Values formatted in <b>bold</b> font are statistically significant at $\alpha < 0.10$ .....	171
Table 6.4.	Spearman's rank correlation coefficients ( $\rho$ ) and associated <i>P</i> -values from correlation of region-specific yellow-phase indices and lagged YOY indices for American eel. Values formatted in <b>bold</b> font are statistically significant at $\alpha < 0.10$ .....	172
Table 6.5.	Summary of the number and types of biological data for American eel compiled from past and current research programs along the Atlantic Coast. ....	173
Table 6.6.	Parameter estimates (standard errors in parentheses) of the allometric length (mm)-weight (g) relation fit to available data for American eel by region, sex, and all data pooled. Asterisks (*) denote standard errors that are $\geq 30\%$ of the parameter estimate. ....	173
Table 6.7.	Parameter estimates (standard errors in parentheses) for the linear regression of length (mm) on age (years) fit to available data for American eel by region, sex, and all data pooled. Asterisks (*) denote standard errors that are $\geq 30\%$ of the parameter estimate. ....	174
Table 6.8.	Parameter estimates (standard errors in parentheses) of the von Bertalanffy age-length model fit to available data for American eel by region, sex, and all data pooled. Values of $L_\infty$ represent length in millimeters. Asterisks (*) denote standard errors that are $\geq 30\%$ of the parameter estimate.....	174
Table 6.9.	Parameter estimates (standard errors in parentheses) of the Gompertz age-length model fit to available data for American eel by region, sex, and all data	

	pooled. Values of $L_{\infty}$ represent length in millimeters. Asterisks (*) denote standard errors that are $\geq 30\%$ of the parameter estimate.....	175
Table 6.10.	Parameter estimates (standard errors in parentheses) of the Richard's age-length model fit to available data for American eel by region, sex, and all data pooled. Values of $L_{\infty}$ represent length in millimeters. Asterisks (*) denote standard errors that are $\geq 30\%$ of the parameter estimate.....	175
Table 6.11.	Parameter estimates (standard errors in parentheses) of the logistic age-length model fit to available data for American eel by region, sex, and all data pooled. Values of $L_{\infty}$ represent length in millimeters. Asterisks (*) denote standard errors that are $\geq 30\%$ of the parameter estimate.....	176
Table 6.12.	Parameter estimates (standard errors in parentheses) of the Schnute age-length model fit to available data for American eel by region, sex, and all data pooled. Values of $L_1$ and $L_2$ represent length in millimeters. Asterisks (*) denote standard errors that are $\geq 30\%$ of the parameter estimate.....	176
Table 6.13.	Calculated AIC values (Akaike weights in parentheses) for age-length models fit to available data for American eel by region, sex, and all data pooled. Values in bold indicate the model with the smallest AIC value and largest Akaike weight for the associated dataset. ....	177
Table 6.14.	Result of power analysis for linear and exponential trends in American eel abundance indices over a ten-year period. Power was calculated according to methods in Gerrodette (1987). ....	178
Table 6.14.	<i>Continued</i> . ....	179
Table 6.15.	Results of the Mann-Kendall trend analysis applied to YOY indices developed from the ASMFC-mandated recruitment surveys. $S$ is the Mann-Kendall statistic, $Z_S$ is the test statistic when $n \geq 10$ , $P$ -value is the two-tailed probability for the trend test, and trend indicates the direction of the trend if a statistically significant temporal trend was detected ( $P$ -value $< \alpha$ ; $\alpha = 0.05$ ). NS = not significant. ....	180
Table 6.16.	Results of the Mann-Kendall trend analysis applied to indices developed from non-ASMFC-mandated recruitment surveys. $S$ is the Mann-Kendall statistic, $Z_S$ is the test statistic when $n \geq 10$ , $P$ -value is the two-tailed probability for the trend test, and trend indicates the direction of the trend if a statistically significant temporal trend was detected ( $P$ -value $< \alpha$ ; $\alpha = 0.05$ ). NS = not significant. The length range of observed American eels is shown in parentheses after the life stage if the information was available. ....	181
Table 6.16.	<i>Continued</i> . ....	182
Table 6.17.	Results of the Mann-Kendall trend analysis applied to regional and coast-wide indices of American eel abundance. $S$ is the Mann-Kendall statistic, $Z_S$ is the test statistic when $n \geq 10$ , $P$ -value is the two-tailed probability for the trend test, and trend indicates the direction of the trend if a statistically significant temporal trend was detected ( $P$ -value $< \alpha$ ; $\alpha = 0.05$ ). NS = not significant. ....	183
Table 6.18.	Results of the meta-analysis to synthesize trends for American eel. The meta-analysis techniques are from Manly (2001) where $S_1$ tests whether at least one of the datasets shows a significant decline through time and $S_2$ tests whether there is consensus among the datasets for a decline. $S_2$ incorporates a weight equal to the number of years of the survey, $n$ . The value of $p$ represents the	

	one-tailed $p$ -value from the Mann-Kendall nonparametric test for a decreasing trend through time.....	184
Table 6.19.	Summary statistics from ARIMA model fits to American eel surveys with 20 or more years of data. Q0.25 is the 25th percentile of the fitted values; $P(<0.25)$ is the probability of the final year of the survey being below Q0.25 with 80% confidence; $r_1$ – $r_3$ are the first three autocorrelations; $\theta$ is the moving average parameter; SE is the standard error of $\theta$ ; and $\sigma_c^2$ is the variance of the index.....	185
Table 6.20.	Traffic Light representation of YOY indices developed from the ASMFC-mandated recruitment surveys. The 25th and 75th percentiles used to define the shading for each index series such that positive (white) values are $> 75$ th percentile, neutral (gray) values are between the 25th and 75th percentiles, and negative (black) values are $< 25$ th percentile.....	186
Table 6.21.	Traffic Light representation of indices developed from non-ASMFC-mandated recruitment surveys. The 25th and 75th percentiles used to define the color boundaries for each index series are also shown. The 25th and 75th percentiles used to define the shading for each index series such that positive (white) values are $> 75$ th percentile, neutral (gray) values are between the 25th and 75th percentiles, and negative (black) values are $< 25$ th percentile. ....	187
Table 6.21.	<i>Continued</i> .....	188
Table 6.22.	Traffic Light representation of regional and coast-wide indices of American eel abundance. The 25th and 75th percentiles used to define the shading for each index series such that positive (white) values are $> 75$ th percentile, neutral (gray) values are between the 25th and 75th percentiles, and negative (black) values are $< 25$ th percentile. ....	189
Table 6.23.	Summary of stochastic sensitivity runs conducted for the DB-SRA model.....	190
Table 6.24.	Summarized results from the DB-SRA (A) single and (B) double $M$ models.....	191

## LIST OF FIGURES

Figure 4.1.	Annual U.S. domestic exports of American eels from districts along the Atlantic coast, 1981–2010. Note that the weights of live exports were not available for 1989 to 1992. ....	192
Figure 4.2.	Annual U.S. domestic exports of American eels from districts along the Atlantic coast, 1981–2010. Note that the weights of live exports were not available for 1989 to 1992. ....	192
Figure 4.3.	Commercial glass eel fishery effort in Maine, 1996–2009. Note: the number of harvesters does not equal the sum of the licensed gears since each harvester may license more than one piece of gear. ....	193
Figure 4.4.	Catch per unit effort in the Maine commercial glass eel fishery per licensed gear (upper graph) and per license holder (lower graph). ....	194
Figure 4.5.	Effort in the Maine commercial yellow eel pot fisheries expressed as number of licensees (upper graph) and number of gear days fished (lower graph). ....	195
Figure 4.6.	Standardized catch per unit effort in the Maine commercial yellow eel pot fisheries expressed as pounds per license holder (upper graph) and pounds per pot days (lower graph). ....	196
Figure 4.7.	Standardized effort and CPUE from the Maine commercial silver eel weir fishery. ....	197
Figure 4.8.	Catch-per-unit-effort in New Hampshire commercial eel pot fishery, 1990–2009. Error bars represent $\pm 2$ standard errors. ....	197
Figure 4.9.	Catch-per-unit-effort in Massachusetts commercial eel pot fishery in Southern New England region, 2001–2009. Error bars represent $\pm 2$ standard errors. ....	198
Figure 4.10.	Effort and CPUE in New Jersey’s commercial eel fishery, 1999–2010. ....	198
Figure 4.11.	Delaware commercial fishery annual mean catch per pot-day fished (lbs), 1999–2010. ....	199
Figure 4.12.	Maryland and Delaware commercial fishery eel pot CPUE (pounds/pot) for Coastal Bays, 1992–2010. ....	199
Figure 4.13.	Maryland commercial fishery eel pot CPUE (lbs/pot) and effort (total pots fished), 1992–2010. ....	200
Figure 4.14.	PRFC commercial fishery eel pot CPUE (pounds/pot) and effort (total pots fished), 1988–2010. ....	200
Figure 4.15.	Annual commercial fishery catch rates (pounds/number pots) for American eels harvested by eel pots from the primary tributaries of the Chesapeake Bay and landed in Virginia, by tributary, 1994–2009. ....	201
Figure 4.16.	Total weight and value of American eel commercial landings in the Gulf of Mexico, 1950–1999. Recent landings are confidential. ....	201
Figure 4.17.	Annual commercial seafisheries landings (live weight) of American eel along Canada’s Atlantic Coast summarized by province, 1972–2009. ....	202
Figure 4.18.	Annual commercial freshwater landings (live weight) of American eel along Canada’s Atlantic Coast summarized by province, 1990–2006. ....	202
Figure 4.19.	Annual commercial landings (live weight) of American eel reported by the FAO from Central and South America, 1975–2008. No landings were reported between 1950 and 1974. ....	203
Figure 5.1.	Total commercial landings of American eel along the U.S. Atlantic Coast, 1950–2010. ....	204

Figure 5.2.	Total commercial landings of American eel by old geographic region along the U.S. Atlantic Coast, 1950–2010.....	204
Figure 5.3.	Watershed-based geographic regions used in the current assessment.....	205
Figure 5.4.	Total metric tons (upper graph) and pounds (lower graph) of American eel commercial landings by new geographic region along the U.S. Atlantic Coast, 1950–2010. Note Gulf of Maine and Southern New England are plotted on the secondary axis.....	206
Figure 5.5.	Estimated value of U.S. American eel landings, 1950–2009.....	207
Figure 5.6.	Proportion of Atlantic coast commercial landings by general gear type, 1950–2010.....	207
Figure 5.7.	Trends in the proportion of Atlantic coast commercial landings by general gear type.....	208
Figure 5.8.	Dealer reported commercial glass eel landings in Maine.....	208
Figure 5.9.	Percentage of New Jersey commercial eel landings by gear.....	209
Figure 5.10.	Average length (centimeters) of eels sampled from New Jersey’s commercial harvest.....	210
Figure 5.11.	Predicted weight at length of American eels sampled from New Jersey’s commercial harvest by area for all years combined (upper graph) and by year for all areas combined (lower graph).....	211
Figure 5.12.	Length-frequency distribution of American eels sampled from Virginia's eel pot landings, 1989–2008. No American eels were available for sampling in 2009 or 2010.....	212
Figure 5.13.	Length distribution of American eels sampled from commercial eel pots with and without escape panel, Pamlico River, 1996.....	212
Figure 5.14.	Length frequency distribution of American eels from the St. Johns River system, Florida. Biological sampling was discontinued after 2006.....	213
Figure 5.15.	Weight-length relationship for American eels in the St. Johns River system, Florida, 2002–2006.....	213
Figure 5.16.	Length-frequency of American eels sampled by the MRFSS angler-intercept survey (Type A catch), 1981–2010.....	214
Figure 5.17.	Locations of ASMFC-mandated annual American eel YOY abundance survey sites that have been sampled for at least 10 years, as of 2010.....	215
Figure 5.18.	GLM-standardized index of abundance for YOY American eels caught by Maine's annual YOY survey in West Harbor Pond, 2001–2010. The error bars represent the standard errors about the estimates.....	216
Figure 5.19.	GLM-standardized index of abundance for YOY American eels caught by New Hampshire's annual YOY survey in the Lamprey River, 2001–2010. The error bars represent the standard errors about the estimates.....	216
Figure 5.20.	GLM-standardized index of abundance for YOY American eels caught by Massachusetts' annual YOY survey in the Jones River, 2001–2010. The error bars represent the standard errors about the estimates.....	217
Figure 5.21.	GLM-standardized index of abundance for American eels caught by Rhode Island's annual YOY survey near Gilbert Stuart Dam, 2000–2010. The error bars represent the standard errors about the estimates.....	217

Figure 5.22. GLM-standardized index of abundance for American eels caught by New York's annual YOY survey in Carman's River, 2001–2010. The error bars represent the standard errors about the estimates. ....	218
Figure 5.23. GLM-standardized index of abundance for YOY American eels caught by New Jersey's annual YOY survey in Patcong Creek, 2000–2010. The error bars represent the standard errors about the estimates. ....	218
Figure 5.24. GLM-standardized index of abundance for American eels caught by Delaware's annual YOY survey near the Millsboro Dam, 2000–2010. The error bars represent the standard errors about the estimates. ....	219
Figure 5.25. Annual index of abundance for American eels caught by Maryland's annual YOY survey in Turville Creek, 2000–2010. The error bars represent the standard errors about the estimates. ....	219
Figure 5.26. GLM-standardized index of abundance for American eels caught by PRFC's annual YOY survey in Clark's Millpond, 2000–2010. The error bars represent the standard errors about the estimates. ....	220
Figure 5.27. GLM-standardized index of abundance for American eels caught by PRFC's annual YOY survey in Gardy's Millpond, 2000–2010. The error bars represent the standard errors about the estimates. ....	220
Figure 5.28. Annual index of abundance for American eels caught by Virginia's annual YOY survey in Bracken's Pond, 2000–2010. The error bars represent the standard errors about the estimates. ....	221
Figure 5.29. GLM-standardized index of abundance for American eels caught by Virginia's annual YOY survey in Kamp's Millpond, 2000–2010. The error bars represent the standard errors about the estimates. ....	221
Figure 5.30. GLM-standardized index of abundance for American eels caught by Virginia's annual YOY survey in Wormley Creek, 2001–2010. The error bars represent the standard errors about the estimates. ....	222
Figure 5.31. GLM-standardized index of abundance for American eels caught by South Carolina's annual YOY survey in Goose Creek, 2000–2010. The error bars represent the standard errors about the estimates. ....	222
Figure 5.32. GLM-standardized index of abundance for American eels caught by Georgia's annual YOY survey near the Altamaha Canal, 2001–2010. The error bars represent the standard errors about the estimates. ....	223
Figure 5.33. Annual index of abundance for American eels caught by Florida's annual YOY survey near Guana River Dam, 2001–2010. The error bars represent the standard errors about the estimates. ....	223
Figure 5.34. Map of Little Egg Inlet Ichthyoplankton and Beaufort Inlet Ichthyoplankton Survey study areas. (Adapted from Sullivan et al. 2006.) ....	224
Figure 5.35. GLM-standardized index of abundance for YOY American eels caught by the Little Egg Inlet Ichthyoplankton Survey, 1992–2010. The error bars represent the standard errors about the estimates. ....	224
Figure 5.36. GLM-standardized index of abundance for American eels caught by the Beaufort Inlet Ichthyoplankton Survey, 1987–2003. The error bars represent the standard errors about the estimates. ....	225

Figure 5.37. CPUE (upper graph) and length frequency (lower graph) of American eels caught as bycatch in the MADMF rainbow smelt survey in the Fore and Jones rivers, 2004–2010. ....	226
Figure 5.38. Annual index of abundance for American eels caught by the CTDEP Electrofishing Survey in the Farmill River, 2001–2010. The error bars represent the standard errors about the estimates. ....	227
Figure 5.39. GLM-standardized index of abundance for American eels caught by the Western Long Island Study, 1984–2010. The error bars represent the standard errors about the estimates. ....	227
Figure 5.40. Length distribution of eel collected by Morrison and Secor (2003, 2004) from tidal portion of the Hudson River estuary, 1997–1999. ....	228
Figure 5.41. Length distribution of eel collected by Machut et al. (2007) from six Hudson River tributaries, 2003–2004. ....	228
Figure 5.42. Annual index of abundance for American eels caught by the NYDEC Alosine Beach Seine Survey, 1980–2009. The error bars represent the standard errors about the estimates. ....	229
Figure 5.43. Annual index of abundance for American eels caught by the NYDEC Striped Bass Beach Seine Survey, 1980–2009. The error bars represent the standard errors about the estimates. ....	229
Figure 5.44. GLM-standardized index of abundance for YOY American eels caught by the HRE Monitoring Program, 1974–2009. The error bars represent the standard errors about the estimates. ....	230
Figure 5.45. GLM-standardized index of abundance for yearling and older American eels caught by the HRE Monitoring Program, 1974–2009. The error bars represent the standard errors about the estimates. ....	230
Figure 5.46. Map of Delaware River Recruitment Survey sampling stations (2011). ....	231
Figure 5.47. GLM-standardized index of abundance for American eels caught by NJDFW's Striped Bass Seine Survey, 1980–2009. The error bars represent the standard errors about the estimates. ....	232
Figure 5.48. Lengths of American eels collected in the University of Delaware Silver Eel Study, by sex. ....	232
Figure 5.49. GLM-standardized index of abundance for American eels caught by the Area 6 Electrofishing Survey, 1999–2010. The error bars represent the standard errors about the estimates. ....	233
Figure 5.50. GLM-standardized index of abundance for American eels caught by the Delaware Trawl Survey, 1982–2010. The error bars represent the standard errors about the estimates. ....	233
Figure 5.51. Length frequency data from upper Delaware electrofishing samples (Source: The Nature Conservancy). ....	234
Figure 5.52. Length-weight relationship for Upper Delaware River samples. ....	234
Figure 5.53. American eel abundance trends during 1984 through 2009 from the Delaware Juvenile Finfish Trawl Survey (solid) and PSEG Impingement Monitoring (open). ....	235
Figure 5.54. GLM-standardized index of abundance for American eels caught by PSEG's Trawl Survey, 1970–2010. The error bars represent the standard errors about the estimates. ....	235



Figure 5.55. Length distribution of American eels collected by the Maryland pot survey in Turville Creek, 2009 and 2010. ....	236
Figure 5.56 Length-frequency of American eel downstream migrants collected from the South Fork of the Shenandoah River in Virginia, 2007–2008. (Data Source: Welsh et al. 2009). ....	236
Figure 5.57. Length-frequency of American eel upstream migrants collected from the Millville Dam eel ladder on the lower Shenandoah River, 2006–2008. (Data Source: Zimmerman 2008). ....	237
Figure 5.58. Age-frequency of American eel upstream migrants collected from the Millville Dam eel ladder on the lower Shenandoah River, 2006–2008. (Data Source: Zimmerman 2008). ....	237
Figure 5.59. Maryland Gravel Run survey silver eel length distribution by sex, 2006–2010. ....	238
Figure 5.60. GLM-standardized index of abundance for American eels caught by the MDDNR Striped Bass Seine Survey, 1966–2010. The error bars represent the standard errors about the estimates. ....	238
Figure 5.61. Length-frequency of American eels collected by VDGIF fishery-independent surveys of Virginia water bodies, 1992–2010. ....	239
Figure 5.62. GLM-standardized index of abundance for American eels caught by the VIMS Juvenile Striped Bass Seine Survey, 1967–2010. The error bars represent the standard errors about the estimates. ....	239
Figure 5.63. GLM-standardized index of abundance for American eels caught by the VIMS Juvenile Striped Bass Seine Survey, 1989–2010. The error bars represent the standard errors about the estimates. ....	240
Figure 5.64. Annual length-frequency distributions of American eels collected from tributaries of the Chesapeake Bay during April through September by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 1980–1990. ....	241
Figure 5.66. Annual length-frequency distributions of American eels collected from tributaries of the Chesapeake Bay during April through September by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 2003–2010. ....	243
Figure 5.67. Indices of relative abundance for four size groups of American eels based on data collected from tributaries of the Chesapeake Bay during April through September by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 1980–2010. Error bars represent upper and lower 95% confidence limits. ....	244
Figure 5.68. Length distribution of American eels sampled from the North Anna River, 1990–2006. ....	245
Figure 5.69. GLM-standardized index of abundance for American eels caught by the North Anna Electrofishing Survey, 1990–2009. The error bars represent the standard errors about the estimates. ....	245
Figure 5.70. Length distribution of eels collected by the estuarine trawl survey in North Carolina waters, 1971–2010. ....	246
Figure 5.71. GLM-standardized index of abundance for American eels caught by the NCDMF Estuarine Trawl Survey, 1989–2010. The error bars represent the standard errors about the estimates. ....	246
Figure 5.72. Length distribution of eels sampled in estuarine and freshwater habitats of Northwest Pamlico Sound and Lake Mattamuskeet, North Carolina, 2002–2003 (Cudney 2004). ....	247

Figure 5.73. Length frequency of American eel caught in eel traps at the Roanoke River Dam, North Carolina, 2005–2009 (Graham, Dominion Power, pers. comm.).	247
Figure 5.74. Length distribution of eel collected by the SC Electrofishing Survey, 2001–2010.	248
Figure 5.75. GLM-standardized index of abundance for American eels caught by the SC Electrofishing Survey, 2001–2010. The error bars represent the standard errors about the estimates.	248
Figure 5.76. American eel weight-length relationship for the Suwannee River, Florida, 1996–2008. Years were combined (n = 38).	249
Figure 5.77. Weight-length relationship for American eels in the FL FWCC lake and marsh electrofishing survey.	249
Figure 5.78. Length frequency distribution of American eels in the FL FWCC lake and marsh electrofishing survey. Mean total length was 472 mm.	250
Figure 6.1. GLM-standardized, short-term index of abundance for YOY American eels along the Atlantic Coast, 2000–2010. The error bars represent the standard errors about the estimates.	251
Figure 6.2. GLM-standardized, long-term index of abundance for YOY American eels along the Atlantic Coast, 1987–2009. The error bars represent the standard errors about the estimates.	251
Figure 6.3. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1967–2010 (40-plus-year index). The error bars represent the standard errors about the estimates.	252
Figure 6.4. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1981–2010 (30-year index). The error bars represent the standard errors about the estimates.	252
Figure 6.5. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1991–2010 (20-year index). The error bars represent the standard errors about the estimates.	253
Figure 6.6. Regional indices of YOY abundance for American eels. The error bars represent the standard errors about the estimates.	254
Figure 6.7. Regional indices of yellow-stage abundance for American eels. The error bars represent the standard errors about the estimates.	255
Figure 6.8. Predicted length-weight relation for American eel based on available data, by region.	256
Figure 6.9. Predicted length-weight relation for American eel based on available data, by sex.	256
Figure 6.10. Observed age-length data (circles) and predicted linear age-length relation (solid line) for American eel based on available data, by region and for all data pooled.	257
Figure 6.11. Observed age-length data (circles) and predicted linear age-length relation (solid line) for American eel based on available data, by sex.	258
Figure 6.12. ARIMA model fits to American eel surveys from the Chesapeake Bay region. The dotted line represents the 25th percentile of the fitted values.	259
Figure 6.13. ARIMA model fits to American eel surveys from the Delaware Bay/Mid-Atlantic Coastal Bays region. The dotted line represents the 25th percentile of the fitted values.	260

Figure 6.14. ARIMA model fits to American eel surveys from the Hudson River region. The dotted line represents the 25th percentile of the fitted values. ....	261
Figure 6.15. ARIMA model fits to American eel survey from the South Atlantic region. The dotted line represents the 25th percentile of the fitted values. ....	262
Figure 6.16. U.S. harvest of American eels used in DB-SRA. Light-colored bars indicate years for which harvest was reconstructed. ....	262
Figure 6.17. Estimated exploitable eel biomass from the DB-SRA single $M$ stanza model. ....	263
Figure 6.18. Distribution of estimated $B_{MSY}$ from the DB-SRA single $M$ stanza model. ....	263
Figure 6.19. Estimated exploitable eel biomass from the DB-SRA double $M$ stanza model. ....	264
Figure 6.20. Distribution of estimated $B_{MSY}$ from the DB-SRA double $M$ stanza model. ....	264
Figure 6.21. Stock status for U.S. American eel population based on the DB-SRA double $M$ stanza model. Biomass vs $B_{MSY}$ (upper graph) and annual exploitation (based on median biomass; lower graph) vs $u_{MSY}$ . ....	265
Figure 6.22. Estimated distribution of $u_{MSY}$ from DB-SRA double $M$ stanza model. ....	266

## TERMS OF REFERENCE

1. Evaluate precision and accuracy of U.S. Atlantic Coast fishery-dependent and fishery-independent data used in the assessment, including the following but not limited to:
  - Discuss the effects of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, ageing accuracy, sample size, standardization of indices) on model inputs and outputs.
  - Report standard errors of inputs and use them to inform the model if possible.
  - Justify weighting or elimination of available data sources.
2. Evaluate adequacy, appropriateness, application, and uncertainty of models or other analytical methods for use in the assessment of the species and estimating U.S. Atlantic Coast population benchmarks.
  - Did the model have difficulty finding a stable solution? Were sensitivity analyses for starting parameter values, priors, etc. and other model diagnostics performed?
  - Have the model strengths and limitations been clearly and thoroughly explained?
  - If using a new model, has it been tested using simulated data?
  - Has the model theory and framework been demonstrated and documented in the stock assessment literature?
3. State and evaluate assumptions made for all models and explain the likely effects of assumption violations on synthesis of input data and model outputs.
4. Recommend U.S. Atlantic Coast stock status as related to reference points (if available). For example:
  - Is the stock below the biomass threshold?
  - Is  $F$  above the threshold?
5. 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.

# **1 INTRODUCTION**

## **1.1 Fisheries Management**

### **1.1.1 Management Unit Definition**

The American eel (*Anguilla rostrata*) is one of two catadromous species in North America and historically occurred in all major rivers from Canada through the Brazil. The management unit for American eels under the jurisdiction of ASMFC includes that portion of the American eel population occurring in the territorial seas and inland waters along the Atlantic coast from Maine to Florida.

### **1.1.2 Regulations & Management**

#### **1.1.2.1 Commercial Fishery Management**

The ASMFC American Eel Management Board first convened in November 1995 and finalized the Fishery Management Plan (FMP) for American Eel in November 1999 (ASMFC 2000a). The major goal of the FMP is to conserve and protect the American eel resource to ensure ecological stability while providing for sustainable fisheries. Each state is responsible for implementing management measures within its jurisdiction to ensure the sustainability of the American eel population that resides within state boundaries. The FMP requires that all states and jurisdictions implement an annual young-of-year (YOY) abundance survey by 2001 in order to monitor annual recruitment of each year's cohort. In addition, the FMP requires all states and jurisdictions to establish a minimum recreational size limit of six inches and a recreational possession limit of no more than 50 eels per person, including crew members involved in party or charter (for-hire) employment for bait purposes during fishing. Recreational fishermen are not allowed to sell eels without a state license. Commercial fisheries management measures stipulate that states and jurisdictions shall maintain existing or more conservative American eel commercial fishery regulations for all life stages. States with minimum size limits for commercial eel fisheries must retain those minimum size limits, unless otherwise approved by the American Eel Management Board. Current commercial fisheries regulations can be found in Table 1. In addition, the ACCSP will require a comprehensive permit/license system for all commercial dealers and fishermen.

##### **1.1.2.1.1 Glass Eel / Elver Fishery**

Glass eel and elver fisheries along the Atlantic Coast are prohibited in all states except Maine and South Carolina. In recent years, Maine is the only state reporting significant glass eel and elver harvest. Maine implemented regulatory changes that increased elver and large eel license fees in 1996. In addition to generating revenue for enforcement and eel research, these changes set both a harvest season and closures during the harvest season. The number, type, and methods of operation of gear units available to each fisher were limited to control fishing effort, as were the allowable fishing areas, and fishing within 46 m of a dam was prohibited (CAEMM 1996). South Carolina could not determine participation in the elver and glass eel fishery in coastal waters until a limited entry permit system was instituted in 1996 (B. McCord, South Carolina Department of Natural Resources, pers. comm.). Ten permits are available to both instate and out-of-state residents. Permit holders abide by monthly effort controls and must report their harvest. There was interest in developing commercial glass eel fisheries in Connecticut, New

Jersey, Virginia, and Florida. Connecticut regulations were minimal until 1996 when the state defined the glass eel as less than 10 cm in length, instituted a glass eel fishing season with a weekly closed period, limited traps, and required monthly catch reporting by logbook. Connecticut prohibited the take or attempted take of glass eels, elvers, and silver eels in 2002. The glass eel and elver fishery in New Jersey was unregulated prior to 1997 when it was restricted to dip nets only and a fishery season was implemented with a Sunday closure. The glass eel and elver fishery was closed in 1998. In Virginia, a six-inch minimum size was passed in 1977. Florida passed regulations in 1998 such that the eel fisheries operate under gear restrictions that do not allow the landings of eels under six inches.

Prior to the implementation of the FMP, Maine was the only state compiling glass eel and elver fishery catch statistics. Under the FMP, all states are now required to submit fishery-dependent information. Poaching of glass eels and elvers is believed to be a serious problem in many states, but enforcement of the regulations is poor due to the nature of the fishery (very mobile, nighttime operation) and low administrative priority.

#### **1.1.2.1.2 Yellow / Silver Eel**

The economically important yellow/silver American eel fishery in Maine occurs in both inland and tidal waters. Large eel fisheries in southern Maine are primarily coastal pot fisheries managed under a license requirement, minimum size limit, or gear and mesh size restrictions. New Hampshire has monitored its yellow eel fishery since 1980; effort reporting in the form of trap haul set-over days for pots or hours for other gears has been mandatory since 1990. Small-scale, commercial eel fisheries occur in Massachusetts and Rhode Island and are mainly conducted in coastal rivers and embayments with pots during May through November. Connecticut has a similar small-scale, seasonal pot fishery for yellow eels in the tidal portions of the Connecticut and Housatonic rivers (S. Gephard, Connecticut Department of Energy and Environmental Protection, pers. comm.). All New England states presently require commercial eel fishing licenses and maintain trip level reporting.

Licensed eel fishing in New York occurred primarily in Lake Ontario (prior to the 1982 closure), the Hudson River, the upper Delaware River (Blake 1982), and in the coastal marine district. A slot limit (greater than 6 inches and less than 14 inches to limit PCB concentration) exists for eels fished in the tidal Hudson River (from the Battery to Troy and all tributaries upstream to the first barrier), Lake Ontario, and St. Lawrence strictly for use as bait or for sale as bait only. Due to PCB contamination of the main stem, commercial fisheries have been closed on the freshwater portions of the Hudson River and its tributaries since 1976. In 1995, New York approved a size limit in marine waters. New Jersey fishery regulations require a commercial license, a minimum mesh, and a minimum size limit. A minimum size limit was set in Delaware in 1995. Delaware mandated catch reporting in 1999 and more detailed effort reporting in 2007.

Maryland and Virginia have primarily pot fisheries for American eels in Chesapeake Bay. Large eels are exported whereas small eels are used for bait in the crab trotline fishery. Catch reports were not required in Virginia prior to 1973 and Maryland did not require licenses until 1981. Effort reporting was not required in Maryland until 1990.

North Carolina has a small, primarily coastal pot fishery. A trip ticket system began in 1994 and a commercial logbook system began in 2007. The majority of landings come from the Albemarle Sound area and additional landings reported from the Pamlico Sound and “other areas”. No catch records are maintained for freshwater inland waters, although landings for inland areas may be

included under “other areas” reported by the state if brokered by a NCDMF-licensed dealer. South Carolina instituted a permitting system over ten years ago to document total eel gear and commercial harvest. Traps, pots, fyke nets, and dip nets are permitted in coastal waters. Fishing for eels in coastal waters is often conducted under the guise of fishing for crabs.

American eel fishing in Georgia was restricted to coastal waters prior to 1980 when inland fishing was permitted (Helfman 1984). Catch, but not effort, data are available because no specific license is required to fish eels. The Florida pot fishery has a minimum mesh size requirement in the fishery and it is operated under a permit system.

### **1.1.2.2 Recreational Fishery**

Few recreational anglers directly target American eels and most landings are incidental when anglers are fishing for other species. Eels are often purchased by recreational fishermen for use as bait for larger sport fish such as striped bass, and some recreational fishermen may catch their own eels to utilize as bait. Current recreational management regulations can be found in Table 1.2. South Carolina is currently in the process of changing their recreational regulations to include a six-inch minimum size and a fifty-fish creel limit.

## **1.2 Stock Assessment History**

In 2005, a stock assessment for American eel was conducted by the ASMFC and reviewed by a panel of independent experts (ASMFC 2005). The peer review panel recognized sufficient shortcomings with the assessment to warrant additional action prior to its use for future technical and management purposes (ASMFC 2006a). The 2005 stock assessment was not accepted by the Board; therefore, the stock status of American eel is still deemed unknown by the ASMFC.

At the February 22, 2006 meeting of the ASMFC American Eel Management Board, the American Eel Stock Assessment Subcommittee and Technical Committee were tasked with reviewing the recommendations from the peer review advisory report and recommending a follow-up plan. Subsequently, a report was issued in October of 2006 containing updated datasets and the short-term analyses suggested by the review panel (ASMFC 2006b). This stock assessment represents the most recent work performed by the ASMFC to ascertain stock status since 2006.

## **1.3 Petitions for ESA Listing**

In response to the extreme declines in American eel abundance in the Saint Lawrence River-Lake Ontario portion of the species’ range, the ASMFC requested that the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) conducted a status review of American eels in 2004. The ASMFC also requested an evaluation of a Distinct Population Segment (DPS) listing under the Endangered Species Act (ESA) for the Saint Lawrence River/Lake Ontario and Lake Champlain/Richelieu River portion of the species range, as well as an evaluation of the entire Atlantic coast American eel population. A preliminary status review conducted by USFWS determined that American eel was not likely to meet the requirements of DPS determinations. However, the USFWS initiated a coast-wide status review of the American eel in coordination with the NMFS and ASMFC. At this same time, two private citizens submitted a petition to the USFWS and NMFS to list American eel under the ESA.

In February 2007, the USFWS announced the completion of a Status Review for American eel (50 CFR Part 17; USFWS 2007). The report concluded that protecting eels as an endangered or threatened species was not warranted. The USFWS did note that while the species' overall population was not in danger of extinction or likely to become so in the foreseeable future, the eel population has "been extirpated from some portions of its historical freshwater habitat over the last 100 years...[and the species abundance has declined] likely as a result of harvest or turbine mortality, or a combination of factors".

In 2010, the Center for Endangered Species Act Reliability filed a petition to the USFWS to consider listing the American eel on the endangered species list. The proposal is based on new information that has become available since the last status review. In September 2011, the USFWS published a positive 90-Day Finding, which stated that the petition contained enough information to warrant conducting a status review (USFWS 2011). The proposed rule is expected to be published in 2012 after USFWS completes the status review.

## **2 LIFE HISTORY**

American eels are found from the southern tip of Greenland, Labrador and the northern Gulf of St. Lawrence in the north, south along the Atlantic and Gulf coasts of North America and eastern Central America to the northeast coast of South America, and into the inland areas of the Mississippi and Great Lakes drainages (Tesch 1977). The American eel is regarded as a single, panmictic breeding population. American eels are found in a variety of habitats throughout their life cycle, including the open ocean, large coastal tributaries, small freshwater streams, and lakes and ponds. They are opportunistic feeders that will eat, depending on their life stage, phytoplankton, zooplankton, insects, crustaceans, and fish. Individuals grow in freshwater or estuarine environments for anywhere from 3 to 30 or more years before maturing and returning to the ocean as adults to spawn once and die.

American eels are confronted with many environmental and human-induced stressors which affect all life stages and may reduce survival. Since all eel mortality is pre-spawning, reproduction can be reduced by these cumulative pressures. Commercial harvest occurs at all American eel life stages (glass, elver, yellow, and silver). Blockages and obstructions that limit upstream migration of American eels have reduced habitat availability and limited the range of the species. Dams may also limit or delay downstream movements of spawning adults. Additionally, downstream mortality may be caused by hydroelectric facilities by impingement or turbine passage. Freshwater habitat degradation resulting in reduced food productivity increases mortality of the freshwater life stages. Predation by fish, birds, and mammals can impact eel populations during all life stages. The non-native swim bladder parasite, *Anguillicoloides crassus*, can decrease swimming ability and reduce the silver eel's ability to reach the spawning grounds. Contaminants also may reduce the reproductive success of American eels because they have a high contaminant bioaccumulation rate (Couillard et al. 1997). Oceanographic changes influencing larval drift and migration may reduce year-class success. American eel, as a panmictic species, could be particularly vulnerable to drastic oceanic variations. An understanding of the requirements of the American eel's different life stages is needed to protect and manage this species.



## 2.1 Stock Definitions

The American eel is a panmictic species, with a single spawning stock that reproduces in the Sargasso Sea. Eel larvae (leptocephali) are randomly dispersed by ocean currents along the Atlantic coasts of northern South, Central, and North America. Genetic research indicates that there is no reproductive isolation of American eels migrating from the Atlantic Coast. Further, any genetic differentiation is a result of natural selection upon a particular cohort within a geographic area rather than actual genetic differences within the species (Awise et al. 1986; Wirth and Bernatchez 2003; Cote et al. 2009).

## 2.2 Migration Patterns

American eels may travel thousands of miles in their lifetime. They are a catadromous fish that spawn in the Sargasso Sea, and the larvae drift on ocean currents until they reach the eastern seaboard of North America. Young eels actively swim upstream to reach estuarine and freshwater habitats, sometimes hundreds of miles upriver. The young eels spend between 3 and 30 or more years in estuarine or freshwater habitats before maturing and migrating back downstream and to the Sargasso Sea to spawn.

Spawning in the Sargasso Sea occurs over a large area from about 19.5°N to about 29°N and 52°W to 79°W (McCleave et al. 1987). Although spawning or mature American eels have never been observed at sea, spawning is thought to occur in the frontal zone and to the south within this region (Kleckner et al. 1983; McCleave et al. 1987; Munk et al. 2010). Based on collections of leptocephali, spawning is assumed to occur from mid-February through April (McCleave et al. 1987).

Once the eggs hatch, the leptocephali use passive transport in the upper 350 m of the currents to begin their migration to the coasts of the western Atlantic (Kleckner and McCleave 1982, 1985; Munk et al. 2010). Most American eel leptocephali are transported west by the Florida Current from the Sargasso Sea and then north on the Gulf Stream Current (Kleckner and McCleave 1982; McCleave 1993) to reach the coast of North America. Leptocephali spend up to 15 months in the ocean before they reach the Atlantic Coast of the U.S. (Kleckner and McCleave 1985). Because of ocean currents, leptocephali are deposited to the Continental Shelf of North America at higher densities from Cape Hatteras north to Quebec (Kleckner and McCleave 1985).

American eels reach the eastern coast of North America in the glass eel stage and begin their upstream migrations. Glass eels actively swim from the Gulf Stream, and it takes 60 to 110 days to reach the coasts of New Jersey and North Carolina, respectively (Powles and Wharlen 2002; Wuenschel and Able 2008). Timing of inshore migration occurs later in the year with increasing latitude. In the southeast U.S., glass eel migrations occur during the late winter and in the Canadian provinces, migration occurs as late as August (Table 2.1). Glass eels and elvers use selective tidal stream transport for migrating upriver (Sheldon and McCleave 1985; McCleave and Wippelhauser 1987). In the St. Lawrence Estuary, eels are able to travel upstream at the rate of 10 to 15 km/day (Dutil et al. 2009), but the speed is reduced to an average of 1 to 2 km/day further up the St. Lawrence River (Verndon and Desrochers 2003). Migration typically occurs at night and is related to reaching a minimum threshold temperature in rivers (usually 10 to 12 degrees Celsius), and the occurrence of a full or new moon and freshets (Haro and Krueger 1988; Martin 1995; Sorensen and Bianchini 1986; Jessop 2003; Schmidt et al. 2009; Sullivan et al. 2009).

Upstream migration typically occurs in the glass eel and elver stage, but yellow American eels sometimes continue upstream migrations (Jessop et al. 2008). Eels settle in a diversity of habitats, ranging from estuaries to freshwater habitats hundreds of miles from the ocean. When upstream migration is complete, eels are usually in the yellow phase and typically set up relatively small home ranges with some exhibiting local seasonal migrations (Oliveira 1997; Jessop et al. 2008; Hammond and Welsh 2009).

Yellow-phase American eels spend 3 to 30 or more years inland before becoming mature, entering the silver phase. Once silver, eels migrate downstream toward the Sargasso Sea. The timing of silver eel downstream migration occurs on a latitudinal cline, with eels leaving the Canadian Provinces in summer through fall and from winter through early spring in the southern U.S. (Table 2.2). During downstream migration, silver eels typically move at night during the darker moon phases, high water flows, and decreasing water temperatures (Hain 1975; Winn et al. 1975; Euston et al. 1998; Haro et al. 2003; Barber 2004; Brown et al. 2009; Welsh et al. 2009). Downstream migrants use tidal transport and travel near the surface but do make vertical migrations (Parker and McCleave 1997). Ocean migrations of silver eels to the Sargasso Sea are thought to take place in the upper few hundred meters of the water column where differences in water masses are most distinct (McCleave et al. 1987).

## **2.3 Life Cycle**

American eels undergo six distinct life stages. The life cycle begins when the eggs hatch and leptocephali (larvae) are carried by ocean currents from the spawning grounds in the Sargasso Sea. The prevailing currents along coastal areas disperse the leptocephali, which metamorphose into glass eels on the continental shelf. Glass eels move toward inland areas and become pigmented elvers before or during their entry into coastal estuaries. Elvers and yellow eels settle in habitats ranging from estuaries to far upstream freshwater reaches. Eels reach the silver stage at maturity and return to the Sargasso Sea, then spawn once and die.

## **2.4 Life Stages**

### **2.4.1 Egg**

American eels spawn in the winter and early spring in the Sargasso Sea, which is a large portion of the western Atlantic Ocean east of the Bahamas and south of Bermuda. Although no eggs have ever been collected in the Sargasso Sea, it is likely they hatch in the vicinity of the spawning area. Hatching probably occurs within a week of spawning, based on egg incubation times for the Japanese eel, *Anguilla japonica* (Kagawa et al. 2005). Spawning is thought to occur between the months of February and April (McCleave et al. 1987; McCleave 2008), based on collections of leptocephali. There is no information available on the required environmental conditions for the eggs.

### **2.4.2 Leptocephali**

After hatching and a brief pre-larval stage, American eels enter a larval or leptocephali stage. The leptocephali are shaped like a willow leaf, laterally compressed, and transparent. Sampled leptocephali have been less than 5 mm total length and up to 70 mm total length and remain in the ocean for 8 to 15 months (Kleckner and McCleave 1985). They are passively transported within ocean currents, and the spatial and temporal distribution of larvae is a result of oceanic

circulation patterns. Leptocephali are positively buoyant allowing them to stay in surface waters where food is more abundant (Tsukamoto et al. 2009). They undergo vertical migrations while in the ocean, being concentrated in the upper 140 m at night and upper 350 m during the day (Kleckner and McCleave 1982; McCleave et al. 1987). Leptocephali grow rapidly from February to October and then growth slows or stops after October. Total lengths of leptocephali increase in the Gulf Stream Current moving north from Florida to North Carolina along the Atlantic Coast (Kleckner and McCleave 1982). At sea, probably at the edge of the continental shelf, the leptocephali undergo a metamorphosis into the glass eel stage.

### **2.4.3 Glass Eel**

The glass eel life stage of American eels begins when the leptocephali metamorphose at sea, on or near the continental shelf (Kleckner and McCleave 1985). Metamorphosis from leptocephali occurs from 6 months (Wang and Tzeng 1998) to 12 months post-hatch (Kleckner and McCleave 1985), usually between the months of October and March. Estimates from otolith ageing indicate metamorphosis from leptocephali to glass eel occurs between 132 and 214 days post-hatch, with duration of metamorphosis ranging from 18 to 80 days (Wang and Tzeng 1998; Arai et al. 2000). Glass eels reach the eastern shores of North America 30 to 80 days after metamorphosis (at age 220 to 284 days; Wang and Tzeng 1998).

The determination of spawning and metamorphosis dates from glass-stage American eel otoliths is somewhat problematic. When estimating hatching dates from back-calculation of otoliths, the spawning season appears to be early August to early October, not corresponding with estimated spawning periods (February to April) based on ocean collection of leptocephali (Kleckner and McCleave 1982). This discrepancy, possibly due to some resorption of the otolith during metamorphosis, indicates that using otolith ageing to back calculate hatching dates of eels may not be accurate (McCleave 2008).

When American eel leptocephali transform into glass eels, they experience a decrease in body length and weight due to loss in water concentration and increase in body thickness (Fahay 1978). Glass eels are transparent with elongated, cylindrical bodies and usually range in length from 48 to 65 mm (Hardy 1978; Kleckner and McCleave 1985). They actively migrate toward land and enter rivers between late winter and summer, with timing related to latitudinal distribution (Table 2.1). Glass eel migration occurs earlier in the southern portion of the range and later in the northern portion. Glass eels are also smaller in southern areas (mean lengths 47.8 mm to 49.0 mm) than in northern areas (mean lengths 58.5 mm to 60.0 mm; Wang and Tzeng 1998, 2000).

Glass-stage American eels arrive into estuaries at 220 to 284 days old, with the youngest glass eels arriving in estuaries in the middle of their range and older glass eels arriving in estuaries at the northern and southern ends of their range (Wang and Tzeng 1998). Glass eels ascend estuaries by drifting on flood tides and holding their position near the bottom on ebb tides, but they also swim upstream along the shore in both tidal and non-tidal waters (Barbin and Krueger 1994). Upstream migration with the glass eel is likely influenced by the detection of the odor of freshwater (Facey and Van Den Avyle 1987; Sullivan et al. 2006).

### **2.4.4 Elver**

The elver life stage of American eels occurs when the glass eels ascend into brackish or freshwater and become pigmented. Elvers are brown in color and are usually fully pigmented at

65 mm to 90 mm in length (Hardy 1978), although pigmented American eel less than 65 mm have been observed in Florida (J. Crumpton, Florida Game and Fresh Water Fish Commission, pers. comm.). Pigmentation is not well correlated with elver size (Haro and Krueger 1988; Wang and Tzeng 2000). Elvers are generally larger in northern locations (Haro and Krueger 1988), and this may be due to additional growth during the extended period in the glass eel phase (62 to 80 days) in the northern part of the range compared to the southern part of the range (32 to 34 days; Wang and Tzeng 1998). Higher condition elvers arrive earlier and colonize upstream habitats, and lower condition elvers arrive later in the season and stay in estuaries (Jessop 1998; Sullivan et al. 2009).

Elvers are active at night and burrow during the day. They move into the water column on flood tides and return to the bottom during ebb tides (McCleave and Kleckner 1982). They swim upstream, drawn by changes in water chemistry and river current velocities (Facey and Van Den Avyle 1987). Upstream migration of glass eels and elvers can occur over a broad period of time from May (during peak migration) through October (Richkus and Whalen 1999). The migration occurs earlier in the southern portion of its range and later in the northern portion (Table 2.1; Helfman et al. 1984a; McCleave and Kleckner 1982).

#### **2.4.5 Yellow Eel**

The yellow eel phase is the last developmental stage of the American eel prior to reaching maturity. By the age of two years, most eels are in the yellow phase. They resemble elvers in body shape and typically have skin coloration with various hues of yellow, brown, and green. They inhabit bays, estuaries, rivers, streams, lakes, and ponds. Depending on where they cease their upstream migration, some yellow eels reach the extreme upper portions of the rivers while others stay behind in the brackish areas. Catadromy is not a requirement for completing the life cycle of the eel as many eels live their entire yellow phase in estuarine or oceanic water (Tsukamoto et al. 1998; Morrison et al. 2003; Lamson et al. 2006). The timing and duration of yellow eel upstream migration is watershed specific and can occur over a broad period of time. Most eels migrate upstream during their first years of life and then establish a home range where they live and grow until maturity. However, a portion of yellow eels continue migrating upstream until they reach sexual maturity (Richkus and Whalen 1999), and other yellow eels migrate repeatedly between fresh and brackish water throughout the yellow stage (Morrison et al. 2003; Jessop et al. 2006; Thibault et al. 2007). Yellow eels typically establish relatively small home ranges, indicated by recaptures frequently occurring within 1 km of the original capture location (Gunning and Shoop 1962; Bozeman et al. 1985; Ford and Mercer 1986; Dutil et al. 1988; Morrison and Secor 2003; Thibault et al. 2007; Cairns 2009). Yellow eels will also return to their original capture location after being displaced (Parker 1995; Lamothe et al. 2000).

American eels become sexually differentiated in the yellow phase by the time they reach 270 mm (Oliveira and McCleave 2000). In the northern portion of their range, female eels mature at greater ages and sizes than in the southern portion (Table 2.2; Helfman et al. 1987). Female eel size and age also increases with increased distance from the ocean within river systems (Table 2.3; Smogor et al. 1995; Goodwin and Angermeier 2003; Morrison and Secor 2003; Owens and Gear 2003). Male eels do not exhibit latitudinal differences in size, with most males mature at less than 400 mm. However, male eels from the northern part of the range take longer to mature than in the southern part of the range (Jessop 2010).

#### 2.4.6 Silver Eel

The silver stage of American eels occurs when yellow eels undergo several physiological changes as they become sexually mature, including: (1) changing color from yellow/green to metallic, bronze/black, (2) fattening of the body, (3) thickening of the skin, (4) enlargement of the eye and change in visual pigment, (5) increased length of the capillaries in the rete of the swim bladder, (6) change in gill structure for osmoregulation in sea water, (7) digestive tract degeneration, (8) enlarging of the pectoral fins, and (9) high percentage of late stage oocyte development (reviewed by Dutil et al. 1987; Facey and Van Den Avyle 1987; McGrath et al. 2003a). Yellow eels begin the transformation into silver eels in their freshwater and estuarine habitats and finish the transition between estuaries and the open ocean (Wenner 1973; Facey and Van Den Avyle 1987).

Size at maturation is different between male and female American eels. Females, on average, are 1.9 times larger than males at maturity (Jessop 2010). Silver male eels are the same size regardless of where they are collected within their geographic range (Jessop 2010). Average male sizes are typically between 300 and 350 mm (Wenner and Musick 1974; Winn et al. 1975; Foster and Brody 1982; Facey and Helfman 1985; Oliveira 1999; Oliveira and McCleave 2000; Goodwin and Angermeier 2003; Barber 2004; Jessop et al. 2009). Maximum male size has been reported as 503 mm (Dolan and Power 1977), but generally mature males are less than 400 mm.

The size of female American eels increases with distance from coastal waters (Ingraham 1999; Goodwin and Angermeier 2003; Morrison and Secor 2003; Jessop 2010). Females may reach maturity at 350 mm in estuarine areas and usually do not exceed 1,200 mm in inland areas. Large female silver eels (greater than 900 mm) are common in the St. Lawrence River (Fournier and Caron 2001; Verreault 2002; McGrath et al. 2003a; Tremblay 2009), but eels exceeding that size are also likely to be found in inland areas of the U.S. as indicated by collections in the Shenandoah River, Virginia (Euston et al. 1998; Goodwin and Angermeier 2003).

Timing of downstream migration for silver-phase American eels varies with latitude (Table 2.2). Silver eels begin their seaward spawning migration from Canadian and New England tributaries during late summer through fall (Dutil et al. 1987; Ingraham 1999; Haro et al. 2003; McGrath et al. 2003a; Brown et al. 2009). Silver eel emigration from a small river in southern Delaware peaked in September, usually in the days following a heavy rainfall (Barber 2004). In the southeastern U.S., silver eel migrations typically occur in the winter or early spring (Harrell and Loyacano 1982; Helfman et al. 1984a; Facey and Helfman 1985). Silver eel emigration at a particular location is likely based on both sex-specific length (rather than age) and distance from coastal waters (Helfman et al. 1987; McGrath et al. 2003a; Morrison and Secor 2003; Tremblay 2009).

American eels migrate long distances to the spawning grounds in the Sargasso Sea. Lake Ontario silver eels travel more than 4,500 km to spawn. One migrating silver eel swam 150 km in two days (Welsh et al. 2009), showing considerable vertical movements in the water column but no behavioral changes associated with diel or tidal cycles (Stasko and Rommel 1977). Little is known about the oceanic spawning migration or the means by which the spawning grounds are located by the eels (Miles 1968). American eels may use the geo-electrical fields generated by ocean currents for orientation (Rommel and Stasko 1973). The depth at which American eels migrate in the ocean has been hypothesized to vary with light intensity and turbidity (Edel 1976). Migration has been suggested to occur within the upper few hundred meters of the water column (Kleckner et al. 1983; McCleave and Kleckner 1985). However, Robins et al. (1979)

photographed two *Anguilla* eels, believed to be pre-spawn American eels, at depths of about 2,000 m (on the floor of the Atlantic Ocean) in the Bahamas. No information exists on the spawning requirements, behavior, or the exact location of spawning within the Sargasso Sea. Adult eels are believed to spawn in the winter and early spring and perish after spawning.

The age of American eels tends to increase moving upstream in tributaries away from the ocean. In the Gulf of St. Lawrence, freshwater eels took 2.4 times as long to reach maturity than their brackish water counterparts (Lamson et al. 2009). In the Hudson River, brackish water female silver eels were 5 to 8 years old, while female silver eels from upstream were 17 to 20 years old (Morrison and Secor 2003). In the lower Potomac River, mature female eels ranged from 5 to 11 years old, but the upstream tributary had females ranging from 10 to 19 years (Goodwin and Angermeier 2003).

Male American eels are typically younger than female eels at maturity (Table 2.2). In Georgia, mean age of silver eels was 5.5 years for males and 8.6 years for females (Facey and Helfman 1985). In the Indian River, Delaware mean silver male age was 7.4 years and 12 years for females (Barber 2004). In Rhode Island, mean silver male age was 10.9 years compared to 12.8 years for silver females (Oliveira 1999). In Nova Scotia, silver males averaged 12.7 years and silver females averaged 19.3 years (Jessop 1987).

## **2.5 Life History Characteristics**

### **2.5.1 Age**

The age of American eels can be determined by taking transverse sections of the sagittal otoliths. Two otolith processing techniques (embedding and sectioning or grinding and polishing) are accepted ageing methods by the ASMFC (ASMFC 2001). American eel otolith ageing methods have been described by Liew (1974), Chisnall and Kalish (1993), and Oliveira (1996).

Several studies have attempted to use daily growth rings to estimate American eel age in the first years of life (Arai et al. 2000; Wang and Tzeng 2000). This method does not accurately estimate age (Tesch 1998) because back-calculation does not reflect the assumed spawning season (McCleave 2008). Using daily growth rings to estimate age is problematic because some of the otolith is lost or resorbed during metamorphosis from leptocephali to glass eel (Cieri and McCleave 2000).

American eels are roughly age one when they reach continental waters, they are typically in the elver stage during age two, and then they become yellow eels by age three. American eels remain in the yellow phase for a variable length of time related to size, sex, and geographic location (Jessop 2010; see also section 2.4.5), until they reach sexual maturity.

Maximum ages tend to be younger in the southern portion of the American eel's distribution and older in the northern areas (Jessop 2010). In the Altamaha River, Georgia, female silver eels were 3 to 6 years (Helfman et al. 1984b). Barber (2004) observed silver female eels ranging from 7 to 20 years in an Atlantic Coast tributary in Delaware. In Nova Scotia, mature female eels ranged from 8 to 43 years (Jessop 1987), and they average 20 years in the St. Lawrence River (Tremblay 2009).

Maturation from the yellow to silver phase in American eels occurs as early as age 2 and as late as age 30 or older (Michener and Eversole 1983; Jessop 1987). Timing of sexual maturity in the

yellow eel has been correlated with sex and specific size ranges and varies considerably along their geographic range (Jessop 2010). Maturity typically occurs at younger ages in the southern portion of the range, and age at maturation increases with increasing latitude (Table 2.2). Female eels reach maturity on average between 5 and 8 years in South Carolina and Georgia (Michener and Eversole 1983; Facey and Helfman 1985), while the average age in the St. Lawrence River is around 20 years (Verreault 2002; Casselman 2003; Tremblay 2009). Males reach maturity typically in 5 years or less in areas from the Chesapeake Bay and south (Foster and Brody 1982; Harrell and Loyacano 1982; Hansen and Eversole 1984; Facey and Helfman 1985), and in coastal areas of Maine and Canada, mean age at maturity for males is about 12 years (Jessop 1987; Oliveira and McCleave 2000).

### **2.5.2 Growth**

During the first year post-hatch, American eels drift on the ocean currents as leptocephali and have similar growth rates throughout their distribution. Estimates of growth rates for the first year of life in the ocean range from 0.187 mm/day (Tesch 1998) to 0.45 mm/day (Arai et al. 2000). Total length decreases during the metamorphosis from leptocephali to glass eel.

Glass-stage American eels have a higher growth rate in the southern portion of their range compared to the north (Wang and Tzeng 1998). In a study comparing glass eels collected in North Carolina and New Brunswick, growth rates were similar for the first 10 to 15 daily growth rings, but later growth was faster in North Carolina than New Brunswick (Powles and Wharlen 2002). Glass eels and elvers also grow faster in brackish water compared to freshwater (Cote et al. 2009).

Glass-stage American eels decrease in total length during transformation to elver stage. The size of elvers at transformation from the glass eel stage increases with distance from spawning ground (Haro and Krueger 1988; Jessop 2010). Elver growth rates are higher than rates for yellow eels, averaging 57 mm/year during their first two years (one year oceanic and one year freshwater) and reaching about 127 mm after the first year in freshwater (Bigelow and Schroeder 1953; Machut et al. 2007).

Once American eels reach the yellow stage, growth is highly variable and is based on sex, age, latitude, salinity, and season (Tables 2.4 and 2.5). Female eels have higher growth rates than males (Helfman et al. 1984a; Fenske et al. 2010; Jessop 2010). In Maine, female eels grew faster than males and rates were noticeably different based on sex at year 4 (Oliveira and McCleave 2002). In Rhode Island, eels larger than 400 mm (females) had a growth rate of 62 mm/yr, compared to the pooled growth rate of 30 mm/year for smaller eels (Oliveira 1997). In the Chesapeake Bay, female eels had a mean growth rate of 71.4 mm/year compared to a growth rate of 64.2 mm/year for males (Fenske et al. 2010). In Charleston Harbor, male eels were smaller than female eels in each age class (Michener and Eversole 1983).

Because brackish waters are generally more productive than freshwater areas, American eels in estuarine or brackish water grow faster than their freshwater counterparts (Helfman et al. 1984a; Cairns et al. 2004; Jessop et al. 2008; Cairns 2009; Jessop et al. 2009; Lamson et al. 2009; Fenske et al. 2010). In the Hudson River, eels grow two to three times faster in brackish water than in fresh or salt water (Morrison and Secor 2003). Estuarine eels are more likely to have food in their stomachs than their freshwater counterparts, which may result in the lower growth rates of eels from freshwater habitats (Thibault et al. 2007). Although freshwater eels have lower

growth rates, they are generally longer as you progress farther inland because of increased residency times (Goodwin and Angermeier 2003). Dams can impact eel growth when progressing inland. Eels above dams grow faster than eels at the base of dams, suggesting growth may be density dependent (Strickland 2002; Machut et al. 2007).

Slower growth occurs in more northern portions of the American eel's distribution compared to the south (Helfman et al. 1984; Richkus and Whalen 1999; Jessop 2010). However, female eels reach a larger maximum size in the northern portion of their range compared to the south (Jessop 2010). Male maximum size is the same throughout their distribution (Jessop 2010). Eel growth is related to seasons, with most growth occurring during spring through fall and very little growth in the winter (Helfman et al. 1984). The shorter growing seasons in the higher latitudes may explain why eels experience slower growth in the northern portions of their range.

Growth rates are highly variable among fish within the same watershed and of the same sex thus total length is not an accurate predictor of age. In the Hudson River, 50-cm long American eels ranged in age from 5 to 29 years (Morrison and Secor 2003). Growth rates decline with age (Jessop et al. 2009) from an average rate of 57 mm/year in the first year of freshwater residence to 25 mm/year for age-20+ eels (Machut et al. 2007). Reaching a predetermined size within a location, regardless of age, may be the most influential factor in inducing sexual maturity (Jessop et al. 2004; Jessop et al. 2009).

Published literature refers to growth rates for American eels derived from measured growth in the field or back-calculated lengths from otolith analysis. Growth rates derived from the same fish using both methods can be very different. Typically, growth measured directly is higher than that derived from otolith back calculation for the same geographic location (Table 2.4; Helfman et al. 1984; Morrison and Secor 2003).

Published length-at-age (Table 2.6) and length-weight (Table 2.7) relationships vary by geographic location.

### **2.5.3 Reproduction**

The sex of American eels can be determined by gross morphological examination (Vladykov 1967; Krueger and Oliveira 1997). Ovaries are frilled ribbon-like organs, and testes are deeply lobed, with lobes broadly overlapping adjacent lobes (Dolan and Power 1977). Chisnall and Kalish (1993) suggest that morphological examination may not be reliable and recommend using an aceto-carminine "squash" method to prepare gonads (Guerrero and Shelton 1974; Columbo et al. 1984; Chisnall and Kalish 1993; Beullens et al. 1997). However, Dolan and Power (1977) argue that gross morphological examination is sufficient because very rarely does a yellow female's gonads slightly resemble testes.

Differentiation between sexes occurs in the yellow eel stage of American eels. Sex can be identified in most eels at a minimum size between 250 mm and 350 mm (Dolan and Power 1977; Oliveira and McCleave 2000). Mature males are generally less than 400 mm (Krueger and Oliveira 1997; Oliveira and McCleave 2000; Morrison and Secor 2003; Weeder and Hammond 2009). Mature females are typically larger than 400 mm and can reach sizes of over 1,200 mm in more northern and inland portions of their range (Goodwin and Angermeier 2003; Tremblay 2009).

Sex ratios are highly variable among locations (Table 2.8), and there are several hypotheses about sex determination in the American eel. The exact role of genetics and the environment in



determining sex in American eels is not known. There is strong evidence for phenotypic or environmental sex determination (Degani and Kushinov 1992; Roncarati et al. 1997). High rearing densities common in aquaculture often produce a preponderance of males (Egusa 1979, cited by Oliveira and McCleave 2002). In a lab experiment with European eel, sex was determined by a combination of hormones and grouping (increased eel density versus solitude; Degani and Kushinov 1992). Density-based effects or habitat type may determine sex, with males found more commonly in downriver sites and females more common in upriver sites (Facey and Helfman 1985; Helfman et al. 1987; Krueger and Oliveira 1999; Oliveira and McCleave 2000; Goodwin and Angermeier 2003; Davey and Jellyman 2005). In Maine, silver eels ranged from 49% to 98% male, and the proportion of males was inversely related to lacustrine (lake) habitat in the drainage (Oliveira et al. 2001).

Sex-linked migration patterns are another possible explanation for why male American eels are typically found in coastal habitats while females tend to be found in more upstream areas (Jessop 2010). Females are found in habitats that are less densely populated with eels so sex may not be a function of density dependence but rather that female eels migrate further upstream than males (Jessop 2010).

Reported estimates of fecundity for American eels range from 0.4 to 22.0 million eggs per female (Table 2.9; Wenner and Musick 1974; Barbin and McCleave 1997; Tremblay 2009). Fecundity estimates are higher in the northern portion of the eel's range because of the larger sizes of migrating female eels from northern areas (Barbin and McCleave 1997).

American eels are thought to spawn in the Sargasso Sea during late winter through spring, but spawning has never been observed. It is also unknown if they have paired or group spawning. Because no spent eel has ever been documented, it is assumed that American eels are semelparous.

#### **2.5.4 Food Habits**

American eel diet varies greatly depending on life stage and habitat. American eel leptocephali and glass eel feeding habits have not been reported. However, the dentition and gape of the mouth suggest that they are capable of feeding on individual zooplankton and phytoplankton. Prey size increases as eels grow, with elvers and small yellow eels consuming mostly benthic macroinvertebrates and larger yellow eels switching primarily to crayfish and fish. Silver eels are thought not to eat during their migration to the Sargasso Sea.

Bigelow and Schroeder (1953) describe the American eel as feeding on whatever prey/food items happen to be found in its habitat. However, eels are selective in that prey ratios in stomach contents are different than in surrounding habitats (Machut 2006). Given their poor eyesight and nocturnal feeding habits (Sorensen et al. 1986), yellow eels probably rely on their keen sense of smell to locate food (Fahay 1978). Yellow eels swallow some types of prey whole but also can tear pieces from large dead fish, crabs, and other items (Facey and Van Den Avyle 1987) by biting and spinning rapidly (Helfman and Clark 1986).

American eels in the elver and yellow stages are carnivores and consume a variety of foods including demersal fishes and benthic invertebrates. The diet of yellow eels is related to the size of the fish, usually with smaller eels eating small soft-bodied prey (Machut 2006). Eels shorter than 300 to 400 mm in inland areas of Maine, New York, New Jersey, Delaware, and South Carolina mainly ate benthic aquatic insect larvae, including chironomids, mayflies, stone flies,

dragonflies, megalopterans, and caddisflies. Larger eels fed primarily on crustaceans (crayfish) and smaller benthic fish (Odgen 1970; Scott and Crossman 1973; Facey and LaBar 1981; Smith 1985; Lookabaugh and Angermeier 1992; Denoncourt and Stauffer 1993; Daniels 1999; Machut 2006). Large yellow eels are also known to be cannibalistic, eating elvers when available (Jessop 2000).

In estuarine waters, American eels primarily fed on polychaetes, crustaceans, and bivalves. Fish were not an important component of the diet, even in larger eels. Seasonally, fish did occur in the diet of intermediate-sized yellow eels during the winter and spring, while insects and mollusks were eaten from spring through fall. Yellow eels in the lower Chesapeake Bay fed on crustaceans including blue crab (*Callinectes sapidus*) and bivalves such as soft-shelled clams (*Mya arenaria*; Wenner and Musick 1975).

### **2.5.5 Natural Mortality**

Very little is known about the natural mortality of American eels. Since eels are highly fecund (Wenner and Musick 1974; Barbin and McCleave 1997; Tremblay 2009), natural mortality is likely very high, particularly during the early life stages. Eel survival is likely impacted by changes in oceanographic conditions, predation, and the spread of the non-native swim bladder nematode.

American eel early life stages are likely highly impacted by changes in oceanographic conditions that affect both survival and transportation to the coast of North America (McCleave 1993; Castonguay et al. 1994b; Friedland et al. 2007; Miller et al. 2009). Global warming may change primary production of open ocean areas and alter food availability for leptocephali, which may contribute to the cause of population declines as seen in American, European (*A. anguilla*), and Japanese eel (Bonhommeau et al. 2008; Miller et al. 2009). Longer migration times, due to changes in ocean currents or temperature, may result in late arrival of glass eels and in turn, increase estuary settlement (Sullivan et al. 2009).

Predation on American eels is a source of natural mortality, but only a small number of diet studies have shown eels comprising significant portions of predator's diets. Fish-eating birds, such as osprey, herons, cormorants, and eagles likely prey on eels (Thompson et al. 2005; ICES 2008). One study in a freshwater tidal portion of the Hudson River found that American eels comprised 21% of the diets of bald eagles (*Haliaeetus leucocephalus*; Thompson et al. 2005). European eels are known to be found in the diets of mammalian predators, such as otter (*Lutra lutra*) and mink (*Mustela vison*; Cuthbert 1979; Britton et al. 2006), and those predators may also target American eels in the U.S. Several piscivorous fish species have been documented to prey on American eel, including striped bass (*Morone saxatilis*) and bluefish (*Pomatomus saltatrix*); however, American eels represented less than 5% of overall diets in those studies (Buckel and Conover 1997; Griffin and Margraf 2003; Walter and Austin 2003). Catfish are known to prey on European eels, and catfish abundance is shown to have a negative relationship with eel abundance (Wysujack and Mehner 2005; Bevacqua et al. 2011). Several catfish species occur in east coast rivers and they may also prey on American eels. Finally, predation by any source may also be influenced by density-dependent factors, such as eels being concentrated in select habitats or at the base of dams (Jessop 2000).

The non-native swim bladder nematode, *A. crassus*, may be reducing American eel survival during the yellow and silver eel life stages. The parasite is native to marine and freshwater areas

of eastern Asia, from Japan and China to Vietnam. The nematode prefers freshwater but can survive brackish or salt water (Kirk et al. 2000). Its native host is the Japanese eel; however, the Japanese eel does not show the pathology of infection like that observed in the American eel (Sokolowski and Dove 2006).

Parasitic swim bladder infections in the American eel caused mortalities in farmed eels (Kirk 2003) and possibly wild eels. Heavy infections by *A. crassus* can lead to enlarged abdomens, swim bladder hemorrhagic lesions, fibrosis, rupture, or collapse of the swim bladder, skin ulcerations, decreased appetite and reduced growth, reduced swimming performance, and a reduced ability of the swim bladder to function as a hydrostatic organ (Sprenkel and Luchtenberg 1991; Thomas and Ollevier 1992; Barse and Secor 1999; Nimeth et al. 2000; Lefebvre et al. 2002; Sokolowski and Dove 2006; Kennedy 2007). The parasite can also increase stress response that may cause secondary bacterial infections and mass mortalities in shallow lakes at warm temperatures (Kennedy 2007; Sjoberg et al. 2009). Swim bladders are irreversibly damaged by the parasite, and infections can result in early migration failure because of reduced swimming performance and inability to regulate depth during migration (Kennedy 2007; Palstra et al. 2007; Sjoberg et al. 2009).

The nematode in the U.S. likely originated from Japan (Wielgoss et al. 2008) and now occurs in most states along the eastern seaboard as well as in the Canadian provinces (Fries et al. 1996; Morrison and Secor 2003; Aieta and Oliveira 2009). In North Carolina, 52% of American eels (26–100% from different rivers) were infected with the swim bladder parasite from 1998 to 1999 (Moser et al. 2001). Chesapeake Bay infection rates were between 10% and 29% in the late 1990s (Barse and Secor 1999) and had increased to between 13% and 82% by 1998 to 1999 (Barse et al. 2001). From 2004 to 2005, there was an over 50% prevalence rate of the parasitic nematode in sampled eels from Maryland's Chesapeake Bay (K. Whiteford, Maryland Department of Natural Resources, pers. comm.). In 2007, infection rates ranged from 17.8% in the James River to 72% in the Sassafrass River, with increasing infection rates in eels in more northern Chesapeake Bay tributaries (Fenske et al. 2010). Prevalence rates in the upper Chesapeake Bay watershed (Shenandoah River) were about 2% in recent years (Zimmerman 2008), but nematodes were only recently discovered in the watershed (mid-2000s), so it is possible that infection rates may increase with time in the upper watershed as well. In the Hudson River, infection rates in the late 1990s were between 0 and 12% (Barse and Secor 1999), but increasing intensity and prevalence of infestation occurred in the Hudson River from 1997 to 2000. In the Hudson, the prevalence was lower in saline locations, with > 60% prevalence of infection in freshwater locations by 2000 (Morrison and Secor 2003). By 2004, Hudson River tributaries had an average of 39% infection rates, and dams and natural waterfalls reduced infections upstream. There were also elevated infection rates in urbanized areas (Machut and Limburg 2008). From Rhode Island to Maine, infection rates ranged from 7% to 76% in 2005, and the provinces of New Brunswick and Nova Scotia had rates from 3% to 30% in 2006 and 2007. No eels sampled from the St. Lawrence River system were infected in 2006 and 2007 (Aieta and Oliveira 2009). Currently, Cape Breton Island, Nova Scotia is the most northern area where the swim bladder parasite infestation in American eels has been documented (Rockwell et al. 2009).

### 2.5.6 Incidental Mortality

Incidental mortality, caused by anthropogenic activities other than harvest, can be attributed to habitat alterations and restrictions as well as mechanical and chemical injuries. Inland habitat alterations and restrictions come primarily in the form of barriers to upstream migration for American eels. These can either be physical (dams) or chemical (areas of poor water quality) factors that limit habitat use by eels. This compression of range through habitat restrictions may increase the significance of predation mortality. The location of dams may restrict eel distribution by limiting upstream movements (Levesque and Whitworth 1987; Goodwin and Angermeier 2003; Verreault et al. 2004; Machut et al. 2007). Eels live in higher densities below dams which may reduce survival by causing swim bladder parasites to spread more thoroughly by modifying sex ratios, lowering growth rates, and restricting movements between feeding areas and home areas (Krueger and Oliveira 1999; Oliveira and McCleave 2000; Strickland 2002; Cairns et al. 2004, Verreault et al. 2004; Machut et al. 2007). Upstream passage at dams, designed specifically for eels, may alleviate some of the problems associated with habitat restrictions.

Mechanical and chemical injuries can occur through the use of hydroelectric turbines, navigation lock, industrial and municipal water intakes, chemical barriers, and contaminants. Impingement, entrainment, and turbine operation, such as at dams, locks, and power plants, which can cause high rates of mortality. Entrainment of American eel elvers that pass through turbines after they pass up fish ladders can reach up to 50% with resulting turbine-related mortality (McGrath et al. 2009). Downstream migrating silver eels also can suffer high turbine mortality when moving through hydroelectric plants (Richkus and Dixon 2003; Carr and Whoriskey 2008; Brown et al. 2009; Welsh et al. 2009). Eels passing through turbines suffer up to 100% mortality at some hydroelectric sites (Carr and Whoriskey 2008). In rivers where eels must successfully pass through several hydroelectric facilities, cumulative mortality rates can be very high (McCleave 2001; Verreault and Dumont 2003; Welsh et al. 2009). Further, dams can cause delays in both upstream and downstream migration, further impacting population dynamics and potentially preventing silver eels reaching the spawning grounds during the spawning season (Richkus and Dixon 2003; Brown 2005; Welsh et al. 2009).

Behavioral barriers have not proven effective at deterring American eels and reducing turbine mortality. Physical barriers may work (Amaral et al. 2003) but are practical only in smaller systems (Richkus and Dixon 2003). Complete turbine shutdown is effective, but predicting when migration will occur can be difficult. Seasonal shutdowns can substantially reduce eel mortalities and should be based on environmental characteristics such as flow, lunar phase, and temperature as well as time of day (Haro et al. 2003; Welsh et al. 2009).

Poor water quality, such as low dissolved oxygen, drastic salinity changes, chemical spills, point source releases, and non-point source releases can cause incidental mortality of American eels. Migration through heavily contaminated areas caused acute mortality of silver eels in the early 1970s in the St. Lawrence River (Dutil et al. 1987) because the eel's ability to osmoregulate between fresh and salt water was impaired. Accumulated contaminants may reduce individual survival and reduce both egg viability and larval survival (Couillard et al. 1997). An analysis of the contaminants in migrating silver eels in the St. Lawrence River showed that the highest concentrations of chemicals were found in the gonads. Concentrations of PCB and DDT were found to be 17% and 28% higher in the gonads than in the carcasses. The chemical levels in the eggs could exceed the thresholds of toxicity for larvae. Also, since the energy with which the

non-feeding migrating females produce eggs is taken from their fat reserves, the chemical levels in the eggs could be even higher at hatching, increasing the likelihood of toxicity to the larvae (Hodson et al. 1994; ICES 2006; Limburg et al. 2008). Bioaccumulation of contaminants for eels is problematic because they live in upstream areas for many years (Lamson et al. 2009). Acute toxicity and bioaccumulation of contaminants (mercury, PCB, pesticides) may reduce health and increase mortality of yellow and silver eels (Castonguay et al. 1994a).

### **3 HABITAT DESCRIPTION**

#### **3.1 Brief Overview**

*Section 3 provides a short description of American eel habitat use. A detailed review of American eel habitat requirements can be found in the Atlantic Coast Diadromous Fish Habitat document (Greene et al. 2009).*

American eels exhibit a highly complex catadromous life cycle and are found in marine, brackish, and freshwater habitats (Adams and Hankinson 1928; Facey and LaBar 1981; Facey and Van Den Avyle 1987; Helfman et al. 1983). Habitat types used by different phases of eels include open ocean, estuaries, rivers, streams, lakes (including land-locked lakes), and ponds (Facey and Van Den Avyle 1987).

Habitat associations and requirements vary by life stage. After hatching in winter and spring in the Sargasso Sea, larval American eels passively migrate to brackish or freshwater along the east coast of North America where they metamorphose into glass eels (Greene et al. 2009). After developing pigment (becoming elvers), some eels start migrating upstream into freshwater while others remain in coastal rivers and estuaries. Upstream migration may continue throughout the yellow phase as well. During maturation, silver eels migrate downstream to the ocean and return to the Sargasso Sea to spawn before dying (Haro and Krueger 1991).

#### **3.2 Habitat Description by Life History Stage**

##### **3.2.1 Spawning Habitat**

American eels spawn in the Sargasso Sea from February to April; however, spawning has never been observed (Facey and Van Den Avyle 1987). The area where American eels are thought to spawn is a high salinity (~36.6 ppt) region with warm surface temperatures (>18.2°C; Kleckner and McCleave 1985). Morphological and physiological evidence suggests that American eels may spawn in the upper 150–200 meters of the water column (Kleckner et al. 1983; McCleave and Kleckner 1985).

Larval eels (leptocephali) migrate from the spawning grounds to the eastern seaboard of North America by the Antilles Current, the Florida Current, and the Gulf Stream (Facey and Van Den Avyle 1987; Munk et al. 2010). The leptocephali drift and swim in the upper 300 m of the ocean for several months (Kleckner and McCleave 1985). By August, American eel larvae occupy the entire Gulf Stream area as far north as the Gulf of Maine (Greene et al. 2009).

##### **3.2.2 Glass Eel and Elver Habitat**

Larval eels metamorphose into glass eels over the continental shelf then enter estuaries and ascend the tidal portion of rivers during winter and spring (Greene et al. 2009). Glass eels drift

on flood tides and hold position near bottom on ebb tides (Wippelhauser and McCleave 1987). They also ascend by active swimming along shore in estuaries above tidal influence (Barbin and Krueger 1994). Glass eels eventually metamorphose into pigmented elvers which burrow or rest in deep water during the day. The presence of soft, undisturbed bottom sediments may be important to migrating elvers for shelter (Deelder 1958; Facey and Van Den Avyle 1987).

Elvers begin migrating upstream to freshwater during the late winter and early spring (Greene et al. 2009; Sorensen and Bianchini 1986). Migration may be triggered by temperatures above 10°C (with maximum activity at temperatures above 20°C) and by changes in water chemistry caused by the intrusion of estuarine water during high spring tides (Sorensen and Bianchini 1986; Jessop 2003). Factors that may affect daily abundance of migrating elvers include tidal height, river water temperature, river discharge, and the temperature differential between bay and river (Greene et al. 2009). Elvers have difficulty swimming in river velocities exceeding 25 cm•s<sup>-1</sup>, which can delay upstream migration (Jessop 2000; Jessop and Harvie 2003).

### **3.2.3 Yellow and Silver Eel Habitat**

Yellow eels are associated with a wide variety of habitat types and exhibit habitat-specific growth, sexual differentiation, and movement patterns (see section 2.4.5). During the day, yellow eels are typically bottom-dwelling; however, habitat preference is not well documented and may vary by size and geographic region (Greene et al. 2009). Eels have been shown to prefer such substrates as weedy bottoms in Lake Champlain (Ford and Mercer 1986), soft sediments in the St. Lawrence River (Chaput et al. 1997), and detritus, hydroid, or shell bottoms in the Chesapeake Bay (Geer 2003). Riparian vegetation and complex substrate may be important to yellow eel in impounded systems (Thomas 2006).

Yellow eels appear to utilize different depth areas depending on time of day, season, and geographic region (Facey and LeBar 1981; Geer 2003; Thomas 2006). Water temperature affects activity and movement of yellow eels with highest activity observed above ~20°C in most settings (Geer 2003; Verdon and Desrochers 2003). Yellow eels are thought to enter torpor at temperatures less than 8°C (Walsh et al. 1983). American eels are typically found in areas with dissolved oxygen concentration in the range of 4–9 mg/L (Geer 2003; Cudney 2004). In general, yellow eels do not have specific water velocity requirements, but stream-dwelling eels have been shown to prefer sites with complex velocity-depth regimes (Wiley et al. 2004).

As yellow eels metamorphose into the silver phase, they migrate seaward in fall and winter months to their spawning grounds in the Sargasso Sea. Temperatures in the range of 9–18°C may trigger downstream migration (Vøllestad et al. 1986; Barbin et al. 1998; Vøllestad 1998). Other factors likely affecting migration include river/stream discharge, odor, light intensity, and moon phase (Greene et al. 2009). Silver eels encounter a wide range of salinities; salinity gradients may help orient eel out of estuaries (Barbin et al. 1998).

Adult oceanic habitat requirements are not known, but they have been shown to inhabit a range of depths throughout the water column from 15 to 400 m (Wenner 1973; Tesch 1978a, 1978b). Although silver eels have been found to migrate at 50–400 meters, the maximum depth recorded for *Anguilla* was 2,000 meters (Robins et al. 1979).

### **3.3 Habitat Areas of Particular Concern**

*Oceanic waters:* The Sargasso Sea is an essential area of reproduction for the panmictic population. Climate change could affect oceanographic conditions that impact survival and transportation of larval eels to the coast of North America (see section 2.5.5).

*Continental shelf:* Glass eel survival in these areas may be impacted by a variety of activities including channel dredging, shoreline filling, contaminant spills and discharges, and overboard spoil disposal. However, the significance of these impacts remains unknown. Changes in salinity in embayments as a result of dredging projects could also alter eel distributions.

*Estuaries and freshwater habitats:* These areas serve as important juvenile, sub-adult, and adult migration corridors as well as areas where feeding and growth is concentrated for juveniles and sub-adults. Human development in and along estuaries, rivers, and streams may have a negative impact on eel health, growth, and survival. Machut et al. (2007) found that the condition (weight) of American eels in six tributaries of the Hudson River in New York was significantly lowered with increasing riparian urbanization.

*Passage:* The blockage of upstream and downstream migrations is a major area of concern for American eels. Upstream passage has been improved in some areas by the removal of dams and the installment of fish passage devices. However, Machut et al. (2007) found that eel densities in Hudson River tributaries were reduced 10-fold and condition (mass) was significantly lower upstream of natural and artificial barriers. In addition, downstream passage at hydropower dams may represent a major source of mortality to pre-spawning adults that has received relatively little attention (Ritter et al. 1997). Busch et al. (1996) used an ecosystem health assessment approach to determine that Atlantic coastal streams from Maine to Florida have over 15,000 dams that can hinder or prevent upstream and downstream fish movement. Such development has resulted in an estimated restriction of or loss of access to 84% of historical stream habitat for diadromous fish.

## **4 FISHERIES DESCRIPTION**

Evidence can be found from historical literature that the American eel was a valuable source of food for indigenous populations in North America. These records are mainly brief references from the early years of European settlement that portray the following seasonal fisheries: winter spearing, spring and fall in-stream weirs to capture migrating eels, and baited wood pots set in the warm months (Lane 1978). These three fishing techniques were passed on to the European colonies and seasonal subsistence fisheries became essential food sources in the 17th and 18th centuries. With relatively little change in the basic fishing methods, subsistence fishing in many locations evolved into commercial activities as coastal populations and commerce grew.

### **4.1 Commercial Fisheries**

Similar to earlier subsistence fisheries, commercial eel fisheries in the United States were poorly documented in the 18th century, but the accounts indicate these fisheries were widespread with local importance. Small-scale eel fisheries were common on the U.S. east coast by the 19th century, mainly supplying local food markets although commerce occurred between major cities. Regulations to preserve commercial eel fisheries in Massachusetts first appeared in statutes for Cape Cod towns starting in 1797. The earliest detailed account of U.S. eel fisheries was provided by Goode (1884) for the period of 1877 to 1880. Eel fisheries during this period were common

from Chesapeake Bay to Maine with the trade market centered in New York and Boston. Fishing methods continued to include small-scale baited pots, winter spearing, and in-stream weirs or traps. Pots set from skiffs or small sailboats appeared to account for a majority of landings. The recorded eel landings in New York alone exceeded a million pounds in 1880. It appears likely that total U.S. landings were in the 1–2 million-pound range for the period reported by Goode (1884). It is presumed that the spring weirs, winter spearing, and summer pot fishing targeted yellow eels and the fall weir fishing targeted silver eels. The marine conger eel (*Conger oceanicus*) may have comprised an unknown proportion of these early records.

U.S. American eel fisheries continued without dramatic changes in the early 20th century, with market centers in the Chesapeake Bay region for blue crab fishing bait and New York and Boston for food markets. Declining U.S. landings in the period leading up to World War II may have been influenced by changing public demand for eels as a food source (Bigelow and Schroeder 1953). Overall, the U.S. American eel fishery in the 20th century experienced declining landings with some stability in meeting local market demands until the onset of the European export market in the 1960s (Lane 1978). This scenario is similar to what occurred in Quebec eel fisheries with the exception of a documented catch peak during the Great Depression as the local subsistence demand soared (Robitaille et al. 2003). In the U.S., the relative stability linked to local demand was disrupted as the export market increased in the 1960s and 1970s. Rising prices for yellow and silver eels for the European export market increased fishing effort and led to harvest peaks from the mid-1970s to early 1980s in the U.S. (Lane 1978; Jessop 1997) and eastern Canada (Jessop 1997; Robitaille et al. 2003).

Increasing demand for glass eels from Asian aquaculture operations occurred at a similar time as the European food market, dramatically increasing prices and fishing effort for glass eels (Jessop 1997; Haro et al. 2000). The fisheries for glass eels were primarily in the Canadian Maritime Provinces and Maine. The catch peaks that resulted from the European and Asian export market demand were followed with declining harvest for most regions since the mid-1980s (Peterson 1997; Jessop 1997; Haro et al. 2000). These conditions prompted management concerns over the status of the American eel population in North America.

#### **4.1.1 Glass Eel Fishery**

Fishing for glass eels (also called elvers) began relatively recently in North America and has been limited to commercial operations that target the spring runs of eels as they enter coastal rivers following their ocean migration from spawning grounds. Glass eel fisheries use in-stream fykes and traps to intercept glass eels on this spring migration. Interest in fishing glass eels developed in the early 1970s in the U.S. as demand increased from Asian aquaculture operations for “seed” stock (Fahay 1978; Keefe 1982). Glass eel fisheries in Canada came later beginning in 1989 with the issuance of experimental licenses in Nova Scotia and New Brunswick (Jessop 1997; Peterson 1997).

The states of Florida, North and South Carolina, Virginia, Massachusetts, and Maine initiated glass eel fisheries in the early 1970s (Fahay 1978; Keefe 1982). The glass eel fisheries failed to develop in Florida, ceased in 1977 in North Carolina, and were prohibited in 1977 by a six-inch minimum size limit in Virginia and a four-inch minimum size limit in Massachusetts (CBP 1991). The Potomac River Fisheries Commission imposed a six-inch minimum size in 1992 for both commercial and recreational fisheries, eliminating glass eel fisheries within their jurisdiction. The Maine glass eel fishery collapsed after 1978 due to market conditions but



continued at a low level until growing substantially in 1994. During the late 1980s or early 1990s, glass eel fisheries were developed or reestablished in Connecticut, Rhode Island, New York, New Jersey, Delaware, and South Carolina, but no catch data are available. Glass eel fisheries do not occur in any Gulf of Mexico states. With the implementation of the ASMFC Interstate Fishery Management Plan for American Eel in 2001 (ASMFC 2000), all Atlantic coast states and jurisdictions except Maine, South Carolina, and Florida implemented a six-inch minimum size limit for American eels. Florida eel fisheries operate under gear restrictions that do not allow the landings of eels under six inches.

Prior to 2010, only the Maine glass eel fishery was consistently active. The fishery operates with relatively few permits and limited entry. Glass eel landings in Maine have been recorded separately from other eel catches since 1994. The peak landings since 1994 occurred in 1995 at 16,599 pounds of glass eels. Landings have been less than 5,000 pounds in the last decade, and the fishery is distinguished by high prices often in the range of \$200–300 per pound. In 2011, anecdotal reports were received of glass eel prices exceeding \$1,000/pound and renewed fishing activity in South Carolina. The increased demand may also have contributed to an increase in illegal poaching in jurisdictions where glass eel fisheries are prohibited.

#### **4.1.2 Yellow Eel Fishery**

The yellow eel life stage is readily captured with baited pots in coastal rivers and freshwater habitats and provides a size range suitable for food and bait markets. This life stage of American eel has been the primary target of U.S. eel fisheries in both historical and modern periods. The U.S. fishery for yellow eels extends from the Gulf of Mexico to Maine. Different geographic regions (Gulf of Mexico, and the North, Mid-, and South Atlantic) have exhibited differing trends and magnitudes in their eel fisheries, which reflect differences in the fisheries and stock abundance among the regions (Fahay 1978). Section 5.0 reviews the fisheries in each region in greater detail.

The dominant gear for targeting yellow eels in U.S. eel fisheries has been baited pots. The practice of using hand spears for winter eel harvest in northeastern coastal rivers was common until fading to an incidental practice in the last two decades. The use of in-river weirs and fykes to capture spring movements of yellow eels has not been a widespread practice but has provided important local fisheries in some regions. The contributions of both spear and other non-pot fisheries have been minor relatively to overall U.S. eel harvests and are incidental in contemporary fisheries.

Harvest patterns in yellow eel fisheries have followed market influences as described in section 4.0. Nineteenth century U.S. harvests are poorly documented; however, the available references (Goode 1884; Bigelow and Schroeder 1953; Lane 1978) portray important local markets driving much higher effort and catch than occurring in the 20th century. After an apparent period of declining demand in the first half of the 20th century, there were catch peaks occurring from approximately 1955–1985 that coincided with increasing market demands from the Chesapeake Bay region crab fisheries and the European food market (Fahay 1978; Lane 1978). The timing of harvest peaks varied among states. By the 1990s, most states experienced declining harvests influenced to an uncertain degree by both the weakening export market and local abundance. The declining U.S. and export food market demand has been partially offset by increasing demand for yellow eels as striped bass bait. This relatively new market feature appears to be driving

many local fisheries in the last decade, although U.S. catch levels are at historic lows, with few regional exceptions.

#### **4.1.3 Silver Eel Fishery**

American eels enter the silver-phase of their life history as they begin their reproductive migration from fresh to marine waters. Silver eels become vulnerable to passive nets and traps set in rivers as they migrate downstream during the fall. Silver eels were targeted by Native Americans and later for commercial food markets because of the high fat content of mature eels, which produced an excellent smoked product. Harvest data and information on silver eel fisheries are poorly documented. Silver eel fisheries have not been nearly as common as yellow eel fisheries in the U.S. past and present. It is likely that niche fisheries occurred at specific rivers along the east coast in historical times leading up to the mid-20th century. A traditional silver eel fishery using fyke nets operated in the Albemare Sound region of North Carolina in late summer and early fall during the mid-1970s with as many as 50 active fishermen (Fahay 1978). Much larger scale silver eel fisheries occurred with fixed traps for much of the 20th century in the St. Lawrence watershed with sharply declining catch in recent decades (Robitaille et al. 2003; Verreault et al. 2003). Under the present ASMFC management plan silver eel fisheries are only allowed in New York and Maine and occur with low levels of catch and effort (ASMFC 2000a).

#### **4.1.4 Bait Fishery**

The use of harvested American eels for bait in other fisheries is not well-described, although it does not appear to have been common before the 20th century nor had the relative importance of food markets. Eel harvesting in the South Atlantic Bight prior to the 1970s was focused primarily on harvesting eels for live bait in sportfisheries and secondarily as bait for blue crab pots (Van Den Avyle 1984). Harvesting eels for crab trotline bait was important in the Maryland eel fishery in the 20th century (Foster and Brody 1982). The proportion of the eel harvest sold for bait declined with the advent of the overseas food market in the 1960s, and this disposition declined further as the increased use of crab pots reduced the need for baited trotlines (Lane 1978).

A more recent development in the marketing of American eels in U.S. fisheries is the use of eels for striped bass, cobia, and catfish bait. Several references that summarize U.S. eel fisheries prior to the 1990s (Fahay 1978; Lane 1978; Van Den Avyle 1984) do not mention this harvest disposition, and more recent references mention the practice with no details (Haro et al. 2000; Collette and Klein-MacPhee 2002). It is likely that the practice of rigging eels for striped bass angling originated early in the 20th century but did not become widespread until recently. Presently, the use of eels as striped bass bait is probably the dominant use of harvested eels in New England and comprises a larger proportion of the Chesapeake Bay eel fishery than any time previous. U.S. eel fishery data does not have the resolution to separate striped bass bait from other dispositions. Commercial eel fishery reporting since the implementation of the ASMFC eel management plan in 2001 has improved and could provide information on this recent development.

#### **4.1.5 Exports**

The weight and value of U.S. domestic exports of American eels from selected districts along the Atlantic coast for 1981–2010 were provided by the NMFS (1981–1988; Fisheries Statistics Division, Silver Spring, MD, pers. comm.) and the United States International Trade

Commission (USITC) DataWeb (1989–2010; pers. comm.). Export values were converted to 2010 dollar values using conversion factors based on the annual average consumer price index (CPI) values, which were obtained from the U.S. Bureau of Labor Statistics (pers. comm.).

Prior to 1989, exports were classified as either fresh/frozen or live. Since 1989, the fresh/frozen group has been separated into two categories—fresh (or fresh or chilled) and frozen. Live export weight data for American eels are not available for the 1989–1992 time period, likely due to differences in reporting requirements during those years (A. Lowther, NOAA Fisheries, pers. comm.; M. Savage, USITC, pers. comm.).

Domestic exports of American eels from the Atlantic coast ranged from 229 thousand to over 6.07 million pounds per year from 1981 through 2010 (Figure 4.1). Live eels comprised the majority (>50%) of exports in 1983–1988, 1993, 1999, and 2003–2005. In more recent years, exports of fresh and frozen eels have dominated, accounting for an average of 76% of the total eel exports per year during 2006 through 2010. The reason that the magnitude of domestic exports exceeds commercial landings in some years may be that export landings records include significant quantities of hagfish misreported as American eel.

The value of American eel exports ranged from 1.83 to 23.5 million dollars per year over the time series (Figure 4.1). Export values decreased during the earliest years in the time series and then generally increased to the peak observed in 1997. The value of exports substantially dropped following the 1997 peak but has shown a generally increasing trend from 1999 through 2010.

The value per pound of exported American eels classified as live has exceeded the value per pound of fresh and frozen eels (combined) throughout the time series (Figure 4.2). The value per pound of fresh and frozen eels ranged from 0.819 to 4.97 dollars per pound per year from 1981 to 2010. The value per pound of fresh and frozen eels has exhibited a general decline over the time series. The value per pound of live exports has varied over the available time series, ranging from 2.53 to 21.8 dollars per pound per year.

#### **4.2 Commercial Catch-Per-Unit-Effort**

Fishery-dependent catch-per-unit-effort (CPUE) was available in some states, but following review of these data they were not considered indicative of trends in the stock as a whole (see section 5 for more details on data inclusion/exclusion decisions). Note that fishery-dependent CPUE is almost exclusively composed of positive trips only; trip reports with zero eels caught are rare because most agencies don't require reports of zero catches.

##### *Maine—Glass Eel*

Estimates of number of licenses sold by gear type are available from 1996 forward as an estimate of effort (Figure 4.3). An average of nearly 2,000 harvesters participated in the glass eel fishery annually during 1996 to 1998. In 1999, the Maine DMR implemented effort restrictions, capping the fishery at 827 participants. Since then, effort has averaged approximately 490 participants, with a range of 267 to 743.

Glass eel dealer reporting has been required since 1999, although voluntary data are available back to 1996. Catch per effort in the fyke net fishery has fluctuated without trend since 1999, averaging 7.85 pounds per fyke net licensed, with a range of 3.2 to 19.2 pounds per fyke (Figure 4.4). CPUE for the dip net fishery was generally less than 1 pound per unit of gear from 1999 to

2004 but increased dramatically in 2005 to 16.7 pounds per net (Figure 4.4). Since then, it has fluctuated without trend between 3.2 and 9.6 pounds per net. Harvest per licensed fisherman has followed a similar trend as the fyke net fishery (Figure 4.4).

Attempts were made to identify major factors influencing the Maine glass eel fishery, such as price per pound, YOY abundance, and participation. Unfortunately, changes in management over time (voluntary/mandatory reporting, effort restriction) and other factors made this difficult because there was no consistent time series of all three datasets.

### *Maine—Yellow Eel*

Mandatory harvester reporting for the yellow eel fishery began in 2007 but is considered less reliable than the dealer data (i.e., harvesters report estimated harvest weights at the trip level while dealers report actual weigh-out for individual transactions; G. Wippelhauser, ME DMR, pers. comm.) and therefore will not be considered further in this assessment. Harvester reporting (monthly summaries) has been required in Maine's coastal and inland yellow eel pot fisheries since 2001, with voluntary data back to 1999.

Two measures of effort are available for the yellow eel pot fishery—records of the number of licenses sold by year are available beginning in 1985, while estimates of total gear days fished are available beginning in 2001 (Figure 4.5). Participation in the coastal and inland fisheries generally increased between 1985 and 1995 but has since declined to between 10 and 15 participants per fishery since 2001 for both fisheries and to less than 10 in the inland fishery since 2007. The coastal fishery exerts approximately 85% of the total pot fishery effort (days) despite participation in the two fisheries being roughly equal over much of the last decade. Since license sales have been relatively static, the decline in pot days for the coastal fishery also suggests a general decline in pot days fished per license since 2001.

Trends in catch per license sold are similar to those of harvest as a result of license sales being relatively constant over the last decade. CPUE generally increased during the early 2000s, peaked in the mid-2000s, and has since returned to previous levels (Figure 4.6). CPUE evaluated against pot effort shows more variability with no distinct trends.

Trends in weir fishery effort provide some insight into the observed harvest patterns. Prior to 1996, effort in the weir fishery was unregulated. In 1996, effort was limited to a maximum of 26 harvesters at 42 sites (P. Bourke, ME DMR, pers comm.). Effort declined from 50 licensed sites in 1995 to just 2 sites in 2002 and has remained below six in all years since 2002 (Figure 4.7). Catch per licensed site appears relatively stable with the exception of one high and one low outlier in 2004 and 2006, respectively.

### *New Hampshire*

The New Hampshire Department of Fish and Game has recorded commercial catch and effort for American eel since 1990. Annual CPUE indices were estimated from annual summaries of trips that reported valid total catch, pot number, and soak duration. Trip level reporting was well documented during this period. The total landings reported were low; therefore, the CPUE statistics are generated from landings and effort that may not represent a commercial fishery but rather a small-scale fishery to catch striped bass bait for personal use. Despite the low levels of catch and effort, the CPUE was routinely higher than observed in nearby states such as Massachusetts. Permit holders appeared to be setting few pots and having catches that

approximated 1 pound/pot/day on average. The general trend for this time series was  $> 1.0$  pounds/pot/day during the 1990s and  $< 1.0$  pounds/pot/day for most of the 2000s (Figure 4.8).

#### *Massachusetts*

Catch-per-unit-effort data were summarized by major coastal drainage areas (Merrimack River, Plum Island Sound, North Coastal Basin, Boston Harbor, South Coastal Basin, Cape Cod, and Buzzards Bay). Annual CPUE indices were computed from annual summaries of trips that reported valid total catch, pot number, and soak duration. Most effort and landings during 2001–2009 occurred in Cape Cod and Buzzards Bay watersheds. Because of the low catches, landings were pooled into the regions of Southern New England (Cape Cod and Buzzards Bay) and Southern Gulf of Maine (all basins north of Cape Cod). The development of indices of abundance from the Massachusetts pot data may be limited because few permit holders are contributing trip-level data and because of apparent changes in fishing practices. In recent years, few participants are targeting larger catches for commercial sales to food or bait markets and most are catching small amounts to supply their own needs bait fishing in the commercial striped bass market. The CPUE for Southern New England during 2001–2009 shows some stability in catch rates with the highest CPUE at the start of the series and in 2009 (Figure 4.9).

#### *Rhode Island*

The Rhode Island Division of Fish and Wildlife began trip-level reporting of commercial catches for American eel in 2007. The time series was considered too short for calculating CPUE but will be revisited in the next stock assessment. The Rhode Island eel potting fishery is similar in scope to those described in Connecticut, Massachusetts, and New Hampshire. The relatively low number of participants and total landings reflect a small-scale, part-time, seasonal fishery. Additional quality assurance review is needed to resolve questions on potential misreporting of conger eel catches and reporting of eel landings under trips with lobster gear codes.

#### *Connecticut*

Connecticut has recorded catch and effort data for their commercial eel pot fishery since 2000. Annual CPUE indices were calculated from annual summaries of trips that reported valid total catch, pot number, and soak duration. An alternative CPUE estimate was also generated using the sum of annual total catch divided by the sum of annual total pots fished. The trends of the two indices for 2000–2008 were essentially identical. Annual trip level CPUE shows a general increasing trend with CPUE  $< 1.0$  pounds/pot/day in the first half of the series and several years exceeding 1.0 pounds/pot/day in the latter half. The Connecticut CPUE values are within the range recorded in New Hampshire and Massachusetts during this time period, and the Connecticut eel pot fishery displays similar characteristics of low participation and small-scale, seasonal operations.

#### *New Jersey*

New Jersey has maintained records of the number of eel licenses sold on an annual basis since 1999. The number of licenses sold has been relatively constant over time, with a minimum of 142 licenses sold in 2001 and a maximum of 202 in 2007 (Figure 4.10). Although not every license sold was active in a given year, these records allow investigation into trends in CPUE (catch per license sold) since 1999. Because effort has been relatively stable, the trend in CPUE has mirrored the trend in harvest. CPUE increased from the time series low of 300 pounds per

license in 2000 to a peak of 900 pounds per license in 2006. CPUE has since fallen by approximately 30%.

#### *Delaware*

Delaware mandated catch and effort reporting from the American eel fishery in 1999. Delaware considers its American eel catch and effort records since 1999 fairly accurate and has calculated an annual commercial CPUE index from 1999 to the present. The annual index value for CPUE is expressed as catch per pot-day fished and is the ratio of all eel pounds harvested by eel pots divided by the total number of eel pot-days fished (1 pot-day = 1 eel pot fished for 1 day). Annual CPUE ranged from 0.99 pounds/pot-day in 2009 to 2.71 pounds/pot-day in 2005 (Figure 4.11). Pot-days fished has varied and CPUE has usually been higher during years in which pot-days fished was below the time series mean.

#### *Maryland and Delaware Coastal Bays*

A commercial CPUE index was calculated for the pot fishery in Maryland (1992–2010) and Delaware (2000–2009) Coastal Bays (Figure 4.12). The annual index value for CPUE is the ratio of the sum of all eel pounds harvested by eel pots and the sum of all eel pots fished. Maryland Coastal Bay eel pot effort in 2001 was reported as 25 pots with 120 pounds of eel harvested. This CPUE, computed as 4.80 pounds/pot, was nearly five times the average for all other years and was considered a severe outlier so the data point was removed. CPUE in Delaware coastal eel pots was 1.53 pounds/pot compared to 0.57 pounds/pot in Maryland's coastal bays. However, pots used in Maryland are typically the smaller cylindrical pots rather than larger square pots commonly used in Delaware. Independently, no trend was apparent in either series. Differences in pot catchability would make it difficult to develop a combined Delaware and Maryland coastal bays CPUE index.

#### *Maryland*

From 1992, when mandatory catch and effort reporting was fully adopted by commercial eelers a commercial CPUE index was calculated for the pot fishery. The annual index value for CPUE is the ratio of the summation of all eel pounds harvested by eel pots and the summation of all eel pots fished. Average annual CPUE has ranged from a low of 0.31 lbs/pot in 1992 to a high of 1.01 lbs/pot in 2006. The CPUE index was relatively flat from 1992–2002, significantly increased from 2003–2006, and slightly declined and moderated from 2007–2010 (Figure 4.13). Total effort measured as the number of eel pots fished steadily declined from 1999 to 2006, leveled off from 2007–2009, and had an approximate 50% increase in 2010. Effort declined 60% from a high of 889,000 pots fished in 1997 to a low of 320,000 pots fished in 2006 and has averaged approximately 417,000 pots fished from 2007–2010. A significant negative correlation was detected between the pot CPUE and pot effort (Pearson product-moment correlation:  $r = -0.78$ ,  $P < 0.01$ ).

#### *Potomac River*

Monthly catch and effort was required of commercial eelers beginning in 1988. In 1990, monthly reporting was changed to mandatory weekly reporting and then mandatory daily reporting began in 1999. The annual index value for CPUE is the ratio of the summation of all eel pounds harvested by eel pots and the summation of all eel pots fished. The same pattern of increasing CPUE with decreasing effort was noted for the PRFC commercial pot index as well Maryland's over the same time frame (Figure 4.14). Average annual CPUE has ranged from 1.11 lbs/pot in

1999 to a high of 2.19 lbs/pot in 2007. CPUE was relatively flat from 1988–2001 but increased from 2002–2007 before moderating back at approximately 1.5 pounds/pot from 2008–2010. Commercial effort in total eel pots fished declined by over 40% in 2002 from the previous year and has continued to gradually decline through 2010. Effort has decreased approximately 85% from a time series high of 225,000 pots in 1994 to a low in 2010 of 34,500 pots.

### *Virginia*

Catch rates were calculated for Virginia's commercial eel pot fishery by dividing the amount of harvest of American eels landed in Virginia (pounds) by the number of eel pots. The catch rates were calculated for the James, York, and Rappahannock rivers using data specific to each river. Only data associated with positive effort are included in the calculations as commercial harvesters only report positive catches to the VMRC. Records where harvest or effort were missing or zero were excluded from the calculations.

Annual catch rates were variable within and among rivers over the time series (Figure 4.15). Catch rates for the James and York rivers demonstrated a decline during the mid- to late 1990s. The peak catch rate occurred in 2002 for both the James and York rivers. The York River catch rates show evidence of a general decline from 2005 through 2009. Catch rates for the Rappahannock River have shown no obvious trends over the time series.

### *North Carolina*

CPUE from the North Carolina trip ticket data are not a reasonable index of abundance for eel because effort has not been recorded consistently in trip or haul units. Many fishermen keep eels caught from multiple trips in pens, then combine and sell the entire batch to a dealer under one trip ticket. In the future, logbook data (which began in 2007) may be useful for computing fishery-dependent index of abundance; logbooks include exact number of trips, eels caught per trip, pots fished, and soak time.

### *Florida*

Commercial catch and effort data collection began in 2006. The time series was considered too short for calculating CPUE but will be revisited in the next stock assessment.

## **4.3 Recreational Fisheries**

Studies and reports that summarize U.S. eel fisheries provide little information on targeted recreational eel fisheries (Bigelow and Schroeder 1953; Fahay 1978; Lane 1978; and Van Den Avyle 1984). The practice of spearing or gigging eels buried in the mud during winter is an eel fishing method that was developed for subsistence fishing but came to have both commercial and sportfishing appeal in the 19th century until recently. Eels are encountered over much of their U.S. range by recreational anglers as bycatch. Van Den Avyle (1984) reported that no major sport fishery for American eels occurred in coastal rivers of the South Atlantic Bight, but incidental catches were made by anglers in estuaries and rivers. Despite the incidental nature of eel hook-and-line catches, the Marine Recreational Fisheries Statistical Survey (MRFSS) does encounter enough observations to generate catch estimates that indicate widespread and common presence as a bycatch species. Starting with 1981 estimates, the MRFSS survey for all major eastern U.S. regions show much higher catch estimates in the 1980s than in the 2000s (NMFS, pers. comm.). For example, the mid-Atlantic region annual estimates averaged over 49 thousand pounds in the 1980s and about 9 thousand pounds in the 2000s. For the North Atlantic, the

decline is sharper: after averaging over 20 thousand pounds annually in the 1980s, no catches have been reported since 1999.

#### **4.4 Subsistence Fisheries**

The harvest of American eels as a food source for subsistence has been portrayed as having importance for Native Americans and European settlers in North America with declining importance after the 19th century. Most accounts are anecdotal and entail brief references in popular literature. The journals of William Bradford and Edward Winslow of the pilgrim settlement in Plymouth, Massachusetts make several references to the abundance and use of eels by Native Americans and the Pilgrims in the 1620s for subsistence (Young 1841). Thoreau recorded his travels to Cape Cod, Massachusetts in the mid-19th century and included several references to being served eels with meals prepared with locally gathered food (Thoreau 1951). Robitaille et al. (2003) considered the subsistence catch of eels in Canada to have been important for indigenous tribes and European settlers with declining importance in the 19th century and minor value in the 20th century with the exception of the Great Depression when the highest recorded Canadian catch was made in the 1930s. These accounts portray fried and smoked eel as a common food gathered for subsistence in coastal regions until recent generations. It is likely that changes in eel abundance and demand have diminished this practice in the 20th century resulting in declining cultural importance of eels in coastal communities.

#### **4.5 Gulf of Mexico**

A small portion of U.S. landings are attributed to the Gulf of Mexico. Landings records in this region were historically collected by the NMFS but have been administered by the Gulf States Marine Fisheries Commission since 1985 (D. Bellais, GSMFC, pers. comm.). Between 1950 and 1999, landings in the Gulf of Mexico ranged between approximately 200 pounds in 1994 and 28,000 pounds in 1985 (Figure 4.16). Landings reported since 1999 have been negligible and are thus confidential. Fahay (1978) reported total U.S. landings of American eels during 1955–1973 with minor landings registered from the U.S. Gulf of Mexico region during about half of those years but never exceeded 1% of total U.S. landings. Note that the Gulf States (including western Florida) are under the jurisdiction of the Gulf States Marine Fisheries Commission and are not subject to ASMFC-led interstate fisheries management.

#### **4.6 Fisheries Outside the United States**

Because of the panmictic status of American eel, fisheries outside the jurisdiction of the United States are relevant to ASMFC management efforts, although they are not subject to management regulations implemented through the ASMFC. Brief descriptions of Canadian eel fisheries and fisheries at locations south of the United States are provided below for perspective on activity at the northern and southern ends of American eel's range. Information on commercial eel landings in Canada and other western Atlantic countries was obtained from the Department of Fisheries and Oceans (DFO) Canada (DFO, pers. comm.) and the Fisheries Department of the Food and Agriculture Organization (FAO) of the United Nations (FAO, pers. comm.), respectively.

##### **4.6.1 Commercial Fisheries in Canada**

American eels are present in Canada from Labrador southward and are considered abundant in the St. Lawrence River watershed, southern Newfoundland, and the Maritimes Provinces (Scott



and Scott 1988). General regional differences are found in Canadian eel fisheries. Quebec fisheries mainly use weirs set in rivers for silver eels, baited setlines and fyke nets are mainly used in Ontario, and the Maritimes utilize a wider variety of baited pots, weirs, traps and spearing. The eel fisheries in the St. Lawrence River main stem, tributaries, and watershed have traditionally had the highest landings among Canadian regions (Lane 1978; and Scott and Scott 1988). Similar to the eastern U.S., eel fisheries occurred with periods of local importance for several centuries in all the Canadian Atlantic provinces.

Robitaille et al. (2003) describe two harvest peaks in Ontario and Quebec that occurred in the 20th century. The first occurred in the 1930s and was driven by economic influences of the Great Depression. The highest total Canadian eel catch recorded came in 1933 at approximately 1,224 tons (Lane 1978) and was probably underreported (Robitaille et al. 2003). Eel catches declined following this peak with likely but undocumented influences of reduced abundance and market demand due to improved economic conditions. The 1950s and 1960s was a period of relative stability with eel fisheries meeting the demand of local markets. The stability was disrupted by the onset of the export markets, first for food markets in Europe and followed by culture markets for juvenile eels in the Far East (Robitaille et al. 2003). This resulted in the second catch peak during 1975–1980 with Ontario and Quebec landings near 800 tons. Lane (1978) reported that total Canadian eel catch ranged from 800 to 1,200 tons from 1965 to 1973—a period of rising harvest to meet export demands. The total harvest weights in Canada were very similar to the U.S. totals during this period. The eel fisheries in the St. Lawrence River main stem, tributaries, and watershed have traditionally had the highest landings among Canadian regions (Lane 1978; and Scott and Scott 1988).

Eel harvest in the Ontario and Quebec Provinces declined quickly from the late 1970s peak to the 1990s (Peterson 1997). Sharp declines occurred in the St. Lawrence estuary weir fishery that targets female silver eels in the 1990s (Verreault et al. 2003). Management concerns from these regions were a significant impetus for the contemporary review of American eel stock status. At the same time that concerns were growing in Quebec and Ontario, landings increased in Nova Scotia and New Brunswick as export markets in the 1990s attracted effort for food eels and glass eels for culture. Declining market demand, implementation of regulations, and likely abundance reductions have reduced effort and catch in most Canadian regions in the last decade. Canadian Provincial and Federal fishery management agencies are now actively engaged in American eel population assessment and restoration.

The DFO Statistical Services Unit maintains fisheries data for Canada and these data were available for 1972–present. Data from Canada's marine and freshwater commercial fisheries are available via online tables that are summarized by species, province, and region (e.g., Scotia-Fundy vs. Gulf). Trends in seafisheries records from 1972 to 2009 indicate a steady decline in commercial eel landings since the early 1990s (Figure 4.17). Available freshwater fisheries records cover a shorter time span (1990–2006) during which time a small decline in freshwater landings is apparent. However, freshwater landings records may be less reliable than seafisheries records (Figure 4.18; note exact repeated numbers between 1998–2000 and 2004–2006), and it is unclear whether overlap in reporting between freshwater fisheries and seafisheries occurs.

#### **4.6.2 Commercial Fisheries in Central and South America**

Studies and reports that summarize U.S. eel fisheries provide no information on commercial eel fisheries in Mexico or the Caribbean Islands other than mentioning that the American eel's range

does extend to these regions (Bigelow and Schroeder 1953; Fahay 1978; Lane 1978; and Van Den Avyle 1984). Annual landings between 1950 and 2008 are available by country and major fishing area from the FAO Fishery Global Statistics Program of the Fisheries Data, Information, and Statistics Unit (FIDI) via online tables. Mexico, the Dominican Republic, and Cuba have reported a small amount of landings (primarily from in-river fisheries) since 1975 (Figure 4.19). It is unknown whether these reports are comprehensive.

## **5 DATA SOURCES**

For this assessment, the committee evaluated nearly 100 fishery-dependent and independent U.S. data sources representing several life stages and geographical and temporal scales. Canadian data sources were examined but not included in this assessment because a Canadian stock assessment was being conducted by DFO concurrently with the U.S. assessment. Hopefully, the two sets of analyses will be considered together and combined to form a West Atlantic assessment in the near future.

Fifty-two fishery-dependent and independent data sources were selected for use in this assessment because they were considered adequate for describing life history characteristics and abundance trends of eels on either a coast-wide or regional basis. After close consideration by the committee, trends in fishery-dependent CPUE were described in section 4 to describe the fisheries themselves but were not included in analyses because they were not thought to represent trend in eel abundance over time due to either poor participation in the fishery (i.e., few fishers) major, unquantified changes in the fishery over time, or insufficient time series.

In addition, some fishery-independent data sources were removed from consideration for one or more of the following reasons:

1. Lacked sufficient time series to identify trends (<10 years)
2. Reported inconsistent sampling methodology (i.e., frequent changes in survey methodology) that could not be accounted for via standardization techniques
3. Resulted in intermittent or rare catches of eel
4. Operated during a time of the year or in an area where when eel are not typically available to sampling gear
5. Used survey gear with rare, uncertain or biased catchability for eel

A summary of all available data sources and a brief description of the reasons any dataset was excluded can be found in Appendix 1. Note that the ASMFC-mandated annual YOY surveys sources are not included in Appendix 1 but are treated separately in section 5.2.1.1.

### **5.1 Fishery-Dependent**

#### **5.1.1 Commercial Fisheries**

The FMP for American eel requires states to report commercial harvest by life stage, gear type, month, and region as defined by the states (ASMFC 2000a). At this time, however, not all states are able to provide this level of information.

### 5.1.1.1 Atlantic Coast

Historical commercial landings data from 1888 to 1940 were transcribed from online U.S. Fish and Fisheries Commission Annual reports (NOAA Central Library Data Imaging Project, pers. comm.).

Commercial landings data collected since the 1900s were obtained from the Atlantic Coastal Cooperative Statistics Program (ACCSP) or from state-specific databases in situations where data flow issues between the states and ACCSP were identified during the 2009 American Eel Data Workshop (see state-specific data collection details below). Since 1950, most landings information on the East Coast has been collected by NMFS through dealer and/or fisherman reporting under a state-federal cooperative program. All historical NMFS data are now housed at ACCSP. Prior to the 1990s, information was summarized annually or monthly; more detailed information became available as states individually began adopting fisherman reports (e.g., trip ticket systems or logbooks).

During 1950 to 2010, Atlantic coast-wide U.S. American eel landings ranged between approximately 664,000 pounds in 1962 and 3.67 million pounds in 1979 (Figure 5.1). After a decline in the 1950s, landings increased to a peak in the 1970s and 1980s before declining again in the 2000s.

Geographic regions used in the 2005 assessment (North, Mid-, and South Atlantic) exhibited differing trends and magnitudes in their eel fisheries (Figure 5.2). The majority of landings were reported in the Mid-Atlantic (New Jersey to Virginia), followed by the South Atlantic (North Carolina to Florida) and North Atlantic (Maine to New York). Since the coast-wide landings peak in the 1970s and 80s North and South Atlantic landings have been minimal compared with Mid Atlantic region landings.

A new set of watershed-based geographic regions were created for this assessment: Gulf of Maine, Southern New England, Hudson River, Delaware Bay/Mid-Atlantic Coast Bays, Chesapeake Bay, and the South Atlantic (Figure 5.3). The temporal extent to which landings could be assigned by region (i.e., divide landings within a state like Massachusetts or Maryland) varied by region (Figure 5.4). The South Atlantic and Chesapeake Bay regions showed distinct large peaks in landings in the early 1980s. Landings in all regions declined throughout the 1990s. Most regions remained stable throughout the 2000s except for Southern New England and Delaware Bay/Mid-Atlantic Coast Bays where landings declined.

The value of U.S. commercial American eel landings as estimated by NMFS has varied between a few hundred thousand dollars (prior to the 1980s) and a peak of \$6.4 million in 1997 (Figure 5.5). Total landings value increased through the 1980s and 1990s, dropped in the late 1990s, and increased again in the 2000s.

Since 1950, the majority (>76%) of American eel landings were caught in pots and traps (Figure 5.6). Fixed nets (e.g., weirs, pound nets) accounted for about 8% of the landings. Approximately 4% of landings were caught using other gears (non-pot/trap or fixed net). About 12% of landings are reported with unknown gear type. Over the last two decades, pots and traps have become the dominant gear reported for most eel landings (Figure 5.7).

#### Potential Biases

NMFS data collection is focused on species that are managed exclusively or jointly at the federal level, although information is also collected on species that are managed at the state level. Other

caveats associated with these data are discussed at the following web site: <http://www.st.nmfs.noaa.gov/st1/commercial/landings/caveat.html>. Because eel is managed by the states and is not a target species for the NMFS, landings information for states that rely on the NMFS estimates may be underreported. In addition, at least a portion of commercial eel landings typically come from non-marine water bodies. Even in states with mandatory reporting, these requirements may not extend outside the marine district, resulting in a potential underestimate of total landings. Despite concern about the level of under reporting, the committee felt that reported landings were indicative of the trend in total landings over time.

In both federal and state landings reports there may be misreporting of other eel species (e.g., conger eel) as American eel either due to data entry mistakes or lack of species-specific reporting requirements (e.g., historical Florida). The committee has vetted the data where possible to eliminate known cases of misreporting by species (e.g., sand eels in Massachusetts); however, an unknown amount of American eel landings used in this assessment may actually be other species of eel; therefore marine landings of American eels in some areas and years may be over reported.

Purchase records made available by the Delaware Valley Fish Company, one of the largest eel dealers in the United States (M. Feigenbaum, DVFC, pers. comm.) were reviewed during the 2005 assessment. In several instances, purchase records from DVFC indicated a larger harvest of eels for a given state and year than were reported as landings by the NMFS. This emphasized the concerns of the Technical Committee that landings may be underreported to the NMFS. However, despite the discrepancies, the trend in total landings reported by NMFS was generally consistent with the trend in landings reported by the DVFC.

### **5.1.1.2 State-specific data collection**

#### **5.1.1.2.1 Maine**

Fishery-dependent data collection in Maine consists of dealer reporting for the glass eel fishery, and harvester reporting for glass eel, yellow eel (eel pot), and silver eel (weir) fisheries.

##### Dealer Reporting

Glass eel dealer reporting has been required since 1999, although voluntary data are available back to 1996 (Figure 5.8). The primary gear used to harvest glass eels is the fyke net, which has accounted for approximately 78% of the landings since 1999. Dip nets are often used as a test gear to evaluate new sites (G. Wippelhauser, ME DMR, pers. comm.), but landings reported from dip net gear has increased since 1999.

##### Harvester Reporting

Mandatory harvester reporting for the glass eel fishery began in 2007, but it is considered less reliable than the dealer data (i.e., harvesters report estimated harvest weights at the trip level while dealers report actual weigh-out for individual transactions; G. Wippelhauser, ME DMR, pers. comm.), and will not be used in the assessment. Harvester reporting (monthly summaries) has been required in Maine's coastal and inland yellow eel pot fisheries since 2001, with voluntary data back to 1999. The yellow eel fishery is dominated by the coastal pot fishery, which averaged more than 95% of the harvest between 1999 and 2008, but the trends in landings are similar between the two fisheries.

### **5.1.1.2.2 New Hampshire**

#### Dealer Reporting

For the years 1955–1990, landings estimates were obtained from the NMFS dealer reporting system (as provided by ACCSP).

#### Harvester Reporting

Beginning in 1990, the New Hampshire Fish and Game Department provided landings and effort estimates from their coastal harvest logbook program.

### **5.1.1.2.3 Massachusetts**

#### Dealer Reporting

American eel landings estimates from 1950 to 1993 were obtained from the NMFS dealer reporting system (as provided by ACCSP). The ACCSP and NMFS harvest records were limited for 1994 to 1999, a period when the European export market declined sharply. Historical notes and memos indicate this was a transition period with declining market demand and local eel abundance influencing reduced landings. Local demand for eels as striped bass bait created effort that may not have been picked up by Federal monitoring focused on larger food markets. For the period of 1994–1996, data found in archived files of phone interviews of coastal towns with eel fisheries were used. For 1995 and 1996, the small amount of additional poundage reported by ACCSP was added to the coastal survey totals. No data were found for 1997–1999. Unfortunately, 1994–2003 was a transition period of declining landings in Massachusetts that was poorly documented and underreported. It is likely that the slope of the decline was more gradual from 1993 to 2004 than seen in the available data. In the absence of actual catch reports, landings for 1997–1999 were estimated as the average of the three years before and after this period (3,456 pounds). The small amount of additional poundage in these years reported by ACCSP was added to the average.

The Massachusetts Division of Marine Fisheries monitoring under the ASMFC American Eel Management Plan began in 2000 with a dedicated effort to improve reporting of commercial eel harvest. The landings reported to ASMFC for 2000 to 2009 are the most accurate among all data sources for Massachusetts' commercial eel harvest. Underreporting of eel harvest for striped bass bait is a negative influence on catch data from this period, and this was likely a larger problem in the first few years of this series when the reporting process was being developed. For this reason, landings from the time period 2000–2003 are highly uncertain due to expected underreporting.

#### Harvester Reporting

Trip-level reporting began in 2004. In general, data quality improved during 2004–2009 (i.e., reports were cross-checked with dealer records and confirmed with phone calls to permitted fishermen). Trip level reporting was requested during 2001–2007, but catch report submittals occurred annually with variable results in the quality of trip level documentation. Since 2008, trip level reporting has been mandatory with monthly reports required. Relatively few fishermen reported landings in the Massachusetts commercial eel fishery during 2001–2009. The number of permit holders has been near 100 in most years, but the number reporting catches has been typically 10–15. The minor commercial landings of this period appear to be historical lows for Massachusetts.

#### **5.1.1.2.4 Rhode Island**

##### Dealer Reporting

American eel landings estimates from 1950 to 2010 for Rhode Island were obtained from ACCSP.

##### Harvester Reporting

The Rhode Island Division of Fish and Wildlife began trip level reporting of commercial catches of American eel in 2007. The fishery has higher catches during spring and fall. The Rhode Island eel pot fishery is similar in approach and landings to those found in Massachusetts and New Hampshire. The relatively low number of participants and total landings reflect a small-scale, part-time, seasonal fishery. However, the data have outstanding questions on the entry of conger eel catches as American eel and catches reported for the lobster pot gear code.

#### **5.1.1.2.5 Connecticut**

##### Dealer Reporting

American eel landings estimates from 1950 to 2010 for Connecticut were obtained from ACCSP.

#### **5.1.1.2.6 New York**

##### Dealer Reporting

American eel landings estimates from 1950 to 2010 for most of New York waters were obtained from ACCSP.

##### Harvester Reporting

New York landings from Lake Ontario were obtained from NMFS and the Hudson River Fisheries Unit of the New York Department of Environmental Conservation and added to landings from other regions of New York. Prior to 1976, eel caught in this fishery primarily were exported to Canada and likely on to Europe. In September 1976, sale of eel from Lake Ontario was banned due to concerns with contaminants. In 1978, the Lake Ontario fishery was reopened to foreign markets only. In 1982, the fishery was closed again due to concerns with contaminants and has remained closed since that time. Landings recorded by NMFS from 1983–1996 are either illegal or misreported. Monthly fisherman reporting has been mandatory since the 1970s; however, underreporting is suspected to be as high as 50% or more (Steve LaPan, NYS DEC, pers. comm.).

#### **5.1.1.2.7 New Jersey**

##### Dealer Reporting

Commercial harvest records for American eel are available from the NMFS beginning in 1950.

##### Harvester Reporting

New Jersey implemented mandatory harvester reporting in 2007 for all licensed eel pot fishermen. It is likely that some landings from less important gears are missed, but data from NMFS indicate that eel pots account for greater than 98% of total harvest. Harvester reported landings estimates have concurred very well with data collected by NMFS. Pots were the primary capture gear throughout the time series, accounting for at least 63% of annual landings in all years except 1955 (Figure 5.9). Pots have accounted for 98% of landings in nearly all years

since 1977. Between 1950 and 1975, several other gears contributed significantly to total landings. Spears accounted for between 5 and 15% of annual landings between 1950 and 1963, but dropped down to generally less than 1% thereafter and have been absent from catch records since 1977. Weir landings made up between 10 and 20% of landings from 1959 to 1974 before tapering off to no landings in all but two years since 1977. Fyke nets and pound nets also posted occasional high landings, each accounting for 15% or more of annual landings in three years during the 1950s. All other gears combined have generally contributed less than 1% of total landings except for a few notable occasions. In 1997, more than 10% of annual harvest was collected with dip nets during the height of the glass eel fishery. In 2006, a total of 26,500 pounds (16.7%) were reported as hand-line harvest, although this could be a coding error since the next largest harvest by hand-line was 270 pounds.

### Biological Sampling

New Jersey began collecting biological samples from the commercial fishery in 2006, including lengths, weights, and hard parts. Ageing work has been delayed due to staff and funding shortages, but length and weight data have been analyzed to characterize the fishery and the resource. Average length of eels harvested has ranged from 416 mm in 2008 to 500 mm in 2006, with a range across all years of 100 mm to 1037 mm (Table 5.1; Figure 5.10). Weight of eels has ranged from 2 g to 1970 g, with annual averages between 170 g and 270 g. The largest averages for both length and weight were observed in 2006 when a single fyke net fisherman provided a number of large, presumably silver eels. The remaining samples were obtained from eel pot fishermen.

Length-weight parameters were fitted using SAS software (Table 5.2). Predicted weight at length shows slight variation between years at sizes larger than 600 mm (Figure 5.11), although this might be due to small samples sizes of large fish. Regional analysis indicates that eels from the Hudson Bay region are smaller than fish from Delaware Bay or New Jersey coastal regions. Eels greater than 600 mm from Delaware Bay are heavier than their counterparts from the other two regions.

#### **5.1.1.2.8 Upper Delaware River**

The Delaware River is one of the longest undammed rivers on the Atlantic coast, providing unhindered access to upstream areas in northern New Jersey, Pennsylvania and New York. Because the main stem has no barriers to fish passage, the upper reaches of the Delaware River are accessible to migratory species such as eel. As such, eels have been the target of commercial and subsistence fisheries throughout history. Eels are captured primarily in fish weirs built midstream during the summer to catch the downstream migrating silver eels in late summer and fall. Records are not available prior to 1998, but recent harvest records indicate fisheries on the Delaware River and the Neversink River, a tributary near Port Jervis, NY. Conversations with a long-time weir harvester indicated that 30 weirs or more were operated in the region historically (commercial weir fisherman, pers. comm.), but effort has declined dramatically, with only two primary harvesters remaining, one on each of the Delaware and Neversink Rivers (M.B. DeLucia, The Nature Conservancy, pers. comm.).

Several sources of data were pooled in an effort to characterize the eel weir fishery in the New York section of the Delaware River and its tributaries. Weir licenses are issued by the NY Special Permitting Unit, which requires annual reporting of the previous year's catch before a new license is issued (C. Schiralli, NYS DEC, pers. comm.). Individual harvester records were

made available for the years 1998 to 2007. Records prior to 1998 were not available. In addition, landings data are recorded in a database maintained by the NY Hudson River Fisheries Unit (K. McShane, NYS DEC, pers. comm.). Again, data were only available since 1998. Third, The Nature Conservancy has maintained a database of annual harvest on the Neversink and Delaware Rivers back to 1990 (M.B. DeLucia, The Nature Conservancy, pers. comm.). Finally, a 30 year history of harvest (1977 to 2007) was made available by an NPS employee who has been receiving harvest estimates from a single fisherman on the Delaware River (D. Hamilton, National Park Service, pers. comm.).

Unfortunately, there are considerable inconsistencies in the values reported in the different datasets. Attempts were made to match up the reports from the SPU and HRFU because harvester level data were available from both datasets. Where inconsistencies were found, information garnered from discussions with SPU and HRFU staff was used to determine the more appropriate value. Data from TNC matched well with data from the SPU for the years 1998 forward. Since data were not available prior to 1998 from either SPU or HRFU, data reported by TNC were used as the sole source of landings. However, it appears that the TNC dataset is incomplete since the landings estimates for the single harvester obtained from NPS often exceeds the harvest estimates of multiple harvesters obtained from TNC for years prior to 1997. Further, since the TNC dataset includes harvests estimates from the harvester reporting to NPS, this provides an indication of under reporting to the data collection entity in these years.

Harvest estimates were variously provided in pounds and numbers. Numbers were converted to pounds using a conversion of one eel = 0.875 pounds (D. Hamilton, National Park Service, pers. comm.). This matches well with information provided by a long time commercial harvester who indicated eels often weigh about 5/8 pounds early in the season, increasing to approximately one pound by the end of the season (commercial weir fisherman, pers. comm.) Pounds harvested by individual harvesters were summed across all harvesters on both the Delaware and Neversink Rivers to produce annual harvest estimates for the upper Delaware system. Because of a small number of active licenses in some years, landings estimates were standardized to maintain confidentiality. Both multi-harvester and single-harvester estimates were standardized using Z-scores (Zar 1998).

The contributions to overall harvest by the single fisherman reporting to NPS are evident in the correlation between the single and multiple harvester trends from 1998 to present. Since 1998 (NYS DEC data), harvest has varied greatly with little observable trend. Landings are often greatly influenced by weather and timing (commercial weir fisherman, pers. comm.). For example, years of high water during the summer can delay building of weirs, resulting in a shortened (or perhaps entirely lost) season. During several years in the early 2000s, hurricanes and tropical storms produced heavy rainfall and flooding that made the weirs unfishable. Overall effort may also contribute to total landings, but records of number of licenses sold are not available for analysis.

Prior to 1997, the trend in harvest depends greatly on the number and avidity of the harvesters, as well as eel abundance and market conditions. However, some insight into the fishery, and possibly population, might be gained using data from the single harvester. Landings in recent years are similar to landings more than three decades ago, but there appear to have been several minor cycles within that time period. Anecdotal accounts of population size structure indicate that fish as large as 5 pounds were once common, but now two pounds is considered large. In addition, “shoestring” eels (possibly males?) once made up 25–50% of the eels captured in the



weirs, but recently the proportion has declined to around 5% (commercial weir fisherman, pers. comm.).

#### **5.1.1.2.9 Delaware**

##### Dealer Reporting

American eel landings estimates prior to 1999 were obtained from the NMFS dealer reporting system (as provided by ACCSP). Total landings estimates for 1996 were provided by Delaware Division of Fish and Wildlife. The 1997 NMFS estimate of landings was far lower than expected and was rejected with Delaware and NMFS agreeing that there would be no official eel landings for Delaware in that year.

##### Harvester Reporting

Delaware mandated catch and effort reporting from the American eel fishery in 1999. NMFS estimates were used when the monthly breakdown concurred with Delaware records; otherwise, NMFS estimates were replaced with state data. From 2000 through 2008, Delaware supplemental landings (reported after the March upload to NMFS) were added to NMFS totals. Estimates from 2009 were provided by Delaware DFW.

##### Biological Sampling

American eels were sampled from the commercial eel pot fishery in Delaware several times annually during 2000 through 2010. The American eels were taken during onboard sampling; typically the contents of one to three randomly-chosen eel pots were kept for analysis. Sampled American eels were measured to the nearest mm, weighed to the nearest 0.1 gram, and, since 2006, dissected for detection of the swim bladder parasite *A. crassus*. Otoliths were extracted from most of the sampled eels and used for ageing. All of the approximately 3,800 American eels sampled have been measured and weighed, and almost 90% of those sampled were aged. The combined American eel samples since 2000 had a mean length of 378 mm, a mean weight of 122.3 g, and a mean age of 4.

#### **5.1.1.2.10 Maryland and Delaware Coastal Bays**

##### Harvester Reporting

Since mandatory catch and effort reporting was initiated in 1992, American eel harvest from Maryland coastal bays averaged 9,954 lbs accounting for less than 4% of Maryland's total harvest. Harvest in Maryland coastal bays was sporadic and at relatively low levels. Average landings in Delaware coastal bays (18,923 lbs) were nearly twice that of Maryland's throughout their respective time series.

##### Biological Sampling

A total of 77 commercial biosamples were collected from Delaware coastal bay eel potters from 2000–2008. Length and weight were collected on all eels and 74 were aged. Approximately 700 biosamples were collected from Maryland coastal bay eelers in 2000 and 2001. Length and weight were collected on all eels and 179 eels were aged. All Maryland eels collected were unculled and randomly sampled. Mean length (mm) and age from Delaware and Maryland coastal bay eel were 531 mm and 4.5 years and 471 mm and 3.4 years, respectively.

### **5.1.1.2.11 Maryland**

#### Harvester Reporting

Commercial eelers in Maryland were first required to be licensed and report harvest of American eel in 1981. Prior eel landings were obtained from the NMFS dealer reporting system. Mandatory monthly catch and effort began in 1990, but was not fully adopted until 1992. Trip level catch and effort reporting was adopted in 2004.

American eel landings estimates for Maryland were obtained from ACCSP with the following caveats. Maryland provided corrected landings estimates in the years 1994, 2004, and 2006. Duplicate records found for the year 1997 were removed. The eel pot fishery in Maryland accounts for over 98% of total eel harvest.

#### Biological Sampling

Since 1997, American eels have been sub sampled from the commercial eel pot fishery in Maryland's portion of the Chesapeake Bay and tributaries and coastal bays. Twelve tributaries have been sampled over the time period. A minimum of 2 selected tributaries are sampled each year. Approximately 100 pounds of yellow eels purchased in 2 separate batches (usually 2–3 weeks between purchases) from commercial eel potters unculled from live boxes. The live boxes contain catches over multiple days. Since a standard weight is purchased from commercial eelers, depending on size 400–1000 commercially harvested yellow eels are sub sampled per selected river per year. Measurements to the nearest mm and weight to the nearest gram were taken from each eel with approximately 100 of those eels subsampled for aging. Since 2004, approximately 150 eels per year were noted for prevalence of swim bladder parasite *A. crassus*. Since 2006, approximately 90 eels per year were subsampled for sex determination. The mean length of an American eel sampled from the eel pot fishery since 1997 has been 358 mm (N=15,600) with the average freshwater age of 4.0 years (n = 2,790). The prevalence rate of 692 subsampled eels for *A. crassus* was 43%. Since 2006, females have outnumbered males by an approximate 2:1 ratio.

### **5.1.1.2.12 Potomac River**

The Potomac River has jurisdiction for the main stem of the Potomac below the Woodrow Wilson Bridge. The eel pot fishery accounts for over 99% of total eel harvest reported to PRFC.

The Potomac River Fisheries Commission provided records of their landings which were later assigned to either Maryland or Virginia as appropriate. Mandatory harvest reporting for Potomac River Fisheries Commission (PRFC) began in 1964. Monthly catch and effort was required of commercial eelers in 1988. In 1990, the catch and effort was changed to mandatory weekly reporting and then mandatory daily reporting began in 1999.

### **5.1.1.2.13 Virginia**

#### Dealer Reporting

American eel landings estimates for Virginia were obtained from the NMFS dealer reporting system (as provided by ACCSP) with the understanding that supplemental landings (corrections) were added annually by port agents on the arbitrary date of December 31 in 1996. The Virginia Marine Resources Commission (VMRC) also likely sent NMFS supplemental landings updates in 1980 and 1988; therefore the NMFS landings estimates were used in place of VMRC records.

In all other years, NMFS/ACCSP and VMRC records aligned well. A portion of the Potomac River Fisheries Commission landings were assigned to Virginia as appropriate.

#### Harvester Reporting

The Virginia Marine Resources Commission (VMRC) began collecting voluntary reports of commercial landings from seafood buyers in 1973. A mandatory harvester reporting system was initiated in 1993 and collects trip-level data on harvest and landings in Virginia. Data collected from the mandatory reporting program are considered reliable starting in 1994, the year after the pilot year of program.

#### Biological Sampling

The VMRC Biological Sampling Program was initiated in 1989 to collect fishery-dependent biological information to support assessment and management activity within the state and coast-wide. There are currently twenty-one species targeted for sampling in the program, although other species, such as American eel, are sampled based on availability and staff time. Limited numbers of American eels have been available to the Biological Sampling Program over the years (Table 5.3). A total of 818 lengths and 787 weights have been collected from American eels to date. No American eels were available for sampling in 2009 or 2010. The majority of American eels sampled have been collected from eel pots and pound nets. American eels collected from eel pots ranged from 244 mm to 768 mm in length (Figure 5.12). The average length of American eels sampled from eel pots (pooled over years) was 428 mm.

### **5.1.1.2.14 North Carolina**

#### Dealer Reporting

American eel landings estimates for North Carolina were obtained from the NMFS dealer reporting system (as provided by ACCSP) prior to 1972.

#### Harvester Reporting

The NC Department of Environment and Natural Resources provided landings estimates for 1972–2009. A trip ticket system began in 1994 and a commercial logbook system began in 2007. However, logbooks were found to be consistently lower than trip tickets and are believed to be limited by underreporting. Reconciliation and verification will be required before this data can be used in future assessments.

#### Biological Sampling

In 1996, length information data on eel caught in commercial pots was collected during a study commissioned by NCDENR (Hutchinson, 1997). This study was designed to determine the loss of legal-sized eel from pots with and without escape panels. Weekly sampling was conducted between May and October 1996 in the Pamlico River. A total of 176 trips were made to sample 4,057 pots fished. Over 6,500 eel across both types of pots were individually measured. Typically, eels between 280 and 360 mm were retained (Figure 5.13). Weight of individual eel was not recorded.

#### **5.1.1.2.15 South Carolina**

##### Dealer Reporting

American eel landings estimates for South Carolina were obtained from the NMFS dealer reporting system (as provided by ACCSP) for years prior to 2008. The South Carolina Department of Natural Resources provided landings for 2008–2010. A commercial glass eel fishery operates in South Carolina, but landings since 2000 have been minimal and are thus confidential. However, in 2011 anecdotal reports were received of glass eel prices exceeding \$1,000/lb and renewed fishing activity in South Carolina. NMFS records do not indicate life stage, so a breakdown of glass versus yellow eel landings was not available.

#### **5.1.1.2.16 Georgia**

##### Dealer Reporting

American eel landings estimates for Georgia were obtained from the NMFS dealer reporting system (as provided by ACCSP) for years prior to 1989. The Georgia Department of Natural Resources provided landings between 1989 and 2003. No commercial landings have been reported to the state of Georgia since 2003, but anecdotal reports suggest harvesting may be ongoing.

#### **5.1.1.2.17 Florida**

##### Dealer Reporting

American eel landings estimates for Florida were obtained from the NMFS dealer reporting system (as provided by ACCSP) for years prior to 1980. From 1980 forward, Florida Fish and Wildlife Research Institute (FWRI) data were used in the assessment. Prior to 2003, FL sent annual landings totals to NMFS.

##### Harvester Reporting

Monthly harvester reporting began in 2003 and a trip ticket system was instituted in July 2006. No species specific “American eel” code was used in Florida data collection until 2006; therefore, “eel” landings prior to 2006 may include other eel landings (e.g., conger eel). Recent NMFS marine data (not used in this assessment) also likely includes other marine eel. Note that eel landings are typically concentrated in a small area; prior to 1997, most commercial eel landings were reported in the St. Johns River, including the areas of Lake Crescent, Lake George, Lake Jesup, Lake Monroe, and the main stem of the St. Johns River. Data recorded include the water body of harvest, the number of pots set, and the weight of American eels harvested. This fishery is primarily a yellow eel fishery with very few reports of silver eels.

##### Biological Sampling

Biological samples were obtained by purchase from eel harvesters from 2002–2006, but no biological samples exist beyond 2006. Data collected includes total length, weight, and sex. Sex data are not reliable because only a portion of the fish was examined histologically and of those that were examined histologically, nearly all were female. Thus, summaries of the biological data presented here combine both sexes (Figure 5.14). A length-weight relationship was estimated from eels sampled in the St. Johns River system, FL (2002–2010; Figure 5.15).

## 5.1.2 Recreational Fisheries

### 5.1.2.1 Data Collection

The primary source of recreational fishery statistics for the Atlantic coast is the Marine Recreational Fishery Statistics Survey (MRFSS) program. The MRFSS collects data on marine recreational fishing to estimate statistics characterizing the catch and effort in marine recreational fisheries. Recreational fisheries statistics for American eels were obtained from the MRFSS online data query (NMFS, pers. comm.). Information on sample sizes was retrieved from the MRFSS raw intercept files.

#### Survey Methods

Data collection consists primarily of two complementary surveys: a telephone household survey and an angler-intercept survey. In 2005, the MRFSS began at-sea sampling of headboat (party boat) fishing trips. Data derived from the telephone survey are used to estimate the number of recreational fishing trips (effort) for each stratum (see Sampling Intensity, below). The intercept and at-sea headboat data are used to estimate catch-per-trip for each species encountered. The estimated number of angler trips is multiplied by the estimated average catch-per-trip to calculate an estimate of total catch for each survey stratum. A more detailed description of the MRFSS sampling methods is provided in the MRFSS User's Manual (ASMFC 1994).

The MRFSS estimates are divided into three catch types depending on availability for sampling. The MRFSS classifies those fish brought to the dock in whole form, which are identified and measured by trained interviewers, as landings (Type A). Fish that are not in whole form (bait, filleted, released dead) when brought to the dock are classified as discards (Type B1), which are reported to the interviewer but identified by the angler. Fish that are released dead during at-sea headboat sampling are also classified as Type B1 discards. The sum of Types A and B1 provides an estimate of total harvest for the recreational fishery. Anglers also report fish that are released live (Type B2) to the interviewer. Those fish that are released alive during the at-sea headboat survey are also considered Type B2 catch. Total recreational catch is considered the sum of the three catch types (A+B1+B2). The numbers of American eels of each catch type that were sampled by the MRFSS are presented in Table 5.4. Numbers of American eel samples reported by the MRFSS angler-intercept survey and at-sea headboat survey, by catch type, 1981–2010..

#### Sampling Intensity

The number of telephone interviews conducted during each wave varies based on the amount of fishing activity expected for the season (NMFS, pers. comm.). Telephone sampling effort is allocated among coastal counties in proportion to household populations. Specifically, the allocation is based on the ratio of the square root of the population within each county to the sum of the square roots of all county populations within the state.

Intercept sampling is random and stratified by year, state, wave (two-month sampling period), and mode (type of fishing). A minimum of 30 intercepts are performed per stratum, though samples are allocated beyond the minimum in proportion to the average fishing pressure of the previous three years.

#### Biological Sampling

The MRFSS interviewers routinely sample fish of Type A catch that are encountered during the angler-intercept survey. Fish discarded during the at-sea headboat survey are also sampled—the

headboat survey is the only source of biological data characterizing discarded catch that are collected by the MRFSS. The sampled fish are weighed to the nearest five one-hundredth (0.05) of a kilogram or the nearest tenth (0.10) of a kilogram (depending on scale used) and measured to the nearest millimeter for the length type appropriate to the morphology of the fish. The numbers of American eel biological samples taken by the MRFSS are summarized in Tables 5.4 and 5.5.

### Biases

Few anglers fishing in the area covered by the MRFSS target or catch American eels. The MRFSS does not cover inland (freshwater) areas, where the majority of recreational fishing for eels is assumed to occur. In addition, the MRFSS intercept component does not capture information from recreational fishermen who use gears other than hook and line, and therefore does not capture the personal-use sector that may use commercial gear types on a limited basis to harvest eels for personal consumption.

The MRFSS estimates are based on a stratified random sampling design and so are designed to be unbiased. There have been a few instances when the random telephone survey was found to be unrepresentative and an average estimate of trips was substituted. Most recently, the 2002 telephone survey data were discarded for waves 2 and 3 and effort estimates were instead based on a three-year average (1999–2001) for those waves. The MRFSS advises that the weight estimates are minimum values and so may not accurately reflect the actual total weight of fish harvested. There have also been differences in sampling coverage over the duration of the survey. Other caveats associated with these data are discussed at the following web site:

<http://www.st.nmfs.gov/st1/recreational/queries/caveat.html>.

Recent concerns regarding the timeliness and accuracy of the MRFSS program prompted the NMFS to request a thorough review of the methods used to collect and analyze marine recreational fisheries data. The National Research Council (NRC) convened a committee to perform the review, which was completed in 2006 (NRC 2006). The review resulted in a number of recommendations for improving the effectiveness and utility of sampling and estimation methods. In response to the recommendations, the NMFS initiated the Marine Recreational Information Program (MRIP), a program designed to improve the quality and accuracy of marine recreational fisheries data. The MRIP program is being phased in gradually and will eventually replace the MRFSS. The objective of the MRIP program is to provide timely and accurate estimates of marine recreational fisheries catch and effort and provide reliable data to support stock assessment and fisheries management decisions. The program will be reviewed periodically and undergo modifications as needed to address changing management needs.

#### **5.1.2.2 Development of Estimates**

Estimates of harvest in terms of numbers are available for all three catch types (Type A, B1, and B2). Weight estimates are only available for recreational harvest (Type A+B1). Details describing how the MRFSS uses data collected from the telephone interviews and angler intercept survey to develop catch and effort estimates can be found in the MRFSS User's Manual (ASMFC 1994). Finalized recreational fishery statistics were available for 1981 through 2010.

The MRFSS is in the process of applying a new methodology for estimating recreational catch (NMFS, pers. comm.). The new estimation method addresses one of the major concerns identified by the NRC review—there is a mismatch between the MRFSS estimation method and

the program's sampling design. The MRFSS plans to apply the new methodology beginning with the 2010 catch estimates. The new method will also be applied to recalculate catch estimates for 2003 through 2009.

Annual length-frequency distributions of American eels sampled by the MRFSS were calculated using the Type A biological sampling data. These data were available for 1981 through 2010.

### **5.1.2.3 Estimates**

Recreational harvest (Type A + B1) of American eels along the Atlantic coast ranged from 3,485 to 161,077 eels per year during 1981 through 2009. In terms of weight, recreational eel harvest ranged from 353 to 157,155 pounds per year during the same time period (Table 5.6). American eel recreational harvest demonstrated an overall decline over the available time series. The number of American eels released alive by recreational anglers ranged from a low of 21,464 eels in 1997 to a high of 126,330 eels in 2003. Live releases of American eels generally declined from the late 1980s through the late 1990s to early 2000s. Numbers of live releases have since increased to levels similar to those observed in the early to mid-1980s.

The precision of the estimated harvest numbers, measured as proportional standard error (PSE), exceeded 20% in all years and exceeded 30% in nineteen of the twenty-nine years for which estimates were available (Table 5.6). The precision of harvest weight estimates exceeded 20% in most years. In some years, the sampling data were insufficient to allow calculation of precision of harvest weight. Estimates of the number of American eels released alive were also associated with low precision, with PSE values exceeding 20% in the majority of years.

The low precision associated with the recreational fishery statistics is due to the limited numbers of American eels that have been encountered during surveys of recreational anglers along the Atlantic Coast (Tables 5.4 and 5.5). These limited numbers are partly due to the design of the MRFSS survey, which does not include the areas and gears assumed to be responsible for the majority of recreational fishing for American eels (see Biases within section 5.1.2.1, this report). As such, the recreational fishery statistics for American eels provided by MRFSS should be interpreted with caution.

Note that recreational fishery statistics and associated precision for 2003 through 2009 are subject to change as the MRFSS plans to recalculate those estimates using the new estimation methodology (see section 5.1.2.2, this report).

The lengths reported for American eels sampled in the MRFSS angler-intercept survey (Type A catch) ranged from 24 mm to 1,104 mm during 1981 to 2009 (Figure 5.16). Smaller recorded lengths are likely recording errors or species misidentifications.

## **5.2 Fishery-Independent Surveys and Studies**

This section summarizes survey data and studies used to inform the stock assessment. Very few fishery-independent surveys target American eels (with the exception of the state-mandated young-of-year surveys and a few surveys in Maryland). All fishery-independent surveys used in this assessment were evaluated using a standard set of criteria (see Appendix 2) that resulted in data-based decisions to inform the analytical framework (primary assumptions regarding the error structure) for each survey independently. Application of these criteria resulted in nearly all surveys being standardized (unless otherwise noted) using a generalized linear model to account for changes in catchability of eel.

## **5.2.1 Annual Young-of-Year Abundance Surveys**

### **5.2.1.1 Coast-wide Mandatory State Surveys**

#### **5.2.1.1.1 Data Collection**

##### Survey Methods

The FMP for American eel requires all states and jurisdictions, except those exempted by the Management Board, to conduct an annual young-of-year (YOY) abundance survey (ASMFC 2000a). The glass eel (YOY) life stage provides the most unique opportunity to assess the annual recruitment of each year's cohort since YOY result from the previous winter's spawning activity and represent individuals of the same age.

The FMP for American eel provides general guidance to the various states and jurisdictions for setting up the mandated YOY survey (ASMFC 2000a). The ASMFC American Eel Technical Committee updated the approved standard protocol for carrying out the mandatory YOY survey shortly after the approval of the FMP (ASMFC 2000b). A number of gear types are permitted, depending on the habitat and geography of the sampling locale. The timing and placement of the young-of-year sampling gear should coincide with periods of peak onshore migration of YOY within the survey region. Sampling locations should be selected based on historical observations of YOY American eel and attempt to provide as wide a geographic distribution as possible.

States are required to weigh and enumerate the catch of eel and to report the catch-per-unit-effort for each sampling day. Standard statistical techniques (sub-sampling) can be applied in instances where the catch of YOY is too large (i.e., several hundred individuals or more) to warrant a complete census. Data collected during the YOY survey are submitted annually as part of each state's annual compliance report for American eel.

A list of the currently active sites is provided in Table 5.7. A map of survey site locations can be found in Figure 5.17.

##### Sampling Intensity

States and jurisdictions must conduct the required YOY survey at a minimum of one location over a six-week period. The sampling gear should be set during periods of rising or flood tides occurring at nighttime hours. The gear should be inspected as often as possible within the designated sampling period.

##### Biological Sampling

Biological sampling is not required, but recommendations were given to provide a standardized format for collection and reporting of samples (ASMFC 2000b). The ASMFC American Eel Technical Committee recommends a minimum of 60 elvers be sub-sampled twice a week during the sampling period. Each individual should be measured for total length and weighed to the nearest 0.01 g. Pigmentation stage should also be noted using Haro and Krueger (1988) as a guide in assigning stage.

##### Biases

In December 2006, the ASMFC held a workshop for those involved in the state annual YOY surveys. At this workshop, one of the issues discussed was timing of the survey. Participants pointed out that the onset of sampling in a given year is occasionally delayed and so the survey may miss part of the peak onshore migration. Criteria for ending sampling vary among states and



years. These criteria range from formal stopping rules to the need for staff to attend to other responsibilities.

Differences related to the location of the survey sites and placement of the sampling gear may affect the comparability of data among sites. The YOY survey sites have varying distances to the ocean, river mouth, and tidal influence. The salinity of sampling locations ranges from marine to freshwater. Some sites are located near obstructions, such as dams, and the distance to obstructions, if present, is variable. Other differences include differences in the placement of traps relative to attraction flow and differences in the percentage of the channel width fished.

#### **5.2.1.1.2 Development of Estimates**

Annual indices of relative YOY abundance were calculated for sites that have been sampled for at least ten years as of 2010 (Table 5.7). Indices were calculated using the protocol outlined in Appendix 2.

The availability of potential covariates varied among sites and years. Though the ASMFC YOY survey protocol requires that states record effort, water temperature, water level, and discharge (ASMFC 2000b), effort and water temperature were the only auxiliary variables consistently available for all sites. Additional variables were considered as covariates in the GLM analysis if the data were available in all years for a particular site.

Spearman's rank correlation coefficient,  $\rho$ , and the associated probability were calculated for all pairs of YOY indices to assess the degree of association among the indices. Indices were considered significantly correlated at  $\alpha = 0.10$ .

#### **5.2.1.1.3 Estimates**

Annual recruitment indices were computed for sixteen sites sampled as part of the ASMFC-mandate (Table 5.8). Water temperature was found to be a significant covariate affecting catchability for most survey sites. Note that effort was not determined to be a significant covariate in the models for any of the survey sites. Most of the survey data were best characterized using a model that had negative binomial errors. For three sites, a stable generalized linear model could not be developed, so arithmetic mean catch per tow was used as an index of abundance.

Trends in the YOY indices were variable within and among survey sites (Figures 5.18–5.33). The degree of correlation between survey sites ranged from significant and negative to significant and positive (Table 5.9).

There were no strong correlations among the YOY indices in the Gulf of Maine region (Table 5.9). In the Southern New England region, only two YOY indices were available—Gilbert Stuart Dam (Rhode Island) and Carman's River (New York), and they were significantly and positively correlated ( $\rho = 0.591$ ,  $P = 0.0556$ ; Table 5.9). Both these indices show an initial decline from 2000 to 2001, a time series peak in 2002, and relatively low levels with limited variability from 2003 to the end of the time series (Figures 5.21—5.22).

In the Delaware Bay and Mid-Atlantic Coastal Bays region, the Patcong Creek (New Jersey; Figure 5.23) YOY index was negatively correlated with both the Millsboro Dam (Delaware; Figure 5.24) and Turville Creek (Maryland; Figure 5.25) YOY indices (Table 5.9). The negative

correlation between the Patcong Creek (New Jersey) and Turville Creek (Maryland) indices was statistically significant ( $\rho = -0.636$ ,  $P = 0.0353$ ).

Correlations among the YOY indices in the Chesapeake Bay region were generally weak (Table 5.9). One exception was the correlation between the Clark's Millpond (PRFC; Figure 5.26) and Gardy's Millpond (PRFC; Figure 5.27) indices, which was significant and negative ( $\rho = -0.664$ ,  $P = 0.0260$ ; Table 5.9).

One significant correlation was detected among the YOY indices in the South Atlantic region. The YOY indices for Goose Creek (South Carolina; Figure 5.31) and Guana River Dam (Florida; Figure 5.33) were significantly and positively correlated ( $\rho = 0.552$ ,  $P = 0.0984$ ; Table 5.9). Both of these indices show a peak in recruitment in 2005.

### **5.2.1.2 Little Egg Inlet Ichthyoplankton Survey**

#### **5.2.1.2.1 Data Collection**

##### Survey Methods

The Rutgers University Marine Field Stations (RUMFS) has been conducting ichthyoplankton sampling near the field station beginning in the late 1980s, and with established protocols since 1991 (Hagan et al. 2003). Data from this sampling program include timing and intensity of glass eel ingress to estuarine habitat (Sullivan et al. 2006, 2009). Raw survey data were provided to the ASMFC for use in this stock assessment.

Survey protocol is described in detail by Hagan et al. (2003); Sullivan et al. (2006) characterize the sampling area. Briefly, sampling is conducted in Little Sheepshead Creek, a small "thoroughfare" across a peninsula within the Great Bay-Little Egg Harbor estuarine system along the southern New Jersey coast (Figure 5.34). Maximum depth in the creek is approximately 3 meters, with a tidal range of approximately 1 meter. A 1-meter plankton net with 1 mm bar mesh is used to sample larval and juvenile fishes recruiting to the estuary. The net is deployed weekly, throughout the year, during night time flood tide from a bridge over Little Sheepshead Creek. During initial years of the survey, a number of sampling strategies were implemented, but methods have been standardized since August 1991. Since then, three 30-minute sets are made in succession once per week at mid-water. Catch from each set is preserved for later identification and enumeration in the lab, and the net is re-set. Flow rate for each set is measured with a flow meter attached to the net. Environmental parameters include surface water temperature and salinity.

#### **5.2.1.2.2 Development of Estimates**

Over the entire time series, eels were observed in all months except September; however, between June and December, less than 20% of all tows were positive for eels. Data were therefore subset to include only data from the months January to May. In addition, data from 1989 to 1991 were removed due to inconsistent sampling methodology. The resulting dataset was evaluated relative to the standardized criteria, and a generalized linear model was developed consistent with those results. The appropriate error structure was applied to the full model which included year, month, tidal flow rate, mean river discharge (USGS station #01409400 Mullica River near Batsto, NJ), and surface salinity. Non-significant factors were removed to produce the final model. A predicted index was developed based on the lowest level of each class variable and mean values of each numeric variable.

### 5.2.1.2.3 Estimates

A negative binomial error structure provided the best fit to the raw data, and this was applied to the full model. All factors considered in the full model were found to be significant (Table 5.10). The overdispersion factor,  $\phi$ , was estimated at 1.05, indicating the negative binomial error structure was appropriate. The predicted Little Egg Inlet index varied without trend from 1992 to 2008, with relative peaks in 1994–1995 and 2007–2008 (Figure 5.35). The long term average for 1992 to 2008 was 1.52 eels per tow, with a range of 0.81 to 2.31. Since 2008, the index has dropped sharply from more than 1.8 eels per tow in 2008 to just 0.33 eels per tow in 2010.

## 5.2.1.3 Beaufort Inlet Ichthyoplankton Survey

### 5.2.1.3.1 Data Collection

#### Survey Methods

The NOAA National Ocean Service laboratory in Beaufort, NC has been conducting bridge-based plankton sampling near Beaufort, NC since 1985. Ingressing glass eels are often captured in the survey, providing an index of glass eel recruitment to the estuary. The sampling location and methodology are described in Sullivan et al. (2006). Beaufort Inlet is a principal connection between the back bays of North Carolina's Outer Banks and the Atlantic Ocean in the region of Beaufort, NC (Figure 5.34). The major systems near Beaufort Inlet include Bogue Sound, Core Sound, Newport River, and North River. Tidal range within the estuary is approximately 1 meter. Approximately 10% of the water entering Beaufort Inlet passes through the Radio Island—Pivers Island channel where sampling occurs.

Sampling is conducted using a 2 m<sup>2</sup> rectangular plankton net with 1 mm mesh. A flow meter is attached to the net to measure flow rates. Four replicate sets have been made at the surface (0–1 m) during night time flood tides at weekly (1985 to 2001) or bi-weekly (2001 to present) intervals. Sampling is conducted from November to April in every year, with occasional sampling in May and October. Tow duration was approximately 5 minutes per tow during 1985 to 1997; since 1998 tows have been standardized to volume sampled (approximately 100 m<sup>3</sup>) rather than tow duration.

### 5.2.1.3.2 Development of Estimates

The survey has occurred every year since the survey began in December 1985, but data were only available through the 2003 sampling season due to a backlog in processing the samples. Over the entire time series, eels were observed in all months sampled except October. In addition, the proportion of positive tows in May and November were considered too low to include these months in the analysis (less than 5% positive for eels). Data from December to April were included in the analysis, with data from December being lagged to the following calendar year. The resulting dataset was evaluated relative to the standardized criteria, and a generalized linear model was developed consistent with those results. The appropriate error structure was applied to the full model which included year, month, tidal flow rate, and mean river discharge (USGS station #02089500 NEUSE RIVER AT KINSTON, NC). Non-significant factors were removed to produce the final model. A predicted index was developed based on the lowest level of each class variable and mean values of each numeric variable.

### **5.2.1.3.3 Estimates**

A negative binomial error structure provided the best fit to the raw data, and this was applied to the full model. All factors considered in the full model except tidal flow were found to be significant (Table 5.10). The overdispersion factor,  $\phi$ , was estimated at 1.14, indicating the negative binomial error structure was appropriate. The predicted Beaufort Inlet index varied without trend from 1987 to 2003, ranging from a low of 0.17 eels per tow in 1999 to a high of 1.54 in 1994 and 1995 (Figure 5.36).

### **5.2.1.4 HRE Monitoring Program**

One additional YOY index was generated from the HRE Monitoring Program in the Hudson River. For more information, see section 5.2.3.4.

## **5.2.2 Southern New England**

### **5.2.2.1 Rainbow Smelt Fyke Net Survey**

#### **5.2.2.1.1 Data Collection**

The Massachusetts Division of Marine Fisheries began monitoring anadromous rainbow smelt (*Osmerus mordax*) populations in 2004 using fyke nets at four coastal rivers and four additional rivers have been added since 2005. The spring fyke net monitoring occurs when resident yellow eels become active and are susceptible to capture as non-target bycatch. The eel bycatch data were evaluated because the eel assessment presently has no fisheries-independent indices of abundance on yellow eel abundance for New England states or the Gulf of Maine region.

#### Survey Methods

The fyke nets are set at mid-channel three nights a week from early March to the third week of May. The fyke net opening is a 4' x 4' box frame with 4' x 4' wings on both sides and the net mesh is ¼ inch delta. Diadromous fish are counted, measured and released. Water chemistry is measured at each site and discharge is available for most sites.

#### Biases

Catch efficiency for American eel in fyke nets is unknown. Some stations have low and intermittent eel catches.

#### **5.2.2.1.2 Development of Estimates**

Eel bycatch data for 2004–2010 were evaluated for potential utility as catch-per-unit-effort and size composition indices. Mean catch per haul with 95% CI was calculated annually for April and May hauls at each station.

#### **5.2.2.1.3 Estimates**

The total catch of eels at the four original stations has ranged from about 100–200 per year. Eel catches peak in May and few eels are seen in March or before water temperatures reach 10°C. The Fore River station (Boston Harbor region) had the highest eel bycatch in most years and peaked in 2010 with 121 eels during 24 hauls (Figure 5.37). Other stations have documented similar size composition and seasonality as the Fore River; however, with lower catch rates and in some cases relatively few occurrences (Figure 5.37). The eel length range for the Fore River in 2010 was 20–90 cm (Figure 5.37) which approximates the length range for all stations during

2004–2010. Overall, the time series is too brief to contribute to the present eel assessment. The smelt fyke net project is an ongoing, annual monitoring series. Therefore, eel bycatch data will be available for consideration in future assessments.

### **5.2.2.2 CTDEP Electrofishing Survey**

#### **5.2.2.2.1 Data Collection**

##### Survey Methods

Connecticut DEP began sampling a 126 m-long section of the Farmill River in 2001. The sample site substrate is coarse sand and cobble. The Farmill River, a tributary of the Housatonic River with a 26 mile<sup>2</sup> watershed, is tidal freshwater at the sampling site in Shelton. There are no barriers to American eel migration between the sampling site and the ocean.

##### Sampling Intensity

The sample section is electrofished annually using the removal method.

##### Biological Sampling

All eels captured are anesthetized, counted, and measured to the nearest mm, then released back into the sample site.

#### **5.2.2.2.2 Development of Estimates**

A population estimate is derived using maximum weighted likelihood.

#### **5.2.2.2.3 Estimates**

Since 2001, American eel density in the Farmill River has increased (Figure 5.38).

### **5.2.2.3 Western Long Island Study**

#### **5.2.2.3.1 Data Collection**

##### Survey Methods

Since 1984, New York DEC has conducted a seine survey targeting yearling striped bass in several western Long Island Sound bays.

A 200-foot (61-m) seine is deployed at fixed stations during May to October. Prior to 2000, sampling was conducted twice per month in May and June and once per month July to October. Since 2000, however, stations are sampled twice per month in all months.

#### **5.2.2.3.2 Development of Estimates**

Environmental data are collected for this survey, but data were not provided until late in the assessment process. As a result, two indices were developed for this survey. An index based only on sample design variables (including year, month, and system) was developed before environmental data were available. The results from this index were used in the ARIMA, Mann-Kendall, power analysis and other trend based methods (See Section 6 for descriptions of these methods). When environmental data were provided, a second index was developed to include these additional predictor variables, but these results were not incorporated into other methods.

The datasets were subset to the months May through August, since other months had low occurrence of eels over the time series. In addition, station selection was not always consistent, so the 41 stations sampled were subset to stations ( $n = 9$ ) that had been sampled at least 123 times over the years (max = 161; all other stations had fewer than 100 observations). A number of environmental parameters have been collected over time, but only two (water temperature and salinity) were retained. Others were dropped due to their unlikely influence on eel catch (e.g., air temperature, wind speed and direction) or not being collected in all years (e.g., dissolved oxygen was not collected until 1987).

The resulting datasets were evaluated relative to the standardized criteria, and a generalized linear model was developed consistent with those results. The appropriate error structure was applied to the full model which included year, month, and system for the dataset without environmental parameters, and year, month, system, water temperature, and salinity for the dataset that included environmental data. Non-significant factors were removed to produce the respective final models.

### **5.2.2.3.3 Estimates**

A negative binomial error structure provided the best fit to both datasets, and this was applied to the full models. All factors considered in the full model that did not include environmental variables were found to be significant (year, month, system; Table 5.10). For the model that included environmental variables, year, month, system, and water temperature were significant while salinity was not. The two indices were highly correlated, with a Pearson correlation coefficient of 0.98. Both indices peaked in 1985, but dropped by approximately 50% to 65% by 1987 (Figure 5.39). Abundance was relatively stable until 1989, but decreased sharply again in 1990. Both indices have been consistently below 5% of their respective peak value since 1990.

## **5.2.3 Hudson River**

### **5.2.3.1 Morrison & Secor Studies**

#### **5.2.3.1.1 Data Collection**

##### Study Methods

Mark recapture experiments were conducted at the six sites during summers 1997–1999. Sites were distributed through the entire length of the estuary but also were chosen to represent similar depths and bottom characteristics (shoal habitats ~2.10 m deep). Eels were tagged using liquid nitrogen brands and insertion of PIT (passive integrated transponder) tags. Branding was used to identify batches of eels according to site and day of capture, whereas PIT tags identified individual eels for growth measurements.

##### Sampling Intensity

Standard 100-cm long  $\times$  25-cm diameter double funnel eel pots were baited with menhaden and soaked overnight. A grid of 36 pots was deployed at each site with pots approximately 200 m apart at all sites. The pots efficiently captured eels between 300 and 750 mm long.

##### Biological Sampling

During June or July, 100 eels were collected for laboratory analysis from three sites (Haverstraw, Newburgh, and Athens) in 1997 and from all six sites in 1998 and 1999. Length measurements

were recorded and gender was identified through gross visual inspection. Paired sagittal otoliths were removed from the eel, and left and right otoliths were randomly selected. Annular rings were counted at least four times for each section, with estimated age calculated as the mean of the counts and error in counts estimated as the difference between the minimum and maximum counts for each otolith.

#### **5.2.3.1.2 Development of Estimates**

Methods for development of life history parameters were described in Morrison and Secor (2003) and Morrison and Secor (2004).

#### **5.2.3.1.3 Estimates**

Morrison and Secor (2003) found that eel length was similar among sites (total length =  $457 \pm 3$  mm; Figure 5.40). Eel age was substantially lower at brackish-water sites ( $8 \pm 4$  years) than at freshwater sites ( $17 \pm 4$  years) and growth was higher at brackish-water sites than freshwater sites ( $80 \text{ mm}\cdot\text{year}^{-1}$  and  $34 \text{ mm}\cdot\text{year}^{-1}$ , respectively). Almost all (97%) examined eels (1999 samples;  $n = 543$ ) were female.

#### **5.2.3.2 Machut et al. Study**

Machut et al. (2007) studied anthropogenic impacts on American eel demographics in six tributaries of the Hudson River, New York. Six tributaries of the Hudson River in New York State were studied: Wynants Kill, Hannacroix Creek, Saw Kill, Black Creek, Peekskill Hollow Brook, and Minisceongo Creek.

#### **5.2.3.2.1 Data Collection**

##### Study Methods

For details on data collection methods, consult Machut et al. (2007). Sampling sites were isolated with 5-mm-diameter nylon-mesh block nets and electrofished with a variable-voltage backpack shocker from June to August 2003 and 2004 to collect yellow-phase American eels. Reduction sampling was performed at each site (three to five passes depending upon catch). All barriers, either natural waterfalls or man-made structures, of at least 0.5 m in height were catalogued by type and measured for height.

##### Sampling Intensity

Of 1,938 American eels captured, 232 eels (a size-stratified random subsample at each sampling site) were then collected. The number of eels collected for analysis at each sampling site depended on the total number of eels collected at site, ranging from 1 (if only 1 eel was collected at that site) to 16 (if numerous eels were available).

##### Biological Sampling

American eels were sedated with clove oil, counted, measured for total length and weight, and any obvious swellings, lesions, and ulcers were noted. Paired sagittal otoliths were removed from the eel, and left and right otoliths were then randomly selected. Age determinations were made on at least three separate occasions for each eel; if differences in estimates between readers could not be resolved, the otolith was discounted from examination (four otoliths or 2% of all the otoliths read). Male gonads were typified by spermatogonium b cells, while females were identified by presence of oocytes.

### 5.2.3.2.2 Development of Estimates

Methods for development of life history parameters were described in Machut et al. (2007).

### 5.2.3.2.3 Estimates

American eels in these six tributaries were generally smaller (Figure 5.41) than reported in the main stem of the Hudson River by Morrison and Secor (2004; Figure 5.40). Eel ranged in total length from 50 to 718 mm (mean = 185 mm; median = 152 mm). Approximately 82% of eels were caught below the first barrier and 94% were caught below the second barrier. Growth rates for tributary American eels ranged from 13 to 114 mm/year (mean = 35 mm; median = 30 mm). Whether an eel was located above or below the first tributary barrier significantly affected growth rates ( $df = 1$ ,  $P = 0.01$ ), eel growth being higher beyond the first barrier (39.3 mm/year) than below the first barrier (30.5 mm/year). The parameters of the von Bertalanffy growth equation were  $L_{\infty} = 929.1 \pm 210.1$  mm (mean  $\pm$  SE),  $K = 0.0404 \pm 0.014$  mm/year, and  $t_0 = -1.431 \pm 0.48$ . Additional analyses and information on length, age, and growth estimates can be found in Machut et al. (2007).

### 5.2.3.3 NYDEC Alosine and Striped Bass Beach Seine Surveys

#### 5.2.3.3.1 Data Collection

##### Survey Methods

The NYDEC has conducted two beach seine surveys annually on the Hudson River between 1980 and the present. The Alosine Survey targets juvenile alosines and the Striped Bass Survey targets, not surprisingly, juvenile striped bass. The Alosine Survey samples from Newburgh to Albany (river miles 55–140) during the months of June to November using a 100 foot center-bag beach seine. The Striped Bass Survey samples the Haverstraw and Tappan Zee Bays and farther north up the Hudson River (river miles 22–140) during the months of June to November using a 200 foot offset-bag beach seine.

##### Biases

These surveys were not designed to target American eel. Standardization of the survey data may provide an index of abundance if all important factors have been accounted for properly in the analysis. Also, catchability of eel has not been quantified with this gear and study design.

##### Biological Sampling

Lengths of individual eel are collected in the Striped Bass Survey; however, the reliability of those measurements was deemed inadequate for use in this stock assessment by NYSDEC personnel because measurements were pooled in 5 mm bins and animals above 400 mm were pooled into one bin. More detailed length information should be available for future stock assessments.

#### 5.2.3.3.2 Development of Estimates

A standardized index of abundance based on the NYDEC Alosine Beach Seine Survey was computed following the steps given in Appendix 2. The initial candidates for covariates included year, month, river mile, latitude, longitude, and water temperature. Data for month were re-coded such that June observations were combined with July and November observations were combined with October because there were too few observations in June and November. Latitude



and river mile were highly and positively correlated (Spearman's rank:  $\rho = 0.997$ ,  $P < 0.001$ ) so latitude was removed as a potential covariate.

A standardized index of abundance based on the NYDEC Striped Bass Beach Seine Survey was computed following the steps given in Appendix 2. The initial candidates for covariates included year, month, river mile, latitude, longitude, and water temperature. Data for month were re-coded such that June observations were combined with July and November observations were combined with October because there were too few observations in June and November. Latitude and river mile were highly and positively correlated (Spearman's rank:  $\rho = 0.980$ ,  $P < 0.001$ ) so latitude was removed as a potential covariate.

#### **5.2.3.3.3 Estimates**

Data from the NYDEC Alosine Beach Seine Survey were modeled assuming a negative binomial error structure (Table 5.10). Year, month, river mile, and water temperature were included as covariates in the final model. The survey index is variable and demonstrates an overall declining trend over the time series (Figure 5.42). Peaks in relative abundance occurred in 1981, 1986, and 2002.

Data from the NYDEC Striped Bass Beach Seine Survey were modeled assuming a negative binomial error structure (Table 5.10). Year, month, river mile, and water temperature were included as covariates in the final model. The survey index is variable and demonstrates an overall declining trend over the time series (Figure 5.43). There is some evidence of an upward trend in the last three years of the time series (2007 through 2009).

#### **5.2.3.4 HRE Monitoring Program**

##### **5.2.3.4.1 Data Collection**

###### Survey Methods

The Hudson River Estuary (HRE) Monitoring Program has been run on behalf of several utility companies with power stations in the Hudson River Estuary since 1974. The Program consists of three different surveys. Data from the HRE Ichthyoplankton Survey was available in time for this assessment.

The HRE Ichthyoplankton survey was designed to sample for YOY striped bass and follows a random sampling design that consists of paired Tucker trawl (targeting surface and channel) and epibenthic sled (targeting bottom) tows. The Hudson River is split into 13 sampling areas of equal volume and each area is divided into 3 strata (shoal, channel, bottom).

###### Sampling Intensity

The HRE survey is conducted primarily between March and October and collects approximately 100–200 samples per week depending on season.

###### Biological Sampling

All eels are measured; however, life stage (YOY vs. yearling or older) was the only data available for this assessment.

## Biases

Multiple sampling design changes have occurred over the time series, including timing, frequency, and volume sampled. This survey was not designed to target eel and generate an index of abundance for stock assessments. Standardization of the survey data may provide an index of YOY and “yearling and older” abundance if all important factors have been accounted for properly in the analysis.

### **5.2.3.4.2 Development of Estimates**

Following the methods outlined in Appendix 2, an index of YOY eel was created using a delta model with a gamma distribution; jackknifed standard error estimates were also calculated. A “yearling plus” index (eel classified as being yearling or older) was generated using a negative binomial generalized linear model with a log link.

### **5.2.3.4.3 Estimates**

Both indices of abundance included the factors year, month, gear (tucker trawl vs. sled), strata (bottom, channel, shoal), river mile, and volume sampled (Table 5.10). The YOY index was highly variable throughout the 1970s and 1980s, increased to a peak in 1993, then declined steadily through to the present (Figure 5.44). The “yearling plus” index showed a clear, steady decline across the time series (Figure 5.45).

## **5.2.4 Delaware Bay Bay/Mid-Atlantic Coastal Bays**

### **5.2.4.1 NJDFW Striped Bass Seine Survey**

#### **5.2.4.1.1 Data Collection**

The New Jersey Bureau of Marine Fisheries has conducted a young of year striped bass seine survey in the Delaware River since 1980. Yellow stage eels are occasionally captured and enumerated. Although the number of sets that are positive for eels is very limited (~225 sets out of 3,200 total), preliminary analysis indicated moderate correlation with landings (when lagged appropriately) and other regional indices.

#### Survey Methods

The Delaware River seine survey is conducted between river miles 53.5 and 126 (Salem Nuclear Plant to Trenton). The survey area is divided into three regions based on salinity (Figure 5.46). Stations are sampled twice per month using a 100-foot bagged seine with 0.25” mesh. Survey methodology has changed considerable since the survey began in 1980. Modifications include changes to station selection, distribution of stations among regions, single/replicate tows, and months sampled. Standardized methodology employed since 1998 includes sampling 32 fixed stations twice per month from June to November. Data collected for eels includes number and min/max length per tow. Other information collected includes tide, water temperature, salinity, and dissolved oxygen.

#### **5.2.4.1.2 Development of Estimates**

Since the survey began in 1980, the months sampled in a year have expanded and contracted a number of times, but in all years except 1980 sampling has occurred in the core months of August through October (August 1980 was not sampled). In addition, the number, location, and sampling strategy (fixed/random) of stations have changed over time. To minimize effects from

changing sampling design, the index is based only on the months August to October and for stations ( $n = 12$ ) that have been sampled at least 170 times since the beginning of the survey (max 188 observations; the next most frequently sampled stations have ~100 observations). The resulting dataset was evaluated relative to the standardized criteria, and a generalized linear model was developed consistent with those results. The appropriate error structure was applied to the full model which included year, month, water temperature, and salinity. Non-significant factors were removed to produce the final model. A predicted index was developed based on the lowest level of each class variable and mean values of each numeric variable.

#### **5.2.4.1.3 Estimates**

A negative binomial error structure provided the best fit to the raw data, and this was applied to the full model. All factors considered in the full model were found to be significant (Table 5.10). The overdispersion factor,  $\phi$ , was estimated at 0.958, indicating the negative binomial error structure was appropriate. The predicted NJ striped bass seine survey index (Figure 5.47) was generally higher early in the time series, with three of the first six years having greater than 0.3 eels per tow, and a maximum of 1.01 eels in 1982. Since 1987, the index has been relatively stable between values of 0.05 and 0.10 eels per tow, with the exception of one high value in 2004.

#### **5.2.4.2 University of Delaware Silver Eel Study**

##### **5.2.4.2.1 Data Collection**

###### Study Methods

University of Delaware's silver eel study was designed to catch emigrating silver eels in Indian River, Delaware to determine their numbers, sex ratio, age and other biological characteristics. Silver eels were captured in two small, freshwater tributaries of Indian River with fyke nets during 2002 and 2003. The fyke nets were fished during August through November, but most silver eels were caught at the start of emigration, typically after the first major rainfall in September. Some yellow eels captured in Indian River were also kept to compare their ages and growth rates to yellow eels captured in brackish water.

###### Sampling Intensity

The fyke nets were checked daily during August through November.

###### Biases

Only eels longer than 250 mm were kept for analysis.

###### Biological Sampling

All eels were measured, weighed, and assessed for pigmentation. The sampled eels were then sexed histologically and had their otoliths removed for ageing.

Sex ratios were determined for American eels from both tidal tributaries. Length, weight, and age at maturity were calculated for males and females. Growth rates of the freshwater yellow and silver eels were compared to those of brackish water yellow eels.

#### **5.2.4.2.2 Estimates**

The male:female ratio was inversely correlated with the percentage of lacustrine habitat in each watershed. The number of silver eels emigrating was positively correlated with water flow. Mature males were significantly smaller than mature females (Figure 5.48). Growth rate was significantly higher in brackish water than in freshwater.

#### **5.2.4.3 Area 6 Electrofishing**

##### **5.2.4.3.1 Data Collection**

###### Survey Methods

Pennsylvania Fish and Boat Commission (PFBC) conducts electrofishing surveys at four fixed sites spread over 72 km of the Delaware River. Sites are located at Yardley (RKM 258), Point Pleasant (RKM 291), Upper Black Eddy (RKM 318), and Raubsville (RKM 330).

###### Sampling Intensity

Sites have been sampled annually from 1999–2010; however, the Upper Black Eddy and Raubsville sites were not sampled in 2000. At each site, six 50-meter sections of shoreline are electrofished for a total of 300 m of shoreline. The number of “pencil eels” is counted within each 50 meter section.

###### Biological Sampling

No other biological sampling is conducted.

##### **5.2.4.3.2 Development of Estimates**

A negative binomial generalized linear model with a log link was used to derive a standard index of abundance for American eel at all four sites following the methods outlined in Appendix 2. The overdispersion factor,  $\phi$ , for the generalized linear model estimated at 1.05, indicating the negative binomial error structure was appropriate.

##### **5.2.4.3.3 Estimates**

Indices of abundance showed a slight decline in 2000, but have remained stable throughout most of the time series (Figure 5.49).

#### **5.2.4.4 Delaware Finfish Trawl Survey**

The Delaware Division of Fish and Wildlife (DEDFW) operates two finfish trawl surveys—one for juvenile finfish and one for adult finfish.

##### **5.2.4.4.1 Data Collection**

###### Survey Methods

###### *Juvenile Survey*

The DEDFW’s Juvenile Finfish Trawl Survey has been monitoring juvenile fish and crab abundance in Delaware’s inshore waters since 1980. At each site, the 19-m R/V *First State* tows a 4.8-m semi-balloon trawl with a 1.3-cm cod endliner. Tows are made against the current for ten minutes.

### *Adult Survey*

The DEDFW's Adult Finfish Trawl Survey was implemented in 1966 as a long-term fisheries-independent monitoring program. The survey is primarily used to monitor the abundance of sub-adult and adult fish. There are several gaps in sampling in the survey's history, but sampling has been consistently performed every year since 1990. There are nine fixed sampling sites, which are all located off shore in the Delaware Bay and lower Delaware River. Tows are made using the 19-m R/V *First State*, which tows 9.1-m otter trawl with 5.1cm cod end liner. Tow duration is twenty minutes, and tows are made against the current.

### Sampling Intensity

#### *Juvenile Survey*

Sampling for the Juvenile Finfish Trawl Survey is conducted monthly from April through October at 23 fixed sites in Delaware Bay, seventeen fixed sites in the Delaware River, and 12 fixed sites in Indian River, Indian River Bay, and Rehoboth Bay.

#### *Adult Survey*

Adult Finfish Trawl Survey sampling is conducted monthly from March through December.

### Biases

#### *Juvenile Survey*

The juvenile component of the survey is a fixed site design. The net used rarely retained eels shorter than 120 mm.

#### *Adult Survey*

The adult component of the survey is a fixed site design. The net used rarely caught eels.

### Biological Sampling

#### *Juvenile Survey*

For the Juvenile Finfish Trawl Survey, the catch from each tow is sorted by species, and individuals are measured and weighed. Ageing of eels captured at the Delaware River sites was begun in 2007 and will be continued. The length of American eels caught during the index period ranged from 55 to 605 mm, with a mean of 248 mm.

#### *Adult Survey*

For the Adult Finfish Trawl Survey, the catch from each tow is sorted by species, and individuals are measured and weighed. The 23 American eels caught since the survey was standardized in 1990 ranged in length from 250 to 675 mm. Most of these eels were caught in either early spring or late fall at salinities ranging from oligohaline to polyhaline.

### **5.2.4.4.2 Development of Estimates**

#### *Juvenile Survey*

A negative binomial generalized linear model with a log link and factors for year, month, salinity, and water temperature (Table 5.10) was used to derive a standardized index of abundance for American eel following the methods outlined in Appendix 2. The overdispersion

factor,  $\phi$ , for the generalized linear model estimated at 1.02, indicating the negative binomial error structure was appropriate.

#### *Adult Survey*

Catches of American eels in the Adult Finfish Trawl Survey were extremely rare and so the data were considered inadequate for deriving an index of relative abundance.

### **5.2.4.4.3 Estimates**

#### *Juvenile Survey*

The index declined from a peak in 1982 through the late 1980s, increased through the early 1990s, and remained stable with inter-annual variation throughout the rest of the time series (Figure 5.50).

#### *Adult Survey*

No index of abundance was developed based on the Adult Finfish Trawl Survey.

### **5.2.4.5 Delaware Tidal Tributary Survey**

#### **5.2.4.5.1 Data Collection**

##### Survey Methods

The DEDFW's Tidal Tributary Fish Habitat Survey was begun in 1996 to evaluate the fish communities and associated habitat in Delaware's tidal tributaries. Two Delaware River tidal tributaries, four Delaware Bay tidal tributaries, and six Inland Bays (Indian River, Indian River Bay and Rehoboth Bay) tidal tributaries were sampled during 1996 through 2005, the final year of the survey. The sampled tidal tributaries were divided into three sections (upper, middle, and lower) based on salinity and fixed trawl sites were established in each section. Each section was sampled with a 3-m semi-balloon trawl that had a 9.5-mm stretch mesh knotless netting liner and was capable of retaining small eels. Tow duration was ten minutes and tows were made with the current.

##### Sampling Intensity

Sampling was conducted twice monthly during May through October.

##### Biases

The survey is a fixed site design. Some of the tidal tributaries were sampled during all ten sampling years, but others were sampled for five years.

##### Biological Sampling

The catch from each tow is sorted by species, and individuals are measured to the nearest mm. Eels were kept for ageing after the American eel FMP was passed in 2000.

##### Estimates

The American eel caught in this survey ranged in length from 48 mm to 710 mm and had a mean length of 208 mm. Abundance varied widely within and between tidal tributaries. American eel abundance was highest in the oligohaline and mesohaline sections of the sampled tidal tributaries.

## **5.2.4.6 Neversink River Electrofishing**

### **5.2.4.6.1 Data Collection**

#### Survey Methods

The USGS and The Nature Conservancy have been monitoring eels in several tributaries of the upper Delaware River since 2006 in an effort to quantify local population densities and biomass, document life history strategies, assess their interrelations with other fish species, and to define the effects of selected factors (including the Neversink Reservoir) on resident eel populations (M.B. Delucia, The Nature Conservancy, pers. comm.; <http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-EF700.html>). The time series of abundance/densities were considered too short for inclusion in the stock assessment, but the biological data collected from these surveys were used to characterize the size structure of eel populations in the Upper Delaware River system.

Sampling has occurred in a number of tributaries, but most of the effort has been focused on the Neversink River. The Neversink forms on the highest peak of the Catskill Mountains, running 55 miles before it empties into the main stem Delaware River at Port Jervis, NY. Other sampling locations include the Beaverkill (a tributary of the Delaware River east branch), Basha Kill (a tributary of the Neversink), and Paradise Pool.

#### Sampling Intensity

Sampling is conducted during summer months using a backpack electroshocker. As such, access to deeper areas is limited. Between 2006 and 2008, a total of 578 eels were sampled for length and weight information.

### **5.2.4.6.2 Estimates**

Average length of all eels was 363 mm, with a range of 147 to 750 mm (Table 5.11; Figure 5.51). Individual weight ranged from 3 to 639 g, with an overall average of 108 g. Length-weight relationships were consistent across the years (Figure 5.52).

## **5.2.4.7 PSEG Impingement Monitoring**

### **5.2.4.7.1 Data Collection**

#### Survey Methods

The Public Service Enterprise Group (PSEG) Nuclear, LLC of New Jersey operates several ecological monitoring programs in the Delaware Estuary. The objective of the PSEG impingement monitoring program is to estimate the seasonal frequency, abundance, and the initial survival of fish species impinged at Units 1 and 2 at the Salem Generating Station. In addition to the biological data, other data recorded for all samples includes the number of pumps and screens in operation, screen speed, tidal stage and elevation, air temperature, sky condition, wind direction, wave height, water temperature, and salinity. Any detritus collected with the sample is weighed to the nearest 0.1 kilogram.

#### Sampling Intensity

Impingement sampling is performed three days per week during January through December. The sampling days are selected randomly within each seven-day weekly sampling time frame. During each 24-hr sampling period, ten samples are collected at approximately 2.5-hr intervals, which allows for monitoring over a complete diel period and two full tidal cycles.

## Biases

The PSEG Impingement Monitoring Survey is a fixed-design survey, and sampling occurs at one site. The potential bias of the survey data could not be evaluated in terms of persistence since there is only one site. The use of a single site also complicated the possibility of applying geostatistical methods to derive model-based estimators using the survey data.

## Biological Sampling

Biological sampling is conducted in the following manner; however, these data were not available for the assessment. Impinged finfish and blue crab are removed from debris for processing. The condition (live, dead, or damaged) of collected individuals is determined, and organisms are then sorted by species. Aggregate counts and weights are recorded for each species observed in each condition category. All individuals of each species in each condition category are measured for length to the nearest millimeter. Subsamples of at least 100 individuals are taken when catches are too large to process in entirety. Individuals are also weighed to the nearest 0.1 gram.

### **5.2.4.7.2 Development of Estimates**

American eel densities were given as number of eels caught per million m<sup>3</sup> of water for each year of impingement sampling.

### **5.2.4.7.3 Estimates**

American eel impingement densities ranged from 0.75 in 1993 to 14.41 in 1986. Impingement samples have not shown an overall trend in American eel density during the 26 year time series (Figure 5.53).

## **5.2.4.8 PSEG Trawl Survey**

### **5.2.4.8.1 Data Collection**

#### Survey Methods

The objective of the PSEG Bottom Trawl Monitoring Program is to develop indices of abundance for target species; American eel is not a target species. Sampling is performed in the Delaware River Estuary from the mouth of the Delaware Bay to just north of the Delaware Memorial Bridge.

The survey uses a stratified random design. Sites are randomly selected from each of eight zones in the Delaware Bay: Zones 1, 2, and 3 (lower bay); Zones 4, 5, and 6 (“middle” bay); and Zones 7 and 8 (upper bay / lower Delaware River). The number of sampling sites within each zone was determined using a Neyman allocation procedure based on the proportional area of each zone and historical fisheries data.

All sampling is performed during the daytime using a 4.9-m semi-balloon otter trawl with 17-ft headrope and 21-ft footrope. The trawl body is nylon net made of #9 thread with 1.5-in stretch (0.75-in square) mesh. The cod end is constructed of #15 thread with 1.25-in stretch (0.625-in square) mesh and fully-rigged with four 2-in I.D. net rings at the top and bottom for lazy line and purse rope. An inner liner of 0.50-in stretch (0.25-in square) mesh #63 knotless nylon netting is inserted and hogtied in the cod end. The trawl doors are 24 inches in length and 12 inches wide and are made of 0.75-in marine ply board, 1.25-in × 1.25-in straps and braces, and a 0.50-in × 2-



in bottom shoe runner. Tow duration is 10 minutes at 6 ft/sec against the direction of the tide. Information on water quality, water clarity, weather, and tidal stage are also recorded at each sampling site.

#### Sampling Intensity

A total of 40 sites are sampled once a month from April through November.

#### Biases

The net used rarely retained eels shorter than 120 mm.

#### Biological Sampling

After each tow, all finfish and invertebrates are identified to the lowest practicable taxonomic level and counted. The lengths of American eels were measured to the nearest millimeter from 1970 through 2001.

#### **5.2.4.8.2 Development of Estimates**

An index of eel abundance was calculated from 1970 to 2010. The abundance index was based on catch per tow of American eels at the Delaware River trawl sites during April through June. A negative binomial generalized linear model with log link was created following the methods outlined in Appendix 2.

#### **5.2.4.8.3 Estimates**

Model factors included year, month, and bottom salinity (Table 5.10). The index of American eel abundance spiked in the mid-1980s and again around 2005 but was otherwise relatively stable (Figure 5.54).

#### **5.2.4.9 Turville Creek Pot Survey**

Maryland DNR Fisheries performed a fishery-independent eel pot survey in 2008 and 2009 in Turville Creek, a tributary to the Isle of Wight Bay in Maryland's coastal bay. The objective of this survey was to collect demographic information on the yellow eel population in the same system in which the young-of-year Maryland's survey had occurred since 2000.

#### **5.2.4.9.1 Data Collection**

##### Survey Methods

Approximately 25 cylindrical pots with galvanized wire mesh of 1.27 x 1.27cm (1/2" x 1/2") were set in fixed locations on individual lines at depths ranging from 3–14 feet. The pots were baited with razor clams (*Tagellus plebius*) and soaked for 48–72 hours. Sample area totaled 2.5 river miles (4 km).

##### Sampling Intensity

Pots were typically fished twice a week for a six-week period from early April to middle of May.

##### Biases

In the second year of the study fixed pot locations were altered as a result of commercial crab pot interference. The section of the river sampled remained relatively the same.

## Biological Sampling

All captured eels were retained, euthanized, measured to the nearest mm and weighed to the nearest gram. Subsamples were taken for age, gonad, and swim bladder analysis. The majority of eels measured were between 300 and 600 mm in length (Figure 5.55).

### **5.2.4.9.2 Estimates**

The 308 eels measured and weighed had a mean length and weight of 429 mm and 155 grams. Ages ranged from 2 to 8 years for the 196 eels aged and the mean freshwater age was 4.0 years. Females comprised 95% of the subsampled eels and approximately 35% of all eels displayed swim bladder parasite infestation.

## **5.2.5 Chesapeake Bay**

### **5.2.5.1 Shenandoah River Study**

Welsh et al. (2009) initiated a project in 2007 to evaluate the upstream and downstream movements of American eels near dams on the Shenandoah River. Length and weight data collected from downstream migrants in 2007 and 2008 were available for analysis.

The study has supported several graduate projects, including Zimmerman's (2008) study of swim bladder infection in yellow-phase upstream migrants. Lengths and a limited number of ages were available from this study.

#### **5.2.5.1.1 Data Collection**

##### Study Methods

###### *Welsh et al. 2009*

American eels collected as part of the downstream migration study were collected upstream of the Luray hydroelectric dam, located on the South Fork of the Shenandoah River in Virginia (Welsh et al. 2009). These eels were collected using hoop nets and backpack and boat electrofishing.

Hoop nets were set in multiple locations within the headwater areas of the South Fork. The nets were constructed of 3.23-cm stretch delta mesh with five 0.75-m diameter hoops and two funnels. Wings were attached to the net to stretch it across the width of the stream, in order to funnel out-migrating eels into the hoops. The wings were weighted to keep them in place when set in the moving water. Stretched seines were placed upriver of the hoop nets to collect debris that would have otherwise clogged the hoop nets.

Boat electrofishing was performed in impoundments and larger sections of the streams with an 18-foot Smith-Root boat using standard umbrella anodes, and the boat hull acted as the cathode. The boat operated at four amps. Backpack electrofishing was conducted in smaller and shallower areas in the headwaters using Smith-Root backpack electrofishers operating at 200 volts.

###### *Zimmerman 2008*

Zimmerman's (2008) American eel samples were collected from an eel ladder on the Millville hydroelectric dam, located in the lower Shenandoah River. The eel ladder is a covered metal sluice that slopes 50° and extends 11 m from the western side of the dam. Three rows of vertical

PVC pipes arranged in a peg board pattern provide substrate for the climbing eels. A pipe at the top of the ladder directs eels into a collection tank that contains a 6.35-mm mesh net.

### Sampling Intensity

*Welsh et al. 2009*

The hoop nets were fished during the five days around the new moons of October and November 2007. Sites in the South River, Middle River, and Christians Creek were sampled in October. In November, sites in the North River, Naked Creek, and Mossy Creek were sampled in addition to the October locations. The nets were set during the late afternoon and early evenings and pulled the following morning. Nets fished approximately 15 hours each night, though periodic clogging prevented the nets from fishing the entire duration of the set.

Backpack and boat electrofishing was conducted in September through November 2007.

*Zimmerman 2008*

Collection tanks in the Millville Dam eel ladder were checked weekly during the summer to early fall during 2006 to 2008.

### Biological Sampling

*Welsh et al. 2009*

Collected American eels were measured for total length, eye height and width, scanned for passive integrated transponder tags (PIT, 2008 only) and color phase (maturity) was determined. The eels were implanted with coded radio tags and released into the South Fork of the Shenandoah River in Virginia.

*Zimmerman 2008*

Collected American eels were measured for total length, the presence and intensity of *A. crassus* was determined, and health of the swim bladder was assessed. Otoliths were collected from a subsample of these eels and processed for ageing.

#### **5.2.5.1.2 Development of Estimates**

*Welsh et al. 2009*

Individual lengths and weights were available from a total of 115 American eels. Most of the sampled eels (n = 71) were silver-phase eels. Twenty-one were large yellow-phase eels and the remaining 23 were considered to be in an intermediate phase between yellow and silver. The observed length-frequency distribution for each phase was calculated. The average length and weight of sampled eels was also computed for each of the observed phases.

*Zimmerman 2008*

The lengths of 242 American eels inspected for the swim bladder nematode were recorded. Otoliths from 42 eels were processed for ageing. The length- and age-frequency distributions for these eels were calculated. Average length and age were also computed.

### 5.2.5.1.3 Estimates

*Welsh et al. 2009*

Lengths of downstream migrating American eels collected by Welsh et al. (2009) ranged in length from 720 mm to 1,018 mm total length (Figure 5.56). Individual weights of these sampled eels ranged from 660 g to 2,660 g. The average length of sampled yellow eels was 814 mm, and the average weight was 1,100 g. Silver eels averaged 871 mm in length and 1,499 g in weight. The eels classified as intermediate phase had an average length of 843 mm and an average weight of 843 g.

*Zimmerman 2008*

Yellow-phase American eels observed in Zimmerman's (2008) study ranged in length from 200 mm to 527 mm, with an average of 351 mm (Figure 5.57). Ages ranged from 4 to 11 years, with an average of 6.74 years (Figure 5.58).

### 5.2.5.2 Sassafras River Study

The primary objective of this study is to characterize the current population segment of American eels in the Sassafras River through a fishery-independent pot survey. This area was specifically chosen because it was previously sampled through a Maryland DNR fishery-independent eel pot study from 1998–2000. The survey was reinitiated in 2006 and is currently ongoing. This study provides the size and age structure, parasite infestation rates, and sex composition of eels in the Sassafras River, as well as a fishery-independent relative abundance index. The Sassafras River is located on the East Upper Chesapeake Bay near the head of the bay. The river is 22 miles long and the drainage encompasses approximately 97 square miles. Tides are diurnal with approximately 0.55 meters (1.8 feet) normal tide range. Salinities predominantly range from 0 to 3.

#### 5.2.5.2.1 Data Collection

##### Study Methods

This Sassafras River eel pot study was replicated from 1998 field survey methods with slight modifications. In the current study, approximately 30 cylindrical pots with galvanized wire mesh of either 0.83 x 0.83cm (1/3" x 1/3") or 1.27 x 1.27cm (1/2" x 1/2") were set in fixed locations on individual lines at depths ranging from 3–20 feet. Sample area totaled 8.7 river miles and divided equally between an 'upper' and 'lower' pot set.

##### Sampling Intensity

Sampling from 2006–2010 occurred for 4–6 weeks from the middle of May to early July. 'Upper' and 'lower' pot sets were sampled on alternate weeks. The pots were baited with razor clams (*Tagellus plebius*) and soaked for 48 hours.

##### Biases

In the 1998–2000 survey only 1/3" x 1/3" mesh pots were used and only a portion of the pots had a 1/2" x 1/2" escape panel installed. All 1/3" x 1/3" mesh pots used in the current study had the escape panel installed. Both menhaden (*Brevoortia tyrannus*) and horseshoe crabs (*Limulus polyphemus*) were used in addition to razor clams in the previous study. Sampling covered approximately 4.5 river miles and consisted primarily of the current study's 'upper' pot set. Sampling in 2000 only occurred on 2 days, both of which were in July.

## Biological Sampling

All captured eels were retained, euthanized by an ice slurry, clove oil, or MS 222 and measured to the nearest mm and weighed to the nearest gram. Subsamples were taken for age, gonad, and swim bladder analysis.

### **5.2.5.2.2 Estimates**

The 4,190 eels measured and weighed had a mean length and weight of 322 mm and 70 g. Ages ranged from 1 to 11 years for the 628 eels aged with a mean freshwater age of 4.7 years (n = 628). Over 60% of the eels have displayed swim bladder parasite infestation. The female/male ratio was 3:2.

### **5.2.5.3 Gravel Run Monitoring**

In 2006, Maryland DNR Fisheries Service initiated a silver eel study at Gravel Run, a first order stream to the Corsica River (Chester River Watershed) approximately 170 river miles (275 km) from the mouth of the Chesapeake Bay. Gravel Run is 4.5 km in length with 4.1 km above the dam. The main objective of this study is to collect biological information on the migratory (“silver”) phase of the American eel that included length, weight, age, parasite infestation, and sex composition.

#### **5.2.5.3.1 Data Collection**

##### Survey Methods

Biological information collected from the non-tidal freshwater silver eel population included out migration timing, abundance, length, weight, age, sex, and swim bladder parasite infestation.

A 2-foot square trap with 1/2” x 1/2” wire mesh was constructed and attached to an eight-foot section of plastic corrugated drain pipe (2 in diameter) that channeled through an out flow pipe on a 4-foot low head dam. This passive gear operates continuously throughout the sampling period and under most conditions 100% of the water above the blockage as well as out migrating silver eels pass through the pipe.

##### Sampling Intensity

The sampling period in association to the expected timing of silver eel migration in Maryland begins in early to mid-October and ends in early December. Monitoring occurs three days a week throughout the sampling period although the trap samples continuously for 40–60 days barring extraneous weather conditions.

##### Biases

Under extremely heavy rain events water is spilled over the dam. This lessens the likelihood of the need for the silver eels to pass through the pipe in the dam and therefore decreased capture probability. Due to the variability and intensity of rain events each year and the inability to predict the number of silver eels spilling during those events, use of abundance estimates would not be recommended.

## Biological Sampling

All captured silver eels were retained, euthanized, measured (mm), weighed (g), aged, sexed, and noted for the presence of the swim bladder parasite *A. crassus*.

### **5.2.5.3.2 Development of Estimates**

Due to the low sample size all silver eel captured from 2006–2010 were used to compute mean length, weight, age and parasite infestation by sex.

### **5.2.5.3.3 Estimates**

Males accounted for 68% of the catch (n = 68) and displayed a mean length and age of 335 mm and 6.2 years (range = 3–11 years), respectively (Figure 5.59). Females comprised 32 % (n = 32) of the total catch and displayed a mean length and age of 600 mm and 9.6 years (range = 7–14 years), respectively. Prevalence rate of swim bladder parasite *A. crassus* for combined sexes was 52%.

### **5.2.5.4 Fenske et al. Study**

The Chesapeake Biological Laboratory (CBL) collected demographic information from the commercial eel pot fishery in selected tributaries of the Chesapeake Bay in 2007 (Fenske et al. 2010).

#### **5.2.5.4.1 Data Collection**

##### Study Methods

Approximately 5,000 American eels were collected from a commercial eeler using 1/2” x 1/2” eel pots in Potomac River, located in the southwestern part of the Maryland Chesapeake Bay near the Maryland/Virginia state line. Additionally, approximately 100 eels were sampled from 6 river systems fished commercially in the Chesapeake Bay. In 5 rivers (4 MD, 1 VA), eels donated by Delaware Valley Fish Company (DVFC), were randomly sampled from tanks segregated by river system. Randomly sampled Patuxent River eels were acquired through the donation of a commercial eeler.

##### Sampling Intensity

Eels from the Potomac River were sampled on 6 separate occasions in the months of June, July, September, and October. Specific dates of harvest were unknown from subsampled eel from 5 rivers that were acquired from the DVFC. Eels were classified as either “fall” or “summer” season. Eels sampled from the Patuxent River were collected on one day in June.

##### Biases

The eels obtained from the DVFC from the James and Potomac rivers were believed to be size graded before the fish were sold; therefore, length, and age distributions compared to other sampled systems may be biased towards larger and older eels.

##### Biological Sampling

The 5,000 eels collected from the Potomac River were anesthetized, measured to the nearest mm, and released back to the river. Length to the nearest mm, weight (g), gender (as identified through gross visual inspection), and age were collected from subsampled eels from James, Potomac, Patuxent, Choptank, Chester, and Sassafra rivers.

#### **5.2.5.4.2 Development of Estimates**

Mean annual growth rate was estimated by dividing TL by age and assumed linear growth. To account for growth that occurred before entry into the Chesapeake Bay region, 57.1 mm and one

year was subtracted from length and age, respectively. Catch curves were calculated for each sub-estuary to obtain loss rate estimates (Ricker1975).

#### **5.2.5.4.3 Estimates**

Length and age ranges for American eels from the Chesapeake Bay were 213–647 mm TL (mean =365 mm) and 3–11 years (mean = 5.8 years), respectively; weight ranged from 14.7 to 590.8 g (mean=98.8 g). Females constituted 71.3% of all sampled eels. The overall range and mean of growth rates for American eels (gender categories combined) in the Chesapeake Bay were 26.7–149.3 and 67.5 mm/year, respectively. Estimated instantaneous loss rates (gender categories combined) ranged from 0.52 per year in the Choptank River to 1.01 per year in the Potomac River (mean [all rivers] = 0.72 per year).

#### **5.2.5.5 MDDNR Striped Bass Seine Survey**

Maryland DNR Fisheries Service conducted a statewide Striped Bass Juvenile Seine Survey from 1954–2010. The primary objective of this survey is to document annual year-class success of young-of-year striped bass. All fish species, including American eel, are enumerated at each sampling station.

##### **5.2.5.5.1 Data Collection**

###### Survey Methods

Sampling of fishes occurred through the use of a 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh. The survey included inconsistent stations and intensity from 1954–1961. Stations were standardized in 1962 and monthly sampling rounds (excursions) were increased to two per site. A third monthly sampling round was added in 1966. A total of 13 fixed stations were sampled with three sampling rounds since 1966. An additional two fixed sites were added in 1970 totaling 15 fixed sampling stations.

###### Sampling Intensity

Since 1966 sampling occurred at each fixed station once a month for three consecutive months starting in July.

###### Biological Sampling

Incidence rate and abundance of American eel during the seine survey was relatively low. At least one eel was captured in 8.0% of fixed stations since 1970. A total of 237 eels were sampled in a total of 1845 sites.

###### Biases

Despite sufficient geographic coverage of Maryland's Chesapeake Bay, site selection for fixed stations was not random. Stations were selected based on four major spawning and nursery areas for striped bass, which included the Head of the Chesapeake Bay, Potomac, Nanticoke, and Choptank rivers.

##### **5.2.5.5.2 Development of Estimates**

Sixteen stations have been sampled relatively consistently since 1966 (two stations were not sampled until 1970 and one more has not been sampled since 2006). Eight of these stations have captured at least 20 eels over the time series (range 20–67, average 35), while the other eight

have caught 11 or fewer eels (average 6.4). Stations with few eel observations were considered to occur in unsuitable habitat and were removed from the analysis.

The remaining data were evaluated relative to the standardized criteria, and a generalized linear model was developed consistent with those results. The appropriate error structure was applied to the full model which included year, month, system, salinity, and water temperature. Non-significant factors were removed to produce the final model. A predicted index was developed based on the lowest level of each class variable and mean values of each numeric variable.

#### **5.2.5.5.3 Estimates**

A negative binomial error structure was found to be most appropriate for the raw data. Year, month, and salinity variables were found to be significant (Table 5.10), while system and water temperature were not. The overdispersion factor,  $\phi$ , was estimated at 0.97, indicating the negative binomial error structure was appropriate. The predicted Maryland striped bass seine survey index (Figure 5.60) peaked in the first year of the time series, decreasing by more than a factor of 10 between 1966 (1.97) and 1967 (0.13). Eel abundance increased gradually through the late 1970s to approximately 0.5 eels per tow, before declining again to approximately 0.05 eels per tow for the years 1990 to 1996. In 1997, the index increased abruptly to 0.6 eels per tow, and has since varied without trend around a mean of 0.4 eels per tow.

#### **5.2.5.6 VGDIF Electrofishing Survey**

The Virginia Department of Game and Inland Fisheries (VDGIF) perform a number of surveys throughout Virginia. Their survey database was queried for all American eel data collected. The majority of American eel observations were collected from the VDGIF's spring and fall community electrofishing sampling. Biologists in years past have been sampling all of Virginia's water bodies looking at fish populations. These surveys generally target sportfish species (i.e., largemouth bass, smallmouth bass, and sunfish).

##### **5.2.5.6.1 Data Collection**

###### Sampling Intensity

The electrofishing sites, length of runs, and timing vary depending on conditions and specific objectives. Rivers are generally sampled either every year or every other year. Smaller creeks and streams are sampled on a rotational or water availability basis.

###### Biological Sampling

The lengths and weights of American eels encountered during the VDGIF electrofishing surveys were made available for evaluation and analysis.

##### **5.2.5.6.2 Development of Estimates**

Lengths and weights of individual American eels collected by the VDGIF electrofishing surveys were available from 1992 to 2010. These data are briefly summarized below. The raw biological data were included in the growth models discussed later in this report (see section 6.2).

##### **5.2.5.6.3 Estimates**

The lengths of American eels sampled by the VDGIF ranged from 34.0 mm to 1,000 mm (Figure 5.61). Weights of American eels ranged from 0.100 g to 850 g.



### **5.2.5.7 VIMS Juvenile Striped Bass Seine Survey**

The Virginia Institute of Marine Science (VIMS) initiated a juvenile striped bass seine survey in 1967, but the survey was not conducted between 1973 and 1979 due to funding cuts. Funding was restored in 1980, and the survey has been conducted in every year since.

#### **5.2.5.7.1 Data Collection**

##### Survey Methods

Sampling strategy has changed multiple times over the duration of the survey, with standardized methods being adopted in 1989. Since then, 40 stations are sampled biweekly from early July through mid September (5 rounds per year) using a 100-foot (30.5 m) seine net. Stations are located in the James, York, and Rappahanock Rivers. Data prior to 1989 are not standardized, and VIMS personnel were hesitant to provide data prior to the standardization. However, data from years prior to the harvest increase observed in the 1970s are limited, making early years of the VIMS seine survey very important in characterizing the population during that time period. VIMS personnel agreed to provide the full time series of data contingent upon adequate mention of the potential for inconsistencies in raw data and the resulting index due to non-standardized sampling methodology (M. Fabrizio, VIMS, pers. comm.). Attempts were made to remove potential biases by subsetting the raw data (described below), but it is unknown if these steps were effective.

#### **5.2.5.7.2 Development of Estimates**

Recognizing the potential hazards of combining non-standardized data with standardized data, an index was developed using the entire time series of data from the VIMS seine survey. Since the survey began, 88 separate stations have been sampled at least once. In an attempt to remove some uncertainty due to survey changes, the data were subset to include eight stations that have been sampled at least 152 times over the time series (max = 179) with six of these being sampled 174 times or more. The number of eel observed at these stations over the entire time series ranged from 1 to 28 (total = 96, average = 12).

Because of the low incidence of eels at stations used for the full time series index (above), and to investigate the potential for error due to using non-standardized data, a second index was developed from the VIMS seine survey using only data since methods were standardized in 1989. Eighteen stations were sampled consistently from 1989 to 2010. Eight of these stations captured at least 12 eels (max = 42, average = 27.6), while the remaining 10 stations captured 0 to 9 eels each (average = 4.2). The eight stations with the highest eel incidence were used to develop the short time series index.

The remaining data for both the long (1967+) and short (1989+) time series were evaluated relative to the standardized criteria, and generalized linear models were developed consistent with those results. A negative binomial error structure provided the best fit to both sets of data. Available predictor variables were the same for both series, and included year, month, system, river, station type (striped bass index station or not), salinity, and water temperature. Non-significant factors were removed to produce the final model.

#### **5.2.5.7.3 Estimates**

For the long time series index, only year and system were significant (Table 5.10). The overdispersion factor,  $\phi$ , was estimated at 0.82, indicating the negative binomial error structure

was appropriate. A predicted index was developed based on the lowest level of each class variable and mean values of each numeric variable (Figure 5.62). The predicted VIMS striped bass seine survey index for 1967+ was highest during the late 1960s, reaching a peak of 0.25 eels per tow in 1968. Abundance declined gradually until 1972. Data are unavailable from 1974 to 1979, but abundance continued or resumed to decline from 1980 to 1988. The predicted index is essentially zero from 1989 to 1993, rose gradually for a number of years, and has been highly variable around a mean of 0.05 (range 0.00 to 0.12) eels per tow for the last decade.

The final model for the short time series index included year, station type, and salinity (Table 5.10). The overdispersion factor,  $\phi$ , was estimated at 1.07, indicating the negative binomial error structure was appropriate. A predicted index was developed based on the lowest level of each class variable and mean values of each numeric variable (Figure 5.63). The predicted VIMS striped bass seine survey index for 1989+ generally increased during the early 1990s, reaching a peak of 0.29 eels per tow in 1997. This was followed by one of the lowest points of the time series in 1998, recovering to the second high point in the time series in 2001. Since 2002 the index has been relatively stable around 0.07 eels per tow, with the exceptions of the two lowest points of the time series in 2003 and 2010.

Despite only moderate correlation (Pearson correlation coefficient = 0.34), the short and long VIMS indices exhibit similar patterns. Both generally increase during the early 1990s, showing peaks around 1996–1997 and 2000–2001, and low points in 1998–1999, 2003, and 2010. The similarity in these patterns lends credibility to the early years of the long time series.

#### **5.2.5.8 VIMS Juvenile Fish & Blue Crab Trawl Survey**

##### **5.2.5.8.1 Data Collection**

###### Survey Methods

The Virginia Institute of Marine Science (VIMS) Juvenile Trawl Survey was implemented in 1955 to monitor the seasonal distribution and abundance of important finfish and invertebrate species occurring in the Chesapeake Bay and its tributaries. The main objective of this survey is to develop indices of relative abundance to track year-class strength of target species.

The survey sites and sampling frequency has not been consistent throughout the history of the survey (Tuckey and Fabrizio 2010). The survey currently employs a mixed design, incorporating both stratified random sites and fixed (historical mid-channel) sites. Prior to 1996, sampling occurred at fixed stations only and these were located generally in deep, mid-channel areas of the rivers. In 1996, random stations were added to the sampling frame in the rivers and account for about 63.3% of the stations sampled in any given year after 1996.

The stratification system is based on depth and latitudinal regions in the bay (random stations), or depth and longitudinal regions in the tributaries (random and fixed stations). Each bay region spans 15 latitudinal minutes and consists of six strata: western and eastern shore shallow (4–12 ft), western and eastern shoal (12–30 ft), central plain (30–42 ft), and deep channel (>42 ft). Each tributary is partitioned into four regions of approximately ten longitudinal minutes, with four depth strata in each (4–12 ft, 12–30 ft, 30–42 ft, and >42 ft). Strata are collapsed in areas where certain depths are limited. In each tributary, fixed stations are spaced at approximately 5-mile intervals from the river mouths up to the freshwater interface. Fixed sites are assigned to strata based on location and depth. The stratified random sites are selected randomly from the National

Ocean Service's Chesapeake Bay bathymetric grid, a database of depth records measured or calculated at 15-cartographic-second intervals.

The trawl gear configuration has been modified a number of times, but was standardized in 1979. The various gear configurations have been compared through extensive sampling in order to standardize the catch rates associated with each gear combination. Currently, a 30-ft semi-balloon otter trawl is towed by the R/V *Fish Hawk* using a 60-ft bridle. The trawl is composed of 1.5-in stretch mesh body, a 0.25-in mesh cod end liner, two 28-in × 19-in steel china-v doors, and an attached tickler chain. Tows are made along the bottom during daylight hours for five minutes. The trawl doors were changed in 1991, but the change did not significantly alter the catch.

### Sampling Intensity

Two to four sites are randomly selected for each bay stratum each month, and the number of sites varies seasonally. In shallow water strata, only one station is sampled per month. Bay sampling is not conducted during January and March, when few target species are available. One to two stations are randomly selected for most river strata each month. Fixed stations are sampled monthly.

### Biological Sampling

The catch from each tow is sorted by species, and fish are enumerated and measured for length and all are released. Lengths are measured to the nearest millimeter using the length type appropriate for the morphology of each species. Random subsamples are taken when catches of a particular species are too large to process efficiently in the field. Invertebrates are identified and some are measured.

The volume of gelatinous zooplankton caught in the net is also measured for each tow because large catches of these organisms may affect the catch (e.g., changes in gear saturation or efficiency).

Hydrographic and station data such as latitude and longitude, depth, tidal current stage, secchi depth, air temperature, wind direction, wind speed, weather conditions, sea state, water temperature, salinity, and dissolved oxygen are also collected. Data characterizing the habitat or substrate type sampled by the trawl have been recorded since May 1998.

#### **5.2.5.8.2 Development of Estimates**

Staff at the VIMS has been revisiting the methods used to analyze the data collected by their various surveys and so the development of estimates based on the VIMS Juvenile Trawl Survey data was performed by VIMS personnel.

The time period spanning from 1980 to 2010 was selected for evaluating observations of American eel in the VIMS Juvenile Trawl Survey. During this time period, the majority of American eels greater than 152 mm (pre-recruits and larger, see below) were encountered in the tributaries (James, York, and Rappahannock rivers) of the Chesapeake Bay. Eels captured in the main stem of the bay accounted for only 0.29% (n = 41 of 14,359 eels) of all eels caught and will not be considered further. A major portion (12,111 out of 14,509 or 83.5%) of the tows contained no eels. Excluding the zero catches, catch per tow ranged between 1 and 363 eels; this large catch occurred in the Rappahannock River in September 1989.

Most of the American eels caught were encountered during April through September. This six-month period encompassed 7,490 tows and 86.4% ( $n = 12,411$ ) of the 14,359 eels captured. The VIMS Juvenile Trawl Survey did not sample in April 1980, 1981, 1982, 1983, or 1988. The index period for American eel is therefore April through September and includes catches from only the rivers; observations from 7,490 tows were retained for calculation of the index of abundance. Most of the eels captured between April and September (80.9%) were taken from fixed stations in the rivers; this association appears to reflect the higher abundance of eels in the rivers during the 1980s and early 1990s when only fixed stations were sampled. Since 1996, when sampling at random stations commenced, about 58.7% of eels were captured at random stations.

Pooling across years, about half of the catch of American eels was obtained in the Rappahannock River (51.5%); the York River produced the lowest proportional catches overall (17.5%); however, these proportions varied among years, indicating large annual variations in catches among the three tributaries. These differences probably reflect random variation in abundance of eels in these systems and are not the result of annual differences in sampling effort among the tributaries (over all years, total sampling effort—7,490 tows—was allocated as 32.4% in the James, 33.9% in the Rappahannock, and 33.7% in the York).

Indices of American eel abundance were calculated for four size groups using data collected from the rivers during April through September from 1980 to 2010 (Figures 5.64–5.66). The size groups were pre-recruits (less than 300 mm but  $> 152$  mm), recruits (300–400 mm), post-recruits ( $\geq 300$  mm), and all ( $> 152$  mm). The indices were calculated as random stratified means (Cochran 1977) using stratum areas as weighting factors. The means were expressed as the numbers of eels per 5-minute tow. No other standardization could be performed because area swept was not measured prior to 1991; thus, this analysis is based on the assumption that each 5-minute tow sampled a consistent area. Within each stratum, the mean catch was estimated using the delta-lognormal model. Total weights varied annually (especially in the beginning of the time series) because the area sampled by the trawl survey varied. The application of the design-based estimator (random stratified mean) requires the assumption that data were randomly sampled within each river (stratum). Thus, catches from fixed river stations were assumed to represent a random sample from the rivers.

The variance of the stratified mean was estimated from 1,000 bootstrap replicates, which were also used to determine the upper and lower confidence bounds on the mean ( $\alpha=0.05$ ).

### **5.2.5.8.3 Estimates**

A decline in abundance since the mid-1980s is apparent and index values during the last 7 years are particularly low. Despite the range of lengths sampled, the standardized index values and temporal pattern in abundance were remarkably consistent regardless of the size group considered to construct the four indices (all eels, pre-recruits, recruits, post-recruits; Figure 5.67). These patterns were inconsistent with other recent presentations of the same data (Figure 4b from Fenske et al. 2011, Figure 28 from ASMFC 2005). These inconsistencies could not be resolved without analysis of the raw data, so the VIMS Juvenile Trawl Survey was not included in this stock assessment.

## **5.2.5.9 North Anna Electrofishing Survey**

### **5.2.5.9.1 Data Collection**

#### Survey Methods

In 1972, the North Anna River was impounded to create Lake Anna, a 3,885 hectare (9,600 acres) reservoir (lake) that provides condenser cooling water for the North Anna Power Station. Adjacent to Lake Anna is a 1,376 hectare (3,400 acre) Waste Heat Treatment Facility that receives the cooling water and transfers excess heat from the water to the atmosphere before discharging into the lake.

Abundance and species composition data for the North Anna River fish assemblage were collected via backpack and seine electrofishing surveys since 1981. An approximately 70-m reach of riffle/run type habitat was sampled at each station with an electric seine. Prior to sampling, each reach was blocked at the downstream end with a 6.5-mm mesh net. Sampling was conducted by working the electric seine from bank to bank in a zigzag pattern from the upstream to the downstream end of the section. Nearby pool type habitats were then sampled for 10 minutes of effort with a via backpack electrofishing. Data for both sampling gear were combined prior through 1989, so only 1990–2009 data were used in this analysis. Water temperatures (°C) were recorded hourly at Station NAR-1 in the lower North Anna River approximately 1 km below the Lake Anna dam.

#### Sampling Intensity

Sample frequency for electrofishing is typically once per month each year in May, July, and September. Consequently, this provides for a total of 24 river electrofishing collections for a typical sample year (12 electric seine and 12 backpack). Some sampling events over the time series were delayed or canceled due to rain and high flows that made sampling unsafe. For analysis, samples were grouped into three time periods: May–June, July–August, and September–November. No sampling occurred in 2003.

#### Biases

Sampling was inconsistent across years, so some years (2003, 2006–2007) did not contain enough observations to estimate CPUE during standardization (see below). Likewise, temperature and dissolved oxygen measurements were inconsistently recorded in earlier years of the study. Length and weight records were available for 1990–2006.

#### Biological Sampling

Most fish collected were preserved in 10% formalin and transported to the laboratory for appropriate processing. Some larger fish were weighed and measured in the field and released. In the laboratory, a maximum of 15 individual specimens of each species were weighed to the nearest 0.1 g and measured to the nearest 1 mm total length. If more than 15 specimens of a species are collected, those in excess of 15 were counted and weighed in bulk.

### **5.2.5.9.2 Development of Estimates**

A negative binomial generalized linear model with a log link was constructed to standardize the electrofishing survey and create an index of abundance for American eel in the North Anna River following the methods outlined in Appendix 2.

### **5.2.5.9.3 Estimates**

The length distribution of eel caught in the electrofishing survey ranged from 36 to 726 mm (mean = 198.6 mm, median = 185 mm). The length distribution exhibits a peak around 200 mm (Figure 5.68).

Year, electrofishing method (seine vs. backpack), time period (May–June, July–August, July–August, or September–October), and station were significant factors in the model (Table 5.10). The standardized abundance index showed a slight decline in the early 1990s followed by a period of steady increase through 2007; a sharp increase was observed in the last two years (Figure 5.69).

## **5.2.6 South Atlantic**

### **5.2.6.1 NCDMF Estuarine Trawl Survey**

In 1971, the DMF initiated a statewide estuarine trawl survey (Program 120). The initial objectives of the survey were to identify the primary nursery areas and produce annual recruitment indices for economically important species such as spot, Atlantic croaker, weakfish, flounders, blue crab, and brown shrimp. Other objectives included monitoring species distribution by season and by area and providing data for evaluation of environmental impact projects.

#### **5.2.6.1.1 Data Collection**

##### Survey Methods & Sampling Intensity

Various gears and methodology have been used in the survey since 1971. In 1978 and 1989 major gear changes and standardization in sampling occurred. In 1978 tow times were set at one minute during the daylight hours. In 1989 an analysis was conducted to determine a more efficient sampling time frame to produce juvenile abundance indices with acceptable precision levels for the target species and the following changes were made: 1) a fixed set of 105 core stations was identified, 2) sampling would be conducted in May and June only, except for July sampling for weakfish (dropped in 1998 because another survey was deemed adequate), and 3) only the 10.5 ft head rope trawl would be used. July sampling for a subset of the cores was reinstated in 2004 in order to produce a better index for spotted sea trout. Additional habitat fields were added in 2008. A daylight one minute tow is made with an otter trawl covering 75 yards. Environmental data taken include water temperature, salinity, dissolved oxygen, depth, and bottom type.

##### Biases

This survey and survey gear were not designed to target American eel or to generate an index of abundance for stock assessments. Standardization of the survey data may provide an index of abundance if all important factors have been accounted for properly in the analysis. Also, catchability of eel has not been quantified with this gear and study design.

##### Biological Sampling

All species taken are identified, sorted and a total number is recorded for each species. For target species, 30–60 individuals are measured.

#### **5.2.6.1.2 Development of Estimates**

A negative binomial generalized linear model with a log link was constructed to standardize the estuarine trawl survey and create an index of abundance for American eel in North Carolina waters following the methods outlined in Appendix 2. Unrealistic water temperature measurements were recorded that could not be resolved, so water temperature was not included in the analysis. Dissolved oxygen, salinity dissolved oxygen, and depth were not recorded consistently across the time series, so they were also not included in the analysis. Bottom type records were re-coded into a condensed set of categories (algae, detritus, grass, no grass, and other).

#### **5.2.6.1.3 Estimates**

The length distribution of eel caught in the estuarine trawl survey ranged from 26 to 921 mm (mean = 213 mm, median = 205 mm). The length distribution is bimodal with one peak around 75 mm and another peak around 175 mm (Figure 5.70).

The final index of abundance included the following factors: year, latitude, longitude, and bottom type (Table 5.10). A downward trend in the index of abundance was apparent from the peak in the mid 1990s to the present (Figure 5.71).

#### **5.2.6.2 Cudney Study**

Cudney (2004) studied an American eel population in North Carolina (northwestern Pamlico Sound, Lake Mattamuskeet, and adjacent canals) between 2002 and 2003 in order to characterize population demographics and critical habitat needs. Lake Mattamuskeet, one of NC's largest coastal lakes, is connected to Pamlico Sound via four major canals. Saltwater intrusion into the lakebed and surrounding areas was managed with water control structures through which eel were able to pass after the installation of flapgates. The area provides excellent eel habitat and is centrally located among coastal eel harvest grounds. No commercial fishery for eel presently exists in the lake; however, an eel processing and distribution plant operated there for a few years in the mid-1970s. Sale of commercial permits to fish on the Mattamuskeet National Wildlife Refuge ceased after the NCDMF enacted a six-inch minimum size limit to protect young eels in North Carolina waters. However, poaching of glass eels and elvers remains a problem.

#### **5.2.6.2.1 Data Collection**

##### Study Methods

For details on data collection, consult Cudney (2004). Eel pots were placed in at least 15 permanent sampling stations through the canals that link Lake Mattamuskeet and Pamlico Sound. Sites were changed during the study based on catch, habitat quality, and the need to supplement eel pots in areas more frequently visited by locals and tourists (pot theft). Sites for eel pots fished in Lake Mattamuskeet were selected using stratified random sampling based on historical vegetation surveys (1989–1997), depth, and distance from shore. Eel were caught using 24-inch and 36-inch eel pots constructed of 0.5-inch square mesh and baited with frozen menhaden.

### Sampling Intensity

Cudney sampled from February 2002 through September 2003. Pots were normally allowed to soak overnight in Lake Mattamuskeet except during instances of severe weather (hurricanes). Pots were checked every two or three days, and all catch was removed and enumerated. A total of 768 eel were sampled for length and weight. Sex ratios were calculated based on a sample of 442 eels and age was determined for 566 eels.

### Biases

Eel pots were removed by visitors and were sometimes found out of the water with the bait or catch removed, baited with chicken necks or other materials, or moved to a new location. On occasion, sampling locations were changed in an attempt to prevent disturbance. In total, 32 eel pots were stolen from the canals for an estimated loss of 127 fishing days.

### Biological Sampling

Cudney weighed and measured a subsample of eel; eels were characterized as either yellow or silver based on coloration, fin shape, eye diameter, and size. Sagittal otoliths were removed and whole mounted otoliths were read by multiple laboratory personnel. Sex was determined through macroscopic observation of gonads and represented a minimum probable sex ratio since histological analysis of gonads was not attempted. Fish were classified as male, female, or undifferentiated/intersexual. Demographic information and physical condition of the local population was comparable to populations in adjacent states.

#### **5.2.6.2.2 Estimates**

Lengths of eels sampled varied between 49 and 719 mm with an average of 438 mm and differed between estuarine and freshwater eels (Figure 5.72). Weights varied between 24 and 1027 g with an average of 197 mm. The average age observed was 5 with a minimum of 2 and a maximum of 14.

#### **5.2.6.3 Roanoke Rapids Dam Studies Data Collection**

Several studies of American eel at the Roanoke River and Roanoke Rapids Dam have been conducted between 1999 and the present by personnel of Dominion Electric Environmental Services. In 1999–2000, an electrofishing study was conducted to compare size, health, and relative abundance of eel in the Roanoke River with that of nearby river systems. From 2005 to the present, eel traps have been used to monitor and collect samples of American eel during passage above the Roanoke Rapids Dam.

##### **5.2.6.3.1 Data Collection**

###### Study Methods

During August to September 1999 and July 18–20 in 2000, eel in the Roanoke River were sampled via backpack electrofishing during low flow conditions (to facilitate wading) in each of three different habitat types (riffle, run, and pool). Blocking nets proved infeasible, so field crews made one pass upstream attempting to cover 2-m wide area a distance of 30 m<sup>2</sup>. Three people used dip nets (640-mm mesh) to collect stunned eel.



### Sampling Intensity

In 1999, four electrofishing stations were sampled; 10 electrofishing stations were sampled during the July 2000 study. During the passage monitoring study (2005–2009 data available), 10 eel traps were used to collect American eels in the Roanoke Rapids bypass on a weekly or biweekly basis. Five of the traps had a 7/16 inch ramp substrate, and four had a 1 inch ramp substrate.

### Biases

Given the pilot study nature of the 1999–2000 work and the short time series collected to date for the passage monitoring study, reliable CPUE trends could not be generated at this time. Also, consistent sampling protocols were not maintained across all years of passage monitoring. If consistent protocols can be successfully maintained into the future, the passage monitoring study will have great value for the next assessment as an index of abundance on the Roanoke River.

### Biological Sampling

For the electrofishing study, 463 eel were collected between 1999 and 2000. Total length (mm) was reported for all animals and weight (g) was reported for all sampled fish. For the passage monitoring study, 14,692 eel were collected and measured for total length. Weight was reported only for eel caught in 2006 through September 2007.

#### **5.2.6.3.2 Estimates**

The average size of eel caught in the passage traps between 2005 and 2009 was 125 mm (range 89–298 mm, median 123 mm; Figure 5.73).

#### **5.2.6.4 South Carolina Electrofishing Survey**

##### **5.2.6.4.1 Data Collection**

###### Survey Methods

The SC electrofishing survey began in May 2001, sampling six strata within estuarine systems along the South Carolina coast. These included the lower and upper Edisto Rivers, the Combahee River, the upper Ashley River, the upper Cooper River, and the North Santee River. Winyah Bay replaced the North Santee stratum in November 2003. The Upper Edisto and Combahee River strata are freshwater, whereas the others have salinities of up to ~10 ppt.

At each randomly chosen site, a 15-minute set was made along the shoreline in a Smith-Root electrofishing boat. Sampling was performed with the boat moving in the direction of the current, which allows stunned fish to be easily netted as they float alongside the boat. Straight shorelines were sampled by shocking at idle-speed approximately 1.5 to 3-m from the bank. More complex locations that contained submerged trees, remnants of old docks, mouths of tributaries and sloughs required more maneuvering with the boat to ensure all areas were sampled.

###### Sampling Intensity

The shorelines of each stratum are partitioned into 926-m (0.5-nautical miles) long intervals, with each one representing a potential sampling site. Prior to each month's sampling, sites are chosen from a table of random numbers without replacement. The number of potential sites in each stratum is: North Santee River = 82; Upper Cooper River = 63; Upper Ashley River = 80; Lower Edisto River = 88; Upper Edisto River = 86; Combahee River = 232; Winyah Bay = 65.

Variability in the number of sites was caused by drought conditions during some years. Since light rainfall reduced freshwater runoff and allowed the penetration of tidal salt water further upriver, additional upstream sites had to be added in some strata, since the effectiveness of the shocking unit declines at salinities of above ~12 ppt.

### Biases

This survey was not designed to target eel and generate an index of abundance for stock assessments. Standardization of the survey data may provide an index of abundance if all important factors have been accounted for properly in the analysis. Also, catchability of eel has not been quantified with this gear and study design.

### Biological Sampling

Captured fish were placed in a live well until the end of each 15 minute set, at which time they were counted and measured. Standard length measures (nearest mm) were taken from the first 25 randomly selected individuals of each species collected. All fish were released alive.

#### **5.2.6.4.2 Development of Estimates**

A negative binomial generalized linear model with a log link was constructed to standardize the electrofishing survey and create an index of abundance for American eel in South Carolina waters following the methods outlined in Appendix 2. The North Santee River stratum was combined with the Winyah Bay stratum (its replacement in the sampling design) for the analysis.

#### **5.2.6.4.3 Estimates**

The length distribution of eel caught in the electrofishing survey ranged from 44 to 890 mm (mean = 370 mm, median = 355 mm). The length distribution is bimodal with one peak around 300 mm and another peak around 525 mm (Figure 5.74).

The abundance index included the following factors: year, strata (river system), water temperature, salinity, and tide (Table 5.10). The trend in the index shows an overall decline from a peak in the early 2000s to present (Figure 5.75).

#### **5.2.6.5 FWRI River Electrofishing**

##### **5.2.6.5.1 Data Collection**

### Survey Methods

The FL FWCC has conducted electrofishing surveys in four rivers from 1996–2008. However, only the Suwannee River has been sampled consistently over this time period and this summary focuses on the data from the Suwannee River.

### Sampling Intensity

The Suwannee River has been sampled from 1996–2008. The number of sites electrofished each year varies between 1 and 6 sites. No sampling occurred in 2001. The timing of sampling varies from year to year.

## Biases

Although the Suwannee River electrofishing survey supplies a time series of relative abundance, the non-standard timing of this sampling within a year brings into question the usefulness of this survey as a relative abundance index.

## Biological Sampling

Lengths and weights of captured eel are measured. A weight-length equation was developed (Figure 5.76).

### **5.2.6.6 FWRI Lake & Marsh Electrofishing**

#### **5.2.6.6.1 Data Collection**

##### Survey Methods

The FL FWCC has conducted electrofishing surveys in more than 50 lake/marsh areas from 2006–2010 as part of their long-term monitoring program. Lakes are chosen to represent all chains of lakes within the state and by their importance to freshwater fisheries. The lakes/marshes where eels have been captured include: Crescent Lake, Dead Lakes, Dear Point Lake, Farm 13/Stick Marsh, L-35B, L-67A Canal, Lake Garcia, Lake George, Lake Harris, Lake Jesup, Lake Monroe, Lake Panasoffkee, Lake Poinsett, Lake Sampson, Ocklawaha River, and St. Johns River. Electrofishing surveys are generally conducted in the fall between September and December. A limited number of surveys have been conducted in the spring, but spring surveys are not included in this summary. Standard electrofishing methods are used in each lake. Each lake is divided into 750 m sections of shoreline and 25 of these sections are randomly sampled during each sampling event.

##### Sampling Intensity

Multiple sites are electrofished during a sampling event within an area with approximately 10 minutes of shock time at a site. Not all areas are sampled each year and the number of sites electrofished within an area varied from 15 to 90.

##### Biological Sampling

Length and weight data of captured eels are collected.

#### **5.2.6.6.2 Development of Estimates**

A weight-length equation was developed from data combined over all areas (Figure 5.77).

#### **5.2.6.6.3 Estimates**

Average total length of American eels collected in this survey was  $472 \pm 136$  ( $\pm$ st. dev.) mm and ranged from 110 to 832 mm (Figure 5.78).

## **6 ASSESSMENT**

### **6.1 Coast-wide Abundance Indices**

Indices of coast-wide abundance for YOY and yellow-phase American eel were developed by combining data from multiple surveys along the coast. Detailed information describing the

surveys included in the coast-wide indices can be found elsewhere in this report as indicated by the relevant section numbers given below.

### **6.1.1 Data Collection**

#### *Coast-wide Recruitment*

Methods of data collection for the ASMFC-mandated YOY abundance surveys, the Little Egg Inlet Ichthyoplankton Survey, and the Beaufort Inlet Ichthyoplankton Survey are described in section 5.2.1. Details describing data collection for the HRE Monitoring Program can be found in section 5.2.3.4.

#### *Coast-wide Yellow-Phase Abundance*

The surveys used to develop the coast-wide yellow-phase abundance indices and the report section providing additional details (in parentheses) were: Western Long Island Study (section 5.2.2.3), HRE Monitoring Program (section 5.2.3.4), NYDEC Alosine and Striped Bass Beach Seine Surveys (section 5.2.3.3), New Jersey Striped Bass Seine Survey (section 5.2.4.1), Delaware Juvenile Finfish Trawl Survey (section 5.2.4.4), PSEG Trawl Survey (section 5.2.4.8), Maryland Striped Bass Seine Survey (section 5.2.5.5), North Anna Electrofishing Survey (section 5.2.5.9), VIMS Juvenile Striped Bass Seine Survey (section 5.2.5.7), and the NCDMF Estuarine Trawl Survey (section 5.2.6.1). Although these surveys catch yellow stage eels, it should be noted that some portion of the catch in these surveys may include elvers as well.

### **6.1.2 Development of Estimates**

#### *Coast-wide Recruitment*

Two coast-wide indices of American eel recruitment were computed—a short-term index and a long-term index. The short- and long-term indices were developed by combining individual standardized indices into a single, coast-wide index using the generalized linear modeling approach (Appendix 2). The short-term recruitment index was based on the standardized indices developed from the ASMFC-mandated annual YOY surveys. The long-term recruitment index was based on the HRE Monitoring Program, Little Egg Inlet Ichthyoplankton Survey, and Beaufort Inlet Ichthyoplankton Survey standardized indices. The covariates considered for inclusion in the model for the short- and long-term indices were year, region, and survey site. The time period used for generating the long-term coast-wide recruitment index was 1987 to 2009. This time period was selected so that index values from at least two of the long-term YOY surveys were available for every year included in the combined index.

#### *Coast-wide Yellow-Phase Abundance*

Three indices of coast-wide, yellow-phase abundance were computed using different time series lengths—twenty, thirty, and forty-plus years. The indices were developed by combining individual standardized indices into coast-wide indices using the generalized linear modeling approach (Appendix 2). The 40-plus-year coast-wide index of yellow-phase abundance was based on the PSEG Trawl Survey, MDDNR Striped Bass Seine Survey, and VIMS Juvenile Striped Bass Seine Survey (long time series) standardized indices. The 1967–2010 time period was used for the 40-plus index because it was the longest time series that could be used for which at least two of the 40-plus-year indices were available for every year included.

The 30-year coast-wide, yellow-phase abundance index included the same survey indices as the 40-plus index as well as the HRE Monitoring Program, NYDEC Alosine Beach Seine Survey, NYDEC Striped Bass Beach Seine, and New Jersey Striped Bass Seine Survey. The 20-year index included the same survey indices as the 30-year index except for the VIMS Juvenile Striped Bass Seine Survey long time series index. Instead, the 20-year yellow-phase abundance index included the short time series index developed from the VIMS Juvenile Striped Bass Seine Survey. In addition, the 20-year index included the Western Long Island Sound Seine Survey, Delaware Trawl Survey, North Anna Electrofishing Survey, and NCDMF Estuarine Trawl Survey standardized indices.

### **6.1.3 Estimates**

#### *Coast-wide Recruitment*

The short- and long-term YOY recruitment indices were developed assuming a lognormal error structure. The final model for both indices included year and survey site as covariates. The estimate of overdispersion ( $\phi$ ) for the short-term recruitment index was 1.34 and the estimate for the long-term index was 0.0416.

The short-term, coast-wide recruitment index is variable and exhibits two periods of decline in the time series (Figure 6.1). The first period of decline occurred from 2001 to 2004 when the index declined from the time-series peak in 2001 to the time-series low in 2004. The index increased from 2004 to 2005 and then steadily declined through 2009.

The long-term, coast-wide index is variable and without trend (Figure 6.2). There is little coherence between the short- and long-term recruitment indices for the period of time over which the indices overlap (Spearman's rank:  $\rho = 0.212$ ,  $P = 0.556$ ).

#### *Coast-wide Yellow-Phase Abundance*

The coast-wide, yellow-phase abundance indices were developed assuming a lognormal error structure. The final model for all three indices included year and survey site as covariates. Overdispersion estimates for the coast-wide 40-plus, 30-year, and 20-year indices of yellow-phase American eel abundance were 0.145, 0.0945, and 0.0644.

The 40-plus yellow-phase index for the coast demonstrates inter-annual variability, and there is no evidence of an overall trend over the time series (Figure 6.3). The 40-plus index does show peaks in yellow-phase abundance occurring in 1985 and 2005. The peak in 1985 is followed by a decline that continues through 1989. The 30-year coast-wide index of yellow-phase American eel abundance also exhibits a decline from 1985 to 1989 (Figure 6.4). After 1989, the 30-year index show little variability or trend throughout the rest of the time series. The 20-year index of yellow-phase abundance shows limited variability and a slightly increasing trend over the time series (Figure 6.5). The three coast-wide, yellow-phase abundance indices are significantly and positively correlated with each other (Spearman's rank:  $P < 0.001$ ).

## **6.2 Regional Abundance Indices**

Indices of regional abundance for YOY and yellow-stage American eel were developed for each of the regions by combining data from relevant surveys within each region (Table 6.1). Note that the regional indices labeled as yellow-stage indices actually reflect the relative abundance of both yellow-stage eels and elvers, in most cases (see Table 5.10).

### 6.2.1 Data Collection

Detailed information describing the surveys included in the regional indices can be found in the sub-section for the associated region within section 5.2 of this report.

### 6.2.2 Development of Estimates

Region-specific indices of YOY and yellow-stage relative abundance were computed for each of the six geographic regions where data were available. Indices of YOY and yellow-stage American eel abundance were developed by combining individual standardized indices (Tables 5.8 and 5.10) using the generalized linear modeling approach (Appendix A). The time period for each regional index was selected so that index values from at least two of the surveys included were available for every year included in the combined index. The surveys used in the development of the regional YOY and yellow-stage indices and the time periods of those indices are listed in Table 6.1.

Spearman's rank correlation coefficient,  $\rho$ , and the associated probability were calculated for all pairs of regional YOY indices and all pairs of regional yellow-stage indices to assess the degree of association among the indices. The correlation analysis was also applied to evaluate the degree of association between the yellow-stage indices and the YOY indices within each region. The YOY indices were lagged by 0–4 years for comparison to the yellow-stage indices. Indices were considered significantly correlated at  $\alpha = 0.10$ .

### 6.2.3 Estimates

All region-specific YOY and yellow-stage indices of American eel abundance were modeled assuming lognormal error structures and the final models all included year and survey as covariates. The Hudson River region YOY index was based on a single recruitment index because only one such index was available for the region (Table 6.1). No yellow-stage indices of American eel abundance were available for the Gulf of Maine so a yellow-stage index could not be developed for the Gulf of Maine.

The regional YOY and yellow-stage indices of American eel abundance are depicted in Figures 6.6 and 6.7. Both the YOY and yellow-stage regional indices are variable among years. All the YOY indices, except in the Hudson River region, are characterized by relatively large standard errors ( $\geq 30\%$  of the index estimates; Figure 6.6). This is partly due to the differences in the magnitudes of the index values among surveys that were combined in developing the region-specific indices.

Among the regional YOY indices for American eel, the South Atlantic index was found to be significantly and positively correlated with Gulf of Maine, Hudson River, and Chesapeake Bay indices ( $P < 0.001$ ; Table 6.2). Significant, positive correlations were also detected between the Gulf of Maine and Hudson River YOY regional indices as well as between the Hudson River and Chesapeake Bay YOY regional indices. There were no statistically significant correlations detected among the region-specific yellow-stage indices (Table 6.3). Few significant correlations were detected between the region-specific yellow-stage and lagged YOY indices (Table 6.4). The Chesapeake Bay yellow-stage index was significantly and negatively correlated with the Chesapeake Bay YOY index that was not lagged ( $\rho = -0.627$ ,  $P = 0.0388$ ). The South Atlantic yellow-stage index was significantly and positively correlated with the South Atlantic YOY index that was lagged three years ( $\rho = 0.750$ ,  $P = 0.0522$ ).

## 6.3 Analyses of Life History Data

### 6.3.1 Growth Meta-Analysis

#### 6.3.1.1 Methods

Biological data for American eel were compiled from a number of past and on-going research programs along the Atlantic Coast and classified into one of the six geographic regions used in this assessment (Table 6.5). The biological data were used to model both the length-weight and age-length relationship for American eel.

The relation of length in millimeters to weight in grams was modeled using the allometric length-weight function. Length-weight parameters were estimated by region, sex, and for all data pooled together. The analysis of the residual sum of squares (ARSS) method was performed to compare the length-weight curves among regions and between sexes (Chen et al. 1992; Haddon 2001). The ARSS method provides a procedure for testing whether two or more nonlinear curves are coincident (i.e., not statistically different). Values were considered statistically significant at  $\alpha < 0.05$ . Note that interpreting the results of this test is partly confounded by the differences in the range of lengths and weights available for the various dataset configurations.

Previous studies that have modeled the age-length relation for American eel have used linear regression (Table 2.6). Linear regression was used here to model the relation of age in years to length in millimeters by region, sex, and for all data pooled together. A test for coincident regressions was applied to test for differences in the regressions among regions and between sexes (Zar 1999). Values were considered statistically significant at  $\alpha < 0.05$ . As with the ARSS test for coincident curves, the results of the test for coincident regressions will be partly confounded by the differences in the range of ages and lengths available for the various dataset configurations.

Alternative age-length models were fit to the available data to determine what model best characterizes American eel growth. The models considered are described below.

One of the most commonly used models to describe the age-length relationship is the von Bertalanffy model, which is given by:

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

where  $L_t$  is length at age  $t$ ,  $L_\infty$  is the theoretical asymptotic average length (if  $K > 0$ ),  $K$  is growth rate at which the asymptote is approached, and  $t_0$  is the hypothetical age at which length is zero.

The Gompertz growth model is a three-parameter sigmoid function and is calculated as:

$$L_t = L_\infty e^{-\frac{1}{K}e^{-K(t-t_0)}}$$

The Richards model is a generalization of the von Bertalanffy model to allow for greater flexibility:

$$L_t = L_\infty [1 - \delta e^{-K(t-t_0)}]^{1/\delta} \quad \delta \neq 0$$

where  $\delta$  is an additional parameter estimated by the model.

The logistic age-length model is equivalent to the Richards model when  $\delta = -1$  and is given by:

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

Schnute provides a general four-parameter model describing a relative, rather than instantaneous, rate of change in growth that contains most of the preceding models as special cases. The model is given by:

$$L_t = \left[ L_1^b + (L_2^b - L_1^b) \frac{1 - e^{-a(t-t_1)}}{1 - e^{-a(t_2-t_1)}} \right]^{\frac{1}{b}}$$

for case 1 (see Schnute 1981) where  $t_1$  and  $t_2$  were specified as the youngest and oldest ages observed,  $L_1$  is length at age  $t_1$ ,  $L_2$  is length at age  $t_2$ , and the parameters  $a$  and  $b$  define the shape of the curve and are not equal to zero for case 1.

Model fits were first evaluated based on convergence status; models that did not successfully converge were removed from consideration for the associated dataset. The fits of models that successfully converged were compared using the Akaike Information Criterion (AIC) for use with sum of squares (Hongzhi 1989; Hilborn and Mangel 1997). This method takes into account both the goodness-of-fit and the number of parameters estimated. The model fit associated with the smallest AIC value is considered the most likely to be correct among the models considered, given the data. Akaike weights were also calculated to quantify the relative probability that each model is correct, given the data and set of candidate models (Burnham and Anderson 2002). AIC and Akaike weights apply to comparisons of different models fit to the same dataset.

### 6.3.1.2 Results

The length-weight model successfully converged when fit to all dataset configurations (Table 6.6). The results of the ARSS indicated that there are statistically significant differences in the length-weight relation among regions ( $F_{10, 49,209} = 295$ ,  $P < 0.001$ ). The fit of the length-weight function to all pooled data was dominated by data from the Chesapeake Bay region (Figure 6.8), which was the source of the majority of length and weight biological samples (Table 6.5). Sex-specific differences between the length-weight parameters were nearly significant ( $F_{2, 4,993} = 2.89$ ,  $P = 0.0555$ ; Figure 6.9).

The parameters estimated from the linear regression of length on age for the various dataset configurations are presented in Table 6.7. There are statistically significant differences in the age-length relation among regions based on the results of the test for coincident regressions ( $F_{10, 13,520} = 659$ ,  $P < 0.001$ ). The final parameter estimates suggest that growth in length with age is fastest in the Delaware Bay/Mid-Atlantic Coastal Bays region and the Chesapeake Bay region (Table 6.7; Figure 6.10). The test for coincident regressions also detected significant differences in the age-length regressions between sexes ( $F_{2, 4,615} = 1,102$ ,  $P < 0.001$ ; Figure 6.11). The results suggest the rate of growth in length with age is faster in females than males (Table 6.7; Figure 6.11).

The various models relating length to age were compared based on ranking of AIC values among candidate models within each dataset configuration. Only models that successfully converged and produced realistic parameter estimates were considered. Estimates from the age-length linear regressions were presented in Table 6.7. The parameter values and associated standard errors



estimated by the nonlinear age-length models are shown in Tables 6.8–6.12. None of the nonlinear models considered successfully converged on all dataset configurations. The only dataset configurations that were successfully fit by all models were all data pooled, Hudson River region, and Delaware Bay/Mid-Atlantic Coastal Bays region. Parameter estimates of the Schnute model for the Southern New England region are considered unrealistic because the resulting curve suggests almost no growth as age increases except at the very oldest ages at which growth appears exponential (Table 6.12).

There was no one model that was found to consistently result in the lowest AIC and highest Akaike weight among the all dataset configurations (Table 6.13). This could be attributed to real differences in growth among the different configurations but one must consider the differences in the number of samples (Table 6.5) and range of ages and lengths available among the various dataset configurations. The comparisons of model fits also indicated all models (that converged) were nearly equally likely in predicting growth in length with age for each dataset configuration (very small differences in AIC values and Akaike weights among models within datasets; Table 6.13). This is not surprising given the broad overlap in lengths of adjacent age classes observed in the data (Figures 6.10 and 6.11), which suggests the relationship between age and length for American eel is not well defined and that age is a poor predictor of length for American eel.

### **6.3.2 SLYME (Sequential Life-table and Yield-per-Recruit Model for the American Eel)**

#### **6.3.2.1 Methods**

In 2008, the American eel SASC applied a life-table model to available data to examine the effects of a maximum size limit on female spawner escapement and egg production. A copy of the report describing the methods and results is presented in Appendix 3.

#### **6.3.2.2 Results**

The SASC feels the SLYME model can be a useful tool for evaluating management options, as long as the assumptions and caveats associated with the model are taken into account.

### **6.4 Trend Analyses**

#### **6.4.1 Power Analysis**

Power analysis was performed on all fishery-independent American eel surveys as a means to evaluate the precision of abundance indices.

##### **6.4.1.1 Methods**

Power analysis followed methods described in Gerrodette (1987) for both potential linear and exponential trends. A linear trend can be modeled as  $A_i = A_1[1+r(i-1)]$  and an exponential trend as  $A_i = A_1(1+r)^{i-1}$  where  $A_i$  is the abundance index in year  $i$ ,  $A_1$  is the abundance index in year 1, and  $r$  is a constant increment of change as a fraction of the initial abundance index  $A_1$ . The overall fractional change in abundance over  $n$  years can be expressed as  $R = r(n - 1)$ .

If  $\alpha$  and  $\beta$  are the probabilities of type 1 and type 2 errors respectively, the power of a linear trend  $(1 - \beta)$  assuming  $CV \sim 1/\sqrt{A}$  can be determined by satisfying the equation:

$$r^2n(n-1)(n+1) \geq 12CV_1^2(z_\alpha + z_\beta)^2 \left\{ 1 + \frac{3r}{2}(n-1) \left[ 1 + \frac{r}{3}(2n-1) + \frac{r^2}{6}n(n-1) \right] \right\}$$

and the power of an exponential trend can be determined by satisfying the equation:

$$[\ln(1+r)]^2n(n-1)(n+1) \geq 12(z_\alpha + z_\beta)^2 \left\{ \frac{1}{n} \sum \ln[CV_1^2(1+r)^{i-1} + 1] \right\}$$

where  $CV_1$  is an estimate of the coefficient of variation of the survey. For each of the surveys, the median CV of the survey was calculated over the entire time series of the survey and used as an estimate of  $CV_1$ . Power was then calculated for an overall change ( $R$ ) of  $\pm 50\%$  over a 10 year time period ( $r = 0.056$ ) for both a linear and exponential trend.

### 6.4.1.2 Results

Median CVs of the surveys ranged from 0.04 to 1.02. Resulting estimates of power were a function of CVs with those surveys having low CVs having high power, and those surveys having high CVs having low power. Power values ranged from 0.11 to 1.00 (Table 6.14). For all surveys, there is greater power to detect a decreasing trend compared to an increasing trend which is a property of surveys whose  $CV \sim 1/\sqrt{A}$ . There was very little difference in power between linear and exponential trends.

The values of power presented in Table 6.14 can be interpreted as the probability of detecting a given linear or exponential trend of  $\pm 50\%$  over a ten year period if it actually occurs. These values do not reflect a retrospective power analysis and a survey with low power value may still be capable of detecting a statistically significant trend if given enough years of data.

## 6.4.2 Mann-Kendall Analysis

### 6.4.2.1 Methods

The Mann-Kendall trend analysis is a non-parametric test for monotonic trend in time-ordered data (Gilbert 1987). The null hypothesis is that the time series is independent and identically distributed—there is no significant trend across time. The test allows for missing values and can account for tied values if present.

The Mann-Kendall test was applied to all local, regional, and coast-wide indices of relative abundance computed in this assessment. A two-tailed test was used to test for the presence of either an upward or downward trend over the entire time series. Trends were considered statistically significant at  $\alpha = 0.05$ .

### 6.4.2.2 Results

#### *Local Indices*

No significant temporal trends were detected among the YOY indices developed from the ASMFC-mandated recruitment surveys (Table 6.15). The Mann-Kendall test found statistically significant trends in eleven of the eighteen other individual indices evaluated; three were upward trends and eight were downward trends (Table 6.16). Significant downward trends were detected in all four indices from the Hudson River region. The test found significant downward trends in two of the three indices from the South Atlantic region. In the Southern New England and

Chesapeake Bay regions, both upward and downward significant trends were detected. The YOY index developed from the HRE Monitoring Program was the only YOY index in which a significant trend was detected, and the trend direction was down.

#### *Regional Indices*

Significant downward trends were detected in both the YOY and yellow-phase indices for the Hudson River region (Table 6.17). The Mann-Kendall test found a significant upward trend in the Chesapeake Bay region's yellow-phase abundance index. A significant downward trend was found in the yellow-phase index for the South Atlantic region.

#### *Coast-wide Indices*

The Mann-Kendall test detected one significant trend among the coast-wide indices (Table 6.17). The 30-year yellow-phase abundance index exhibited a significant downward trend.

### **6.4.3 Manly Analysis**

A meta-analysis was conducted to determine if there was consensus among fishery-independent survey indices for a coast-wide decline in American eel. Meta-analysis is a statistical approach that combines the results from independent datasets to determine if the datasets are showing the same patterns. The meta-analysis techniques employed in this analysis are described by Manly (2001).

#### **6.4.3.1 Methods**

American eel surveys were grouped according to life stages (yellow vs. YOY) and one-tailed  $p$ -values from the Mann-Kendall test for trend were used in the meta-analysis (Manly 2001). Two meta-analysis techniques were used.

Fisher's method tests the hypothesis that at least one of the indices showed a significant decline through time. The test statistic was calculated as  $S_1 = -2\sum \log_e(p_i)$ , where  $p_i$  is the one-tailed  $p$ -value that tests for a negative trend from the  $i$ th index. The one-tailed  $p$ -value is used because we are interested in whether the index has declined through time. If the null hypothesis is true for a test of significance, then the  $p$ -value from the test has a uniform distribution between 0 and 1, and if  $p$  has a uniform distribution, then  $-2\log_e(p)$  has a chi-square distribution with 2 degrees of freedom. The test statistic,  $S_1$ , is then compared to a chi-square distribution with  $2n$  degrees of freedom, where  $n$  equals the number of independent surveys considered.

The Liptak-Stouffer method tests the hypothesis that there is consensus for a decline supported the entire set of indices. The individual one-tailed  $p$ -values were converted to  $z$ -scores. If the null hypothesis is true for all indices, the  $z$ -scores are distributed as a normal random variable with mean equal to 0 and variance equal to  $1/\sqrt{n}$ . This allows for weighting the results from different indices differently. The test statistic is  $S_2 = \sum w_i z_i / \sqrt{\sum w_i^2}$  where  $w_i$  is the weight of the  $i$ th index. In this analysis, the number of years of survey data was used as the weight for the  $i$ th index. A level of  $\alpha = 0.05$  was used in meta-analyses for tests of significance.

#### **6.4.3.2 Results**

At least one of the indices for both life stages showed a decline through time (yellow eels:  $S_1 = 174.82$ ,  $p < 0.01$ ; YOY eels:  $S_1 = 65.80$ ,  $p < 0.01$ ; Table 6.18). Also, there was consensus for a

decline for both life stages through time (yellow eels:  $S_2 = -6.29$ ,  $p < 0.01$ ; YOY eels:  $S_2 = -15.10$ ,  $p < 0.01$ ).

#### 6.4.4 ARIMA

Fishery-independent surveys for American eel can be quite variable, making inferences about population trends uncertain. Observed time series of abundance indices represents true changes in abundance, within survey sampling error, and varying catchability over time. One approach to minimize measurement error in the survey estimates is by using autoregressive integrated moving average models (ARIMA, Box and Jenkins 1976). The ARIMA approach derives fitted estimates of abundance over the entire time series whose variance is less than the variance of the observed series (Pennington 1986). This approach is commonly used to gain insight in stock assessments where enough data for size or age-structured assessments (e.g., yield per recruit, catch at age) is not yet available.

Helser and Hayes (1995) extended Pennington's (1986) application of ARIMA models to fisheries survey data to infer population status relative to an index-based reference point. This methodology yields a probability of the fitted index value of a particular year being less than the reference point [ $p(\text{index}_t < \text{reference})$ ]. Helser et al. (2002) suggested using a two-tiered approach when evaluating reference points whereby not only is the probability of being below (or above) the reference point estimated, the statistical level of confidence is also specified. The confidence level can be thought of as a one-tailed  $\alpha$ -probability from typical statistical hypothesis testing. For example, if the  $p(\text{index}_t < \text{reference}) = 0.90$  at an 80% confidence level, there is strong evidence that the index of the year in question is less than the reference point. This methodology characterizes both the uncertainty in the index of abundance and in the chosen reference point. Helser and Hayes (1995) suggested the lower quartile (25th percentile) of the fitted abundance index as the reference point in an analysis of Atlantic wolfish (*Anarhichas lupus*) data. The use of the lower quartile as a reference point is arbitrary, but does provide a reasonable reference point for comparison for data with relatively high and low abundance over a range of years.

##### 6.4.4.1 Methods

The purpose of this analysis was to fit ARIMA models to time series of eel abundance indices to infer the status of the population(s). The ARIMA model fitting procedure of Pennington (1986) and bootstrapped estimates of the probability of being less than an index-based reference point (25th percentile, Helser and Hayes 1995) were coded in R (R code developed by Gary Nelson, Massachusetts Division of Marine Fisheries). Index values were  $\log_e$  transformed ( $\log_e[\text{index} + 0.01]$  in cases where "0" values were observed) prior to ARIMA model fitting. The reported probabilities of being less than the 25th percentile reference point correspond to 80% confidence levels. Only time series with 20 or more years of index values were used in ARIMA modeling because the 25th percentile reference point can be unstable with few observations.

##### 6.4.4.2 Results

Twelve surveys contained 20 or more years of data and were used in ARIMA modeling (Table 6.19). Trends in fitted ARIMA values varied among regions, but were fairly consistent within regions. Surveys from the Chesapeake Bay and Delaware Bay/Mid-Atlantic Coastal Bays regions (Figures 6.12 and 6.13) showed no consistent increasing or decreasing trends. Also, the probability of the terminal year of surveys from the Chesapeake Bay and Delaware Bay/Mid-

Atlantic Coastal Bays regions being less than the 25th percentile benchmark was relatively low, ranging from 0.003 to 0.164. However, surveys from the Hudson River region tended to show consistent declines and probabilities of the terminal year being less than the 25th percentile benchmark ranged from 0.259 to 0.548 (Figure 6.14). There was only one survey from the South Atlantic region (NCDMF Estuarine Trawl Survey) and it showed a consistent decreasing trend and the probability of the terminal year being less than the 25th percentile benchmark was 0.308 (Figure 6.15).

## **6.4.5 Traffic Light Method**

### **6.4.5.1 Methods**

The Traffic Light approach was first introduced as a precautionary approach to fisheries management that can incorporate a variety of qualitative and quantitative information, or indicators, for describing the relative status of the stock and that is easily understood by stakeholders and non-technical personnel (Caddy 1998, 1999). Relevant information may include fishing mortality, biomass, recruitment, length and age at maturity, and spatial distribution (Halliday et al. 2001). The selected indicators are assigned colors in order to normalize the different indicators to a common scale; this process is called scaling. A common approach is to employ a three-color system in which indicator values in each year are assigned a green, yellow, or red 'signal' based on the state of the indicator relative to stock health. Typically, the color green is indicative of a positive stock condition, yellow is indicative of an uncertain or transitioning stock condition, and red is indicative of an undesirable stock condition. The ASMFC has incorporated a grayscale version of the Traffic Light approach into the assessment of American lobster stocks in order to provide a simple characterization of the status of individual stocks (ASMFC 2006c, 2009).

The Traffic Light approach was applied to all individual, regional, and coast-wide indices of relative abundance computed in this assessment. The strict scaling method, one of the simplest scaling methods, was used to assign each annual index value to one of three color categories—white, gray, or black which replace the traditional green, yellow, or red. The 25th and 75th percentiles of each index series were calculated in order to determine color boundaries. Each annual value within an index was compared to the percentiles computed for that series. If an index value was greater than the 75th percentile for the time series, that value was assigned the color white. If an index value was less than the 25th percentile for the time series, that value was assigned the color black. Index values that were less than or equal to the 75th percentile and greater than or equal to the 25th percentile were assigned the color gray. Note that the assignment of color is sensitive to the choice of color boundaries.

### **6.4.5.2 Results**

#### *Local Indices*

The Traffic Light representation of the YOY indices demonstrates variability in recruitment trends within and among survey sites (Table 6.20). The Traffic Light analysis suggests that recruitment was relatively high in 2001 at most sites. The year 2009 was characterized by moderate to relatively low recruitment at the majority of the survey sites.

With the exception of the CTDEP Electrofishing Survey and the Beaufort Inlet Ichthyoplankton Survey indices, all indices in the Southern New England, Hudson River, and South Atlantic

regions show a progression from white to black signals throughout their time series (Table 6.21). In contrast, the three longest indices from the Delaware Bay/Mid-Atlantic Coastal Bays region exhibit a progression from black to white signals. Indices from the Chesapeake Bay region demonstrate mostly black signals during the 1990s.

The VIMS Juvenile Striped Bass Seine Survey long time series index of yellow-phase abundance exhibited relatively high abundance during 1967 to 1972—the earliest years of that index time series (Table 6.21). All years from 1973 to 1978 were assigned black signals for the PSEG Trawl Survey index of elver and yellow-phase abundance. Mostly white signals are observed for the 1980s for yellow-phase abundance indices derived from the Western Long Island Sound Survey, the HRE Monitoring Program, the NYDEC Alosine Beach Seine Survey, and the NYDEC Striped Bass Beach Seine Survey. The MDDNR Striped Bass Seine Survey index of yellow-phase abundance is characterized by black signals for all years from 1990 to 1996. Abundance of yearling and older American eels appeared relatively low during the late 1990s through the 2000s based on the HRE Monitoring Program. The NYDEC Striped Bass Beach Seine Survey elver and yellow-phase index also suggests abundance was relatively low during most of the 2000s.

### *Regional Indices*

The Hudson River region indices of YOY and yellow-phase American eel abundance exhibit mostly white signals in the early years of their time series (Table 6.22). All but one year from 1974 to 1980 were assigned white signals for the Hudson River region YOY index. All years from 1981 to 1987 were characterized by white signals for the Hudson River region yellow-phase index. The Hudson River region YOY and yellow-phase indices show black signals during most of the 2000s. The Southern New England YOY index progress from gray and red to white signals over its time series while the South Atlantic YOY and yellow-phase indices transition from mostly white to gray and black signals. The Chesapeake Bay index of yellow-phase abundance was assigned mostly black signals during 1990 to 1995 and mostly white signals during 2003 to 2009.

### *Coast-wide Indices*

The coast-wide YOY indices are mostly white during the early years of their respective time series and transition to mostly gray and black signals throughout the rest of the time series (Table 6.22). The 30-year and 40-plus-year indices of coast-wide yellow-phase abundance show white signals during most of the 1980s. All three coast-wide indices of yellow-phase abundance suggest moderate to relatively low abundance of yellow-phase American eels during the early to mid-1990s.

## **6.5 SEINE (Survival Estimation In Non-Equilibrium Situations)**

The Survival Estimates in Non-Equilibrium (SEINE) model was used in exploratory analyses to estimate mortality rates from changes in eel length. The SEINE model is derived from the Beverton and Holt Mortality Estimator that is based on the premise that if a fish population is at equilibrium the mean length will be inversely proportional to the population mortality rate. The Beverton and Holt Mortality Estimator requires equilibrium conditions because changes in length likely will occur gradually after changes in mortality. The assumptions of equilibrium can be difficult to satisfy for many situations involving overfishing when limited fish population data are available. Gedamke and Hoenig (2006) developed the SEINE model from the Beverton and

Holt Mortality Estimator specifically to allow the estimation of instantaneous total mortality from length data in non-equilibrium conditions. The SEINE model requires only von Bertalanffy growth parameters ( $K$  and  $L_\infty$ ), length of first capture ( $L_c$ , smallest size of capture by fishery or sampling gear), and annual mean length larger than  $L_c$ . Regional von Bertalanffy parameters were estimated from age-length data for this assessment (see section 6.3.1, this report). SEINE analyses were made using Fisheries Methods in R (Nelson 2009).

The application of the SEINE model to eel length datasets did not produce mortality estimates that were useful for this assessment. All U.S. fishery-independent surveys with eel length data were reviewed and few had long-term (>10 years) random sampling of eel length. Secondly, the SEINE model requires an input for the years when a fishery or management event would have caused a shift in mortality. None of the data series had both long term length data available and actions expected to cause mortality shifts. Finally, the life history of eel could limit the suitability of the SEINE model given their sexual dimorphism, variable age at length, semelparity, and variable sex ratio among watersheds. The survey with perhaps the most potential is the HRE Monitoring Program ichthyoplankton survey with > 20 year duration and a significant management event (fishery was closed due to tissue contamination); however, the length data were not available for this assessment.

## **6.6 DB-SRA (Depletion-Based Stock Reduction Analysis)**

### **6.6.1 Methods**

#### *Model Description*

Depletion Based Stock Reduction Analysis (DB-SRA) is a modification of the Stock Reduction Analysis (SRA) methodology that can be used in data poor situations. SRA was first introduced by Kimura and Tagart (1982) and improved by Kimura et al. (1984). Using catch data and a time series of abundance, the model strives to determine stock size and recruitment rates over time that could have produced the observed population trend given the harvest information. The original model was not widely accepted because it provided only a single, exceedingly unlikely, trajectory of stock size and recruitment (Walters et al. 2006). Walters et al. (2006) improved the method by incorporating stochasticity through Monte Carlo simulation of input parameters to produce a distribution of potential stock sizes over time, providing the ability to describe the statistical probability of biomass and MSY-based reference points.

While Walters et al. (2006) promote stochastic SRA as a useful complement to traditional assessment methodologies, many species do not have sufficient data to run a traditional model or even SRA. In order to provide management advice in these data poor situations, a number of methodologies have recently been developed. One such model is Depletion-Corrected Average Catch (DCAC), an extension of the potential yield formula that can provide useful estimates of long term sustainable yield (MacCall 2009). Input requirements are limited to a time series of observed harvest, an estimated stock depletion level, and biologically based life history parameters ( $M$ ,  $F_{MSY}:M$  [hereafter referred to as the  $F$ -ratio],  $B_{MSY}:K$  [or  $B$ -peak]) and their associated uncertainty values. Monte Carlo distributions of the input parameters are developed and used in conjunction with the harvest data to derive a probability distribution of long term sustainable yield (MacCall 2009).

Depletion-Based Stock Reduction Analysis was first introduced by Dick and MacCall (2011), borrowing aspects of SRA (Kimura and Tagart 1982; Kimura et al. 1984; Walters et al. 2006) and DCAC (MacCall 2009). A full description of the model is provided in Dick and MacCall (2011) but is summarized below.

Implementation of traditional SRA requires a time series of abundance (absolute or relative) which is generally lacking in data poor situations. DB-SRA relaxes that requirement by utilizing a distribution of assumed relative abundance (percent stock depletion) in a recent year (Dick and MacCall 2011). Other data inputs include a time series of harvest, age at maturity, and the same suite of biologically based life history parameters used in DCAC ( $M$ ,  $F$ -ratio, and  $B$ -peak). A major assumption of the model is that the stock is at carrying capacity ( $K$ ) at the beginning of the time series.

Implementation of the model is through a delay difference biomass model:

$$B_t = B_{t-1} + P(B_{t-a}) - C_{t-1}$$

where  $B$  is biomass,  $P$  is production,  $a$  is the median age at maturity, and  $C$  is harvest weight. Any production function can be used, but the current model is based on a hybrid of the Pella-Tomlinson-Fletcher and Schaefer models. Dick and MacCall (2011) argue that this parameterization best captures production rates at all levels of biomass, and the hybridization method is fully described in their manuscript. A solver routine is required to iteratively solve for  $K$  such that recent biomass relative to  $K$  satisfies the input assumed depletion level.

Outputs of the model include a biomass trajectory and estimates of a number of “leading parameters” that are directly useful to management, including  $K$ ,  $MSY$ ,  $B_{MSY}$ , and  $F_{MSY}$ . Statistical distributions of each of these outputs are achieved through Monte Carlo simulation of uncertainty in input parameter values.

### *Model Development*

For the 2011 eel stock assessment, a version of DB-SRA was coded in the R software language, version 2.13.0 for Windows (R Development Core Team 2011), based on the pseudo-code provided in Appendices A and B of Dick and MacCall (2011). The resulting code was ground truthed by replicating (harvest data, input parameter means, uncertainty levels, and error distributions) the NMFS Southwest Fisheries Science Center (SWFSC) DB-SRA model for bank rockfish (*Sebastes rufus*) and comparing results to the SWFSC results used to establish overfishing limits for the species (E.J. Dick, NMFS SWFSC, pers. comm.). Although the results were not exactly the same, biomass trends and production curves followed similar patterns in similar scales.

### *Input Data*

American eel commercial harvest data collected from 1950 to 2010 were compiled as described in section 5.1.1. Prior to 1950, harvest estimates were taken from historical NMFS annual reports (1889–1938; NOAA Central Library Data Imaging Project) and from the NMFS redbook series (1937–1950). Missing data points between 1880 and 1923 were generated using the following process.

1. Calculate the average reported harvest between 1880 and 1923.



2. For each year harvest was reported, calculate the difference between reported harvest and the mean harvest.
3. For years without harvest reports, the average harvest in up to three years of available data prior to and succeeding the missing value (max six years of available data) was calculated and added to a randomly sampled harvest residual.
4. Repeat step 3 one hundred times for each missing value.
5. Estimate harvest as the average of the 100 iterations in a given year.

The resulting harvest trend is shown in Figure 6.16.

Given the lack of knowledge in eel population characteristics, input parameters for preliminary runs were selected based on general knowledge of production theory and proxy information from other species. In addition, because of this lack of knowledge, as well as the potential for latitudinal trends in parameter values, uncertainty in the inputs was modeled using a uniform distribution for the Monte Carlo simulations. Natural mortality,  $M$ , was assumed to range from 0.15 to 0.25. This range captures the variability in maximum age reported from northern and southern portions of the U.S. population and is consistent with available data (section 2) and other analyses by the Technical Committee (e.g., SLYME). An  $F$ -ratio of 1.0 is used commonly when no other information is available, so this was selected as a median value for the  $F$ -ratio. The median  $F$ -ratio of 0.80 used by Dick and MacCall (2011) was selected as a lower bound in the eel model, and an upper bound was selected equidistant from the median ( $F$ -ratio range 0.80 to 1.20). The range for  $B$ -peak of 0.25 to 0.50 was selected because it includes both the default Gompertz and Schaefer values for  $B_{MSY}:K$  (~0.37 and 0.50, respectively) and incorporates the median values used by Dick and MacCall to represent two species groups (0.25 for flatfish, 0.40 for rockfish) with different life history strategies that potentially bracket that of eel.

The input range for the ratio of recent biomass to  $K$  (referred to as  $B$ -ratio) in preliminary runs was developed in a stepwise manner. The oldest available index data for eel are from the late 1960s. In preliminary runs, the DB-SRA biomass from around 1970 was compared to biomass at  $K$  to estimate depletion level in 1970. Then, ratios of survey index values in recent years relative to index values around 1970 were developed for a number of surveys (MD seine, VIMS seine, HRE Monitoring). Ratios of  $B_{1970}:K$  and  $I_{Recent}:I_{1970}$  were multiplied to estimate depletion level in recent years. This method provided estimates of biomass in 2010 that were approximately 3 to 10% of preliminary  $K$  values.

The range for  $B$ -ratio used in the preferred models was developed slightly differently than for preliminary runs, as a result of more appropriate data being available when final model runs were performed. Rather than using individual indices, the  $B$ -ratio range was developed using results of the coast-wide yellow eel GLMs for 20-year and 30-year time series. These indices incorporate data from multiple regions and more likely represent the overall coast-wide trend in abundance than a single index or the 40+ year index which only includes data from a single region (Chesapeake Bay). The fitted 20-year and 30-year indices were each smoothed using a three-year average to reduce variability, and the relative change in index values between the 1991–1993 average and the 2008–2010 average was calculated. For both indices, abundance increased approximately 10% over the specified time period. Results from preliminary runs investigating different  $B$ -ratio scenarios (see *Sensitivity Analyses* section below) indicated that a median  $B$ -ratio of approximately 10% produced a similar biomass trend in recent years as the 20-year and

30-year indices. To account for uncertainty in the information provided by the indices, a  $B$ -ratio range of 5–15% was used in the final runs.

### *Sensitivity Analyses*

One major assumption of DB-SRA is that biomass in the first year of the time series is at an unfished level. In addition, Wetzel and Punt (2011) found DB-SRA to be sensitive to incorrectly specified input values, particularly the ratio of recent stock size to  $K$ . Finally, as described in section 2, life history characteristics of American eel in U.S. waters differ among the sexes and follow latitudinal trends, making selection of input parameters difficult.

To investigate the sensitivity of the model to potentially miss-specified input parameters, a number of sensitivity runs were conducted (Table 6.23). Sensitivity runs took two forms. First, a set of deterministic runs was conducted across a range of values for each input parameter. A total of 108 runs were conducted, one for each combination of four values of  $M$ , three values of  $F_{MSY}:M$ , three values of  $B_{MSY}:K$ , and three values of  $B_{Recent}:K$ . These runs provided insight into model performance and directional effects of the different input parameters on the results.

The second form of sensitivity consisted of eight runs using input ranges detailed above for  $M$ ,  $F$ -ratio, and  $B$ -peak but varying harvest levels, the harvest time series, or  $B$ -ratio. These runs provided insight into the sensitivity of model results to incorrect input data and violation of the assumption that the stock was at carrying capacity at the beginning of the time series.

### *Alternate Model Framework*

The original DB-SRA model was constructed under the assumption of a single level of  $M$  for the entire time series. This is likely an invalid assumption given changes in environmental and climatic conditions, predation, parasitism, habitat availability, and other factors. For example, it is well known that dam construction in the U.S. has limited upstream habitat availability to diadromous species such as eel. As such, the assumption of single  $M$  over time is likely violated. To investigate potential effects of decreasing habitat availability, an alternate version of DB-SRA was coded that incorporated two stanzas of natural mortality,  $M$ . Dam construction in the U.S. occurred primarily in the years following World War II, peaking in the 1960s (Water Encyclopedia, <http://www.waterencyclopedia.com/Da-En/Dams.html>). In the two-stanza model,  $M$  was assumed to be constant at relatively low levels (0.15–0.25) from 1880 through 1969. The second  $M$  stanza began in 1970, at which time  $M$  increased in a single step and was assumed constant for the remainder of the time series.

This methodology assumes the eel population can support a certain level of total mortality (e.g.,  $Z_{MSY}$ ) that is constant through time. Dam construction is assumed to result in an increase in natural mortality, which would require a decrease in the fishing mortality level that produces MSY.

Inputs to the two-stanza model were the same as for the one-stanza model for initial  $M$ , initial  $F$ -ratio, and  $B$ -peak. Increased  $M$  in the second stanza results in a decrease in the  $F$ -ratio, producing a lower fishing mortality threshold. Sensitivity runs were conducted investigating alternate harvest scenarios,  $B$ -ratios, the timing of the  $M$  increase, and the extent of the change in  $M$  (Table 6.23). Estimates for  $B$ -ratio in the two-stanza model were chosen as described above for the one-stanza model.

### *Potential Biases*

There are a number of assumptions regarding the model and inputs that, if violated, could affect the output of the model. Many of these were investigated through sensitivity analyses as described above, including incorrect harvest estimates, initial biomass at carrying capacity, the ratio of recent biomass to  $K$ , and single  $M$  over time assumptions. A number of other potential biases are discussed below.

One of the model input requirements is the median age at maturity. Maturity was assumed to occur at age 8 for eels. This value was selected as a compromise of the differences between sexes and across latitude. No “official” sensitivity runs were conducted regarding this parameter; however, preliminary runs comparing maturity at age 4 and 8 showed  $K$  and  $MSY$  were approximately 10–20% higher for age 8 than age 4 (results not shown). Incorrect specification of the age at maturity could potentially bias the results.

Another issue concerning the age at maturity is that the DB-SRA models only mature biomass, and therefore assumes harvest is of mature animals only. Given eels’ catadromous and semelparous life history, nearly all fishing mortality for the species occurs prior to maturity, and this assumption is clearly violated. For the eel model, biomass and associated parameters are in terms of fishable biomass. In the population biomass equation, production in a given year is based on the stock biomass eight years previous (median age at maturity = 8). Eels generally recruit to the fishery at around age four (K. Whiteford, MD DNR, pers. comm.; J. Clark, DNREC, pers. comm.) and undergo four years of fishing mortality before maturity. The production delay of eight years is still valid, as it takes four years for fish that enter the fishery to become mature and an additional four years until the new cohort recruits to the fishery. Violation of the assumption of maturity does affect the production function. If total mortality between ages 4 and 8 were constant, the result would be simply a shift in the production curve. Because mortality is not constant, the relationship between age-4 biomass and age-8 biomass varies. The directional effect this has on production at a given biomass (over vs underestimate) depends on whether harvest between age 4 and 8 is above or below average, as well as the biomass relative to  $B_{MSY}$  (i.e., ascending or descending limb of the production curve).

Another concern of implementing this model for the U.S. eel population is that the U.S. encompasses only a portion of the species range. Trends and reference points developed through this model are therefore only relevant to the U.S. fishery and population. Harvest pressure, habitat availability, and other factors that occur outside the U.S. were not considered in the model, but because of the panmictic nature of the stock, these factors could affect model performance and/or influence the ability of the U.S. to achieve its management goals. Preliminary runs were conducted using combined U.S. and Canada harvest, but are not described here for the reasons given in section 5.

One final concern is that the DB-SRA relies almost entirely on catch data and does not account for the contribution of unfished areas to production. The degree to which fished and unfished areas contribute to the entire population’s production is unknown.

Sensitivity runs were conducted to investigate the effect of possible error in early harvest estimates on the model. It is assumed that recent estimates are known without error; however, inaccurate harvest data in the model would likely lead to biased model results, particularly if there is a consistent directionality in the error.

The minimal data requirements for DB-SRA require that all input values be carefully considered, based on biologically sound information, and supported by available data where possible. This is because it is easy to “lead” the model to a given result based on input values. For example, if the  $B_{MSY}:K$  ratio is set at 0.40 and the ratio of  $B_{Recent}:K$  is input as 0.30, the model will indicate that the stock is not overfished in the terminal year (i.e., assuming  $B_{Target} = B_{MSY} = 0.4K$  and  $B_{Threshold} = \frac{1}{2}B_{Target} = 0.2K$ , current biomass is  $0.3K$  and is therefore not overfished). All attempts were made to ensure inputs for the eel model are biologically sound and based on available data. As noted above, a number of sensitivity runs were conducted to investigate model sensitivity to miss-specification of inputs. However, results of this model are conditional on the inputs, and any error in the input parameters could carry through to the results.

## 6.6.2 Results

### Single $M$ Stanza Model

The preferred single  $M$  stanza model produced a median carrying capacity estimate of approximately 18,200 mt (inter-quartile range 17,300-19,200 mt; Figure 6.17). Biomass dropped quickly in the early years of the time series, falling to less than 5,000 mt within the first decade. Between 1890 and 1934, biomass never exceeded 3,500 mt and fell below 1,000 mt during 1902–1905 and 1932–1934. Biomass began a gradual increase in 1935, rising to more than 5,000 mt by 1969 and a peak of 5,400 mt in 1974. Subsequent increases in harvest due to the export market reduced biomass to less than 2,000 mt by the early 1980s and below 1,000 mt once again in 1997. Since 1998, biomass has been increasing gradually, with a median estimate of 1,817 mt (inter-quartile range 1,355–2,276 mt) in the terminal year of 2011.

Median biomass at MSY was estimated at approximately 6,770 mt, with a maximum sustainable yield of 1,057 mt (Table 6.24; Figure 6.18). MSY is attained at a median annual exploitation rate of  $u_{MSY} = 0.158$ . Observed annual exploitation rate in recent years averaged approximately  $u = 0.221$ , based on the median biomass estimates.

### Double $M$ Stanza Model

Median carrying capacity for the preferred double  $M$  stanza model of 18,275 mt (inter-quartile range 17,365–19,325 mt) was very similar to that of the single  $M$  model (Figure 6.19). In addition, the biomass trajectory followed closely that of the single  $M$  model, but at slightly higher median values and wider inter-quartile range. The differences were most apparent from around 1930 to 2000. Median biomass increased from a low of approximately 1,025 mt in 1933 to a relative peak of 9,520 mt in 1969. This was reduced to a low of 1,305 mt by 1997, but has since recovered to approximately 1,846 mt in 2011 (inter-quartile range 1,380–2,310). As opposed to the single  $M$  stanza model, the double  $M$  stanza model displayed a recent peak biomass in the late 1960s/early 1970s which corresponds with peaks observed in fishery-independent surveys from the Chesapeake Bay region during the same time period.

Median biomass at MSY was estimated at approximately 6,820 mt (Table 6.24; Figure 6.20). In the early years (lower  $M$ ) maximum sustainable yield was estimated at 1,060 mt, but this dropped to 810 mt due to increased  $M$  since 1970. Median annual exploitation rates that achieve MSY were estimated at  $u_{MSY} = 0.159$  in the early period and  $u_{MSY} = 0.123$  in recent years. Average observed annual exploitation rate since 2008 was approximately  $u = 0.204$  based on the median biomass estimates.

## Sensitivity

Results of deterministic sensitivity runs were generally consistent with generic production theory. For example, increases in natural mortality resulted in a lower  $K$  but higher MSY. Similar results were observed for  $F$ -ratio and  $B$ -peak within the parameter ranges evaluated. Wetzel and Punt (2011) found that overestimating  $B$ -ratio led to overestimates of the harvest level in all cases. The deterministic sensitivity runs confirmed that increasing the  $B$ -ratio value often increased estimated  $K$  and MSY values, but this phenomenon abated at higher combinations of  $M$  and  $F$ -ratio, which included the range of values used in the preferred runs. Deterministic sensitivity runs also indicated that the model became unstable at higher combinations of  $M$ ,  $F$ -ratio, and  $B$ -peak, often producing estimates of  $K$  in the millions of metric tons.

For the single stanza model, stochastic sensitivity runs indicate that increasing harvest early on in the time series or extending the time series prior to 1880 generally led to an increase in estimated carrying capacity and MSY. Runs starting in 1925 and 1970 had lower carrying capacity relative to runs starting in 1880, but the 1970 run had higher  $K$  than the 1925 run. These results are possibly due to the higher harvest levels in the early years of the time series for the 1970 run. Increasing the  $B$ -ratio level had minimal effect on  $K$  and MSY at the ranges evaluated. This is contrary to the results of Wetzel and Punt (2011), although the deterministic sensitivity confirmed their findings within a different range of input values.

Stochastic sensitivity results for the double  $M$  stanza model were similar to those for the single stanza model. Decreasing harvest early on lowered  $K$  and MSY, and these estimates were not sensitive to the input  $B$ -ratio over the ranges evaluated. Changing the timing of the change in  $M$  from 1970 to 1960 had minimal effect on the outputs. The double  $M$  model had similar estimates of  $K$  as the single  $M$  model, and initial estimates of MSY were also similar; however, MSY decreased by approximately 24% after the increase in  $M$ .

## **6.7 Age-structured Production Model**

The age-structured production model constructed to assess eel in the Potomac River by Fenske et al. (2011) was modified for use in the Delaware Bay and in Maryland waters of the Chesapeake Bay. The Potomac River model estimates fishing mortality and biomass dynamics by incorporating sex- and age-specific maturation mortality and selectivity in a surplus production model framework. Recruitment to the fishery is estimated freely in each year using an index of recruitment to the first age in the model and age-specific catch information. Catchability can be assumed constant or time-varying using a random walk, white noise, effort-dependent, or density-dependent catchability model. The Fenske et al. (2011) model was pursued as a method for obtaining population estimates and biological reference points on a regional basis without assuming an explicit stock-recruitment curve.

### **6.7.1 Methods**

In implementing this model for Delaware Bay, the code was modified to fit multiple years of unsexed age composition data in both the fishery and survey for fish ages 2 to 12. Survey and catch data were available from 1982 to 2009. The Delaware trawl survey was split into an index of age 2s (fish  $\leq 290$  mm) and an overall index of abundance (fish  $> 290$  mm). Unsexed age composition data were available from the survey from 1997 to 2009. Unsexed aged catch information was available from 2003 to 2009. Effort in the form of pots per day was used to estimate effort-dependent time-varying catchability between 1999 and 2009. Maturity- and

weight-at-age were borrowed from the Potomac River model. Selectivity was calculated using observed proportions caught at age for fully selected ages. For ages that are not fully selected, the difference between observed and back-calculated (predicted) catch at age was used to approximate selectivity.

In implementing the Potomac River model for Maryland waters, the code was modified to fit multiple years of sexed age composition data for fish ages 2 to 12. The Maryland seine survey was used as an index of age-2 fish and annual CPUE from the fishery was used as an index of overall abundance. Survey and catch data spanning 1992 to 2010 were used in the model. A sex-specific catch-at-age matrix was generated using age and length sampling information from 1997 to 2010. Effort in the form of pot days was used to estimate effort- and density-dependent time-varying catchability between 1992 and 2010. Maturity-, selectivity-, and weight-at-age were calculated from Maryland's eel sampling program data.

### **6.7.2 Results**

Despite numerous attempts to reconfigure and tune the Delaware Bay model, the model did not converge on a stable solution. We suspect that the lack of sex-specific information in the catch and survey data and the lack of contrast in available survey trends hindered our ability to achieve convergence. The Maryland model repeatedly converged on a solution that tightly fit the commercial CPUE index and the catch-at-age, but did not fit the recruitment index at all. Depending on the form of time-varying catchability estimated, a much smaller plus class was required in order to achieve convergence. We suspect the Maryland seine survey is not an adequate index of age-2 animals in the population and that a lack of information about the age and maturity structure of the yellow eel population may limit application of this model to the Maryland eel population. The SASC did not feel comfortable recommending this model for management given its reliance on a commercial CPUE index and lack of adequate fit to a recruitment index.

## **7 STOCK STATUS DETERMINATION**

### **7.1 Status Determination Criteria**

Reference points for determining the stock status of American eel in the U.S. were developed using the DB-SRA model<sup>2</sup>, a recently developed assessment methodology for use in data poor situations (see section 6.6, this report; Dick and MacCall 2011). Although DB-SRA is not a traditional data-rich assessment methodology, there is substantial support for its use in management. The method received positive feedback during a formal peer review of data-poor assessment methods (SWFSC 2011), and it is the principle method of estimating reference points on the U.S. west coast for data-poor species (E.J. Dick, NMFS SWFSC, pers. comm.).

The DB-SRA was run assuming a single  $M$  over time and also run assuming a one-time change in  $M$  over time (the double  $M$  or two stanza model). Results of the single and double  $M$  stanza models were very similar; however, the Technical Committee preferred the double  $M$  model as it

<sup>2</sup> Note that DB-SRA reference points were not accepted for management use by the Peer Review Panel. The TC now recommends stock status be declared depleted based on trend analyses and biomass trends estimated by the DB-SRA. Refer to the Preface and the Peer Review Report for more information.

takes into account changes in habitat availability that may have possible implications for the stock and fishery. The reference points are therefore based on the results of the double  $M$  model.

The U.S. American eel resource will be considered overfished if stock biomass falls below the biomass threshold ( $B_{\text{Threshold}}$ ), which is defined as half of the biomass that produces maximum sustainable yield ( $B_{\text{MSY}}$ ). The double  $M$  DB-SRA model estimated the biomass target at  $B_{\text{Target}} = B_{\text{MSY}} = 6,820$  mt (inter quartile range 6,095–7,579 mt; Table 6.24; Figure 6.21), resulting in a median threshold value of  $B_{\text{Threshold}} = 3,410$  mt.

American eels in the U.S. will be considered to be experiencing overfishing if the exploitation rate exceeds the exploitation level that produces maximum sustainable yield ( $u_{\text{MSY}}$ ). The double  $M$  DB-SRA model estimated this value at  $u_{\text{MSY}} = 0.159$  (inter quartile range 0.143–0.175; Table 6.24; Figure 6.22) for the early period but, since 1970, the estimate decreased to  $u_{\text{MSY}} = 0.123$  (inter quartile range 0.108–0.138).<sup>3</sup>

Note that Wetzel and Punt (2011) found that DB-SRA often miss-specified harvest limits in their simulation study; however, they found that in most instances the model underestimated true values, suggesting that the method is conservative. The authors also stated that conservative estimates are often preferred in data-poor situations that are associated with a high degree of uncertainty. For these reasons, the Technical Committee is comfortable proposing the above mentioned reference points for the U.S. American eel population.

## 7.2 Current Stock Status

The double  $M$  DB-SRA model estimated that median biomass for U.S. American eels in 2011 was 1,846 mt (Figure 6.21), which is approximately 54% of the overfished reference point ( $B_{\text{Threshold}} = 3,410$  mt). Exploitation rate in 2010, relative to the median biomass level, was estimated at  $u_{2010} = 0.215$  (Figure 6.21), which exceeds the overfishing reference point by about 75% (recent  $u_{\text{MSY}} = 0.123$ ). Based on these results, the U.S. American eel population is overfished and overfishing is occurring.<sup>4</sup>

## 8 DISCUSSION & CONCLUSIONS

Assessment of the American eel population is complex. Life history traits such as size, age, density, growth rate, sex ratio, and maturity exhibit both spatial and temporal variation throughout the species' range. The GLM analyses performed here indicate that the impact of environmental variables such as water temperature, salinity, and discharge on local abundance is similarly variable. In the U.S., all life stages are subject to fishing pressure, and the degree of fishing also varies through time and space. In addition to fishing, other factors that may negatively affect the eel population include habitat loss and alteration, productivity and food web alterations, predation, turbine mortality, changing climatic and oceanic conditions, toxins and contaminants, and disease (these factors are discussed in detail in the literature; see Haro et al. 2000, GMCME 2007, and DFO 2011c for general information regarding the potential impacts of these factors). As with the fisheries, the impact of these factors at local scales is not well understood, and the impact on the population as a whole, if any, is even less understood.

---

<sup>3</sup> Note that DB-SRA reference points were not accepted for management use by the Peer Review Panel. The TC now recommends stock status be declared depleted based on trend analyses and biomass trends estimated by the DB-SRA. Refer to the Preface and the Peer Review Report for more information.

<sup>4</sup> See footnote 3.

The assessment is further complicated by limitations in the available data. Incomplete or underreporting of fisheries landings is a common concern in stock assessments. The FMP for American Eel addressed this issue by providing guidelines for standardized and consistent reporting of commercial fisheries data (ASMFC 2000a); however, the FMP was adopted in 2000 and American eels have been harvested for over a hundred years so a considerable portion of the landings history is questionable. Illegal poaching provides another data limitation. Though glass eel fisheries are limited to a few locations, increases in the value of the glass eels (>\$300/lb) often leads to increased poaching in areas where these fisheries are prohibited, resulting in undocumented losses that may be significant. Additionally, there are few reliable long-term fishery-independent data sources available in the U.S. for characterizing trends in American eel abundance. Those that are available likely reflect local trends and were not designed to target eels. Of all the U.S. data sources that are available, the majority originate from the Delaware Bay/Mid-Atlantic Coastal Bays and Chesapeake Bay regions, which presents a spatial bias in the data. Finally, there are currently no standardized programs for monitoring escapement, which makes it difficult to base management on a desired escapement level as is currently done in Europe to facilitate the recovery of European eels (EC 2007).

The data evaluated in this assessment provide evidence of declining or, at least, neutral abundance of American eel in the U.S in recent decades. All three trend analysis methods (Mann-Kendall, Manly, and ARIMA) detected significant downward trends in numerous indices over the time period examined. The Mann-Kendall test detected a significant trend in the 30-year yellow-phase abundance index (Table 6.17). The Manly meta-analysis showed a decline in at least one of the indices for both yellow and YOY life stages (Table 6.18). Also, there was consensus for a decline for both life stages through time. Both the ARIMA and Mann-Kendall analyses indicate decreasing trends in the Hudson River and South Atlantic regions (Tables 6.17 and 6.19). In contrast, survey indices from the Chesapeake Bay and Delaware Bay/Mid-Atlantic Coastal Bays regions showed no consistent increasing or decreasing trends. Overall, however, the prevalence of significant downward trends in multiple surveys across the coast is cause for concern. In addition, historical catch-based results from this assessment's DB-SRA showed a decline in stock biomass coast-wide from the mid- to late 1990s, and there has been evidence of a slight increase since the late 1990s.

The DB-SRA results indicate that the American eel resource in the U.S. is overfished and overfishing is occurring relative to MSY-based reference points given the assumptions made (particularly the depletion level and  $B_{MSY}/K$ ). The use of the term "overfished" suggests that fishing is the primary reason for the currently reduced levels of biomass;<sup>5</sup> however, it is important to recognize that multiple sources of mortality have been contributing to the reduced biomass levels, and it is difficult, if not impossible, to determine the degree to which different mortality sources have negatively impacted the stock over time. Significant levels of harvest in the 1970s is considered a major factor contributing to the current low biomass levels, but other factors such as habitat loss, predation, and disease have also played a role. Although fishery landings and effort in recent times have declined in most regions (with the possible exception of the glass eel fishery), current levels of fishing effort may still be too high given the additional stressors affecting the stock such as habitat loss, passage mortality, climate change, and disease.

<sup>5</sup> Note that DB-SRA reference points were not accepted for management use by the Peer Review Panel. The TC now recommends stock status be declared depleted based on trend analyses and biomass trends estimated by the DB-SRA. Refer to the Preface and the Peer Review Report for more information.



Fishing on all life stages of eel, particularly YOY and out-migrating silver eels, could be particularly detrimental to the stock (see Appendix 3), especially if other sources of mortality (e.g., turbine mortality, changing oceanographic conditions) cannot be readily controlled.

In 2000, the ICES Working Group on Eels met to discuss the status and conservation of American eels (ICES 2001). The group concluded “that reductions in habitat, declining or neutral trends in abundance, severe decline in abundance in northern areas, continuous exploitation and unknown oceanographic effects support the adoption of the Precautionary Approach in management.” The precautionary approach calls for the assumption that a stock-recruitment relationship exists. For American eels, recruitment to a particular area is independent of the spawners that came from that area. Due to the panmictic nature of the species and because the relative contribution to the spawning stock from different regions is unknown, there is a need for international coordination of management efforts (Petersen 1997; ASMFC 2000a, 2002, 2006a; Haro et al. 2000; ICES 2001; Goodwin and Angermeier 2003; Cairns and Casselman 2004; DFO 2007, 2011a; Casselman and Cairns 2009; Vélez-Espino and Koops 2010; Fenske 2011). Currently, there is no Canada-wide assessment for American eel, but status reviews have been performed for regions within Canada (e.g., Newfoundland and Labrador: Veinott and Clark 2011; Ontario: Mathers and Pratt 2011, Pratt and Mathers 2011; southern Gulf of St. Lawrence: Cairns et al. 2007; also see DFO 2011c). In 2010, a scientific peer review of information on American eel in eastern Canada was held in response to a request from COSEWIC for an updated report and to a request from Canada’s DFO Ecosystem and Fisheries Management (DFO 2011c).

Following completion of the Canadian regional and U.S. stock assessments, the American eel resource would benefit from a coast-wide assessment that included both Canadian and U.S. data sources. Recent Canadian efforts to map eel habitat, dam locations, and areas of concentrated fishing pressure along the Atlantic coastline may allow for an assessment that accounts for regional differences in habitat availability and sources of mortality. ~~In conclusion, the status of the American eel resource in the U.S. is overfished with overfishing occurring~~<sup>6</sup> due to a combination of fishing pressure on all life stages, other anthropogenic effects such as habitat loss and passage mortality, disease, and climate changes leading to shifting oceanographic conditions. Evidence of a decline in the American eel population throughout the species’ range is further supported by the literature (for example, see Castonguay et al. 1994a; Jessop 1997; Petersen 1997; Richkus and Whalen 1999, 2000; ASMFC 2000a, 2006a; Haro et al. 2000; Beak International 2001; ICES 2001; Anonymous 2003; Casselman 2003; Geer 2003; Wirth and Bernatchez 2003; Cairns and Casselman 2004; Verreault et al. 2004; DFO 2005, 2006, 2007, 2009a, 2009b, 2010, 2011a, 2011b, 2011c; COSEWIC 2006; Casselman and Marcogliese 2007; Casselman and Cairns 2009; Fenske 2011; Mathers and Pratt 2011; Pratt and Mathers 2011; USFWS 2011; Veinott and Clarke 2011). Management efforts to reduce mortality on American eels in the U.S. are warranted. Collaboration with Canada to cooperatively monitor, assess, and manage American eels should provide a more complete and accurate picture of the resource. A formal Memorandum of Understanding between the ASMFC and the Great Lakes Fisheries Commission to coordinate management and science approaches for eel conservation across the

<sup>6</sup> Note that DB-SRA reference points were not accepted for management use by the Peer Review Panel. The TC now recommends stock status be declared depleted based on trend analyses and biomass trends estimated by the DB-SRA. Refer to the Preface and the Peer Review Report for more information.

North American range is near completion and would be a major step forward for American eel management.

## **9 INTEGRATED PEER REVIEW RECOMMENDATIONS**

The ASMFC's Management and Science Committee requested an integrated peer review process be pursued for the current American eel stock assessment with the goal of contracting an individual with appropriate expertise who could provide the Stock Assessment Subcommittee with initial feedback on the stock assessment during the process (i.e., prior to completion of the Stock Assessment Report and final peer review). Dr. Joseph Hightower attended the second American eel Assessment Workshop held May 23–36, 2011 and wrote a summary report conveying suggestions for improving the stock assessment (ASMFC 2011). A brief summary of the main points from his report and the SASC's response are provided below.

1. Pursue the VIMS trawl survey data and the few other surveys that had consistent methods through time and extend back in time to periods of higher abundance.
  - Completed—see Appendix 1 and section 5. See section 5.2.5.8.3 for discussion of decisions regarding VIMS trawl survey data.
2. Some datasets were initially dropped because of consistently low eel catches. Reexamine as they are long time series (e.g., Maryland striped bass seine survey) that may still be of value.
  - Completed—see Appendix 1 and section 5.
3. Utilize consistent methodology for analyzing the relative abundance data. In the draft assessment, some datasets were analyzed using a negative binomial distribution whereas others were done assuming a lognormal. A consistent approach for model fitting and selection, including how AICs will be used and reported, and in the types of variables included as covariates will insure that year-to-year differences among surveys are not due to variation in the methods used for analysis. There is also the issue of samples with a zero catch when the lognormal distribution is used.
  - Completed—see Appendix 2 and section 5.2.
4. There are clear limits to what is feasible for eels in terms of stock assessment model complexity because fishery-dependent and fishery-independent data are limited. Mann-Kendall tests of CPUE trends and traffic light table methods seem worthwhile to apply as complements to more detailed models that can incorporate the additional biological information contained in most surveys.
  - Completed—see sections 6 and 7.
5. Rather than pursuing a long list of models, a better approach would be to select two or three that appear best suited to the species' biology and the available data, then fully explore those models (see specific comments and recommendations by model type above). Relative abundance data from one or more surveys or a synthesis of multiple surveys would be needed for AIM, surplus production, SRA, or any of the more complex models. Getting a valid coast-wide index or multiple regional indices if that is found to be more appropriate, over a sufficient time frame to show contrast in population size will be the key to a successful assessment.

- Completed—see section 6. Coast-wide and regional GLMs were generated for use in trend analyses and surplus production modeling. One additional method that is independent of indices, DB-SRA, was also presented.
6. Consider the different approaches being taken for American eel compared to that of the European eel. There appears to be a consensus that the dramatic decline in the European eel is due to recruitment overfishing.
- European eel management concentrates on escapement which we have little to no information on in the U.S. Therefore, quantitative reference points using the DB-SRA and trend-based indicators were pursued.

## 10 RESEARCH RECOMMENDATIONS

The following research recommendations are based on input from the ASMFC American Eel Technical Committee and Stock Assessment Subcommittee as well as from panel members of the 2006 ASMFC American eel stock assessment. A single asterisk (\*) denotes short-term recommendations and two asterisks (\*\*) denote long-term recommendations. Recommendations formatted in **bold** identify improvements needed for the next benchmark assessment.

### Data Collection

#### *Fisheries Catch and Effort*

- **Improve accuracy of commercial catch and effort data**
  - Compare buyer reports to reported state landings\*
  - Improve compliance with landings and effort reporting requirements as outlined in the ASMFC FMP for American eel (see ASMFC 2000a for specific requirements)\*
  - Require standardized reporting of trip-level landings and effort data for all states in inland waters; data should be collected using the ACCSP standards for collection of catch and effort data (ACCSP 2004)\*
- Estimate catch and effort in personal-use and bait fisheries
  - Monitor catch and effort in personal-use fisheries that are not currently covered by the MRFSS or commercial fisheries monitoring programs\*
  - Implement a special-use permit for use of commercial fixed gear (e.g., pots and traps) to harvest American eels for personal use; special-use permit holders should be subject to the same reporting requirements for landings and effort as the commercial fishery\*\*
  - Improve monitoring of catch and effort in bait fisheries (commercial and personal-use)\*
- Estimated non-directed fishery losses
  - Recommend monitoring of discards in targeted and non-targeted fisheries\*
  - Continue to require states to report non-harvest losses in their annual compliance reports\*
- **Characterize the length, weight, age, and sex structure of commercially harvested American eels along the Atlantic Coast over time**
  - Require that states collect biological information by life stage (potentially through collaborative monitoring and research programs with dealers) including length, weight,

age, and sex through fishery-dependent sampling programs; biological samples should be collected from gear types that target each life stage; at a minimum, length samples should be routinely collected from commercial fisheries\*

- Finish protocol for sampling fisheries; SASC has draft protocol in development\*
- Improve estimates of recreational catch and effort
  - Collect site-specific information on the recreational harvest of American eels in inland waters; this could be addressed by expanding the MRIP into inland areas\*\*
- Improve knowledge of fisheries occurring south of the U.S. and within the species' range that may affect the U.S. portion of the stock (i.e., West Indies, Mexico, Central America, and South America)\*\*

#### *Socioeconomic Considerations*

- Perform economics studies to determine the value of the fishery and the impact of regulatory management\*\*
- Improve knowledge regarding subsistence fisheries
  - Review the historic participation level of subsistence fishers and relevant issues brought forth with respect to those subsistence fishers involved with American eel\*\*
  - Investigate American eel harvest and resource by subsistence harvesters (e.g., Native American tribes, Asian and European ethnic groups)\*\*

#### *Distribution, Abundance, & Growth*

- **Improve understanding of the distribution and frequency of occurrence of American eels along the Atlantic Coast over time**
  - Maintain and update the list of fisheries-independent surveys that have caught American eels and note the appropriate contact person for each survey\*
  - Request that states record the number of eels caught by fishery-independent surveys; recommend states collect biological information by life stage including length, weight, age, and sex of eels caught in fishery-independent sampling programs; at a minimum, length samples should be routinely collected from fishery-independent surveys\*
  - Encourage states to implement surveys that directly target and measure abundance of yellow- and silver-stage American eels, especially in states where few targeted eel surveys are conducted\*\*
  - A coast-wide sampling program for yellow and silver American eels should be developed using standardized and statistically robust methodologies\*\*
- Improve understanding of coast-wide recruitment trends
  - Continue the ASMFC-mandated YOY surveys; these surveys could be particularly valuable as an early warning signal of recruitment failure\*
  - Develop proceedings document for the 2006 ASMFC YOY Survey Workshop; follow-up on decisions and recommendations made at the workshop\*

- Examine age at entry of glass eel into estuaries and freshwater\*\*
- Develop monitoring framework to provide information for future modeling on the influence of environmental factors and climate change on recruitment\*\*
- Improve knowledge and understanding of the portion of the American eel population occurring south of the U.S. (i.e., West Indies, Mexico, Central America, and South America)\*\*

## Future Research

### *Biology*

- Improve understanding of the leptocephalus stage of American eel
  - Examine the mechanisms for exit from the Sargasso Sea and transport across the continental shelf\*\*
  - Examine the mode of nutrition for leptocephalus in the ocean\*\*
- Improve understanding of impact of contaminants as sources of mortality and non-lethal population stressors
  - Investigate the effects of environmental contaminants on fecundity, natural mortality, and overall health\*\*
  - Research the effects of bioaccumulation with respect to impacts on survival and growth (by age) and effect on maturation and reproductive success\*\*
- **Improve understanding of impact of *Anguillicoloides crassus* on American eel**
  - Investigate the prevalence and incidence of infection by the nematode parasite *A. crassus* across the species range\*
  - Research the effects of the swim bladder parasite *A. crassus* on the American eel's growth and maturation, migration to the Sargasso Sea, and the spawning potential\*
  - Investigate the impact of the introduction of *A. crassus* into areas that are presently free of the parasite\*\*
- **Improve understanding of spawning and maturation**
  - Investigate relation between fecundity and length and fecundity and weight for females throughout their range\*\*
  - Identify triggering mechanism for metamorphosis to mature adult, silver eel life stage, with specific emphasis on the size and age of the onset of maturity, by sex; a maturity schedule (proportion mature by size or age) would be extremely useful in combination with migration rates\*\*
  - Research mechanisms of recognition of the spawning area by silver eel, mate location in the Sargasso Sea, spawning behavior, and gonadal development in maturation\*\*
  - Examine migratory routes and guidance mechanisms for silver eel in the ocean\*\*
- Improve understanding of predator-prey relationships\*\*

- Investigating the mechanisms driving sexual determination and the potential management implications\*\*

### *Passage & Habitat*

- **Improve upstream and downstream passage for all life stages of American eels**
  - Develop design standards for upstream passage devices for eels; this will be a product (at least partial design guidelines) from the ASMFC 2011 Eel Passage Workshop, so this research need may be partially met in the near term\*
  - Investigate, develop, and improve technologies for American eel passage upstream and downstream at various barriers for each life stage; in particular, investigate low-cost alternatives to traditional fishway designs for passage of eel\*\*
- Improve understanding of the impact of barriers on upstream and downstream movement
  - Evaluate the impact, both upstream and downstream, of barriers to eel movement with respect to population and distribution effects; determine relative contribution of historic loss of habitat to potential eel population and reproductive capacity\*\*
  - Recommend monitoring of upstream and downstream movement at migratory barriers that are efficient at passing eels (e.g., fish ladder/lift counts); data that should be collected include presence/absence, abundance, and biological information; provide standardized protocols for monitoring eels at passage facilities; coordinate compilation of these data; provide guidance on the need and purpose of site-specific monitoring\*\*
- **Improve understanding of habitat needs and availability**
  - Assess characteristics and distribution of American eel habitat and value of habitat with respect to growth and sex determination; develop GIS of American eel habitat in U.S.\*\*
  - Assess available drainage area over time to account for temporal changes in carrying capacity; develop GIS of major passage barriers\*\*
- Improve understanding of within-drainage behavior and movement and the exchange between freshwater and estuarine systems\*\*
- Improve estimates of mortality associated with upstream and downstream passage
  - Monitor non-harvest losses such as impingement, entrainment, spill, and hydropower turbine mortality\*
- Evaluate eel impingement and entrainment at facilities with NPDES authorization for large water withdrawals; quantify regional mortality and determine if indices of abundance could be established as specific facilities\*\*
- Investigate best methods for reintroducing eels into a watershed; examine approaches for determining optimum density\*

## Assessment Methodology & Management Support

- Coordinate monitoring, assessment, and management among agencies that have jurisdiction within the species' range (e.g., ASMFC, GLFC, Canada DFO)\*\*
- Perform a joint U.S.-Canadian stock assessment\*
- Perform periodic stock assessments (every 5–7 years) and establish sustainable reference points for American eel are required to develop a sustainable harvest rate in addition to determining whether the population is stable, decreasing, or increasing
  - Develop new assessment models (e.g., delay-difference model) specific to eel life history and fit to available indices\*\*
  - **Conduct intensive age and growth studies at regional index sites to support development of reference points and estimates of exploitation\***
  - Develop GIS-type model that incorporates habitat type, abundance, contamination, and other environmental factors\*\*
  - Develop population targets based on habitat availability at the regional and local level\*\*
- Implement large-scale (coast-wide or regional) tagging studies of eels at different life stages; tagging studies could address a number of issues including:
  - Natural, fishing, and discard mortality; survival\*\*
  - Growth\*\*
  - Passage mortality\*\*
  - Movement, migration, and residency\*\*
  - Validation of ageing methods\*\*
  - Reporting rates\*\*
  - Tag shedding or tag attrition rates\*\*

## 11 LITERATURE CITED

- Adams, C.C., and T.L. Hankinson. 1928. The ecology and economics of Oneida Lake fish. Transactions of the American Fisheries Society 45(3):155–169.
- ACCSP (Atlantic Coastal Cooperative Statistics Program). 2004. The program design of the Atlantic Coastal Cooperative Statistics Program, 2nd edition. Approved November 2004. 109 p. Available (January 2011): <http://www.accsp.org/DOCUMENTS/programdesign/programdesign2ndedition.PDF>
- ASMFC (Atlantic States Marine Fisheries Commission). 1994. MRFSS user's manual: a guide to use of the National Marine Fisheries Service Marine Recreational Fisheries Statistics Survey Database. ASMFC, Special Report No. 37, Washington, D.C. Available (March 2011): [http://www.st.nmfs.noaa.gov/st1/recreational/pubs/data\\_users/index.html](http://www.st.nmfs.noaa.gov/st1/recreational/pubs/data_users/index.html).
- \_\_\_\_\_. 2000a. Interstate fishery management plan for American eel (*Anguilla rostrata*). ASMFC, Fishery Management Report No. 36, Washington, D.C. 93 p.
- \_\_\_\_\_. 2000b. Standard procedures for American eel young of the year survey: substituting the protocol outlined in the interstate fishery management plan for American eel. Prepared by the AMSFC American Eel Technical Committee. ASMFC, Washington, D.C. 3 p.
- \_\_\_\_\_. 2001. Proceedings of the workshop on ageing and sexing American eel. ASMFC, Special Report No. 72, Washington, D.C. 25 p.
- \_\_\_\_\_. 2002. Stock assessment methodologies for American eel. ASMFC American Eel Stock Assessment Subcommittee report to the ASMFC American Eel Management Board. ASMFC, Washington, D.C. 6 p.
- \_\_\_\_\_. 2005. American eel stock assessment report for peer review. ASMFC, Washington, D.C. 121 p.
- \_\_\_\_\_. 2006a. Terms of reference and advisory report to the American eel stock assessment peer review. ASMFC, Stock Assessment Report No. 06-01, Washington, D.C. 29 p.
- \_\_\_\_\_. 2006b. Update of the American eel stock assessment report. ASMFC, Washington, D.C. 51 p.
- \_\_\_\_\_. 2006c. American lobster stock assessment report for peer review. ASMFC, Stock Assessment Report No. 06-03 (Suppl.), Washington, D.C. 352 p.
- \_\_\_\_\_. 2008. Addendum II to the fishery management plan for American eel. Approved October 23, 2008. ASMFC, Washington, D.C. 7 p.
- \_\_\_\_\_. 2009. American lobster stock assessment report for peer review. ASMFC, Stock Assessment Report No. 09-01 (Suppl.), Washington, D.C. 298 p.
- \_\_\_\_\_. 2011. Integrated Peer Review Report of the American Eel Stock Assessment. ASMFC, Stock Assessment Report No. 11-01, Washington, D.C. 11 p.



- Amaral, S.V., F.C. Winchell, B.J. McMahon, and D.A. Dixon. 2003. Evaluation of angled bar racks and louvers for guiding silver phase American eels. Pages 367–376 *In*: D.A. Dixon (editor), Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Anonymous. 2003. Worldwide decline of eel resources necessitates immediate action: Québec Declaration of Concern. *Fisheries* 28(12):28–30.
- Arai, T., T. Otake, and K. Tsukamoto. 2000. Timing of metamorphosis and larval segregation of the Atlantic eels *Anguilla rostrata* and *A. anguilla*, as revealed by otolith microstructure and microchemistry. *Marine Biology* 137(1):39–45.
- Avise, J.C., G.S. Helfman, N.C. Saunders, and L.S. Hales. 1986. Mitochondrial DNA differentiation in North Atlantic eels: population genetic consequences of an unusual life history pattern. *Proceedings of the National Academy of Sciences of the United States of America* 83(12):4350–4354.
- Barber, R.E. 2004. Sex ratio of silver American eels (*Anguilla rostrata*) migrating out of two southern Delaware streams. Master's thesis. University of Delaware, Newark. 93 p.
- Barbin, G.P., and W.H. Krueger. 1994. Behavior and swimming performance of elvers of the American eel, *Anguilla rostrata*, in an experimental flume. *Journal of Fish Biology* 45(1):111–121.
- Barbin, G.P., S.J. Parker, and J.D. McCleave. 1998. Olfactory clues play a critical role in the estuarine migration of silver-phase American eels. *Environmental Biology of Fishes* 53:283–291.
- Barse, A.M., and D.H. Secor. 1999. An exotic nematode parasite of the American eel. *Fisheries* 24(2):6–10.
- Barse, A.M., S.A. McGuire, M.A. Vinoses, L.E. Elerman, and J.A. Weeder. 2001. The swimbladder nematode *Anguillicola crassus* in American eels (*Anguilla rostrata*) from middle and upper regions of Chesapeake Bay. *Journal of Parasitology* 87(6):1366–1370.
- Beak International. 2001. The decline of American eel (*Anguilla rostrata*) in the Lake Ontario/St. Lawrence River ecosystem: a modeling approach to identification of data gaps and research priorities. American Eel White Paper prepared for the Great Lakes Fishery Commission, Lake Ontario Committee. Available (December 2011): <http://www.glfrc.org/lakecom/loc/eel.pdf>
- Beullens, K., E.H. Eding, F. Ollevier, J. Komen, and C.J.J. Richter. 1997. Sex differentiation, changes in length, weight and eye size before and after metamorphosis of European eel (*Anguilla anguilla* L.) maintained in captivity. *Aquaculture* 153(1-2):151–162.
- Bevacqua, D., M. Andrello, P. Meli, S. Vincenzi, G.A. De Leo, and A.J. Crivelli. Density-dependent and inter-specific interactions affecting European eel settlement in freshwater habitats. *Hydrobiologia* 671:259–265.
- Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. *Fishery Bulletin* 53(1). 577 p.

- Bonhommeau, S., E. Chassot, B. Planque, E. Rivot, A.H. Knap, and O. Le Pape. 2008. Impact of climate on eel populations of the Northern Hemisphere. *Marine Ecology Progress Series* 373:71–80.
- Bonhommeau, S., E. Chassot, and E. Rivot. 2008. Fluctuations in European eel (*Anguilla anguilla*) recruitment resulting from environmental changes in the Sargasso Sea. *Fisheries Oceanography* 17(1):32–44.
- Box, G.E. and G.M. Jenkins. 1976. *Time series analysis: forecasting and control*, revised ed. Holden-Day, Oakland, CA.
- Bozeman, E.L., G.S. Helfman, and T. Richardson. 1985. Population size and home range of American eels in a Georgia tidal creek. *Transactions of the American Fisheries Society* 114(6):821–825.
- Britton, J.R., J. Pegg, J.S. Shepherd, and S. Toms. 2006. Revealing the prey items of the otter *Lutra lutra* in South West England using stomach contents analysis. *Folia Zoologica* 55(2):167–174.
- Brown, L., A. Haro, and T. Castro-Santos. 2009. Three-dimensional movement of silver-phase American eels in the forebay of a small hydroelectric facility. Pages 271–291 *In*: J.M. Casselman and D.K. Cairns (editors), *Eels at the edge: science, status, and conservation concerns*. American Fisheries Society, Symposium 58, Bethesda, Maryland. 449 p.
- Buckel, J.A. and D.O. Conover. 1997. Movements, feeding periods, and daily ration of piscivorous young-of-the-year bluefish, *Pomatomus saltatrix*, in the Hudson River estuary. *Fishery Bulletin* 95(4):665–679.
- Burnham, K.P., and D.R. Anderson. 2002. *Model selection and multimodel inference: a practical information-theoretic approach*, 2nd edition. Springer-Verlag, New York. 488 p.
- Busch, W-D.N., and S.J. Lary. 1996. Assessment of habitat impairments impacting the aquatic resources of Lake Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 53(S1):113–120.
- Caddy, J.F. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. *FAO Fisheries Technical Paper No. 379*. 30 p.
- Caddy, J.F. 1999. Deciding on precautionary management measures for a stock based on a suite of limit reference points (LRPs) as a basis for a multi-LRP harvest law. *NAFO Scientific Council Studies* 32:55–68.
- Cairns, C.M. 2009. Population ecology of yellow-phase American eels (*Anguilla rostrata*) in the St. Jones River, Delaware. Master's thesis. Delaware State University, Dover.
- Cairns, D.K., and J.M. Casselman (co-chairs). 2004. Inaugural meeting of the Canadian Eel Science Working Group. *DFO Canadian Science Advisory Secretariat Proceedings Series* 2004/017. 69 p.

- Cairns, D.K., D.L. Omilusik, P.H. Leblanc, E.G. Atkinson, D.S. Moore, and N. McDonald. 2007. American eel abundance indicators in the southern Gulf of St. Lawrence. Canadian Data Report of Fisheries and Aquatic Sciences 1192. 125 p.
- Carr, J.W., and F.G. Whoriskey. 2008. Migration of silver American eels past a hydroelectric dam and through a coastal zone. Fisheries Management and Ecology 15(5-6):393–400.
- Casselman, J.M. 2003. Dynamics of resources of the American eel, *Anguilla rostrata*: declining abundance in the 1990s. Pages 255–274 (chapter 18) In: K. Aida, K. Tsukamoto, and K. Yamauchi (editors), Eel biology. Springer-Verlag, New York. 497 p.
- Casselman, J.M., and D.K. Cairns (editors). 2009. Eels at the edge: science, status, and conservation concerns. American Fisheries Society, Symposium 58, Bethesda, Maryland. 449 p.
- Casselman, J.M., and L.A. Marcogliese. 2007. Research into the relationship between abundance, harvest, and value by region for American eel. Completion Report, Great Lakes Fishery Commission, Fishery Research Program.
- Castonguay, M., P.V. Hodson, C. Couillard, M.J. Eckersley, J.-D. Dutil, and G. Verreault. 1994a. Why is recruitment of the American eel, *Anguilla rostrata*, declining in the St. Lawrence River and Gulf? Canadian Journal of Fisheries and Aquatic Sciences 51(2):479–488.
- Castonguay, M., and P.V. Hodson, C. Moriarty, K.F. Drinkwater, and B.M. Jessop. 1994b. Is there a role in the ocean environment in American and European eel decline? Fisheries Oceanography 3(3):197–203.
- Chaput, G., A. Locke, and D. Cairns. 1997. Status of American eel (*Anguilla rostrata*) from the southern Gulf of St. Lawrence. Pages 69–93 In: R. H. Peterson, editor. The American eel in Eastern Canada: Stock status and management strategies. Proceedings of Eel Management Workshop, January 13–14, 1997, Quebec City, QC. Canadian Technical Reports of Fisheries and Aquatic Science No. 2196.
- Chen, Y., D.A. Jackson, and H.H. Harvey. 1992. A comparison for von Bertalanffy and polynomial functions in modeling fish growth data. Canadian Journal of Fisheries and Aquatic Sciences 49(6):1228–1235.
- Chisnall, B.L., and J.M. Kalish. 1993. Age validation and movement of freshwater eels (*Anguilla dieffenbachii* and *A. australis*) in a New Zealand pastoral stream. New Zealand Journal of Marine and Freshwater Research 27(3):333–338.
- Cieri, M.D., and J.D. McCleave. 2000. Discrepancies between otoliths of larvae and juveniles of the American eel: is something fishy happening at metamorphosis? Journal of Fish Biology 57(5):1189–1198.
- Cochran, W.G. 1977. Sampling techniques, 3rd edition. John Wiley & Sons, New York. 428 p.
- COSEWIC. 2006. COSEWIC assessment and status report on the American eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. 71 p.

Available (December 2011):

[http://www.sararegistry.gc.ca/virtual\\_sara/files/cosewic/sr\\_american\\_eel\\_e.pdf](http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_american_eel_e.pdf).

- Columbo, G., G. Grandi, and R. Rossi. 1984. Gonad differentiation and body growth in *Anguilla anguilla* L. *Journal of Fish Biology* 24(2):215–228.
- Cote, C.L., M. Castonguay, G. Verreault, and L. Bernatchez. 2009. Differential effects of origin and salinity rearing conditions on growth of glass eels of the American eel *Anguilla rostrata*: implications for stocking programmes. *Journal of Fish Biology* 74(9):1934–1948.
- Cudney, J.L. 2004. Population demographics and critical habitat of American eel (*Anguilla rostrata*) in Northwestern Pamlico Sound and Lake Mattamuskeet, North Carolina. Master's thesis. East Carolina University, Greenville, North Carolina.
- Cuthbert, J.H. 1979. Food studies of feral mink *Mustela vison* in Scotland. *Fisheries Management* 10:17–25.
- Daniels, L.R. 1999. Diet of American eels (*Anguilla rostrata* LeSueur) in five freshwater lakes, Maine, U.S.A. Master's thesis. University of Maine, Orono. 61 p.
- Davey, A.J.H, and D.J. Jellyman. 2005. Sex determination in freshwater eels and management options for manipulation of sex. *Reviews in Fish Biology and Fisheries*. 15(1-2):37–52.
- Deelder, C.L. 1958. On the behaviour of elvers (*Anguilla vulgaris* Turt.) migrating from the sea into fresh water. *ICES Journal of Marine Science* 24:135–146.
- Denoncourt, C.E., and J.R. Stauffer Jr. 1993. Feeding selectivity of the American eel *Anguilla rostrata* (LeSueur) in the upper Delaware River. *American Midland Naturalist* 129(2):301–308.
- DFO (Department of Fisheries and Oceans Canada). 2005. Second meeting of the Canadian Eel Science Working Group, 24–25 January 2005. DFO Canadian Science Advisory Secretariat Proceedings Series 2005/013. 49 p.
- \_\_\_\_\_. 2006. Third meeting of the Canadian Eel Science Working Group, 13–14 October 2005. DFO Canadian Science Advisory Secretariat Proceedings Series 2006/048. 45 p.
- \_\_\_\_\_. 2007. Fourth Meeting of the Canadian Eel Science Working Group, 3–4 October 2006. DFO Canadian Science Advisory Secretariat Proceedings Series 2007/003. 60 p.
- \_\_\_\_\_. 2009a. Fifth Meeting of the Canadian Eel Science Working Group, 3–5 October 2007. DFO Canadian Science Advisory Secretariat Proceedings Series 2008/027. 58 p.
- \_\_\_\_\_. 2009b. Zonal Science Peer Review of the American eel (*Anguilla rostrata*) prior to assessment by COSEWIC; 11–12 October, 2005. DFO Canadian Science Advisory Secretariat Proceedings Series 2009/028. 66 p.
- \_\_\_\_\_. 2010. Status of American Eel and progress on achieving management goals. DFO Canadian Science Advisory Secretariat Science Advisory Report 2010/062. 26 p.

- \_\_\_\_\_. 2011a. Seventh meeting of the Canadian Eel Science Working Group, 14-16 October 2009. DFO Canadian Science Advisory Secretariat Proceedings Series 2011/035. 59 p.
- \_\_\_\_\_. 2011b. Eighth meeting of the Canadian Eel Science Working Group, 30 August 2010, Ottawa, ON. Canadian Technical Report of Fisheries and Aquatic Sciences 2919. iii + 16 p.
- \_\_\_\_\_. 2011c. Proceedings of the Zonal Advisory Process on the pre-COSEWIC review and evaluation of progress on management objectives for the American eel, August 31 to September 3, 2010. DFO Canadian Science Advisory Secretariat Proceedings Series 2011/028. vi + 55 p.
- 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.
- Dolan, J.A., and G. Power. 1977. Sex ratio of American eels, *Anguilla rostrata*, from the Matamek River system, Quebec, with remarks on problems in sexual identification. *Journal of the Fisheries Research Board of Canada* 34:294–299.
- Dutil, J.-D., M. Besner, and S.D. McCormick. 1987. Osmoregulatory and ionoregulatory changes and associated mortalities during the transition of maturing American eels to a marine environment. Pages 175–190 *In*: M.J. Dadswell, R.J. Klauda, C.M. Moffitt, and R.L. Saunders (editors), *Common strategies of anadromous and catadromous fishes*. American Fisheries Society, Symposium 1, Bethesda, Maryland. 561 p.
- Dutil, J.-D., P. Dumont, D.K. Cairns, P.S. Galbraith, G. Verreault, M. Castonguay, and S. Proulx. 2009. *Anguilla rostrata* glass eel migration and recruitment in the estuary and Gulf of St. Lawrence. *Journal of Fish Biology* 74(9):1970–1984.
- Dutil, J.-D., A. Giroux, A. Kemp, G. Lavoie, and J.-P. Dallaire. 1988. Tidal influence on movements and on daily cycle of activity of American eels. *Transactions of the American Fisheries Society* 117(5):488–494.
- EC (European Council). 2007. Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. *Official Journal of the European Union* L 248, 22 September 2007. 7 p.
- Edel, R.K. 1976. Activity rhythms of maturing American eels (*Anguilla rostrata*). *Marine Biology* 36(3):283–289.
- Egusa, S. 1979. Notes on the culture of the European eel (*Anguilla anguilla* L.) in Japanese eel-farming ponds. *Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer*. 174:51–58.
- Euston, E.T., D.E. Royer, C.L. Simons. 1998. American eels and hydro plants: clues to eel passage. *Hydro Review* (August) 17(4):94–103.
- Facey, D.E., and G.S. Helfman. 1985. Reproductive migrations of American eels in Georgia. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 39:132–138.

- Facey, D.E., and G.W. LaBar. 1981. Biology of American eels in Lake Champlain, Vermont. *Transactions of the American Fisheries Society* 110(3):396–402.
- Facey, D.E., and M.J. Van Den Avyle. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)—American eel. USFWS Biological Report 82 (11.74). U.S. Army Corps of Engineers, TR EL-82-4. 28 p.
- Fahay, M.P. 1978. Biological and fisheries data on American eel, *Anguilla rostrata* (LeSueur). National Marine Fisheries Service Northeast Fisheries Center, Sandy Hook Laboratory, Technical Series Report 17, Highlands, N.J. 96 p.
- Fenske, K.H., D.H. Secor, and M.J. Wilberg. 2010. Demographics and parasitism of American eels in the Chesapeake Bay, USA. *Transactions of the American Fisheries Society* 139:1699–1710.
- Fenske, K.H., M.J. Wilberg, D.H. Secor, and M.C. Fabrizio. 2011. An age- and sex-structured assessment model for American eels (*Anguilla rostrata*) in the Potomac River, Maryland. *Canadian Journal of Fisheries and Aquatic Sciences* 68:1024–1037.
- Ford, T.E., and E. Mercer. 1986. Density, size distribution and home range of American eels, *Anguilla rostrata*, in a Massachusetts salt marsh. *Environmental Biology of Fishes* 17(4):309–314.
- Foster, J.W.S., and R.W. Brody. 1982. Status report: the American eel fishery in Maryland, 1982. Maryland Department of Natural Resources, Tidewater Administration, Tidal Fisheries Division, Annapolis, Maryland. 27 p.
- Fournier, D., and F. Caron. 2001. *Travaux de recherché sur l'anguille d'Americanerique (Anguilla rostrata) de la Petite rivere de la Trinite en 1999 et 2000. Societe de la faune et des parcs du Quebec, Direction de la recherché sur la faune, Quebec.*
- Friedland, K.D., M.J. Miller, and B. Knights. 2007. Oceanic changes in the Sargasso Sea and declines in recruitment of the European eel. *ICES Journal of Marine Science* 64(3):519–530.
- Fries, L.T., D.J. Williams, and K.S. Johnson. 1996. Occurrence of *Anguillicola crassus*, an exotic parasitic swim bladder nematode of eels, in the southeastern United States. *Transactions of the American Fisheries Society* 125(5):794–797.
- Geer, P. J. 2003. Distribution, relative abundance, and habitat use of American eel *Anguilla rostrata* in the Virginia portion of the Chesapeake Bay. Pages 101–115 *In*: D.A. Dixon (editor), *Biology, management, and protection of catadromous eels*. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Gerrodette, T. 1987. A power analysis for detecting trends. *Ecology* 68: 1364–1372.
- Gilbert, R.O. 1987. *Statistical methods for environmental pollution monitoring*. Van Nostrand Reinhold, New York. 320 p.

- GMCME (Gulf of Maine Council on the Marine Environment). 2007. American eels: restoring a vanishing resource in the Gulf of Maine. 12 p. Available (December 2011): [http://www.wildlife.state.nh.us/marine/marine\\_PDFs/American\\_Eels\\_GulfOfMaine.pdf](http://www.wildlife.state.nh.us/marine/marine_PDFs/American_Eels_GulfOfMaine.pdf)
- Goode, G.B. 1884. The fisheries and fishery industries of the United States.
- Goodwin, K.R., and P.L. Angermeier. 2003. Demographic characteristics of American eel in the Potomac River drainage, Virginia. *Transactions of the American Fisheries Society* 132(3):524–535.
- 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. ASMFC, Habitat Management Series No. 9, Washington, D.C.
- Griffin, J.C., and F.J. Margraf. 2003. The diet of Chesapeake Bay striped bass in the late 1950s. *Fisheries Management and Ecology* 10:323–328.
- Guerrero, R.D. III, and W.L. Shelton. 1974. An aceto-carminic squash method for sexing juvenile fishes. *The Progressive Fish Culturist* 36:56.
- Gunning, G.E., and C.R. Shoop. 1962. Restricted movements of the American eel, *Anguilla rostrata* (LeSueur), in freshwater streams, with comments on growth rate. *Tulane Studies in Zoology* 9(5):265–272.
- Haddon, M. 2001. Modelling and quantitative methods in fisheries. Chapman and Hall/CRC, Boca Raton, FL. 406 p.
- Hain, J.H.W. 1975. The behaviour of migratory eels, *Anguilla rostrata*, in response to current, salinity and lunar period. *Helgoländer Meeresuntersuchungen* 27(2):211–233.
- Halliday, R.G., L.P. Fanning, and R.K. Mohn. 2001. Use of the traffic light method in fishery management planning. Canadian Science Advisory Secretariat Research Document 2001/108. 41 p.
- Hammond, S.D., and S.A. Welsh. 2009. Seasonal movements of large yellow American eels downstream of a hydroelectric dam, Shenandoah River, West Virginia. Pages 309–323 *In: J.M. Casselman and D.K. Cairns (editors), Eels at the edge: science, status, and conservation concerns. American Fisheries Society, Symposium 58, Bethesda, Maryland.* 449 p.
- Hansen, R.A., and A.G. Eversole. 1984. Age, growth, and sex ratio of American eels in brackish-water portions of a South Carolina river. *Transactions of the American Fisheries Society* 113(6):744–749.
- Hardy Jr., J.D. 1978. Development of fishes of the Mid-Atlantic Bight: an atlas of egg, larval and juvenile stages. Vol. II: Anguillidae through Syngnathidae. FWS/OBS- 7812.
- Haro, A., T. Castro-Santos, K. Whalen, G. Wippelhauser, and L. McLaughlin. 2003. Simulated effects of hydroelectric project regulation on mortality of American eels. Pages 357–365

- In*: D.A. Dixon (editor), Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Haro, A.J., and W.H. Krueger. 1988. Pigmentation, size, and migration of elvers (*Anguilla rostrata* (Lesueur)) in a coastal Rhode Island stream. *Canadian Journal of Zoology* 66(11):2528–2533.
- Haro, A.J., and W.H. Krueger. 1991. Pigmentation, otolith rings, and upstream migration of Juvenile American eels (*Anguilla rostrata*) in a coastal Rhode Island stream. *Canadian Journal of Zoology* 69(3):812–814.
- Haro, A., W. Richkus, K. Whalen, A. Hoar, W-D. Busch, S. Lary, T. Brush, and D. Dixon. 2000. Population decline of the American eel: implications for research and management. *Fisheries* 25(9):7–16.
- Harrell, R.M., and H.A. Loyacano. 1982. Age, growth and sex ratio of the American eel in the Cooper River, South Carolina. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 34(1980):349–359.
- Helfman, G.S., E.L. Bozeman, and E.B. Brothers. 1984.1984. Comparison of American eel growth rates from tag returns and length-age analyses. *Fishery Bulletin* 82(3):519–522.
- Helfman, G.S., D.L. Stoneburner, E.L. Bozeman, P.A. Christian, and R. Whalen. 1983. Ultrasonic telemetry of American eel movements in a tidal creek. *Transactions of the American Fisheries Society* 112:105–110.
- 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.
- Helser, T.E., T. Sharov, and D.M. Kahn. 2002. A stochastic decision-based approach to assessing the Delaware Bay blue crab (*Callinectes sapidus*) stock. Pages 63–82 *In*: J.M. Berkson, L.L. Kline, and D.J. Orth (editors), *Incorporating uncertainty into fishery models*. American Fisheries Society, Symposium 27, Bethesda, Maryland. 208 p.
- Hilborn, R., and M. Mangel. 1997. *The ecological detective: confronting models with data*. Princeton University Press, Princeton, NJ. 315 p.
- Hodson, P.V., M. Castonguay, C.M. Couillard, C. Desjardins, E. Pellitier, and R. McLeod. 1994. Spatial and temporal variations in chemical contamination of American eels, *Anguilla rostrata*, captured in the estuary of the St. Lawrence River. *Canadian Journal of Fisheries and Aquatic Sciences* 51(2):464–478.
- Hongzhi, A. 1989. Fast stepwise procedures of selection of variables by using AIC and BIC criteria. *Acta Mathematicae Applicatae Sinica* 5:60–67.
- ICES (International Council for the Exploration of the Sea). 2001. Report of the EIFAC/ICES Working Group on Eels. 28 August–1 September 2000, St. Andrews, N.B., Canada. ICES CM 2001/ACFM:03. 87 p.
- \_\_\_\_\_. 2002. Report of the ICES/EIFAC Working Group on Eels. 28–31 August 2001, ICES Headquarters. ICES CM 2002/ACFM:03. 55 p.



- \_\_\_\_\_. 2003. Report of the ICES/EIFAC Working Group on Eels. 2–6 September 2002, Nantes, France. ICES CM 2003/ACFM:06. 84 p.
- \_\_\_\_\_. 2004. Report of the ICES/EIFAC Working Group on Eels. 7–11 October 2003, Sukarrieta, Spain. ICES CM 2004/ACFM:09. 207 p.
- \_\_\_\_\_. 2005. Report of the ICES/EIFAC Working Group on Eels (WGEEL). 22–26 November 2004, Galway, Ireland. ICES CM 2005/ I:01. 36 p.
- \_\_\_\_\_. 2006. Report of the 2006 session of the Joint EIFAC/ICES Working Group on Eels. 23–27 January 2006, Rome, Italy. ICES CM 2006/ACFM:16. 352 p.
- \_\_\_\_\_. 2008. Report of the 2007 session of the Joint EIFAC/ICES Working Group on Eels. 3–7 September 2007, Bordeaux, France. ICES CM 2008/ACOME:15. 138 p.
- \_\_\_\_\_. 2009a. Report of the 2008 session of the Joint EIFAC/ICES Working Group on Eels. 3–9 September 2008, Leuven, Belgium. ICES CM 2009/ACOM:15. 192 p.
- \_\_\_\_\_. 2009b. Report of the 2009 session of the Joint EIFAC/ICES Working Group on Eels. 7–12 September 2009, Göteborg, Sweden. ICES CM 2009/ACOM:15. 117 p.
- Ingraham, D.L. 1999. Sex ratios and maturation patterns of the American eel, *Anguilla rostrata* (La Sueur), in four locations of the Saint John River system, New Brunswick. Master's thesis. University of New Brunswick. 118 p.
- Jessop, B.M. 1997. An overview of European and American eel stocks, fisheries and management issues. Pages 6–20 *In*: R.H. Peterson (editor), The American eel in Eastern Canada: stock status and management strategies. Proceedings of Eel Workshop, January 13–14, 1997, Québec City, QC. Canadian Technical Report of Fisheries and Aquatic Sciences 2196. 191 p.
- Jessop, B.M. 1998. Geographic and seasonal variation in biological characteristics of American eel elvers in the Bay of Fundy area and on the Atlantic coast of Nova Scotia. Canadian Journal of Zoology 76(12):2172–2185.
- Jessop, B.M. 2000. Estimates of population size and instream mortality rate of American eel elvers in a Nova Scotia river. Transactions of the American Fisheries Society 129(2):514–526.
- Jessop, B.M. 2003. Annual variability in the effects of water temperature, discharge, and tidal state on the migration of American eel elvers from estuary to river. Pages 3–16 *In*: D.A. Dixon (editor), Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Jessop, B.M. 2008. Life history of American eel *Anguilla rostrata*: new insights from otolith microchemistry. Aquatic Biology 1(3):205–216.
- Jessop, B.M. 2010. Geographic effects on American eel (*Anguilla rostrata*) life history characteristics and strategies. Canadian Journal of Fisheries and Aquatic Sciences 67(2):326–346.

- Jessop, B.M., and C.J. Harvie. 2003. A CUSUM analysis of discharge patterns by a hydroelectric dam and discussion of potential effects on the upstream migration of American eel elvers. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2454.
- Jessop, B.M., J.-C. Shiao, Y. Iizuka, and W.-N. Tzeng. 2006. Migration of juvenile American eels *Anguilla rostrata* between freshwater and estuary, as revealed by otolith microchemistry. *Marine Ecology Progress Series* 310:219–233.
- Kagawa, H., H. Tanaka, H. Ohta, T. Unuma, and K. Nomura. 2005. The first success of glass eel reproduction in the world: basic biology on fish reproduction advances new applied technology in aquaculture. *Fish Physiology and Biochemistry* 31(2–3):193–199.
- Keefe, S.G. 1982. The American eel fishery in the commercial waters of North Carolina. Pages 50–51 *In*: K.H. Loftus (editor), Proceedings of the 1980 North American Eel Conference. Ontario Fisheries Technical Report Number 4. Ontario Ministry of Natural Resources, Toronto, Canada. 97 p.
- Kennedy, C.R. 2007. The pathogenic helminth parasites of eels. *Journal of Fish Diseases* 30(6):319–334.
- Kimura, D.K., and J.V. Tagart. 1982. Stock reduction analysis, another solution to the catch equations. *Canadian Journal of Fisheries and Aquatic Sciences* 39:1467–1472.
- Kimura, D.K., J.W. Balsiger, and D.H. Ito. 1984. Generalized stock reduction analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 41:1325–1333.
- Kirk, R.S. 2003. The impact of *Anguillicola crassus* on European eels. *Fisheries Management and Ecology* 10(6):385–394.
- Kleckner, R.C., and J.D. McCleave. 1982. Entry of migrating American eel leptocephali into the Gulf Stream System. *Helgoländer Meeresuntersuchungen* 35(3):329–339.
- Kleckner, R.C., and J.D. McCleave. 1985. Spatial and temporal distribution of American eel larvae in relation to North Atlantic Ocean current systems. *Dana* 4:67–92.
- Kleckner, R.C., J.D. McCleave, and G.S. Wippelhauser. 1983. Spawning of American eel, *Anguilla rostrata*, relative to thermal fronts in the Sargasso Sea. *Environmental Biology of Fishes* 9(3-4):289–293.
- Lamothe, P.J., M. Gallagher, D.P. Chivers, and J.R. Moring. 2000. Homing and movement of yellow-phase American eels in freshwater ponds. *Environmental Biology of Fishes* 58(4):393–399.
- Lamson, H.M., J.-C. Shiao, Y. Iizuka, W.-N. Tzeng, and D.K. Cairns. 2006. Movement patterns of American eels (*Anguilla rostrata*) between salt- and freshwater in a coastal watershed, based on otolith microchemistry. *Marine Biology* 149(6):1567–1576.
- Lane, J.P. 1978. Eels and their utilization. *Marine Fisheries Review* 40(4):1–20.
- Lefebvre, F., P. Contournet, and A.J. Crivelli. 2002. The health state of the eel swimbladder as a measure of parasite pressure by *Anguillicola crassus*. *Parasitology* 124(4):457–463.

- Levesque, J.R., and W.R. Whitworth. 1987. Age class distribution and size of American eel (*Anguilla rostrata*) in the Shetucket/Thames River, Connecticut. *Journal of Freshwater Ecology* 4(1):17–22.
- Lookabaugh, P.S., and P.L. Angermeier. 1992. Diet patterns of American eel, *Anguilla rostrata*, in the James River Drainage, Virginia. *Journal of Freshwater Ecology* 7(4):425–431.
- Liew, P.K.L. 1974. Age determination of American eels based on the structure of their otoliths. Pages 124–136 *In*: T.B. Bagenal (editor), *Proceedings of an International Symposium on the Ageing of Fish*, University of Reading, Unwin Brothers, Surrey, England. 234 p.
- Limburg, K.E., L.S. Machut, P. Jeffers, and R.E. Schmidt. 2008. Low PCB concentrations observed in American eel (*Anguilla rostrata*) in six Hudson River tributaries. *Northeastern Naturalist* 15(2):215–226.
- MacCall, A.D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. *ICES Journal of marine Science* 66:2267–2271.
- Machut, L.S. 2006. Population dynamics, *Anguillicola crassus* infection, and feeding selectivity of American eel (*Anguilla rostrata*) in tributaries of the Hudson River, New York. Master's thesis. State University of New York, Syracuse. 176 p.
- Machut, L.S., and K.E. Limburg. 2008. *Anguillicola crassus* infection in *Anguilla rostrata* from small tributaries of the Hudson River watershed, New York, USA. *Diseases of Aquatic Organisms* 79(1):37–45.
- Machut, L.S., K.E. Limburg, R.E. Schmidt, and D. Dittman. 2007. Anthropogenic impacts on American eel demographics in Hudson River tributaries, New York. *Transactions of the American Fisheries Society* 136(6):1699–1713.
- Manly, B.F.J. 2001. *Statistics for Environmental Science and Management*. Chapman and Hall.
- Martin, M.H. 1995. The effects of temperature, river flow, and tidal cycles on the onset of glass eel and elver migration into fresh water in the American eel. *Journal of Fish Biology* 46(5):891–902.
- Mathers, A., and T.C. Pratt. 2011. 2010 Update on the status and progress on management goals for American Eel in Ontario. *Canadian Science Advisory Secretariat Research Document* 2011/046. vi + 18 p.
- McCleave, J.D. 1993. Physical and behavioural controls on the oceanic distribution and migration of leptocephali. *Journal of Fish Biology* 43(Supplement A):243–273.
- McCleave, J.D. 2008. Contrasts between spawning times of *Anguilla* species estimated from larval sampling at sea and from otolith analysis of recruiting glass eels. *Marine Biology* 155(3):249–262.
- McCleave, J.D., R.C. Kleckner, and M. Castonguay. 1987. Reproductive sympatry of American and European eels and implications for migration and taxonomy. Pages 286–297 *In*: M.J. Dadswell, R.J. Klauda, C.M. Moffitt, and R.L. Saunders (editors), *Common strategies of*

- anadromous and catadromous fishes. American Fisheries Society, Symposium 1, Bethesda, Maryland. 561 p.
- McCleave, J.D., and G. Wippelhauser. 1987. Behavioral aspects of selective tidal stream transport in juvenile American eels. Pages 138–150 *In*: M.J. Dadswell, R.J. Klauda, C.M. Moffitt, and R.L. Saunders (editors), Common strategies of anadromous and catadromous fishes. American Fisheries Society, Symposium 1, Bethesda, Maryland. 561 p.
- McGrath, K.J., J. Bernier, S. Ault, J.-D. Dutil, and K. Reid. 2003a. Differentiating downstream migrating American eels *Anguilla rostrata* from resident eels in the St. Lawrence River. Pages 315–327 *In*: D.A. Dixon (editor), Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Michener, W.K., and A.G. Eversole. 1983. Age, growth, and sex ratio of American eels in Charleston Harbor, South Carolina. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 37:422–431.
- Miles, S.G. 1968. Laboratory experiments on the orientation of the adult American eel, *Anguilla rostrata*. Journal of the Fisheries Research Board of Canada 25:2143–2155.
- Miller, M.J., S. Kimura, K.D. Friedland, B. Knights, H. Kim, D.J. Jellyman, and K. Tsukamoto. 2009. Review of ocean-atmospheric factors in the Atlantic and Pacific oceans influencing spawning and recruitment of Anguillid eels. Pages 231–249 *In*: A. 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. 943 p.
- Morrison, W.E., and D.H. Secor. 2003. Demographic attributes of yellow-phase American eels (*Anguilla rostrata*) in the Hudson River estuary. Canadian Journal of Fisheries and Aquatic Sciences 60(12):1487–1501.
- Morrison, W.E., D.H. Secor, and P.M. Piccoli. 2003. Estuarine habitat use by Hudson River American eels as determined by otolith strontium:calcium ratios. Pages 87–99 *In*: D.A. Dixon (editor), Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Munk, P., M.M. Hansen, G.E. Maes, T.G. Nielsen, M. Castonguay, L. Riemann, H. Sparholt, T.D. Als, K. Aarestrup, N.G. Andersen, and M. Bachler. 2010. Oceanic fronts in the Sargasso Sea control the early life and drift of Atlantic eels. Proceedings of the Royal Society of London, Series B, Biological Sciences 277(1700):3593–3599.
- Nimeth, K., P. Zwerger, J. Wurtz, W. Salvenmoser, and B. Pelster. 2000. Infection of the glass-eel swimbladder with the nematode *Anguillicola crassus*. Parasitology 121(1):75–83.
- Oliveira, K. 1997. Movements and growth rates of yellow-phase American eels in the Annaquatucket River, Rhode Island. Transactions of the American Fisheries Society 126(4):638–646.

- Oliveira, K. 1999. Life history characteristics and strategies of the American eel, *Anguilla rostrata*. Canadian Journal of Fisheries and Aquatic Science 56(5):795–802.
- Oliveira, K., and J.D. McCleave. 2000. Variation in population and life history traits of the American eel, *Anguilla rostrata*, in four rivers in Maine. Environmental Biology of Fishes 59(2):141–151.
- Owens, S.J., and P.J. Geer. 2003. Size and age of American eels collected from tributaries of the Virginia portion of Chesapeake Bay. Pages 117–124 In: D.A. Dixon (editor), Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Palstra, A.P., D.F.M. Heppener, V.J.T. van Ginneken, C. Székely, and G.E.E.J.M. van den Thillart. 2007. Swimming performance of silver eels is severely impaired by the swim-bladder parasite *Anguillicola crassus*. Journal of Experimental Marine Biology and Ecology 352(1):244–256.
- Parker, S.J. 1995. Homing ability and home range of yellow-phase American eels in a tidally dominated estuary. Journal of Marine Biological Association of the U.K. 75(1):127–140.
- Parker, S.J., and J.D. McCleave. 1997. Selective tidal stream transport by American eels during homing movements and estuarine migration. Journal of Marine Biological Association of the United Kingdom 77(3):871–889.
- Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fishery Bulletin 84(3):519–525.
- Petersen, R.H. (editor). 1997. The American eel in eastern Canada: stock status and management strategies. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2196. 191 p.
- Pollock, K.H., C.M. Jones, and T.L. Brown. 1994. Angler survey methods and their applications in fisheries management. American Fisheries Society, Symposium 25, Bethesda, Maryland.
- Powles, P.M., and S.M. Warlen. 2002. Recruitment season, size, and age of young American eels (*Anguilla rostrata*) entering an estuary near Beaufort, North Carolina. Fishery Bulletin 100(2):299–306.
- Pratt, T.C., and A. Mathers. 2011. 2010 Update on the status of American eel (*Anguilla rostrata*) in Ontario. DFO Canadian Science Advisory Secretariat Research Document 2011/050. vi + 18 p.
- Punt, A.E., T. I. Walker, B.L. Taylor, and F. Pribac. 2000. Standardization of catch and effort data in a spatially-structured shark fishery. Fisheries Research 45:129–145.
- R Development Core Team, 2011. R: a language and environment for statistical computing. R Foundation for Statistical Computing. Available (April 2011): [www.R-project.org](http://www.R-project.org).
- Richkus, W.A., and K.G. Whalen. 1999. American eel (*Anguilla rostrata*) scoping study report: a literature and data review of life history, stock status, population dynamics, and

- hydroelectric facility impacts. Electric Power Research Institute, Final Report TR-111873, Palo Alto, CA. 126 p.
- Ritter, J.A., M. Stanfield, and R.H. Peterson. 1997. Final discussion. *In*: R.H. Peterson (editor), The American eel in Eastern Canada: stock status and management strategies. Proceedings of Eel Workshop, January 13–14, 1997, Québec City, QC. Canadian Technical Report of Fisheries and Aquatic Sciences 2196: v + 174 p.
- Robins, C.R., D.M. Cohen, and C.H. Robins. 1979. The eels, *Anguilla* and *Histiobranchus*, photographed on the floor of the deep Atlantic in the Bahamas. *Bulletin of Marine Science* 29:401–405.
- Robitaille, J.A., P. Bérubé, S. Tremblay, and G. Verreault. 2003. Eel fishing in the Great Lakes/St. Lawrence River system during the 20th Century: signs of overfishing. Pages 253–262 *In*: D.A. Dixon (editor), Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Rockwell, L.S., K.M.M. Jones, and D.K. Cone. 2009. First record of *Anguillicoloides crassus* (Nematoda) in American eels (*Anguilla rostrata*) in Canadian estuaries, Cape Breton, Nova Scotia. *Journal of Parasitology* 95(2):483–486.
- Rommel Jr., S.A., and A.B. Stasko. 1973. Electronavigation by eels. *Sea Frontiers* 19(4):219–223.
- Roncarati, A., P. Melotti, O. Mordenti, and L. Gennari. 1997. Influence of stocking density of European eel (*Anguilla anguilla*, L.) elvers on sex differentiation and zootechnical performances. *Journal of Applied Ichthyology* 13(3):131–136.
- Schmidt, R.E., C.M. O'Reilly, and D. Miller. 2009. Observations of American eels using an upland passage facility and effects of passage on the population structure. *North American Journal of Fisheries Management* 29(3):715–720.
- Schnute, J. 1981. A versatile growth model with statistically stable parameters. *Canadian Journal of Fisheries and Aquatic Sciences* 38(9):1128–1140.
- Scott, W.B., and M.G. Scott. 1988. Atlantic fishes of Canada. *Canadian Bulletin of Fisheries and Aquatic Sciences* 219:1–731. 731 p.
- Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. *Fisheries Research Board of Canada Bulletin* 184. 966 p.
- Sheldon, M.R., and J.D. McCleave. 1985. Abundance of glass eels of the American eel, *Anguilla rostrata*, in mid-channel and near shore during estuarine migration. *Naturaliste Canadien (Rev. Ecol. Syst.)* 112:425–430.
- Sjöberg, N.B., E. Petersson, H. Wickström, and S. Hansson. 2009. Effects of the swimbladder parasite *Anguillicola crassus* on the migration of European silver eels *Anguilla anguilla* in the Baltic Sea. *Journal of Fish Biology* 74(9):2158–2170.

- Smogor, R.A., P.L. Angermeier, and C.K. Gaylord. 1995. Distribution and abundance of American eels in Virginia streams: tests of null models across spatial scales. *Transactions of the American Fisheries Society* 124(6):789–803.
- Sokolowski, M.S., and A.D.M. Dove. 2006. Histopathological examination of wild American eels infected with *Anguillicola crassus*. *Journal of Aquatic Animal Health* 18(4):257–262.
- Sorensen, P.W., and M.L. Bianchini. 1986. Environmental correlates of the freshwater migration of elvers of the American eel in a Rhode Island brook. *Transactions of the American Fisheries Society* 115(2):258–268.
- Sprenkel, G., and H. Luchtenberg. 1991. Infection by endoparasites reduces maximum swimming speed of European smelt *Osmerus eperlanus* and European eel *Anguilla anguilla*. *Diseases of Aquatic Organisms* 11:31–35.
- Stasko, A.B., and S. Rommel Jr. 1977. Ultrasonic tracking of Atlantic salmon and eel. *Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer* 170:36–40.
- Strickland, P.A. 2002. American eel distribution and growth in selected tributaries of the James River. Master's thesis. Virginia Polytechnic Institute and State University, Blacksburg. 82 p.
- Sullivan, M.C., K.W. Able, J.A. Hare, and H.J. Walsh. 2006. *Anguilla rostrata* glass eel ingress into two, U.S. east coast estuaries: patterns, processes and implications for adult abundance. *Journal of Fish Biology* 69(4):1081–1101.
- Sullivan, M.C., M.J. Wuenschel, and K.W. Able. 2009. Inter and intra-estuary variability in ingress, condition and settlement of the American eel *Anguilla rostrata*: implications for estimating and understanding recruitment. *Journal of Fish Biology* 74(9):1949–1969.
- SWFSC (Southwest Fisheries Science Center). 2011. Assessment methods for data-poor stocks—report of the review panel meeting. Attachment 6, April 25–29, 2011, Santa Cruz, CA. 24 p. Available (December 2011): [http://www.pcouncil.org/wp-content/uploads/E2a\\_ATT6\\_DATAPOOR\\_RVW\\_JUN2011BB.pdf](http://www.pcouncil.org/wp-content/uploads/E2a_ATT6_DATAPOOR_RVW_JUN2011BB.pdf)
- Tesch, R.W. 1977. The eel: biology and management of anguillid eels. Chapman and Hall, London. 434 p.
- Tesch, F.-W. 1978a. Telemetric observations on the spawning migration of the eel (*Anguilla anguilla*) west of the European continental shelf. *Environmental Biology of Fishes* 3:203–209.
- Tesch, F.-W. 1978b. Horizontal and vertical swimming of eels during the spawning migration at the edge of the continental shelf. Pages 378–391 *In*: K. Schmidt-Koenig, and W. T. Keeton (editors), *Animal migration, navigation and homing*. Springer-Verlag, Berlin, Germany.

- Tesch, F.W. 1998. Age and growth rates of North Atlantic eel larvae (*Anguilla* sp.), based on published length data. *Helgoländer Meeresuntersuchungen* 52(1):75–83.
- Thibault, I., J.J. Dodson, and F. Caron. 2007. Yellow-stage American eel movements determined by microtagging and acoustic telemetry in the St. Jean River watershed, Gaspé, Quebec, Canada. *Journal of Fish Biology* 71(4):1095–1112.
- Thomas, J. 2006. American eel behavioral patterns in Silver Lake, Dover, Delaware. Master's thesis. Delaware State University, Dover.
- Thomas, K., and F. Ollevier. 1992. Paratenic hosts of the swim bladder nematode *Anguillicola crassus*. *Diseases of Aquatic Organisms* 13:165–174.
- Thompson, C.M., P.E. Nye, G.A. Schmidt, and D.K. Garcelon. 2005. Foraging ecology of bald eagles in a freshwater tidal system. *Journal of Wildlife Management* 69(2):609–617.
- Thoreau, H.D. 1865. Cape Cod, 1988 edition. Princeton University Press, Princeton, NJ. 452 p.
- Tremblay, V. 2009. Reproductive strategy of female American eels among five subpopulations in the St. Lawrence River watershed. Pages 85–102 *In*: J.M. Casselman and D.K. Cairns (editors), *Eels at the edge: science, status, and conservation concerns*. American Fisheries Society, Symposium 58, Bethesda, Maryland. 449 p.
- Tsukamoto, K., Y. Yamada, A. Okamura, T. Kaneko, H. Tanaka, M.J. Miller, N. Horie, N. Mikawa, T. Utoh, and S. Tanaka. 2009. Positive buoyancy in eel leptocephali: an adaptation for life in the ocean surface layer. *Marine Biology* 156(5):835–846.
- Tuckey, T.D., and M.C. Fabrizio. 2010. Estimating relative juvenile abundance of ecologically important finfish in the Virginia portion of Chesapeake Bay. Virginia Institute of Marine Science, Annual report to the Virginia Marine Resources Commission, Project No. F-104-R-14, Gloucester Point, Virginia. 84 p.
- USFWS (U.S. Fish and Wildlife Service). 2007. Endangered and threatened wildlife and plants—12-month finding on a petition to list the American eel as threatened or endangered. Notice of 12-month petition finding. *Federal Register* 72:22(2 February 2007):4967–4997.
- USFWS. 2011. Endangered and threatened wildlife and plants—90-day finding on a petition to list the American eel as threatened. Proposed rules. *Federal Register* 76:189(29 September 2011):60431–60444.
- Van Den Avyle, M.J. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic)—American eel. USFWS FWS/OBS-82/11.24. U.S. Army Corps of Engineers, TR EL-82-4. 20 p.
- Veinott, G., and K. Clarke. 2011. Status of American eel in Newfoundland and Labrador Region: prepared for the pre-COSEWIC and Eel Zonal Advisory Process (ZAP), Ottawa, August 31 to Sept 3, 2010. DFO Canadian Science Advisory Secretariat Research Document 2010/138. iv + 20 p.



- Vélez-Espino, L.A., and M.A. Koops. 2010. A synthesis of the ecological processes influencing variation in life history and movement patterns of American eel: towards a global assessment. *Reviews in Fish Biology and Fisheries* 20(2):163–186.
- Verdon, R., and D. Desrochers. 2003. Upstream migratory movements of American eel *Anguilla rostrata* between the Beauharnois and Moses-Saunders power dams on the St. Lawrence River. Pages 139–151 *In*: D.A. Dixon (editor), *Biology, management, and protection of catadromous eels*. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Verreault, G. 2002. *Dynamique de la sous-population d'anguilles d'Amérique (Anguilla rostrata) du bassin versant de la rivière du Sud-Ouest. Mémoire de Maîtrise en gestion de la faune et ses habitats. Société de la faune et des parcs du Québec, Direction de l'aménagement de la faune de la région du Bas St-Laurent. Université du Québec à Rimouski.*
- Verreault, G., W. Dargere, and R. Tardif. 2009. American eel movements, growth, and sex ratio following translocation. Pages 129–136 *In*: J.M. Casselman and D.K. Cairns (editors), *Eels at the edge: science, status, and conservation concerns*. American Fisheries Society, Symposium 58, Bethesda, Maryland. 449 p.
- Verreault, G., P. Dumont, and Y. Mailhot. 2004. Habitat losses and anthropogenic barriers as a cause of population decline for American eel (*Anguilla rostrata*) in the St. Lawrence watershed, Canada. *ICES CM 2004/S:04*. 12 p.
- Verreault, G., P. Pettigrew, R. Tardif, and G. Pouliot. 2003. The exploitation of the migrating silver American eel in the St. Lawrence River estuary, Quebec, Canada. Pages 225–234 *In*: D.A. Dixon (editor), *Biology, management, and protection of catadromous eels*. American Fisheries Society, Symposium 33, Bethesda, Maryland. 388 p.
- Vladykov, V.D. 1966. Remarks on the American eel (*Anguilla rostrata* LeSueur). Sizes of elvers entering streams; the relative abundance of adult males and females; and present economic importance of eels in North America. *Verhandlungen des Internationalen Verein Limnologie* 16:1007–1017.
- Vladykov, V.D., and P.K.L. Liew. 1982. Sex of American eels (*Anguilla rostrata*) collected as elvers in two different streams along the eastern shore of Canada, and raised in the same freshwater pond in Ontario. Pages 88–93 *In*: K.H. Loftus (editor), *Proceedings of the 1980 North American Eel Conference*. Ontario Ministry of Natural Resources, Ontario Fisheries Technical Report Number 4, Toronto, Canada.
- Vøllestad, L.A., B. Jonsson, N.A. Hvidsten, T. Næsje, Ø. Haraldstad, and J. Ruud-Hansen. 1986. Environmental factors regulating the seaward migration of European silver eels (*Anguilla anguilla*). *Canadian Journal of Fisheries and Aquatic Sciences* 43:1909–1916.
- Walsh, P.J., G.D. Foster, and T.W. Moon. 1983. The effects of temperature on metabolism of the American eel *Anguilla rostrata* (LeSueur): Compensation in the summer and torpor in the winter. *Physiological Zoology* 56:532–540.

- Walter III, J.F., and H.M. Austin. 2003. Diet composition of large striped bass (*Morone saxatilis*) in the Chesapeake Bay. *Fishery Bulletin* 101(2):414–423.
- Walters, C.J., Martell S.J.D., and Korman, J. 2006. A stochastic approach to stock reduction analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 63:212–223.
- Wang, C.H., and W.-N. Tzeng. 1998. Interpretation of geographic variation in size of American eel *Anguilla rostrata* elvers on the Atlantic coast of North America using their life history and otolith ageing. *Marine Ecology Progress Series* 168:35–43.
- Weeder, J.A., and S.D. Hammond. 2009. Age, growth, mortality, and sex ratio of American eels in Maryland's Chesapeake Bay. Pages 113–128 *In*: J.M. Casselman and D.K. Cairns (editors), *Eels at the edge: science, status, and conservation concerns*. American Fisheries Society, Symposium 58, Bethesda, Maryland. 449 p.
- Welsh, S.A., D.R. Smith, S. Eyler, J.L. Zimmerman, and M.T. Mandt. 2009. Migration of silver-phase and yellow-phase American eels in relation to hydroelectric dams on the Shenandoah River. Phase 1 Final Report. West Virginia Cooperative Fish and Wildlife Research Unit, West Virginia University. 134 p.
- Wenner, C.A. 1973. Occurrence of American eels, *Anguilla rostrata*, in waters overlying the eastern North American continental shelf. *Journal of the Fisheries Research Board of Canada* 30:1752–1755.
- Wenner, C.A., and J.A. Musick. 1974. Fecundity and gonad observations of the American eel, *Anguilla rostrata*, migrating from Chesapeake Bay, Virginia. *Journal of the Fisheries Research Board of Canada* 31:1387–1391.
- Wetzel, C.R., and A.E. Punt. 2011. Model performance for the determination of appropriate harvest levels in the case of data-poor stocks. *Fisheries Research* 110(2):342–355.
- Wielgoss, S., H. Taraschewski, A. Meyer, and T. Wirth. 2008. Population structure of the parasitic nematode *Anguillicola crassus*, an invader of declining North Atlantic eel stocks. *Molecular Ecology* 17(15):3478–3495.
- Wiley, D.J., R.P. Morgan II, R.H. Hilderbrand, R.L. Raesly, and D.L. Shumway. 2004. Relations between physical habitat and American eel abundance in five river basins in Maryland. *Transactions of the American Fisheries Society* 133:515–526.
- Winn, H.E., W.A. Richkus, and L.K. Winn. 1975. Sexual dimorphism and natural movements of the American eel (*Anguilla rostrata*) in Rhode Island streams and estuaries. *Helgoländer Meeresuntersuchungen* 27(2):156–166.
- Wippelhauser, G.S., and J.D. McCleave. 1987. Precision of behavior of migrating juvenile American eels (*Anguilla rostrata*) utilizing selective tidal stream transport. *ICES Journal of Marine Science* 44(1):80–89.
- Wirth, T., and L. Bernatchez. 2003. Decline of North Atlantic eels: a fatal synergy? *Proceedings of the Royal Society of London, Series B, Biological Sciences* 270(1516):681–688.

- Wuenschel, M.J., and K.W. Able. 2008. Swimming ability of eels (*Anguilla rostrata*, *Conger oceanicus*) at estuarine ingress: contrasting patterns of cross-shelf transport? *Marine Biology* 154(5):775–786.
- Wysujack, K. and T. Mehner. 2005. Can feeding of European catfish prevent cyprinids from reaching a size refuge? *Ecology of Freshwater Fish* 14:87–95.
- Young, A. 1841. *Chronicles of the pilgrim fathers of the colony of Plymouth: from 1602–1625*, 2005 edition. Cosimo Classics, New York, NY. 372 p.
- Zar, J.H. 1999. *Biostatistical analysis*, 4th edition. Prentice Hall, Upper Saddle River, New Jersey.
- Zimmerman, J.L. 2008. Rates of swim bladder parasite Infection and PIT tag retention in upstream migrant American eels of the Upper Potomac River Drainage. Master's thesis. West Virginia University, Morgantown. 74 p.

## 12 TABLES

Table 1.1. Commercial fishery regulations for American eels as of 2012, by state. For specifics on licenses, gear restrictions, and area restrictions, please contact the individual state.

State	Size Limit	License/Permit	Other
ME		Harvester license; dealer license and reporting	Seasonal closures; gear restrictions
NH	6"	Commercial saltwater license and wholesaler license; monthly reporting	50/day for bait; gear restrictions in freshwater
MA	6"	Commercial permit with annual catch report requirement; registration for dealers with purchase record requirement	Nets, pots, spears, and angling only; mesh restrictions; each of 52 coastal towns has its own regulations
RI	6"	Commercial fishing license	
CT	6"	Commercial license; dealer reporting	Gear restrictions
NY	6"	Commercial harvester license and reporting; dealer license.	Gear restrictions
NJ	6"	License required	Gear restrictions
PA	NO COMMERCIAL FISHERY		
DE	6"	License required	Commercial fishing in tidal waters only; gear restrictions
MD	6"	Licensed required with monthly reporting	Prohibited in non-tidal waters; gear restrictions
DC	NO COMMERCIAL FISHERY		
PRFC	6"	Harvester license and reporting	Gear restrictions
VA	6"	License with two-year delayed entry system; monthly reporting	Mesh size restrictions on eel pots; bait limit of 50 eels/day; seasonal closures
NC	6"	Standard Commercial Fishing License for all commercial fishing	Mesh size restrictions on eel pots; bait limit of 50 eels/day; seasonal closures
SC		License for commercial fishing and sale; permits by gear and area fished; monthly reporting	Gear restrictions
GA	6"	Personal commercial fishing license and commercial fishing boat license; harvester/dealer reporting	Gear restrictions on traps and pots; area restrictions
FL		Permits and licenses	Gear restrictions

Table 1.2. Recreational fishery regulations for American eels as of 2012, by state. For specifics on licenses, gear restrictions, and area restrictions, please contact the individual state.

<b>State</b>	<b>Size Limit</b>	<b>Possession Limit</b>	<b>Other</b>
ME	6"	50 eels/person/day	Gear restrictions; license requirement and seasonal closures (inland waters only)
NH	6"	50 eels/person/day	Coastal harvest permit needed if taking eels other than by angling; gear restrictions in freshwater
MA	6"	50 eels/person/day	Nets, pots, spears, and angling only; mesh restrictions; each of 52 coastal towns has its own regulations
RI	6"	50 eels/person/day	
CT	6"	50 eels/person/day	
NY	6"	50 eels/person/day	Additional length restrictions in specific inland waters
NJ	6"	50 eels/person/day	Two pot limit/person
PA	6"	50 eels/person/day	Gear restrictions
DE	6"	50 eels/person/day	Two pot limit/person
MD	6"	25/person/day limit in non-tidal areas	Gear restrictions.
DC	6"	10 eels/person/day	Five trap limit
PRFC	6"	50 eels/person/day	
VA	6"	50 eels/person/day	Recreational license; two pot limit; mandatory annual catch report; mesh size restrictions on eel pots
NC	6"	50 eels/person/day	Gear restrictions; non-commercial special device license; two eel pots allowed under Recreational Commercial Gear license
SC	None	None	Gear restrictions and gear license fees
GA	None	None	
FL	None	None	Gear restrictions

Table 2.1. Timing and average length reported for glass-stage American eel upstream migrants in various locations.

<b>Location</b>	<b>Peak Timing</b>	<b>Average Length (mm)</b>	<b>Reference</b>
N. Gulf of St. Lawrence	Jun–Aug	62	Dutil et al. 1989
Gulf of St. Lawrence	May–Jul		Dutil et al. 2009
Various locations, Nova Scotia	Apr–Jun	59.5–64.8	Jessop 1998
Nova Scotia	May–Jul	60.3	Jessop 2003
East R., Nova Scotia	May	60	Wang and Tzeng 2000
Musquash R., New Bruns.	Apr	60	Wang and Tzeng 2000
Annaquatucket R., RI	Apr–May	58	Haro and Krueger 1988
Annaquatucket R., RI	Apr	59	Wang and Tzeng 2000
Gilbert Stuart Brook, RI	May	58	Sorenson and Bianchini 1986
Little Egg Inlet, NJ	Jan–Jun	48.7–68.1	Wuenschel and Able 2008
Indian R., DE	Jan–Apr	57	Clark 2009
North Carolina	Mar	48	Wang and Tzeng 2000
Beaufort, NC	Feb–Mar	53.6	Powles and Warlen 2002
Albemarle Sound, NC	Feb–Mar	57.7	Overton and Rulifson 2009
Altamaha R., GA	late winter	52	Helfman et al. 1984b
Florida	Jan–Feb	49	Wang and Tzeng 2000
Haiti	Dec	48	Wang and Tzeng 2000

Table 2.2. Average length, age, and timing reported for migrating silver-phase American eels in various locations, by sex. Length and age ranges are in parentheses.

Location	Migration Timing	Female		Male		Reference
		Length (mm)	Age (yrs)	Length (mm)	Age (yrs)	
St. Lawrence R. (Upper)	Jun–Oct	915 to 1,000 (890–1,123)	20, 21			Casselman 2003; McGrath et al. 2003a; Tremblay 2009; McGrath et al. 2009
St. Lawrence River	Aug–Nov	853 (475–1,000)	13, 14			Hurley 1972; Dutil et al. 1987; Fournier and Caron 2001; Verreault et al. 2003; Tremblay 2009
St. Lawrence (estuarine)	Aug–Nov	650 to 1,043 (526–1,219)	20 to 23			Dutil et al. 1987; Couillard et al. 1997; Verreault 2002; McGrath et al. 2003a; Verreault et al. 2003; Tremblay 2009
Newfoundland	Aug–Sept	590 to 778 (431–931)	6 to 19 (3–32)	340 (329–361)	(4–15)	Gray and Andrews 1970, 1971; Bouillon and Haedrich 1985; Jessop et al. 2009
New Brunswick	July–Oct	417 to 565 (284–733)		317, 326		Smith and Saunders 1955; Ingraham 1999
Nova Scotia	Aug–Nov	491 to 610 (394–945)	19 (8–43)	392 (346–473)	12.7 (6–18)	Jessop 1987; Carr and Whoriskey 2008
Maine	Aug–Oct	(502–538)	15 to 16 (6–18)	(344–359)	12 to 13	Oliveira and McCleave 2000; Haro et al. 2003
Southeast of Cape Cod	Nov	642		373		Wenner 1973
Rhode Island	Sept–Dec	475 to 537 (410–867)	12.8 (6–20)	(323–335) (228–400)	10.9 (4–15)	Winn et al. 1975; Bianchini et al. 1983, cited by Helfman et al. 1987; Krueger and Oliveira 1997; Oliveira 1999
Connecticut River	Sept–Oct	707				Brown et al. 2009
Indian River, DE	Aug–Nov	571 (367–774)	12 (7–20)	330 (264–412)	7.4 (4–16)	Barber 2004
E of Assateague Is., MD	Dec	636 (609–658)				Wenner 1973
Chesapeake Bay, MD	Oct			306 (275–360)	5.1 (3–10)	Foster and Brody 1982
Chesapeake Bay, VA	Nov	(366–452)		(395–438)		Wenner 1973
Southeast of Ches. Bay	Dec	551 (512–579)				Wenner 1973
Cape Charles, VA	Nov	633 (418–845)		372 (339–438)		Wenner and Musick 1974
Potomac R., VA		(600–800)	(5–11)	350		Goodwin and Angermeier 2003
Shenandoah R., WV	Sep–Dec	869, 872 (560–1,118)	(10–19)			Euston et al. 1998; Goodwin and Angermeier 2003
Cooper R., SC		543, 646 (369–834)	6, 7.6	257, 318 (214–322)	3	Harrell and Loyacano 1982
Charleston Harbor, SC		550	5.8	317	2.7	Michener and Eversole 1983
Altamaha R., GA	Oct–Mar	584, 587 (413–682)	5, 8.6 (4–13)	329 (282–411)	4.1, 5.5 (3–10)	Helfman et al. 1984b; Facey and Helfman 1985

Table 2.3. Average length and age reported for yellow-phase American eels in various locations, by salinity and sex. Length and age ranges are in parentheses.

Location	Salinity	Sex	Length (mm)	Age (years)	Reference
Castors R., Newfoundland	fresh	female	512 (464–576)	18.4 (11–28)	Jessop et al. 2009
Muddy Hole, Newfoundland	brackish	female	440 (335–662)	6.2 (3–10)	Jessop et al. 2009
Lake Champlain, VT	fresh	female	670 (430–900)	15.9 (8–23)	Facey and LaBar 1981
Hudson R., NY	fresh	female	464	(7–30)	Morrison and Secor 2003
Hudson R., NY	brackish	pooled	440	(3–39)	Morrison and Secor 2003
Various locations, NJ	fresh	pooled	350 (145–850)	10 (3–19)	Ogden 1970
Susquehanna R., MD	both	pooled	327 (210–580)	8.5 (5–17)	Foster and Brody 1981
Upper Ches. Bay, MD	both	pooled	377 (226–658)	7 (3–14)	Foster and Brody 1981
Ches. Bay, MD & VA	both	pooled	365 (213–647)	5.8 (3–11)	Fenske et al. 2010
Ches. Bay Tribs., VA	both	pooled	110–560 (60–776)	3–6 (1–18)	Owens and Gear 2003
James R., VA	fresh	unk.	(174–775)		Strickland 2002
Charleston Harbor, SC	brackish	male	317	2.7	Michener and Eversole 1983
Charleston Harbor, SC	brackish	female	437 (213–719)	4.3 (2–6)	Michener and Eversole 1983
Cooper R., SC	fresh	male	257, 318 (214–322)	3	Harrell and Loyacano 1982
Cooper R., SC	fresh	female	397, 425 (280–577)	5	Harrell and Loyacano 1982
Cooper R., SC	brackish	male	(260–406)	2.8 (1–5)	Hansen and Eversole 1984
Cooper R., SC	brackish	female	(287–687)	4.4 (2–12)	Hansen and Eversole 1984
Altamaha R., GA	fresh	pooled	(211–625)	6.2 (3–13)	Helfman et al. 1984b
Altamaha R., GA	brackish	pooled	(249–537)	4.6 (2–7)	Helfman et al. 1984b



Table 2.4. Average growth rate (mm/year) reported for American eels in various locations, by estimation method and salinity.

<b>Location</b>	<b>Method</b>	<b>Salinity</b>	<b>Growth Rate (mm/yr)</b>	<b>Reference</b>
St. Lawrence R., QU	direct measure	fresh	40	Verreault et al. 2009
Gulf of St. Lawrence	back calculated	brackish	94	Lamson et al. 2009
Gulf of St. Lawrence	back calculated	fresh	45	Lamson et al. 2009
Lake Ontario	back calculated	fresh	54.9	Hurley 1972
East River, NS	back calculated	fresh	21.7	Jessop et al. 2006
East River, NS	back calculated	brackish	26.6	Jessop et al. 2006
Medway & LaHave R., NS	back calculated	fresh	41–51	Jessop 1987
Maine rivers (male)	back calculated	fresh	28.9	Oliveira and McCleave 2002
Maine rivers (female)	back calculated	fresh	31.9	Oliveira and McCleave 2002
Annaquatucket R., RI	direct measure	fresh	29.9	Oliveira 1997
Annaquatucket R., RI (male)	back calculated	fresh	31	Oliveira 1999
Annaquatucket R., RI (female)	back calculated	fresh	40	Oliveira 1999
Hudson R., NY	back calculated	both	39	Mattes 1989, cited in Morrison and Secor 2003
Hudson R., NY	back calculated	brackish	55	Morrison and Secor 2003
Hudson R., NY	back calculated	fresh	28	Morrison and Secor 2003
Hudson R., NY	direct measure	brackish	80	Morrison and Secor 2003
Hudson R., NY	direct measure	fresh	34	Morrison and Secor 2003
Hudson R., NY	back calculated	unk.	35	Machut et al. 2007
Indian R., DE	back calculated	brackish	83	Barber 2004
Indian R., DE	back calculated	fresh	47	Barber 2004
Delaware Bay, DE	back calculated	brackish	32	Clark 2009
Ches. Bay, MD & VA	back calculated	both	68	Fenske et al. 2010
Shenandoah R., VA	direct measure	fresh	43	Goodwin 1999
James R., VA	direct measure	fresh	18–43	Strickland 2002
James R., VA	direct measure	fresh	32–43	Roghair et al. 2003
Cooper R., SC	back calculated	fresh	53.5	Harrell 1977
Cooper R., SC	back calculated	brackish	27–69	Hansen and Eversole 1984
Altamaha R., GA	direct measure	both	57	Helfman et al. 1984a
Altamaha R., GA	back calculated	both	44	Helfman et al. 1984a
Altamaha R., GA	back calculated	brackish	53	Helfman et al. 1984b
Altamaha R., GA	back calculated	brackish	50	Helfman et al. 1984b
Louisiana	direct measure	fresh	128 & 325	Gunning and Shoop 1962

Table 2.5. Average length (mm) at age reported for American eels in various locations. Age includes only years spent inland (i.e., does not include first oceanic year).

Location	Age												Reference
	1	2	3	4	5	6	7	8	9	10	11	12	
Topsail Pond, NFL				249	277	343	418	493	553	652	706	748	Bouillon and Haedrich 1985
Nanticoke R., MD	258	299	311	365	439	484	501	541	557	561	575	613	Weeder and Hammond 2009
Wye R., MD	300	397	464	524	591	750							Weeder and Hammond 2009
Assawoman Bay, MD	320	381	466	523	557	583	539						Weeder and Hammond 2009
Pocomoke R., MD		485	572	638	643	647	650	680	670				Weeder and Hammond 2009
Ches. Bay, MD		334	382	442	466	480	476	504	527	490	565	578	K. Whiteford (pers. comm.)
Ches. Bay, VA	204	274	346	451	476	493	476	536	624		528		Owens and Gear 2003
Cooper R., SC	224	249	337	403	490	536	596	612	638	509	680	690	Harrell and Loyacano 1982
Cooper R., SC	292	361	411	455	482	511	580	514	611			551	Hansen and Eversole 1984
Altamaha R., GA	242	310	361	403	442	460							Helfman et al. 1984a
Bermuda	226	334	418	472	489								Boetius and Boetius 1967, cited in Harrell and Loyacano 1982

Table 2.6. Parameter estimates for the linear regression of length in millimeters on age in years reported for American eel in previous studies. An asterisk (\*) denotes studies for which the biological data were available for inclusion in the current assessment.

<b>Location</b>	<b>Collection Period</b>	<b>n</b>	<b>Intercept</b>	<b>Slope</b>	<b>Reference</b>
Sheepscot River, ME	Aug–Sep 1996; Jun–Jul 1997	646	77.9	23.7	Oliveira and McCleave 2000 *
Medomak River, ME	Aug–Sep 1996; Jun–Jul 1997	592	119	20.7	Oliveira and McCleave 2000 *
Pleasant River, ME	Aug–Sep 1996; Jun–Jul 1997	378	76.6	23.4	Oliveira and McCleave 2000 *
East Machias River, ME	Aug–Sep 1996; Jun–Jul 1997	709	94.6	24.2	Oliveira and McCleave 2000 *
4 rivers pooled, ME	Aug–Sep 1996; Jun–Jul 1997	2,325	87.8	23.4	Oliveira and McCleave 2000 *
Lake Champlain, VT		426	375	18.8	Facey and LaBar 1981
Lake Mattamuskeet-Pamlico Sound drainage, NC	Feb 2002–Sep 2003	565	379	12.5	Rulifson et al. 2004 *
Altamaha River, GA (estuary)	Fall 1980–Summer 1981 (average)	203	142	49.7	Helfman et al. 1984b
Altamaha River, GA (freshwater)	Fall 1980–Summer 1981 (average)	215	69.3	53.4	Helfman et al. 1984b

Table 2.7. Parameter estimates of the allometric relation of length in millimeters to weight in grams reported for American eel in previous studies. An asterisk (\*) denotes studies for which the biological data were available for inclusion in the current assessment.

Location	Collection Period	n	a	b	Reference
Sheepscot River, ME	Aug–Sep 1996; Jun–Jul 1997	870	7.03E-07	3.15	Oliveira and McCleave 2000 *
Medomak River, ME	Aug–Sep 1996; Jun–Jul 1997	981	1.14E-06	3.07	Oliveira and McCleave 2000 *
Pleasant River, ME	Aug–Sep 1996; Jun–Jul 1997	502	1.18E-06	3.07	Oliveira and McCleave 2000 *
East Machias River, ME	Aug–Sep 1996; Jun–Jul 1997	763	1.13E-06	3.07	Oliveira and McCleave 2000 *
4 rivers pooled, ME	Aug–Sep 1996; Jun–Jul 1997	3,116	9.84E-07	3.09	Oliveira and McCleave 2000 *
Lake Champlain, VT		426	9.33E-04	3.17	Facey and LaBar 1981
New York Bight		5	2.15E-06	2.99	Wilk et al. 1978
James River, VA	1997–2000	174	3.00E-06	2.91	Owens and Geer 2003 *
York River, VA	1997–2000	255	8.03E-07	3.15	Owens and Geer 2003 *
Rappahannock River, VA	1997–2000	187	3.12E-06	2.91	Owens and Geer 2003 *
Lake Mattamuskeet-Pamlico Sound drainage, NC	Feb 2002–Sep 2003	759	5.99E-06	2.81	Rulifson et al. 2004 *
White Oak River, NC	May–Jun 2002	270	2.42E-07	3.41	Hightower and Nesnow 2006
White Oak River, NC	Jul–Aug 2003	218	2.07E-07	3.41	Hightower and Nesnow 2006
Pinopolis Dam, Cooper River, SC	Sep 1975–Sep 1976	258	2.40E-07	3.36	Harrell and Loyacano 1982
Wadboo Creek, Cooper River, SC	Jun–Dec 1975	157	6.03E-07	3.20	Harrell and Loyacano 1982
Cooper River, SC		462	1.41E-06	3.07	Hansen and Eversole 1984
Charlestown Harbor, SC	Jul 1978–Sep 1979	475?	1.92E-06	3.07	Michener and Eversole 1983
Altamaha River, GA (estuary)	Fall 1980	86	2.78E-07	3.32	Helfman et al. 1984b
Altamaha River, GA (freshwater)	Fall 1980	145	3.04E-07	3.31	Helfman et al. 1984b
Altamaha River, GA (estuary)	Winter 1981	305	9.82E-07	3.10	Helfman et al. 1984b
Altamaha River, GA (freshwater)	Winter 1981	265	2.69E-07	3.32	Helfman et al. 1984b
Altamaha River, GA (estuary)	Spring 1981	109	1.58E-06	3.04	Helfman et al. 1984b
Altamaha River, GA (freshwater)	Spring 1981	327	1.19E-06	3.09	Helfman et al. 1984b
Altamaha River, GA (estuary)	Summer 1981	59	4.42E-07	3.25	Helfman et al. 1984b
Altamaha River, GA (freshwater)	Summer 1981	73	7.13E-07	3.15	Helfman et al. 1984b

Table 2.8. Percentage of females reported for American eels in various locations, by salinity.

Location	Salinity	% Female	Reference
Newfoundland	fresh	94	Vladykov 1966
Newfoundland	fresh	99	Gray and Andrews 1970
Newfoundland	brackish	100	Gray and Andrews 1970
New Brunswick	fresh	80	Vladykov 1966
Nova Scotia	fresh	100	Vladykov 1966
Medway R., NS	fresh	97	Jessop 1987
LaHave R., NS	fresh	100	Jessop 1987
Quebec	fresh	99	Vladykov 1966
Matamek R., QU	brackish	95	Dolan and Power 1977
Matamek R., QU	fresh	99	Dolan and Power 1977
Ontario	fresh	100	Vladykov 1966
Maine Rivers	both	24	Oliveira et al. 2001
Lake Champlain, VT	fresh	100	Facey and LaBar 1981
Massachusetts	brackish	91	Vladykov 1966
Rhode Island rivers	fresh	12	Winn et al. 1975
Rhode Island rivers	brackish	45	Winn et al. 1975
Pawcatucket R., RI	fresh	90	Bianchini et al. 1983, cited by Helfman et al. 1987
Coastal rivers, RI	fresh	11	Bianchini et al. 1983, cited by Helfman et al. 1987
Annaquatucket R., RI	fresh	5	Oliveira 1999
New York	brackish	67	Vladykov 1966
Hudson R., NY	both	97	Morrison and Secor 2003
Hudson R., NY	fresh	100	Morrison and Secor 2003
New Jersey	brackish	42	Vladykov 1966
Indian R., DE	fresh	22	Barber 2004
Upper Ches. Bay, MD	both	100	Foster and Brody 1982
Chesapeake Bay, MD <sup>7</sup>	both	40	Weeder and Hammond 2009
Ches. Bay, VA & MD <sup>8</sup>	both	71	Fenske et al. 2010
Potomac R., VA	both	71	Goodwin and Angermeier 2003
Shenandoah R., VA	fresh	100	Goodwin and Angermeier 2003
Cooper R., SC	fresh	98	Harrell and Loyacano 1982
Charleston Harbor, SC	brackish	93	Michener and Eversole 1983
Cooper R., SC	brackish	96	Hansen and Eversole 1984
Altamaha R., GA	brackish	64	Helfman et al. 1984b
Altamaha R., GA	fresh	94	Helfman et al. 1984b
Georgia rivers	brackish	64	Helfman et al. 1987
Georgia rivers	fresh	82	Helfman et al. 1987
Florida	brackish	47	Vladykov 1966
Mississippi	brackish	95	Ross et al. 1984, cited by Helfman et al. 1987
Louisiana	brackish	17	Vladykov 1966
Bermuda	brackish	96	Boetius and Boetius 1967, cited by Harrell and Loyacano 1982
Trinidad	brackish	62	Vladykov 1966

<sup>7</sup> 29% undifferentiated

<sup>8</sup> 23% intersexual, 4% undifferentiated

Table 2.9. Parameters of the allometric fecundity (F)-length (L) and fecundity-weight (W) relationship for American eels estimated by studies in various locations. The length range of individual eels used in the study and estimated fecundity values are also given. These parameter values apply to length measured in millimeters and weight measured in grams. The unit for fecundity is millions of eggs.

Location	Gear	Collection Period	n	Length		Weight		Length Range (mm)	Estimated Fecundity (millions of eggs)	Reference
				$F = \alpha L^\beta$		$F = \alpha W^\beta$				
				$\alpha$	$\beta$	$\alpha$	$\beta$			
St. Lawrence	Various traps	Sep–Oct 2001; Aug–Sep 2002	150	1.57	2.29	35,237	0.762	532–1,159	3.4–22	Tremblay 2009
Various rivers, ME	Weirs & fyke nets	Oct–Nov 1996	63	0.0198	2.96	14,608	0.915	450–1,130	1.84–19.9	Barbin & McCleave 1997
Chesapeake Bay, VA	Commercial pound nets	Nov 1970	21	5.07E-05	3.74	1,694	1.12	420–720	0.4–2.6	Wenner & Musick 1974

Table 5.1. Summary of (A) length (mm) and (B) weight (g) data from New Jersey commercial biosamples.

(A)	<b>Statistic</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>
	Average	500.39	479.45	416.37	472.57	443.67
	St Dev	106.47	112.09	146.17	99.74	87.76
	Min	234	232	100	128	252
	Max	1,030	751	768	792	744
	n	457	237	547	478	399

(B)	<b>Statistic</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>
	Average	278.47	233.92	170.41	216.94	181.84
	St Dev	201.55	175.69	157.62	127.25	137.07
	Min	20	10	2	2	27
	Max	1,970	840	975	910	1,075
	n	457	237	547	478	399

Table 5.2. Length-weight parameters from New Jersey commercial biosamples.

<b>Year</b>	<b>Region</b>	<b><i>a</i></b>	<b>Approx SE[<i>a</i>]</b>	<b><i>b</i></b>	<b>Approx SE[<i>b</i>]</b>
2006	All areas	1.08E-06	2.21E-07	3.0951	0.0318
2007	All areas	3.27E-07	1.98E-07	3.2732	0.0947
2008	All areas	8.65E-07	2.13E-07	3.1083	0.0384
2009	All areas	3.48E-06	1.09E-06	2.8957	0.0494
2010	All areas	4.64E-08	1.31E-08	3.5930	0.0447
All years	Coast	5.08E-07	8.80E-08	3.2034	0.027
All years	Delaware Bay	1.56E-07	3.26E-08	3.4036	0.0333
All years	Hudson	1.25E-08	1.45E-08	3.7526	0.1783
All years	All areas	6.84E-07	8.67E-08	3.1576	0.0198

Table 5.3. Numbers of American eels available for sampling in the VMRC’s Biological Sampling Program, by gear, 1989–2010. Other gears include fyke net, crab pot, and gill net.

Year	Eel Pot		Pound Net		Other	
	Lengths	Weights	Lengths	Weights	Lengths	Weights
1989	192	192	2	2	0	0
1990	186	186	0	0	0	0
1991	216	216	0	0	0	0
1992	0	0	0	0	0	0
1993	0	0	2	2	0	0
1994	50	50	0	0	3	1
1995	0	0	0	0	0	0
1996	0	0	1	1	0	0
1997	0	0	5	4	0	0
1998	0	0	6	4	6	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	1	1	0	0
2002	0	0	1	0	0	0
2003	0	0	3	3	17	17
2004	0	0	24	16	0	0
2005	59	59	7	7	0	0
2006	0	0	10	3	0	0
2007	0	0	19	19	0	0
2008	0	0	8	4	0	0
2009	0	0	0	0	0	0
2010	0	0	0	0	0	0



Table 5.4. Numbers of American eel samples reported by the MRFSS angler-intercept survey and at-sea headboat survey, by catch type, 1981–2010.

Year	Type A	Type B1		Type B2	
	Intercept	Intercept	Headboat	Intercept	Headboat
1981	22	75		94	
1982	75	44		43	
1983	28	19		73	
1984	28	12		26	
1985	53	17		91	
1986	62	41		138	
1987	16	34		49	
1988	35	36		74	
1989	57	31		150	
1990	36	16		154	
1991	113	30		123	
1992	13	25		101	
1993	224	40		101	
1994	98	48		89	
1995	23	6		96	
1996	18	29		77	
1997	9	8		50	
1998	7	3		84	
1999	4	7		70	
2000	7	5		43	
2001	1	8		44	
2002	6	10		79	
2003	16	16		155	
2004	13	16		99	
2005	7	3	1	65	1
2006	7	3	0	76	2
2007	39	7	0	73	1
2008	4	5	0	66	8
2009	9	4	0	75	7
2010	14	22	0	117	2

Table 5.5. Numbers of American eels that available for biological sampling in the MRFSS angler-intercept survey and at-sea headboat survey, by survey component, 1981–2010.

Year	Intercept (Type A)		Headboat (Type B2)
	Weighed	Measured	Measured
1981	21	21	
1982	46	49	
1983	16	16	
1984	22	22	
1985	30	27	
1986	25	18	
1987	13	10	
1988	28	27	
1989	47	29	
1990	12	17	
1991	37	35	
1992	3	3	
1993	15	32	
1994	21	13	
1995	2	2	
1996	5	5	
1997	7	7	
1998	3	4	
1999	1	2	
2000	7	7	
2001	0	1	
2002	1	2	
2003	0	2	
2004	11	13	
2005	4	6	1
2006	3	3	1
2007	3	4	0
2008	2	3	6
2009	4	4	6
2010	6	6	1

Table 5.6. Estimates of recreational fishery harvest and released alive for American eels along the Atlantic coast, 1981–2010. The precision of each estimate, measured as proportional standard error (PSE), is also given.

Year	Harvest (Type A + B1)				Released Alive (Type B2)	
	Numbers	PSE[Numbers]	Weight (pounds)	PSE[Weight]	Numbers	PSE[Numbers]
1981	85,858	22.6	71,943	34.6	94,136	28.0
1982	144,376	28.3	94,187	32.3	68,314	34.2
1983	88,190	40.2	76,310	50.2	67,258	21.1
1984	59,528	22.9	56,380	36.2	39,603	32.1
1985	161,077	37.3	157,155	10.9	68,338	25.2
1986	101,192	24.5	80,920	26.4	97,240	18.3
1987	37,761	29.0	28,060	41.0	52,729	26.7
1988	62,419	21.8	29,639	15.4	84,050	27.9
1989	50,199	20.7	66,665	19.2	91,119	15.9
1990	24,333	24.1	13,133	34.1	80,366	15.9
1991	77,712	28.5	57,315	29.6	64,312	22.2
1992	31,286	33.2	1,955		44,836	25.3
1993	71,313	35.7	43,715	51.1	70,133	21.3
1994	49,652	28.6	24,782	42.4	56,329	16.6
1995	9,199	54.6	939		51,820	23.8
1996	20,554	31.2	6,312	46.6	45,111	17.8
1997	15,521	56.1	6,565	51.9	21,464	22.7
1998	6,238	38.9	3,331	78.7	46,455	21.8
1999	5,651	42.8	359		45,467	50.6
2000	27,078	74.1	13,247	82.9	38,672	27.9
2001	10,805	76.6			24,704	20.9
2002	5,568	35.5	584		38,538	16.4
2003	31,093	60.4			126,330	17.3
2004	23,129	37.0	13,411	55.9	90,829	24.8
2005	8,362	49.7	2,469	98.3	50,702	21.2
2006	19,717	44.2	11,043	45.2	66,307	24.5
2007	57,986	56.9	49,068	76.8	82,385	26.6
2008	3,485	53.5	353	100.1	45,323	23.0
2009	6,213	46.4	5,600	32.4	56,522	20.0
2010	60,202	67.7	25,922	87.3	75,102	25.3

Table 5.7. Currently active sampling sites for the ASMFC-mandated annual American eel YOY abundance survey. Sites formatted in **bold** font have been sampled for at least 10 years as of 2010.

State	Site	Gear	Start Year
<b>ME</b>	<b>West Harbor Pond</b>	<b>Irish Elver Ramp</b>	2001
<b>NH</b>	<b>Lamprey River</b>	<b>Irish Elver Trap</b>	2001
MA	Acushnet River Reservoir	Sheldon Elver Trap	2005
MA	Acushnet River Sawmill	Sheldon Elver Trap	2005
MA	Cold Brook	Irish Elver Ramp	2008
<b>MA</b>	<b>Jones River</b>	<b>Sheldon Elver Trap</b>	2001
MA	Parker River	Sheldon Elver Trap	2004
MA	Saugus River	Sheldon Elver Trap	2005
MA	Saugus River	Irish Elver Ramp	2007
MA	Wankinco River	Irish Elver Ramp	2009
<b>RI</b>	<b>Gilbert Stuart Dam (Pettasquamscutt River)</b>	<b>Irish Elver Ramp</b>	2000
RI	Hamilton Fish Ladder (Annaquatucket River)	Irish Elver Ramp	2004
CT	Ingham Hill	Irish Elver Ramp	2007
<b>NY</b>	<b>Carman's River</b>	<b>Fyke Net</b>	2000
PA	Poquessing Creek	Modified Minnow Trap	2008
PA	Poquessing Creek	Lift Net	2008
PA	Poquessing Creek	Backback Electrofisher	2008
<b>NJ</b>	<b>Patcong Creek</b>	<b>Fyke Net</b>	2000
<b>DE</b>	<b>Millsboro Dam (Indian River)</b>	<b>Fyke Net</b>	2000
<b>MD</b>	<b>Turville Creek</b>	<b>Irish Elver Ramp</b>	2000
DC	Anacostia River, Washington Channel, and Rock Creek	eel pots, boat and backpack e-fishing, and Irish elver traps	2005
<b>PRFC</b>	<b>Clark's Millpond (Coan River)</b>	<b>Irish Elver Ramp</b>	2000
<b>PRFC</b>	<b>Gardy's Millpond (Yeocomico River)</b>	<b>Irish Elver Ramp</b>	2000
<b>VA</b>	<b>Bracken's Pond (York River)</b>	<b>Irish Elver Ramp</b>	2000
<b>VA</b>	<b>Kamp's Millpond (Rappahannock River)</b>	<b>Irish Elver Ramp</b>	2000
VA	Warehams Pond (James River)	Irish Elver Ramp	2003
<b>VA</b>	<b>Wormley Creek (York River)</b>	<b>Irish Elver Ramp</b>	2001
<b>SC</b>	<b>Goose Creek (Cooper River)</b>	<b>Fyke Net</b>	2000
<b>GA</b>	<b>Altamaha Canal</b>	<b>Fyke Net</b>	2001
GA	Hudson Creek	Fyke Net	2003
<b>FL</b>	<b>Guana River Dam</b>	<b>Dip Net</b>	2001

Table 5.8. Summary of GLM analyses used to standardize YOY indices developed from the ASMFC-mandated recruitment surveys. Phi is the overdispersion parameter.

Region	State	Location	Years	Gear	GLM?	Error Structure	Response	Predictors	Phi
Gulf of Maine	ME	West Harbor Pond	2001–2010	Irish Elver Ramp	Y	NB	Catch	Year+WaterTemp	1.02
	NH	Lamprey River	2001–2010	Irish Elver Trap	Y	LN	Catch	Year+WaterTemp	1.92
	MA	Jones River	2001–2010	Sheldon Elver Trap	Y	NB	Catch	Year+Discharge	0.952
Southern New England	RI	Gilbert Stuart Dam	2000–2010	Irish Elver Ramp	Y	NB	Catch	Year+WaterTemp+Water Level	1.46
	NY	Carman's River	2000–2010	Fyke Net	Y	NB	Catch	Year+WaterTemp	1.90
Delaware Bay/ Mid-Atlantic Coastal Bays	NJ	Patcong Creek	2000–2009	Fyke Net	Y	NB	Catch	Year+WaterTemp	1.67
	DE	Millsboro Dam	2000–2010	Fyke Net	Y	NB	Catch	Year+Discharge	1.41
	MD	Turville Creek	2000–2010	Irish Elver Ramp	N				
Chesapeake Bay	PRFC	Clark's Millpond	2000–2010	Irish Elver Ramp	Y	NB	Catch	Year+WaterTemp	1.69
	PRFC	Gardy's Millpond	2000–2010	Irish Elver Ramp	Y	Delta-gamma	Catch	Year+WaterTemp	
	VA	Bracken's Pond	2000–2010	Irish Elver Ramp	N				
	VA	Kamp's Millpond	2000–2010	Irish Elver Ramp	Y	NB	Catch	Year+WaterTemp	1.64
	VA	Wormley Creek	2001–2010	Irish Elver Ramp	Y	NB	Catch	Year+WaterTemp	1.50
South Atlantic	SC	Goose Creek	2000–2010	Fyke Net	Y	LN	Catch	Year+WaterTemp+Water Level	1.36
	GA	Altamaha Canal	2001–2010	Fyke Net	Y	LN	Catch	Year+WaterTemp	1.11
	FL	Guana River Dam	2001–2010	Dip Net	N				

Table 5.9. Spearman's rank correlation between YOY indices developed from the ASMFC-mandated recruitment surveys. Values formatted in **bold** font are statistically significant at  $\alpha < 0.10$ .

	Region	Gulf of Maine			Southern New England		Delaware Bay & Mid-Atlantic Coastal Bays			Chesapeake Bay					South Atlantic	
Region	Survey Site	West Harbor Pond (ME)	Lamprey River (NH)	Jones River (MA)	Gilbert Stuart Dam (RI)	Carman's River (NY)	Patcong Creek (NJ)	Millsboro Dam (DE)	Turville Creek (MD)	Clark's Millpond (PRFC)	Gardy's Millpond (PRFC)	Bracken's Pond (VA)	Kamp's Millpond (VA)	Wormley Creek (VA)	Goose Creek (SC)	Altamaha Canal (GA)
Gulf of Maine	Lamprey River (NH)	0.0424														
	Jones River (MA)	0.164	-0.248													
Southern New England	Gilbert Stuart Dam (RI)	0.236	0.164	-0.0424												
	Carman's River (NY)	-0.127	0.0182	-0.297	<b>0.591</b>											
Delaware Bay & Mid-Atlantic Coastal Bays	Patcong Creek (NJ)	-0.0182	0.370	0.176	0.436	0.236										
	Millsboro Dam (DE)	-0.139	-0.0545	0.491	-0.191	<b>-0.655</b>	-0.0636									
	Turville Creek (MD)	0.00606	-0.261	-0.0909	-0.155	-0.436	<b>-0.636</b>	0.418								
Chesapeake Bay	Clark's Millpond (PRFC)	-0.212	0.0424	-0.406	0.0455	0.118	0.209	-0.0818	-0.345							
	Gardy's Millpond (PRFC)	<b>0.648</b>	-0.200	0.103	0.500	0.364	-0.0636	-0.282	0.173	<b>-0.664</b>						
	Bracken's Pond (VA)	-0.188	-0.224	<b>0.685</b>	0.118	-0.236	-0.245	<b>0.636</b>	0.236	-0.200	-0.00909					
	Kamp's Millpond (VA)	<b>0.600</b>	0.406	-0.0303	0.164	0.0182	-0.0364	-0.00909	-0.273	0.0636	0.173	-0.0545				
	Wormley Creek (VA)	-0.152	0.309	-0.224	0.0788	-0.442	-0.152	<b>0.685</b>	0.479	0.248	-0.309	0.382	0.0667			
South Atlantic	Goose Creek (SC)	<b>0.564</b>	-0.0667	0.333	0.136	-0.0818	0.355	0.118	-0.255	-0.291	0.436	-0.164	<b>0.573</b>	-0.248		
	Altamaha Canal (GA)	-0.0424	0.188	0.309	-0.382	-0.200	0.0182	0.394	-0.127	-0.406	0.0667	0.200	0.0424	0.176	0.297	
	Guana River Dam (FL)	<b>0.770</b>	-0.0182	0.418	0.248	-0.236	-0.103	0.164	0.0303	-0.139	0.382	0.273	<b>0.709</b>	-0.0788	<b>0.552</b>	-0.236

Table 5.10. Summary of GLM analyses used to standardize fisheries-independent indices developed from non-ASMFC-mandated surveys. Phi is the overdispersion parameter.

Region	State	Survey	Location	Years	Gear	Life Stage(s)	GLM?	Error Structure	Response	Predictors	Phi
Southern New England	CT	CTDEP Electrofishing	Farmill River	2001–2010	Electrofishing	Elver & Yellow	N				
	NY	Western Long Island Study <sup>9</sup>	Long Island Sound	1984–2010	Seine	Yellow	Y	NB	Catch	Year+Month+System	0.611
Hudson River	NY	HRE Monitoring <sup>10</sup>	Hudson River	1974–2009	Epibenthic Sled and Tucker Trawl	YOY	Y	Delta-gamma	Catch	Year+Month+Gear+Strata+RiverMile+Volume	
	NY	HRE Monitoring <sup>9,11</sup>	Hudson River	1974–2009	Epibenthic Sled and Tucker Trawl	Yearling and older	Y	NB	Catch	Year+Month+Gear+Strata+RiverMile+Volume	1.66
	NY	NYDEC Alosine Beach Seine <sup>9,11</sup>	Hudson River	1980–2009	Seine	Elver & Yellow	Y	NB	Catch	Year+Month+RiverMile+WaterTemp	1.25
	NY	NYDEC Striped Bass Beach Seine <sup>9,11</sup>	Hudson River	1980–2009	Seine	Elver & Yellow	Y	NB	Catch	Year+Month+RiverMile+WaterTemp	1.28
Delaware Bay/ Mid-Atlantic Coastal Bays	NJ	Little Egg Inlet Ichthyoplankton <sup>10</sup>	Little Egg Harbor	1992–2010	Plankton Net	YOY	Y	NB	Catch	Year+Month+Tidal Flow+Discharge+Salinity	1.05
	NJ	NJDFW Striped Bass Seine <sup>9,11</sup>	Delaware Bay	1980–2009	Seine	Yellow	Y	NB	Catch	Year+Month+Temp+Salinity	0.958
	DE	Delaware Trawl Survey <sup>9</sup>	Delaware River	1982–2010	Trawl	Elver & Yellow	Y	NB	Catch	Year+Month+Salinity+WaterTemp	1.02
	DE	PSEG Trawl <sup>9,11,12</sup>	Delaware River	1970–2010	Trawl	Elver & Yellow	Y	NB	Catch	Year+Month+BottomSalinity	1.85
	PA	Area 6 Electrofishing	Delaware River	1999–2010	Electrofishing	Elver	Y	NB	Catch	Year+Site	1.05
Chesapeake Bay	MD	MDDNR Striped Bass Seine <sup>9,11,12</sup>	Chesapeake Bay	1966–2010	Seine	Yellow	Y	NB	Catch	Year+Month+Salinity	0.973
	VA	North Anna Electrofishing <sup>9</sup>	North Anna River	1990–2009	Electrofishing	Elver & Yellow	Y	NB	Catch	Year+GearType+TimePeriod+Station	1.20
	VA	VIMS Juvenile Striped Bass Seine--long <sup>11,12</sup>	Lower Ches Bay & Tribs	1967–1973; 1980–2010	Seine	Yellow	Y	NB	Catch	Year+System	0.751
	VA	VIMS Juvenile Striped Bass Seine--short <sup>9</sup>	Lower Ches Bay & Tribs	1989–2010	Seine	Yellow	Y	NB	Catch	Year+Station Type+Salinity	1.07
South Atlantic	NC	Beaufort Inlet Ichthyoplankton <sup>10</sup>	Beaufort Inlet	1987–2003	Plankton Net	YOY	Y	NB	Catch	Year+Month+Discharge	1.14
	NC	NCDMF Estuarine Trawl <sup>9</sup>	NC waters	1989–2010	Trawl	Elver & Yellow	Y	NB	Catch	Year+Lat+Lon+BottomType	1.51
	SC	SC Electrofishing	SC waters	2001–2010	Electrofishing	Elver & Yellow	Y	NB	Catch	Year+Strata+WaterTemp+Salinity+TideCode	1.22

<sup>9</sup> Included in calculation of 20-year coast-wide, yellow-phase abundance index

<sup>10</sup> Included in calculation of long-term coast-wide recruitment index

<sup>11</sup> Included in calculation of 30-year coast-wide, yellow-phase abundance index

<sup>12</sup> Included in calculation of 40-plus coast-wide, yellow-phase abundance index

Table 5.11. Summary (A) length and (B) weight information by year from the Upper Delaware, all locations combined.

(A)

<b>Statistic</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>All</b>
Average	357.35	362.98	377.79	362.88
St Dev	111.37	93.28	113.84	108.38
Min	147	189	172	147
Max	750	665	685	750
n	331	125	122	578

(B)

<b>Statistic</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>All</b>
Average	105.39	102.48	121.83	108.23
St Dev	104.18	81.68	117.04	102.79
Min	3	9	7	3
Max	588	490	639	639
n	331	125	122	578



Table 6.1. Summary of surveys used in development of region-specific indices of American eel relative abundance. Asterisks (\*) denote the ASMFC-mandated recruitment surveys.

Region	Life Stage	Time Period	Survey
Gulf of Maine	YOY	2001–2010	West Harbor Pond (ME) *
			Lamprey River (NH) *
			Jones River (MA) *
	Yellow		<i>none available</i>
Southern New England	YOY	2000–2010	Gilbert Stuart Dam (RI) *
			Carman's River (NY) *
	Yellow	2000–2010	CTDEP Electrofishing Survey (CT)
			Western Long Island Study (NY)
Hudson River	YOY	1974–2009	HRE Monitoring Program (NY)
			HRE Monitoring Program (NY)
	Yellow	1980–2009	NYDEC Alosine Beach Seine Survey (NY)
			NYDEC Striped Bass Beach Seine Survey (NY)
Delaware Bay/ Mid-Atlantic Coastal Bays	YOY	2000–2010	Little Egg Inlet Ichthyoplankton Survey (NJ)
			Patcong Creek (NJ) *
			Millsboro Dam (DE) *
			Turville Creek (MD) *
	Yellow	1999–2010	NJDFW Striped Bass Seine (NJ)
			Delaware Trawl Survey (DE)
			PSEG Trawl Survey (DE)
			Area 6 Electrofishing Survey (PA)
Chesapeake Bay	YOY	2000–2010	Clark's Millpond (PRFC) *
			Gardy's Millpond (PRFC) *
			Bracken's Pond (VA) *
			Kamp's Millpond (VA) *
			Wormley Creek (VA) *
	Yellow	1990–2010	MDDNR Striped Bass Seine (MD)
			North Anna Electrofishing Survey (VA)
South Atlantic	YOY	2001–2010	Beaufort Inlet Ichthyoplankton Survey (NC)
			Goose Creek (SC) *
			Altamaha Canal (SC) *
			Guana River Dam (FL) *
	Yellow	2001–2010	NCDMF Estuarine Trawl Survey (NC)
			SC Electrofishing Survey (SC)

Table 6.2. Spearman's rank correlation between regional YOY indices for American eel. Values formatted in **bold** font are statistically significant at  $\alpha < 0.10$ .

	Gulf of Maine	Southern New England	Hudson River	Delaware Bay/ Mid-Atlantic Coastal Bays	Chesapeake Bay
Southern New England	0.333				
Hudson River	<b>0.633</b>	0.261			
Delaware Bay/ Mid-Atlantic Coastal Bays	0.370	-0.191	0.309		
Chesapeake Bay	0.273	0.155	<b>0.879</b>	0.364	
South Atlantic	<b>0.612</b>	0.212	<b>0.767</b>	0.212	<b>0.612</b>

Table 6.3. Spearman's rank correlation between regional yellow-phase indices for American eel. Values formatted in **bold** font are statistically significant at  $\alpha < 0.10$ .

	Southern New England	Hudson River	Delaware Bay/ Mid-Atlantic Coastal Bays	Chesapeake Bay
Hudson River	0.400			
Delaware Bay/ Mid-Atlantic Coastal Bays	-0.139	0.164		
Chesapeake Bay	0.442	-0.323	0.462	
South Atlantic	-0.442	0.100	0.309	-0.00606

Table 6.4. Spearman's rank correlation coefficients ( $\rho$ ) and associated  $P$ -values from correlation of region-specific yellow-phase indices and lagged YOY indices for American eel. Values formatted in **bold** font are statistically significant at  $\alpha < 0.10$ .

Region	Yellow vs.	Lag (years)	$\rho$	$P >  \rho $
Southern New England	YOY	0	-0.139	0.701
		1	-0.261	0.467
		2	-0.233	0.546
		3	-0.0476	0.911
		4	-0.429	0.337
Hudson River	YOY	0	-0.197	0.357
		1	0.0178	0.936
		2	-0.168	0.456
		3	0.0364	0.876
		4	-0.0677	0.777
Delaware Bay/ Mid-Atlantic Coastal Bays	YOY	0	0.0545	0.873
		1	-0.491	0.150
		2	-0.0333	0.932
		3	0.0476	0.911
		4	0.0357	0.939
Chesapeake Bay	YOY	0	<b>-0.627</b>	0.0388
		1	-0.176	0.627
		2	-0.0167	0.966
		3	0.310	0.456
		4	0.179	0.702
South Atlantic	YOY	0	0.224	0.533
		1	0.317	0.406
		2	0.381	0.352
		3	<b>0.750</b>	0.0522
		4	0.257	0.623

Table 6.5. Summary of the number and types of biological data for American eel compiled from past and current research programs along the Atlantic Coast.

Region	Type	Length			Weight			Age		
		Male	Female	Other	Male	Female	Other	Male	Female	Other
Gulf of Maine	Fish-Dep			56			55			
	Fish-Ind	1,978	2,036	11,581	1,419	1,324	623	873	872	622
Southern New England	Fish-Dep			187			196			
	Fish-Ind	402	73					847	117	
Hudson River	Fish-Dep			56			55			
	Fish-Ind	30	701	2,078	22	70	2,068	28	699	148
Del Bay/Mid-Atlantic Coastal Bays	Fish-Dep			6,718			6,680			3,624
	Fish-Ind	8	54	743	8	54	743	8	54	134
Chesapeake Bay	Fish-Dep	143	813	20,094	143	813	13,939	138	785	2,480
	Fish-Ind	156	240	11,547	156	240	10,009	152	237	1,050
	Mixed <sup>13</sup>			594						594
South Atlantic	Fish-Dep	1	332	4,486	1	332	1,443			
	Fish-Ind	15	404	24,392	15	401	8,563	11	296	264

Table 6.6. Parameter estimates (standard errors in parentheses) of the allometric length (mm)-weight (g) relation fit to available data for American eel by region, sex, and all data pooled. Asterisks (\*) denote standard errors that are  $\geq 30\%$  of the parameter estimate.

Class	Subset	n	a	b
None	All	49,221	3.87E-07 (6.77E-09)	3.25 (0.00270)
Region	Gulf of Maine	3,420	6.49E-07 (3.54E-08)	3.17 (0.00834)
	Southern New England	143	3.88E-05 (3.30E-05*)	2.56 (0.131)
	Hudson River	2,215	1.27E-06 (1.99E-07)	3.06 (0.0244)
	Del Bay/Mid-Atl Coastal Bays	7,468	2.15E-07 (1.20E-08)	3.35 (0.00877)
	Chesapeake Bay	25,230	3.44E-07 (7.21E-09)	3.27 (0.00322)
	South Atlantic	10,745	1.00E-07 (5.72E-09)	3.48 (0.00902)
Sex	Male	1,764	2.88E-06 (4.66E-07)	2.91 (0.0275)
	Female	3,233	6.97E-07 (4.32E-08)	3.16 (0.00960)

<sup>13</sup> Data provided by one study included samples from both fisheries-dependent and fisheries-independent sources and these data could not be separated by collection type

Table 6.7. Parameter estimates (standard errors in parentheses) for the linear regression of length (mm) on age (years) fit to available data for American eel by region, sex, and all data pooled. Asterisks (\*) denote standard errors that are  $\geq 30\%$  of the parameter estimate.

Class	Subset	n	Intercept	Slope
None	All	13,532	329 (1.72)	8.33 (0.235)
Region	Gulf of Maine	2,356	87.5 (2.96)	23.5 (0.271)
	Southern New England	475	192 (18.7)	14.5 (1.57)
	Hudson River	875	238 (7.68)	13.7 (0.556)
	Del Bay/Mid-Atl Coastal Bays	3,820	243 (4.28)	37.0 (1.04)
	Chesapeake Bay	5,436	267 (3.61)	27.5 (0.731)
	South Atlantic	570	375 (13.5)	12.9 (2.68)
Sex	Male	1,604	279 (2.58)	4.76 (0.254)
	Female	3,015	368 (3.31)	6.70 (0.295)

Table 6.8. Parameter estimates (standard errors in parentheses) of the von Bertalanffy age-length model fit to available data for American eel by region, sex, and all data pooled. Values of  $L_{\infty}$  represent length in millimeters. Asterisks (\*) denote standard errors that are  $\geq 30\%$  of the parameter estimate.

Class	Subset	n	$L_{\infty}$	$K$	$t_0$
None	All	13,532	420 (1.81)	0.573 (0.0219)	-0.110 (0.0781*)
Region	Gulf of Maine	2,356	1,397 (191)	0.0220 (0.00392)	-2.15 (0.254)
	Southern New England	475	<i>failed to converge</i>		
	Hudson River	875	484 (5.36)	0.230 (0.0133)	0.347 (0.139*)
	Del Bay/Mid-Atl Coastal Bays	3,820	636 (41.6)	0.165 (0.0290)	-1.94 (0.385)
	Chesapeake Bay	5,436	779 (93.3)	0.0751 (0.0188)	-4.92 (0.711)
	South Atlantic	570	504 (42.7)	0.258 (0.176*)	-3.31 (3.20*)
Sex	Male	1,604	<i>failed to converge</i>		
	Female	3,015	<i>failed to converge</i>		

Table 6.9. Parameter estimates (standard errors in parentheses) of the Gompertz age-length model fit to available data for American eel by region, sex, and all data pooled. Values of  $L_{\infty}$  represent length in millimeters. Asterisks (\*) denote standard errors that are  $\geq 30\%$  of the parameter estimate.

Class	Subset	n	$L_{\infty}$	$K$	$t_0$
None	All	13,532	418 (1.72)	0.687 (0.0265)	-0.0297 (0.136*)
Region	Gulf of Maine	2,356	735 (26.4)	0.0944 (0.00451)	-17.2 (1.33)
	Southern New England	475	<i>failed to converge</i>		
	Hudson River	875	473 (4.30)	0.359 (0.0203)	-0.266 (0.382*)
	Del Bay/Mid-Atl Coastal Bays	3,820	588 (25.7)	0.259 (0.0302)	-4.84 (1.05)
	Chesapeake Bay	5,436	675 (46.8)	0.138 (0.0192)	-14.4 (2.70)
	South Atlantic	570	502 (39.4)	0.289 (0.179*)	-6.65 (7.12*)
Sex	Male	1,604	<i>failed to converge</i>		
	Female	3,015	1,425 (1,796*)	0.0130 (0.0141*)	-312 (353*)

Table 6.10. Parameter estimates (standard errors in parentheses) of the Richard's age-length model fit to available data for American eel by region, sex, and all data pooled. Values of  $L_{\infty}$  represent length in millimeters. Asterisks (\*) denote standard errors that are  $\geq 30\%$  of the parameter estimate.

Class	Subset	n	$L_{\infty}$	$K$	$t_0$	$\delta$
None	All	13,532	415 (1.76)	1.05 (0.133)	1.69 (0.273)	-3.32 (1.11*)
Region	Gulf of Maine	2,356	<i>failed to converge</i>			
	Southern New England	475	<i>failed to converge</i>			
	Hudson River	875	478 (5.57)	0.292 (0.0453)	1.66 (0.776*)	0.506 (0.355*)
	Del Bay/Mid-Atl Coastal Bays	3,820	541 (28.1)	0.484 (0.203*)	2.40 (1.03*)	-2.40 (2.12*)
	Chesapeake Bay	5,436	<i>failed to converge</i>			
	South Atlantic	570	<i>failed to converge</i>			
Sex	Male	1,604	835 (2,810*)	0.252 (2.11*)	61.4 (231*)	-16.8 (140*)
	Female	3,015	514 (16.9)	1.11 (1.32*)	16.6 (2.39)	-69.0 (81.7*)

Table 6.11. Parameter estimates (standard errors in parentheses) of the logistic age-length model fit to available data for American eel by region, sex, and all data pooled. Values of  $L_{\infty}$  represent length in millimeters. Asterisks (\*) denote standard errors that are  $\geq 30\%$  of the parameter estimate.

Class	Subset	n	$L_{\infty}$	$K$	$t_0$
None	All	13,532	417 (1.66)	0.797 (0.0311)	0.974 (0.0557)
Region	Gulf of Maine	2,356	631 (14.8)	0.165 (0.00525)	9.67 (0.320)
	Southern New England	475	<i>failed to converge</i>		
	Hudson River	875	468 (3.96)	0.495 (0.0293)	3.74 (0.134)
	Del Bay/Mid-Atl Coastal Bays	3,820	562 (19.2)	0.353 (0.0316)	1.51 (0.156)
	Chesapeake Bay	5,436	629 (31.9)	0.200 (0.0197)	1.94 (0.475)
	South Atlantic	570	500 (36.8)	0.319 (0.183*)	-1.55 (1.76*)
Sex	Male	1,604	<i>failed to converge</i>		
	Female	3,015	929 (475*)	0.0291 (0.0140*)	14.4 (35.4*)

Table 6.12. Parameter estimates (standard errors in parentheses) of the Schnute age-length model fit to available data for American eel by region, sex, and all data pooled. Values of  $L_1$  and  $L_2$  represent length in millimeters. Asterisks (\*) denote standard errors that are  $\geq 30\%$  of the parameter estimate.

Class	Subset	n	$L_1$	$L_2$	$a$	$b$
None	All	13,532	223 (6.17)	415 (1.76)	1.05 (0.133)	-3.32 (1.11*)
Region	Gulf of Maine	2,356	97.5 (5.86)	733 (29.8)	0.0371 (0.0191*)	0.794 (0.253*)
	Southern New England <sup>14</sup>	475	338 (6.65)	663 (49.1)	-1.39 (1.04*)	16.6 (14.4*)
	Hudson River	875	72.7 (12.2)	478 (5.56)	0.292 (0.0453)	0.507 (0.355*)
	Del Bay/Mid-Atl Coastal Bays	3,820	261 (8.91)	536 (20.8)	0.484 (0.203*)	-2.40 (2.12*)
	Chesapeake Bay	5,436	266 (8.45)	717 (42.9)	-0.151 (0.101*)	4.49 (1.47*)
	South Atlantic	570	<i>failed to converge</i>			
Sex	Male	1,604	<i>failed to converge</i>			
	Female	3,015	<i>failed to converge</i>			

<sup>14</sup> Parameter estimates considered unrealistic

Table 6.13. Calculated AIC values (Akaike weights in parentheses) for age-length models fit to available data for American eel by region, sex, and all data pooled. Values in bold indicate the model with the smallest AIC value and largest Akaike weight for the associated dataset.

Class	Subset	Linear	von Bertalanffy	Gompertz	Richards	Logistic	Schnute
None	All	18.9806 (0.16235)	18.9187 (0.16745)	18.9180 (0.16752)	<b>18.9175 (0.16756)</b>	18.9176 (0.16755)	<b>18.9175 (0.16756)</b>
Region	Gulf of Maine	16.014 (0.19927)	<b>16.000 (0.20065)</b>	16.004 (0.20030)		16.015 (0.19920)	16.001 (0.20059)
	Southern New England	<b>14.5 (1.00)</b>					
	Hudson River	16.0695 (0.14004)	15.6563 (0.17218)	15.6557 (0.17222)	<b>15.6555 (0.17224)</b>	15.6691 (0.17108)	<b>15.6555 (0.17224)</b>
	Del Bay/Mid-Atl Coastal Bays	17.1333 (0.16585)	17.1221 (0.16678)	17.1215 (0.16683)	17.1215 (0.16683)	<b>17.1211 (0.16686)</b>	17.1215 (0.16683)
	Chesapeake Bay	17.968 (0.19980)	17.966 (0.20007)	17.966 (0.20003)		17.966 (0.19998)	<b>17.965 (0.20012)</b>
	South Atlantic	15.6313 (0.24964)	15.6276 (0.25011)	15.6275 (0.25012)		<b>15.6274 (0.25013)</b>	
Sex	Male	14.549 (0.4999)			<b>14.548 (0.5001)</b>		
	Female	16.979 (0.2500)		16.980 (0.2499)	<b>16.977 (0.2503)</b>	16.980 (0.2499)	



Table 6.14. Result of power analysis for linear and exponential trends in American eel abundance indices over a ten-year period. Power was calculated according to methods in Gerrodette (1987).

Region	Life Stage	Survey	State	Median	Linear Trend		Exponential Trend	
				CV	+50%	-50%	+50%	-50%
Gulf of Maine	YOY	YOY Survey—Jones River	MA	0.36	0.30	0.43	0.31	0.45
	YOY	YOY Survey—Lamprey River	NH	0.34	0.34	0.47	0.35	0.50
	YOY	YOY Survey—West Harbor Pond	ME	0.52	0.20	0.27	0.21	0.30
Southern New England	Elver & Yellow	CTDEP Electrofishing	CT	0.043	1.0	1.0	1.0	1.0
	YOY	YOY Survey—Carman's River	NY	0.20	0.65	0.83	0.65	0.84
	YOY	YOY Survey—Gilbert Stuart Dam	RI	0.24	0.53	0.72	0.54	0.73
Hudson River	Elver & Yellow	NYDEC Alosine Beach Seine	NY	0.18	0.75	0.91	0.75	0.91
	Elver & Yellow	NYDEC Striped Bass Beach Seine	NY	0.24	0.52	0.70	0.52	0.72
	Yearling and Older	HRE Monitoring Program	NY	0.078	1.0	1.0	1.0	1.0
	Yellow	Western Long Island Study	NY	1.0	0.11	0.13	0.12	0.17
	YOY	HRE Monitoring Program	NY	0.16	0.84	0.96	0.84	0.96
Delaware Bay/Mid-Atlantic Coastal Bays	Elver	Area 6 Electrofishing	PA	0.18	0.74	0.90	0.74	0.91
	Elver & Yellow	Delaware Trawl Survey	DE	0.35	0.33	0.46	0.34	0.48
	Elver & Yellow	PSEG Trawl Survey	DE	0.45	0.24	0.33	0.25	0.36
	Yellow	NJDFW Striped Bass Seine Survey	NJ	0.60	0.17	0.23	0.18	0.26
	YOY	Little Egg Inlet Ichthyoplankton Survey	NJ	0.19	0.72	0.89	0.72	0.89
	YOY	YOY Survey—Millsboro Dam	DE	0.31	0.38	0.53	0.39	0.55
	YOY	YOY Survey—Patcong Creek	NJ	0.25	0.50	0.68	0.51	0.70
	YOY	YOY Survey—Turville Creek	MD	0.26	0.47	0.64	0.47	0.66

Table 6.14. *Continued.*

Region	Life Stage	Survey	State	Median CV	Linear Trend		Exponential Trend	
					+50%	-50%	+50%	-50%
Chesapeake Bay	Elver & Yellow	North Anna Electrofishing Survey	VA	0.24	0.54	0.72	0.54	0.74
	Yellow	MD Striped Bass Seine Survey	MD	0.66	0.15	0.20	0.17	0.23
	Yellow	VIMS Juvenile SB Seine Survey—long	VA	0.74	0.14	0.18	0.15	0.21
	Yellow	VIMS Juvenile SB Seine Survey—short	VA	0.55	0.19	0.25	0.20	0.28
	YOY	YOY Survey—Bracken's Pond	VA	0.24	0.52	0.70	0.53	0.72
	YOY	YOY Survey—Clark's Millpond	PRFC	0.28	0.43	0.59	0.44	0.61
	YOY	YOY Survey—Gardy's Millpond	PRFC	0.32	0.37	0.52	0.38	0.54
	YOY	YOY Survey—Kamp's Millpond	VA	0.26	0.47	0.65	0.48	0.67
	YOY	YOY Survey—Wormley Creek	VA	0.24	0.54	0.72	0.54	0.74
South Atlantic	Elver & Yellow	NCDMF Estuarine Trawl Survey	NC	0.28	0.44	0.61	0.44	0.62
	Elver & Yellow	SC Electrofishing Survey	SC	0.097	0.99	1.0	0.99	1.0
	YOY	Beaufort Inlet Ichthyoplankton Survey	NC	0.21	0.63	0.82	0.64	0.83
	YOY	YOY Survey—Altamaha Canal	GA	0.32	0.36	0.50	0.37	0.53
	YOY	YOY Survey—Goose Creek	SC	0.78	0.13	0.17	0.15	0.20
	YOY	YOY Survey—Guana River Dam	FL	0.28	0.43	0.60	0.44	0.62

Table 6.15. Results of the Mann-Kendall trend analysis applied to YOY indices developed from the ASMFC-mandated recruitment surveys.  $S$  is the Mann-Kendall statistic,  $Z_S$  is the test statistic when  $n \geq 10$ ,  $P$ -value is the two-tailed probability for the trend test, and trend indicates the direction of the trend if a statistically significant temporal trend was detected ( $P$ -value  $< \alpha$ ;  $\alpha = 0.05$ ). NS = not significant.

Region	State	Location	Gear	Time Period	n *	$S$	$Z_S$	$P$ -value	Trend
Gulf of Maine	ME	West Harbor Pond	Irish Elver Ramp	2001–2010	10	-3	-0.179	0.858	NS
	NH	Lamprey River	Irish Elver Trap	2001–2010	10	-7	-0.537	0.592	NS
	MA	Jones River	Sheldon Elver Trap	2001–2010	10	-15	-1.25	0.211	NS
Southern New England	RI	Gilbert Stuart Dam	Irish Elver Ramp	2000–2010	11	-11	-0.778	0.436	NS
	NY	Carman's River	Fyke Net	2000–2010	11	-15	-1.09	0.276	NS
Delaware Bay/ Mid-Atlantic Coastal Bays	NJ	Patcong Creek	Fyke Net	2000–2009	10	13	1.07	0.283	NS
	DE	Millsboro Dam	Fyke Net	2000–2010	11	-5	-0.311	0.755	NS
	MD	Turville Creek	Irish Elver Ramp	2000–2010	11	9	0.623	0.533	NS
Chesapeake Bay	PRFC	Clark's Millpond	Irish Elver Ramp	2000–2010	11	13	0.934	0.350	NS
	PRFC	Gardy's Millpond	Irish Elver Ramp	2000–2010	11	-13	-0.934	0.350	NS
	VA	Bracken's Pond	Irish Elver Ramp	2000–2010	11	-19	-1.40	0.161	NS
	VA	Kamp's Millpond	Irish Elver Ramp	2000–2010	11	-17	-1.25	0.213	NS
	VA	Wormley Creek	Irish Elver Ramp	2001–2010	10	-1	0	1.00	NS
South Atlantic	SC	Goose Creek	Fyke Net	2000–2010	11	-13	-0.934	0.350	NS
	GA	Altamaha Canal	Fyke Net	2001–2010	10	-15	-1.25	0.211	NS
	FL	Guana River Dam	Dip Net	2001–2010	10	-3	-0.179	0.858	NS

\* Years with missing values included in count

Table 6.16. Results of the Mann-Kendall trend analysis applied to indices developed from non-ASMFC-mandated recruitment surveys.  $S$  is the Mann-Kendall statistic,  $Z_S$  is the test statistic when  $n \geq 10$ ,  $P$ -value is the two-tailed probability for the trend test, and trend indicates the direction of the trend if a statistically significant temporal trend was detected ( $P$ -value  $< \alpha$ ;  $\alpha = 0.05$ ). NS = not significant. The length range of observed American eels is shown in parentheses after the life stage if the information was available.

Region	Survey	Gear	Life Stage	Time Period	n *	S	$Z_S$	P-value	Trend
Southern New England	CTDEP Electrofishing Survey	Electrofishing	Elver & Yellow (50–590 mm)	2001–2010	10	23	1.97	0.0491	↑
	Western Long Island Study	Seine	Yellow (35–770 mm)	1984–2010	27	-152	-3.18	0.00148	↓
Hudson River	HRE Monitoring Program	Epibenthic Sled and Tucker Trawl	YOY	1974–2009	36	-167	-2.96	0.00306	↓
	HRE Monitoring Program	Epibenthic Sled and Tucker Trawl	Yearling and Older	1974–2009	36	-394	-5.35	8.65E-08	↓
	NYDEC Alosine Beach Seine	Seine	Elver & Yellow	1980–2009	30	-149	-2.64	0.00828	↓
	NYDEC Striped Bass Beach Seine	Seine	Elver & Yellow	1980–2009	30	-273	-4.85	1.22E-06	↓
Delaware Bay/ Mid-Atlantic Coastal Bays	Little Egg Inlet Ichthyoplankton Survey	Ichthyoplankton Net	YOY	1992–2010	19	-45	-1.54	0.124	NS
	NJDFW Striped Bass Seine Survey	Seine	Yellow (50–750 mm)	1980–2009	30	39	0.678	0.498	NS
	Delaware Trawl Survey	Trawl	Elver & Yellow (55–690 mm)	1982–2010	29	42	0.769	0.442	NS
	PSEG Trawl Survey	Trawl	Elver & Yellow (97–602 mm)	1970–2010	41	163	2.04	0.0417	↑
	Area 6 Electrofishing	Electrofishing	Elver	1999–2010	12	6	0.343	0.732	NS

\* Years with missing values included in count

Table 6.16. *Continued.*

Region	Survey	Gear	Life Stage	Time Period	n *	S	Z <sub>S</sub>	P-value	Trend
Chesapeake Bay	MDDNR Striped Bass Seine Survey	Seine	Yellow (77–687 mm)	1966–2010	45	-41	-0.391	0.696	NS
	North Anna Electrofishing Survey	Electrofishing	Elver & Yellow (32–726 mm)	1990–2009	20	107	3.71	0.000209	↑
	VIMS Juvenile Striped Bass Seine Survey—short	Seine	Yellow	1989–2010	22	-25	-0.677	0.499	NS
	VIMS Juvenile Striped Bass Seine Survey—long	Seine	Yellow	1967–2010	44	-159	-7.29	3.03E-13	↓
South Atlantic	Beaufort Inlet Ichthyoplankton Survey	Ichthyoplankton Net	YOY	1987–2003	17	-30	-1.19	0.232	NS
	NCDMF Estuarine Trawl Survey	Trawl	Elver & Yellow (26–921 mm)	1989–2010	22	-93	-2.59	0.00948	↓
	SC Electrofishing Survey	Electrofishing	Elver & Yellow (44–890 mm)	2001–2010	10	-29	-2.50	0.0123	↓

\* Years with missing values included in count

Table 6.17. Results of the Mann-Kendall trend analysis applied to regional and coast-wide indices of American eel abundance.  $S$  is the Mann-Kendall statistic,  $Z_S$  is the test statistic when  $n \geq 10$ ,  $P$ -value is the two-tailed probability for the trend test, and trend indicates the direction of the trend if a statistically significant temporal trend was detected ( $P$ -value  $< \alpha$ ;  $\alpha = 0.05$ ). NS = not significant.

Region	Life Stage	Time Period	n *	$S$	$Z_S$	$P$ -value	Trend
Gulf of Maine	YOY	2001–2010	10	-15	-1.25	0.211	NS
Southern New England	YOY	2000–2010	11	-15	-1.09	0.276	NS
	Yellow	2001–2010	10	21	1.79	0.0736	NS
Hudson River	YOY	1974–2009	36	-167	-2.96	0.00306	↓
	Yellow	1980–2009	30	-297	-5.28	0	↓
Delaware Bay/ Mid-Atlantic Coastal Bays	YOY	2000–2010	10	5	0.311	0.755	NS
	Yellow	1999–2010	12	-4	-0.206	0.837	NS
Chesapeake Bay	YOY	2000–2010	11	-21	-1.56	0.119	NS
	Yellow	1990–2010	21	108	3.23	0.00123	↑
South Atlantic	YOY	2001–2010	10	-17	-1.43	0.152	NS
	Yellow	2001–2010	10	-25	-2.15	0.0318	↓
Atlantic Coast	YOY (short-term)	2000–2010	11	-21	-1.56	0.119	NS
	YOY (long-term)	1987–2009	23	-39	-1.00	0.316	NS
	Yellow (40+ year)	1967–2010	44	52	0.516	0.606	NS
	Yellow (30-year)	1981–2010	30	-129	-2.28	0.0224	↓
	Yellow (20-year)	1991–2010	20	60	1.91	0.0556	NS

\* Years with missing values included in count

Table 6.18. Results of the meta-analysis to synthesize trends for American eel. The meta-analysis techniques are from Manly (2001) where  $S_1$  tests whether at least one of the datasets shows a significant decline through time and  $S_2$  tests whether there is consensus among the datasets for a decline.  $S_2$  incorporates a weight equal to the number of years of the survey,  $n$ . The value of  $p$  represents the one-tailed  $p$ -value from the Mann-Kendall nonparametric test for a decreasing trend through time.

Life stage	Survey	$n$	$p$	Meta-analysis statistics
Yellow	Area 6 Electrofishing	12	0.63	$S_1: 175$ $df: 30$ $P(X^2 > S_1   df): < 0.01$ $S_2: -6.29$ $P(Z > S_2): < 0.01$
	CTDEP Electrofishing Survey	10	0.98	
	NYDEC Alosine Beach Seine	30	0.0041	
	NYDEC Striped Bass Beach Seine	30	6.1E-07	
	Delaware Trawl Survey	29	0.78	
	PSEG Trawl Survey	41	0.98	
	North Anna Electrofishing Survey	20	1.0	
	NCDMF Estuarine Trawl Survey	22	0.0047	
	SC Electrofishing Survey	10	0.0061	
	HRE Monitoring Program	36	4.3E-08	
	Western Long Island Study	27	7.4E-04	
	NJDFW Striped Bass Seine Survey	30	0.75	
	MD Striped Bass Seine Survey	45	0.35	
	VIMS Juvenile Striped Bass Seine Survey—short	22	0.25	
VIMS Juvenile Striped Bass Seine Survey—long	44	1.5E-13		
YOY	YOY Survey—West Harbor Pond	10	0.43	$S_1: 65.8$ $df: 38$ $P(X^2 > S_1   df): < 0.01$ $S_2: -15.1$ $P(Z > S_2): < 0.01$
	YOY Survey—Lamprey River	10	0.30	
	YOY Survey—Jones River	10	0.11	
	YOY Survey—Gilbert Stuart Dam	11	0.22	
	YOY Survey—Carman's River	11	0.14	
	HRE Monitoring Program	36	0.0015	
	Little Egg Inlet Ichthyoplankton Survey	19	0.062	
	YOY Survey—Patcong Creek	11	0.86	
	YOY Survey—Millsboro Dam	11	0.38	
	YOY Survey—Turville Creek	11	0.73	
	YOY Survey—Clarks Millpond	11	0.82	
	YOY Survey—Gardys Millpond	11	0.18	
	YOY Survey—Brackens Pond	11	0.081	
	YOY Survey—Kamps Millpond	11	0.11	
	YOY Survey—Wormley Creek	10	0.50	
	Beaufort Inlet Ichthyoplankton Survey	17	0.12	
	YOY Survey—Goose Creek	11	0.18	
	YOY Survey—Altamaha Canal	10	0.11	
	YOY Survey—Guana River Dam	10	0.43	

Table 6.19. Summary statistics from ARIMA model fits to American eel surveys with 20 or more years of data. Q0.25 is the 25th percentile of the fitted values;  $P(<0.25)$  is the probability of the final year of the survey being below Q0.25 with 80% confidence;  $r_1$ – $r_3$  are the first three autocorrelations;  $\theta$  is the moving average parameter; SE is the standard error of  $\theta$ ; and  $\sigma_c^2$  is the variance of the index.

Region	Survey	Final Year	Q0.25	$P(<0.25)$	n	r1	r2	r3	$\theta$	SE	$\sigma_c^2$
Hudson River	Western Long Island Study	2010	-4.24	0.513	27	-0.32	-0.1	-0.02	0.26	0.17	0.42
	HRE Monitoring Program	2009	-3.96	0.548	30	-0.21	-0.18	-0.04	0.07	0.2	1.24
	HRE Monitoring Program	2009	-2.14	0.259	36	-0.07	-0.24	0.24	0.41	0.15	0.29
	NYDEC Alosine Beach Seine	2009	-1.20	0.316	30	-0.37	0.06	-0.15	0.64	0.16	0.29
	NYDEC Striped Bass Beach Seine	2009	-1.30	0.47	30	0.02	-0.15	-0.11	0.44	0.48	0.22
Delaware Bay/Mid-Atlantic Coastal Bays	NJDFW Striped Bass Seine Survey	2009	-2.55	0.003	30	-0.2	-0.42	0.12	1	0.12	1.08
	Delaware Trawl Survey	2010	-0.68	0.141	29	-0.36	-0.1	0.2	0.97	0.3	0.27
	PSEG Trawl Survey	2010	-0.60	0.069	38	-0.13	-0.01	-0.26	0.93	0.18	1.39
Chesapeake Bay	MD Striped Bass Seine Survey	2010	-1.70	0.116	45	-0.27	0.01	-0.12	0.83	0.22	1.49
	VIMS Juvenile SB Seine Survey—short	2010	-2.53	0.164	22	-0.24	-0.39	-0.01	0.9	0.49	0.39
	VIMS Juvenile SB Seine Survey—long	2010	-3.36	0.062	38	-0.26	-0.44	0.15	0.66	0.13	0.87
South Atlantic	NCDMF Estuarine Trawl Survey	2010	-1.99	0.308	22	-0.58	0.13	0.04	0.77	0.12	0.45



Table 6.20. Traffic Light representation of YOY indices developed from the ASMFC-mandated recruitment surveys. The 25th and 75th percentiles used to define the shading for each index series such that positive (white) values are > 75th percentile, neutral (gray) values are between the 25th and 75th percentiles, and negative (black) values are < 25th percentile.

Region		Gulf of Maine			Southern New England		Delaware Bay/ Mid-Atlantic			Chesapeake Bay					South Atlantic		
State		ME	NH	MA	RI	NY	NJ	DE	MD	PRFC		VA			SC	GA	FL
Location		West Harbor Dam	Lamprey River	Jones River	Gilbert Stuart Dam	Carman's River	Patcong Creek	Millsboro Dam	Turville Creek	Clark's Millpond	Gardy's Millpond	Bracken's Pond	Kamp's Millpond	Wormley Creek	Goose Creek	Altamaha Canal	Guana River Dam
Year	2000				356	43.3	55.7	4,454	5,423	0.334	28.5	1,038	15.4		16.2		
	2001	3,861	5.28	543	27.5	7.59	300	11,736	6,162	0.176	23.2	480	136	908	246	9.84	102
	2002	1,187	18.3	93.0	679	345	2,182	3,344	647	2.68	4.49	128	474	481	144	1.27	24.2
	2003	523	1.71	902	3.38	6.34	57.1	8,180	3,489	0.528	1.98	981	61.2	207	105	1.39	47.9
	2004	88.3	3.53	118	6.59	25.2	63.4	5,092	3,422	3.52	0.964	348	8.48	797	4.49	1.55	7.84
	2005	3,719	1.85	809	48.2	16.0	712	5,307	1,263	4.90	2.78	741	91.0	378	101	1.19	150
	2006	138	42.8	492	20.8	7.32	3,502	6,812	1,377	1.44	1.04	520	7.50	877	36.9	3.11	8.55
	2007	105	0.882	449	44.6	11.3	318	12,904	7,362	1.79	4.47	866	3.93	1,430	80.0	1.31	12.4
	2008	1,894	0.997	219	10.1	14.7	291	1,166	3,171	0.646	7.24	21.2	17.3	125	141	1.69	15.9
	2009	1,406	2.408	264	35.7	23.5	356	846	4,260	0.606	6.28	1.64	4.61	113	56.8	0.723	18.5
2010	1,845	4.97	39.2	16.5	6.04		6,539	8,636	3.28	1.94	412	66.2	2,575	34.8	0.878	30.6	
%ile	25th	235	1.74	143	13.3	7.45	120	3,899	2,274	0.567	1.96	238	7.99	250	35.8	1.21	13.2
	75th	1,882	5.20	530	46.4	24.4	623	7,496	5,793	2.98	6.76	804	78.6	900	123	1.66	43.6

Table 6.21. Traffic Light representation of indices developed from non-ASMFC-mandated recruitment surveys. The 25th and 75th percentiles used to define the color boundaries for each index series are also shown. The 25th and 75th percentiles used to define the shading for each index series such that positive (white) values are > 75th percentile, neutral (gray) values are between the 25th and 75th percentiles, and negative (black) values are < 25th percentile.

Region		Southern New England			Hudson River			Delaware Bay/ Mid-Atlantic Coastal Bays					
Survey	CTDEP Electrofishing	Western Long Island Sound	HRE Monitoring		NYDEC Alosine Beach Seine	NYDEC Striped Bass Beach Seine	Little Egg Inlet Ichthyoplankton	NJDEP Striped Bass Seine	Delaware Trawl	PSEG Trawl	Area 6 Electrofishing		
Life Stage	E/Y	Y	YOY	E/Y	E/Y	E/Y	YOY	Y	E/Y	E/Y	E		
Year	1966												
	1967												
	1968												
	1969												
	1970											0.437	
	1971											0.641	
	1972											0.487	
	1973											0.268	
	1974			0.197	1.39							0.212	
	1975			0.0799	1.63							0.276	
	1976			0.0843	1.11							0.328	
	1977			0.0328	0.603							0.208	
	1978			0.106	0.382							0.189	
	1979			0.247	0.350							1.25	
	1980			0.0684	0.496	1.13	0.401					0.480	
	1981			0.00235	0.667	1.18	1.14		7.74E-14	0.0901		2.14	
	1982				0.593	0.620	1.28		1.01	1.50			
	1983				0.799	0.665	1.40		0.531	0.600			
	1984		0.367	0.000961	1.24	0.287	1.36		2.59E-14	0.451	5.24		
	1985		0.691		0.702	0.578	0.720		0.174	0.318	8.02		
	1986		0.177		0.618	0.990	0.434		0.349	0.486	2.49		
	1987		0.0719		0.843	0.704	0.729		1.73E-14	0.370	2.38		
	1988		0.0670	0.00546	0.322	0.490	0.990		0.0933	0.379	2.65E-11		
	1989		0.0932	0.0368	0.371	0.357	0.633		0.0669	0.368	0.277		
	1990		0.0102		0.538	0.315	0.673		0.0456	0.240	0.709		
	1991		0.00810	0.0593	0.399	0.267	0.646		0.0257	0.359	0.275		
	1992		0.0168	0.0587	0.182	0.341	0.517	1.43	0.0866	1.009	0.484		
	1993		0.0240	0.218	0.183	0.237	0.228	1.77	0.0315	0.697	0.503		
	1994		0.0114	0.0864	0.257	0.234	0.385	2.32	0.126	0.166			
	1995		2.22E-16	0.0456	0.256	0.260	0.346	2.30	0.0559	0.718	0.549		
	1996		2.22E-16	0.0450	0.403	0.344	0.271	1.55	0.0881	0.563	0.0815		
	1997		2.22E-16	0.0263	0.133	0.0739	0.613	1.36	0.0818	0.626	1.04		
	1998		0.0108	0.0387	0.0857	0.368	0.317	1.76	0.0445	0.650	0.919		
	1999		2.22E-16	0.0160	0.0812	0.494	0.423	1.09	0.0504	0.986	0.887	23.4	
	2000		0.0130	0.0365	0.0670	0.423	0.236	0.845	0.0739	0.231	0.490	8.64	
	2001		257	0.00630	0.0595	0.167	0.350	0.210	1.37	0.0580	0.793	0.692	30.6
	2002		179	0.00750	0.0277	0.0324	0.782	0.222	1.22	0.0758	0.614	0.625	23.0
	2003		151	0.0174	0.0320	0.107	0.274	0.318	1.03	0.0531	0.419	1.38	18.0
	2004		272	0.0237	0.0133	0.126	0.484	0.389	0.806	0.326	1.30	0.962	25.1
	2005		225	0.0175	0.0557	0.0768	0.166	0.142	1.61	0.132	0.907	3.13	17.1
	2006		227	2.22E-16	0.0143	0.0877	0.256	0.141	1.68	0.131	0.542	1.17	23.3
	2007		241	0.0122	0.0247	0.165	0.405	0.140	1.81	0.0967	0.615	0.604	26.3
	2008		340	2.22E-16	0.00926	0.0922	0.404	0.232	1.82	0.0813	0.360	0.644	23.1
	2009		283	0.00790	0.00994	0.191	0.197	0.385	0.996	0.167	0.742	1.36	32.4
	2010		337	2.22E-16					0.332		0.469	0.547	17.5
	25th		226	0.00315	0.0182	0.132	0.245		1.06	0.0511	0.370	0.356	17.8
%ile	75th		280	0.0239	0.0662	0.607	0.557		1.77	0.130	0.718	1.14	25.4

Table 6.21. *Continued.*

Region		Chesapeake Bay				South Atlantic		
Survey		MDDNR Striped Bass Seine	North Anna Electrofishing	VIMS Juvenile Striped Bass Seine—short	VIMS Juvenile Striped Bass Seine—long	Beaufort Inlet Ichthyoplankton	NCDMF Estuarine Trawl	SC Electrofishing
Life Stage		Y	E/Y	Y	Y	YOY	E/Y	E/Y
Year	1966	1.97						
	1967	0.132			0.184			
	1968	0.202			0.247			
	1969	0.109			0.144			
	1970	0.503			0.121			
	1971	0.521			0.190			
	1972	2.22E-16			0.117			
	1973	0.0967			0			
	1974	0.242						
	1975	0.929						
	1976	0.380						
	1977	0.527						
	1978	0.651						
	1979	0.620						
	1980	0.285			0.0801			
	1981	0.407			0.109			
	1982	0.255			0.0701			
	1983	2.58E-16			0			
	1984	0.313			0.0667			
	1985	0.337			0.0256			
	1986	0.195			0.0276			
	1987	0.166			0.0256	0.643		
	1988	0.505			0.0434	1.02		
	1989	0.122		0.0989	0	0.842	0.146	
	1990	0.0529	6.72	0.0441	0	0.624	0.561	
1991	2.22E-16	6.15	0.0512	0	0.260	0.307		
1992	0.0604	6.94	0.0735	0	1.13	0.348		
1993	0.0632	3.34	0.0894	0.0219	0.610	0.199		
1994	0.0545	3.82	0.114	0	1.54	0.315		
1995	0.0765	5.26	0.0822	0.0430	1.54	0.192		
1996	0.0583	9.34	0.209	0.0602	0.609	0.363		
1997	0.588	7.30	0.287	0.0621	0.330	0.114		
1998	0.366	5.74	0.0354	0.0420	1.10	0.113		
1999	0.539	7.45	0.108	0.0219	0.170	0.364		
2000	0.363	7.57	0.167	0.0861	0.280	0.0351		
2001	0.198	11.6	0.235	0.0602	0.409	0.131	1.06	
2002	0.211	6.28	0.0894	0.0406	0.959	0.185	0.804	
2003	0.894		0.0299	0	0.406	0.106	1.27	
2004	0.395	18.5	0.0912	0.0420		0.279	0.973	
2005	0.900	10.9	0.0675	0.0892		0.169	0.947	
2006	0.0546	11.6	0.0979	0		0.112	0.852	
2007	0.0661	10.6	0.0665	0.0213		0.0925	0.703	
2008	0.595	23.8	0.0734	0.0694		0.143	0.667	
2009	0.256	33.6	0.0888	0.126		0.0422	0.803	
2010	0.237		0.0317	0.0420		0.161	0.692	
%ile	25th	0.0967	6.21	0.0667	0.0215	0.406	0.113	0.728
	75th	0.505	11.3	0.106	0.0846	1.02	0.300	0.966

Table 6.22. Traffic Light representation of regional and coast-wide indices of American eel abundance. The 25th and 75th percentiles used to define the shading for each index series such that positive (white) values are > 75th percentile, neutral (gray) values are between the 25th and 75th percentiles, and negative (black) values are < 25th percentile.

Life Stage	Region	Gulf of Maine	Southern New		Hudson River		Delaware Bay/ Mid-Atlantic Coastal		Chesapeake Bay		South Atlantic		Atlantic Coast				
	YOY	YOY	Y	YOY	Y	YOY	Y	YOY	Y	YOY	Y	YOY (short-term)	YOY (long-term)	Y (40+ year)	Y (30-year)	Y (20-year)	
Year	1967																0.805
	1968																0.887
	1969																0.767
	1970																0.830
	1971																0.924
	1972																0.669
	1973																0.608
	1974				0.197												0.587
	1975				0.0799												0.851
	1976				0.0843												0.690
	1977				0.0328												0.690
	1978				0.106												0.720
	1979				0.247												1.13
	1980				0.0684	1.03											0.759
	1981				0.00235	1.34											1.13 1.15
	1982					1.17											0.804 1.17
	1983					1.29											0.612 1.05
	1984				0.000961	1.24											1.37 1.19
	1985					1.05											1.54 1.21
	1986					1.05											1.02 1.05
	1987					1.14								1.14	0.997	0.997	
	1988				0.00546	0.965								1.29	0.645	0.790	
	1989				0.0368	0.856								1.25	0.619	0.732	
	1990					0.903				0.624				1.11	0.690	0.781	
	1991				0.0593	0.837				0.590				0.961	0.575	0.696	1.05
	1992				0.0587	0.756				0.644				1.30	0.647	0.711	1.14
	1993				0.218	0.647				0.523				1.36	0.661	0.663	0.988
	1994				0.0864	0.714				0.548				1.70	0.645	0.731	1.01
	1995				0.0456	0.711				0.600				1.49	0.686	0.705	1.06
	1996				0.0450	0.758				0.758				1.21	0.563	0.671	1.10
	1997				0.0263	0.669				0.908				1.03	0.974	0.804	1.19
	1998				0.0387	0.675				0.687				1.37	0.868	0.761	1.09
	1999				0.0160	0.734				0.825				0.916	0.904	0.803	1.24
	2000		103		0.0365	0.659	1.58	14.5	632	0.804			4.89	0.897	0.789	0.728	1.05
	2001	1,034	12.4	252	0.0595	0.668	3.44	23.7	803	0.884	2.08	0.680	7.62	1.10	0.770	0.722	1.17
	2002	575	399	211	0.0277	0.715	2.30	21.1	696	0.682	0.924	0.649	7.26	1.17	0.751	0.739	1.10
	2003	457	4.25	196	0.0320	0.658	1.71	21.3	408	0.987	0.913	0.710	3.21	1.01	1.09	0.831	1.19
	2004	157	11.1	264	0.0133	0.740	1.49	28.4	349	1.04	0.169	0.735	2.05	0.955	0.886	0.847	1.40
	2005	863	23.4	239	0.0557	0.568	2.43	28.5	692	1.01	1.13	0.675	6.00	1.21	1.43	0.894	1.31
	2006	646	10.6	236	0.0143	0.595	3.96	23.5	328	0.765	0.410	0.624	3.80	1.17	0.77	0.699	1.11
	2007	181	19.0	246	0.0247	0.659	3.93	21.9	466	0.737	0.473	0.579	3.67	1.20	0.684	0.688	1.09
	2008	384	10.5	288	0.00926	0.662	1.71	19.9	172	1.19	0.660	0.594	2.48	1.24	0.888	0.769	1.22
	2009	462	24.4	265	0.00994	0.681	1.60	27.8	80.0	1.19	0.422	0.577	2.09	1.04	0.953	0.818	1.32
	2010	332	8.70	287			2.74	17.8	744	0.719	0.440	0.609	4.13		0.743	0.720	1.04
%ile	25th	345	10.5	236	0.0182	0.669	1.66	20.8	338	0.644	0.427	0.598	2.84	1.03	0.680	0.721	1.05
	75th	629	23.9	265	0.0662	1.01	3.09	24.7	694	0.908	0.922	0.679	5.44	1.27	0.909	0.882	1.20

Table 6.23. Summary of stochastic sensitivity runs conducted for the DB-SRA model.

Run	$M^*$	$M$ regime	Initial $F:M^*$	$B.mnpl^*$	$B.ratio^*$	Harvest
1	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	3–10%	Reconstructed harvest
2	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	3–10%	<b>Lower harvest 1880–1885</b>
3	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	3–10%	<b>High harvest 1870–1879</b>
4	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	3–10%	<b>Ramp up harvest 1870–1879</b>
5	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	3–10%	<b>Start in 1925</b>
6	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	3–10%	<b>Start in 1970</b>
7	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	<b>18–25%</b>	Reconstructed harvest
7A	0.15 to 0.25	Constant	0.8 to 1.2	0.25 to 0.5	<b>40–50%</b>	Reconstructed harvest
8	0.15 to 0.25	<b>increase by 20–40% in 1970</b>	0.8 to 1.2	0.25 to 0.5	3–10%	Reconstructed harvest
9	0.15 to 0.25	<b>increase by 15–30% in 1970</b>	0.8 to 1.2	0.25 to 0.5	3–10%	Reconstructed harvest
10	0.15 to 0.25	<b>increase by 15–30% in 1970</b>	0.8 to 1.2	0.25 to 0.5	<b>15–25%</b>	Reconstructed harvest
11	0.15 to 0.25	<b>increase by 15–30% in 1970</b>	0.8 to 1.2	0.25 to 0.5	<b>40–50%</b>	Reconstructed harvest
12	0.15 to 0.25	<b>increase by 15–30% in 1970</b>	0.8 to 1.2	0.25 to 0.5	<b>15–25%</b>	<b>Run 2 harvest</b>
13	0.15 to 0.25	<b>increase by 15–30% in 1960</b>	0.8 to 1.2	0.25 to 0.5	<b>15–25%</b>	Reconstructed harvest

Table 6.24. Summarized results from the DB-SRA (A) single and (B) double  $M$  models.

(A) Single  $M$  stanza model

Parameter	Percentile								
	0.025	0.05	0.1	0.25	0.5	0.75	0.9	0.95	0.975
$K$	16,220	16,405	16,686	17,314	18,219	19,180	20,126	20,704	21,253
$B_{MSY}$	5,080	5,218	5,439	5,991	6,770	7,550	8,134	8,440	8,664
$F_{MSY}$	0.1344	0.1408	0.1493	0.1687	0.1901	0.2119	0.2304	0.2388	0.2443
$u_{MSY}$	0.1165	0.1213	0.1280	0.1425	0.1579	0.1729	0.1854	0.1913	0.1948
MSY	755	789	834	926	1,057	1,190	1,292	1,338	1,368

(B) Double  $M$  stanza model

Parameter	Percentile								
	0.025	0.05	0.1	0.25	0.5	0.75	0.9	0.95	0.975
$K$	16,274	16,445	16,744	17,365	18,274	19,324	21,214	22,496	23,595
$B_{MSY}$	5,085	5,299	5,561	6,095	6,823	7,579	8,194	8,581	8,912
$F_{MSY-early}$	0.1358	0.1420	0.1510	0.1696	0.1922	0.2155	0.2349	0.2441	0.2500
$F_{MSY-late}$	0.0976	0.1037	0.1115	0.1281	0.1481	0.1685	0.1869	0.1956	0.2018
$u_{MSY-early}$	0.1176	0.1224	0.1293	0.1433	0.1592	0.1751	0.1885	0.1948	0.1986
$u_{MSY-late}$	0.0840	0.0890	0.0949	0.1076	0.1225	0.1376	0.1505	0.1568	0.1609
MSY-early	827	850	880	945	1,060	1,197	1,305	1,374	1,510
MSY-late	614	636	660	711	810	930	1,041	1,110	1,178

13 FIGURES

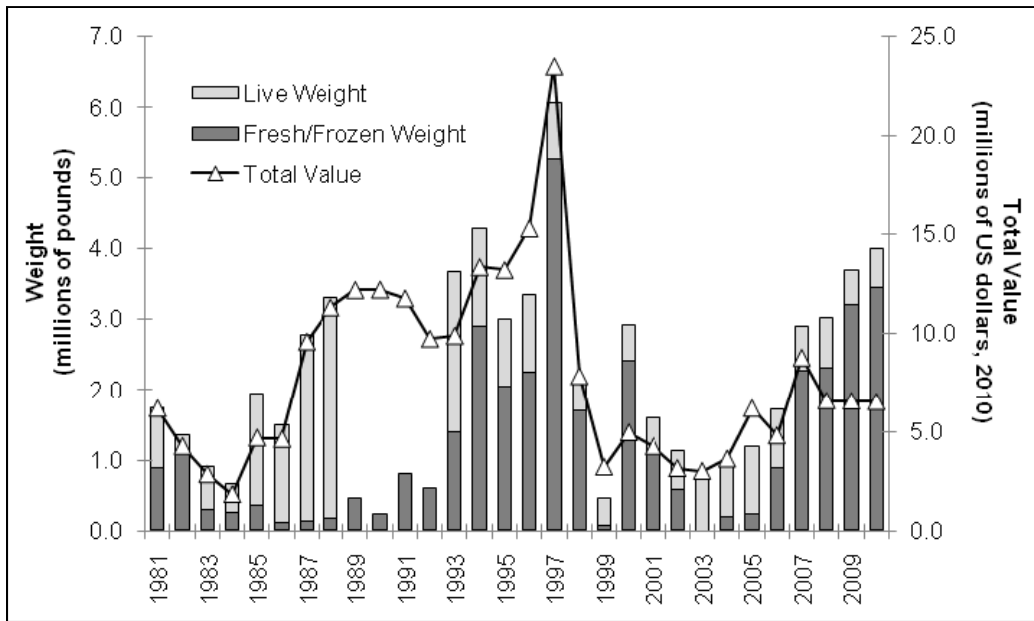


Figure 4.1. Annual U.S. domestic exports of American eels from districts along the Atlantic coast, 1981–2010. Note that the weights of live exports were not available for 1989 to 1992.

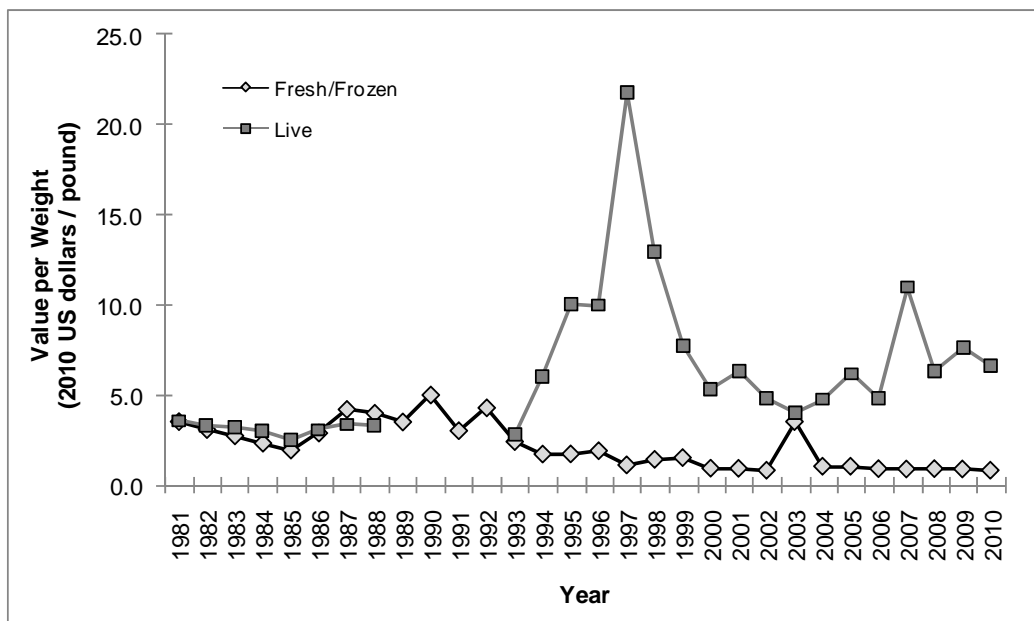


Figure 4.2. Annual U.S. domestic exports of American eels from districts along the Atlantic coast, 1981–2010. Note that the weights of live exports were not available for 1989 to 1992.

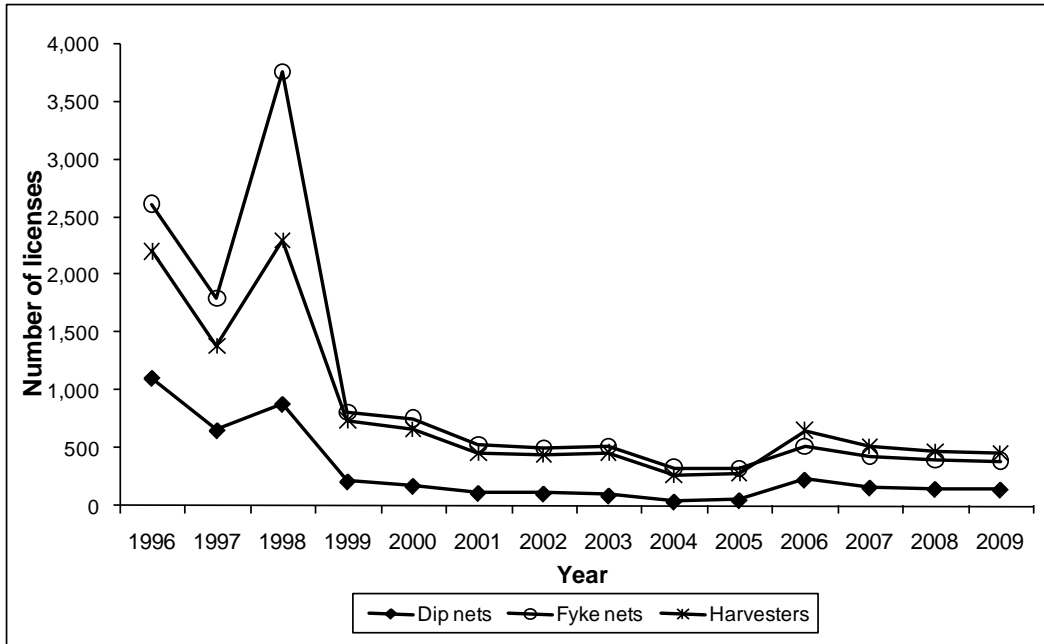


Figure 4.3. Commercial glass eel fishery effort in Maine, 1996–2009. Note: the number of harvesters does not equal the sum of the licensed gears since each harvester may license more than one piece of gear.



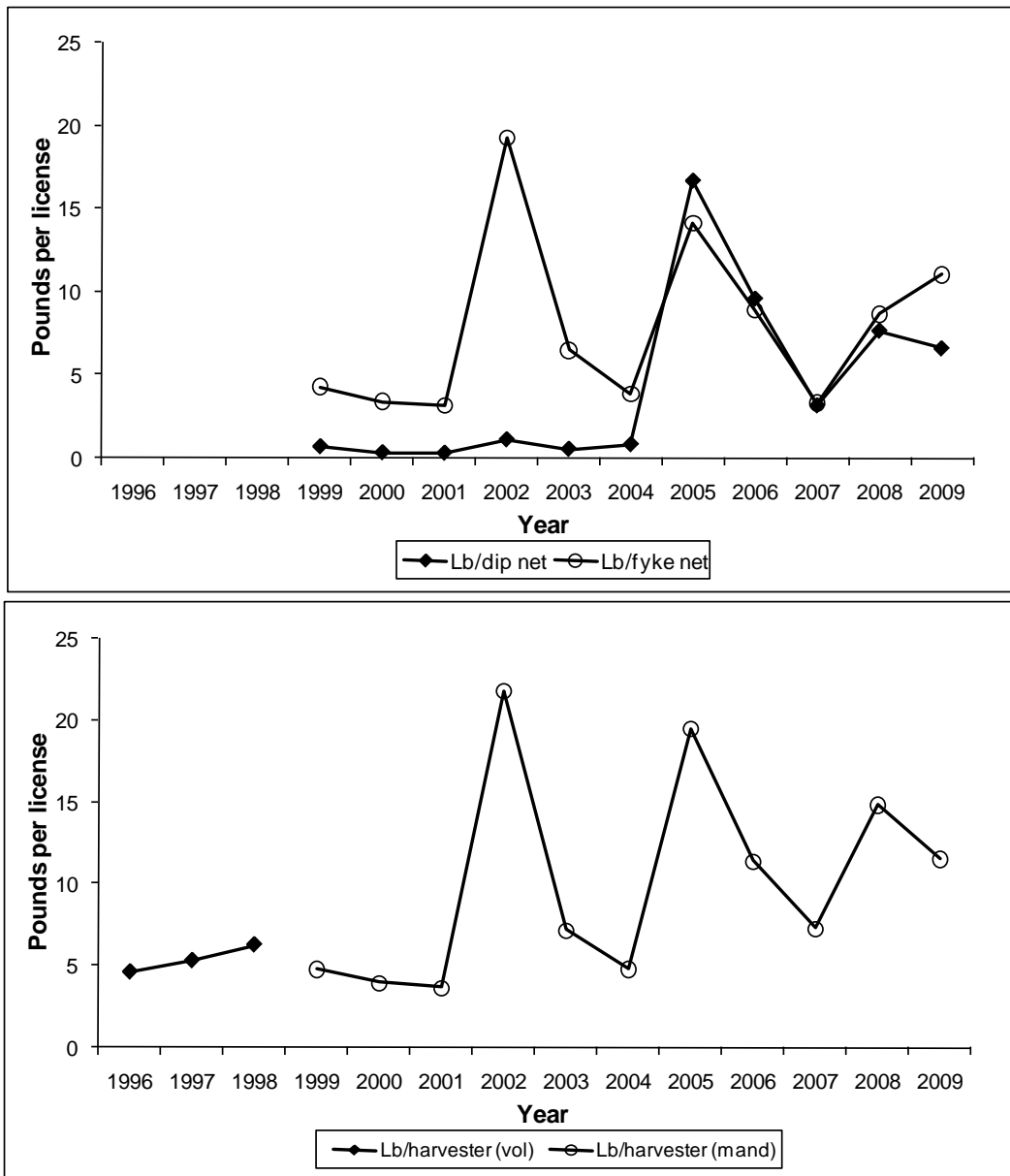


Figure 4.4. Catch per unit effort in the Maine commercial glass eel fishery per licensed gear (upper graph) and per license holder (lower graph).

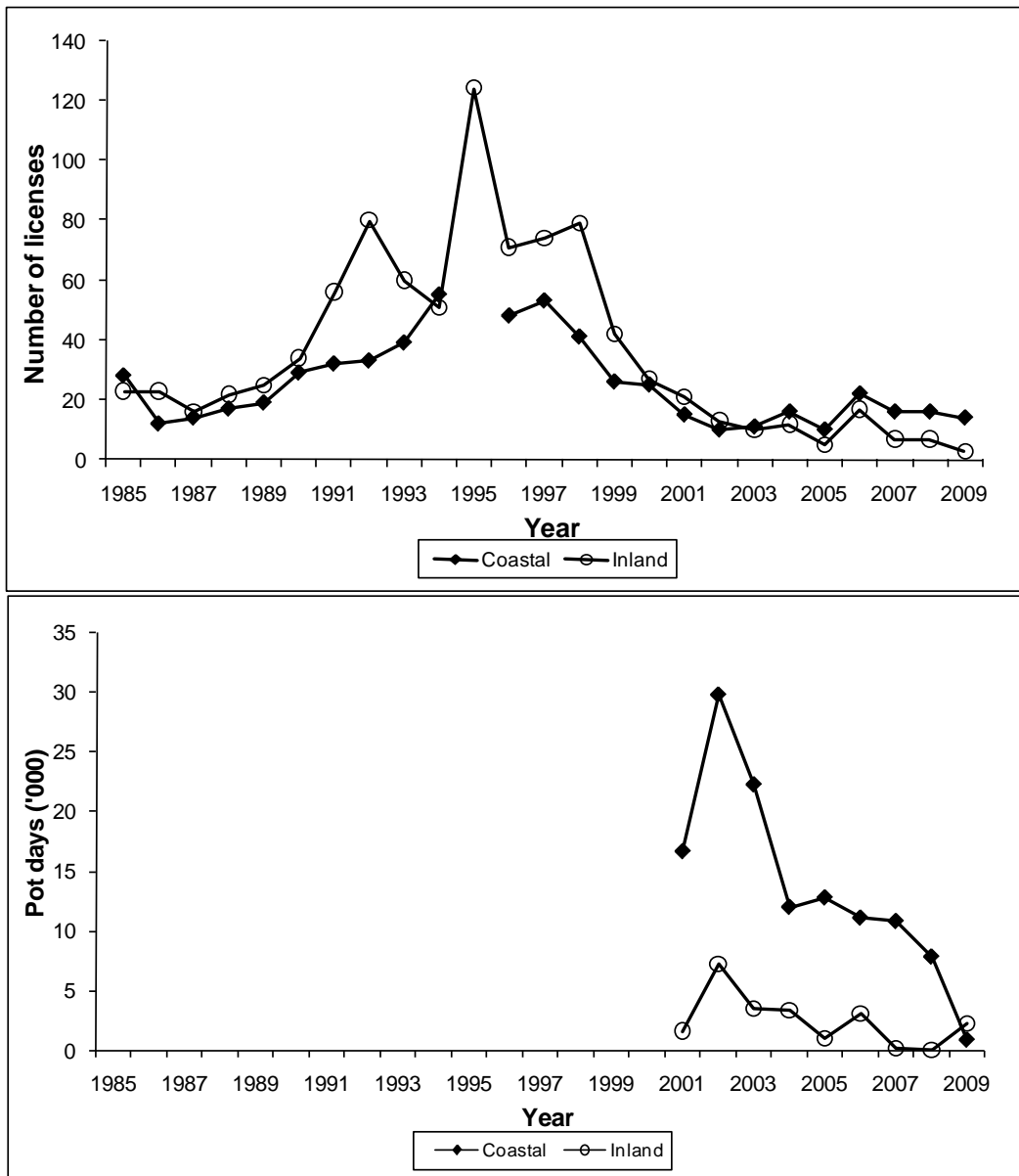


Figure 4.5. Effort in the Maine commercial yellow eel pot fisheries expressed as number of licensees (upper graph) and number of gear days fished (lower graph).

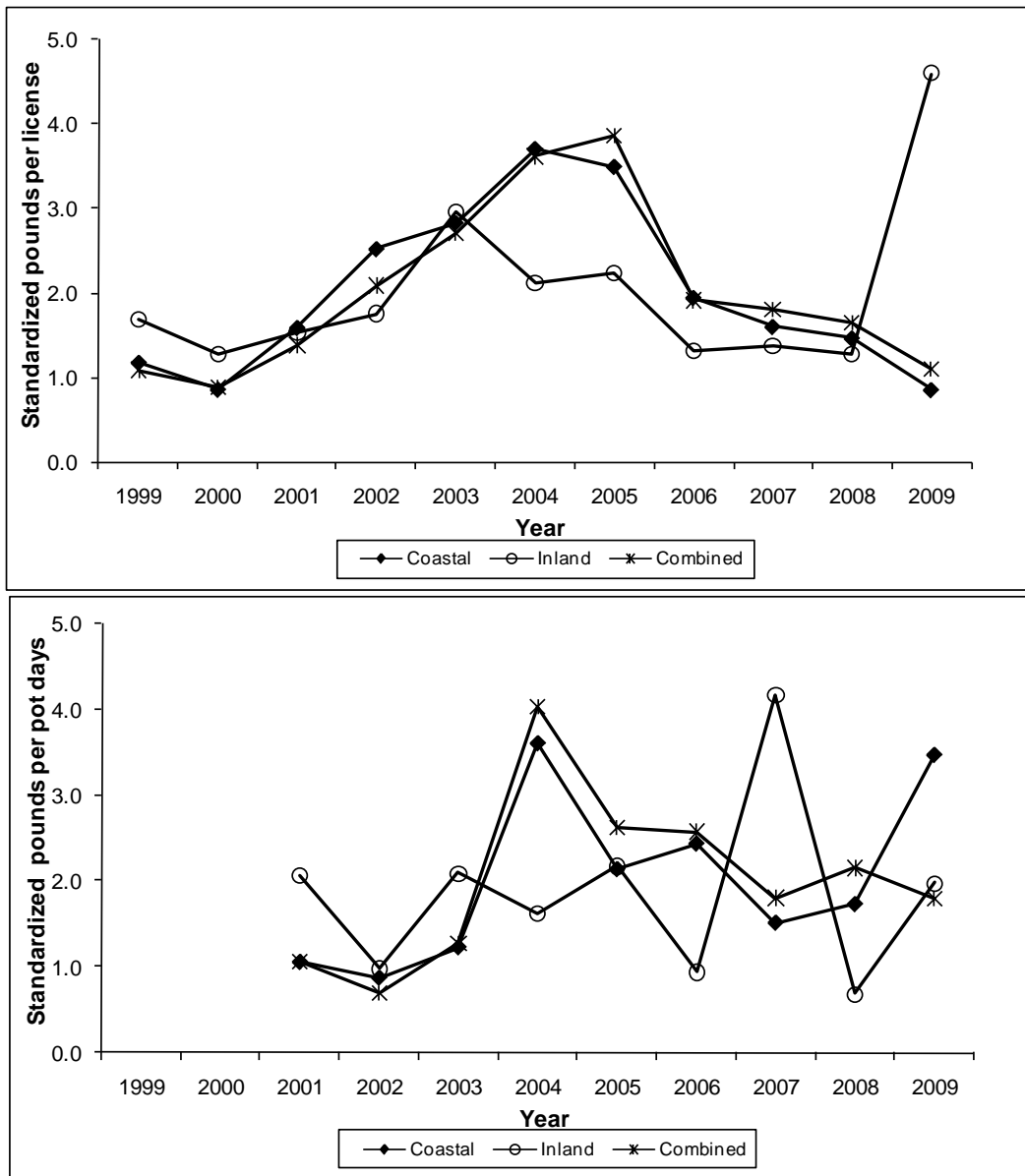


Figure 4.6. Standardized catch per unit effort in the Maine commercial yellow eel pot fisheries expressed as pounds per license holder (upper graph) and pounds per pot days (lower graph).

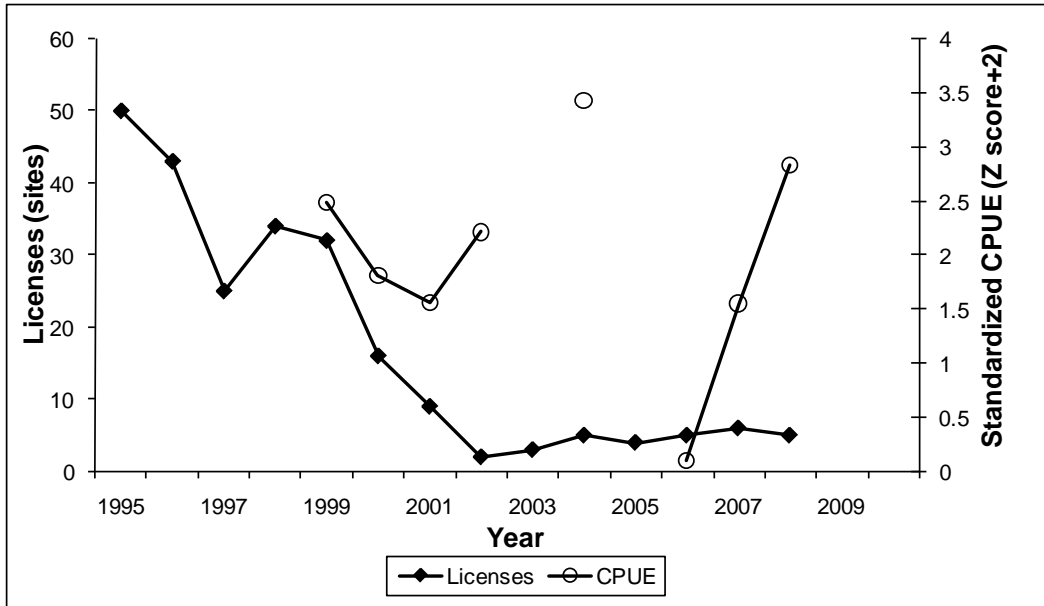


Figure 4.7. Standardized effort and CPUE from the Maine commercial silver eel weir fishery.

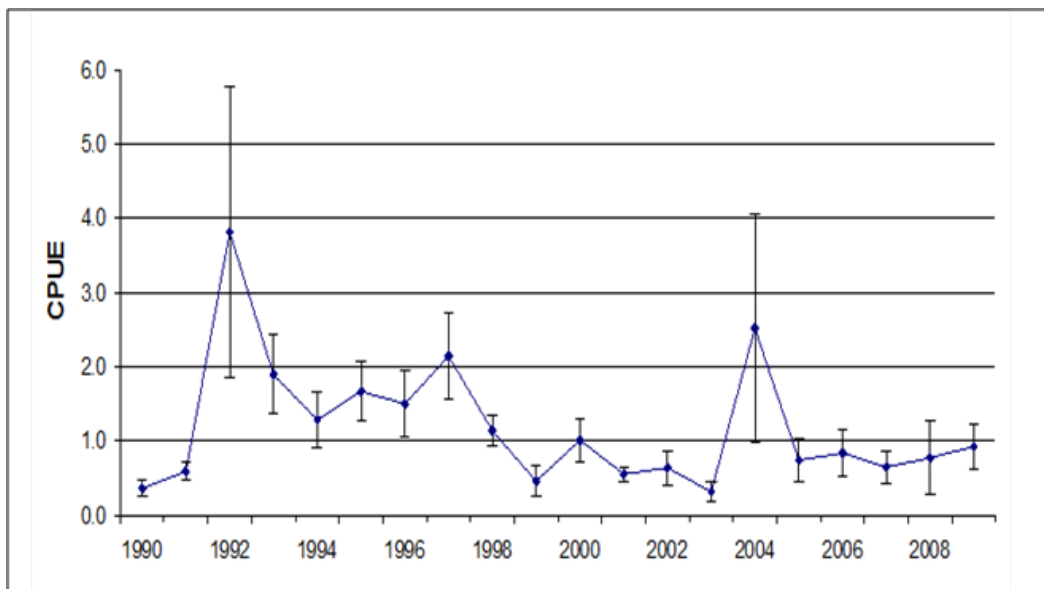


Figure 4.8. Catch-per-unit-effort in New Hampshire commercial eel pot fishery, 1990–2009. Error bars represent  $\pm 2$  standard errors.

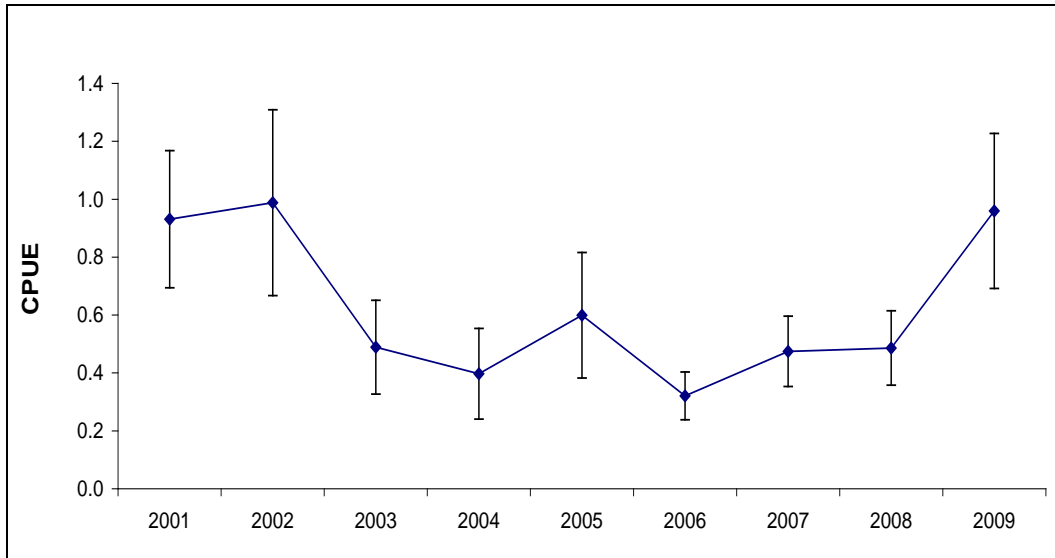


Figure 4.9. Catch-per-unit-effort in Massachusetts commercial eel pot fishery in Southern New England region, 2001–2009. Error bars represent  $\pm 2$  standard errors.

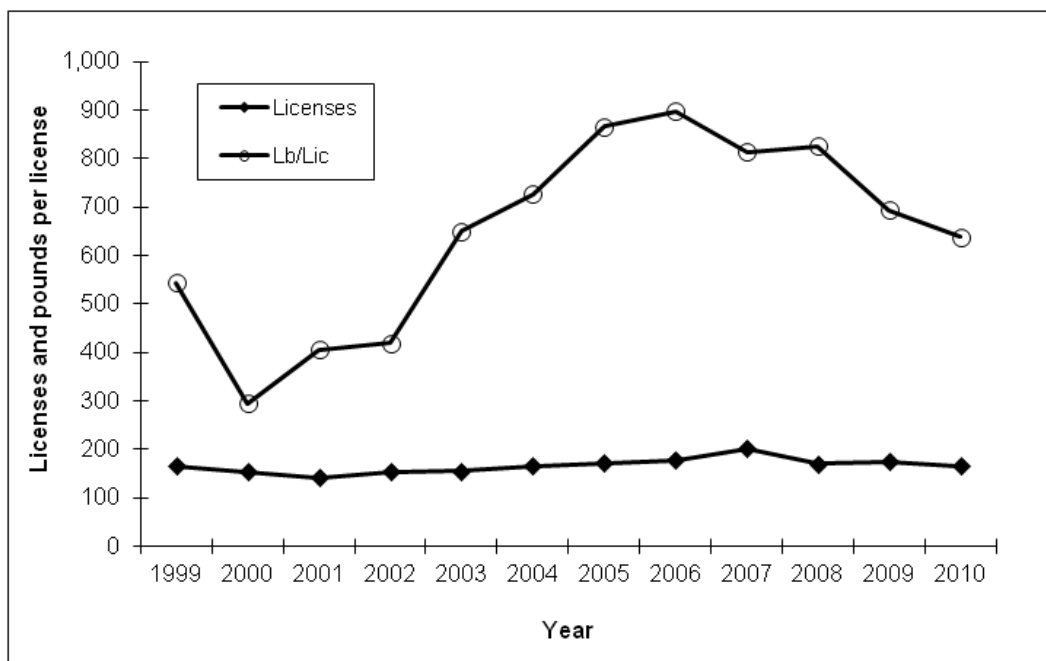


Figure 4.10. Effort and CPUE in New Jersey's commercial eel fishery, 1999–2010.

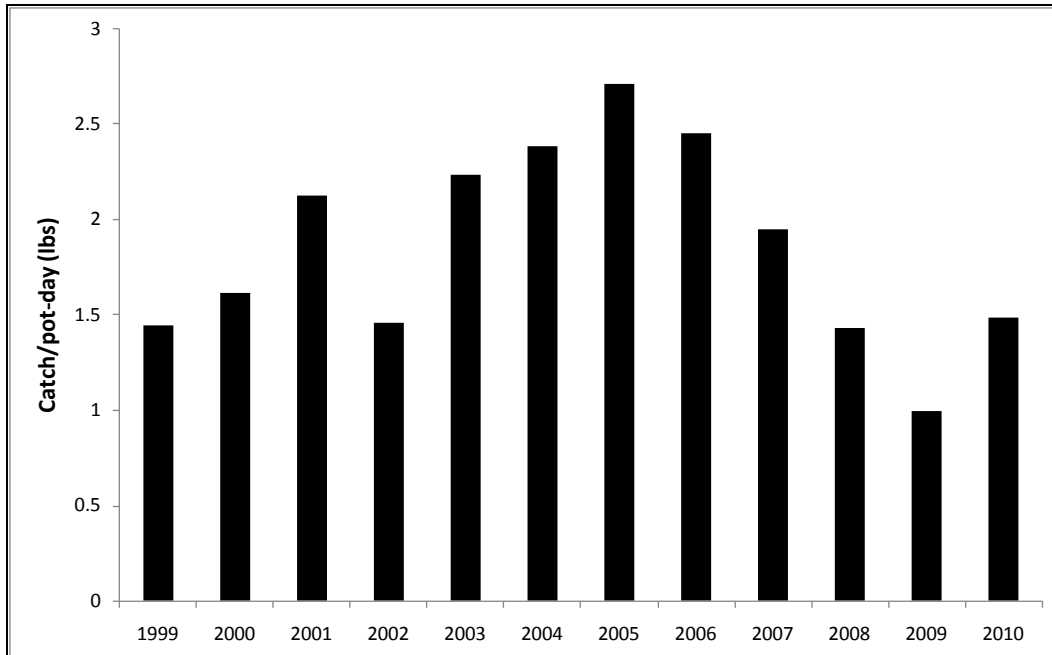


Figure 4.11. Delaware commercial fishery annual mean catch per pot-day fished (lbs), 1999–2010.

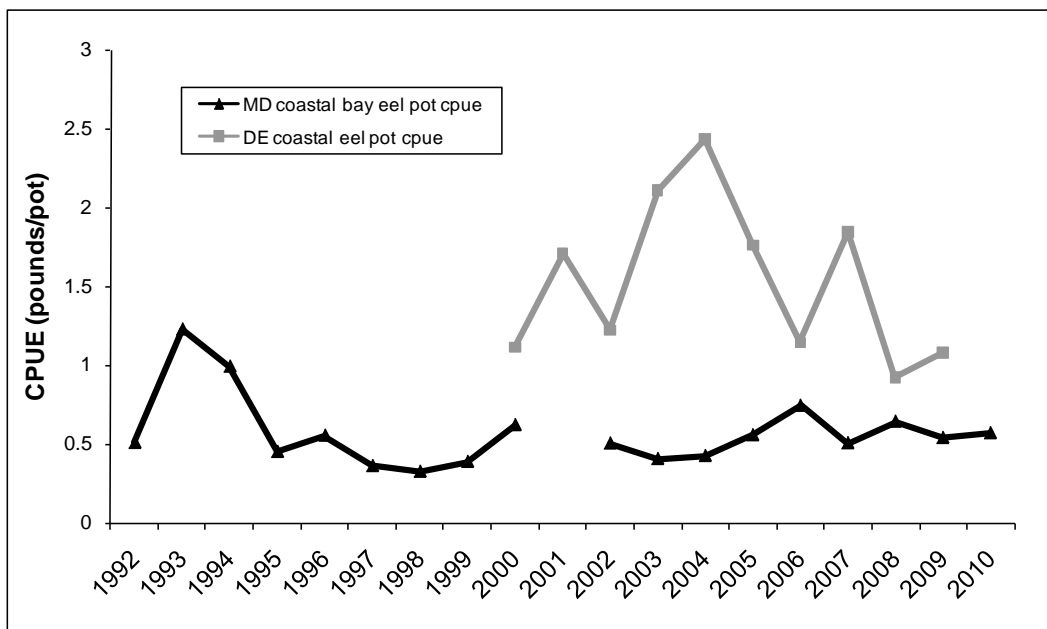


Figure 4.12. Maryland and Delaware commercial fishery eel pot CPUE (pounds/pot) for Coastal Bays, 1992–2010.

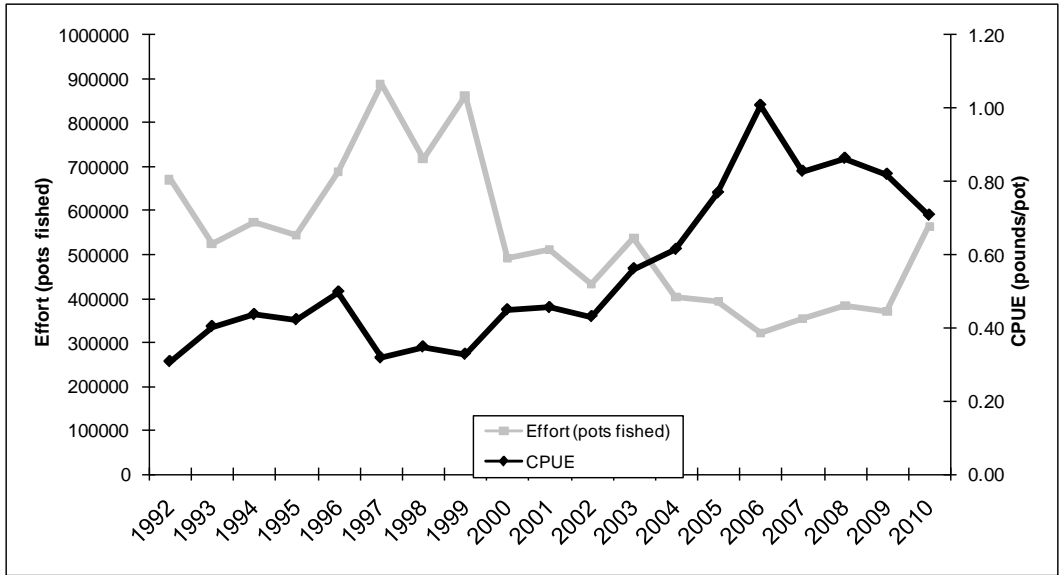


Figure 4.13. Maryland commercial fishery eel pot CPUE (lbs/pot) and effort (total pots fished), 1992–2010.

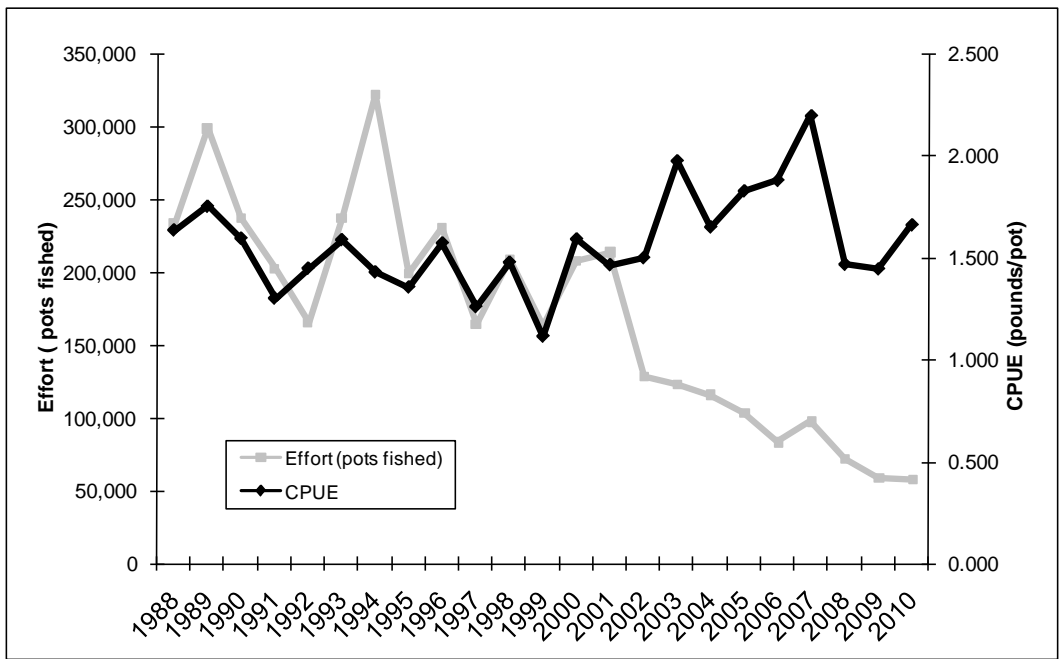


Figure 4.14. PRFC commercial fishery eel pot CPUE (pounds/pot) and effort (total pots fished), 1988–2010.

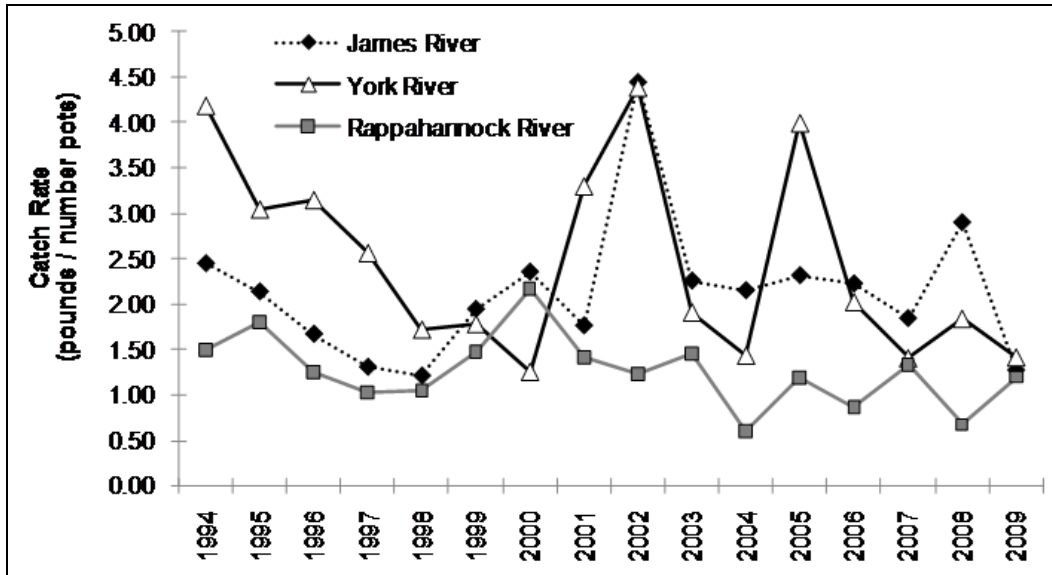


Figure 4.15. Annual commercial fishery catch rates (pounds/number pots) for American eels harvested by eel pots from the primary tributaries of the Chesapeake Bay and landed in Virginia, by tributary, 1994–2009.

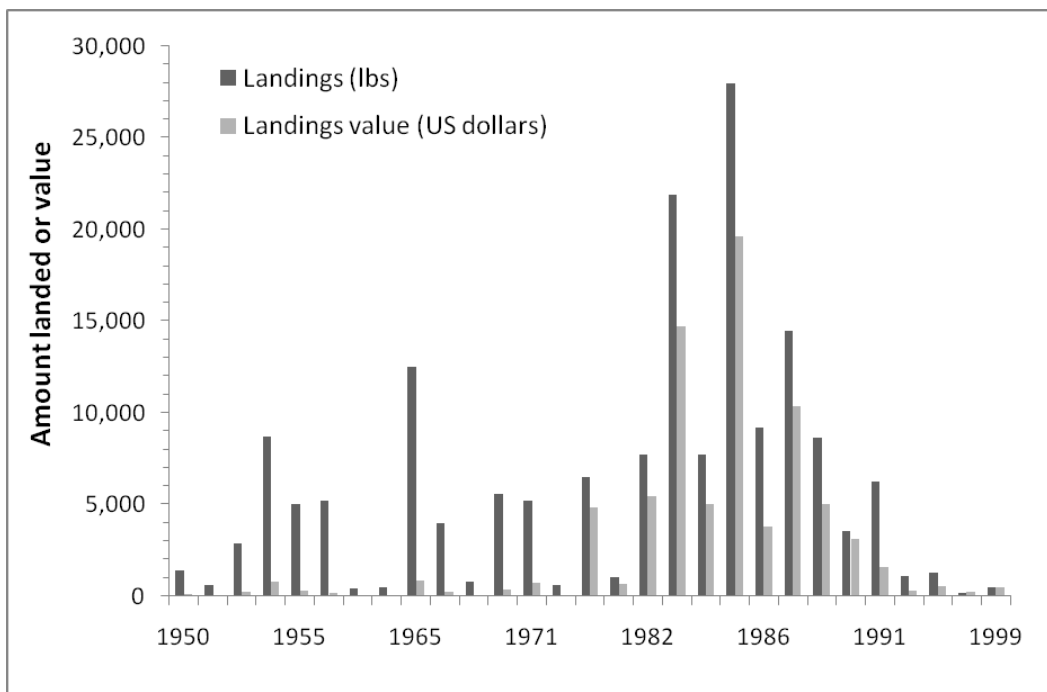


Figure 4.16. Total weight and value of American eel commercial landings in the Gulf of Mexico, 1950–1999. Recent landings are confidential.



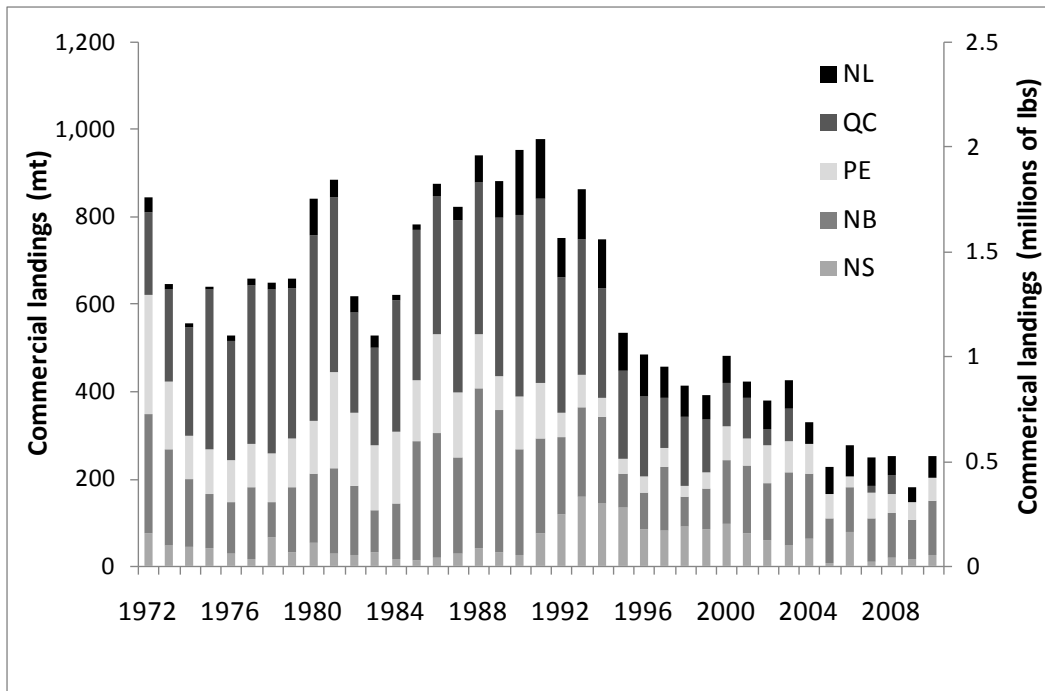


Figure 4.17. Annual commercial fisheries landings (live weight) of American eel along Canada's Atlantic Coast summarized by province, 1972–2009.

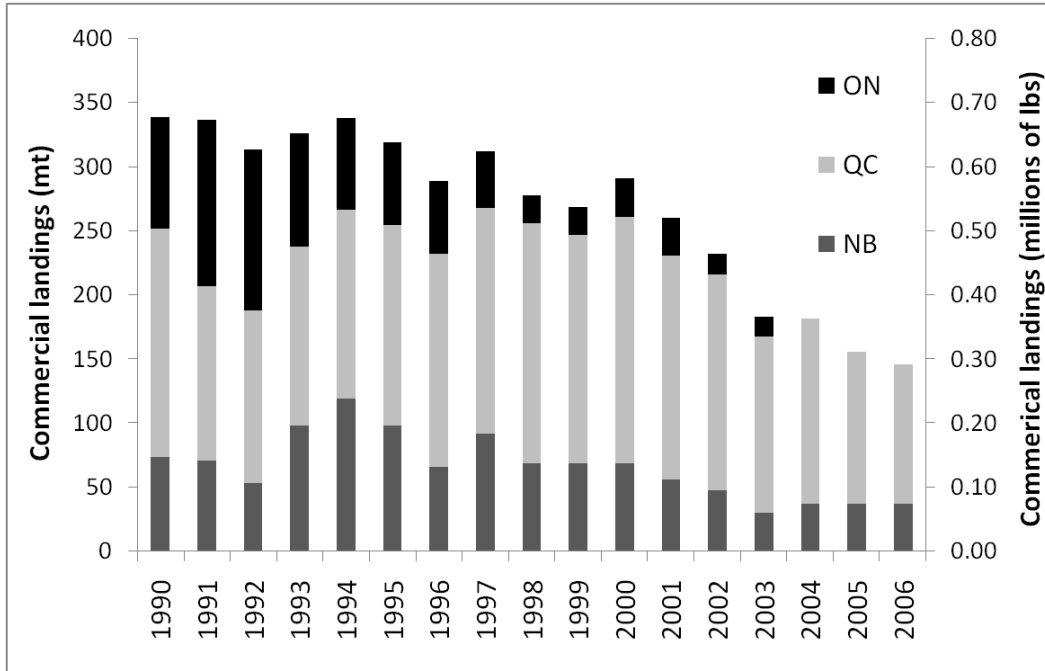


Figure 4.18. Annual commercial freshwater landings (live weight) of American eel along Canada's Atlantic Coast summarized by province, 1990–2006.

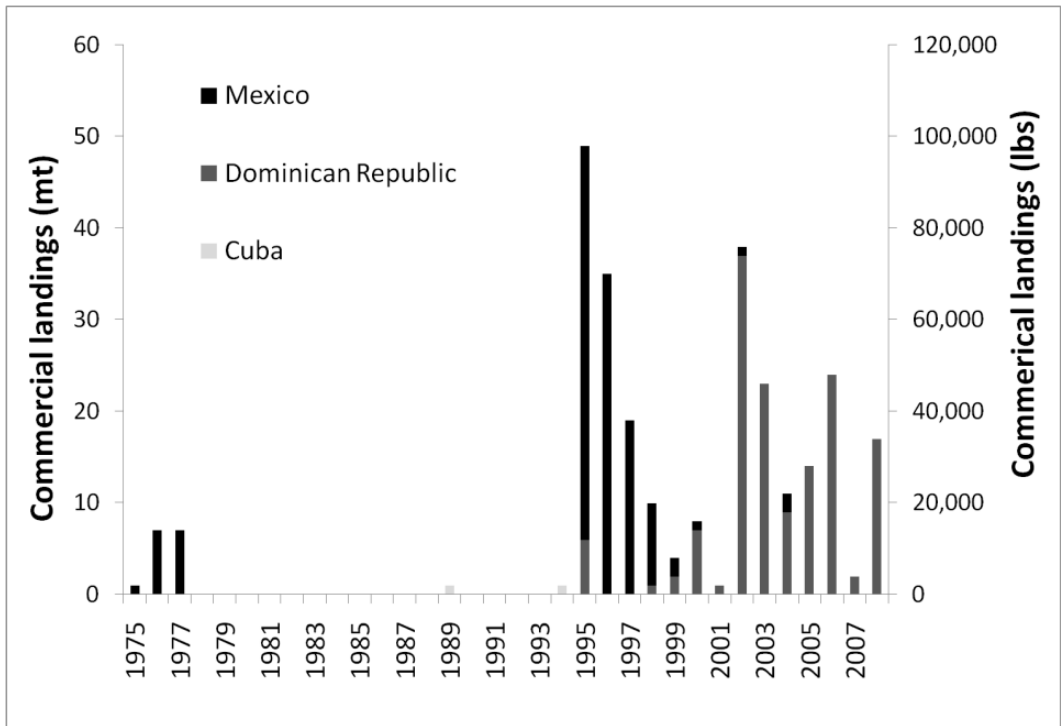


Figure 4.19. Annual commercial landings (live weight) of American eel reported by the FAO from Central and South America, 1975–2008. No landings were reported between 1950 and 1974.

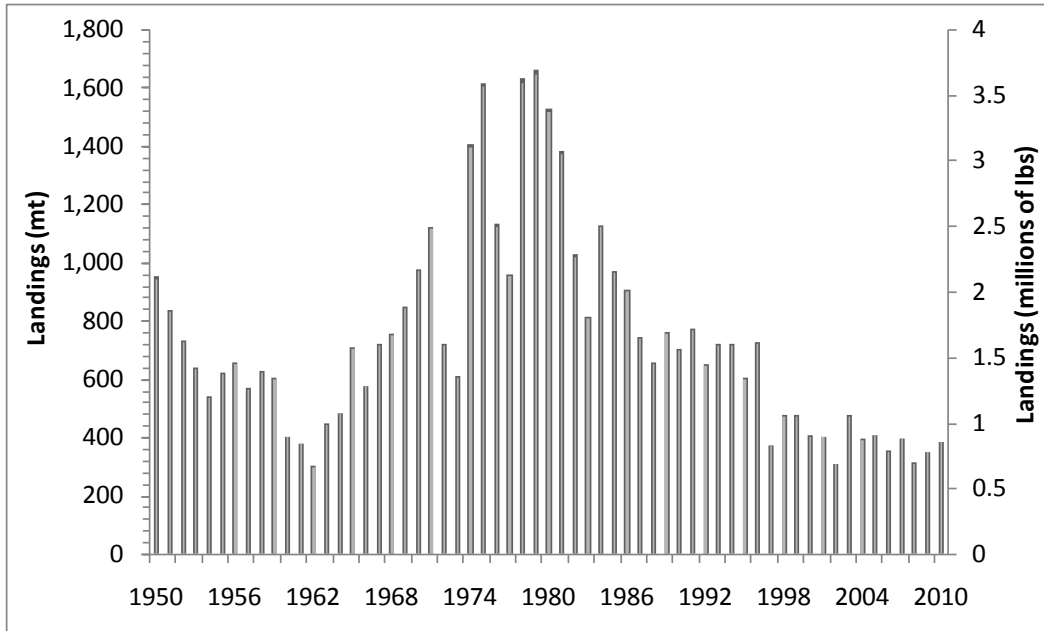


Figure 5.1. Total commercial landings of American eel along the U.S. Atlantic Coast, 1950–2010.

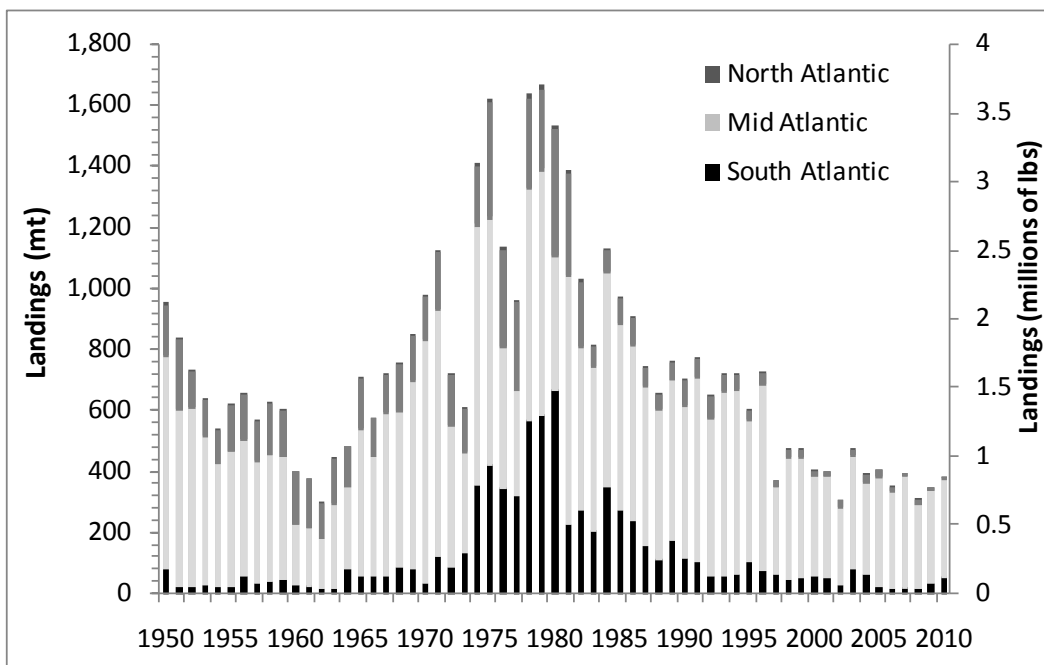


Figure 5.2. Total commercial landings of American eel by old geographic region along the U.S. Atlantic Coast, 1950–2010.

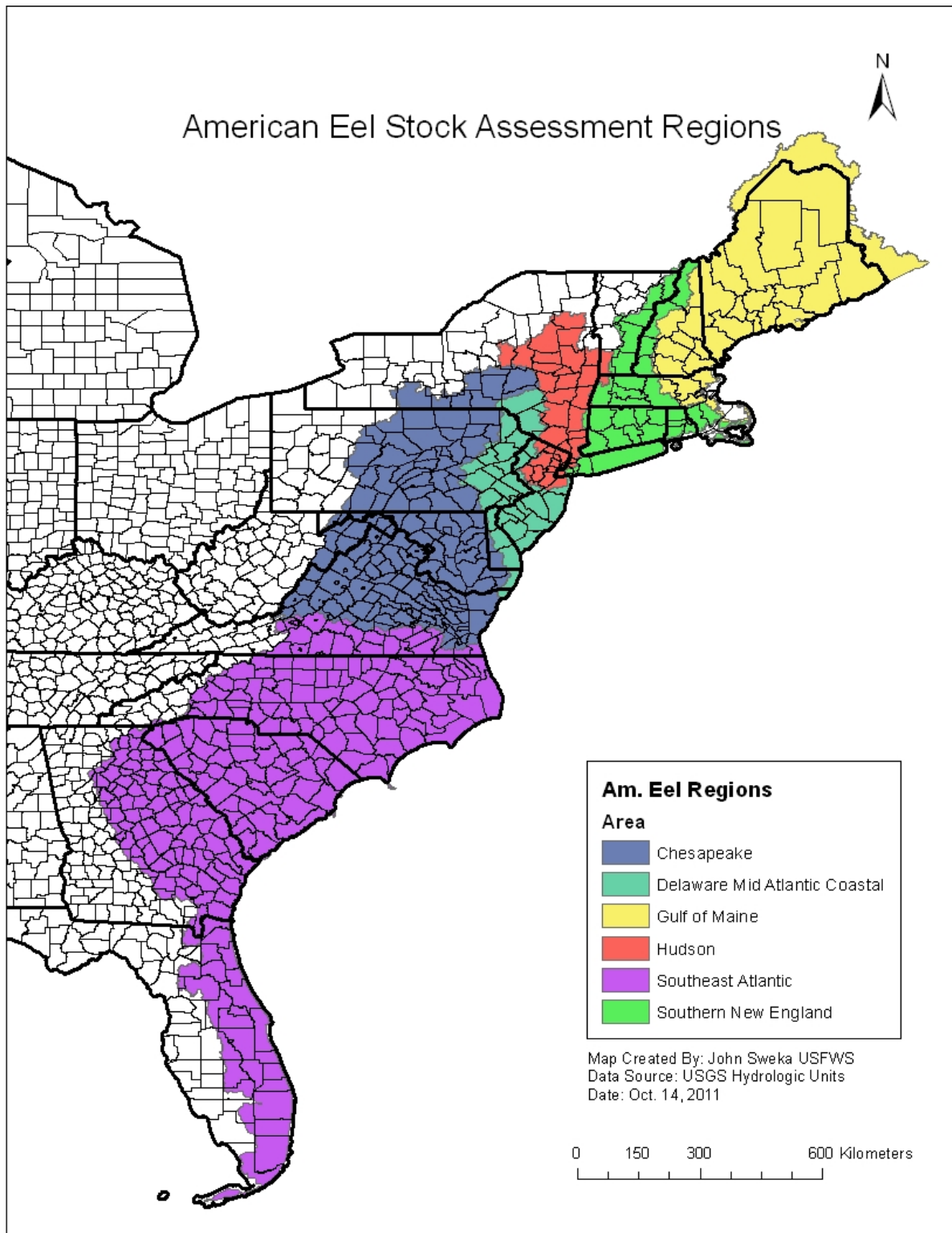


Figure 5.3. Watershed-based geographic regions used in the current assessment.

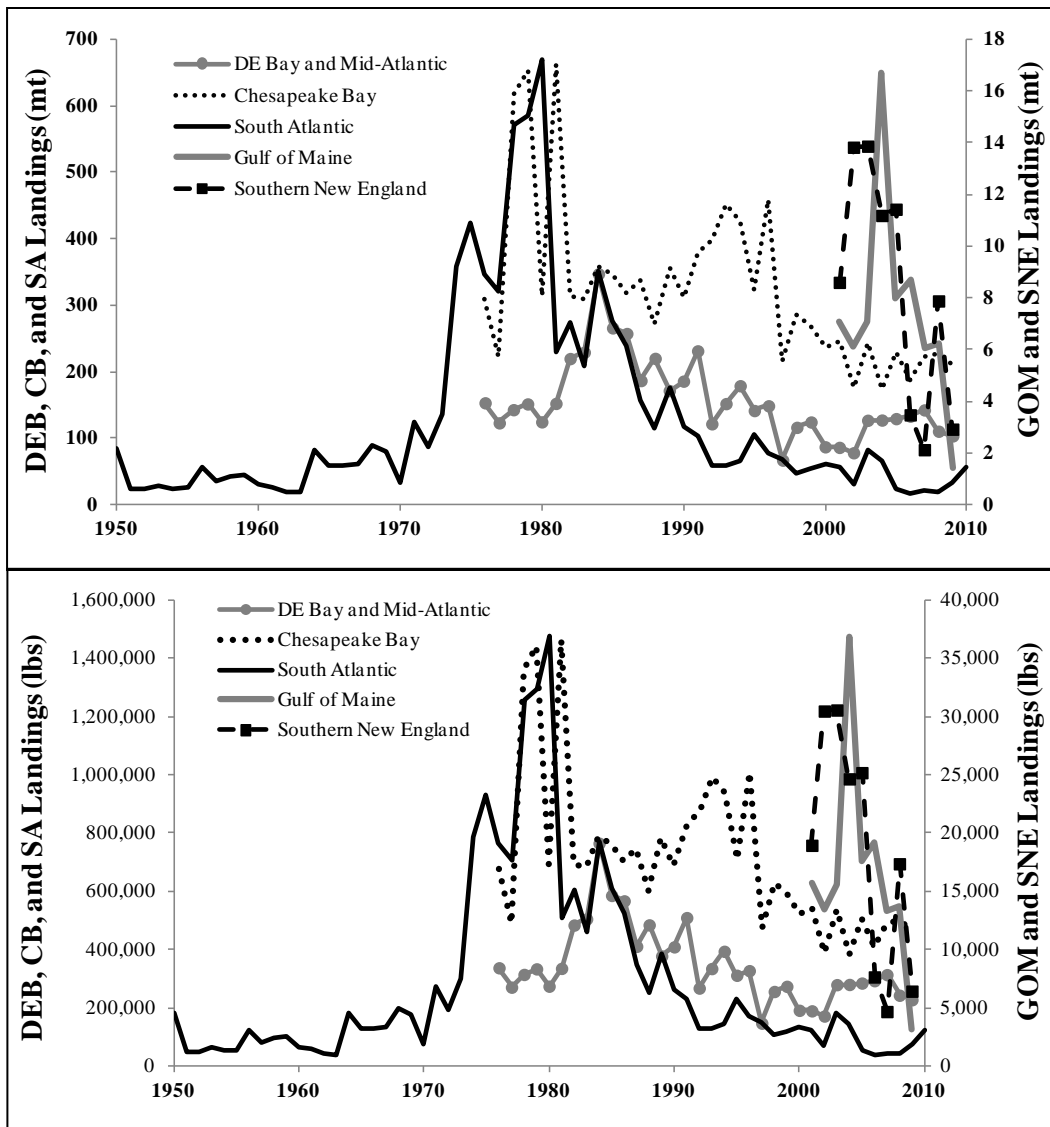


Figure 5.4. Total metric tons (upper graph) and pounds (lower graph) of American eel commercial landings by new geographic region along the U.S. Atlantic Coast, 1950–2010. Note Gulf of Maine and Southern New England are plotted on the secondary axis.

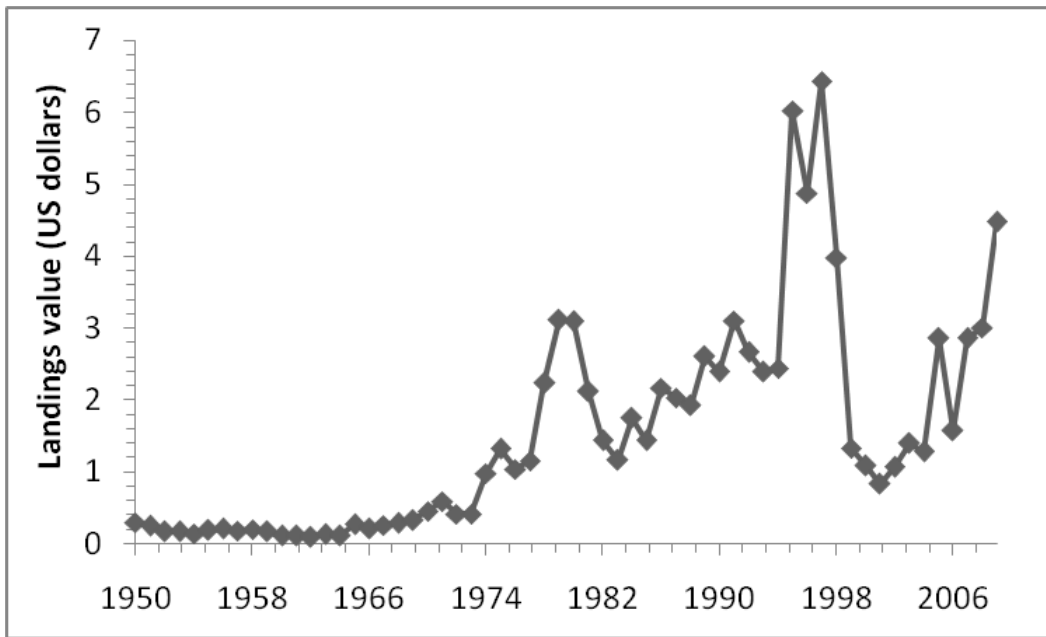


Figure 5.5. Estimated value of U.S. American eel landings, 1950–2009.

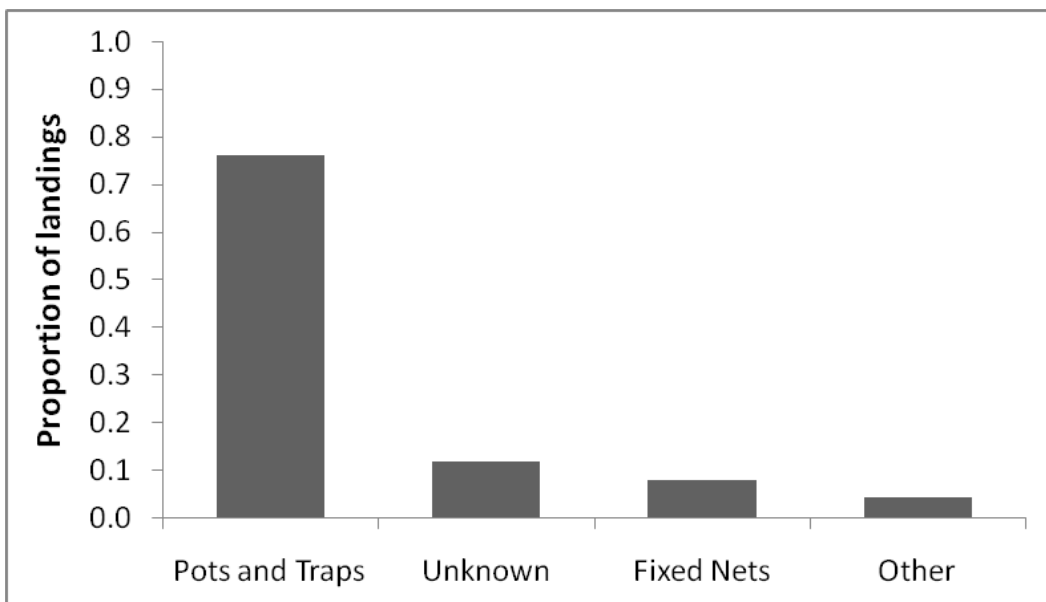


Figure 5.6. Proportion of Atlantic coast commercial landings by general gear type, 1950–2010.

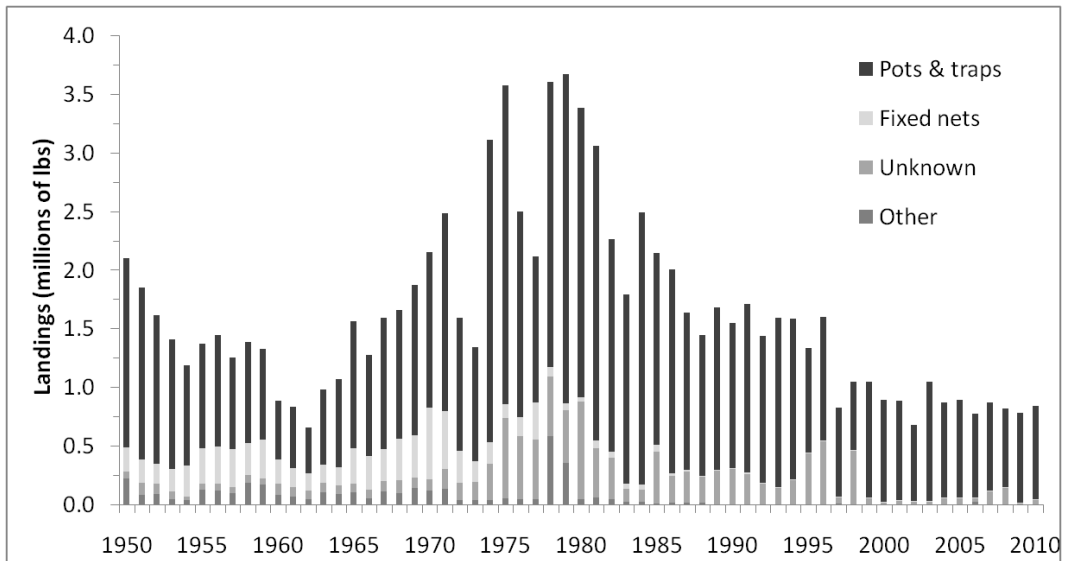


Figure 5.7. Trends in the proportion of Atlantic coast commercial landings by general gear type.

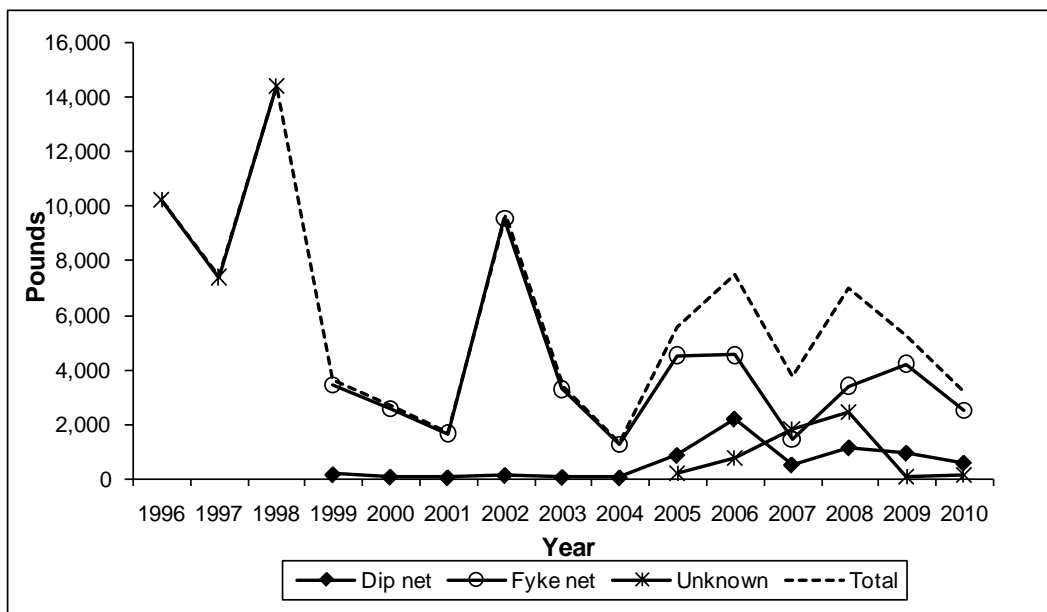


Figure 5.8. Dealer reported commercial glass eel landings in Maine.

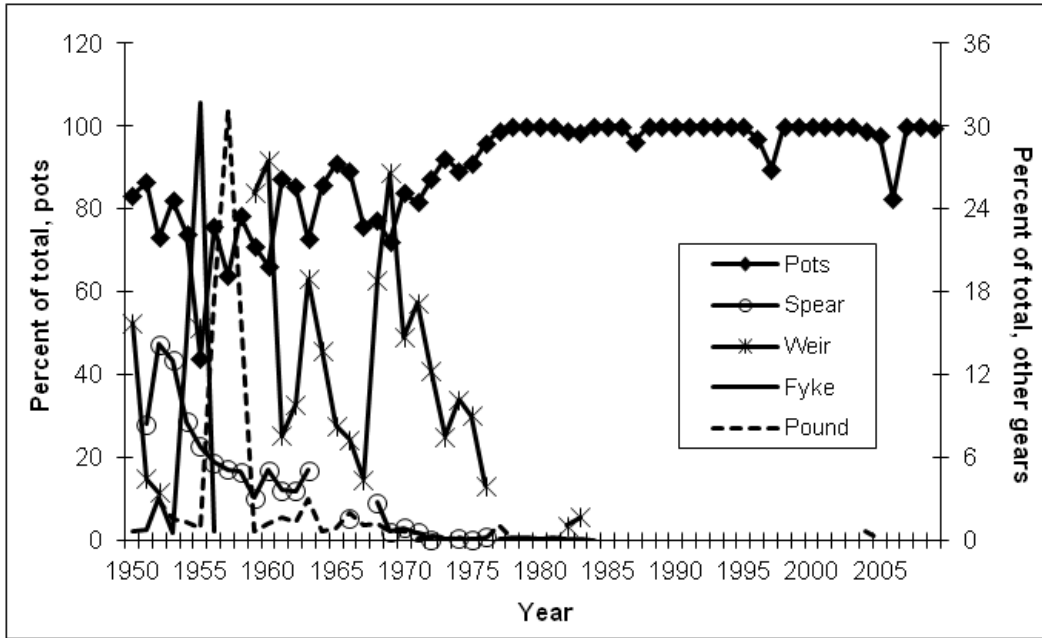


Figure 5.9. Percentage of New Jersey commercial eel landings by gear.



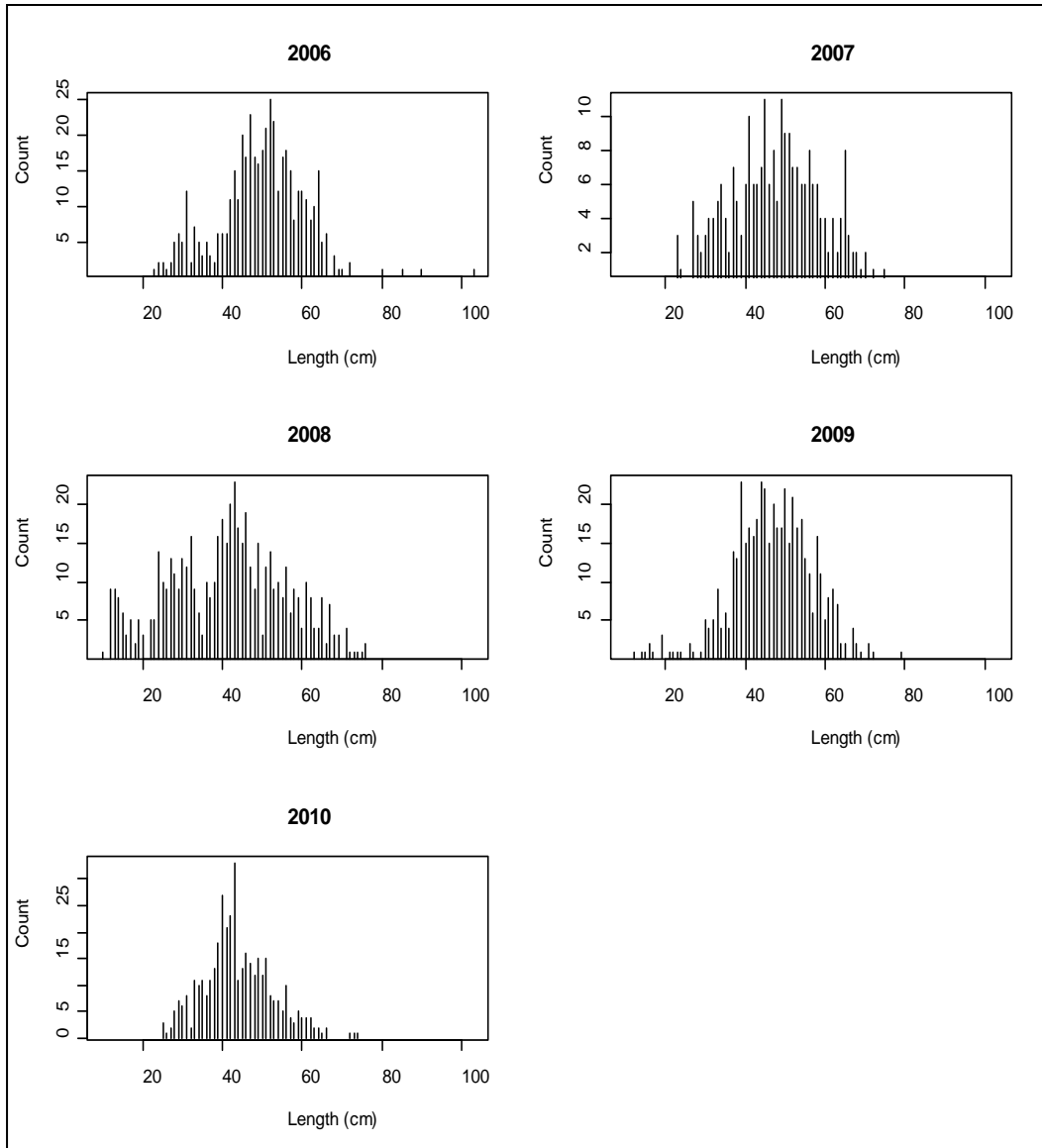


Figure 5.10. Average length (centimeters) of eels sampled from New Jersey’s commercial harvest.

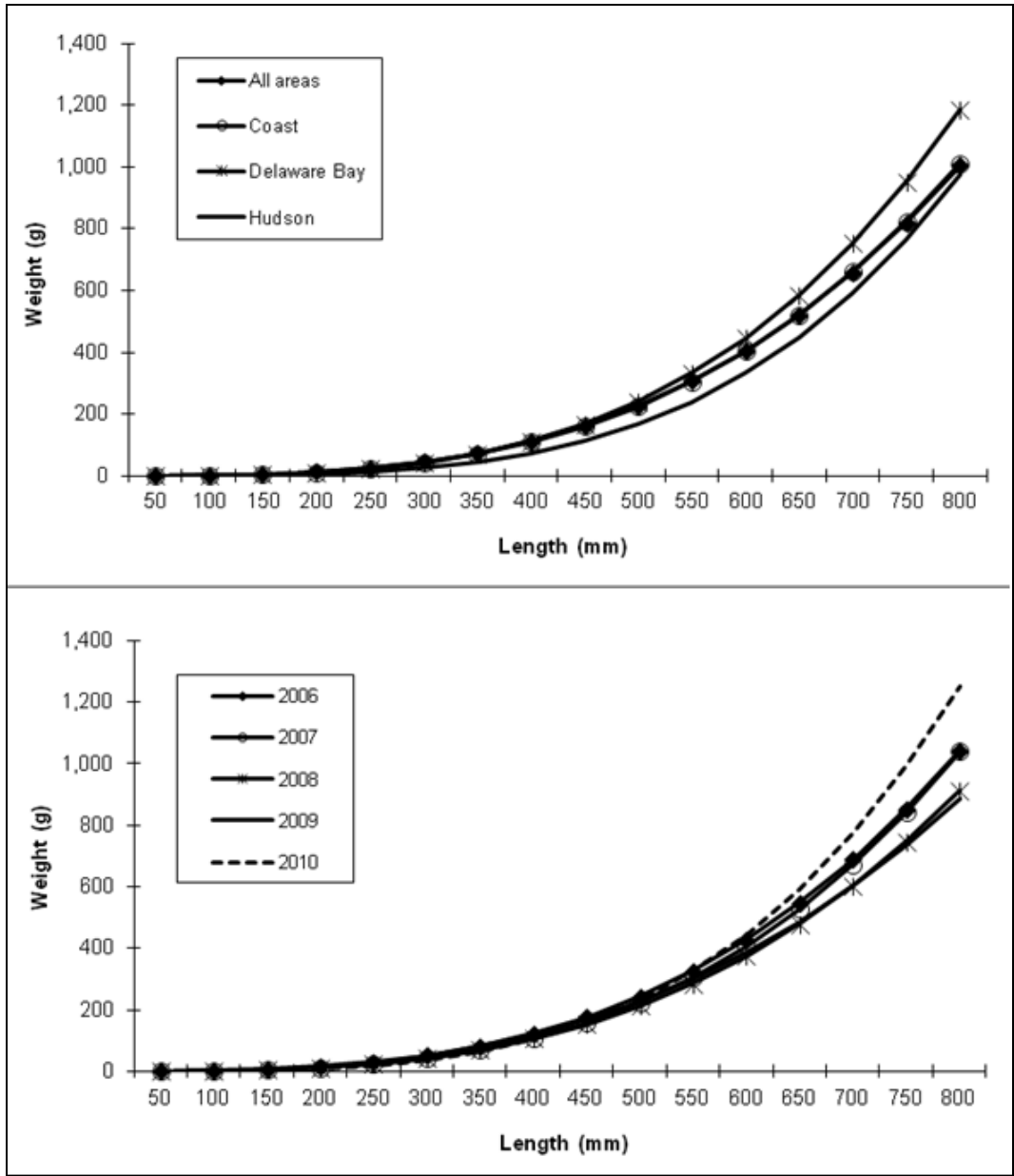


Figure 5.11. Predicted weight at length of American eels sampled from New Jersey's commercial harvest by area for all years combined (upper graph) and by year for all areas combined (lower graph).

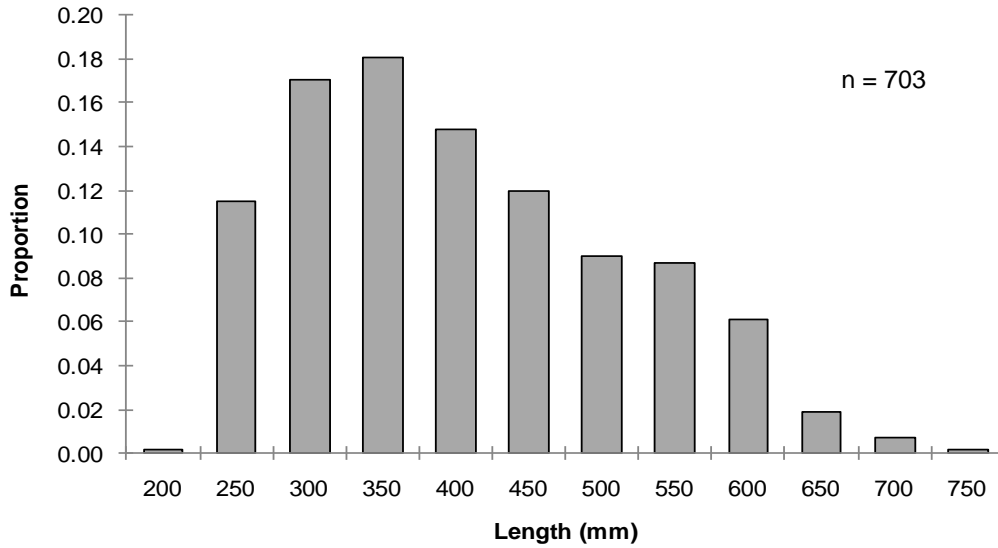


Figure 5.12. Length-frequency distribution of American eels sampled from Virginia's eel pot landings, 1989–2008. No American eels were available for sampling in 2009 or 2010.

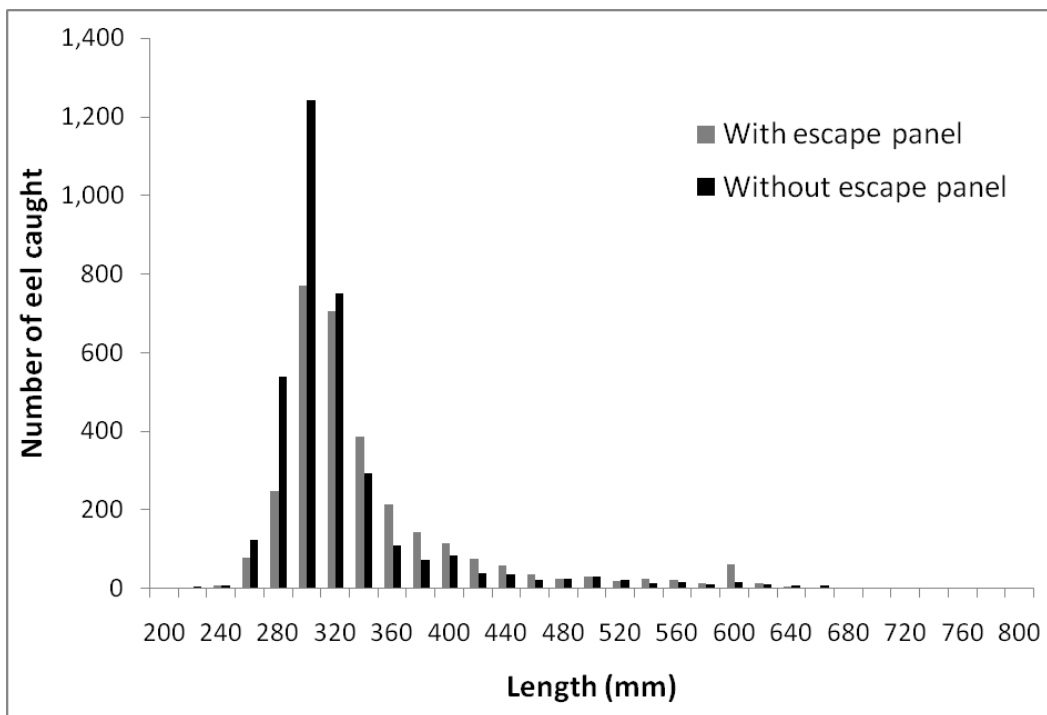


Figure 5.13. Length distribution of American eels sampled from commercial eel pots with and without escape panel, Pamlico River, 1996.

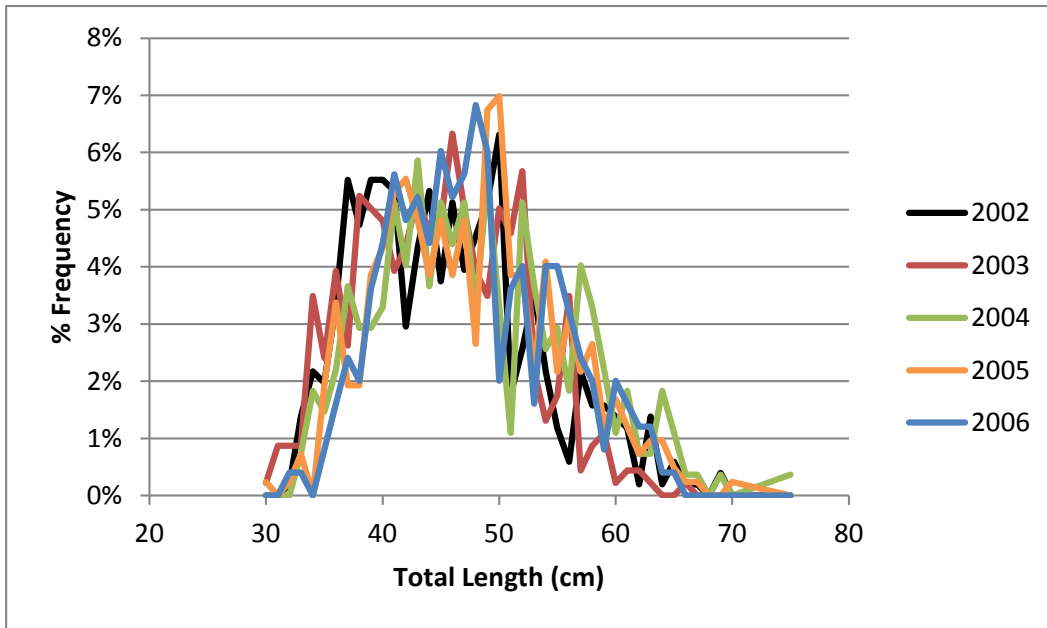


Figure 5.14. Length frequency distribution of American eels from the St. Johns River system, Florida. Biological sampling was discontinued after 2006.

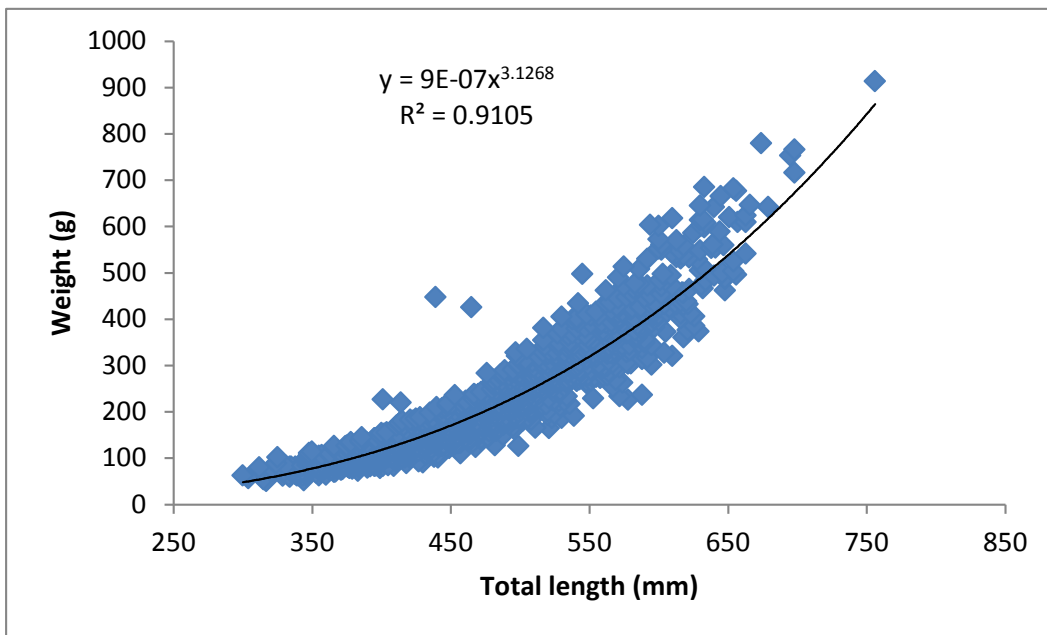


Figure 5.15. Weight-length relationship for American eels in the St. Johns River system, Florida, 2002–2006.

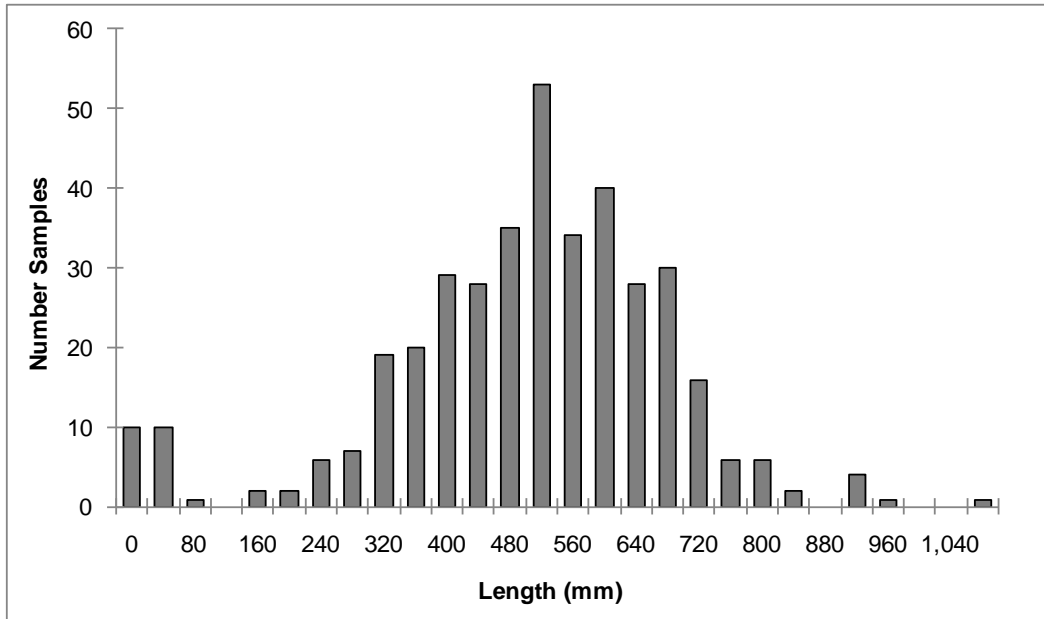


Figure 5.16. Length-frequency of American eels sampled by the MRFSS angler-intercept survey (Type A catch), 1981–2010.

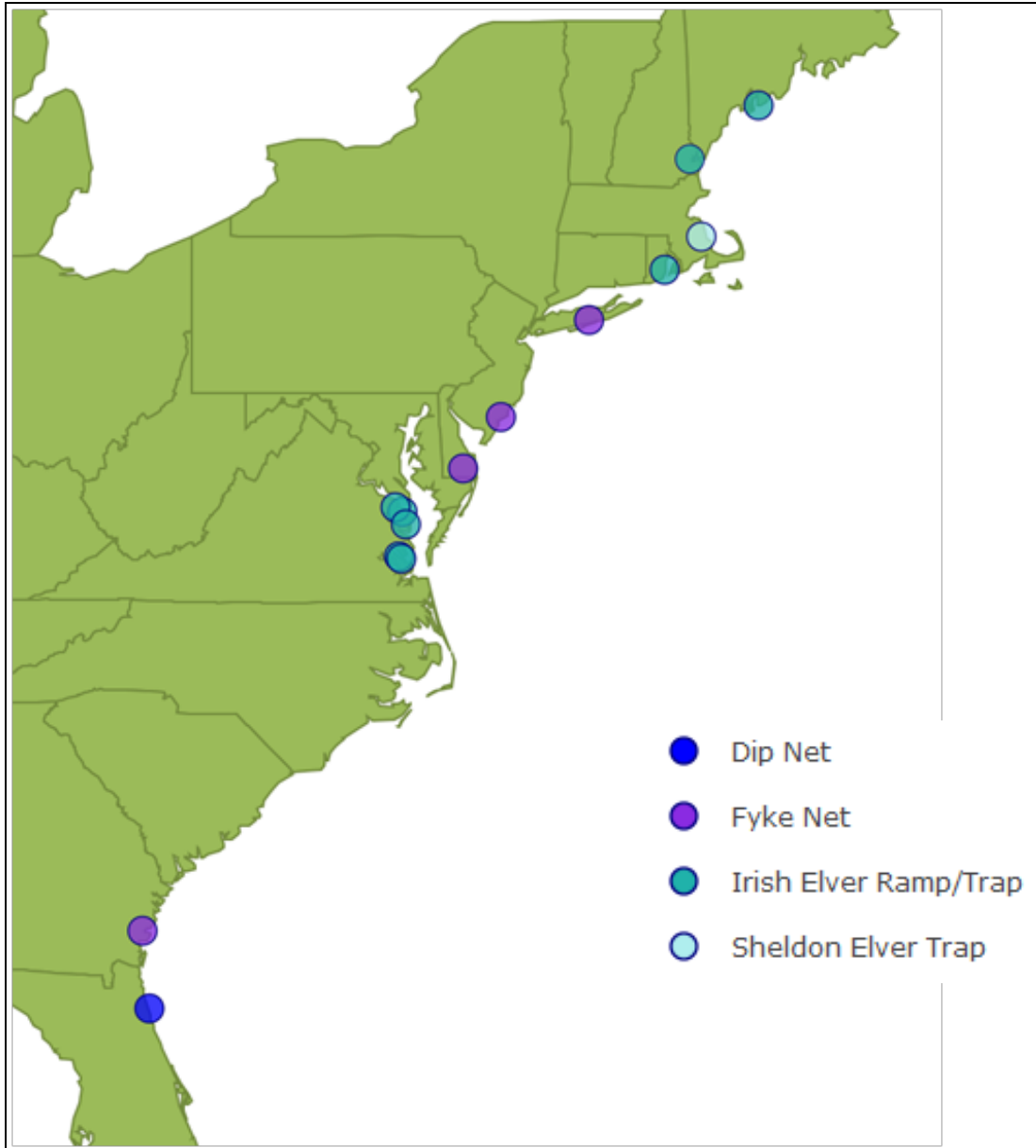


Figure 5.17. Locations of ASMFC-mandated annual American eel YOY abundance survey sites that have been sampled for at least 10 years, as of 2010.

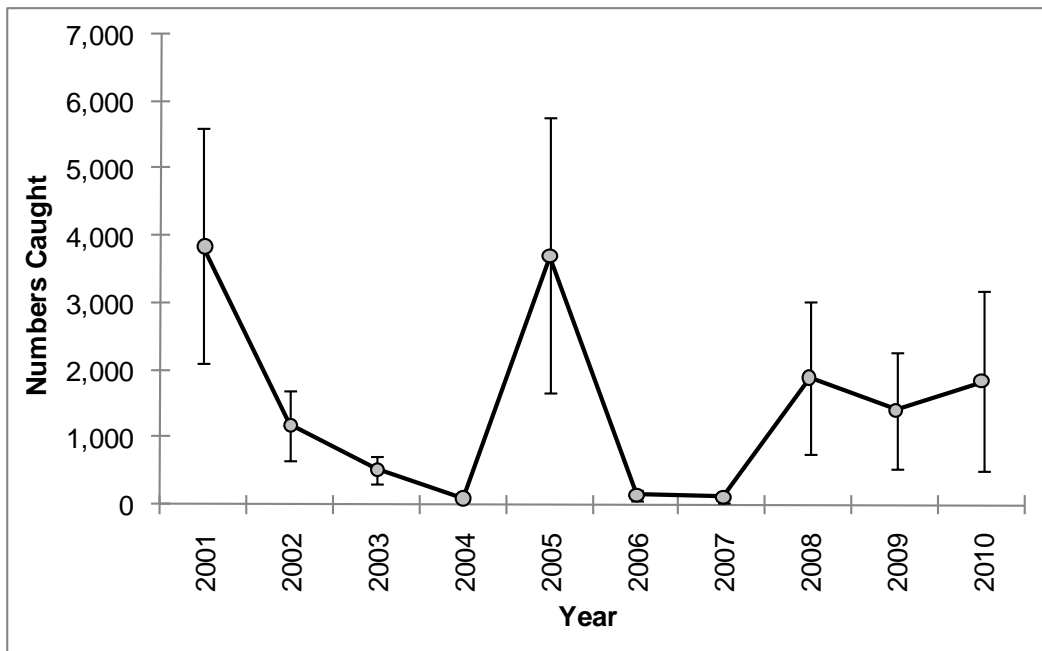


Figure 5.18. GLM-standardized index of abundance for YOY American eels caught by Maine's annual YOY survey in West Harbor Pond, 2001–2010. The error bars represent the standard errors about the estimates.

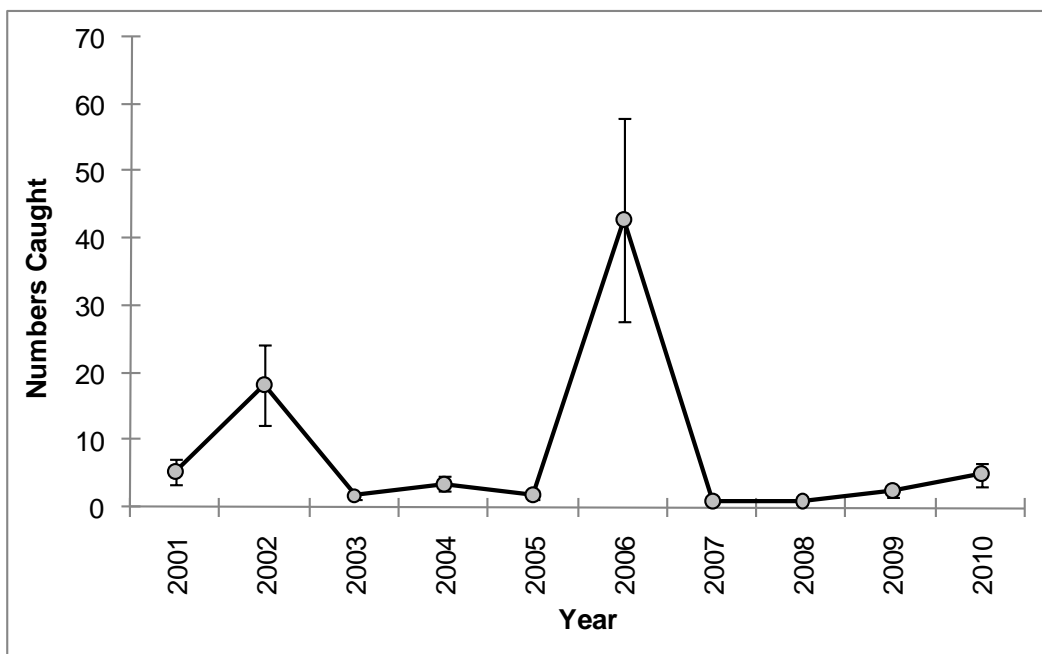


Figure 5.19. GLM-standardized index of abundance for YOY American eels caught by New Hampshire's annual YOY survey in the Lamprey River, 2001–2010. The error bars represent the standard errors about the estimates.

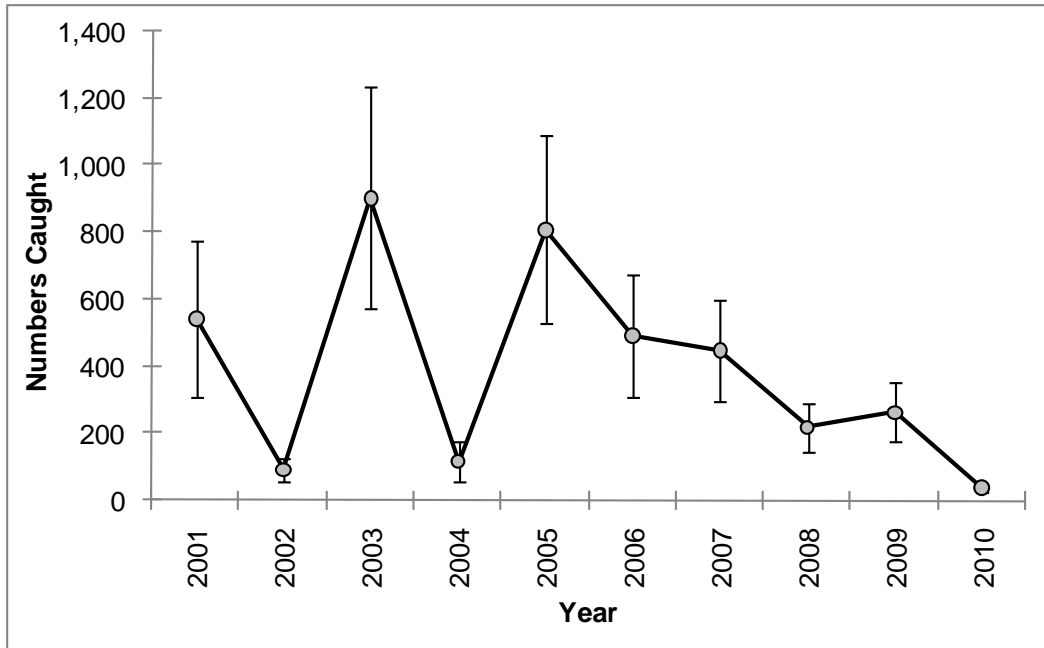


Figure 5.20. GLM-standardized index of abundance for YOY American eels caught by Massachusetts' annual YOY survey in the Jones River, 2001–2010. The error bars represent the standard errors about the estimates.

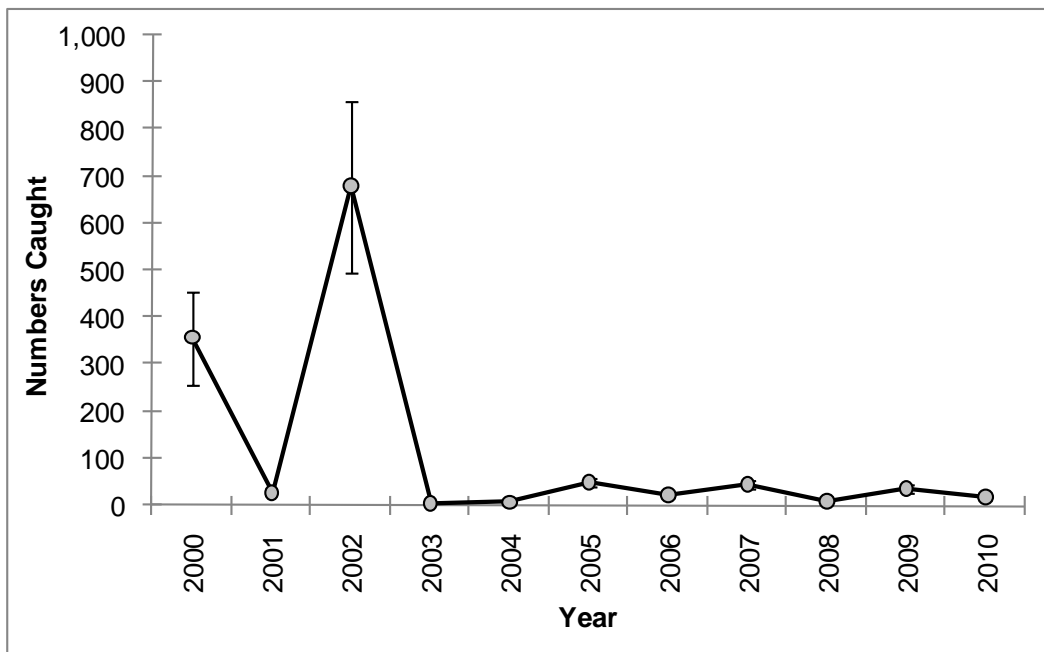


Figure 5.21. GLM-standardized index of abundance for American eels caught by Rhode Island's annual YOY survey near Gilbert Stuart Dam, 2000–2010. The error bars represent the standard errors about the estimates.



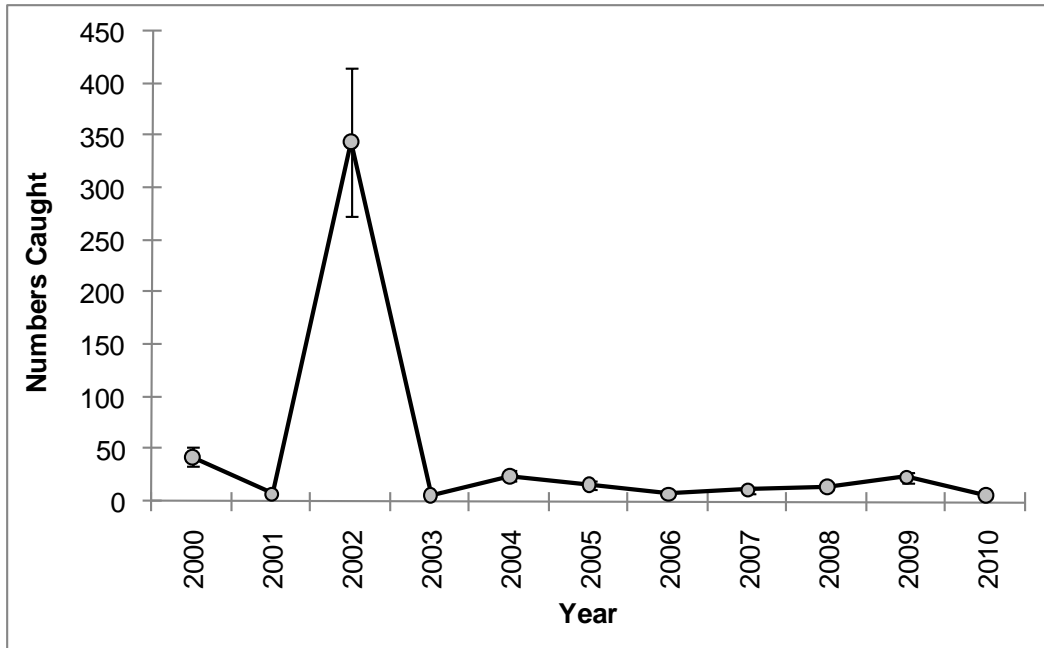


Figure 5.22. GLM-standardized index of abundance for American eels caught by New York's annual YOY survey in Carman's River, 2001–2010. The error bars represent the standard errors about the estimates.

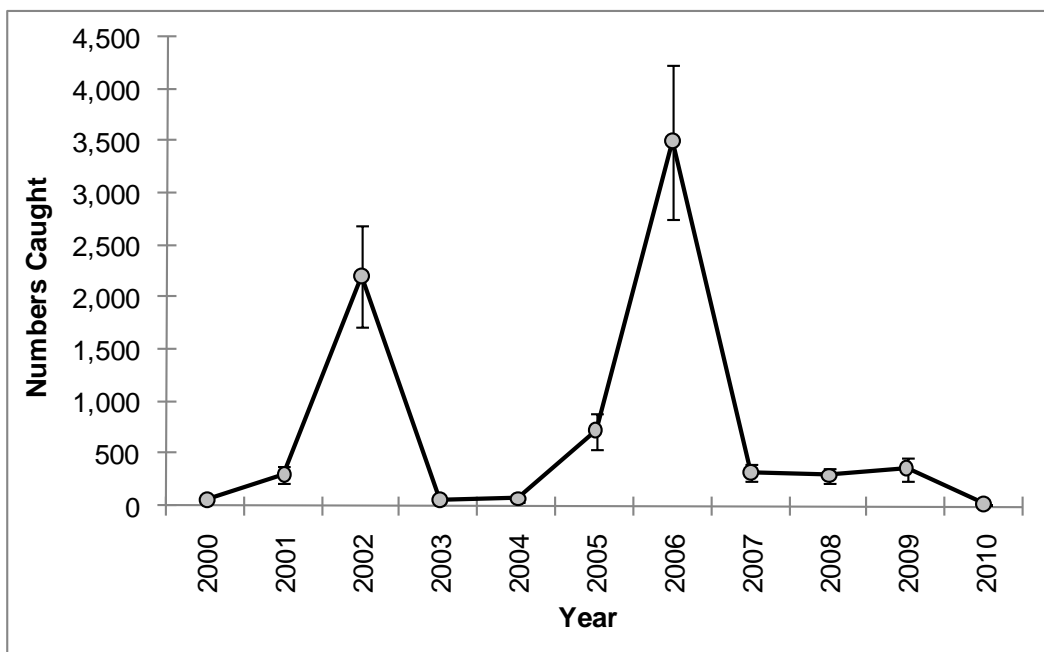


Figure 5.23. GLM-standardized index of abundance for YOY American eels caught by New Jersey's annual YOY survey in Patcong Creek, 2000–2010. The error bars represent the standard errors about the estimates.

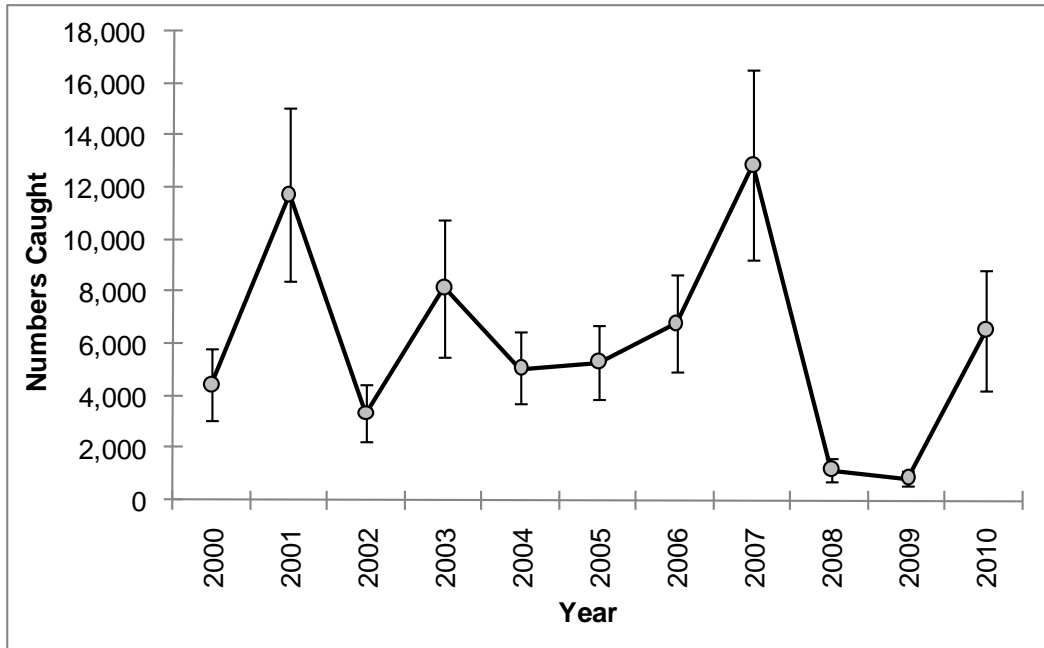


Figure 5.24. GLM-standardized index of abundance for American eels caught by Delaware's annual YOY survey near the Millsboro Dam, 2000–2010. The error bars represent the standard errors about the estimates.

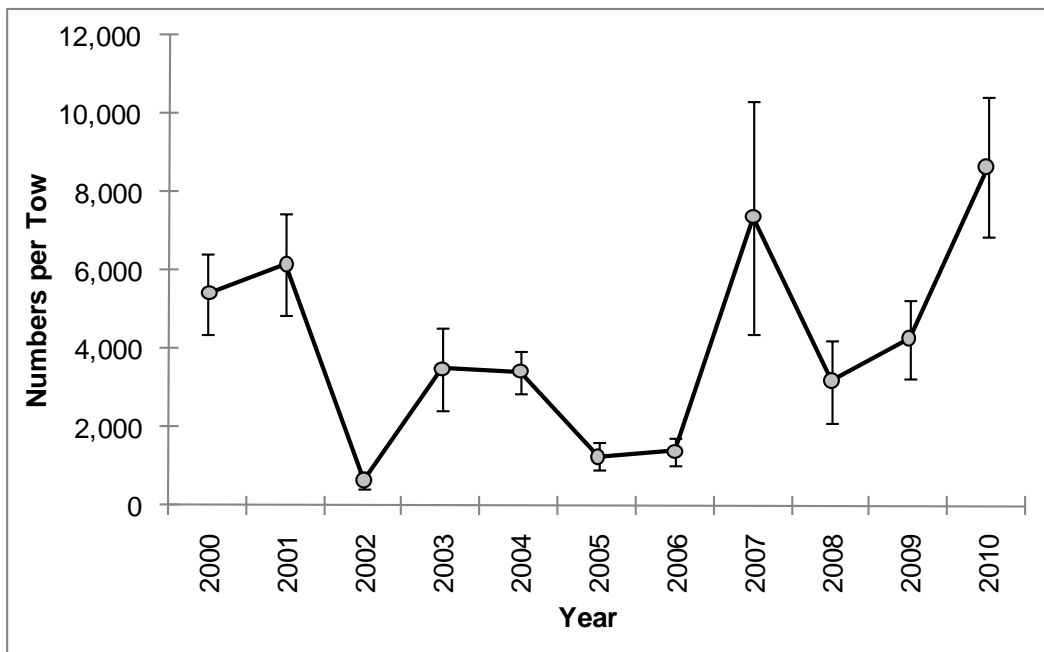


Figure 5.25. Annual index of abundance for American eels caught by Maryland's annual YOY survey in Turville Creek, 2000–2010. The error bars represent the standard errors about the estimates.

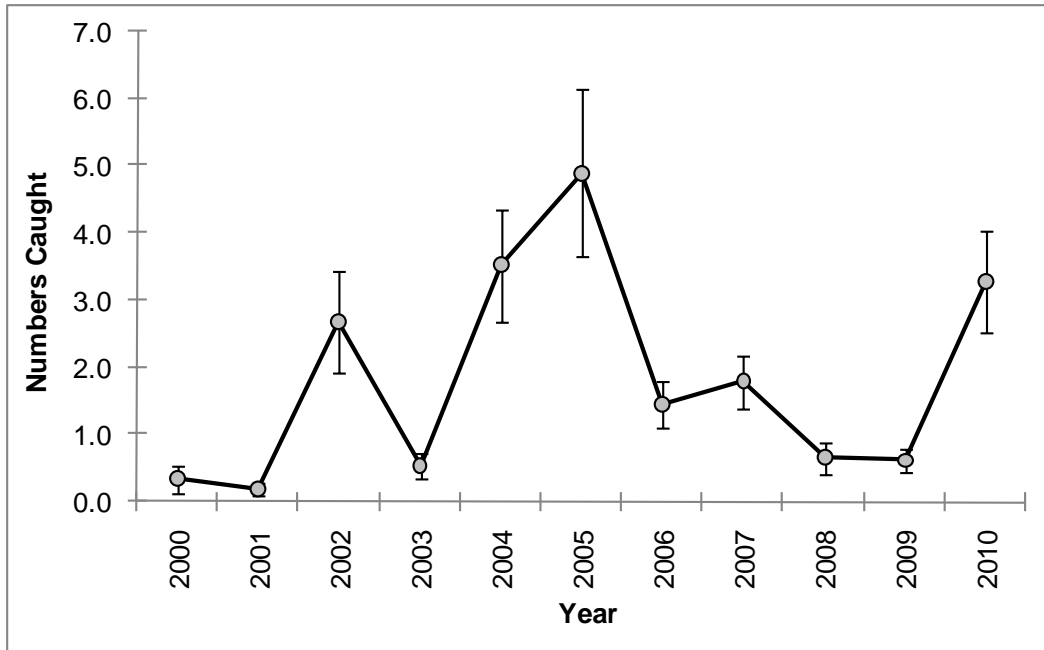


Figure 5.26. GLM-standardized index of abundance for American eels caught by PRFC's annual YOY survey in Clark's Millpond, 2000–2010. The error bars represent the standard errors about the estimates.

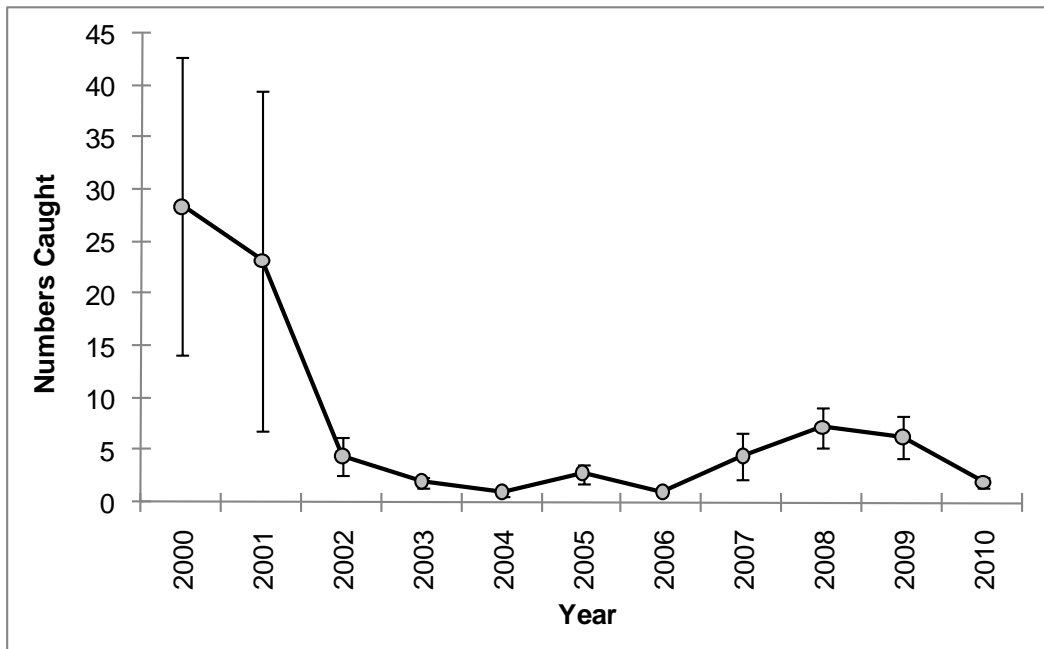


Figure 5.27. GLM-standardized index of abundance for American eels caught by PRFC's annual YOY survey in Gardy's Millpond, 2000–2010. The error bars represent the standard errors about the estimates.

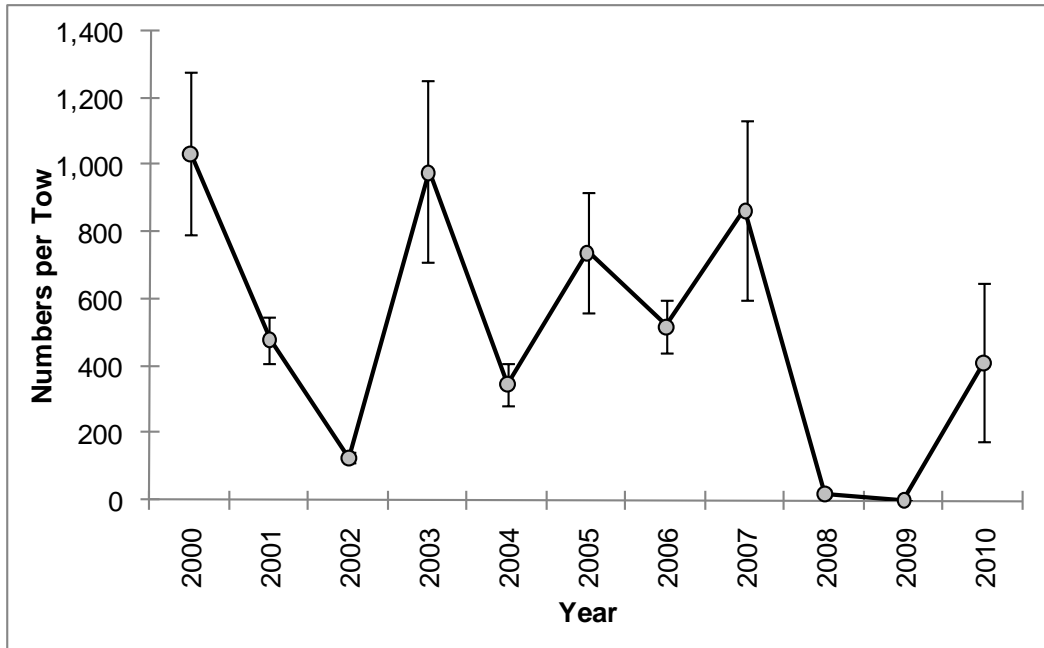


Figure 5.28. Annual index of abundance for American eels caught by Virginia's annual YOY survey in Bracken's Pond, 2000–2010. The error bars represent the standard errors about the estimates.

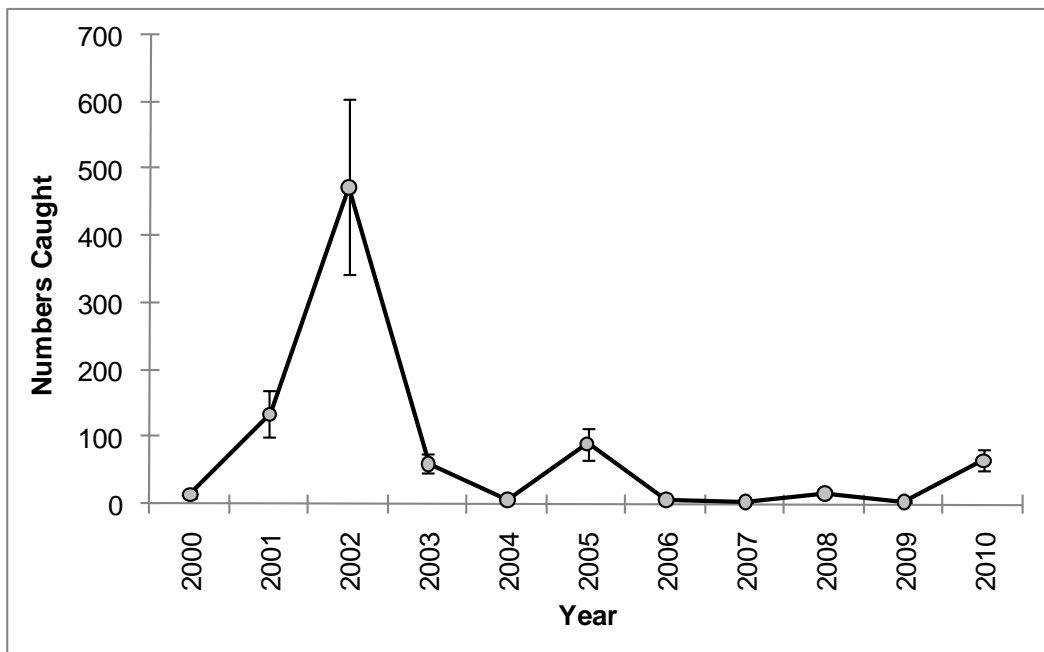


Figure 5.29. GLM-standardized index of abundance for American eels caught by Virginia's annual YOY survey in Kamp's Millpond, 2000–2010. The error bars represent the standard errors about the estimates.

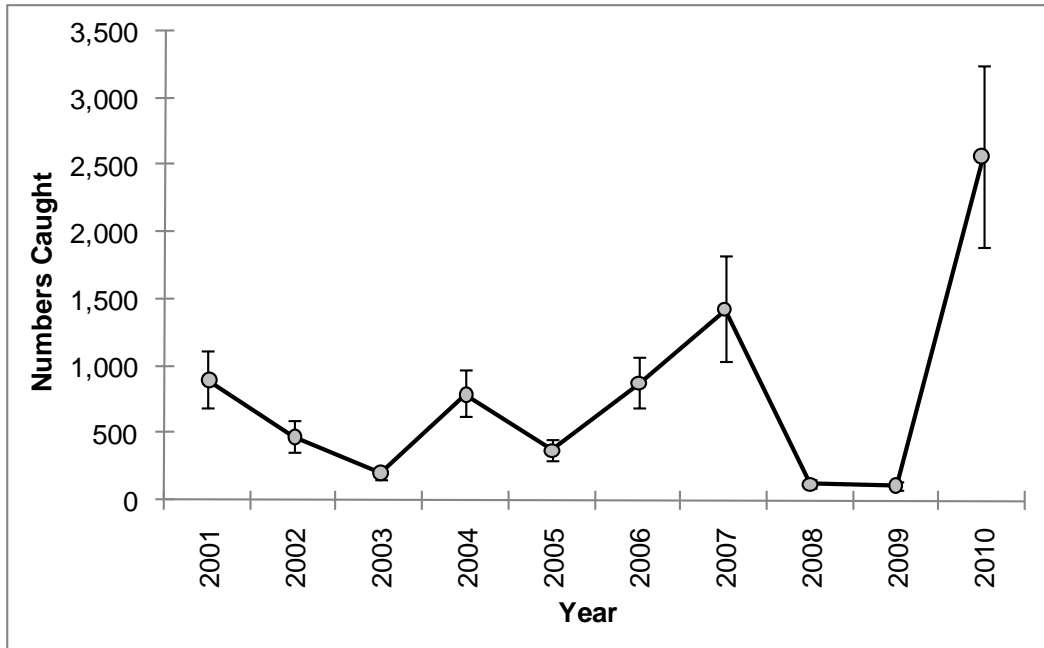


Figure 5.30. GLM-standardized index of abundance for American eels caught by Virginia's annual YOY survey in Wormley Creek, 2001–2010. The error bars represent the standard errors about the estimates.

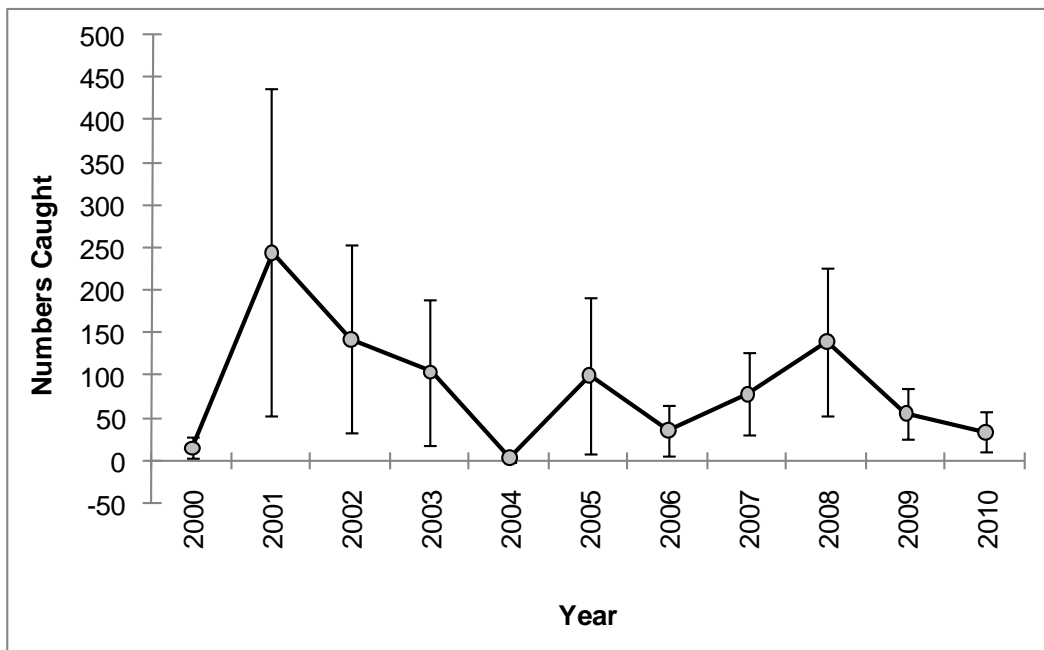


Figure 5.31. GLM-standardized index of abundance for American eels caught by South Carolina's annual YOY survey in Goose Creek, 2000–2010. The error bars represent the standard errors about the estimates.

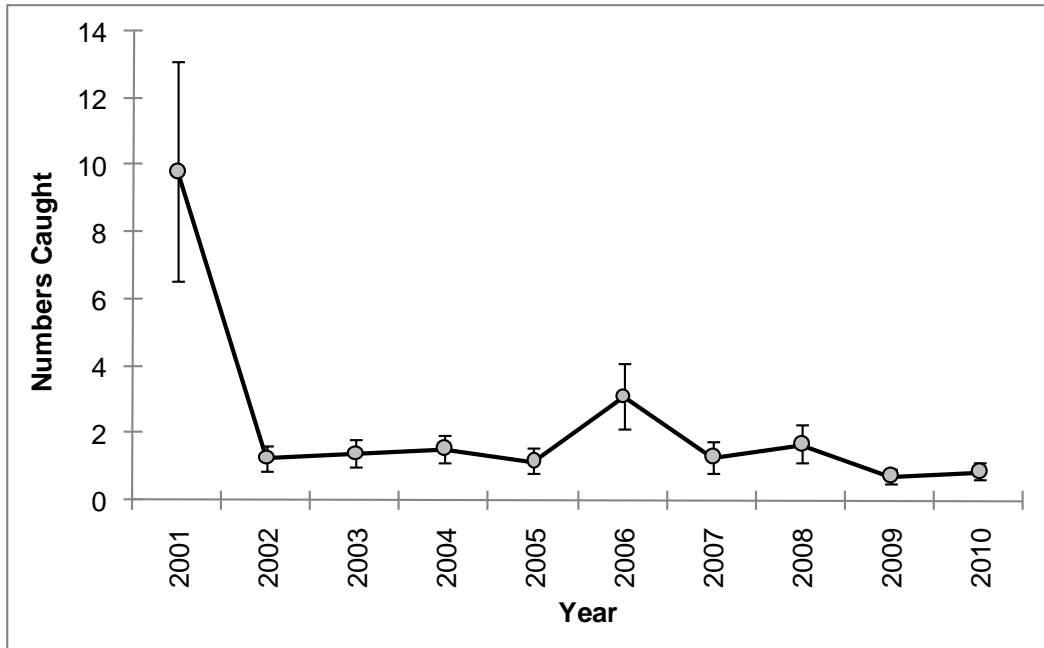


Figure 5.32. GLM-standardized index of abundance for American eels caught by Georgia's annual YOY survey near the Altamaha Canal, 2001–2010. The error bars represent the standard errors about the estimates.

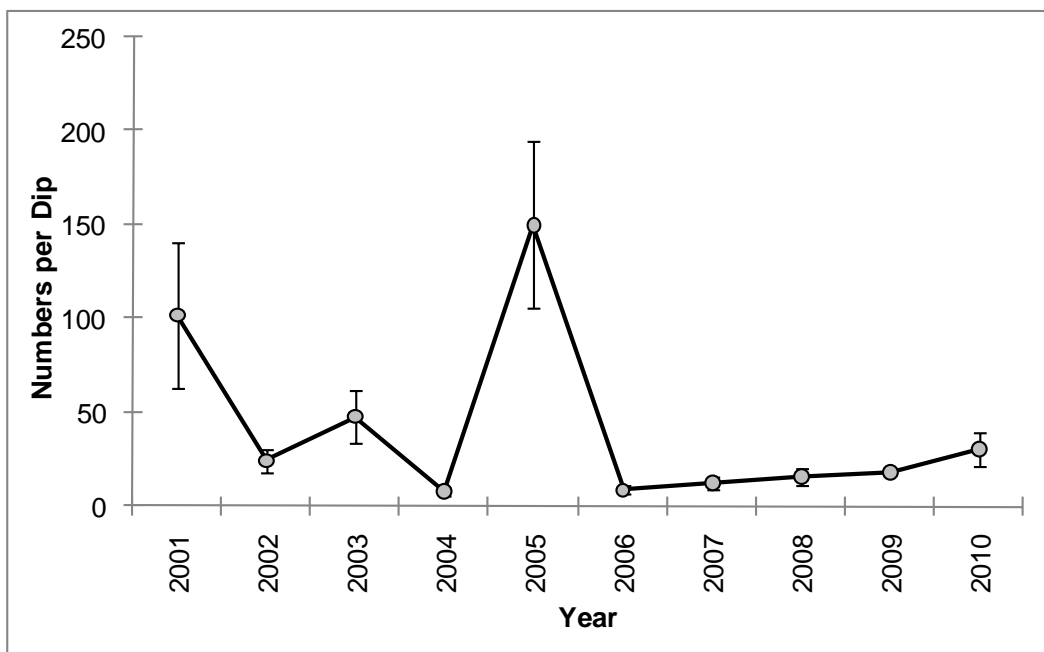


Figure 5.33. Annual index of abundance for American eels caught by Florida's annual YOY survey near Guana River Dam, 2001–2010. The error bars represent the standard errors about the estimates.

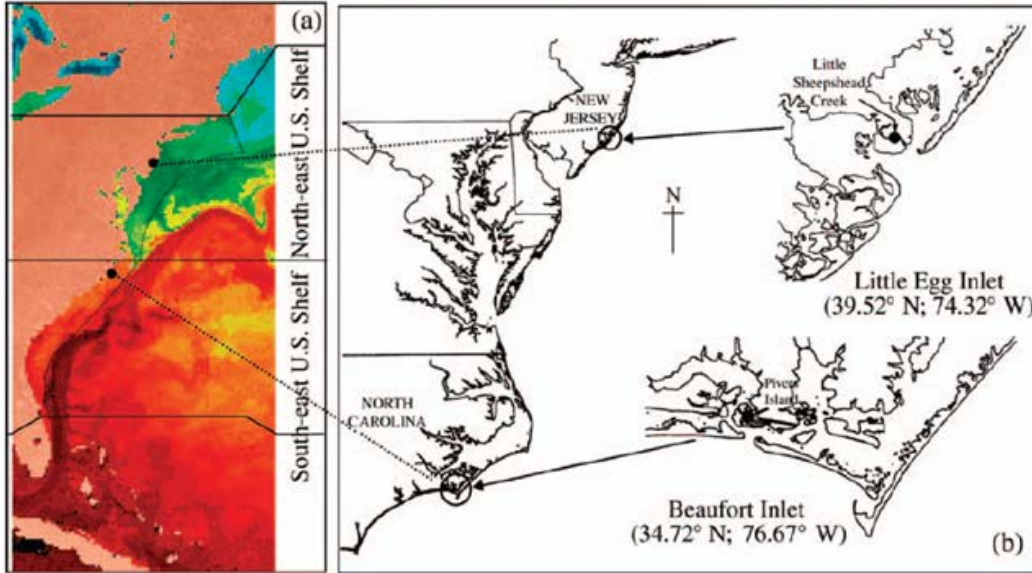


Figure 5.34. Map of Little Egg Inlet Ichthyoplankton and Beaufort Inlet Ichthyoplankton Survey study areas. (Adapted from Sullivan et al. 2006.)

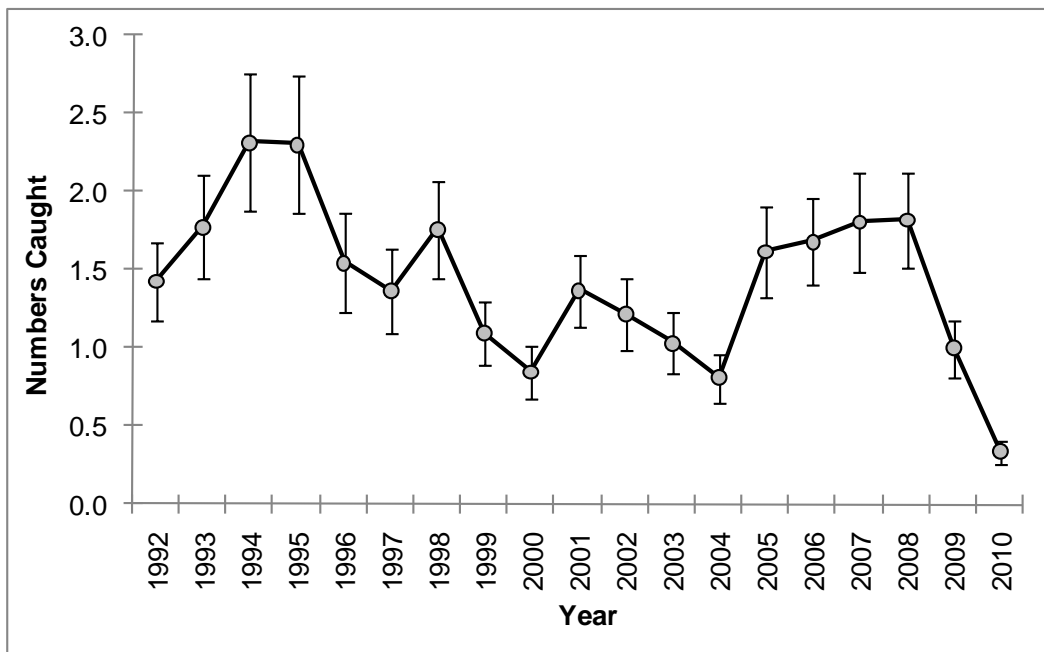


Figure 5.35. GLM-standardized index of abundance for YOY American eels caught by the Little Egg Inlet Ichthyoplankton Survey, 1992–2010. The error bars represent the standard errors about the estimates.

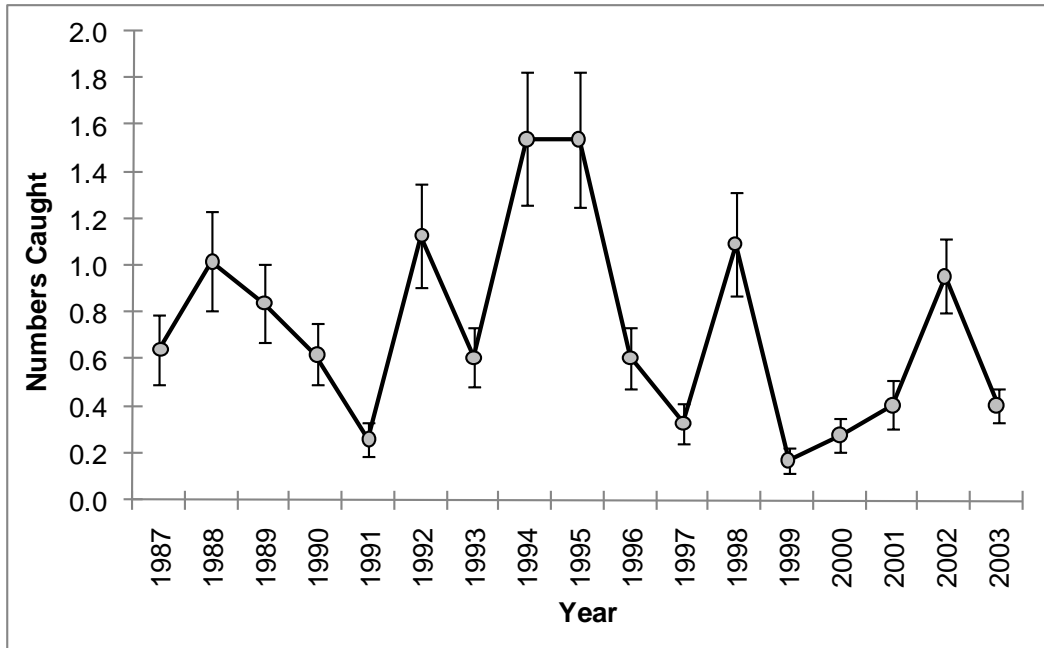


Figure 5.36. GLM-standardized index of abundance for American eels caught by the Beaufort Inlet Ichthyoplankton Survey, 1987–2003. The error bars represent the standard errors about the estimates.



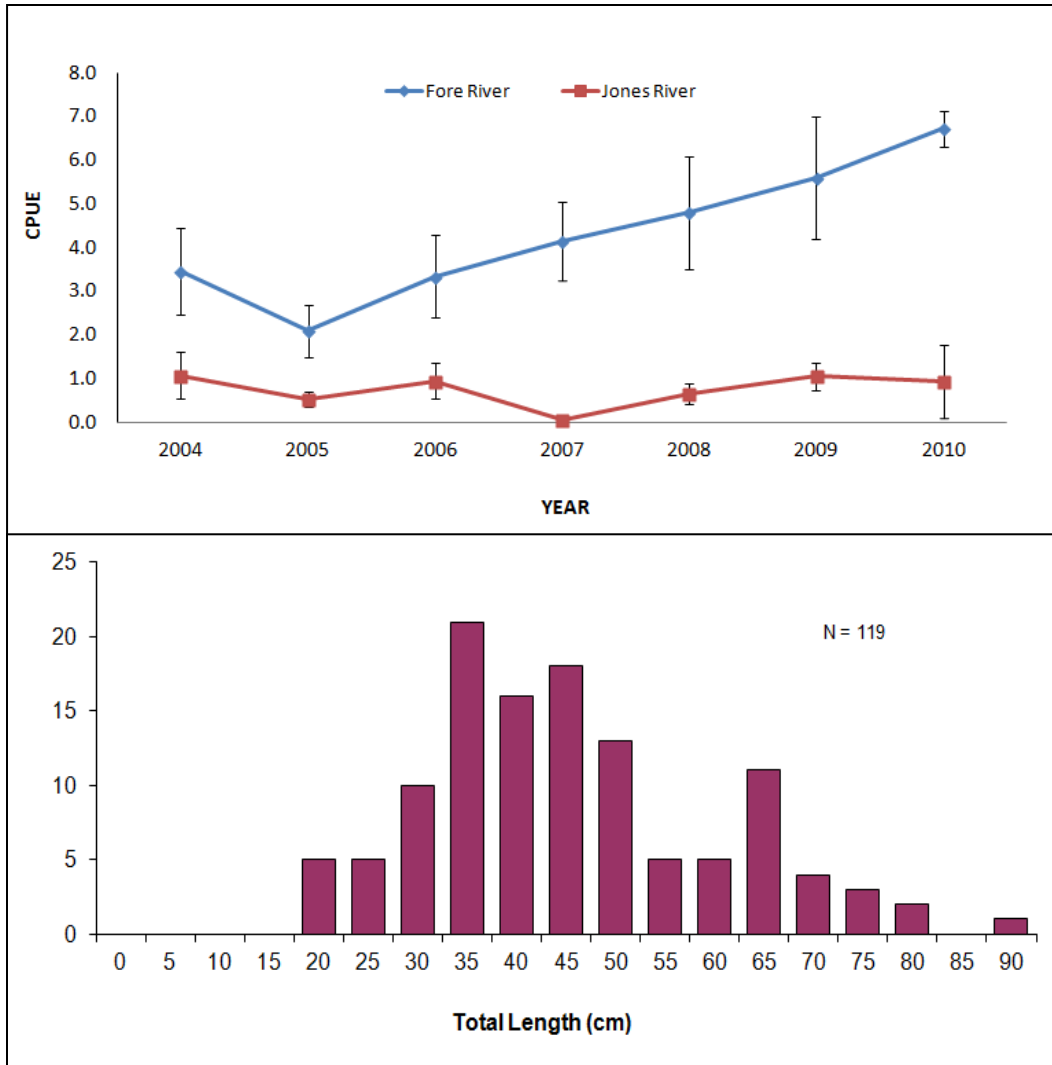


Figure 5.37. CPUE (upper graph) and length frequency (lower graph) of American eels caught as bycatch in the MADMF rainbow smelt survey in the Fore and Jones rivers, 2004–2010.

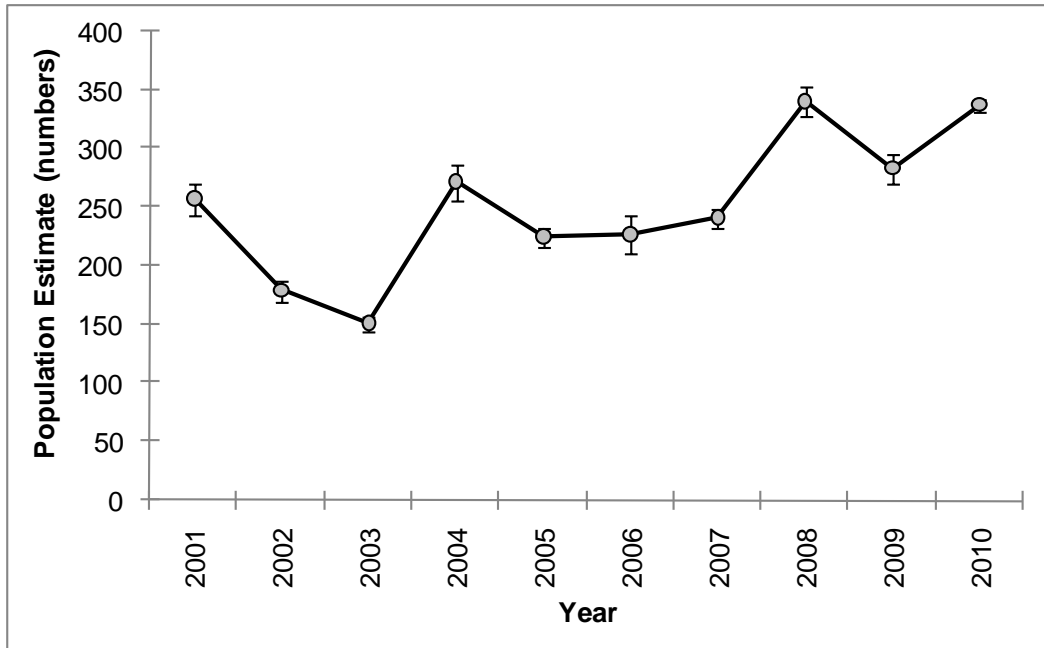


Figure 5.38. Annual index of abundance for American eels caught by the CTDEP Electrofishing Survey in the Farmill River, 2001–2010. The error bars represent the standard errors about the estimates.

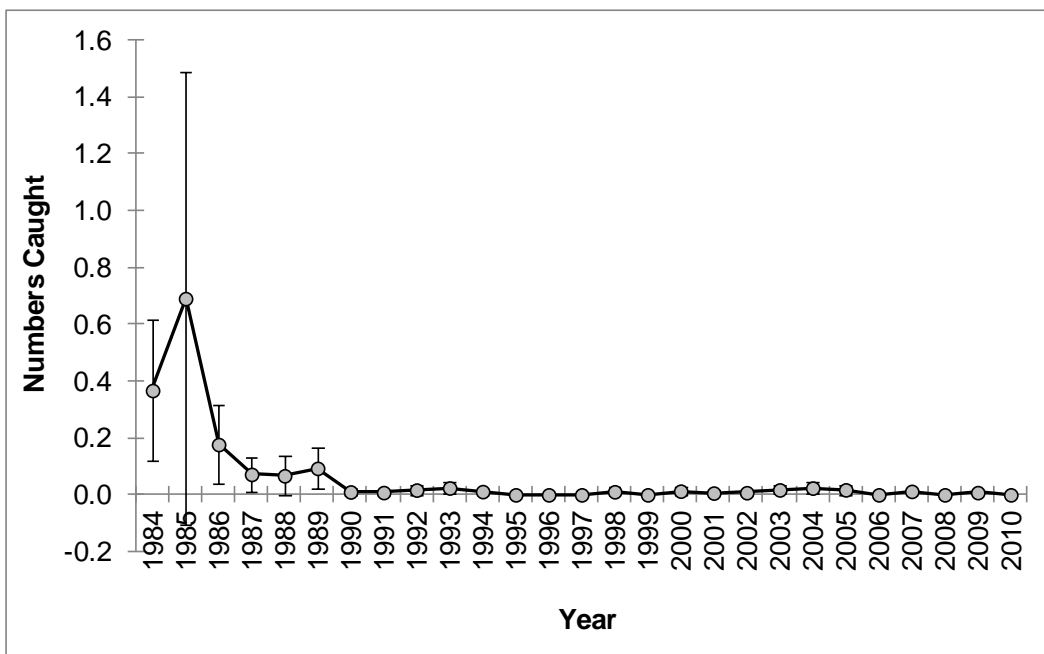


Figure 5.39. GLM-standardized index of abundance for American eels caught by the Western Long Island Study, 1984–2010. The error bars represent the standard errors about the estimates.

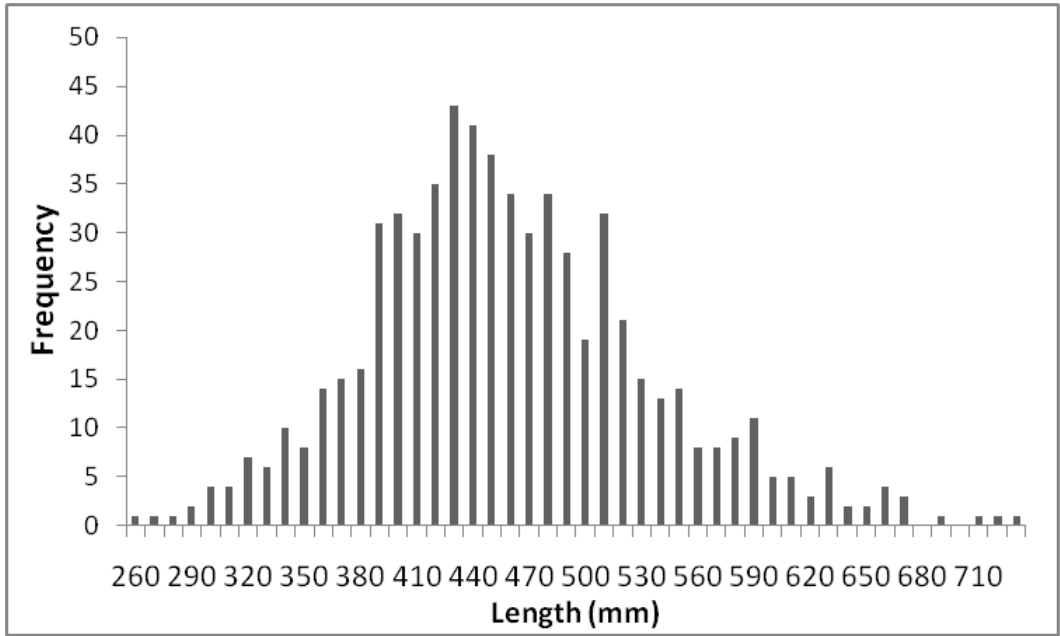


Figure 5.40. Length distribution of eel collected by Morrison and Secor (2003, 2004) from tidal portion of the Hudson River estuary, 1997–1999.

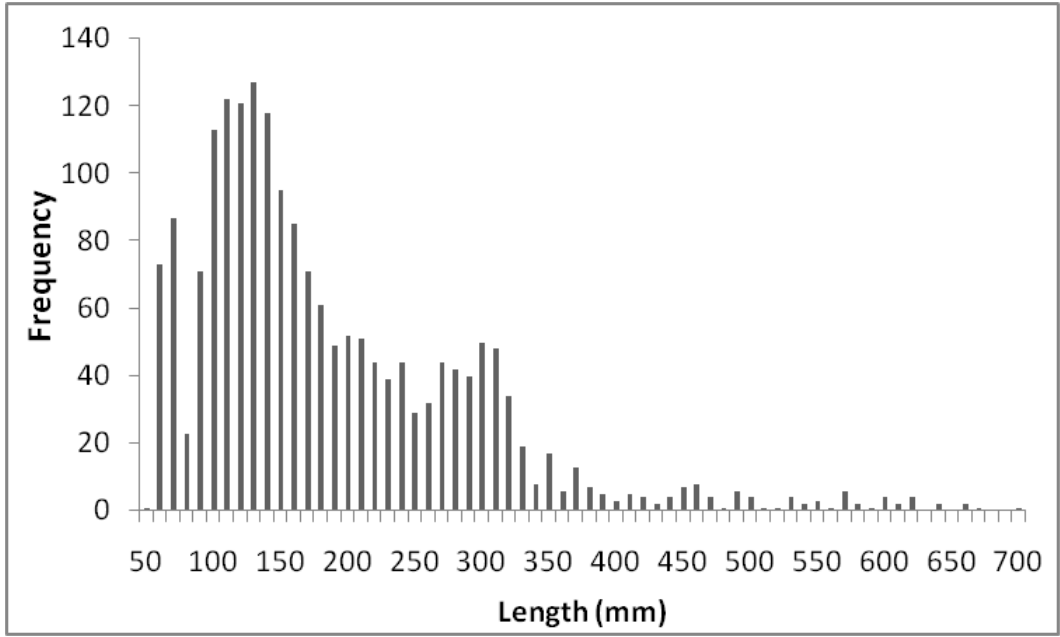


Figure 5.41. Length distribution of eel collected by Machut et al. (2007) from six Hudson River tributaries, 2003–2004.

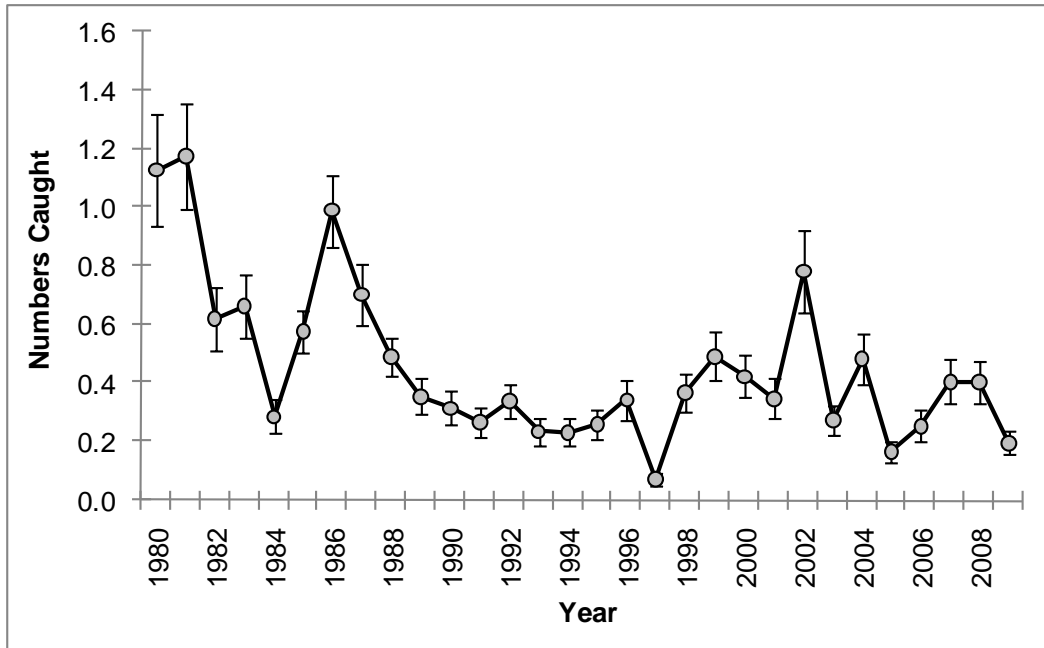


Figure 5.42. Annual index of abundance for American eels caught by the NYDEC Alosine Beach Seine Survey, 1980–2009. The error bars represent the standard errors about the estimates.

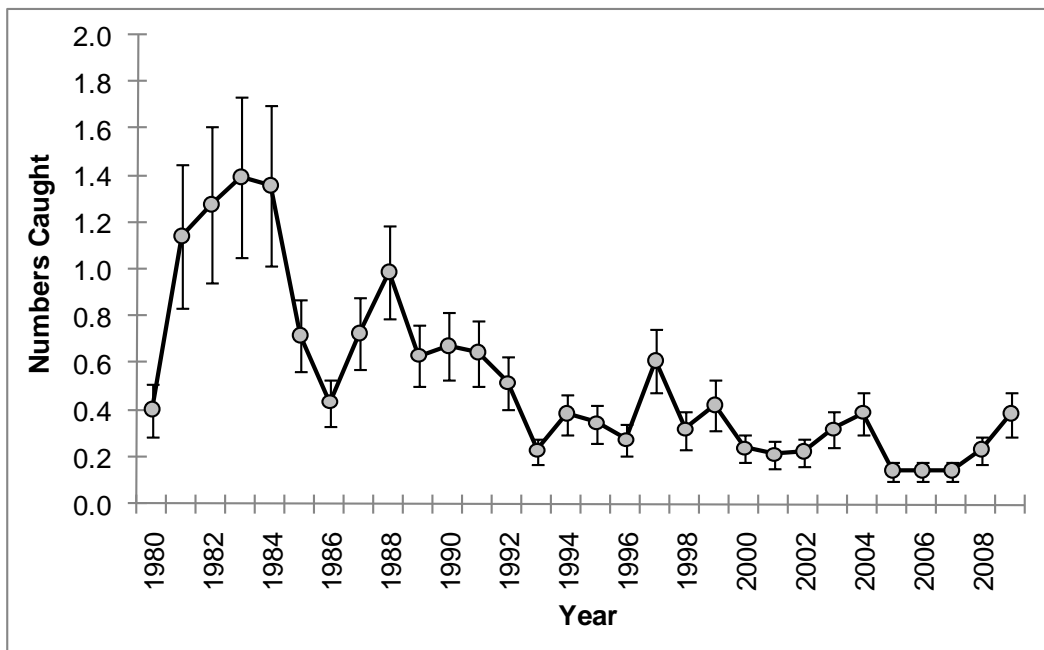


Figure 5.43. Annual index of abundance for American eels caught by the NYDEC Striped Bass Beach Seine Survey, 1980–2009. The error bars represent the standard errors about the estimates.

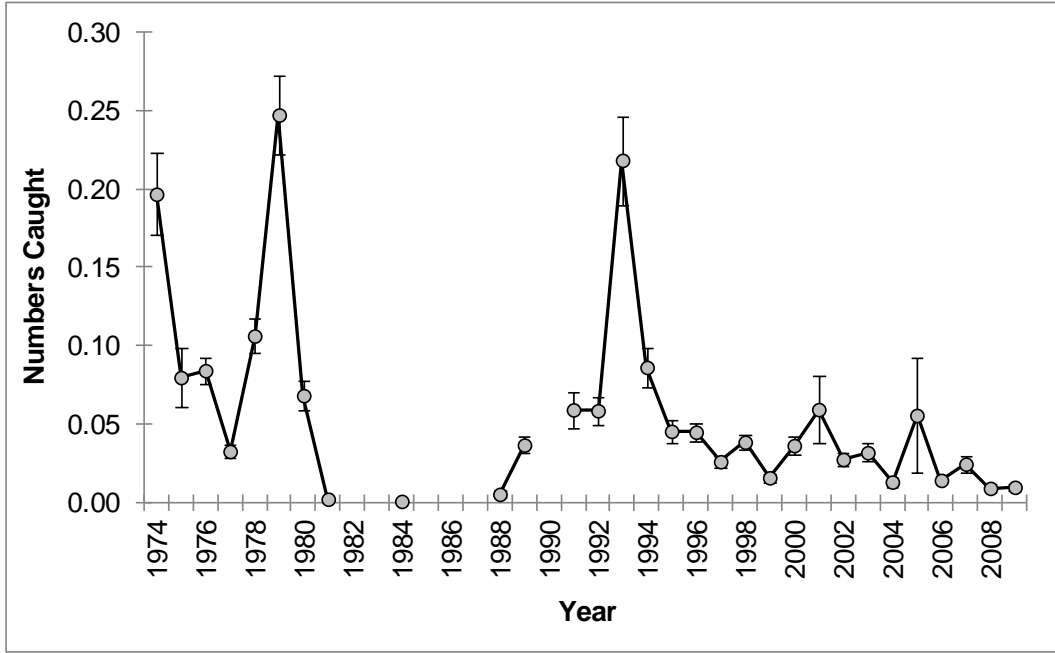


Figure 5.44. GLM-standardized index of abundance for YOY American eels caught by the HRE Monitoring Program, 1974–2009. The error bars represent the standard errors about the estimates.

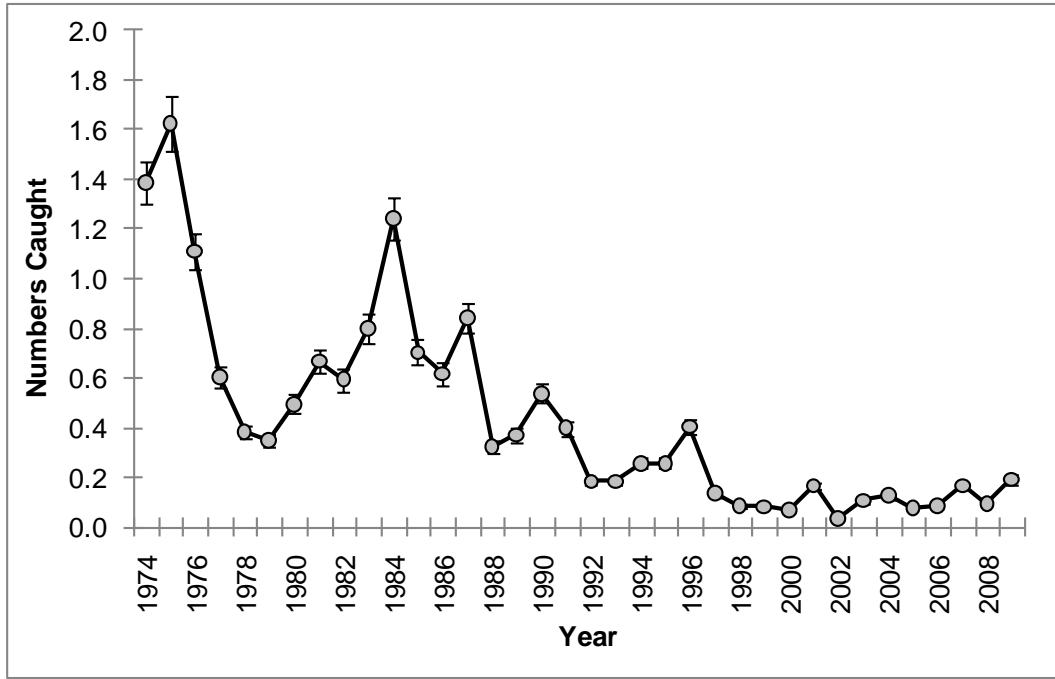


Figure 5.45. GLM-standardized index of abundance for yearling and older American eels caught by the HRE Monitoring Program, 1974–2009. The error bars represent the standard errors about the estimates.

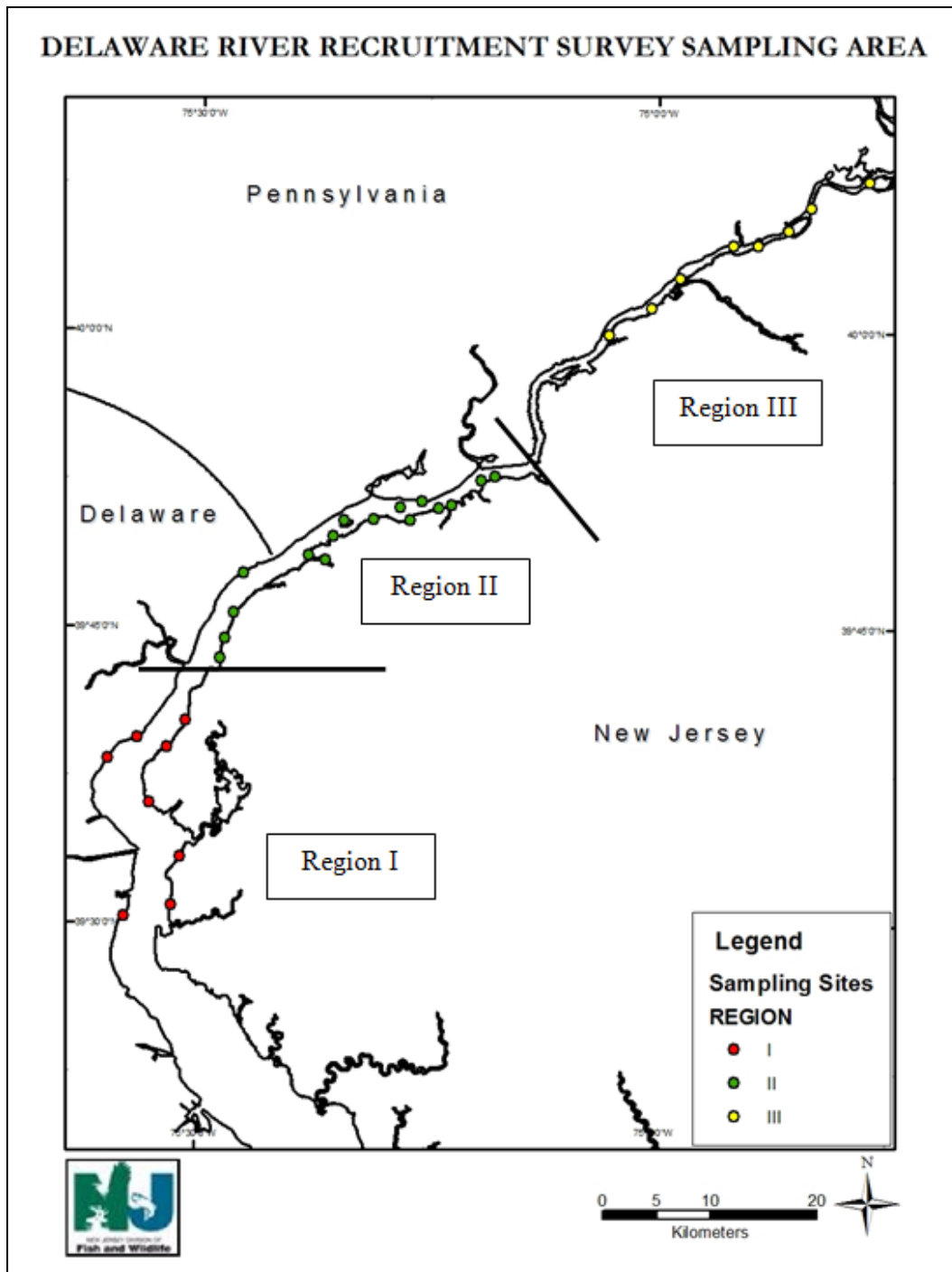


Figure 5.46. Map of Delaware River Recruitment Survey sampling stations (2011).

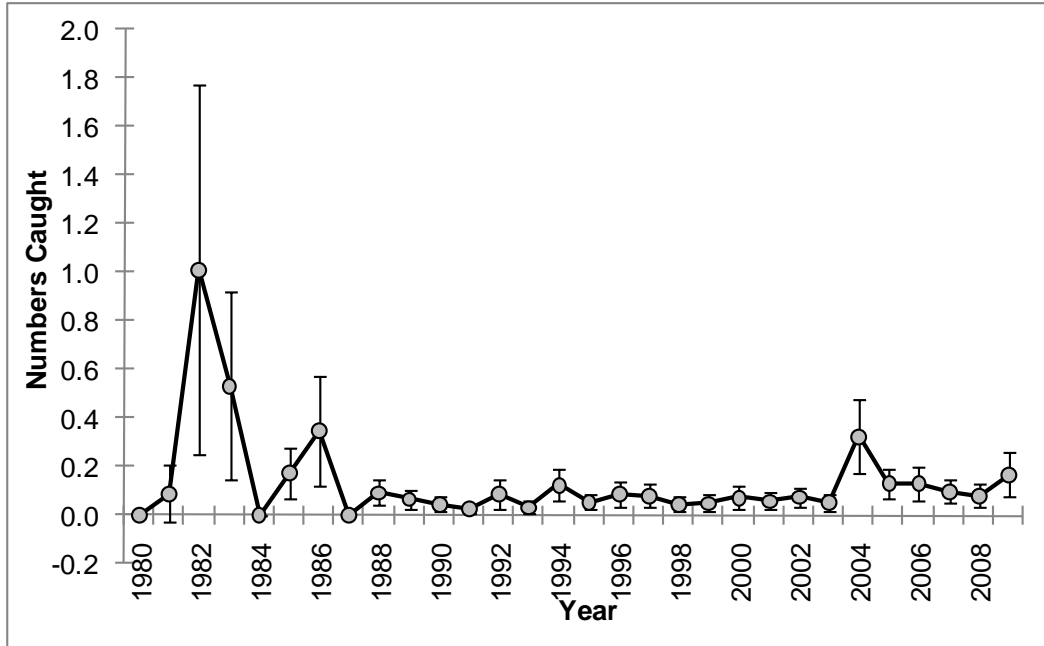


Figure 5.47. GLM-standardized index of abundance for American eels caught by NJDFW's Striped Bass Seine Survey, 1980–2009. The error bars represent the standard errors about the estimates.

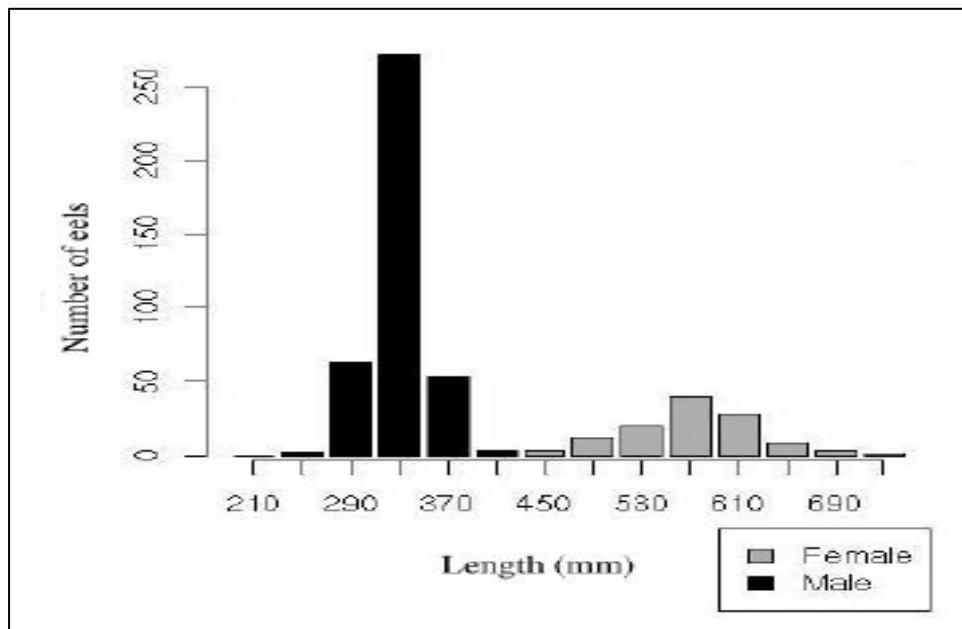


Figure 5.48. Lengths of American eels collected in the University of Delaware Silver Eel Study, by sex.

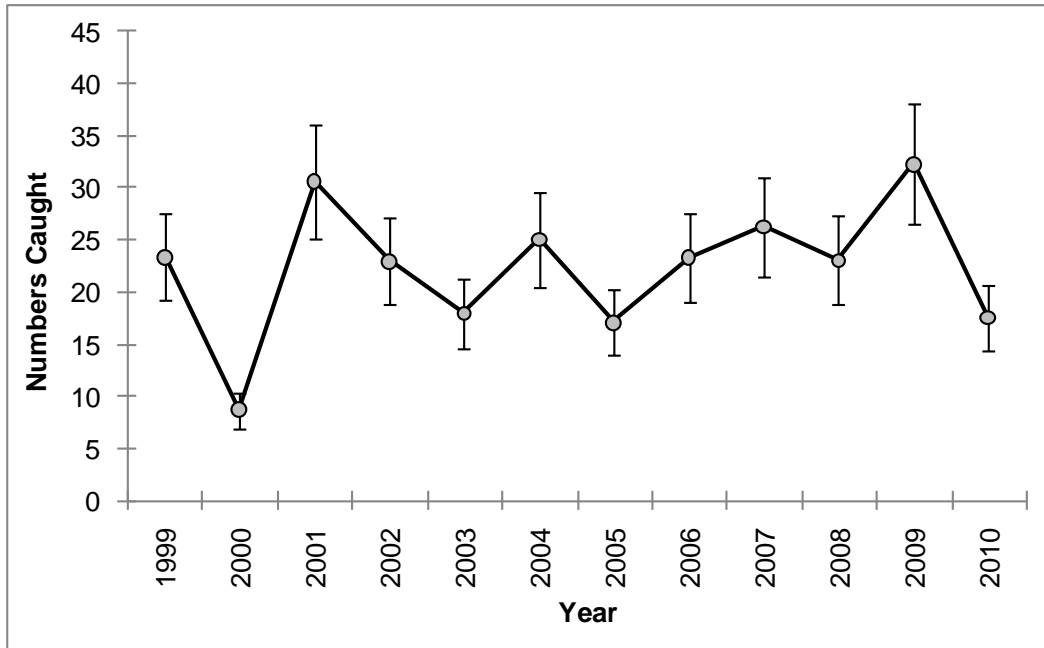


Figure 5.49. GLM-standardized index of abundance for American eels caught by the Area 6 Electrofishing Survey, 1999–2010. The error bars represent the standard errors about the estimates.

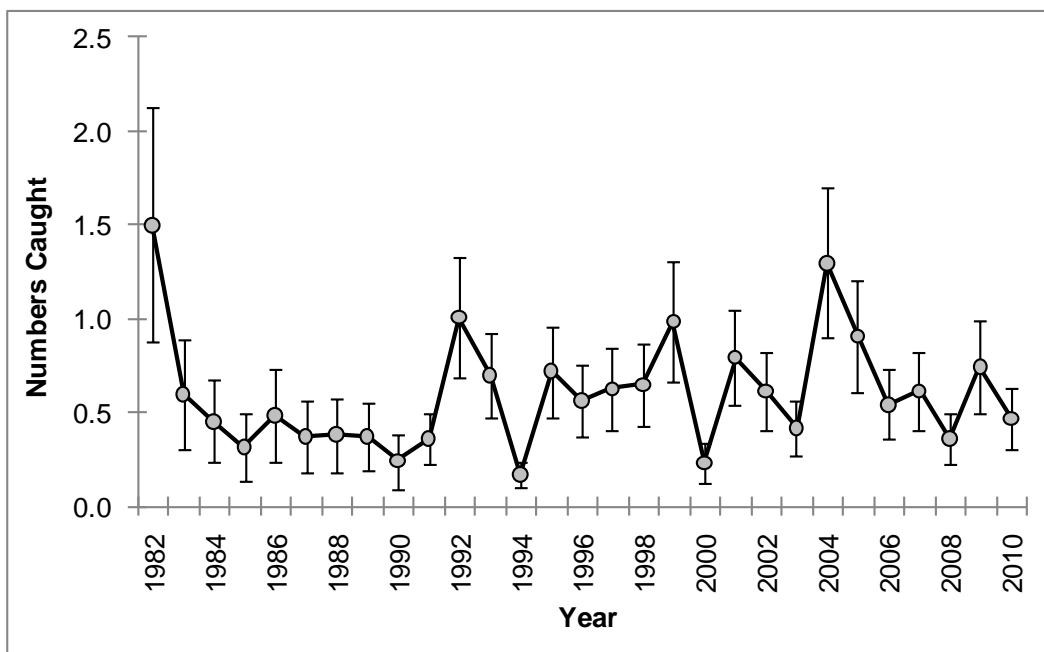


Figure 5.50. GLM-standardized index of abundance for American eels caught by the Delaware Trawl Survey, 1982–2010. The error bars represent the standard errors about the estimates.



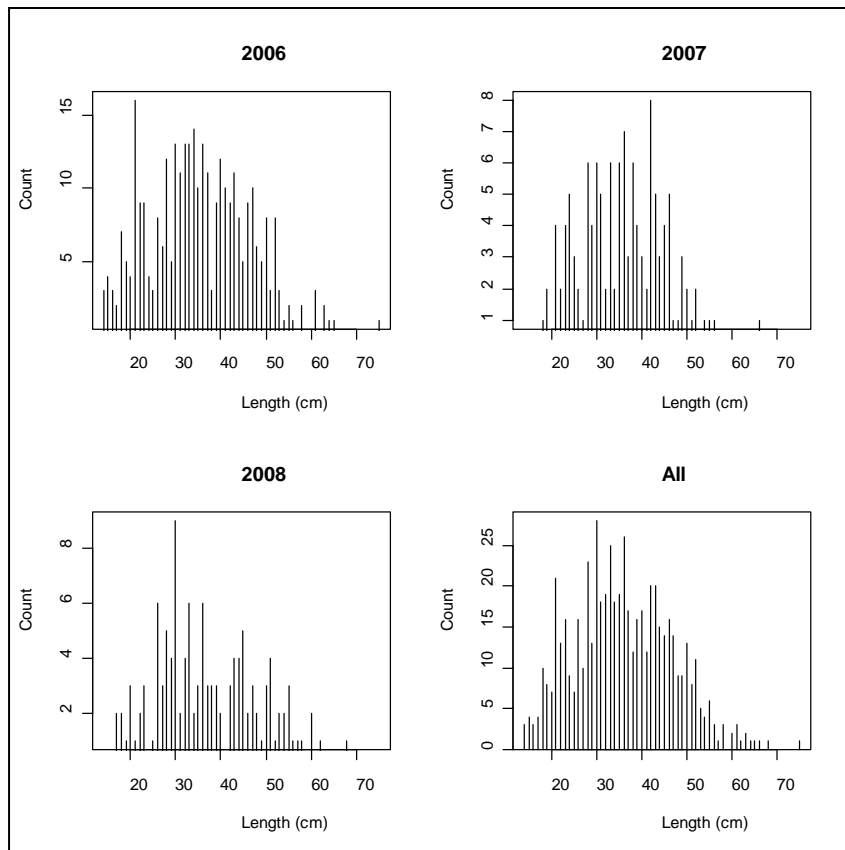


Figure 5.51. Length frequency data from upper Delaware electrofishing samples (Source: The Nature Conservancy).

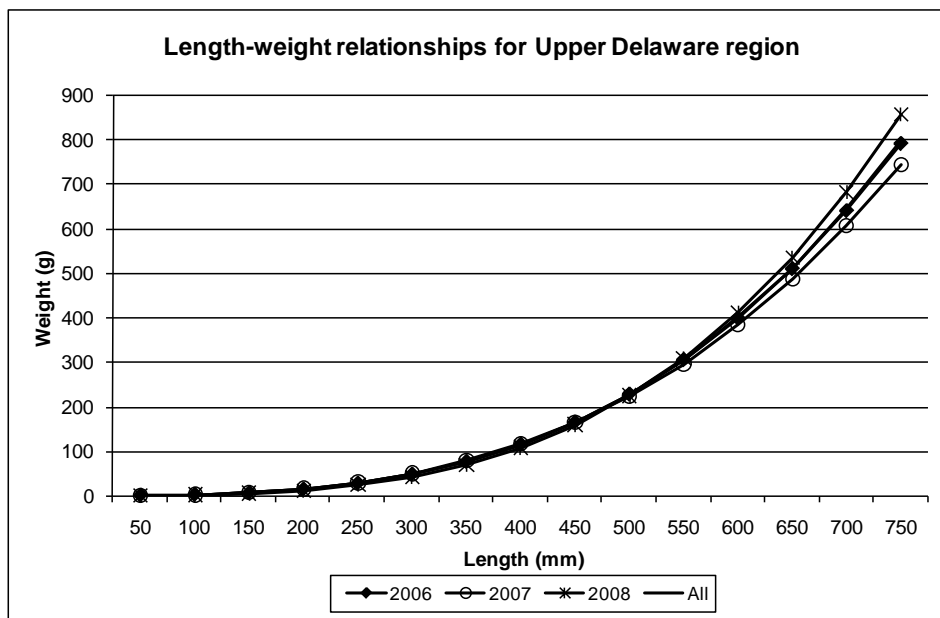


Figure 5.52. Length-weight relationship for Upper Delaware River samples.

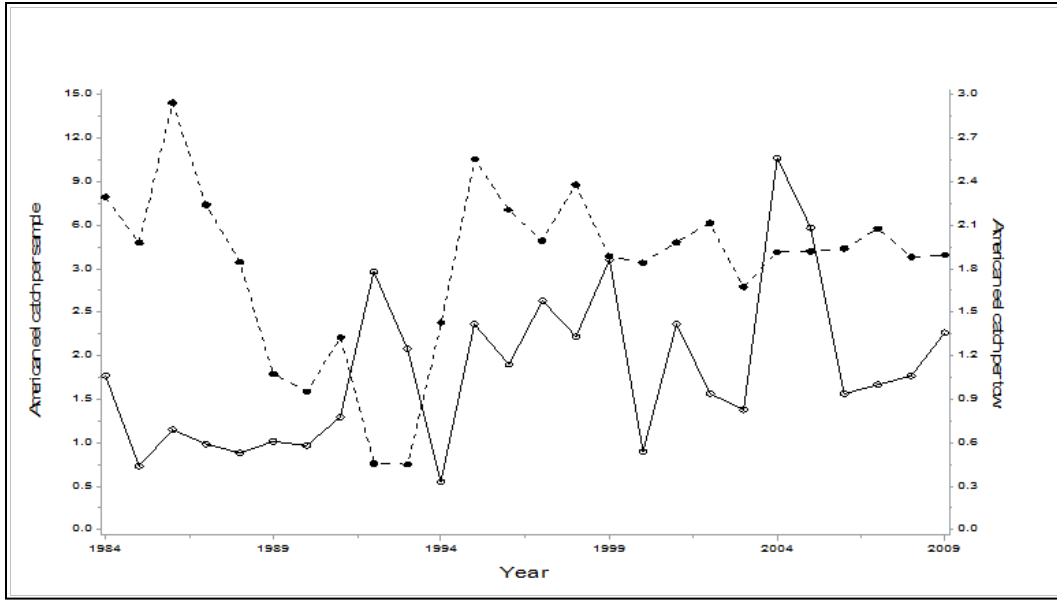


Figure 5.53. American eel abundance trends during 1984 through 2009 from the Delaware Juvenile Finfish Trawl Survey (solid) and PSEG Impingement Monitoring (open).

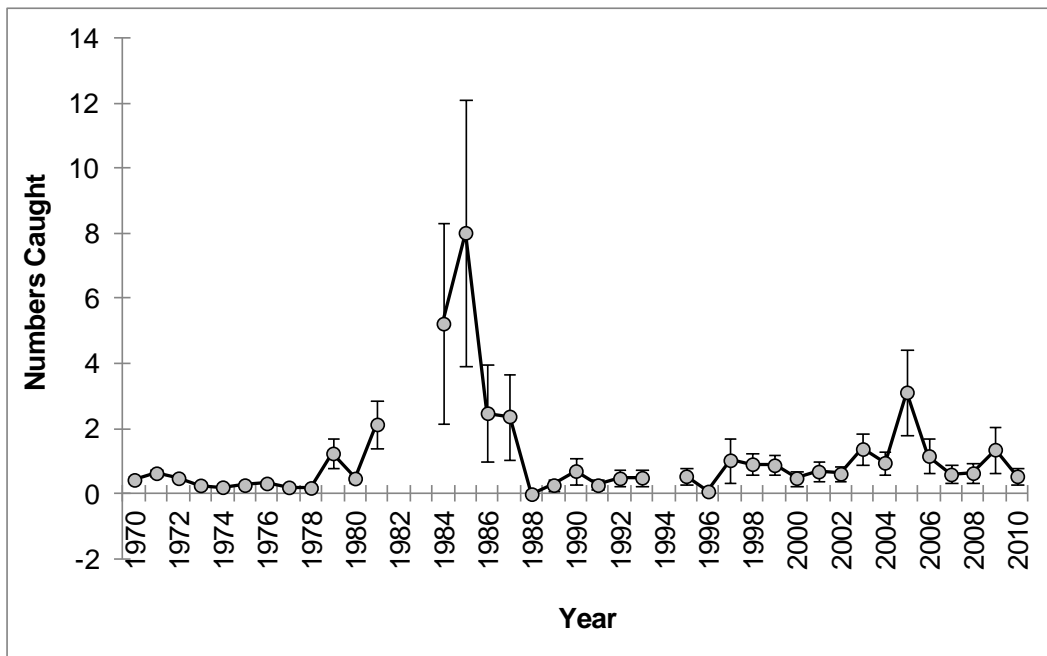


Figure 5.54. GLM-standardized index of abundance for American eels caught by PSEG's Trawl Survey, 1970–2010. The error bars represent the standard errors about the estimates.

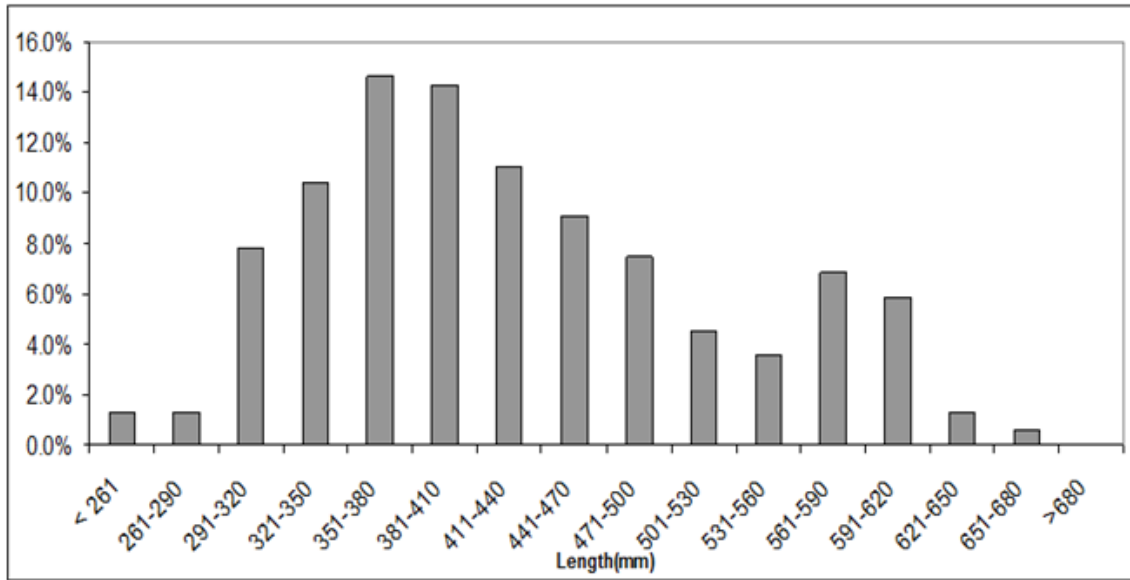


Figure 5.55. Length distribution of American eels collected by the Maryland pot survey in Turville Creek, 2009 and 2010.

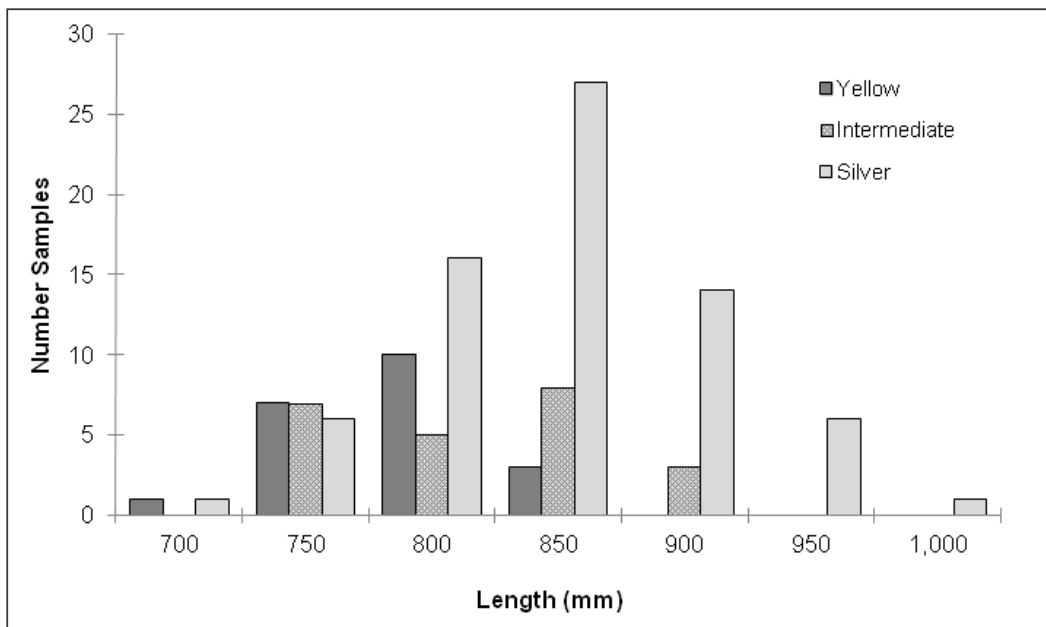


Figure 5.56 Length-frequency of American eel downstream migrants collected from the South Fork of the Shenandoah River in Virginia, 2007–2008. (Data Source: Welsh et al. 2009).

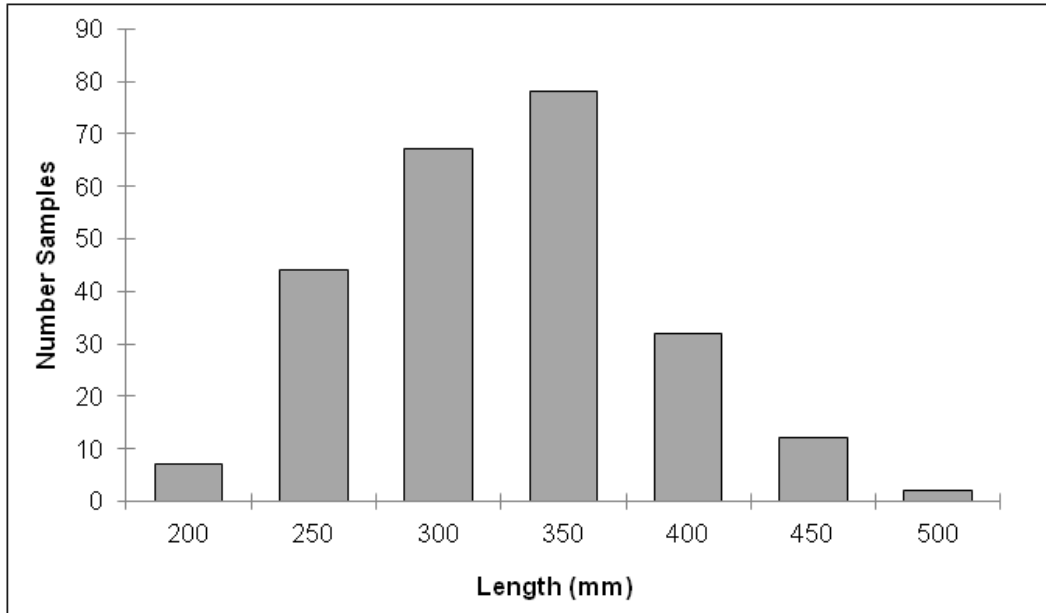


Figure 5.57. Length-frequency of American eel upstream migrants collected from the Millville Dam eel ladder on the lower Shenandoah River, 2006–2008. (Data Source: Zimmerman 2008).

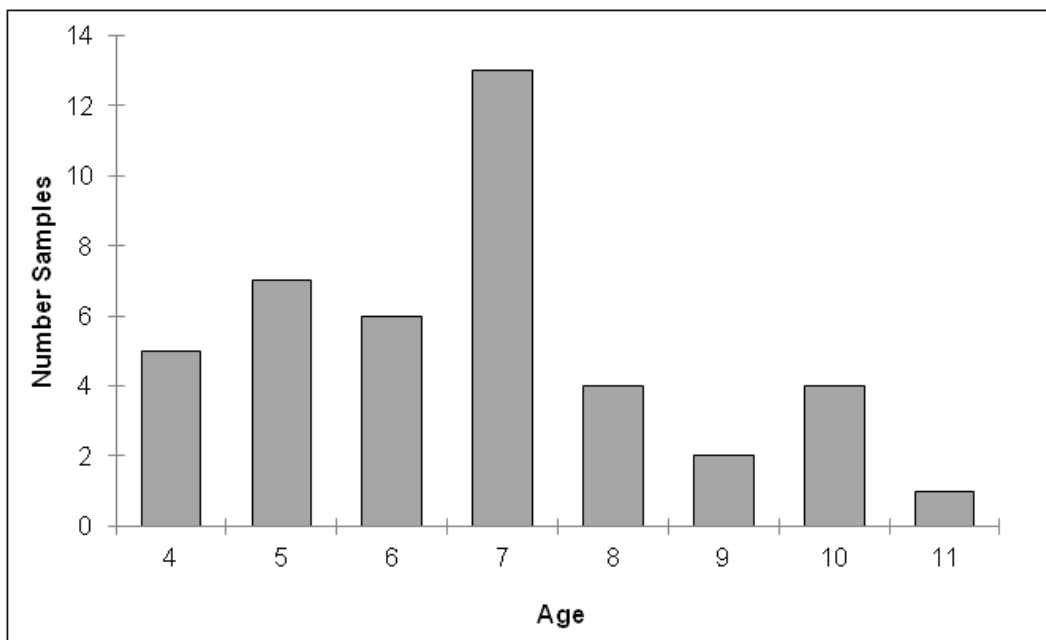


Figure 5.58. Age-frequency of American eel upstream migrants collected from the Millville Dam eel ladder on the lower Shenandoah River, 2006–2008. (Data Source: Zimmerman 2008).

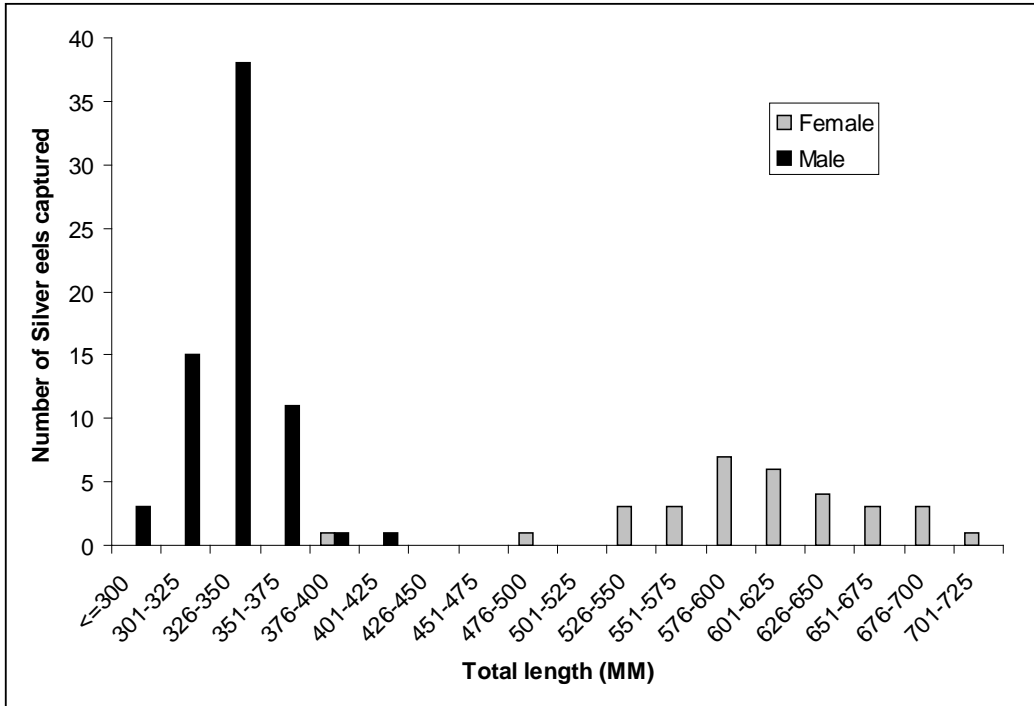


Figure 5.59. Maryland Gravel Run survey silver eel length distribution by sex, 2006–2010.

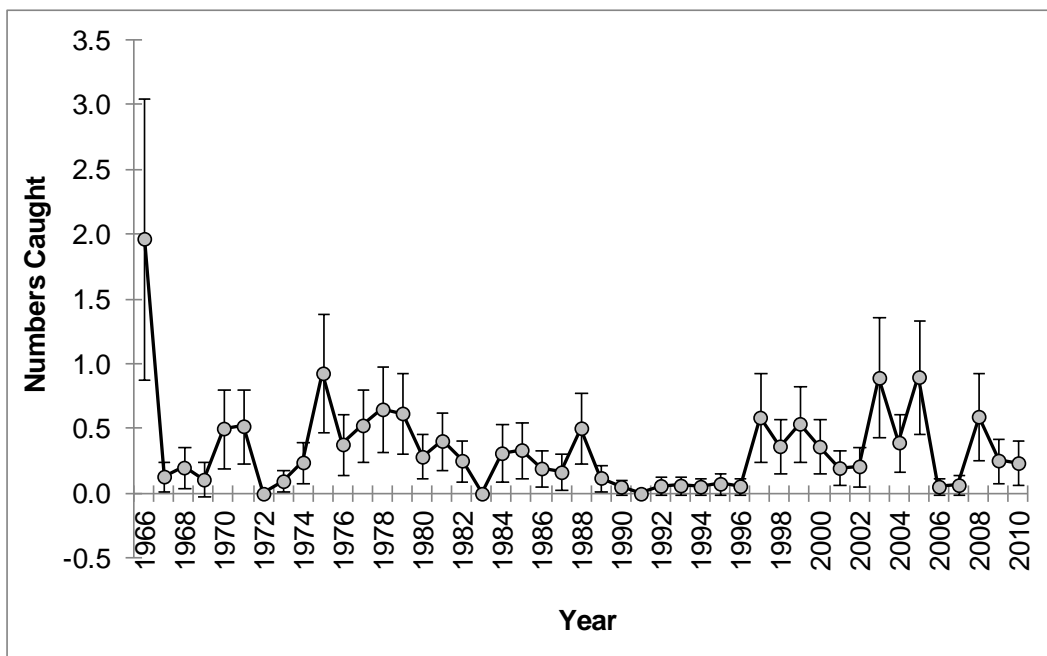


Figure 5.60. GLM-standardized index of abundance for American eels caught by the MDDNR Striped Bass Seine Survey, 1966–2010. The error bars represent the standard errors about the estimates.

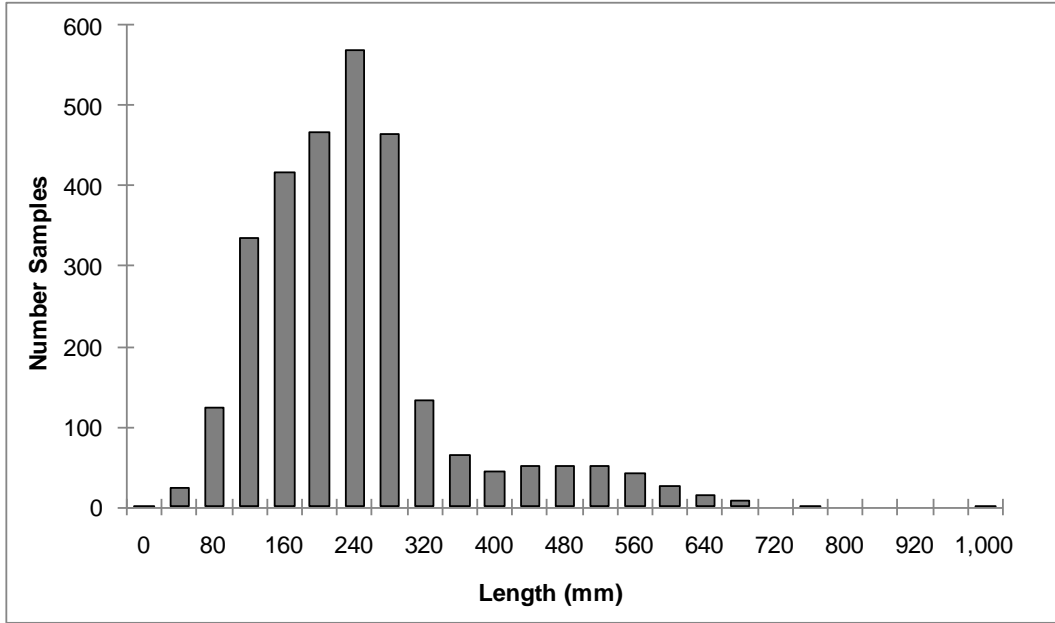


Figure 5.61. Length-frequency of American eels collected by VDGIF fishery-independent surveys of Virginia water bodies, 1992–2010.

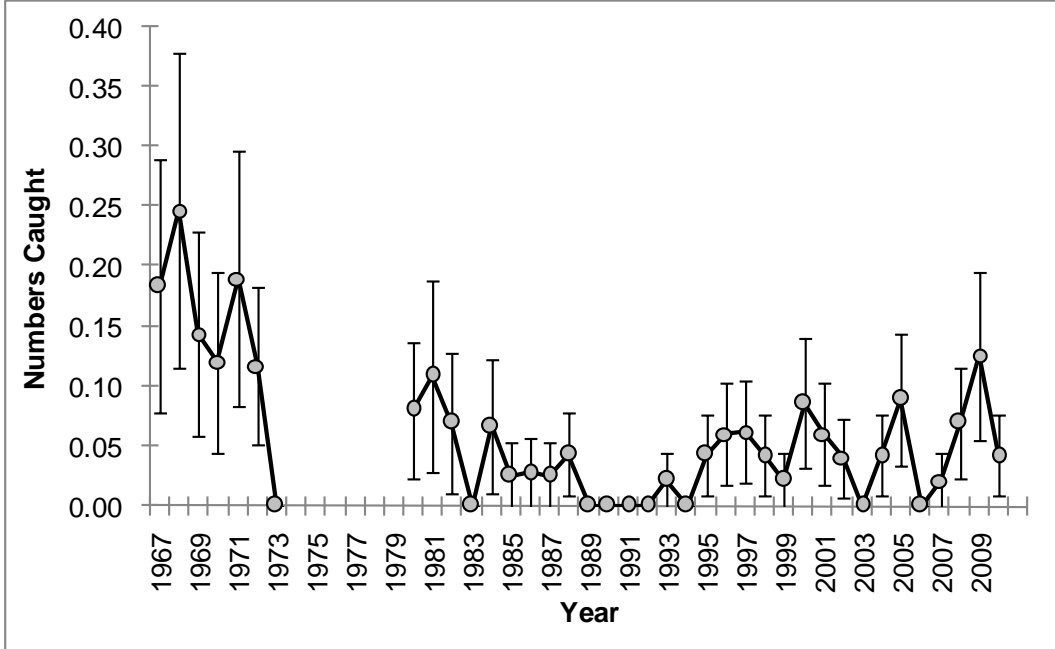


Figure 5.62. GLM-standardized index of abundance for American eels caught by the VIMS Juvenile Striped Bass Seine Survey, 1967–2010. The error bars represent the standard errors about the estimates.

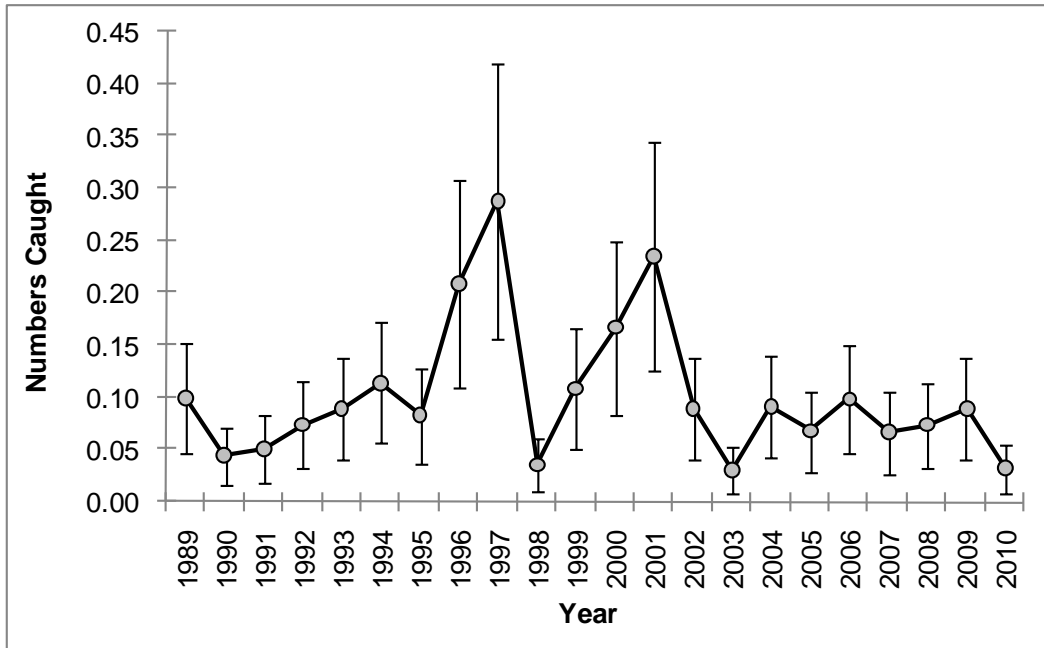


Figure 5.63. GLM-standardized index of abundance for American eels caught by the VIMS Juvenile Striped Bass Seine Survey, 1989–2010. The error bars represent the standard errors about the estimates.

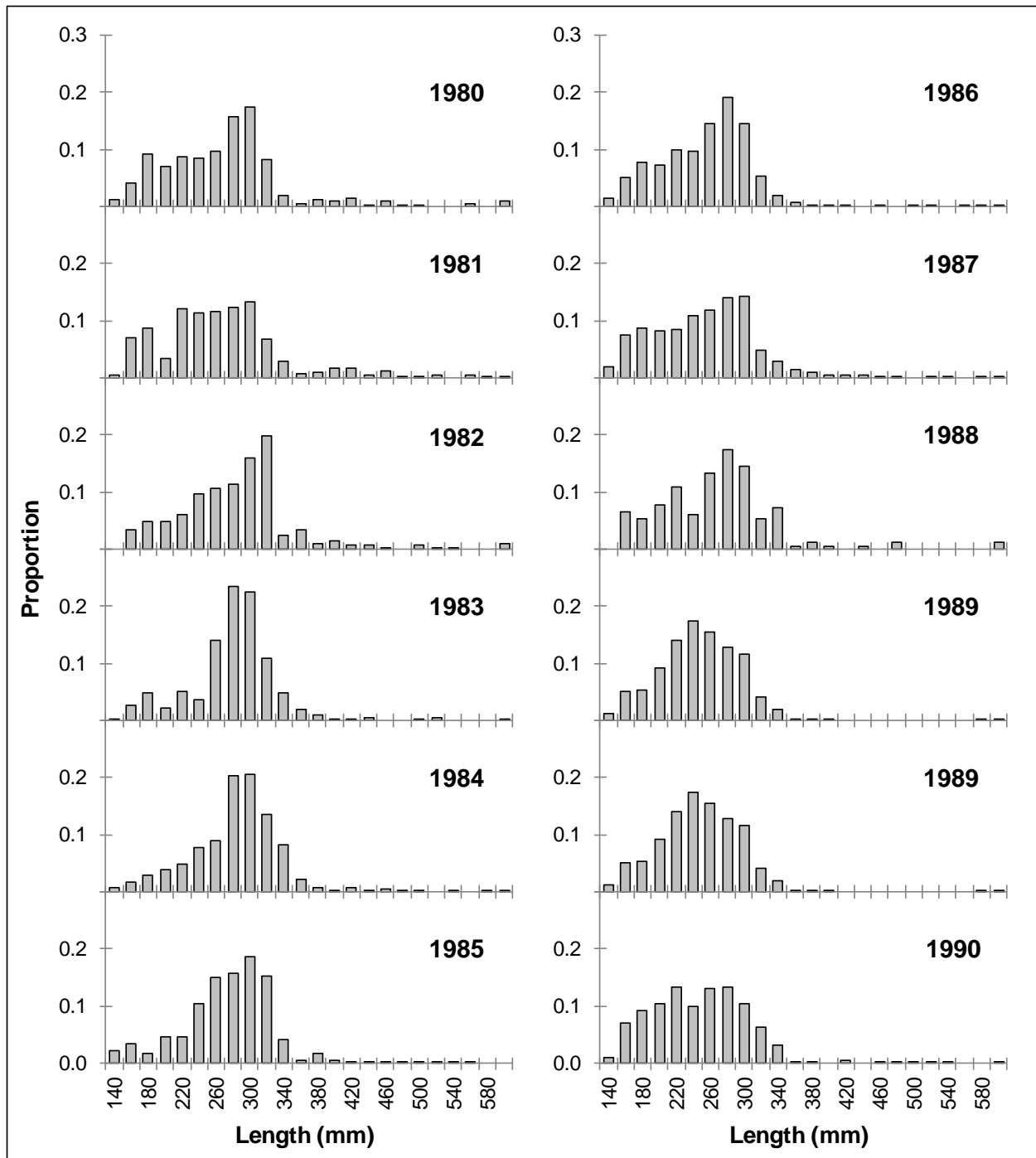


Figure 5.64. Annual length-frequency distributions of American eels collected from tributaries of the Chesapeake Bay during April through September by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 1980–1990.



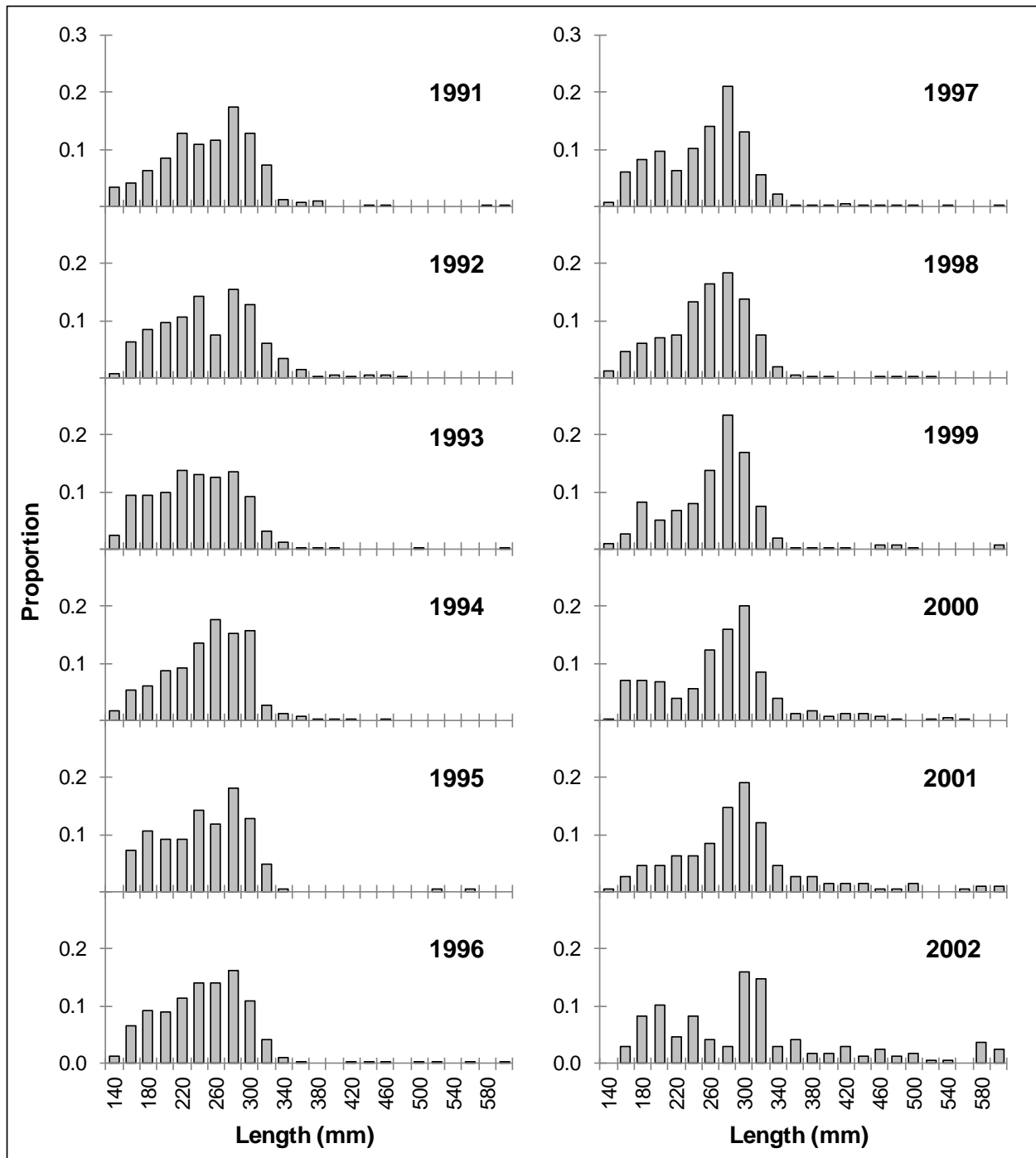


Figure 5.65. Annual length-frequency distributions of American eels collected from tributaries of the Chesapeake Bay during April through September by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 1991–2002.

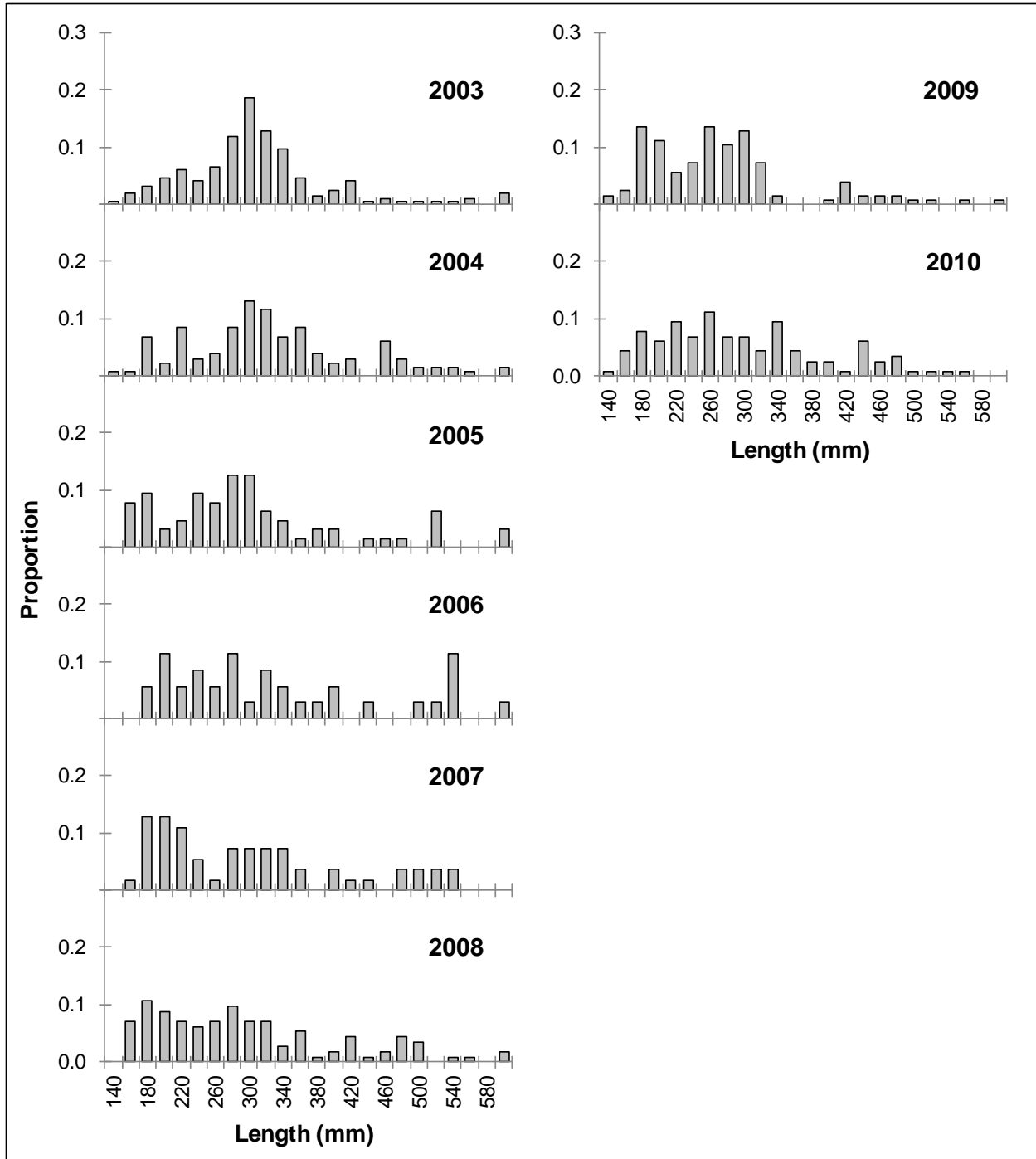


Figure 5.66. Annual length-frequency distributions of American eels collected from tributaries of the Chesapeake Bay during April through September by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 2003–2010.

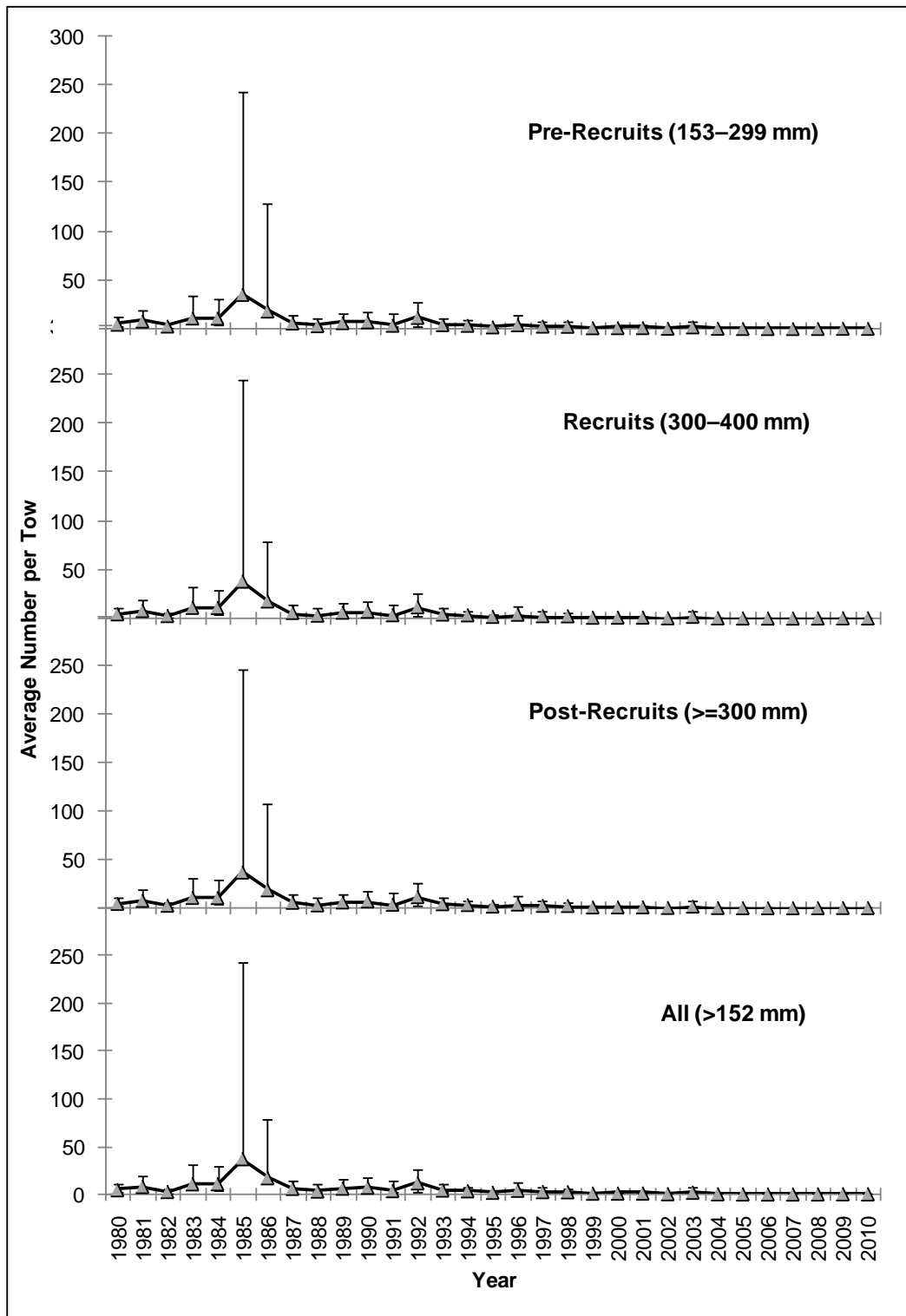


Figure 5.67. Indices of relative abundance for four size groups of American eels based on data collected from tributaries of the Chesapeake Bay during April through September by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 1980–2010. Error bars represent upper and lower 95% confidence limits.

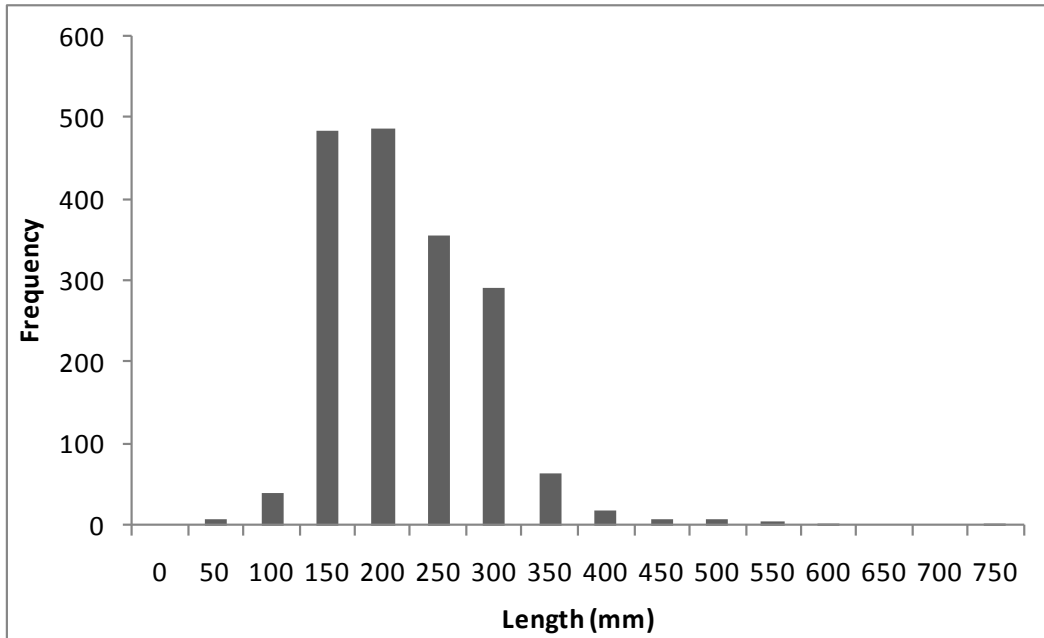


Figure 5.68. Length distribution of American eels sampled from the North Anna River, 1990–2006.

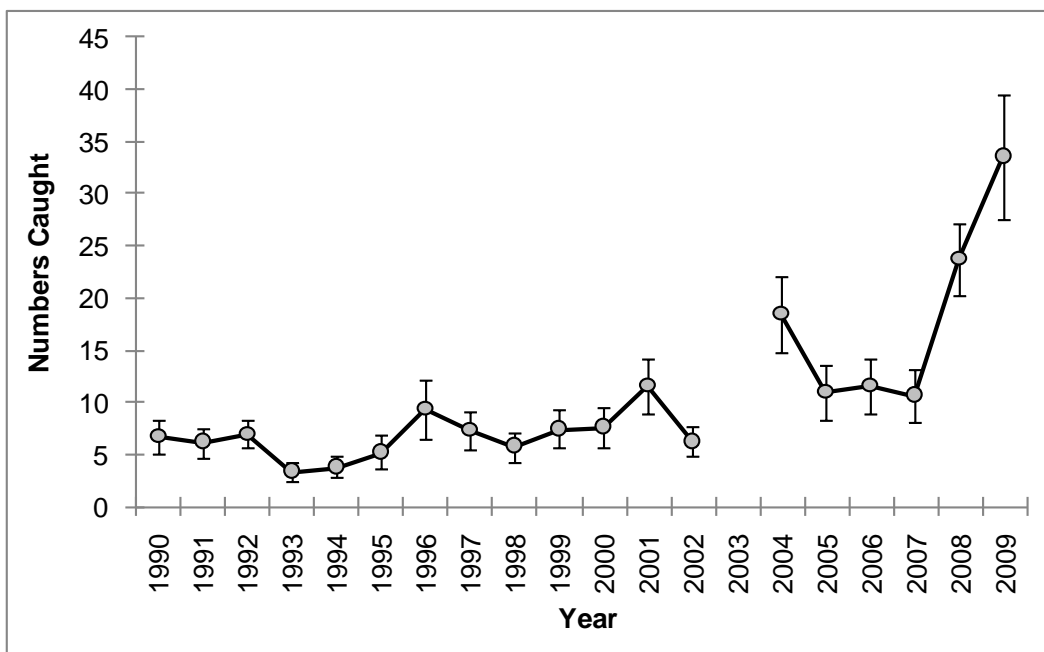


Figure 5.69. GLM-standardized index of abundance for American eels caught by the North Anna Electrofishing Survey, 1990–2009. The error bars represent the standard errors about the estimates.

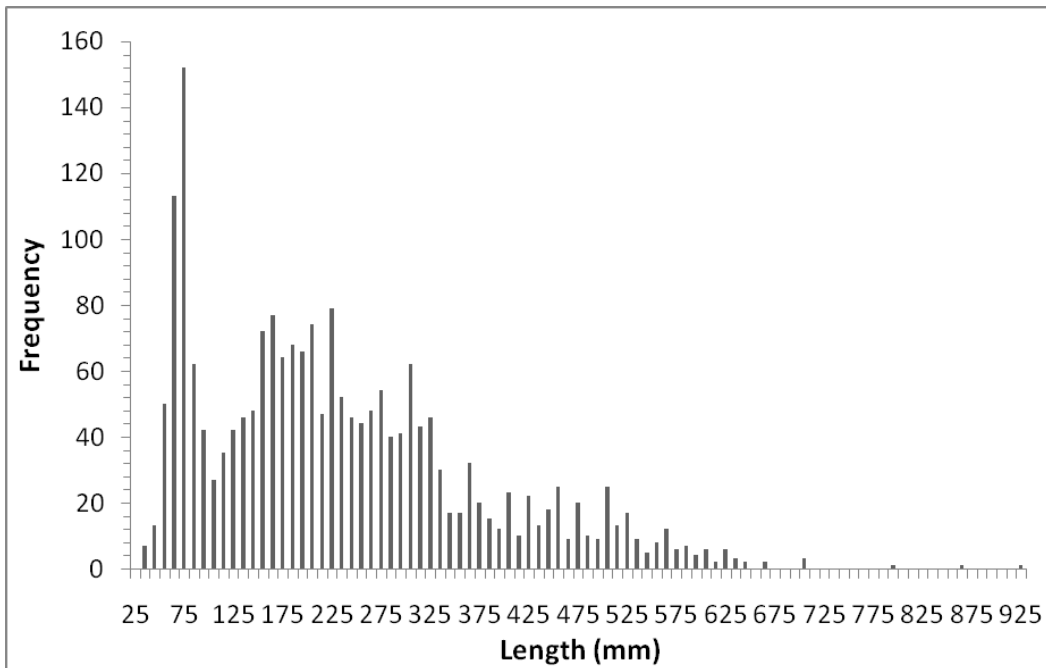


Figure 5.70. Length distribution of eels collected by the estuarine trawl survey in North Carolina waters, 1971–2010.

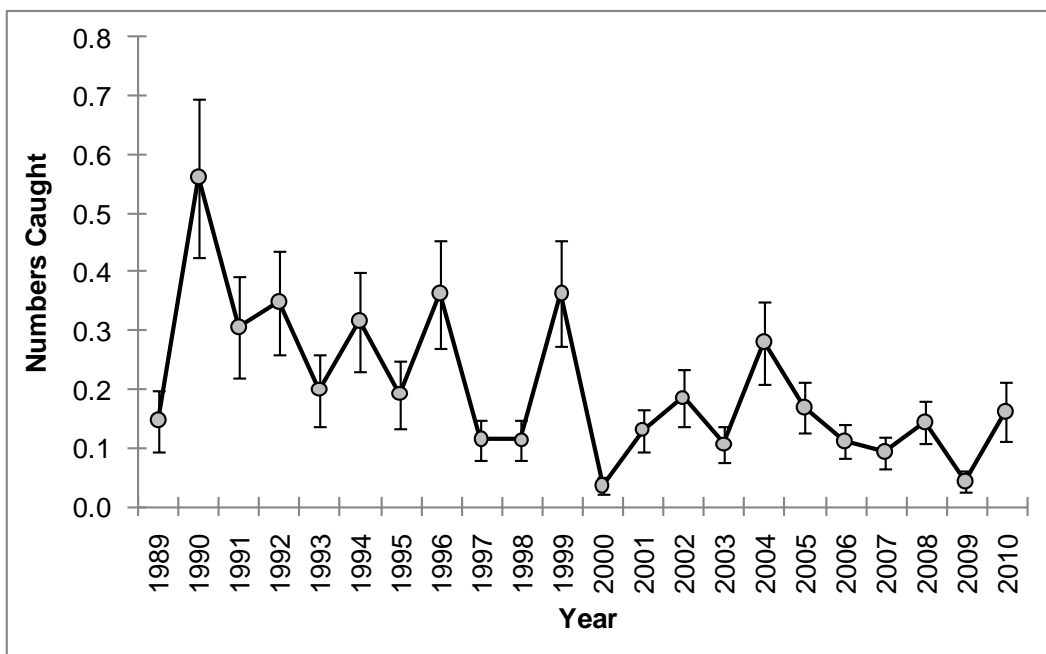


Figure 5.71. GLM-standardized index of abundance for American eels caught by the NCDMF Estuarine Trawl Survey, 1989–2010. The error bars represent the standard errors about the estimates.

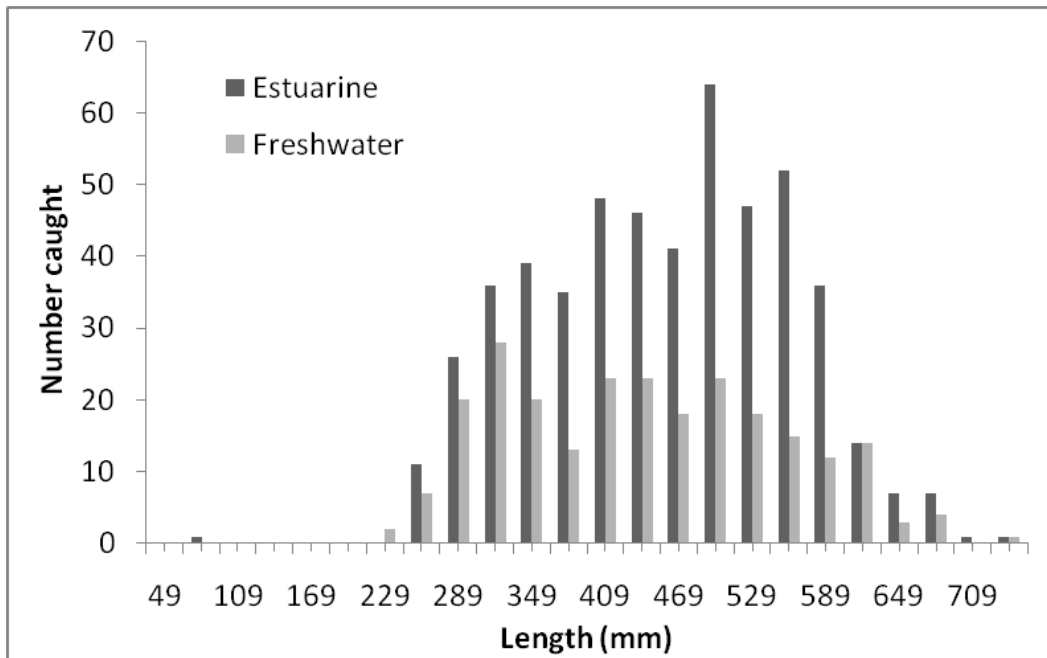


Figure 5.72. Length distribution of eels sampled in estuarine and freshwater habitats of Northwest Pamlico Sound and Lake Mattamuskeet, North Carolina, 2002–2003 (Cudney 2004).

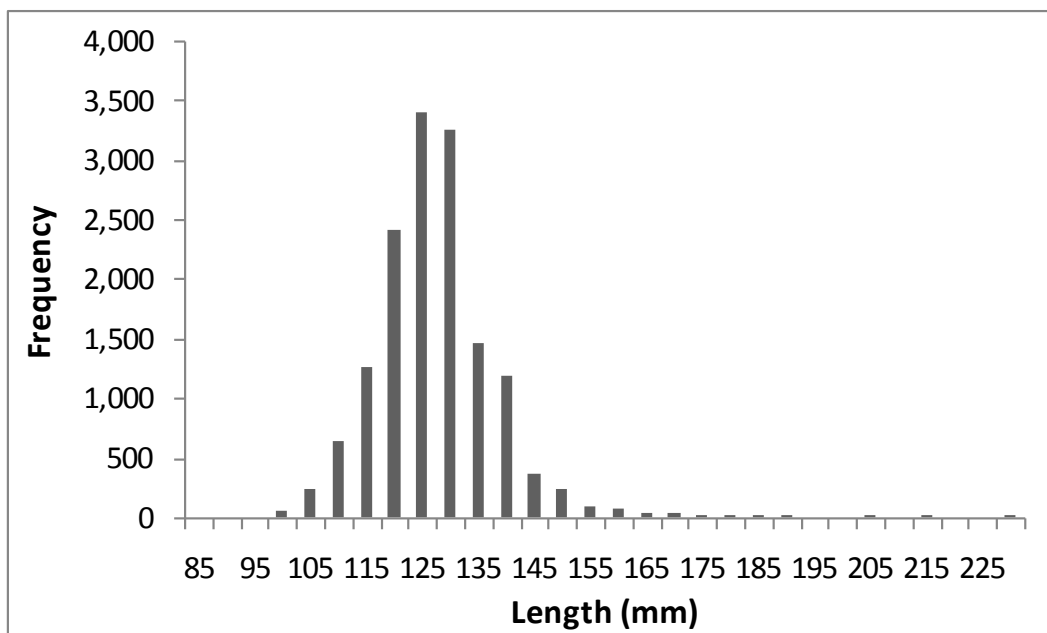


Figure 5.73. Length frequency of American eel caught in eel traps at the Roanoke River Dam, North Carolina, 2005–2009 (Graham, Dominion Power, pers. comm.).

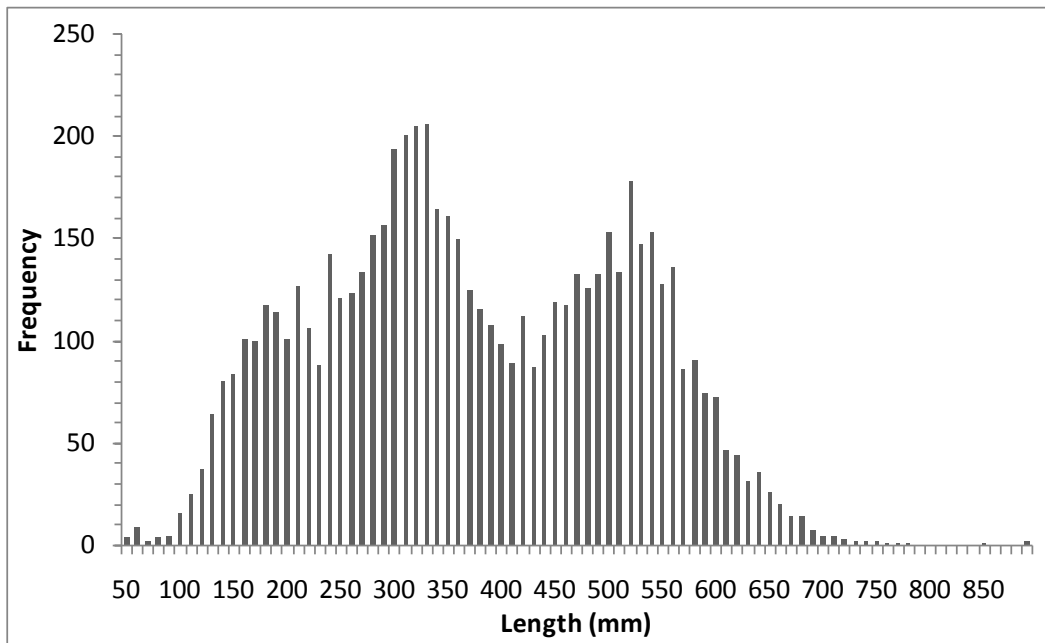


Figure 5.74. Length distribution of eel collected by the SC Electrofishing Survey, 2001–2010.

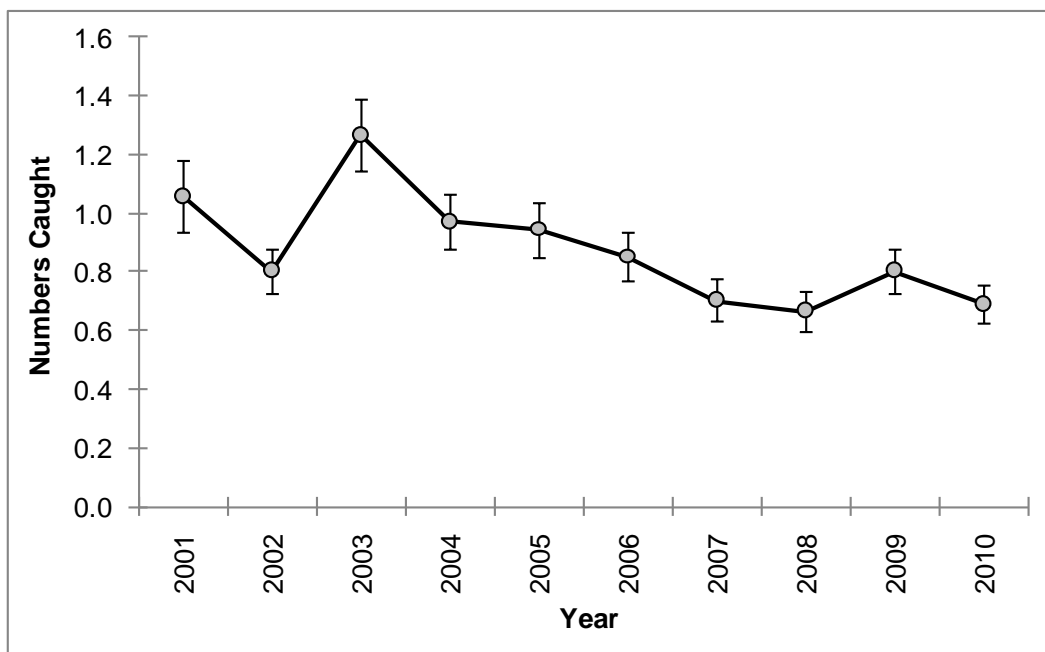


Figure 5.75. GLM-standardized index of abundance for American eels caught by the SC Electrofishing Survey, 2001–2010. The error bars represent the standard errors about the estimates.

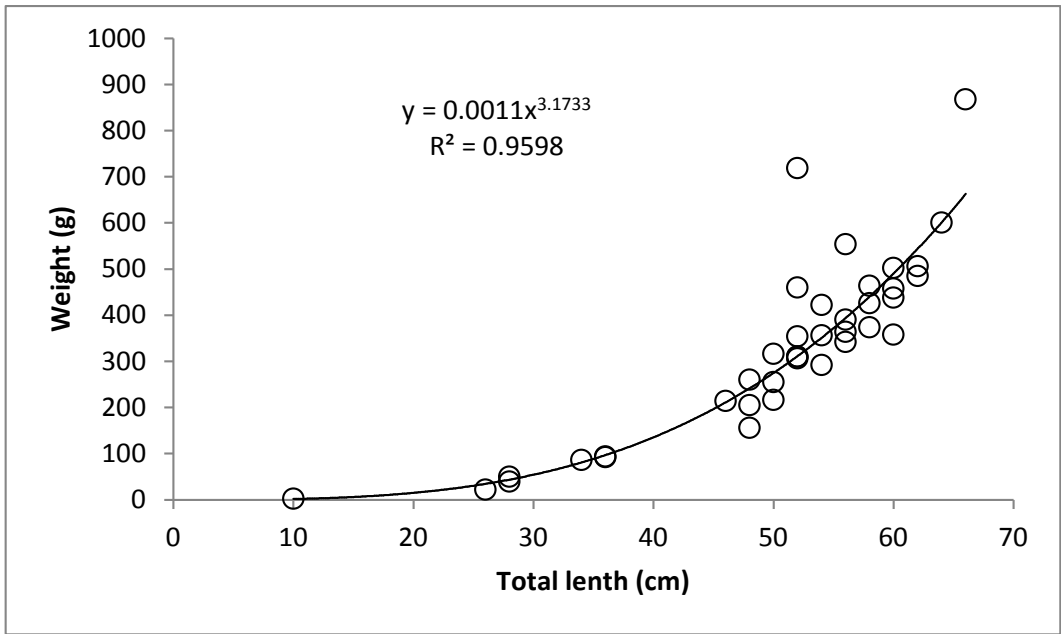


Figure 5.76. American eel weight-length relationship for the Suwannee River, Florida, 1996–2008. Years were combined (n = 38).

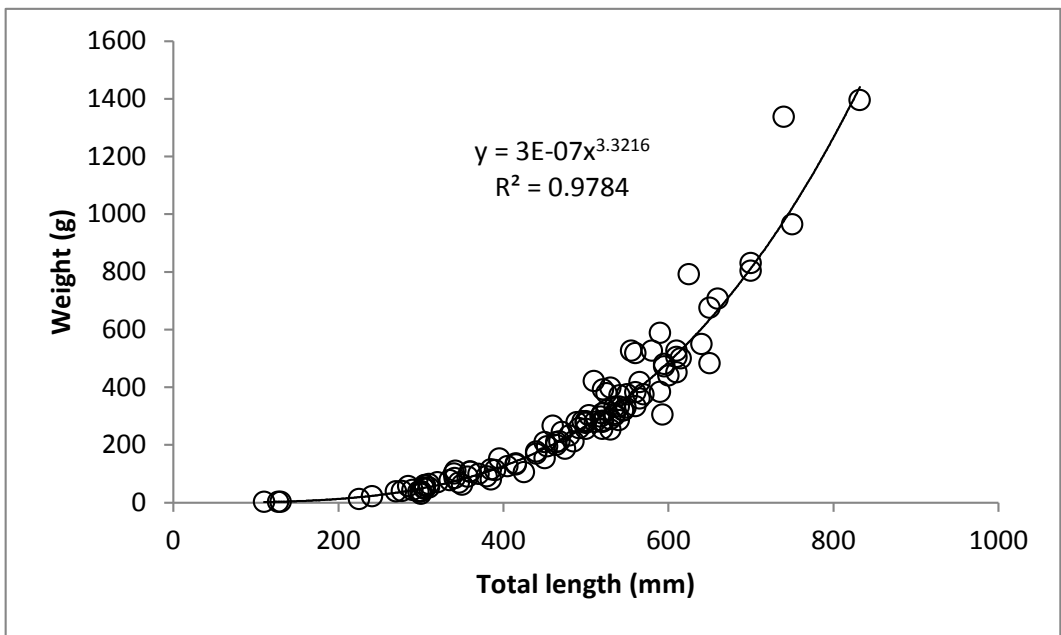


Figure 5.77. Weight-length relationship for American eels in the FL FWCC lake and marsh electrofishing survey.



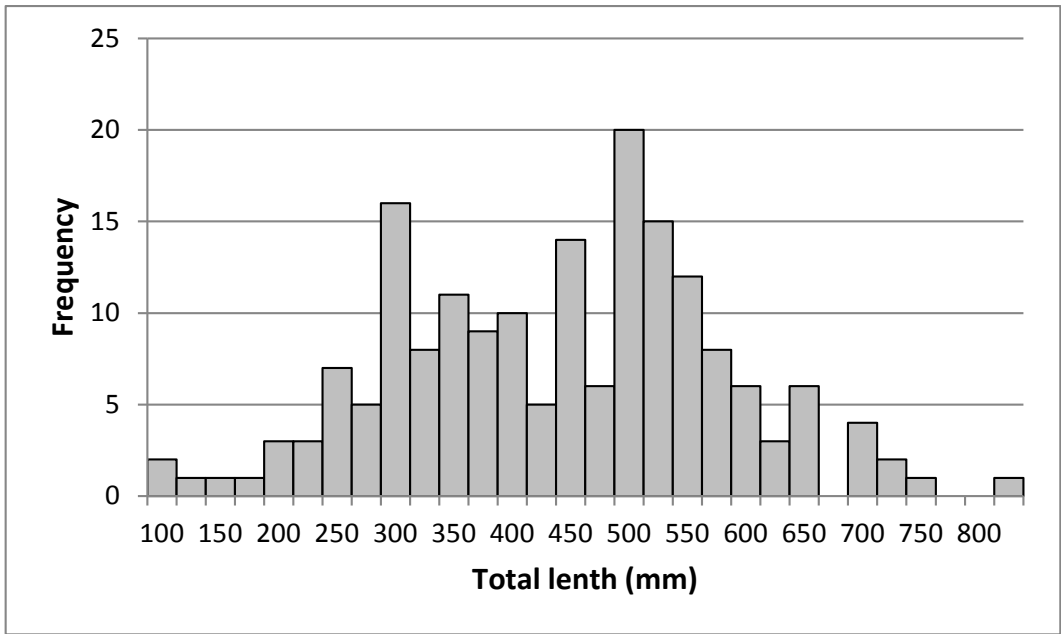


Figure 5.78. Length frequency distribution of American eels in the FL FWCC lake and marsh electrofishing survey. Mean total length was 472 mm.

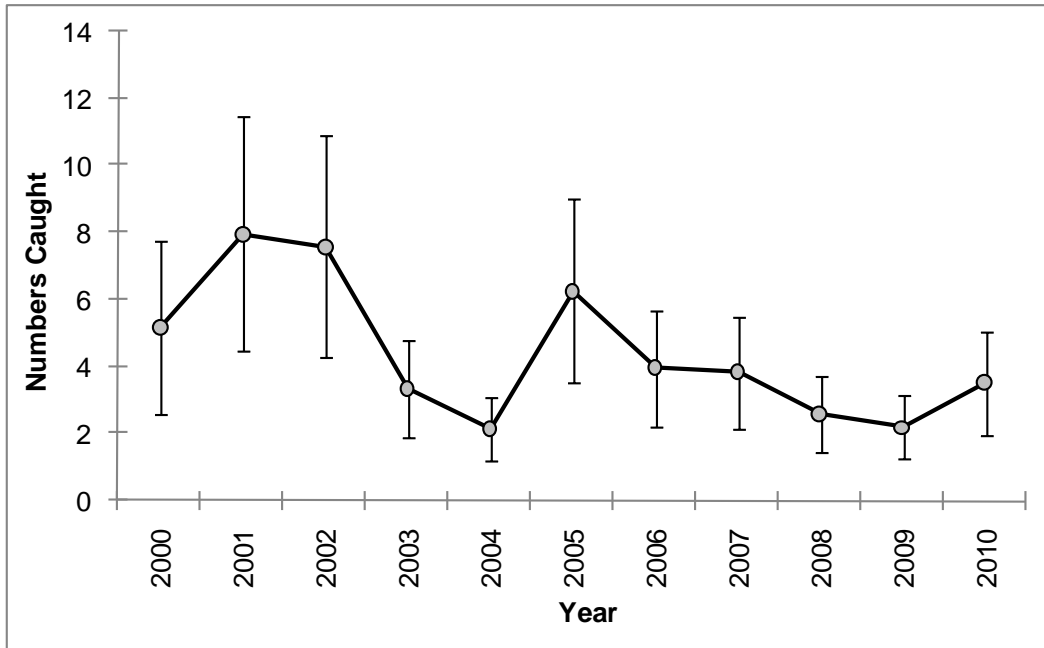


Figure 6.1. GLM-standardized, short-term index of abundance for YOY American eels along the Atlantic Coast, 2000–2010. The error bars represent the standard errors about the estimates.

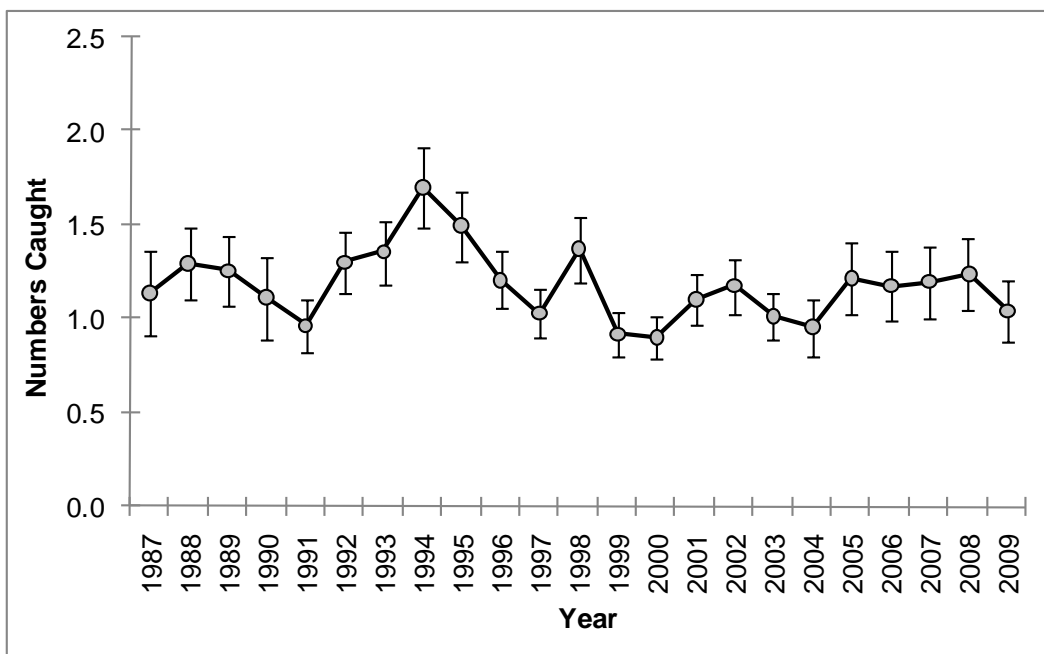


Figure 6.2. GLM-standardized, long-term index of abundance for YOY American eels along the Atlantic Coast, 1987–2009. The error bars represent the standard errors about the estimates.

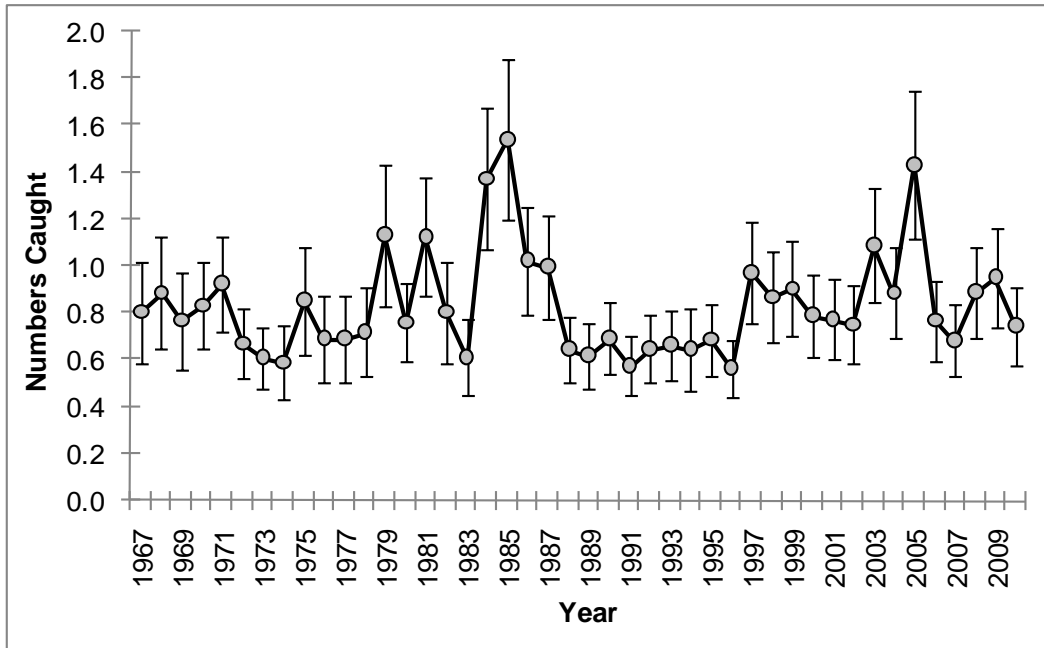


Figure 6.3. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1967–2010 (40-plus-year index). The error bars represent the standard errors about the estimates.

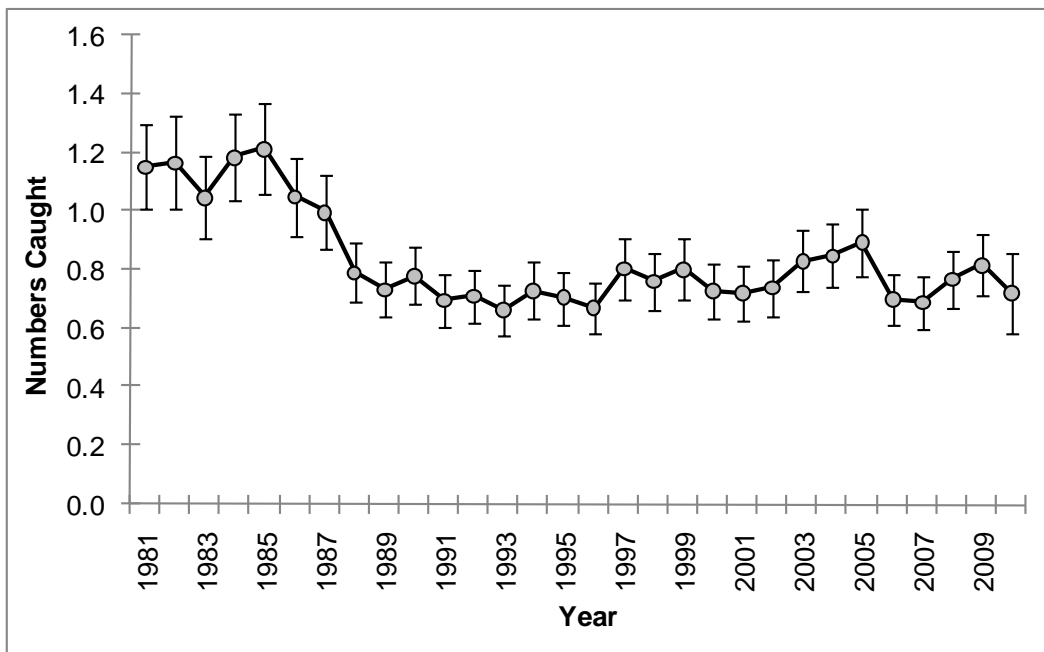


Figure 6.4. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1981–2010 (30-year index). The error bars represent the standard errors about the estimates.

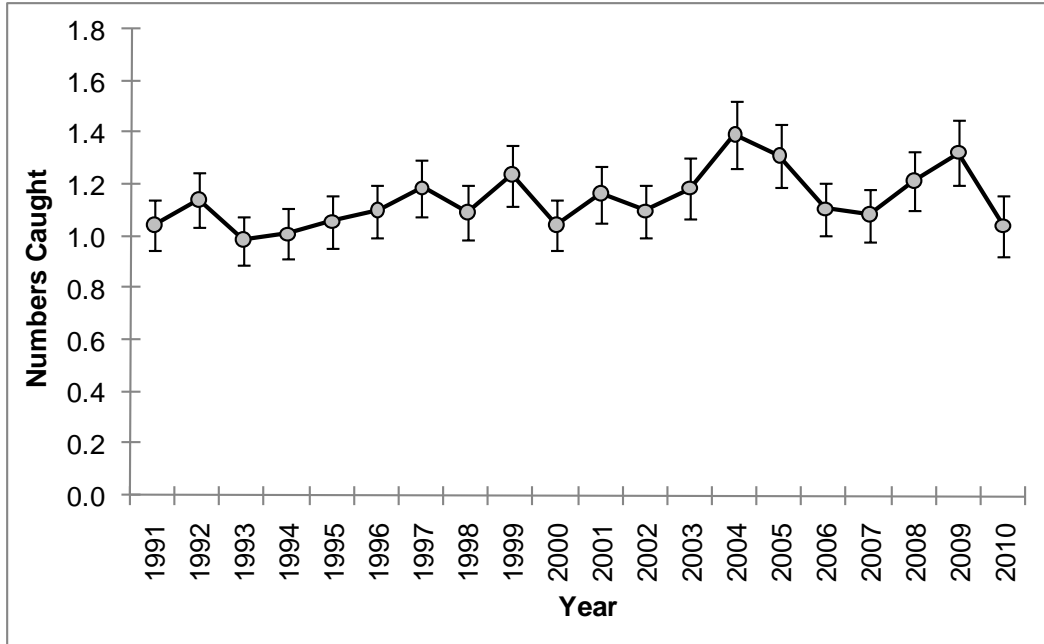


Figure 6.5. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1991–2010 (20-year index). The error bars represent the standard errors about the estimates.

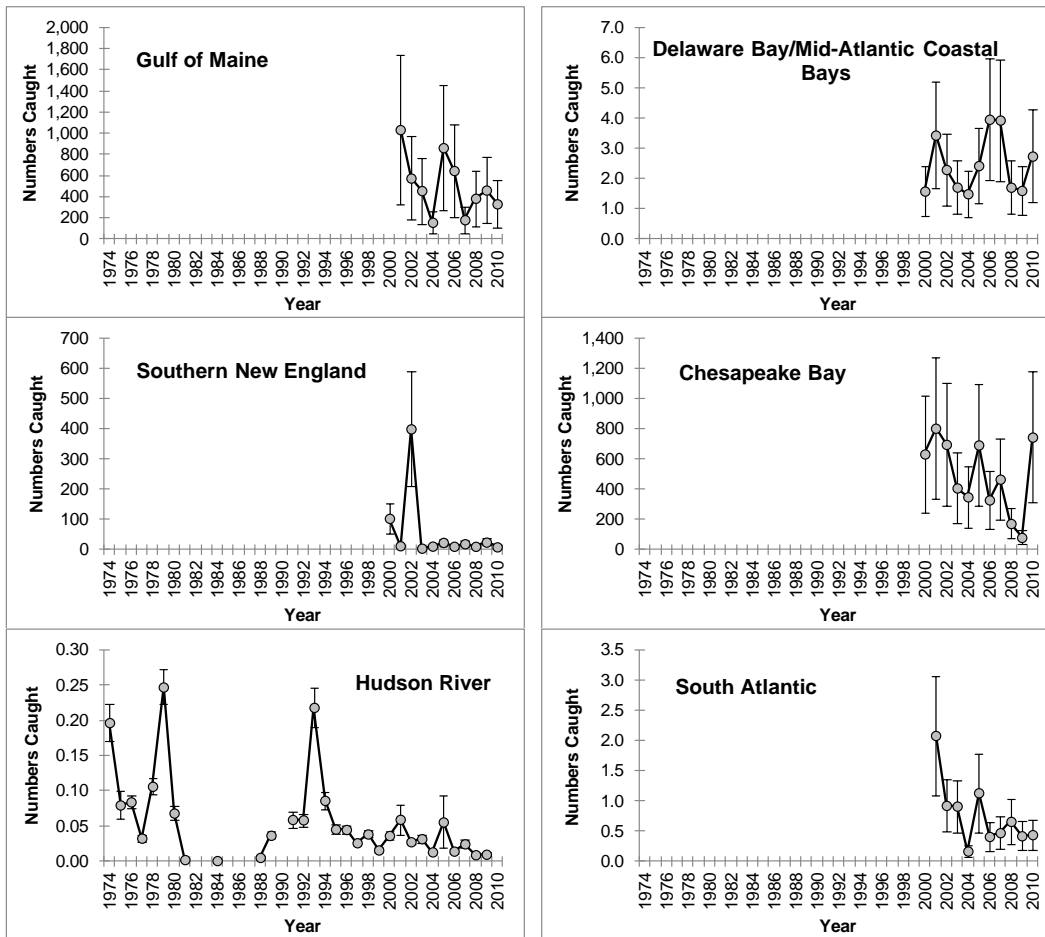


Figure 6.6. Regional indices of YOY abundance for American eels. The error bars represent the standard errors about the estimates.

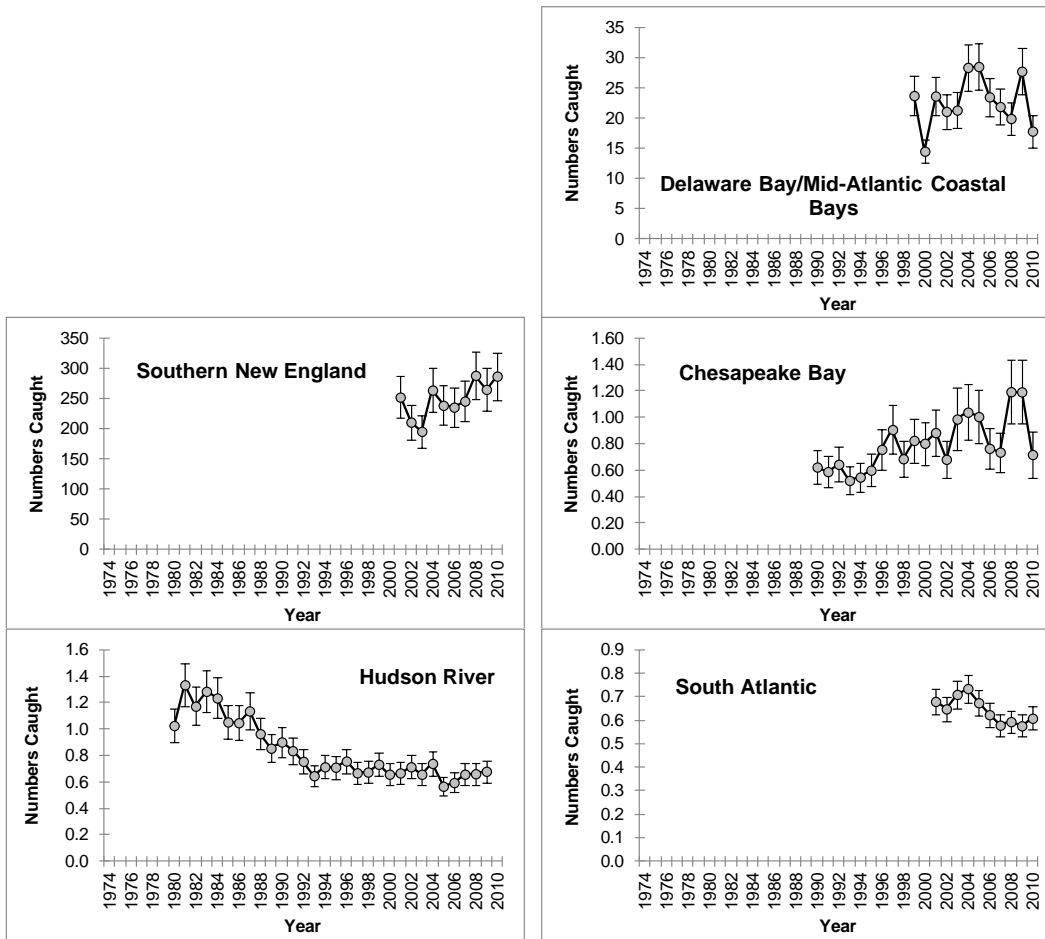


Figure 6.7. Regional indices of yellow-stage abundance for American eels. The error bars represent the standard errors about the estimates.

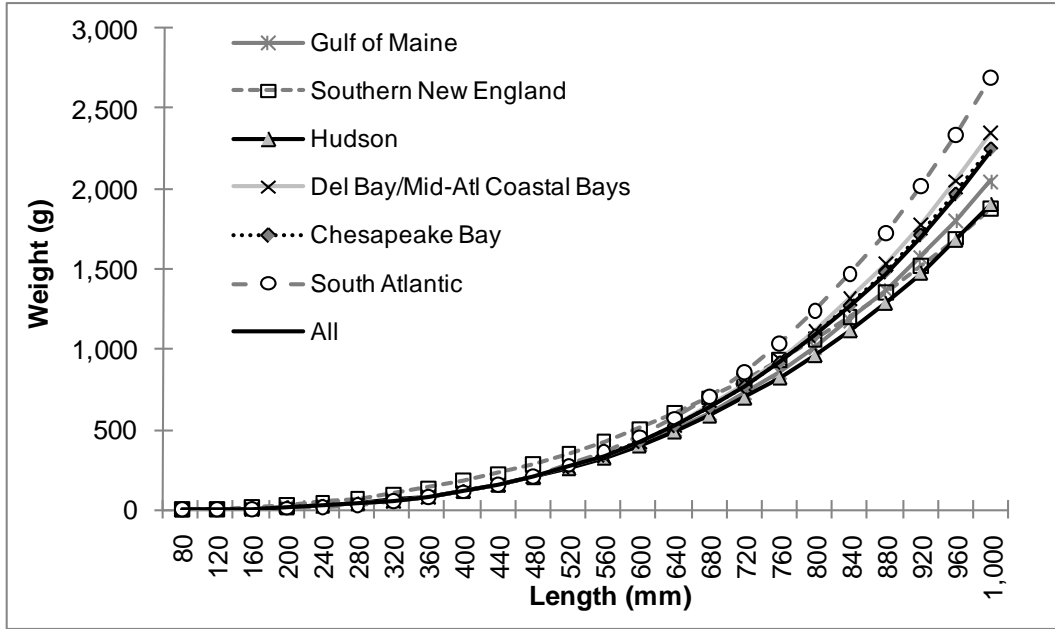


Figure 6.8. Predicted length-weight relation for American eel based on available data, by region.

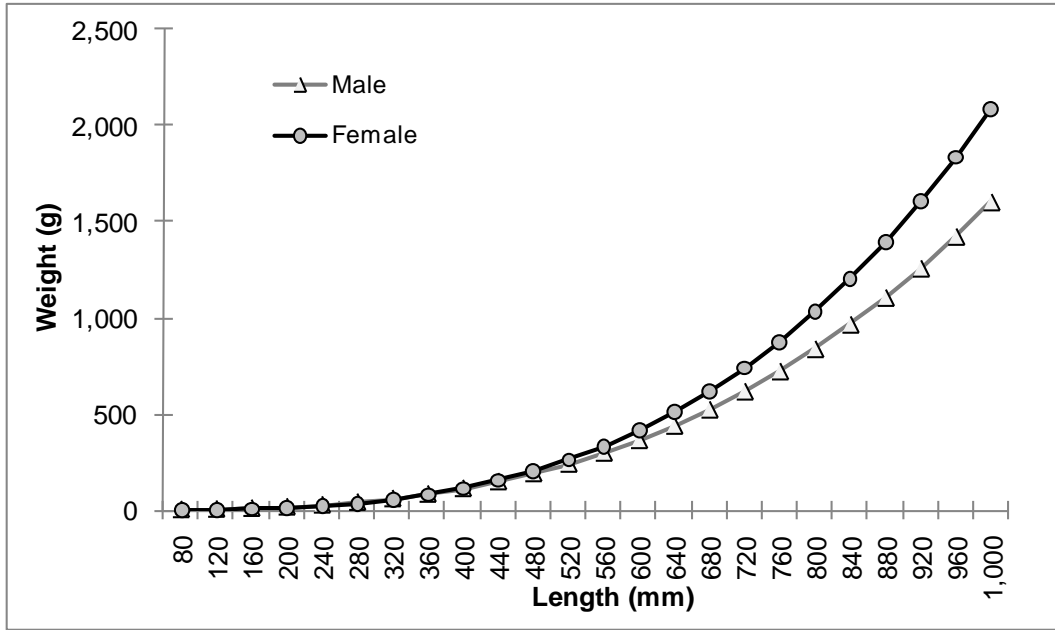


Figure 6.9. Predicted length-weight relation for American eel based on available data, by sex.

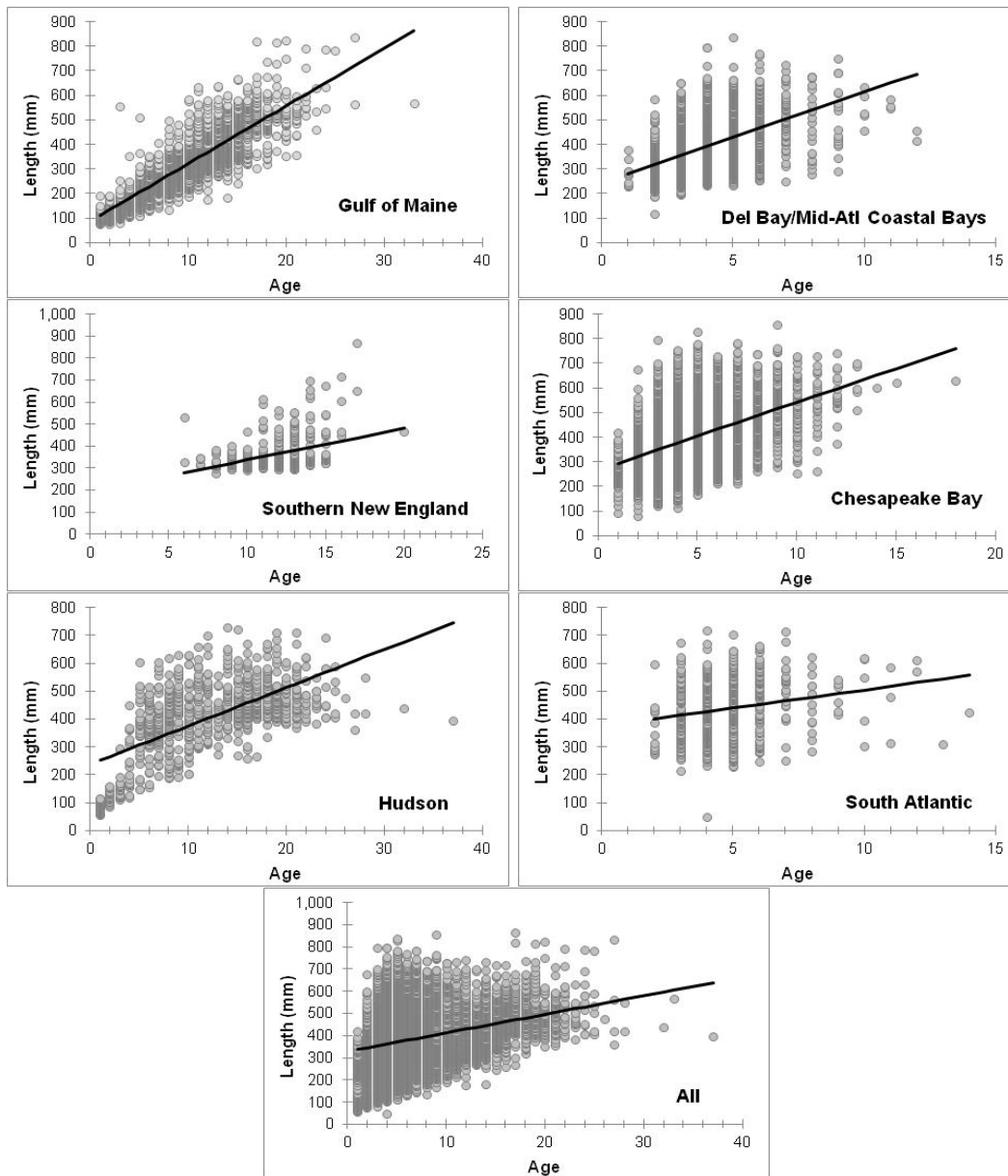


Figure 6.10. Observed age-length data (circles) and predicted linear age-length relation (solid line) for American eel based on available data, by region and for all data pooled.



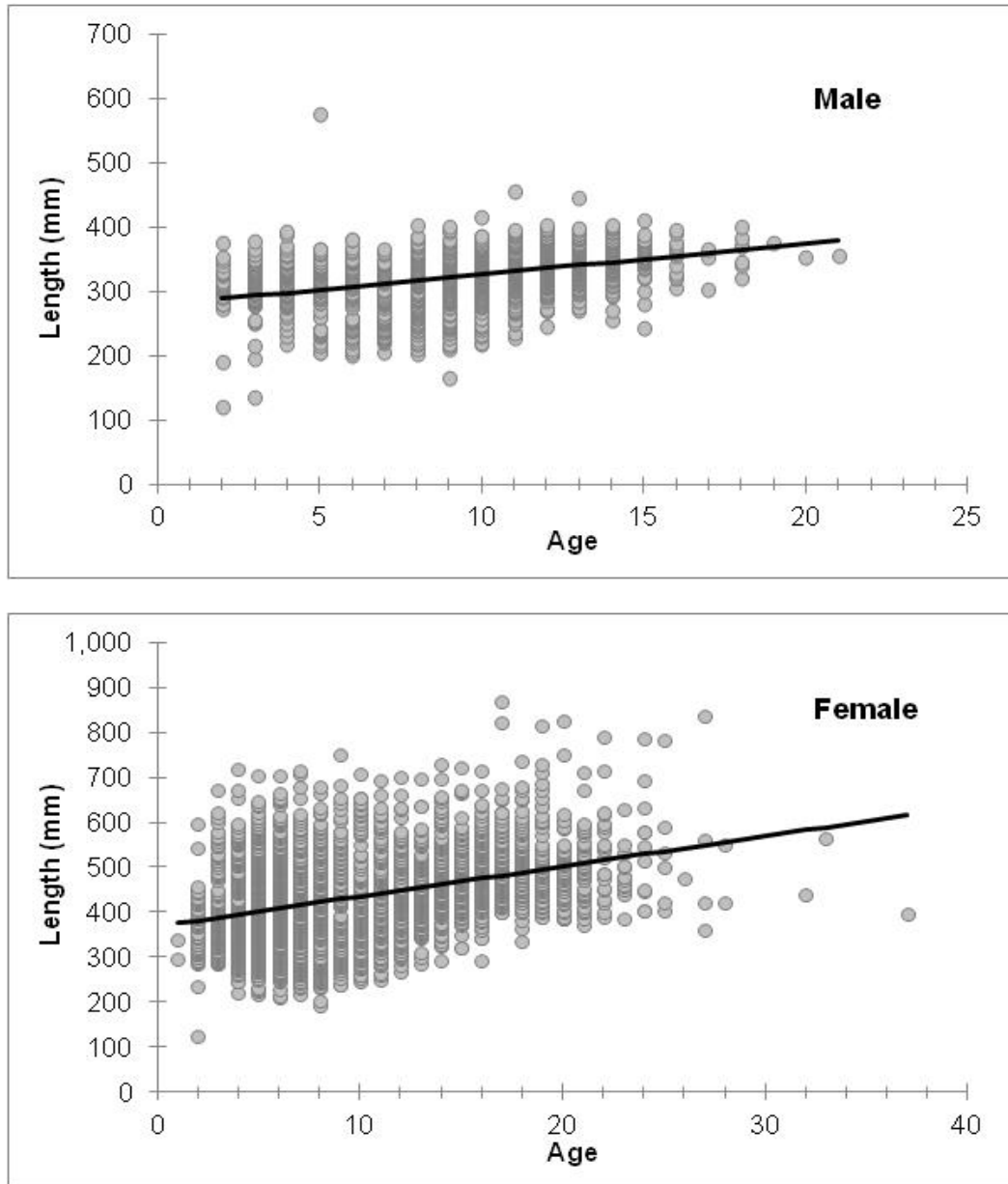


Figure 6.11. Observed age-length data (circles) and predicted linear age-length relation (solid line) for American eel based on available data, by sex.

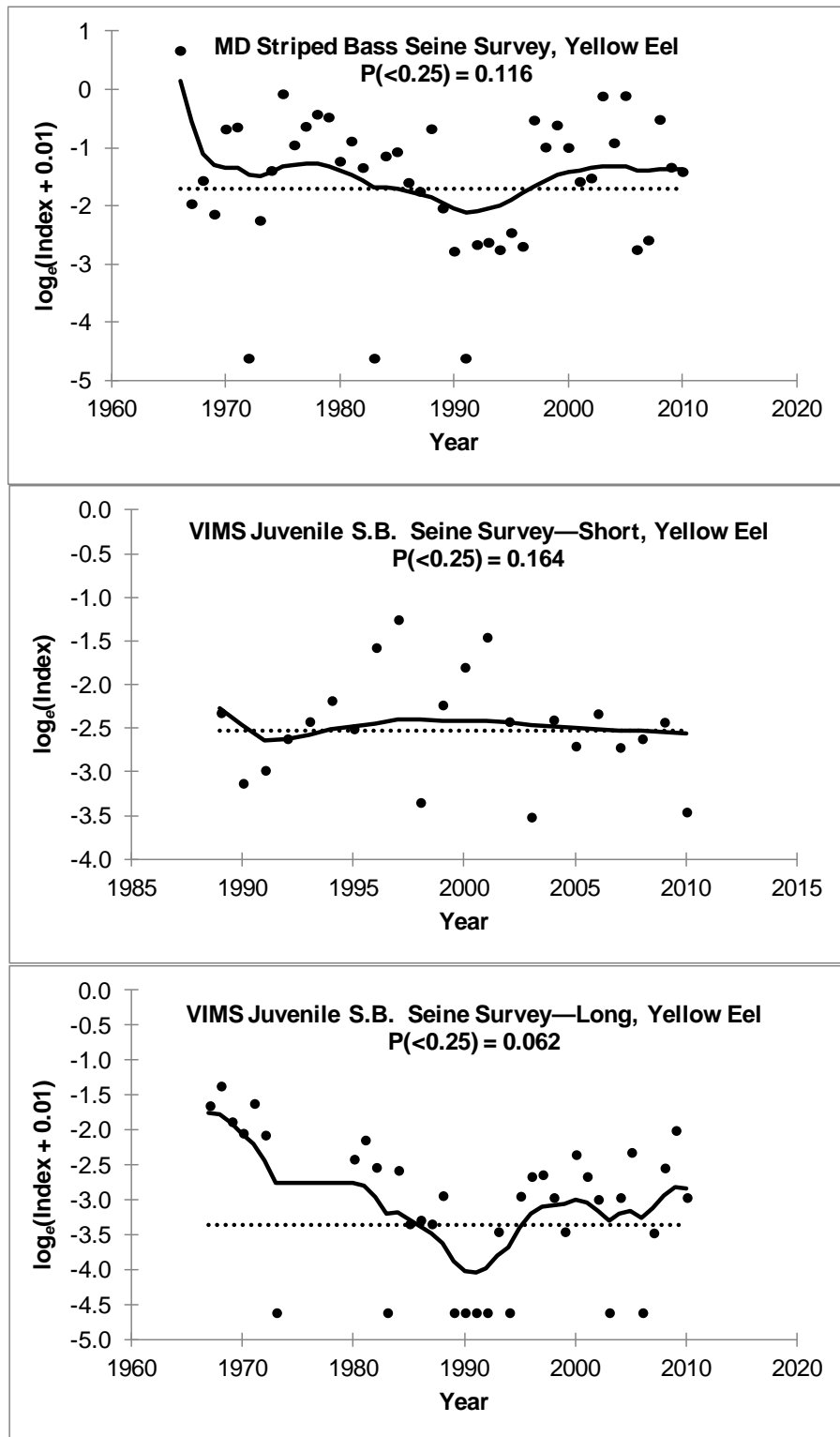


Figure 6.12. ARIMA model fits to American eel surveys from the Chesapeake Bay region. The dotted line represents the 25th percentile of the fitted values.

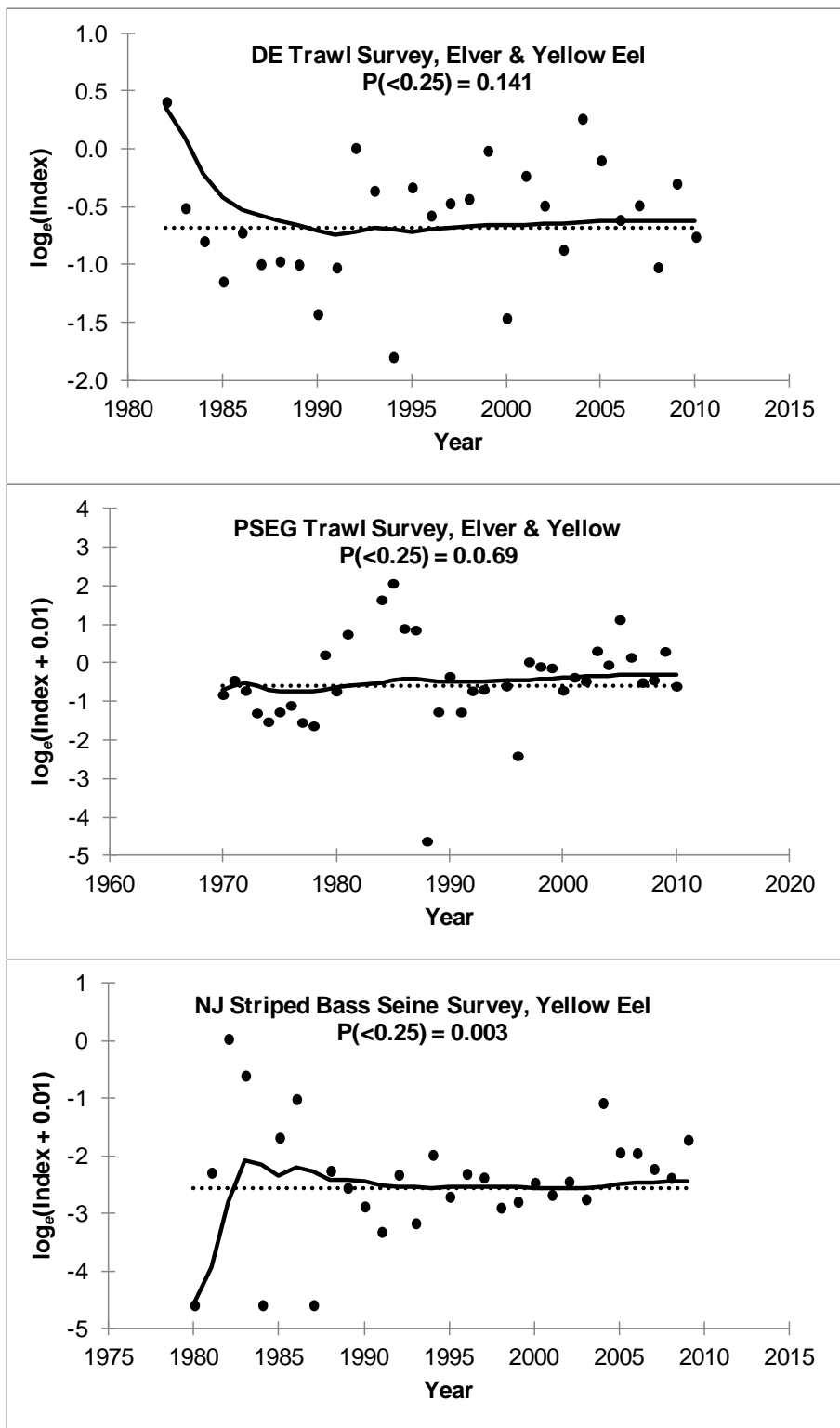


Figure 6.13. ARIMA model fits to American eel surveys from the Delaware Bay/Mid-Atlantic Coastal Bays region. The dotted line represents the 25th percentile of the fitted values.

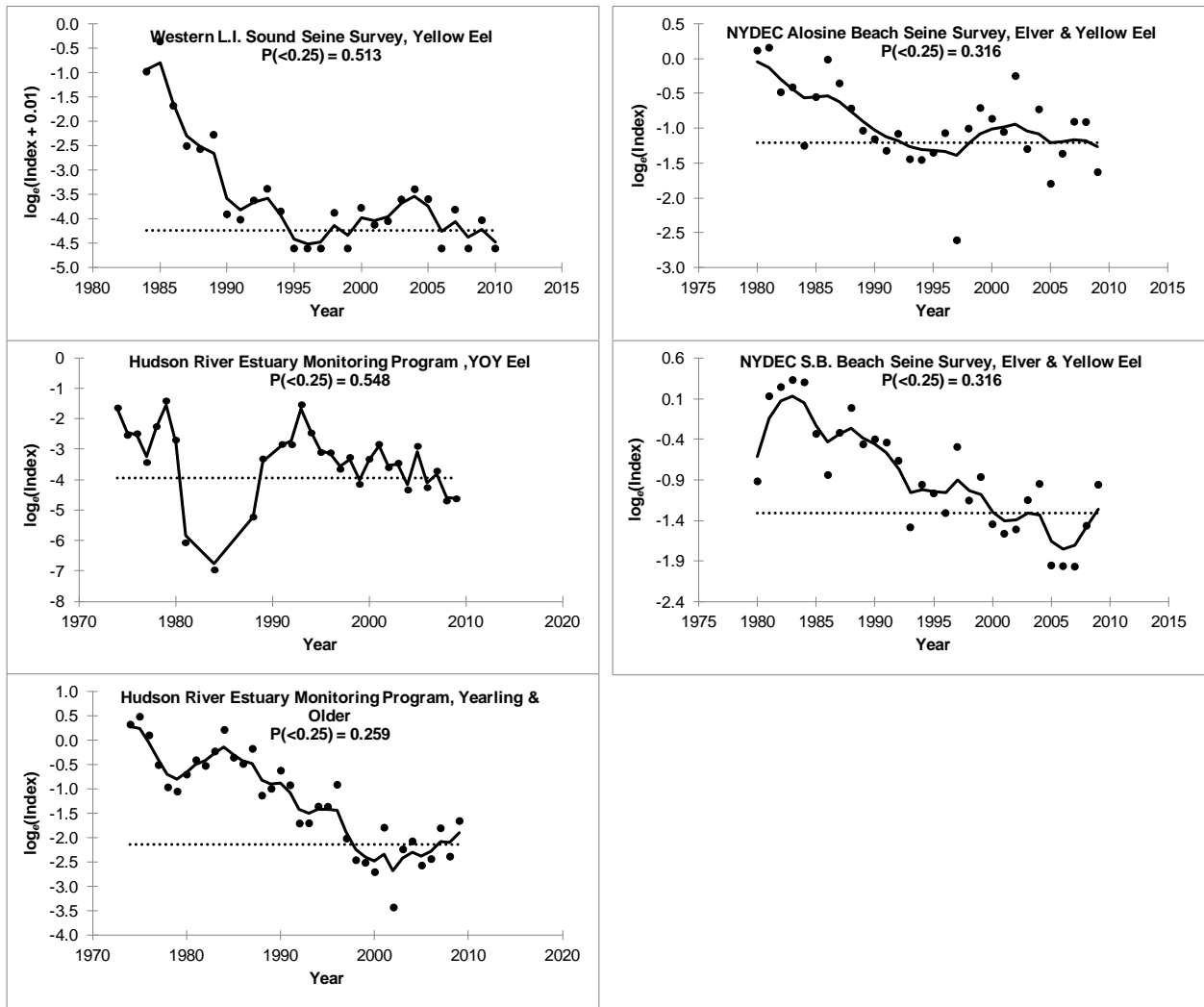


Figure 6.14. ARIMA model fits to American eel surveys from the Hudson River region. The dotted line represents the 25th percentile of the fitted values.

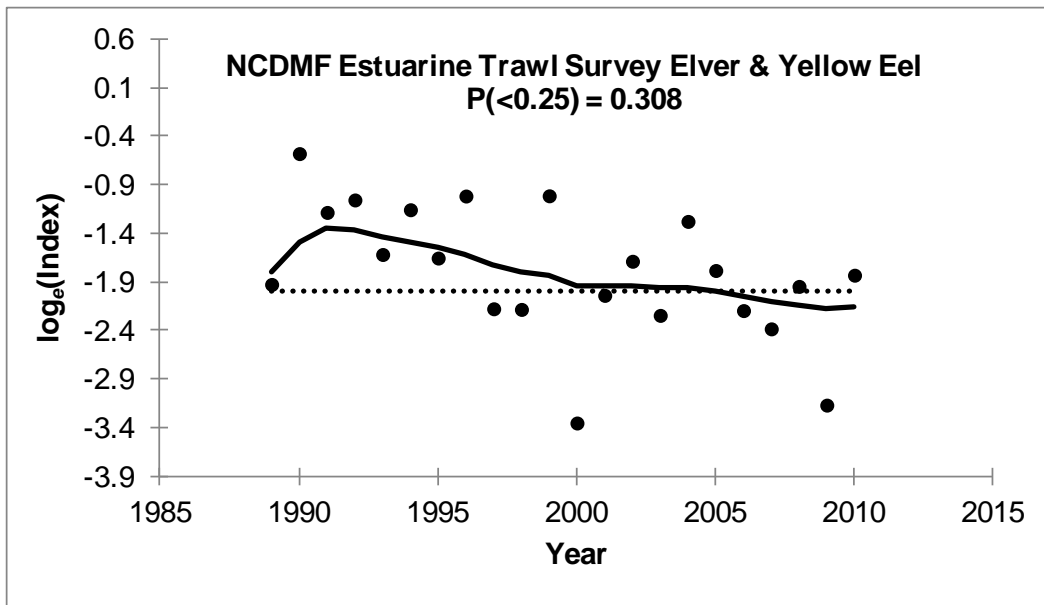


Figure 6.15. ARIMA model fits to American eel survey from the South Atlantic region. The dotted line represents the 25th percentile of the fitted values.

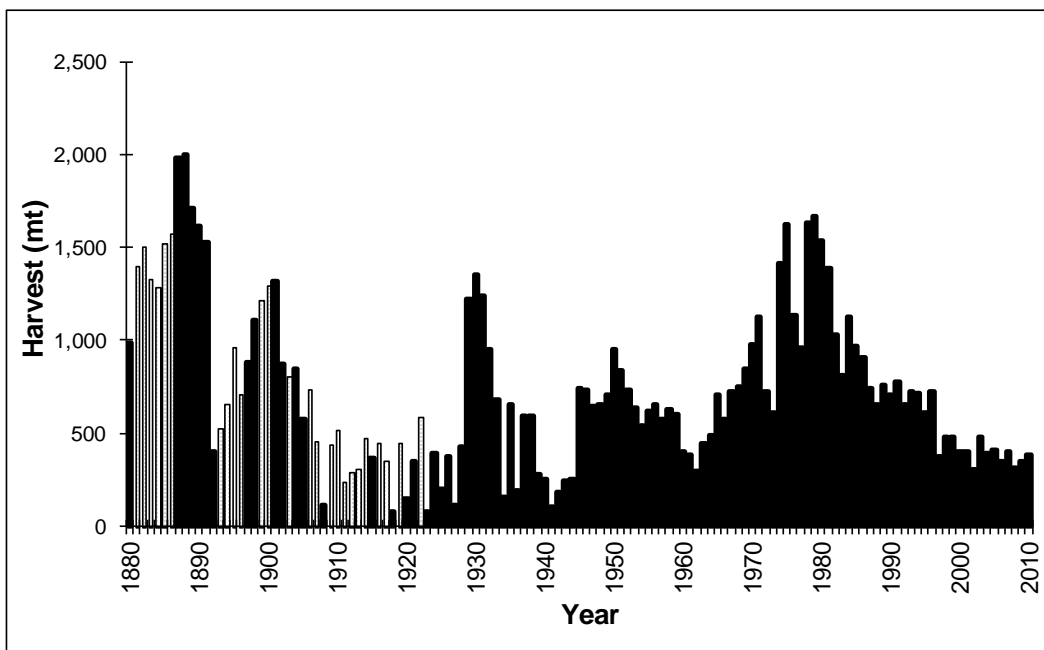


Figure 6.16. U.S. harvest of American eels used in DB-SRA. Light-colored bars indicate years for which harvest was reconstructed.

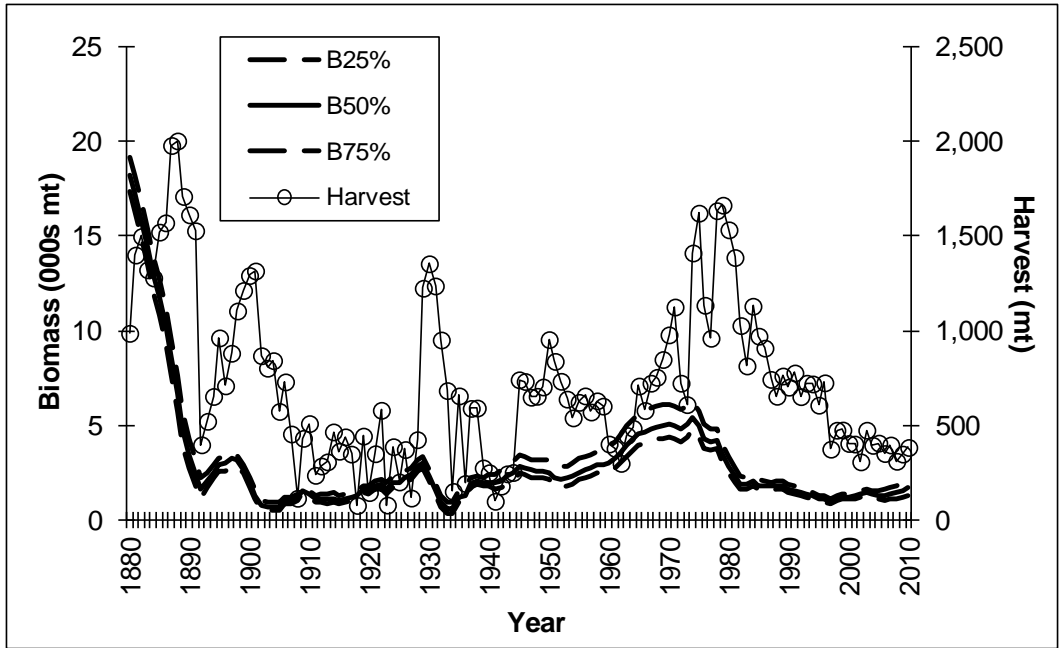


Figure 6.17. Estimated exploitable eel biomass from the DB-SRA single *M* stanza model.

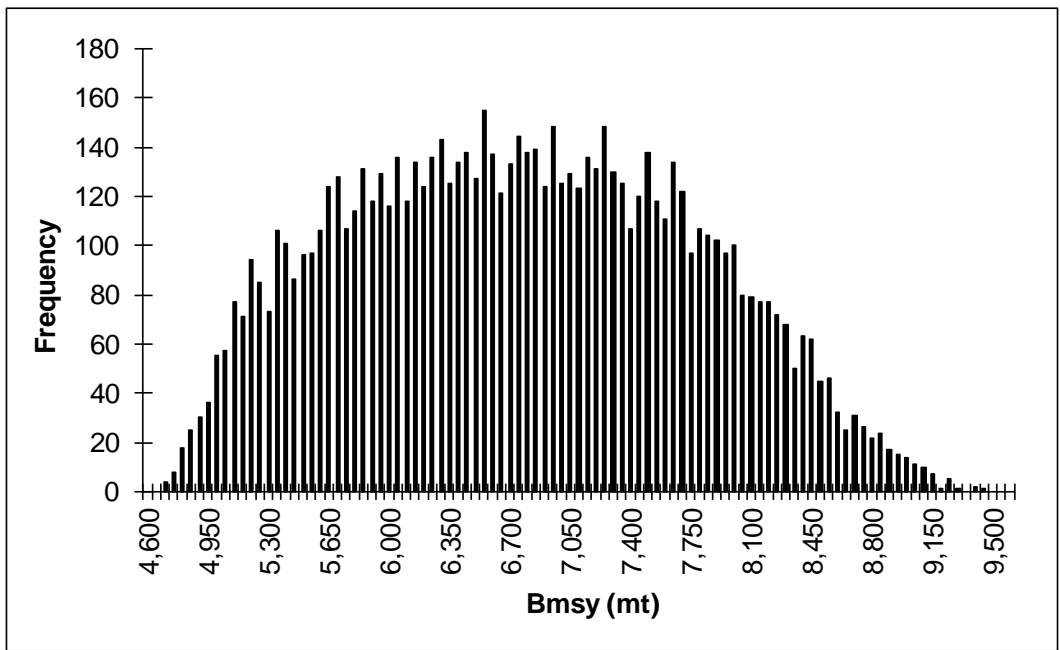


Figure 6.18. Distribution of estimated  $B_{MSY}$  from the DB-SRA single *M* stanza model.

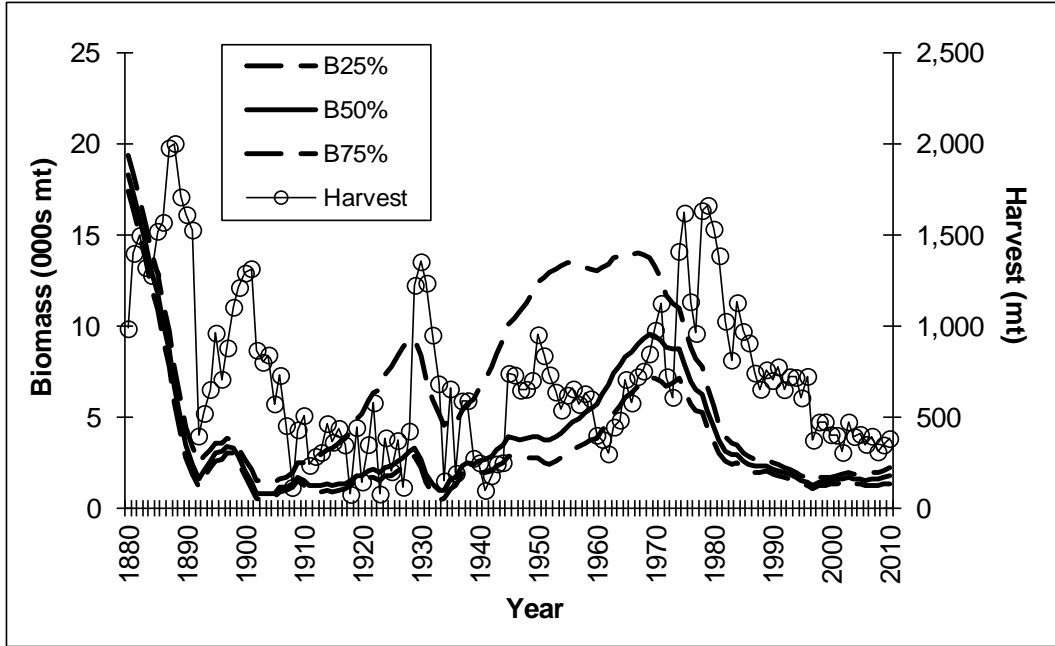


Figure 6.19. Estimated exploitable eel biomass from the DB-SRA double *M* stanza model.

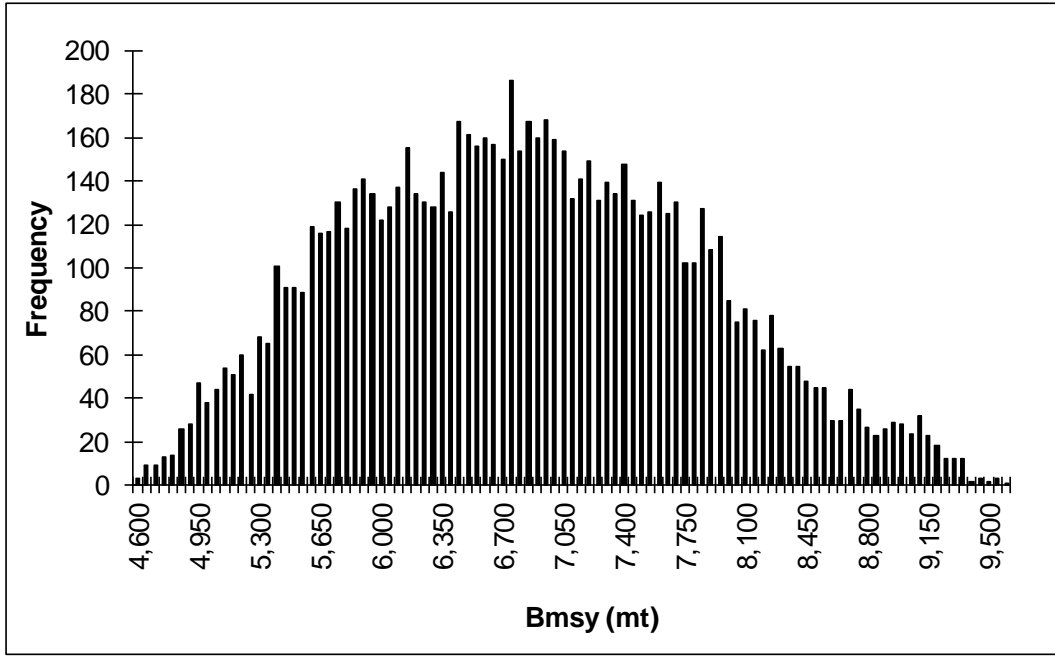


Figure 6.20. Distribution of estimated  $B_{MSY}$  from the DB-SRA double *M* stanza model.

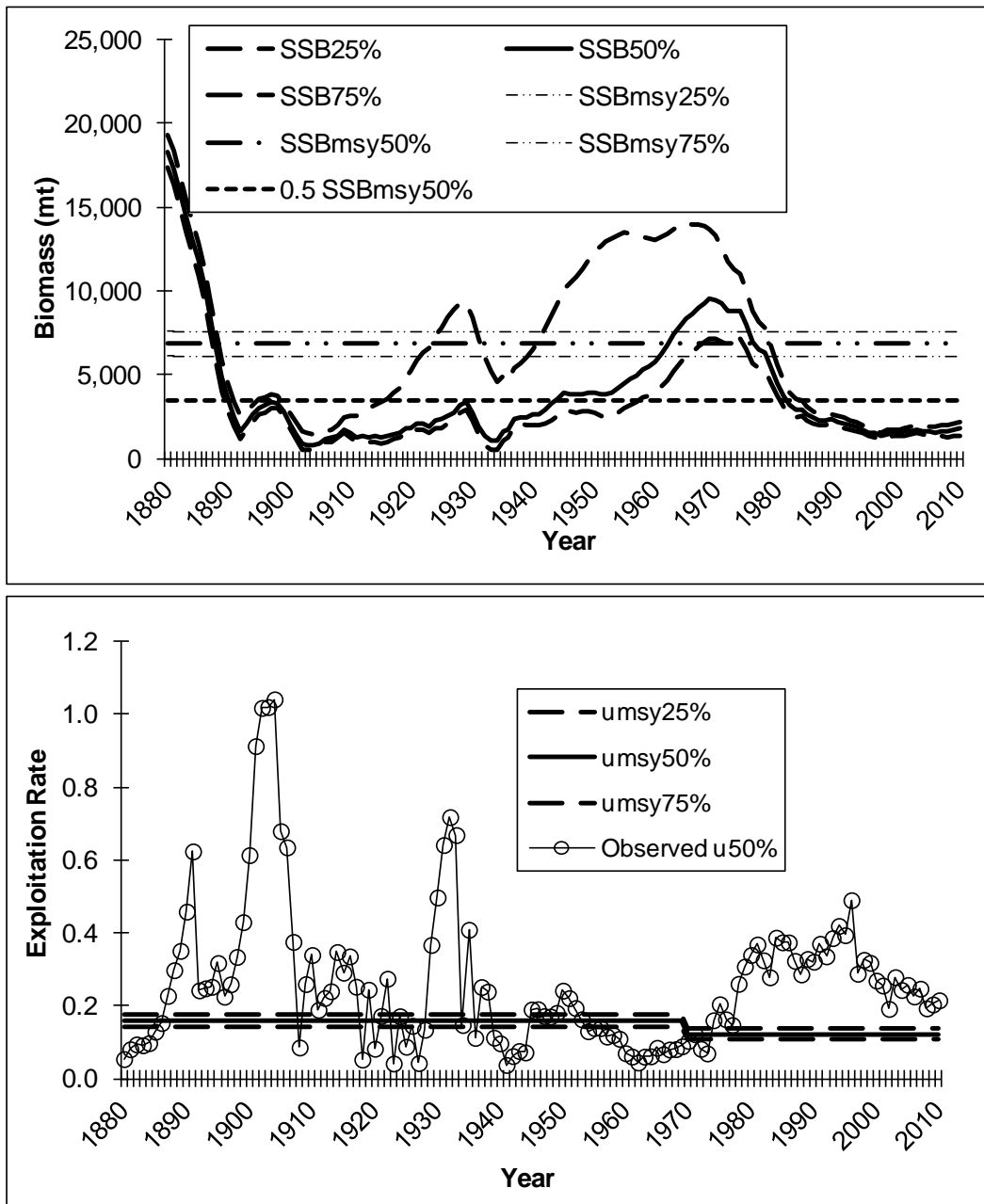


Figure 6.21. Stock status for U.S. American eel population based on the DB-SRA double  $M$  stanza model. Biomass vs  $B_{MSY}$  (upper graph) and annual exploitation (based on median biomass; lower graph) vs  $u_{MSY}$ .



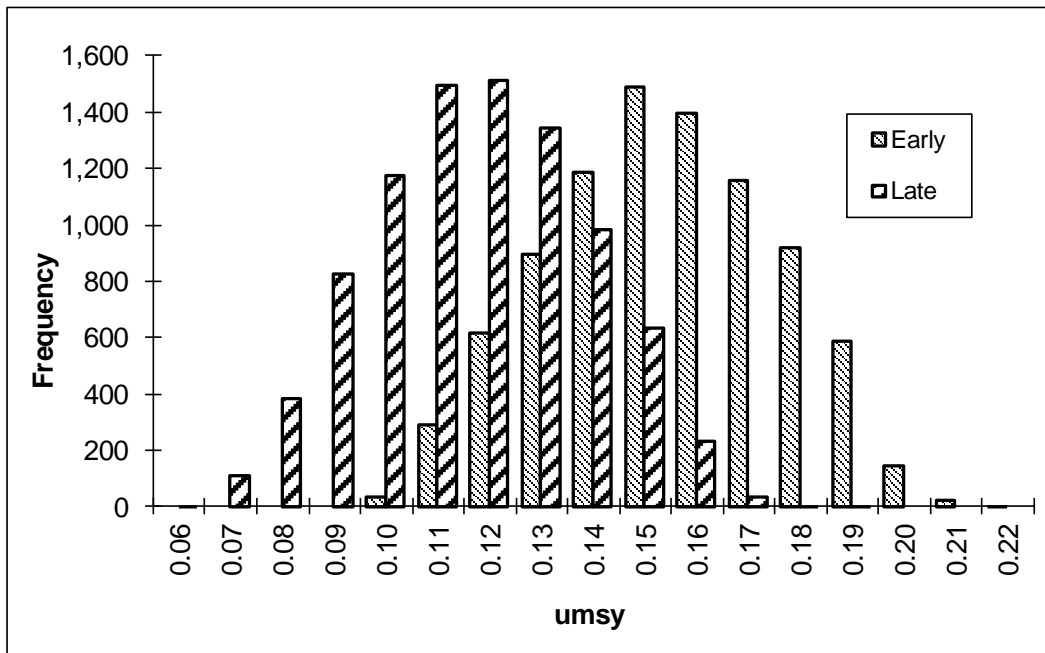


Figure 6.22. Estimated distribution of  $u_{MSY}$  from DB-SRA double  $M$  stanza model.

**APPENDIX 1A. Summary of data sources included in assessment<sup>15</sup>.**

Region	State	Data Source	Data Type	Description	Location	Years	Method	Stage	Index	Bio Data
Gulf of Maine	ME	UMass	FI	Oliveira study	Maine rivers	1996–1998	Fyke, Weir, Electrofishing	S/Y		X
	ME	MEDMR	FI	Fort Halifax Dam	Sebasticook River	1999–2008	Dip net, Ladder	Y		X
	MA	MADMF	FD-comm	MA smelt bycatch	8 coastal rivers	2005–2011	Fyke net	Y		X
Southern New England	RI	UMass	FI	Oliveira study	Annaquatucket River	1990–1991	Fyke net	S		X
	CT	CTDEP	FI	CT electrofishing survey	Farmill River	2001–2009	Electrofishing	Y	X	
	NY	NYDEC	FI	Western Long Island Sound Survey	LIS	1984–2010	Seine	Y	X	
Hudson River	NY	NYDEC	FI	Hudson River Estuary Monitoring Program	Hudson River	1974–2009	Epibenthic sled and Tucker trawl	E/Y	X	
	NY	NYDEC	FI	Alosine survey	Hudson River	1980–2009	Beach seine	E/Y	X	
	NY	NYDEC	FI	Striped bass survey	Hudson River	1980–2009	Beach seine	E/Y	X	
	NJ	NJDEP	FD-comm	Commercial sampling	Hudson River	2008	Pot	Y		X
	NY	UMCES CBL	FI	Morrison study	Hudson River	1997–1999	Pot	Y		X
	NY	SUNY ESF	FI	Machut study	Hudson River	2003–2004	Electrofishing	E/Y		X
Delaware Bay/Mid-Atl Coastal Bays	PA	PAFBC	FI	PA Area 6 electrofishing	Non-tidal Delaware River	1999–2010	Electrofishing	E/Y	X	
	NY	TNC	FD-comm	Neversink tagging study	Neversink River	2008	Tagging	Y		X
	NY	TNC	FI	Neversink Electroshocking	Neversink River & tribs	2006–2008	Electrofishing	Y		X
	NJ	NJDFG	FI	NJ striped bass seine	Tidal DE River	1985–2009	Beach seine	Y	X	
	NJ	NJDFW	FD-comm	Commercial sampling	Statewide	2006–2010	Pot	Y		X
	DE/NJ	PSEG	FI	PSEG impingement	DE Bay	1984–2009	Impingement	Y		X
	DE/NJ	PSEG	FI	PSEG trawl studies	DE Bay	1970–2009	Trawl	Y	X	
	DE	DEDFW	FI	DE juvenile trawl survey	Delaware River	1982–2010	Trawl	Y	X	X
	DE	DEDFW	FI	DE adult trawl survey	Delaware River	1990–2009	Trawl	Y		X
	DE	DEDFW	FI	DE tidal tribs survey	Delaware River	1996–2005	Trawl	E/Y		X
	DE	UDE	FI	Fox silver eel study	Indian River	2002–2003	Fyke net	S		X
	DE	DEDFW	FD-comm	Commercial sampling	Statewide	2000–2010	Pot	Y		X
	MD	MDDNR	FD-comm	Fisheries-Eel Project	Assawoman Bay	2001–2002	Pot	Y		X
MD	MDDNR	FI	Turville Creek Survey	Turville Creek	2009–2010	Pot	Y		X	

<sup>15</sup> This table does not include the ASMFC-mandated annual YOY recruitment surveys.

APPENDIX 1A. *Continued.*

Region	State	Data Source	Data Type	Description	Location	Years	Method	Stage	Index	Bio Data
Chesapeake Bay	WV	USFWS	FI	Shenandoah River study	Shenandoah River	2003–2009	Ladder count	Y		X
	WV	USFWS	FI	Silver eel turbine mortality	Shenandoah River	2007–2010	Electrofishing/ tag	Y/S		X
	WV	USFWS	FI	Shenandoah River study	Shenandoah River	2003–2005	Ladder	Y		X
	WV	USFWS	FI	Parasite infection rates	Shenandoah River	2006–2008	Ladder	Y		X
	MD	MDDNR	FD-comm	Fisheries-Eel Project	Statewide	1997–2010	mostly pots	Y		X
	MD	MDDNR	FI	Fisheries-Eel Project	Statewide	1997–2010	mostly pots	All		X
	MD	USFWS	FI	Pot study	Susquehanna River	2005	Pot	Y		X
	MD	MDDNR	FI	Sassafrass River survey	Sassafrass River	1998–2010	Pot	Y		X
	MD	MDDNR	FI	Gravel Run	Corsica River	2006–2010	Trap at low head dam	S		
	MD	MDDNR	FI	Juvenile striped bass seine		1966–2010	Beach seine	Y	X	
	MD/VA	UMCES CBL	FI	Fenske study	Potomac River	2007	Pot	Y		X
	VA	VMRC	FD-comm	Sanpling	Statewide	1993–2008	mostly pots	Y		X
	VA	VDGIF	FI	Electrofishing	Statewide	1992–2010	Electrofishing	E/Y		X
	VA	Dominion Power	FI	Utilities study	North Anna River	1990–2009	Electrofishing	Y	X	X
VA	VIMS	FI	Striped bass seine survey	Chesapeake Bay	1967–1973, 1980–2010	Seine	E/Y	X		
South Atlantic	VA	VDGIF	FI	Electrofishing	Nottoway River	2000–2010	Electrofishing	Y		X
	NC	Dominion Power	FI	Trap study	Roanoke River	2005–2009	Trap	E/Y		X
	NC	Dominion Power	FI	Pot study	Roanoke River	1999	Pot	Y		X
	NC	Dominion Power	FI	Electrofishing	Roanoke River	1999–2000	Electrofishing	Y		X
	NC	NCDMF	FI	NC Program 120	Statewide	1989–2010 (index), 1971– 2010 (biodata)	Trawl	E/Y	X	X
	NC	ECU	FI	Cudney study	Lake Mattamuskeet	2002–2003	Pot	Y/S		X
	NC	NCDMF	FD	Hutchinson Study	Pamlico River	1996	Pot	Y		X
	SC	SCDNR	FI	SC red drum electrofishing	Multiple river systems	2001–2010	Electrofishing	Y	X	X
	FL	FMRI	FD-comm	Commercial sampling	St. Johns River	2001–2006	Pot	Y		X
	FL	FWRI	FI	Lake City Regional Office River survey	Suwannee River & others	1996–2008	Electrofishing	Y		X
	FL	FWRI	FI	Long Term Freshwater Fisheries Monitoring	12 lakes & marshes	2007–2008	Electrofishing	Y		X

**APPENDIX 1B. Summary of reviewed data sources deemed inadequate for assessment<sup>16</sup>.**

Region	State	Data Source	Data Type	Description	Location	Years Available	Collection Method	Stage/Length Range	Justification for exclusion
GOM	ME	MEDMF	FI	Fort Halifax Dam	Sebasticook River	2000–2008	Ladder census	Yellow	Short time series (1999 used dip nets and dam removed in 2008)
GOM	MA/NH	USFWS	FI	Dam survey	Merrimack River	2000–2001	Electrofishing	Yellow	Upstream of dam, low eel catch
GOM	MA	MADMF	FD	MA smelt bycatch	8 coastal rivers	2005–2011	Fyke net	Yellow	Short time series - consider in future
GOM/SNE	MA	MADMF	FI	Dam passage monitoring	~6 river systems	variable (2004+)	Eel ramp, Sheldon trap	YOY and ages 1+	Short time series - consider in future
SNE	MA	UMass	FI	Paskamansett River study	Paskamansett River	2001–present	Fyke net	Silver	Eels not processed aged yet; also all males - consider in future
SNE	CT	CTDEP	FI	Dam passage monitoring	~6 river systems	variable (2000+)	Passage counts	Elver/Yellow	Short time series - consider in future
SNE	RI	RIDEM	FI	Trawl survey	Narragansett Bay, Rhode Island, & Block Island Sound	1979–2010	Trawl	Elver/Yellow	Eels rarely caught
SNE	RI	RIDEM	FI	Juvenile finfish survey	Narragansett Bay	1986–2010	Beach seine	Elver/Yellow	Eels rarely caught
SNE	CT	USFWS	FI	Pot survey	Connecticut River	2009	Pot survey	Yellow	Short time series - consider in future
HR	NY	NYDEC	FI	Dam impingement monitoring	Hudson River	1973–2009	Dam sampling	Silver/Yellow	Collection inconsistent, incidental catch (not direct passage)
HR	NY	NYDEC	FI	HRE Monitoring Program (Fall Shoals and Beach Seine)	Hudson River	1970s–2008	Beach seine and trawl	Elver/Yellow	Data not available, consider in future
DER/DEBay	DE	DEDFW	FD	Fox study	St. Jones River	2005–2009	Pot/tagging	Yellow	Data not available, consider in future
DER/DEBay	NJ	NJDFG	FD	NJ fisheries sampling	Statewide	2006–2010	Pot, weir, fyke net	Yellow	Ages collected, not yet processed

<sup>16</sup> This table does not include the ASMFC-mandated annual YOY recruitment surveys.

**APPENDIX 1B. *Continued.***

Region	State	Data Source	Data Type	Description	Location	Years Available	Collection Method	Stage/Length Range	Justification for exclusion
DER/DEBay	NJ	NJDFG	FD	NJ fisheries sampling	Statewide	2006–2010	Pot, weir, fyke net	Yellow	Ages collected, not yet processed
DER/DEBay	PA	PAFBC	FI	Small mouth bass survey	Delaware & Lehigh rivers	2005–2009	Electrofishing	Elver	Short time series - consider in future
DER/DEBay	PA	PAFBC	FI	Passage sampling	Lehigh River	2005–2011	Passage counts	Elver/Yellow	Missing years, 2 sites sampled
DER/DEBay	PA	PAFBC	FI	Warmwater stream survey	Tribs of Delaware River	2007–2009	Electrofishing	Elver/Yellow	Missing years, 2 sites sampled
DER/DEBay	PA	Acad NS	FI	Electrofishing study	Tidal tribs of Delaware River	1995–2004	Electrofishing	Glass/Yellow	Locations and sampling methodology changed
DEBay/ ChesBay	DE/MD/ VA	UDE/CBL/ VIMS	FI	Ichthyoplankton survey	Delaware & Chesapeake Bay	2007–2009	Neuston net	Lepto/Glass	Short time series - consider in future
ChesBay	DC	DC Fisheries	FI	Electrofishing survey	Potomac & Anacostia rivers	2005–2009	Boat electrofishing	Elver/Yellow	Short time series - consider in future
ChesBay	DC	DC Fisheries	FI	Pot survey	Potomac & Anacostia rivers	2008–2009	Pot survey	Yellow	Short time series - consider in future
ChesBay	MD	MDDNR	FI	Juvenile fish & blue crab survey	Chesapeake Bay	1991–2010	Trawl	Yellow	Only one river, eels rarely caught
ChesBay	VA	VIMS	FI	Juvenile fish & blue crab survey	Chesapeake Bay	1980–2010	Trawl	Elver/Yellow	Indices of different length eels produced nearly identical trends
SA	NC	NCDMF	FD	NC Fishery	Statewide	1994–2009	Trip ticket	Yellow	Unkown # of trips per trip ticket due to penning
SA	NC	NCDMF	FD	NC Fishery	Statewide	2007–2009	Logbooks	Yellow	Short time series - consider in future
SA	NC	NCWRC	FI	Electrofishing survey	Roanoke, Tar, Neuse, & Cape Fear rivers	1979–2004	Electrofishing	Yellow	Unable to collect eels from vessel until 2010 - consider in future
SA	NC	NCWRC	FI	Yellow perch monitoring	Chowan River & tribs	2005–2010	Plankton net	Elver	Short time series, eel rarely caught
SA	NC	Dominion Power	FI	Pot and electrofishing CPUE	Roanoke River	2005–2009	Pot & electrofishing	Elver/Yellow	Short time series; consider in future

**APPENDIX 1B. *Continued.***

<b>Region</b>	<b>State</b>	<b>Data Source</b>	<b>Data Type</b>	<b>Description</b>	<b>Location</b>	<b>Years Available</b>	<b>Collection Method</b>	<b>Stage/Length Range</b>	<b>Justification for exclusion</b>
SA	SC	SCDNR	FI	Juvenile marsh fish monitoring	Tidal marshes	1986–1994	Rotenone	Elver	Eels rarely caught
SA	SC	SCDNR	FD	Trammel net survey	Estuaries	1991–2010	Trammel net	Elver/Yellow	Eels rarely caught
SA	SC	SCDNR	FD	Biological sampling	SC waters	2000–2008	Trip level reports	Elver/Yellow	Very small fishery
SA	GA	GADNR	FI	Stream electrofishing study	Multiple streams statewide	1998–2002	Electrofishing	Unknown	No biological data, missing years, eels rarely caught
SA	FL	FWRI	FD	Biological sampling	4 lakes and St. Johns River	2006–2009	Trip ticket	Yellow	Short time series - consider in future
SA	FL	FWRI	FI	Seine & trawl surveys	5 bays/rivers	1989–2008	Mixed seine, trawl	Yellow	Mixed gears, eel rarely caught
SA	FL	FLGFWFC	FI	Blocknet & electrofishing studies	Multiple water bodies statewide	1973–2000	Block net & electrofishing studies	Yellow	Total weights/lengths, locations changed
SA	FL	FWRI	FI	Electrofishing	South Florida	2002–2004	Electrofishing	Yellow	Short time series, eel rarely caught
SA	FL	FWRI	FI	Electrofishing	South Florida	2000–2003	Electrofishing	Yellow	Short time series, eel rarely caught
SA	FL	FWRI	FI	Electrofishing	Gopher, Santa Fe, Withlacoochee Rivers	1996–2008	Electrofishing	Yellow	Inconsistent sampling locations

## APPENDIX 2. Description of index standardization methodology.

1. Identify response variable. If data were collected using a standardized effort unit (e.g., electrofishing catch/15 min sampling event or catch/tow trawl surveys), model numbers caught (not CPUE). If concerned about changes in effort in the dataset, model catch as a function of effort and other covariates. If testing multiple models, make sure the response variables are the same.
2. Identify explanatory variables and associated data type (e.g., categorical, continuous):
  - Year will always be included as a categorical explanatory variable in all models.
  - Include a small subset of other appropriate variables using the literature and expert judgment if necessary. Do not include all potential variables - only ones that might be affecting **catchability (not abundance)** or you may standardize away the factors that actually affect trends in abundance.
  - Scatterplot each potential covariate...
  - If obvious breaks or groupings appear, (e.g., seasons, depth/habitat categories, etc.) make that a categorical variable. Otherwise, make it a continuous variable if no obvious breaks in the data. Always assign year as a categorical variables to estimate year effects. For all categorical variables, check to make sure you have adequate number of samples in each category or your model will blow up. Lump categories if necessary/meaningful. If not, categories with no samples should be eliminated (data points removed from dataset) because the model cannot provide estimates for that factor if there are no observations. If there are only a few observations in that category, try to run the model (if it blows up, you'll have to go back and remove it).
  - If two or more variables are highly ( $>0.9$ ) or logically correlated, pick the one that makes the most sense biologically if possible; for example, don't include both temperature and dissolved oxygen, or latitude and river system. If desperate, include interaction terms (with anything but year) as an initial test if you're not sure how things will pan out, but don't include interaction terms in the final model (nearly impossible to interpret and calculate final year effect for index).
  - Check if any factor is orders of magnitude different from others and adjust accordingly (turn 1,000,000 into 1 "million" to be on scale with other measurements in model).
3. Plot histogram of number of animals caught. Determine if there is a large gap between # of zeros and next highest bar (e.g., determine if you tend to either catch either no animals or a lot of animals).
  - If so, use delta approach (R code from Erik Williams, NMFS Beaufort) which models pres-abs with binomial model and positive tows with a different distribution (usually lognormal or gamma).
  - Otherwise, proceed to other generalized/general linear models in next step.

4. If delta methods are not appropriate, identify what distributional assumptions might be. Plot catch rate vs. variance in catch rate aggregated by each categorical factor and compare pattern with figures from Punt et al. (2000). A linear relationship supports an overdispersed Poisson error model, and variance in catch rate proportional to the square of the average catch rate suggests the log-normal and gamma error models. The negative binomial error model implies that the variance in catch rate is a function of both the average catch rate and the square of the average catch rate. Choose from below depending on outcome of mean-variance inspection. Avoid transformations of your response variable or covariates.
  - If lognormal or gamma error models are implied, perform the gamma. If you must for some reason use the lognormal, model catch as Gaussian with log link to avoid transforming catch. If you must for some reason model CPUE, use  $\log_e[\text{CPUE} + \min(\text{value}/2) \sim \cdot]$
  - If Poisson error model is implied, run the basic Poisson model (implying data are probably not overdispersed) and compare with the zero-inflated Poisson using the Vuong test. (Note: you will not be able to compare zero-inflated models with other sub-models in step 6).
  - If the negative binomial error models are implied, run the basic negative binomial model and compare with the zero-inflated negative binomial using the Vuong test. (Note: you will not be able to compare zero-inflated models with other sub-models in step 6).
5. Select the appropriate canonical link function (relates mean of response variable to explanatory variables) for the model you've selected. Gamma – inverse. Poisson and negative binomial – log.
6. If all factors in the final model are not significant, run all sub-models and select best model as one with lowest AIC. If too many covariates are included for this to be practical, use stepwise selection of covariates (or better yet, reconsider what covariates you are including). You will not be able to do this for the zero-inflated models.
7. Evaluate goodness-of-fit.
  - Check for overdispersion; if is  $> 2$  suggests overdispersion. NA for Poisson model.
  - Plot standardized residuals against fitted values; presence of pattern may suggest overdispersion, miss-specification of link function, missing covariate, outliers
8. If desired, perform back-transformation and include bias correction. Pull out mean year effects and SEs.



**APPENDIX 3. SLYME model report.**

**American Eel SLYME Model:**

**Report to the  
ASMFC American Eel Technical Committee**

July 2008

Prepared by:

ASMFC American Eel Stock Assessment Subcommittee

Laura M. Lee (VMRC), *Chair*

Jeffrey Brust (NJDEP)

Keith Whiteford (MDDNR)

John Clark (DNREC), *Technical Committee Chair*

Erika Robbins (ASMFC), *FMP Coordinator*

## **BACKGROUND**

The ASMFC American Eel Management Board initiated the development of Draft Addendum II in January 2007 to propose measures that would facilitate escapement of silver eel as a means to improve American eel recruitment and abundance. The Management Board asked the Technical Committee (TC) and Advisory Panel (AP) to consider closed seasons, gear restrictions, size limits, or a combination of these measures to reduce the harvest of emigrating eels. The TC and AP were asked to comment on the draft addendum, though both groups felt more information was needed in order to evaluate the proposed options. The Management Board requested the Stock Assessment Subcommittee (SASC) quantify the potential benefits of a maximum size limit. The SASC proposed a life-table approach to examine the potential impact of a maximum size limit on the population's egg production. The TC supported this approach. In August 2007, the Management Board approved the use of the life-table model, known as SLYME, to aid in the evaluation of implementing a maximum size limit. In May 2008, Management Board asked the SASC to also consider various slot limits in their evaluations.

## **INTRODUCTION**

Although the available data for American eel in the U.S. have not been sufficient to perform a reliable quantitative assessment of the population size or fishing mortality rates (ASMFC 2001, 2006), there has been evidence that the stock has declined and is at or near low levels (ASMFC 2000, 2001, 2006; USFWS 2007). The ASMFC American Eel Management Board initiated Draft Addendum II based on a concern about evidence of declines in abundance of the yellow eel life-stage of American eel. The primary management objective of this Draft Addendum was to propose measures to facilitate escapement of silver eels during or just prior to their spawning migration with the intent of halting any further declines in eel abundance. Given the proposed measures, the ASMFC American Eel TC agreed with the advice from the American Eel SASC that implementing a maximum size limit was a feasible way to increase silver eel escapement.

In the absence of estimates of stock size and exploitation rates, the SASC proposed the use of a per-recruit approach to evaluate the potential impacts of maximum size limits. The SLYME (Sequential Life-table and Yield-per-recruit Model for the American Eel) model was initially developed by David Cairns (DFO Canada) for the August 2000 meeting of the ICES Working Group on Eels. The model was used to evaluate the effect of the Prince Edward Island American eel fishery on spawning escapement. The model has since undergone several revisions and was most recently updated in 2003. The SASC used a modified version of the deterministic SLYME model to investigate the effects of different maximum size limits on female spawner escapement and egg production.

Although a stock-recruitment relationship for American eel has not been quantified, it is believed that an increase in the number of silver eels that escape and are allowed to spawn will ultimately increase juvenile recruitment and future production. Imposing a maximum size limit will reduce exploitation of large eels, allowing the opportunity for more eels to mature and undertake their spawning migration. The current model shows the relative impact of varying fishing mortalities on egg production and the relative increases in egg production as a result of changing the maximum harvest size limits.

At the May 2008 Management Board meeting, the use of slot limits was suggested. Participants were interested in whether increasing the current minimum size limit (6.0 inches) would add to the potential benefits gained from a maximum size limit. The SASC evaluated the impact of various slot limits on egg production in addition to the evaluation of maximum size limits alone.

Minimum size regulations have been a key component of Canada's American eel management strategy for the past twenty five years in the Maritime Provinces. Canada's most recent American eel management plan went into effect in 2003. The goal of the plan is a 50% reduction in eel harvest to be achieved through minimum size regulations, seasonal closures, limited entry to the fishery and limits on gear spacing. The minimum size has been increased several times since 2003 and the 2008 minimum size limits range from approximately 12 inches (30 cm) in Newfoundland to approximately 21 inches (53 cm) in the Gulf of St. Lawrence drainages of Nova Scotia, New Brunswick, and Prince Edward Island. Canada's glass eel fishery is exempted from the minimum size regulations. Canada does not have a bait eel fishery, so the large minimum size does not have as negative an economic impact on the Canadian eel fishery as it would have on the U.S. eel fishery.

## **MODEL STRUCTURE AND DATA**

A detailed description of the model equations and notation is available from members of the SASC.

The SLYME model describes effects of growth and mortality on the population by age class from the time glass eels arrive at the coast to the time adult eels deposit eggs during spawning.

Important assumptions of the model include:

- The portion of the population that resides in areas where American eels are exploited make some contribution to the spawning population.
- Under the current management regime, recruitment to the coast has been constant.
- All glass eel recruitment to the coast is instantaneous and occurs March 1.
- All glass eel fishing is instantaneous and occurs one day after glass eel arrival.
- All glass eels surviving the glass eel fishery join the segment of the population residing in continental waters.
- The yellow eel life stage is discrete, without immigration or emigration.
- Fishing for resident eels occurs year round and is concurrent with natural mortality.
- All eels greater than 400 mm (15.75 in) are considered females.
- Silver eel emigration is instantaneous and occurs on October 1.
- The silver eel fishery is instantaneous and occurs one day after emigration.
- The fishery for emigrating silver eels is geographically separate from the resident eel fishery.
- Spawning occurs February 27.
- Growth and mortality processes are density-independent.

Several researchers generously provided raw data collected from studies on American eel (Table 1). Inputs required by the model were primarily derived from these data. Access to the raw data enabled the SASC to combine or subset datasets based on appropriate stratification in order to provide a representative characterization of the stock under ASMFC management. When possible, data collected from systems that are known to be exploited were used. If a required parameter could not be estimated from the available data, a literature review was performed to solicit values for the model. Efforts were made to apply data that could be considered representative of the coast-wide stock, though many of literature studies were limited in geographic scope. The SLYME framework models males and females separately and so sex-specific input data were used when possible. Sampled eels  $\geq 400$  mm (15.75 in) in length were assumed to be female (Krueger and Oliveira 1997; Oliveira and McCleave 2000).

The SLYME model calculates the number of American eels remaining in each age class following mortality, harvest, and emigration. Assumption regarding the initial number of glass eels recruiting to the coast and the maximum age ( $T$ ) must be specified by the user. The model is sex-specific so the user must provide a value for the proportion of eels that are destined to become males. The glass eel fishery is prosecuted the day after arrival to the continent. The number of glass eels harvested is based on exploitation rate specific to the fishery that is supplied by the user. Glass eels not harvested by the glass eel fishery join the population residing in continental waters. Biological sampling data collected from the ASMFC-mandated annual young-of-year (YOY) survey were used to compute length and weight of age-0 eels that have not yet joined the continental segment of the stock. These data occasionally include lengths of older eels, so the length distributions from each state were examined by year to identify and exclude these older eels. The data suggested an upper limit of 75 mm (2.95 in) was an appropriate cut-off for age-0 eels. The average length and weight of individual eels  $\leq 75$  mm (2.95 in) were computed.

Growth in length for continental eels age-0 and older was described as a function of age. Weight was modeled as a function of length. Parameters describing the growth rates of American eels were estimated from the available biological data on individuals age 1 and older.

Natural mortality,  $M$ , was described as a function of weight based on a modified version of Lorenzen's (1996) equation:

$$M_t = \gamma 3.00 W_t^{-0.288}$$

where  $\gamma$  is an adjustment factor and  $W_t$  is weight at age  $t$ . The exponent value (-0.288) is considered fairly stable (McGurk 1996), but the coefficient value (3.00) may vary (D. Cairns, DFO Canada, pers. comm.). Application of the SLYME model to other systems applied an adjustment factor to account for the variability.

The model assumes that fishing for American eels that reside in continental waters occurs year-round and is concurrent with natural mortality. Catch curves were applied to fishery-dependent age samples to estimate total mortality rates for ages considered fully recruited to the gear. Catch curves were calculated within cohorts for cohorts that could be tracked for

three or more years. The catch curves were computed assuming both constant and variable age at full recruitment. Estimates of total mortality were used as a starting point for determining an appropriate input estimate for resident fishing mortality. The user inputs an assumed fishing mortality rate for the resident fishery, which is allocated to each age class based on a vector of partial recruitment-at-age. The partial recruitment represents the proportion of each age class caught by the fishing gear. To determine the partial recruitment vector, catch-at-age was combined across years and sources; the ages of full recruitment were estimated by eye and a negative exponential curve was fit to these ages. The relationship was then applied to ages that are not fully recruited in order to estimate how many would be harvested if they were fully recruited. Partial recruitment-at-age was calculated as the observed number recruited-at-age divided by the potential fully recruited harvest at that age.

A fraction of the resident eels that survive the resident fishery were assumed to begin their spawning migration. The maturity of American eels is more dependent on length than age. A logistic function was fit to available data to predict the proportion of female eels that were mature at length. Maturity was modeled as a function of length in the SLYME model based on the logistic parameter estimates. The migrating silver eels were subject to an emigrant fishery the day after migration. The emigrant fishery catch was calculated based on an assumed fishing mortality rate and partial recruitment vector specific to the fishery. Both the resident and emigrant fisheries assumed no mortality on American eels less than the current minimum size limit (6.0 inches).

Fecundity was modeled as an allometric function of length. The number of eggs produced in each age class was calculated by multiplying the estimated fecundity-at-age by the number of female spawners that survived the emigrant fishery and subsequent natural mortality. The number of eggs was summed over all age classes to provide an estimate of total production. Dividing the total production by the initial number of recruits gave the number of eggs-per-recruit, which was the metric used in evaluating potential maximum size limits and slot limits.

The impact of maximum size limits and slot limits on the modeled population was investigated by setting fishing mortality rates equal to zero for eels exceeding the legal size given the maximum size or slot limit under consideration. The sensitivity of the results to assumptions made about the input parameters was also evaluated. Ranges of values were used in different model scenarios to understand how changing assumptions about the input parameters (e.g., proportion of future males, glass eel exploitation rate, maximum age, resident fishing mortality rate, emigrant fishing mortality rate) influenced results.

The amount of yield that would be foregone under a maximum size or slot limit was calculated to estimate the “cost” to the fishery of the size limit options evaluated. The percent of landings that would be considered illegal was calculated based on available data for recent years. The costs were calculated both in terms of landed numbers and landed weights. The costs associated with the various maximum size and slot limits were then compared against the increase in EPR that was predicted for the associate size limit.

## RESULTS

### Estimation of Input Parameters

The initial number of glass eels recruiting to continental waters was set equal to 1,000,000. Sex ratios were computed from available data where the sex of individuals was recorded. The percentage of males observed was highly variable among life stages and sampling locations, ranging from 1–97% where total sample sizes  $\geq 50$  individuals. In datasets that also identified life stage, 32–64% of yellow-stage eels were male while 45–97% of silver-stage eels were male (where  $n \geq 50$ ). The SASC also reviewed the literature for research on American eel sex ratios in the U.S. and found that published estimates were also variable (Michener 1980; Harell and Loyacano 1982; Hansen and Eversole 1984; Helfman et al. 1984; Oliveira and McCleave 2000; Rulifson et al. 2004). The percent of males in published studies ranged from 3–97% depending on the life stage, habitat, and sampling location. Initial runs of the model assumed 50% of the recruits were destined to become male. Alternate configurations of the model assumed proportions of future males that ranged from 10-90%. The maximum age observed in exploited areas was 15 years (one individual). Approximately 99% of aged samples from those areas were younger than 10 years. The maximum age observed from all areas (fished and unfished) was 33 years.

Based on the annual YOY survey, the average length of age-0 American eels was 56.7 mm (2.23 in) with an average weight of 0.150 g (3.31E-04 lbs). The von Bertalanffy growth curve was fit to available data to estimate the age-length relationship. The best fit parameter estimates were:  $L_{\infty} = 28.2$  inches,  $K = 0.22$ ,  $t_0 = -1.63$ . The relationship of weight to length was modeled using an allometric function. The length-weight parameter values from the best-fit were:  $a = 2.70E-05$ ,  $b = 3.31$ .

There was limited information available to determine an appropriate adjustment factor for Lorenzen's natural mortality equation. As a starting point, the SASC assumed  $\gamma = 0.164$ , the value assumed in recent applications of the SLYME model to Canadian data (D. Cairns, pers. comm.).

Few glass eel fisheries are currently active, so a relatively small value was assumed for the exploitation rate in this fishery. An exploitation rate value of 0.01 was assumed for initial runs. Alternate runs considered values ranging from 0–0.75. The age distribution of commercially caught American eels suggested that female American eels are fully recruited to the resident fishery by age 3 or 4 (Figure 1). The catch curves estimated total mortality rates ranging from 0.14–0.77 or 0.19–0.60 depending on whether age at full recruitment is assumed variable or constant. Average total mortality was estimated at 0.50 when age at full recruitment was assumed constant (age-4). Assuming variable age at full recruitment, the average value among cohorts was 0.46. Subtracting the average of the estimated natural mortality rates at age for ages 4 and older ( $M_{\text{avg}, 4+} = 0.04$ ) suggested remaining loss could be 0.46 or 0.42 for fully recruited ages, depending on the assumption regarding age at full recruitment. A review of previous research identified only one estimate of yellow eel fishing mortality in the U.S. A study in Maryland estimated instantaneous fishing mortality for selected systems to equal 0.43 (J. Weeder, NOAA Marine Fisheries, pers. comm.). For initial runs, a value of 0.43 was assumed for resident fishing mortality.

A logistic curve was fit to available data to predict female maturity at length (Figure 2). No age or size composition data from silver eel fisheries were available for estimating mortality rates or deriving a partial recruitment vector. No published estimates of emigrant fishing mortality in the U.S. were found. One study on silver eels in the St. Lawrence River Estuary, Canada estimated instantaneous fishing mortality at about 0.26 (Caron and Verreault 1997). The SLYME model assumed a value of 0.26 for instantaneous fishing mortality in the emigrant fishery during initial runs. In the absence of available data, partial recruitment to the emigrant fishery was assumed equal to 1.0 for all ages.

Data for deriving a function for fecundity were not available in the data provided to the SASC. A review of the literature yielded only two studies that estimated fecundity for American eels in U.S. sampling locations (Wenner and Musick 1974; Barbin and McCleave 1997). Though both studies were limited by small sample sizes ( $n = 21$  and  $n = 63$ , respectively) and limited geographic and temporal scope, the SASC decided to use the parameter estimates from the more recent study. A preliminary analysis comparing cumulative fecundity at size as a percent of total fecundity showed only minor differences in the two relationships. This suggests that perceived benefits of a size limit would be comparable using either relationship.

#### Eggs-per-Recruit

The estimated number of eggs-per-recruit (EPR), based on the initial values assumed for the input parameters, was compared to the EPR calculated under various model scenarios that considered a range of values for select input parameters. EPR was inversely related to the value assumed for the proportion of the stock destined to become males (Figure 3). That is, increasing the number of males resulted in decreasing EPR. The estimated EPR was also sensitive to the value assumed for the Lorenzen adjustment factor,  $\gamma$  (Figure 4). An increase in  $\gamma$  results in an increase in natural mortality-at-age, which results in a decrease in the EPR estimate. Increases in the assumed rate of glass eel fishery exploitation resulted in decreasing EPR; this effect was most noticeable at exploitation rates  $\geq 0.50$  (Figure 5).

Maximum size limits ranging from 16–28 inches at 1-inch intervals were applied to the simulated population to evaluate the impact on stock productivity. As the assumed maximum size increased, the estimated EPR increased (Figure 6). Maximum size limits ranging from 24–28 inches provided less than a 1.0% increase in EPR (Figure 7). A maximum size of 23 inches resulted in a potential 2.4% increase in EPR. As one would expect, the estimated gain in EPR increased as the maximum size limit considered decreased. The largest predicted gain in EPR expectedly occurred at the smallest maximum size limit evaluated, 16 inches. At this maximum size, the EPR was predicted to increase by 133% relative to the base model.

The effect of a maximum size limit on stock productivity was also evaluated assuming a range of values for the minimum size limit. For this slot limit analysis, the estimated change in EPR was calculated for various combinations of minimum and maximum size limits relative to the base model, which assumed no maximum size limit and a minimum size limit equal to the current minimum size (6.0 inches). The slot limit analysis suggested the gain in EPR achieved from coupling minimum sizes less than 17 inches with a maximum size limit



was only marginal compared to the gain in EPR predicted for the maximum size limit alone (generally < 8%; Table 2; Figure 7). Slot limit combinations with fairly narrow (< 5 inches) slots and minimum sizes > 17 inches could provide an estimated 42–123% increase in EPR (Table 2). Combinations with larger slots ( $\geq 5$  inches) at minimum sizes > 17 inches were estimated to provide increases in EPR ranging from 16–66%. Recall that the gain in EPR achieved from these maximum sizes ( $\geq 22$  inches) alone was less than 12% relative to the base model (Figure 7). As such, these larger maximum sizes made only a small contribution to the predicted increase in EPR achieved from those slot combinations.

The sensitivity of EPR estimates at different maximum size limits was evaluated by varying assumptions about the values of selected input parameters (Figures 8–10). The relationship of EPR to changes in the assumed values for proportion of future males, Lorenzen adjustment factor, and glass eel fishery exploitation rates to the maximum size limits considered was similar to trends for the base model (Figures 3–5), with varying magnitude. One of the largest sources of uncertainty with the input parameters was the harvest mortality of resident and emigrating eels. The impact of this uncertainty on productivity was evaluated by calculating EPR over a range of assumed values for the resident and emigrant fisheries (Figure 10). Increasing the fishing mortality rate in either fishery expectedly results in a decreased EPR. The evaluation showed that EPR was more sensitive to changes in the harvest of emigrating eels than the harvest of resident eels.

#### Costs to the Fishery

The percentage of commercial landings exceeding a range of proposed size limits was calculated for selected states to estimate the amount of landings that would be considered illegal for those size limits. Data for estimating these costs were only available from New Jersey, Delaware, Maryland, and Florida. The three most recent years of available data from each state were used. Data collected during 2005–2007 were provided from Delaware and Maryland. New Jersey data were available from 2006 and 2007. Data provided by Florida were available from 2004–2006.

The percent of landings greater than each of the maximum size limits evaluated was calculated for each state and year. The percentage values were then averaged across years for each state to provide the estimated cost in terms of both landed numbers and landed weight. For all states evaluated the costs in landed numbers and landed weight decreased as the maximum size increased (Figure 11). The percentage of landings in terms of weight that would be considered illegal exceeded the percentage that would be considered illegal in terms of numbers. The cost in weight and numbers of the various maximum size limits considered varied among the states. For example, approximately 94% of New Jersey's landings in weight would be foregone if a maximum size limit of 16 inches were imposed. However, Delaware would lose an estimated 42% of their landings in weight for a 16-inch maximum size limit.

The comparison of costs to the fishery to gains in egg production demonstrated that as predicted EPR increased, so did the expected loss to the fishery. Gains in EPR greater than 50% were predicted to cost a minimum of 25% in commercially landed weight, depending on the maximum size and the state affected (Figures 12–15). At maximum size limits greater

than 22 inches, the expected gains in EPR were less than 3%. However, the cost in landings could range from 8% to 41% in weight.

The percentage values of landings in each state that have exceeded the slot limit combinations considered are shown in Tables 3–6. The costs of the various slot limit combinations to each state were variable. In general the costs in terms of landed weight exceeded the costs in landed numbers for slots with smaller minimum and smaller maximum sizes. As both the minimum and maximum sizes of the slot increased, the costs in terms of landed numbers increased relative to the costs in terms of landed weight. The slot combinations predicted to provide larger increases in EPR (Table 2) were those associated with the higher costs to the fishery (Tables 3–6).

## **DISCUSSION**

The results of the per-recruit analyses suggested there could be a potential gain in American eel stock productivity by imposing a maximum size limit. Larger maximum size limits were predicted to result in higher egg production. However, as the predicted gains in EPR increased, so did the estimated cost to the fishery. The cost analysis showed that even nominal gains in EPR could still result in substantial losses to the fishery. The model results also showed that a slot limit could also potentially benefit egg production. Slot limit combinations that included minimum sizes greater than 16 inches were predicted to increase EPR from 16% to 123% relative to the base model. Though, the gain in EPR relative to a maximum size limit alone was estimated to yield an increase of 16% to 70% at slots with minimum sizes greater than 16 inches. Slots with minimum sizes less than 17 inches were predicted to provide less than an 8% increase in EPR relative to maximum sizes alone.

An effective maximum size limit should result in an increase in the number of emigrating female eels, but information on the size at which female eels emigrate is limited. A recent study found that female eels emigrated from Indian River in southern Delaware during September and November in 2002 and 2003 and their length ranged from 14.4–29.3 inches (367–744 mm) with an average length of 22.6 inches (571 mm; Barber 2004). Although this size range for female emigration could not be confirmed for the entire distribution range of the American eel, coast-wide similarities in the length range of commercially caught eels suggested that a maximum size limit based on the mean length of emigrating female eels in Delaware could increase the number of female eels emigrating to spawn.

Sex ratios estimated from available data were variable, as were estimates found in the literature (Michener 1980; Harell and Loyacano 1982; Hansen and Eversole 1984; Helfman et al. 1984; Oliveira and McCleave 2000; Rulifson et al. 2004). Sex ratios may be different among life stages (this report; Oliveira and McCleave 2000). Future work with the SLYME model may want to consider different sex ratios for the yellow and silver stage segments of the population.

American eels residing in waters along the U.S. East Coast are considered a single unit and were treated as such in the model. However, literature studies and analyses performed for this report have demonstrated evidence of spatial and temporal differences in life history, timing of events (e.g., recruitment to the continent, emigration), and exploitation patterns throughout

the species range. Biological sampling of American eel has improved in recent years, but is still not comprehensive. Both fishery-dependent and -independent data gaps exist for different geographic regions, gear types, life stages, unexploited systems, and time periods. Data from sampled areas were used to supplement areas lacking information; this required the assumption that available data were representative of unsampled areas. Efforts to improve data collection throughout the American eel's range are needed if the reliability of this and other models is to be increased. In the meantime, regional models or a single model that incorporates regional-weighted data could provide more appropriate results and should be considered for future work.

The estimated gains in EPR and costs to the fishery are relative and the assumptions made in developing the model must be considered when evaluating the results. The reliability of the results is largely dependent on the degree to which these assumptions hold and so should be interpreted with caution. Numerous assumptions were needed because of the complex life history of the American eel and the uncertainty regarding stock size and mortality. For instance, the assumption that glass eel arrival at the coast and silver eel emigration occur during one day on a coast-wide basis is not accurate, but it's considered necessary to simplify the assumption for carrying out model computations. The assumption of constant effort implies that harvest rates will not change. An increase in fishing pressure would reduce the predicted EPR and so could limit the effectiveness of a maximum size or slot limit. Two of the weakest assumptions were those made for the exploitation rate and partial recruitment at age in the emigrant fishery. No data were available to characterize the composition of the catch and only one estimate of exploitation rate—from Canada—could be found. The evaluation of the effect of exploitation rates on resident and emigrating eels demonstrated that EPR was sensitive to fishing mortality in the emigrant fishery.

The assumption that all female eels age-4 and older are fully vulnerable to the resident fishery may not be representative of the entire U.S. stock. Large-size eels (> 27.6 in or 700 mm) that have large girths (> 2.0 in or 50.8 mm) are likely not fully selected by pots, the primary commercial gear that harvests American eels (K. Whiteford, Maryland Department of Natural Resources, pers. comm.). However, the maximum length attained by females in the model was 27.5 inches (698.5 mm) when the maximum age was assumed to equal 15 years. As such, it is assumed that female eels in the simulated population do not reach the length and girth at which their selectivity becomes limited.

The costs to the states were dependent on the length and weight composition of recent landings. The characterization of landings was based upon biological samples collected from commercial landings in each of the states. The estimation of costs is therefore dependent upon how well those biological samples represent the landings as a whole.

The estimated gains in EPR assumed all other factors contributing to pre-spawning mortality remained constant. Many factors besides fishing are known or expected to affect overall mortality, including impediments to upstream migration, turbine mortality during out-migration, loss/alteration of habitat, predation and competition, harvest in areas outside the Atlantic coast, and so on. Increases in mortality due to these factors would reduce the estimated gain in EPR. Conversely, decreases in mortality from these factors could increase

the expected gain in EPR. The contribution of the various sources of mortality, including harvest, to the total mortality of American eel is unknown. The impact of reducing fishing mortality will depend on the degree to which harvest mortality contributes to the total mortality. Efforts to reduce or eliminate any source of anthropogenic would benefit the stock and promote the rebuilding.

Incorrect input values or violation of assumptions would result in different model results; however, it is not possible to characterize the directionality of all differences (i.e., would results be higher or lower). In addition, many of the parameters are interrelated, and may work to amplify or dampen the effects of incorrect starting values. The SASC performed several analyses in an effort to evaluate confidence in model estimates. Sensitivity analyses were conducted with input values to determine which parameters had the greatest effect on model results. Also, where multiple input values were available, these were often used to estimate bounds on model results. The SASC has recommended that further sensitivity analyses, including addition of stochastic growth and recruitment, be performed to provide a better understanding of the model's sensitivity to input assumptions.

The relative gains in EPR estimated by the model should be considered upper bounds of potential benefits. The model evaluated the response of the exploited segment of the stock to size limit regulations as eels in exploited areas are the ones directly impacted by fishery restrictions (i.e., size limits will only apply to fished areas). As such, the predicted increases in EPR are relative to the portion of the stock that is subject to exploitation, given the assumption that eels emigrating from exploited areas contribute to the spawning population. The proportion of the stock that is exploited is not known and the relative contribution of spawners from fished and unfished areas is unknown, so the actual observed benefit can not be predicted. In addition, the American eel population is panmictic and extends beyond the Atlantic seaboard. Increases in escapement resulting from U.S. management measures have the potential to benefit the species anywhere within its range (i.e., U.S. management could result in increased recruitment anywhere from Labrador to Brazil).

The SASC believes that the results of the SLYME model provide a reasonable insight into the effects of imposing a maximum size limit or slot limit, as long as consideration for the underlying assumptions is given. The costs associated with the potential management scenarios evaluated should be weighed against the estimated gain in egg production, keeping in mind that the impact on recruitment is unknown. Additionally, issues of enforceability and the ability of the commercial fishery to conform to size limit regulations should be evaluated.

## REFERENCES

- ASMFC (Atlantic States Marine Fisheries Commission). 2000. Interstate fishery management plan for American eel. ASMFC, Fishery Management Report No. 36, Washington, D.C. 93p.
- ASMFC. 2001. Stock assessment methodologies and approaches for American eel. Report of the ASMFC American Eel Stock Assessment Subcommittee to the American Eel Management Board, August 2001. ASMFC, Washington, D.C. 8p.
- ASMFC. 2006. Terms of reference and advisory report to the American eel stock assessment peer review. ASMFC, Stock Assessment Report No. 06-01, Washington, D.C. 29p.
- Barber, R.E. 2004. Sex ratio of silver American eels (*Anguilla rostrata*) migrating out of two southern Delaware streams. M.S. Thesis. University of Delaware, Newark. 93p.
- Barbin, G.P. and J.D. McCleave. 1997. Fecundity of the American eel *Anguilla rostrata* at 45° N in Maine, U.S.A. *Journal of Fish Biology* 51(4):840–847.
- Caron, F. and G. Verreault. 1997. Le reseau sentinelle de l'anguille. Pages 144–160 *In*: R.H. Petersen (editor), *The American eel in Eastern Canada: Stock Status and Management Strategies*. Proceedings of Eel Workshop, January 13–14, 1997, Quebec City, QC. Biological Station, St. Andrews, NB. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2196. 191p.
- Hansen, R.A. and A.G. Eversole. 1984. Age, growth, and sex ratio of American eels in brackish-water portions of a South Carolina river. *Transactions of the American Fisheries Society* 113(6):744–749.
- Harell, R.M. and H.A. Loyacano. 1982. Age, growth and sex ratio of the American eel in the Cooper River, South Carolina. Pages 349–359 *In*: Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies, Nashville, Tennessee (USA), 9–12 November 1980. Vol. 34.
- Helfman, G.S., E.L. Bozeman and E.B. Brothers. 1984. Size, age, and sex of American eels in a Georgia river. *Transactions of the American Fisheries Society* 113(2):132–141.
- Krueger, W.H. and K. Oliveira. 1997. Sex, size, and gonad morphology of silver American eels *Anguilla rostrata*. *Copeia* 1997(2):415–420.
- 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):627–647.
- McGurk, M.D. 1996. Allometry of marine mortality of Pacific salmon. *Fishery Bulletin* 94:77–88.

- Michener, W.K. 1980. Age, growth, and sex ratio of the American eel, *Anguilla rostrata* (LeSueur), from Charleston Harbor, South Carolina. M.S. Thesis. Clemson University, Clemson, S.C. 49p.
- Oliveira, K. and J.D. McCleave. 2000. Variation in population and life history traits of the American eel, *Anguilla rostrata*, in four rivers in Maine. *Environmental Biology of Fishes* 59(2):141–151.
- Rulifson, R.A., C. Cahoon and J.L. Cudney. 2004. Critical habitat assessment and population demographics of the American eel fishery in northwestern Pamlico Sound, North Carolina. Fishery Resource Grant Program, Project No. 02-EP-13, Final Report. 13 April 2004. 109p.
- USFWS (U. S. Fish and Wildlife Service). 2007. Endangered and threatened wildlife and plants; 12-month finding on a petition to list the American eel as threatened or endangered. *Federal Register* 72:22(2 February 2007): 4967–4997.
- Wenner, C.A. and J.A. Musick. 1974. Fecundity and gonad observation of the American eel, *Anguilla rostrata*, migrating from Chesapeake Bay, Virginia. *Journal of the Fisheries Research Board of Canada* 31:1387–1391.

**Table 1.** Summary of raw datasets provided to the SASC for evaluation.

Name	Affiliation	Sampling Region	Start	End	Length	Weight	Age	Sex	Stage	Comment
Various	ASMFC States/Juris.	Multiple	2000	2005	X	X				Annual YOY surveys
K. Oliveira	UMass Dartmouth	Maine	1996	1998	X	X	X	X	X	
K. Oliveira	UMass Dartmouth	Massachusetts			X	X		X	X	
K. Oliveira	UMass Dartmouth	Rhode Island	1990	1991	X		X	X	X	Silver eel sampling
W. Morrison	UMaryland CEES	New York	1998	1999	X	X		X		Unexploited system
V. Vecchio*	NY Dept. Env. Cons.	New York	2002	2002	X	X				Electrofishing
V. Vecchio*	NY Dept. Env. Cons.	New York	2002	2006	X	X				Fyke survey
K. Strait	PSEG	New Jersey	1998	2001	X					Trawl survey
J. Brust	NJ Dept. Env. Prot.	New Jersey	2006	2006	X	X				Commercial sampling
C. Cairns	Delaware State Univ.	Delaware	2005	2006	X	X				Tagging study
J. Clark	DE DNREC	Delaware	2000	2006	X	X	X			Commercial sampling
K. Whiteford	MD Dept. Nat. Res.	Maryland	1999	2001	X	X	X			Freshwater sampling
K. Whiteford	MD Dept. Nat. Res.	Maryland	1997	2006	X	X	X	X		Commercial sampling
K. Whiteford	MD Dept. Nat. Res.	Maryland	1997	2006	X	X	X	X		Pot survey
M. Montane	VIMS	Virginia	1997	2005	X	X	X			Trawl survey
J. Cimino	VA Marine Res. Comm.	Virginia	1989	2008	X	X		X		Commercial sampling
H. Hildebrand	Univ. West VA.	West Virginia	2003	2004	X	X	X			Shenandoah River
R. Graham	Dominion Power	North Carolina	2000	2005	X	X				Roanoke Rapids
J. Cudney	ECU	North Carolina	2002	2003	X	X	X	X	X	
K. Bonvechio	FL FWCC	Florida	2002	2006	X	X		X		

\* Currently with NOAA Marine Fisheries

**Table 2.** Estimated percentage (%) increase in eggs-per-recruit for various combinations of potential slot limits relative to the base model (current minimum size limit\* = 6.0 inches; no maximum size limit).

		Slot Minimum Size (in)													
		6 *	8	9	10	11	12	13	14	15	16	17	18	19	20
Slot Maximum Size (in)	16	133	133	133	133	133	133	135	137	137					
	17	115	115	115	115	115	115	117	119	119	132				
	18	92	92	92	92	92	92	93	95	95	106	123			
	19	65	65	65	65	65	65	67	68	68	78	92	114		
	20	40	40	40	40	40	40	41	42	42	50	62	80	106	
	21	22	22	23	23	23	23	23	24	24	32	42	58	79	108
	22	12	12	12	12	12	12	12	13	13	20	29	43	63	88
	23	2	2	2	2	2	2	3	4	4	10	19	31	48	70
	24	0.3	0.3	0.3	0.3	0.4	0.4	1	2	2	8	16	29	45	66
	25	0.03	0.03	0.04	0.04	0.06	0.06	1	2	2	8	16	28	45	65
	26	0.0001	0.0001	0.01	0.01	0.03	0.03	1	2	2	8	16	28	45	65
	27	0	0	0.01	0.01	0.03	0.03	1	2	2	8	16	28	45	65
	28	0	0	0.01	0.01	0.03	0.03	1	2	2	8	16	28	45	65
none	0	0	0.01	0.01	0.03	0.03	1	2	2	8	16	28	45	65	



**Table 3.** Estimated percentage of New Jersey’s commercial landings in number (A) and weight (lb; B), exceeding the associated slot limit combination.

<b>A</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	79	79	80	82	85	89	93	96					
	<b>17</b>	72	72	74	75	78	83	86	90	93				
	<b>18</b>	64	64	65	67	70	74	78	81	85	91			
	<b>19</b>	54	54	55	57	60	64	68	71	75	82	90		
	<b>20</b>	45	45	47	48	51	55	59	63	66	73	82	91	
	<b>21</b>	35	35	36	37	41	45	49	52	56	62	71	81	89
	<b>22</b>	27	27	28	30	33	37	41	44	48	55	63	73	82
	<b>23</b>	19	19	21	22	25	30	33	37	41	47	56	65	74
	<b>24</b>	14	14	15	17	20	24	28	31	35	42	50	60	69
	<b>25</b>	9	9	11	12	15	19	23	26	30	37	45	55	64
	<b>26</b>	4	4	5	7	10	14	18	21	25	31	40	50	59
	<b>27</b>	2	2	3	5	8	12	16	19	23	30	38	48	57
<b>28</b>	1	1	2	4	7	11	15	18	22	29	37	47	56	

<b>B</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	94	94	95	95	95	96	97	98					
	<b>17</b>	91	91	91	91	92	93	94	95	97				
	<b>18</b>	85	85	85	86	86	87	88	89	91	94			
	<b>19</b>	78	78	78	79	79	80	81	82	84	87	93		
	<b>20</b>	71	71	71	71	72	73	74	75	77	80	86	93	
	<b>21</b>	60	60	60	60	61	62	63	64	66	69	75	82	89
	<b>22</b>	51	51	51	51	52	53	54	55	57	60	66	73	80
	<b>23</b>	41	41	41	41	42	43	44	45	47	50	56	63	70
	<b>24</b>	32	32	32	33	33	34	35	36	38	41	47	54	61
	<b>25</b>	23	23	23	23	24	25	26	27	29	32	38	45	52
	<b>26</b>	11	11	11	11	12	13	14	15	17	20	26	33	40
	<b>27</b>	7	7	7	7	8	8	10	11	12	16	21	28	36
<b>28</b>	4	4	5	5	5	6	7	8	10	13	19	26	33	

**Table 4.** Estimated percentage of Delaware’s commercial landings in number (A) and weight (lb; B), exceeding the associated slot limit combination.

<b>A</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	17	19	26	41	60	75	85	94					
	<b>17</b>	12	14	22	36	56	71	81	89	96				
	<b>18</b>	9	11	19	33	53	68	78	87	93	97			
	<b>19</b>	8	10	17	31	51	66	76	85	91	95	98		
	<b>20</b>	6	8	15	30	49	64	75	83	89	94	96	98	
	<b>21</b>	4	6	14	28	48	63	73	82	88	92	95	97	99
	<b>22</b>	3	5	12	27	46	61	72	80	86	91	93	95	97
	<b>23</b>	2	4	11	26	45	60	70	79	85	89	92	94	96
	<b>24</b>	1	3	10	25	44	60	70	78	84	89	92	93	95
	<b>25</b>	0.3	2	10	24	44	59	69	77	84	88	91	93	94
	<b>26</b>	0.1	2	10	24	44	59	69	77	83	88	91	93	94
	<b>27</b>	0.1	2	10	24	44	59	69	77	83	88	91	93	94
<b>28</b>	0.1	2	10	24	44	59	69	77	83	88	91	93	94	

<b>B</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	42	43	46	52	64	74	83	92					
	<b>17</b>	35	36	39	46	57	68	76	85	93				
	<b>18</b>	30	31	34	41	52	62	71	80	88	95			
	<b>19</b>	26	27	30	36	47	58	67	76	84	91	96		
	<b>20</b>	22	22	25	32	43	54	63	72	80	86	92	96	
	<b>21</b>	18	18	21	28	39	50	58	67	75	82	87	92	96
	<b>22</b>	13	13	16	23	34	45	54	63	71	77	82	87	91
	<b>23</b>	8	9	12	19	30	41	49	58	66	73	78	82	87
	<b>24</b>	5	5	8	15	26	37	45	55	63	69	74	79	83
	<b>25</b>	1	2	5	12	23	33	42	51	59	66	71	75	79
	<b>26</b>	0.04	1	4	10	21	32	41	50	58	65	70	74	78
	<b>27</b>	0.04	1	4	10	21	32	41	50	58	65	70	74	78
<b>28</b>	0.04	1	4	10	21	32	41	50	58	65	70	74	78	

**Table 5.** Estimated percentage of Maryland’s commercial landings in number (A) and weight (lb; B), exceeding the associated slot limit combination.

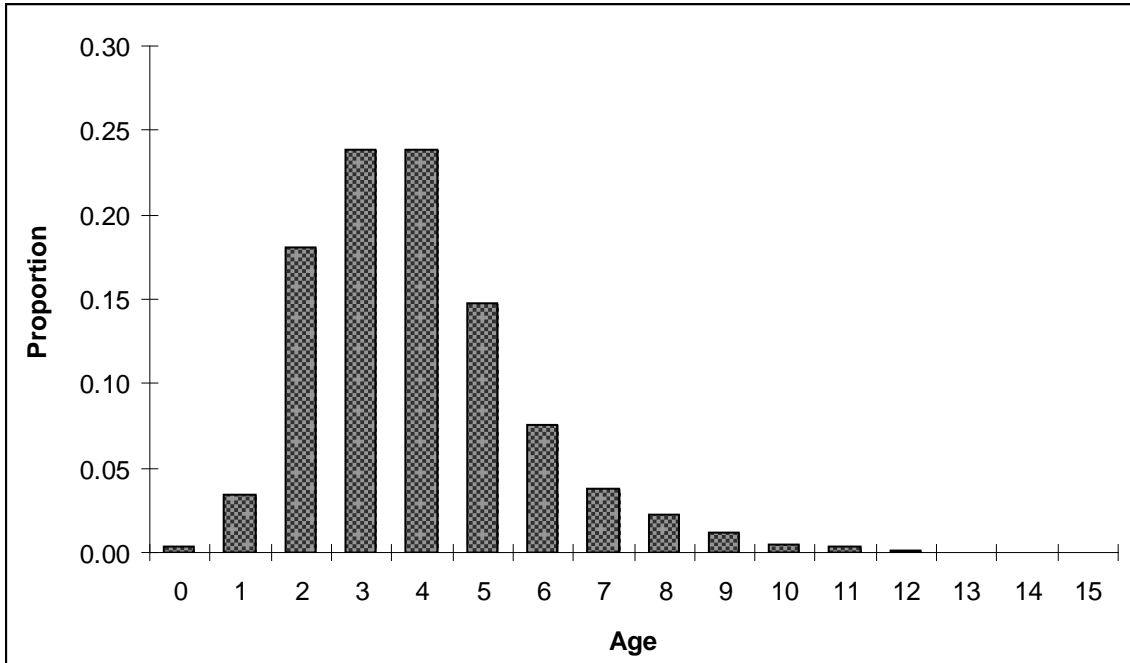
<b>A</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	22	23	26	36	57	78	89	96					
	<b>17</b>	18	19	22	32	52	73	85	91	96				
	<b>18</b>	14	15	18	28	49	69	81	88	92	96			
	<b>19</b>	12	12	15	26	46	67	78	85	89	93	97		
	<b>20</b>	9	10	13	23	43	64	75	82	86	91	94	97	
	<b>21</b>	7	7	10	20	41	62	73	80	84	88	92	95	98
	<b>22</b>	5	5	8	19	39	60	71	78	82	86	90	93	96
	<b>23</b>	3	4	7	17	37	58	69	76	80	85	88	91	94
	<b>24</b>	2	3	6	16	36	57	69	75	79	84	88	90	93
	<b>25</b>	1	2	5	15	35	56	68	74	78	83	86	89	92
	<b>26</b>	0.4	1	4	14	35	55	67	74	78	82	86	89	92
	<b>27</b>	0.2	1	4	14	34	55	67	73	78	82	86	89	91
<b>28</b>	0.1	1	4	14	34	55	67	73	78	82	86	88	91	

<b>B</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	59	59	59	62	71	81	89	95					
	<b>17</b>	52	53	53	56	65	75	83	89	94				
	<b>18</b>	45	46	46	49	58	68	76	82	87	93			
	<b>19</b>	40	40	40	43	52	62	70	76	81	87	94		
	<b>20</b>	33	33	34	37	45	56	64	69	75	81	88	94	
	<b>21</b>	27	28	28	31	39	50	58	64	69	75	82	88	94
	<b>22</b>	21	21	22	25	33	44	52	57	63	69	76	82	88
	<b>23</b>	15	15	16	19	27	38	45	51	56	63	70	75	82
	<b>24</b>	11	11	12	15	23	34	41	47	52	58	65	71	78
	<b>25</b>	6	6	7	9	18	28	36	42	47	53	60	66	73
	<b>26</b>	2	3	3	6	14	25	33	39	44	50	57	63	69
	<b>27</b>	1	1	2	5	13	24	31	37	42	48	56	61	68
<b>28</b>	0.3	1	1	4	13	23	31	37	42	48	55	61	67	

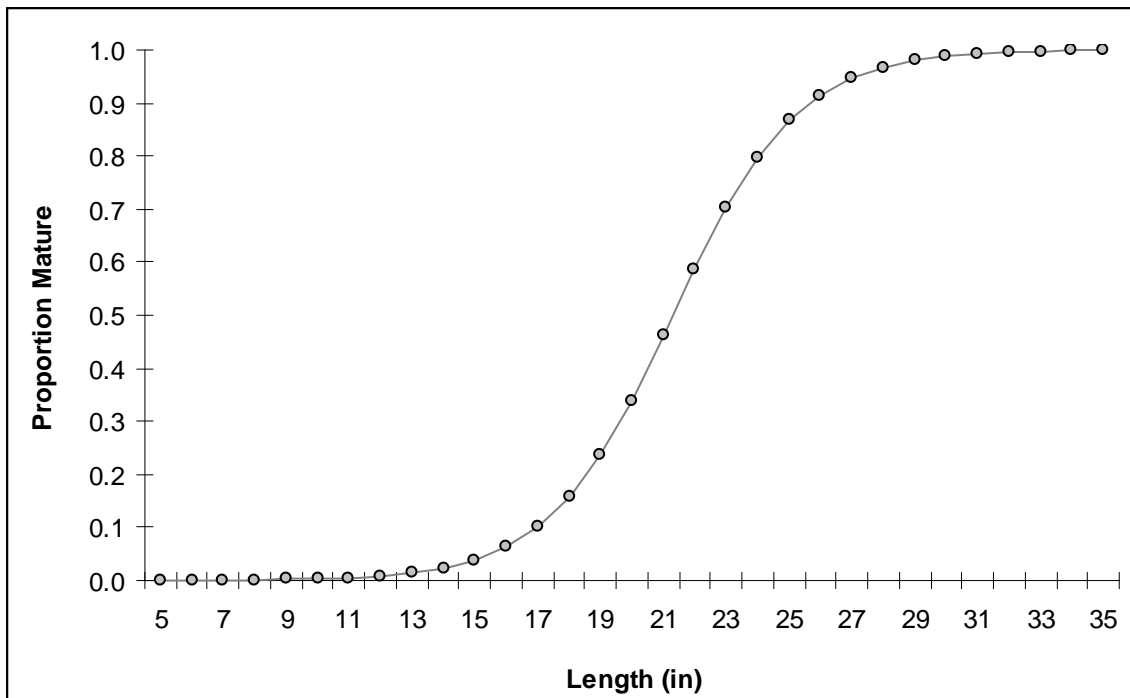
**Table 6.** Estimated percentage of Florida’s commercial landings in number (A) and weight (lb; B), exceeding the associated slot limit combination.

<b>A</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	82	82	82	82	82	82	84	91					
	<b>17</b>	68	68	68	68	68	69	71	78	87				
	<b>18</b>	57	57	57	57	57	57	59	66	75	88			
	<b>19</b>	46	46	46	46	46	46	48	55	64	77	89		
	<b>20</b>	33	33	33	33	33	33	35	42	51	64	76	87	
	<b>21</b>	24	24	24	24	24	25	26	33	42	56	67	78	91
	<b>22</b>	16	16	16	16	16	17	18	25	34	48	59	70	83
	<b>23</b>	9	9	9	9	9	10	12	19	28	41	53	64	77
	<b>24</b>	6	6	6	6	6	6	8	15	24	37	49	60	73
	<b>25</b>	2	2	2	2	2	3	5	11	20	34	45	56	69
	<b>26</b>	0.5	0.5	0.5	0.5	1	1	3	10	19	32	44	55	68
	<b>27</b>	0.2	0.2	0.2	0.2	0.3	1	3	9	19	32	43	55	68
<b>28</b>	0.1	0.1	0.1	0.1	0.2	1	3	9	18	32	43	54	67	

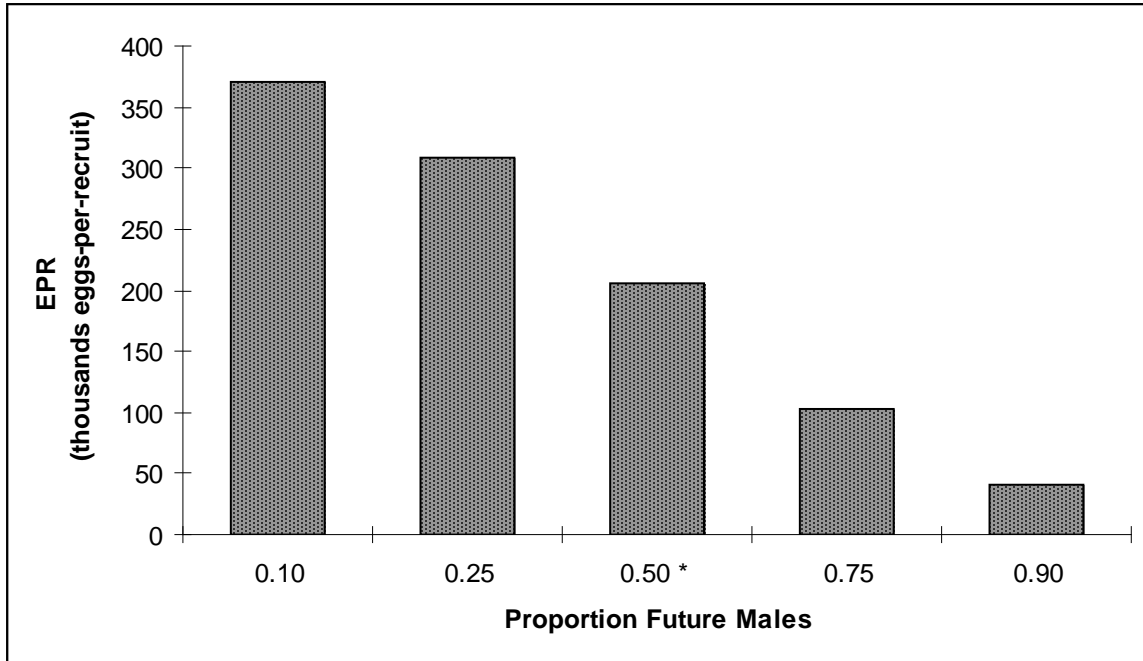
<b>B</b>		<b>Slot Minimum Size (in)</b>												
		<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Slot Maximum Size (in)</b>	<b>16</b>	92	92	92	92	92	92	93	95					
	<b>17</b>	84	84	84	84	84	84	84	87	92				
	<b>18</b>	75	75	75	75	75	75	76	79	83	91			
	<b>19</b>	65	65	65	65	65	66	66	69	74	82	90		
	<b>20</b>	52	52	52	52	52	52	53	56	60	69	77	87	
	<b>21</b>	42	42	42	42	42	42	43	45	50	58	67	76	90
	<b>22</b>	30	30	30	30	30	31	31	34	39	47	55	65	78
	<b>23</b>	20	20	20	20	20	20	20	23	28	36	45	54	68
	<b>24</b>	13	13	13	13	13	13	13	16	21	29	38	47	61
	<b>25</b>	5	5	5	5	5	5	6	9	13	22	30	40	53
	<b>26</b>	2	2	2	2	2	2	2	5	10	18	27	36	49
	<b>27</b>	1	1	1	1	1	1	1	4	9	17	26	35	49
<b>28</b>	0.3	0.3	0.3	0.3	0.4	1	1	4	9	17	25	35	48	



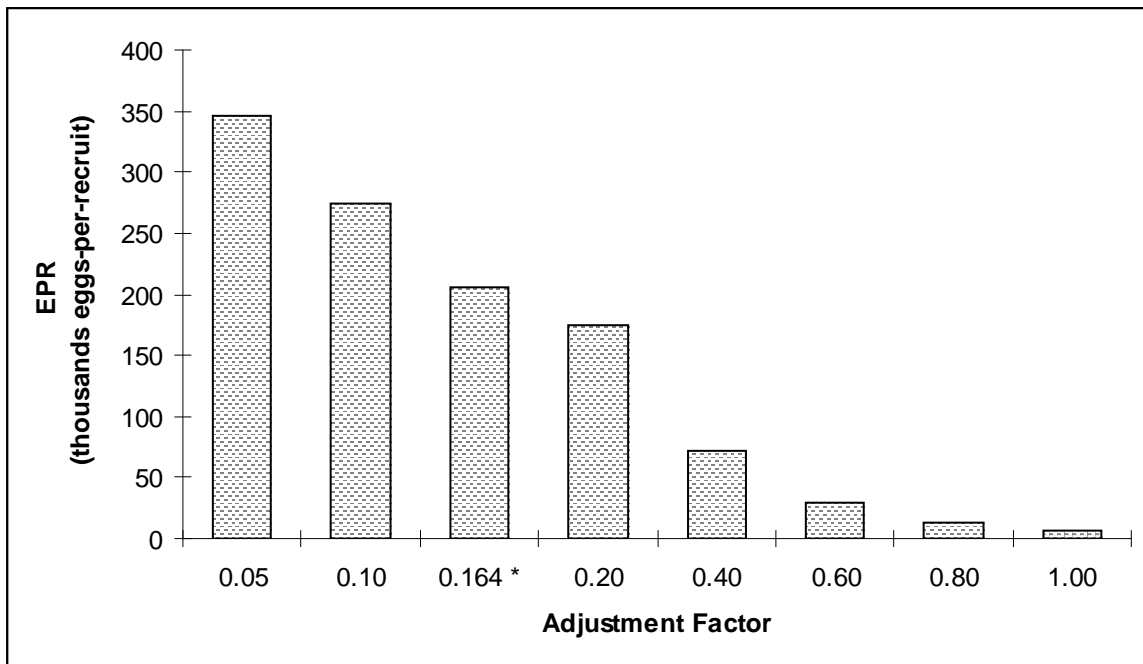
**Figure 1.** Proportion of American eels at age based on samples from the commercial fishery.



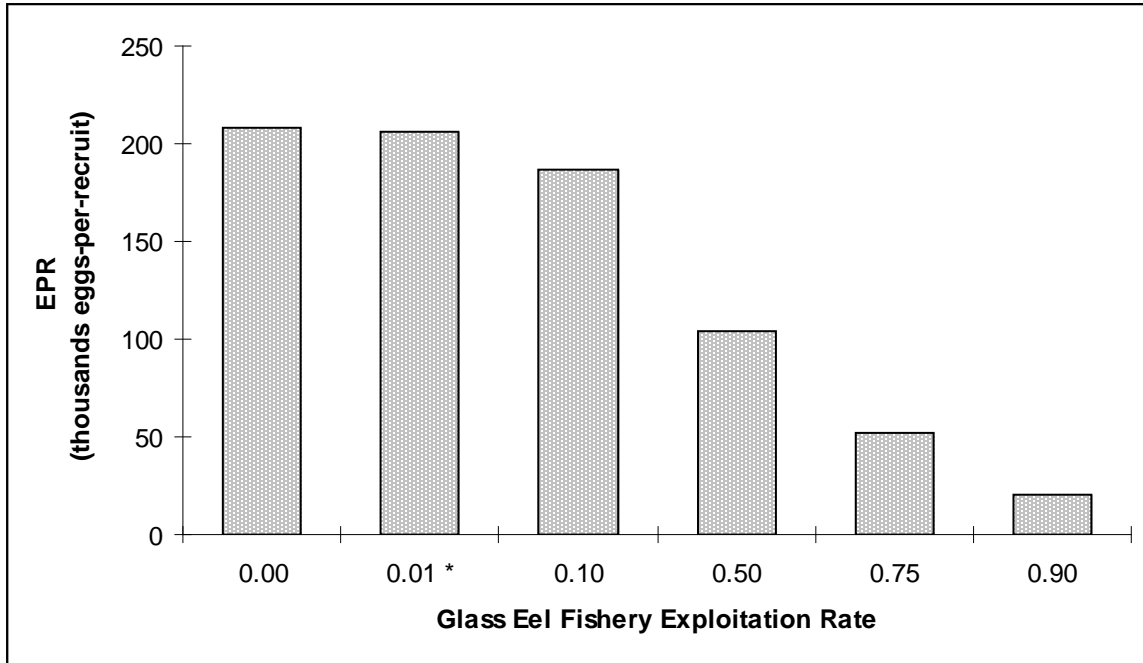
**Figure 2.** Maturity-at-length for American eel based on best fit of logistic curve to available data.



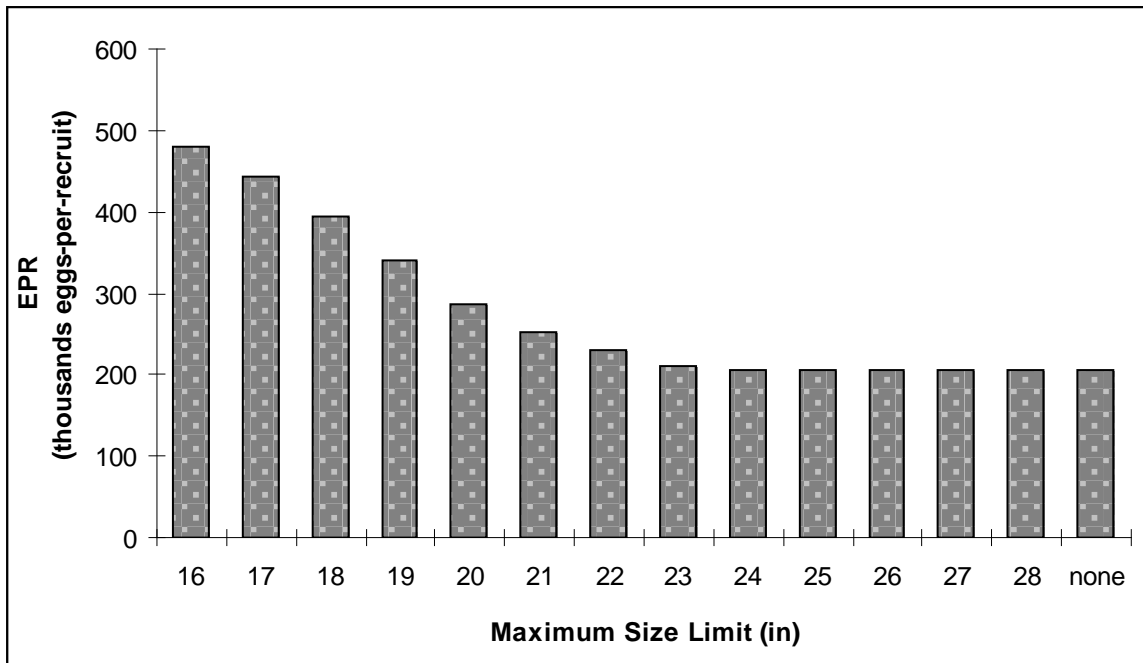
**Figure 3.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) over a range of assumed values for the proportion of the stock destined to become male. Asterisk indicates value assumed for initial run.



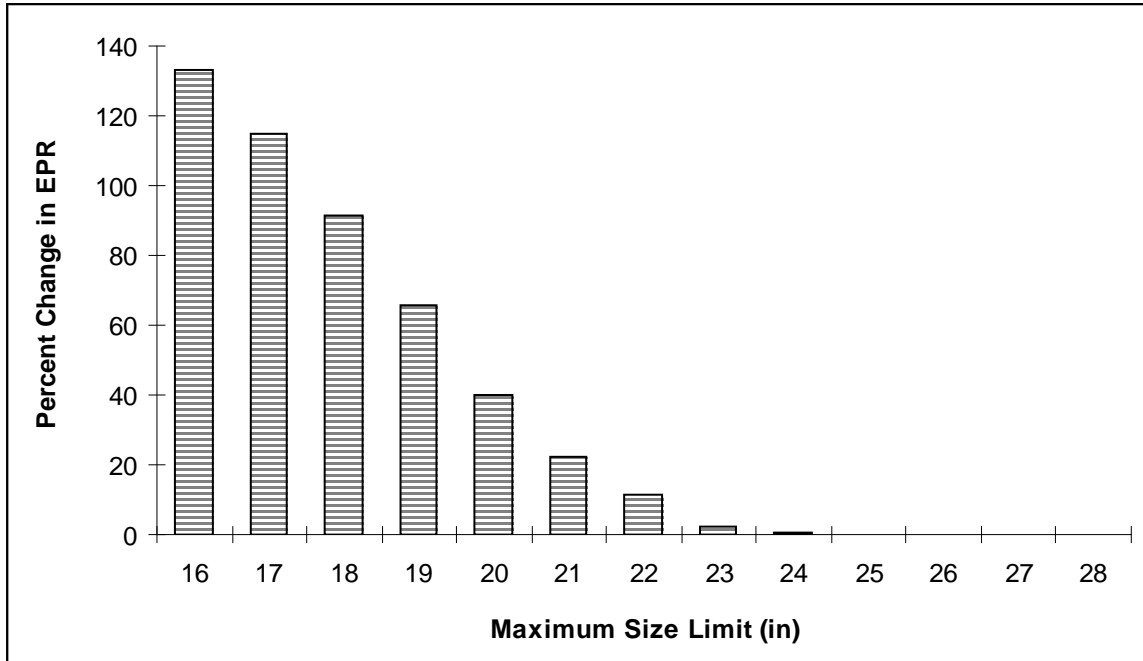
**Figure 4.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) over a range of assumed values for the adjustment factor ( $\gamma$ ) to the Lorenzen equation relating weight and natural mortality. Asterisk indicates value assumed for initial run.



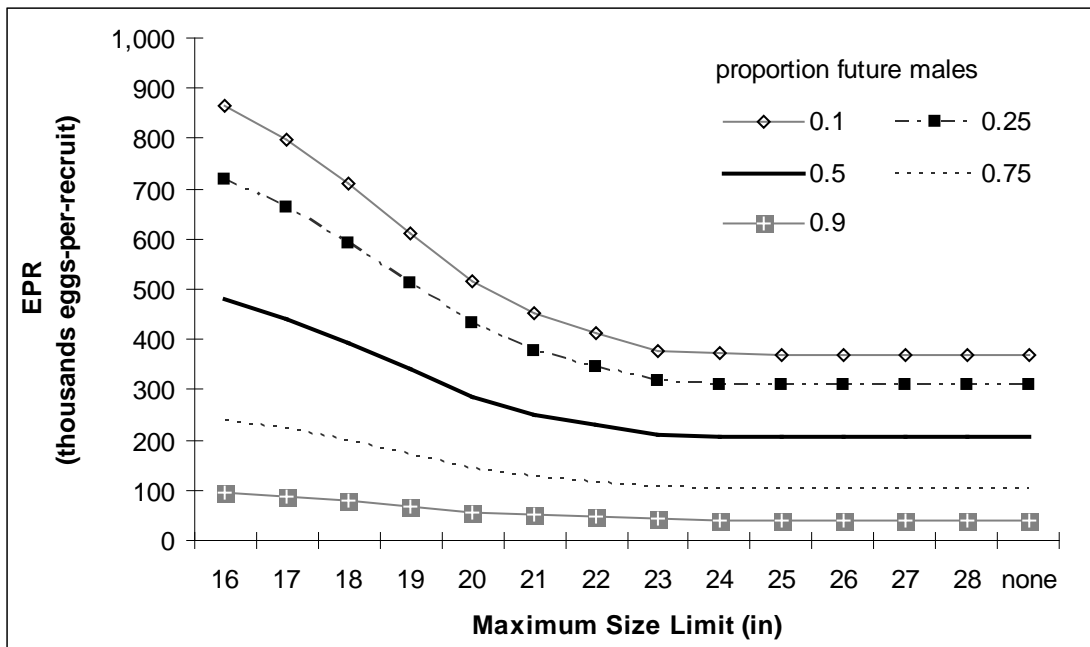
**Figure 5.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) over a range of assumed exploitation rates for the glass eel fishery. Asterisk indicates value assumed for initial run.



**Figure 6.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) for various potential maximum size limits.

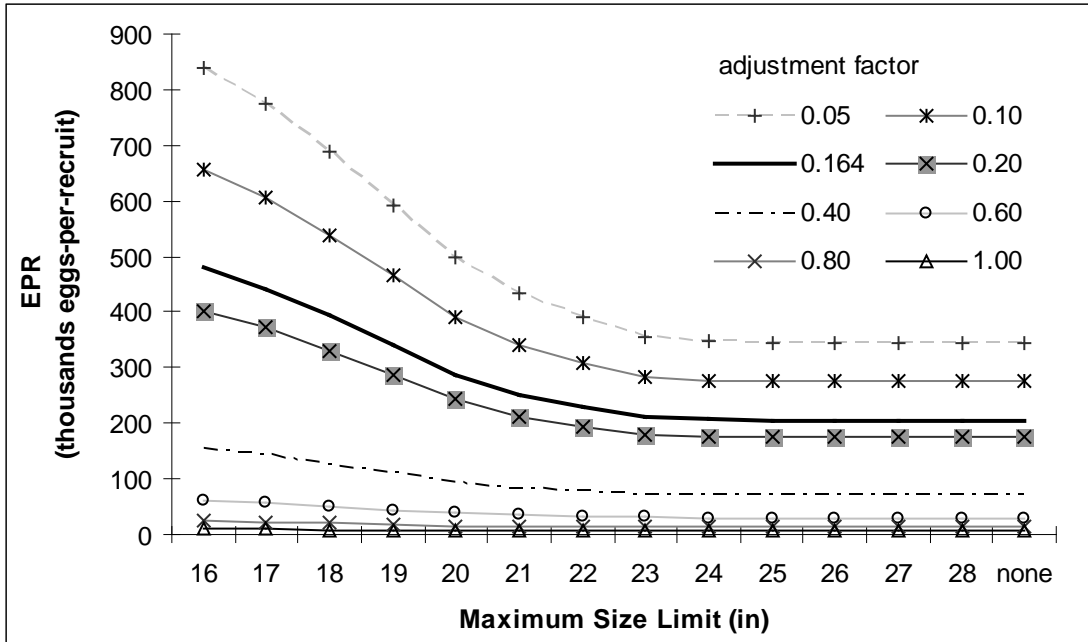


**Figure 7.** Estimated percentage (%) increase in eggs-per-recruit for various maximum size limits relative to the base model (current minimum size limit = 6.0 inches; no maximum size limit).

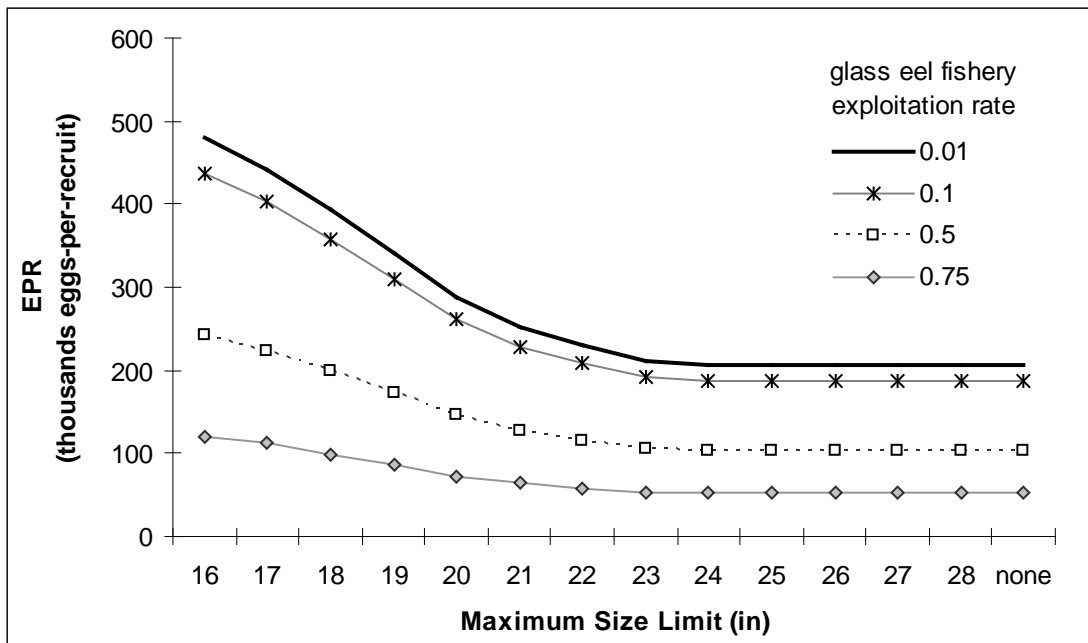


**Figure 8.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) for various maximum size limits over a range of assumed values for the proportion of the stock destined to become males.

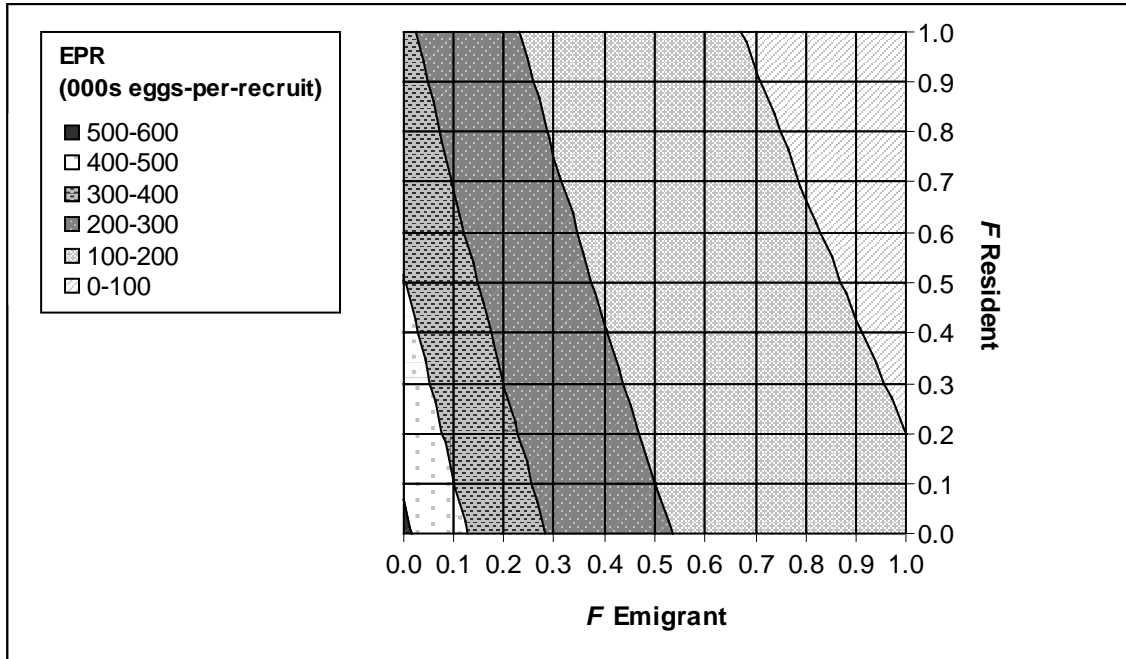




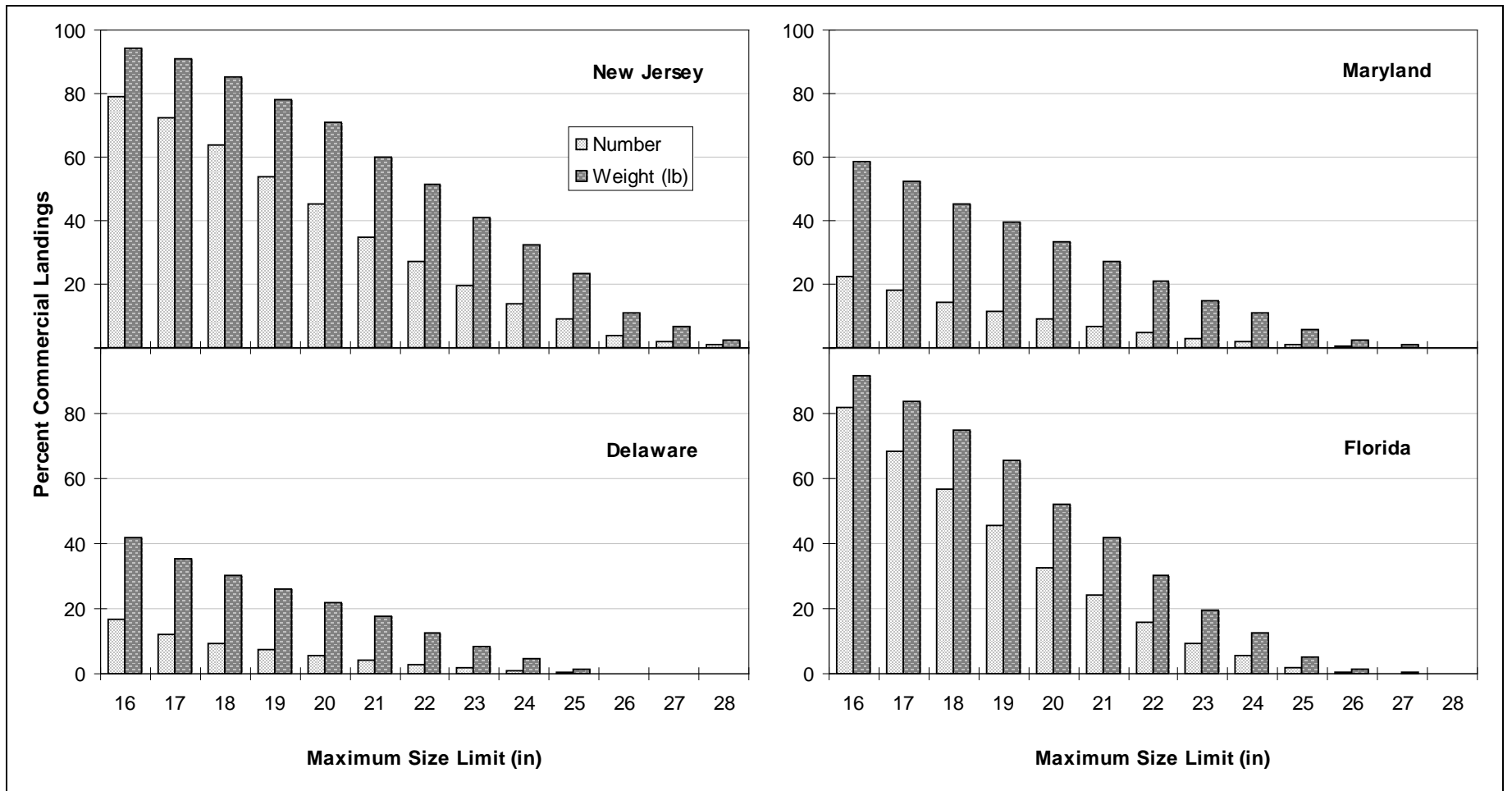
**Figure 9.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) for various maximum size limits over a range of assumed values for the adjustment factor ( $\gamma$ ) to the Lorenzen equation relating weight and natural mortality.



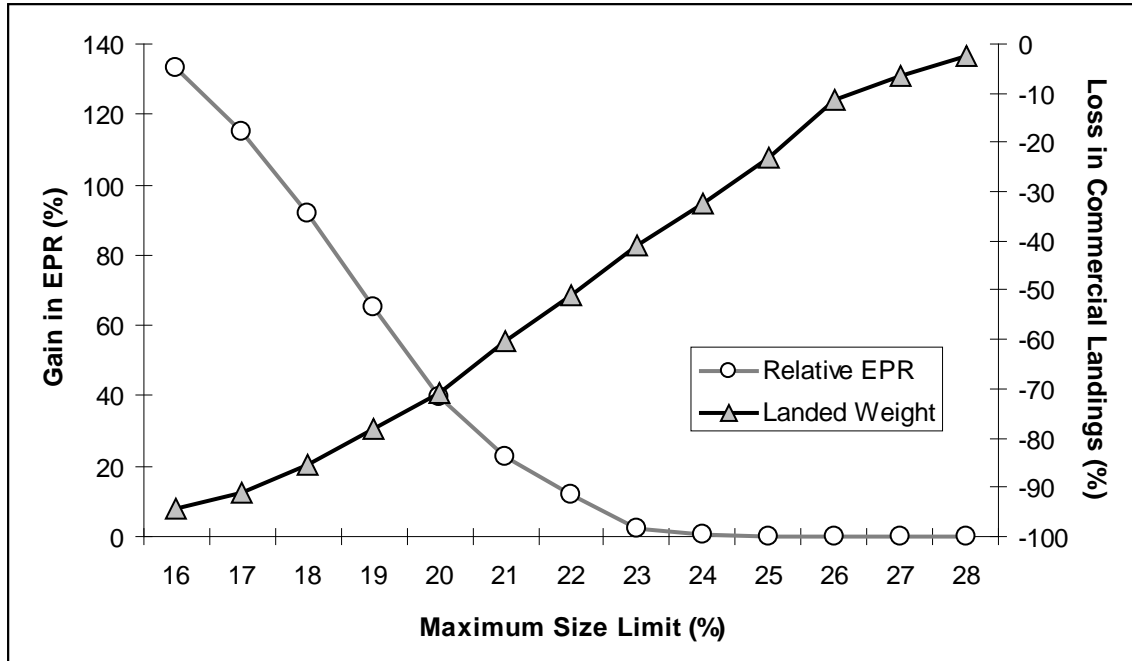
**Figure 10.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) for various maximum size limits over a range of assumed exploitation rates for the glass eel fishery.



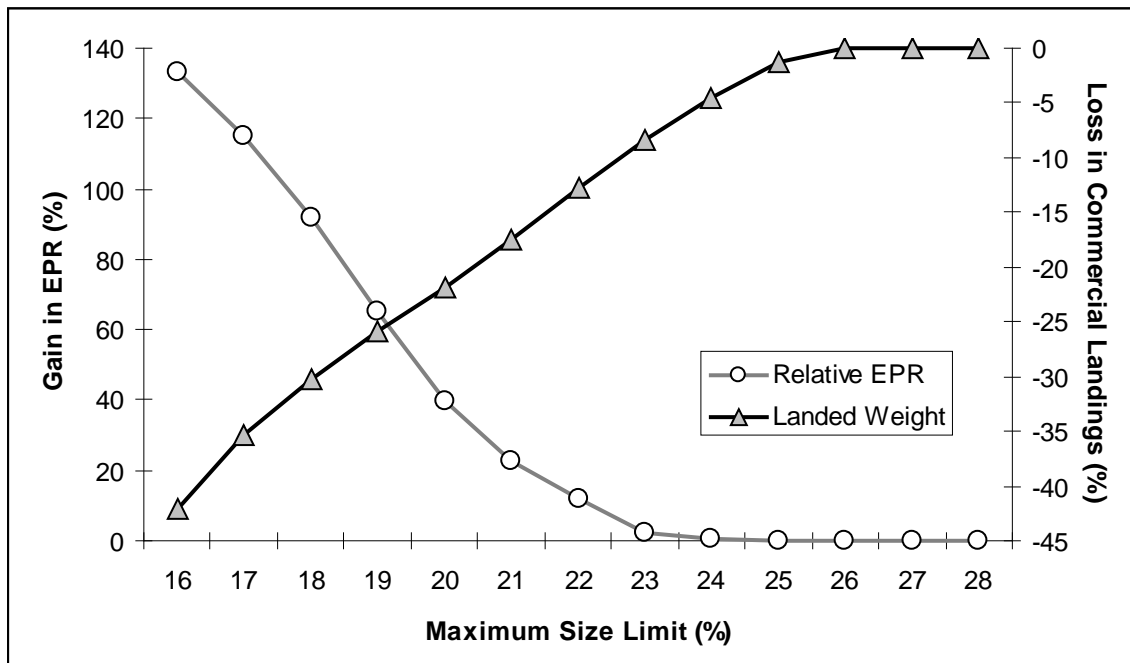
**Figure 10.** Estimated number of eggs-per-recruit (thousands of eggs/recruit) over a range of assumed fishing mortality rates for the resident ( $F_{Resident}$ ) and emigrant ( $F_{Emigrant}$ ) fisheries.



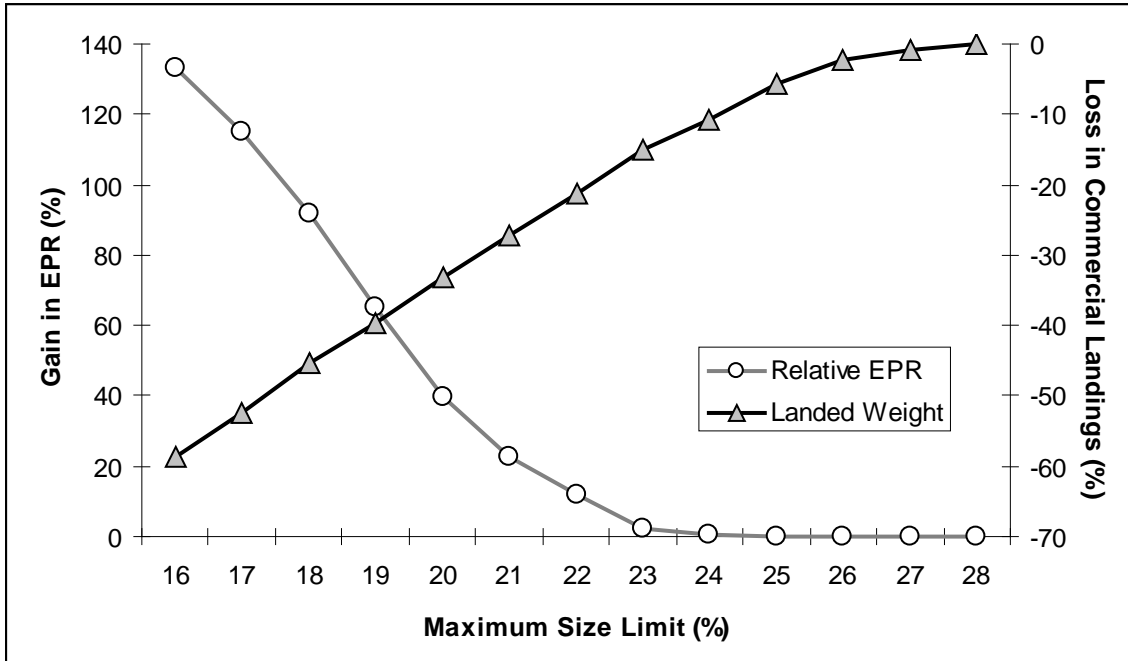
**Figure 11.** Estimated percentage of commercial landings, in terms of weight (lb) and numbers, greater than the maximum size limits considered, for selected states.



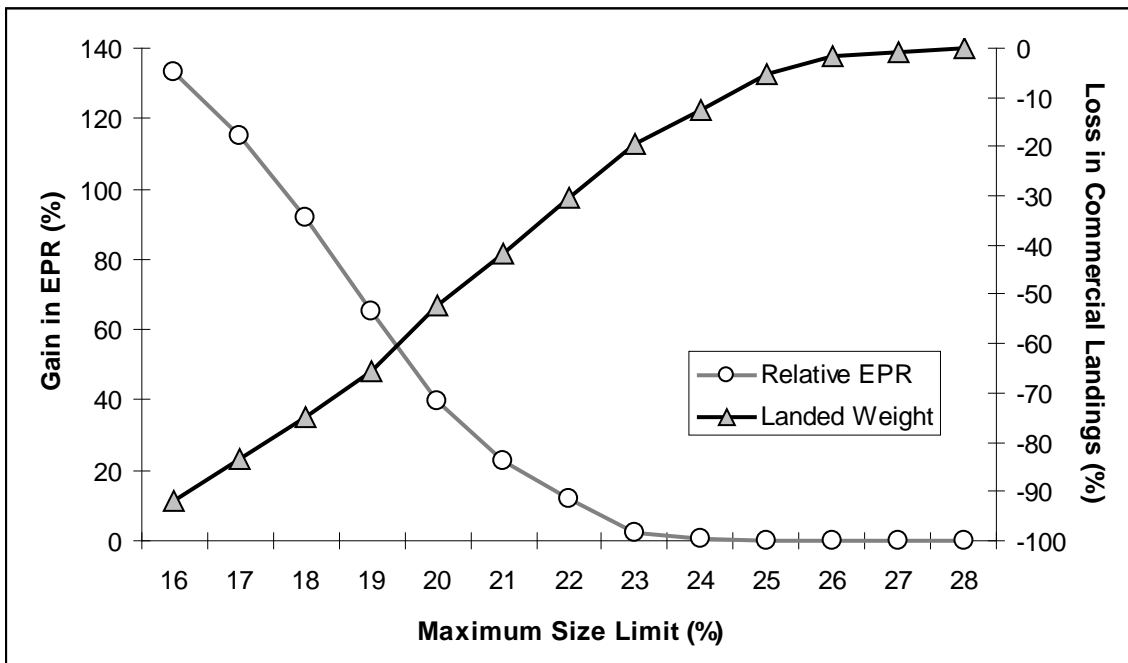
**Figure 12.** Estimated increase (%) in eggs-per-recruit versus the estimated loss (%) in commercially landed weight for various maximum size limits based on New Jersey's commercial landings.



**Figure 13.** Estimated increase (%) in eggs-per-recruit versus the estimated loss (%) in commercially landed weight for various maximum size limits based on Delaware's commercial landings.



**Figure 14.** Estimated increase (%) in eggs-per-recruit versus the estimated loss (%) in commercially landed weight for various maximum size limits based on Maryland's commercial landings.



**Figure 15.** Estimated increase (%) in eggs-per-recruit versus the estimated loss (%) in commercially landed weight for various maximum size limits based on Florida's commercial landings.

**Atlantic States Marine Fisheries Commission**

1050 N. Highland Street, Suite 200A-N

Arlington, VA 22032

703.842.0740 (p) 703.842.0741 (f)

[www.asmfc.org](http://www.asmfc.org) [info@asmfc.org](mailto:info@asmfc.org)

