Stock Assessment Report No. 06-01
of the

Atlantic States Marine Fisheries Commission

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

January 2006

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

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to the American Eel Stock Assessment Peer Review

Conducted on
December 13 – 15, 2005
Washington, DC

Prepared by the
ASMFC American Eel Stock Assessment Review Panel

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A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA05NMF4741025

Preface

Summary of the Commission 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, 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 evaluation of input data, model development, model assumptions, scientific advice, and 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 NMFS, 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 NMFS and the Canada Department of Fisheries and Oceans (DFO).

4. A Commission stock assessment review panel conducted by 3-4 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).

Write assessment history and other background information here.

The American Eel Stock Assessment Peer Review was held on December 13-15, 2005 in Washington, D.C.

Purpose of the Terms of Reference and Advisory Report

The Terms of Reference and Advisory Report provides summary information concerning the American Eel stock assessment and results of the External Peer Review to evaluate the accuracy of the data and assessment methods for this species. Specific details of the assessment are documented in a supplemental report entitled American Eel Stock Assessment Report for Peer Review. A copy of the supplemental report can be obtained via the Commission's website at www.asmfc.org under the American eel page or by contacting the Commission at (202) 289-6400.

Acknowledgments

The Atlantic States Marine Fisheries Commission (ASMFC or Commission) thanks all of the individuals who contributed to the development of the American Eel Stock Assessment and the Terms of Reference and Advisory Report. The Commission extends its appreciation to the American Eel Stock Assessment Peer Review Panel (Dr. David Secor - Chair, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science; Mr. Gerald Chaput, Canada Department of Fisheries and Oceans, New Brunswick; Dr. Jeremy Collie, School of Oceanography, University of Rhode Island; and Dr. Joseph Hightower, USGS/NC Cooperative Fish and Wildlife Research Unit, North Carolina State University) for their efforts evaluating the stock assessment and developing this Terms of Reference and Advisory Report.

The Commission and the American Eel Review Panel thanks the ASMFC American Eel Technical Committee and Stock Assessment Subcommittee (SASC) members who developed the consensus stock assessment report, especially Dr. Matthew Cieri (Maine Division of Marine Resources) for his dedication to the completion of the stock assessment, serving as Chair of the SASC, and presenting the report to the American Eel Review Panel. We would also like to thank Mr. Jeffrey Brust, New Jersey Bureau of Marine Fisheries of the American Eel Stock Assessment Subcommittee for his valuable input.

The Commission appreciates the efforts of Commission staff Ms. Lydia Munger and Mr. Patrick Kilduff for logistical and administrative support during the peer review and preparation of this report.

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Terms of Reference for the American Eel Peer Review

1. Evaluate adequacy, appropriateness, and uncertainty of available fishery-dependent and fishery-independent data sources for use in the stock assessment.

Time series of American eel (*Anguilla rostrata*) landings, effort, and fishery-independent indices were made available to the American Eel Stock Assessment Subcommittee (SASC) at the American Eel Data Workshop held May 2005 in Baltimore. The SASC vetted these and reached consensus that many lacked sufficient duration, consistent or appropriate methodologies, or were otherwise unreliable indicators of eel abundance. The SASC concluded that only nine series were sufficiently reliable for inclusion in assessing American eel stock trends.

The Data Workshop mechanism resulted in collection of data in an appropriate format for SASC deliberations, but the Peer Review Panel felt there were several important datasets not included. The Panel was made aware of several relevant datasets that had become available since the Data Workshop, in addition to datasets that had been used in past American eel assessment activities. These were not present in the assessment due to lack of a data "advocate" at the Data Workshop. The Panel recognized that the Data Workshop was an important step in the assessment activity, but was concerned that important datasets were excluded because American Eel Technical Committee (TC) or SASC members did not actively pursue datasets likely to be valuable (e.g., several used by Richkus and Whalen 1999 and listed in Table 10 of the Assessment).

Published data and information were inadequately presented and utilized in this benchmark assessment for American eel. The Panel noted that while substantive information on biological and ecological attributes of American eel (i.e., growth, mortality, migration, and abundance) had accrued over the past six years, only 3 of >120 research citations were from the period 2000-2006. Further, an important American eel assessment conducted by a team of Canadian, European, and U.S. scientists under the auspices of the International Council for the Exploration of the Sea (ICES 2001) was not referenced. This document presented stock trends and suggested biological reference points, which would have provided a valuable starting point for the ASMFC assessment effort. Finally, substantial advances in approaches in stock assessment have been published for European eel (*Anguilla anguilla*) that would have relevancy to this assessment.

The assessment did not represent biological data sets (e.g., length and age structure, sex ratios), yet collection of these were emphasized in the 2000 FMP (ASMFC 2000). The Panel believes vetting and inclusion of such data sets are important steps that were overlooked in the Data Workshop process.

The Panel recommends that all datasets considered by SASC should be more fully documented with basic characteristics of those datasets (e.g., location, gear, begin-end year, index units), and brief justification for inclusion/exclusion to make this process more transparent. Table 10 of the Assessment provides a structure for this type of documentation. For those datasets included in the assessment, within-year variances should be given when available to support evaluation of the precision of individual time series. Additionally, arithmetic means as well as geometric means (medians) should be provided as possible inputs for trend analysis and assessment models.

2. Evaluate adequacy, appropriateness, application, and uncertainty of models or other analytical methods for use in the assessment of the species and estimating population benchmarks.

Surplus Production Model

The American Eel Technical Committee examined the data requirements of various stock assessments (Table 1). Age-structured assessments were not possible because age data were not routinely collected for American eel. The SASC explored the usefulness of surplus-production models, as implemented in the ASPIC program. Several ASPIC models were run with various permutations of five relative abundance indices. However, convergence problems were encountered in fitting the ASPIC model and no key run was obtained. The different indices showed conflicting trends, such that they could not be fitted simultaneously by a single model. Of the two runs presented, one was more optimistic, suggesting that biomass has been above B_{msy} for most of the time series; the other fit was more pessimistic, suggesting $B<B_{msy}$ for the entire time series. One reason for this uncertainty may be a lack of contrast in apparent population size over time.

The Panel supported initial exploration of the data with the ASPIC model, and thought this and other surplus-production models hold sufficient promise; but the Panel felt that these models should have been more carefully explored as part of the current assessment. The strengths of this approach to this assessment are the long duration of the catch data, and relatively long-duration relative abundance indices. The Panel was concerned about the reliability of the fishery-dependent indices, namely the recreational and commercial CPUE indices. It was unclear whether recreational effort (as measured by the MRFSS survey) was valid for American eel. Commercial CPUE was obtained by combining several quite different measures of effort (e.g. license holders versus pot-days). Still, the Panel believes the current application of the surplus production model is incomplete. Additional needed analyses include:

- Report the parameter estimates and standard errors of each model fit;
- Run regional versions of the surplus-production model (e.g., Canada and USA);

- Perform sensitivity analyses to explore the implications of underreporting of catch data;
- Use the VIMS survey data from 1955-1978 as a separate index due to a gear change;
- Introduce appropriate time lags in the biomass-dynamics equation because the catch and abundance indices apply to eels ages 2 and older;
- Report goodness-of-fit statistics to compare different models runs; where alternative models are nested they can be compared with the Akaike Information Criterion.

These extensions of the surplus-production model may require a customized program. The Panel also discussed the feasibility of constructing a Collie-Sissenwine or delay-difference model for American eel (Deriso 1980; Collie and Sissenwine 1983). In addition to the data requirements of the production model, a delay-difference model would require estimates of natural mortality, age selectivity to the fishery, and growth rate parameters. A delay-difference model could describe the eel life history more realistically, with biologically meaningful parameters. However, the delay-difference model usually involves estimating more parameters, which could compound the convergence problems.

Trend Analysis

The SASC collected a broad range of abundance indices and qualitatively assessed abundance trends of American eel. The Panel agreed that most of these indices are indicators of stock status, but felt that more formal methods should be used to assess temporal trends. Formal methods of multivariate trend analysis exist (e.g., Saila 1993). The significance of temporal trends should be estimated, along with the statistical power of each index to detect a trend.

The SASC standardized the various abundance indices with a Z-transformation. Averaging Z-transformed time series of different durations is inappropriate because each index is standardized to a different baseline, which can result in biased temporal trends. The Panel did not feel that these biases were large enough to alter the qualitative patterns in the aggregate indices (yellow eel abundance and eel pot CPUE). However, the Panel recommends that these indices should be examined independently and also combined with a Generalized Linear Model (GLM) as described in the Advisory Report (see Data and Assessment).

Quantiles of time series can be used as a basis for index-based biological reference points (e.g., is the recent 3-year mean abundance above 20% of the historical distribution?). Ideally, the recent abundance should be compared with a fixed historical period; otherwise the reference point changes with each new year, such that the reference level would decline with a declining stock.

3. Estimate and evaluate fishery status and stock status, and the uncertainty of these estimates, using appropriate data sources.

There are no defined biological reference points in terms of either spawning stock biomass or fishing rates for the American Eel management unit (U.S. Atlantic states' territorial seas and inland waters). As well, there are presently no measures of absolute abundance or of fisheries exploitation rates with which to assess stock status. The Panel concurred with the conclusions of the SASC that stock status could not be described in absolute terms. Rather, a small number of fishery dependent and fishery independent indices (n=9; Table 20) were examined in the context of relative change over time.

Commercial landings for the management unit over the period 1950 to 2003 peaked at c. 1500 metric tons during 1975 to 1982 and recent landings have decreased c. two-fold to levels observed in the earlier portion of the time series (Figure 1). The highest landings are reported from the Chesapeake Bay. It is uncertain to what extent this multi-decadal cycle in landings is due to variations in effort and/or variations in abundance, and the Panel agreed with the SASC that landings should not be considered an indicator of stock status trend. The Panel noted however that the pattern of increased landings in the late 1970s followed by declining landings was similar in kind to decadal patterns in some of the fishery independent indices. Therefore, landings may well be a coarse indicator of overall eel abundance in this management unit.

The fishery dependent indicators available to the SASC were recent, of short duration, and inconsistent in the quantification of the effort units. The Panel concluded that despite the limitations of these data to assess stock status, the continued collection of such information may provide in the longer term, indices of eel abundance on regional and coastwide scales.

Fishery independent indicators available to the SASC comprised glass eel indices in the south and mid-Atlantic regions and yellow eel indices from freshwater and tidal areas distributed from the mid-Atlantic region north into Canada and Lake Ontario. The SASC presented a summary of seven of these indices and concluded that the indices were trending down or there was no trend over the time period examined. The Panel rejected the approach used to calculate a coastwide yellow eel abundance index for reasons explained previously under Term of Reference 2. The Panel examined in more detail those indices evaluated by the SASC. An alternate trend analysis for each index separately provided a similar conclusion to that originally provided by the SASC, i.e., none of the yellow eel indices had a statistically significant increasing trend, whereas three indices covering a period from the mid-1970s to 2004 had a statistically significant declining trend. Two of these indices, Lake Ontario and the VIMS Chesapeake Bay index, had strong and statistically significant declining trends over the recent 1994 to 2004 time period with ten-year declines in the order of 50% in the Chesapeake Bay index to 99% in the Lake Ontario indices.

The glass eel data from the South-Atlantic (Beaufort Inlet, North Carolina) and the mid-Atlantic (Little Egg Inlet, New Jersey) were presented but were not used by the SASC in the context of assessing stock status because there were no observed trends in the series and they were not linearly correlated to each other. The Panel felt that these indices were a valuable asset and interpreted the absence of a declining trend in glass eel abundance in either series over the last 14 to 15 years as the only positive indicator that recruitment, at least to the glass eel stage to these portions of the coast, had not declined in concert with some of the yellow eel indices.

Based upon data and analysis presented in the assessment, the Panel concurs that eel abundance was likely much higher in the late 1970s to mid 1980s, prompting concern about current spawning stock and recruitment levels. The introduction of a broad scale young-of-the-year (YOY) eel index in the 17 states and jurisdictions from Maine to Florida was considered by the Panel to be a useful initiative in the near future that could provide either an index of sustained recruitment over the historical coastal range, an early warning of potential range contraction of this species, or both.

The Panel agreed with the conclusion that the abundance of yellow eel has declined in the last two decades and that the stock is at or near documented low levels. If the decline noted in the yellow eel indices represents a coast- or species-wide phenomenon, then there is risk that spawning stock biomass has also declined, leading to increased likelihood of recruitment failure.

4. If possible, estimate biological reference points (or appropriate proxies), and evaluate fishery and stock status relative to these reference points.

The SASC stated that they lacked sufficient data to develop reference points or quantify stock status. Such reference points are extremely important and the Panel felt that SASC overlooked approaches to define biological reference points such as those developed for American and European eels by the International Council for the Exploration of the Seas (ICES 2001, 2002). There are a number of approaches to arrive at reference points under conditions of data-limited assessments. The simplest approach is to develop relative reference points; for example, using a historical mean or maximum value of a survey index as a first approximation to virgin biomass (ICES 2002). Current survey indices can be compared to that benchmark level as an initial proxy for stock status. A simple proxy for detecting recruitment failure would be an index based on elver presence/absence at monitoring sites. Another feasible approach would be to develop proxies based on the size distribution in survey catches. That approach could be used to monitor for recruitment failure or the loss of larger and older eels from an area (Richkus and Whalen 1999). Other useful proxies are to monitor for range contraction (as proposed for Atlantic menhaden) or recruitment indices that fall below some specified level (as successfully utilized for Atlantic striped bass recovery).

A more data-intensive but feasible approach is the development of reference points based on spawning biomass per recruit (SPR). These calculations have been done for both American and European eel populations (ICES 2001; 2002) using simple population models and basic life history data (maturity schedules, natural mortality, and growth). An advantage of this approach is that reference points can be developed regionally based on differences in growth or maturity schedule over the species' range (ICES 2001). This reference point has precedence in the assessment of Atlantic sturgeon (ASMFC 1998) and Atlantic menhaden (ASMFC 2004).

To estimate the current stock status relative to the SPR reference point, estimates of fishing mortality (F) are needed. The simplest approach for estimating F is a catch curve analysis of age composition data (ICES 2001). F could also be estimated based on differences in age or length distributions between fished and unfished areas, as was done for American eels in Prince Edward Island (ICES 2001). Another approach would be to generate swept-area estimates of biomass for ongoing trawl surveys and to estimate F from the ratio of area-specific landings to estimated abundance. There are also many published density and abundance estimates for American eel, including a recent large-scale study in the Hudson River estuary (Morrison and Secor 2004).

Regional broad-scale mark-recapture experiments could provide new data (i.e., abundance, exploitation rate, growth, natural mortality, migration) for future assessments.

The most cost-effective approach for marking and recovery of tagged eels would be a cooperative study with commercial fishers. A potentially efficient strategy for recovery of tagged eels would be to cooperate with commercial eel dealers (who handle the largest fraction of the total commercial harvest). In particular, recovery of tagged eels would provide direct and region-specific estimates of the exploitation rate, which could then be used to estimate F.

Regardless of the approach for determining reference points, mortality rates should be the focus for future monitoring and assessment because all eel mortality is pre-spawning mortality (Castonguay et al. 1994). Over the years that an eel remains in estuarine or fresh waters, the cumulative mortality prior to out-migration can substantially lower escapement. This is not only an issue regarding harvest but also turbine mortality for silver eels migrating downstream through dams.

5. Develop recommendations for future research to improve data collection and future assessments.

The Peer Review Panel recommends that, in the short term, efforts on the following recommendations would lead to an improved assessment. All categories of recommendations are important; within each, the Panel ranked recommendations according to priority in developing the next ASMFC eel stock assessment.

Landings and Effort:

1. Improved trip-level monitoring of landings and effort data by state. Efforts to improve this database should include stakeholder involvement and could be pursued through an ASMFC workshop. It is essential to consider data handling and analysis as well as improved data collection.
2. Improved monitoring of catch and effort in bait fisheries (commercial and personal-use).

Demographics:

1. Length sampling should be conducted routinely in commercial fisheries.
2. Minimally, length (and ideally other biological characteristics) should be monitored routinely in fishery-independent surveys.
3. Intensive age and growth studies should be conducted at regional index sites to support development of reference points and estimates of exploitation.
4. Collaborative monitoring and research programs with dealers provide a valuable opportunity to estimate age structure and abundance on a regional basis.

Abundance Indices:

1. Priority should be given to sustain the ASMFC-mandated YOY survey conducted by the states, as a coast-wide index of recruitment. This could be particularly valuable as an early warning signal of recruitment failure. The Panel also found useful the two long-term glass eel monitoring projects conducted by Rutgers University and the National Marine Fisheries Service (NMFS). The VIMS trawl survey is an essential long-term dataset for monitoring yellow eel abundance.
2. Increased and improved monitoring of upstream movement at migratory barriers.

Data Analysis and Assessment

1. Develop biological reference points, giving priority to the SPR approach, which has precedence in ICES assessments for eels.

2. Analyze the data regionally.
3. Measure the within-year variance of abundance indices to quantify index precision.
4. Develop assessment models (e.g. Delay-difference model) specific to eel life history and fit to available indices.

Mortality and Habitat:

1. Undertake regional mark and recapture program to estimate fishing rates.
2. Monitor non-harvest losses such as impingement and entrainment mortality and hydropower turbine mortality.
3. Assess available drainage area over time to account for temporal changes in carrying capacity.
4. Contaminants and the invasive parasite *Anguillacola crassus* should continue to be monitored and investigated as sources of mortality and non-lethal population stressors.

Summary Evaluation

The panel recognized sufficient shortcomings of the current assessment to warrant additional action prior to its use for future technical and management purposes. Overall, we believed that TORs 1 and 2 were partially met, and that TORs 3 and 4 were insufficient in response by the SASC. We recognized that the ASPIC run was presented as a preliminary effort in an Appendix rather than in the formal Assessment. Still, had no surplus-production model been attempted, the Panel would have reached the conclusion that TOR 2 was insufficiently met.

The Panel recommends that the American Eel Technical Committee resolve the following issues and update the assessment according to the following actions.

Issue 1. Improved trend analysis (TORs 1 and 3).

- The SASC should include a broader range of datasets (i.e., those included in ICES 2001 and Richkus and Whalen 1999 assessments; the Delaware Trawl Data; and the two glass eel indices (Little Egg Inlet, NJ and Beaufort Inlet, NC)) in their assessment of trends.
- For all series (relative abundance and CPUE data), both geometric means and arithmetic means should be reported and where available, within year variances shown.
- Trend analysis should be conducted based upon GLM approaches and computation of instantaneous annual rates of change over decadal periods, rather than the Z-score approach adopted in the current assessment.
- For the two glass eel indices, trends should be re-analyzed based upon arithmetic rather than geometric means. The latter caused significant biases in early trends.

Issue 2. Evaluation of biological reference points (TOR 4).

- The SASC should develop a range of alternative SPR reference points following approaches developed in the ICES American eel assessment (ICES 2001).
- The SASC should provide a critical discussion on the possibility of developing those reference points presented in the Panel Review under TOR 4 above.

Issue 3. Improved presentation and testing of the ASPIC model (TOR 2).

- The ASPIC runs should be presented as part of the formal assessment, rather than as an appendix.
- Report the parameter estimates and standard errors of each ASPIC model run's fit.
- Run regional versions of the ASPIC model (e.g., Canada and the USA; the Chesapeake Bay). Use the VIMS survey data from 1955-1978 as a separate index due to a gear change.
- Perform sensitivity analyses to explore the implications of underreporting of catch data.
- Report goodness-of-fit statistics to compare different model runs.

Advisory Report

Status of Stocks

The management unit for American eel (*Anguilla rostrata*) is its distribution across territorial and inland waters along the Atlantic coast from Maine to Florida. There are no defined biological reference points in terms of either spawning stock biomass or fishing rates for this management unit. As well, there are presently no measures of absolute abundance or fisheries exploitation rates with which to assess stock status.

Commercial landings for the management unit over the period 1950 to 2003 peaked during 1975 to 1982 at approximately 1500 metric tons. Landings during the past two decades have decreased over two-fold to levels observed in the earlier portion of the time series (Figure 1). The most important landings are reported from the Mid-Atlantic.

The American Eel Stock Assessment Subcommittee (SASC) presented a summary of seven yellow eel abundance indices and concluded that the indices were trending down or there was no trend over the time period examined. A trend analysis conducted by the Peer Review Panel indicated that none of the yellow eel indices had a statistically significant increasing trend, whereas three indices covering the period from the mid-1970s to 2004 had a statistically significant declining trend (Figure 2). Two of these indices, Lake Ontario and the VIMS

Chesapeake Bay index, had strong statistically significant declining trends over the recent 1994 to 2004 time period with declines on the order of 50% in the Chesapeake Bay index to 99% in the Lake Ontario indices.

Based upon data and analysis presented in the assessment, the Panel concurs that eel abundance was likely much higher in the late 1970s to mid 1980s. The abundance of yellow eel has declined in the last two decades and the stock is at or near documented low levels. Should the decline in the yellow eel indices represent a coast- or species-wide phenomenon, then there is a real risk that spawning stock biomass has also declined. If these declines are due to an unsustainable rate of total mortality (combined effects of fishing, habitat loss and degradation, dams, climate, and disease), recruitment failure is a possible consequence.

Stock Identification and Distribution

The American eel is found and exploited in fresh, brackish and coastal waters from the southern tip of Greenland to northeast South America along the western Atlantic Ocean. The species has a catadromous life cycle: spawning by adults (silver eels) occurs in the Sargasso Sea, larval stage *leptocephali* occur in pelagic ocean waters, glass eels ingress into nearshore estuarine and freshwater systems that also serve as growth habitats for juvenile elver and yellow eel stages. Because the species is semelparous (i.e., adults spawn once and die), vital rates and abundances pertinent to population dynamics pertain only to pre-spawning stages. Further, it remains unclear which regions and habitats contribute most to the production of spawners.

Management Unit

The specific management unit for the American Eel Fishery Management Plan is the portion of the American eel population occurring in the territorial seas and inland waters along the Atlantic coast from Maine to Florida. Dams and other impoundments have dramatically curtailed the inland distribution of eels in comparison to historical patterns of occurrence.

Significant numbers of eel occur in regions and habitats that are outside the jurisdictional boundaries of the state agencies participating in the ASMFC. These include watersheds in the Gulf of Mexico, Caribbean and Canada; upstream freshwater reaches that are managed by inland fish and wildlife agencies of ASMFC member states and regional institutions such as Fisheries and Oceans Canada, the Gulf States Marine Fisheries Commission, and those waters within Native American Reservations where Tribal Governments have jurisdiction. Therefore, effective American eel management will require coordination between ASMFC and other relevant jurisdictions and agencies. An initial assessment activity in 2000 conducted under the auspices of the

International Council for the Exploration of the Seas involving Canadian, European, and U.S. scientists sets a valuable precedent for such coordination.

Fishery Description

The U.S. fishery for American eel extends from Maine to the Gulf of Mexico. All Atlantic coast states except for Maine, South Carolina, and Florida have implemented a six-inch minimum size limit for American eel. Significant glass eel harvests continue only in Maine. Harvests principally target yellow eels in tidal estuaries and large rivers. Eel pots account for 80% of the harvest. Most harvests of yellow eels are shipped live to Europe through relatively few dealers. Effort and landings are likely driven in part by European market demand. Bait eel, taken by both commercial and recreational sectors, also represent an important and possibly expanding portion of harvest, which is not well monitored. Recreational landings of eels not used for bait are poorly known, but probably represent an insignificant portion of overall harvest.

Landings

The American Eel FMP requires states to report commercial harvest by life stage and gear type by month and region as defined by the states. At this time, however, not all states are able to provide this level of information. U.S. commercial landings were retrieved from on-line automated summary programs maintained by the NMFS.

U.S. commercial landings have varied between 290 and 1790 mt since 1950 with the largest harvests occurring 1974 to 1985 (Figure 1). Landings declined steadily from nearly 1000 mt in 1950 to a time series low of 290 mt in 1962 before increasing gradually to the time series maximum in 1979. Between 1980 and 2002, reported landings exhibited a gradual decline to 291 mt before rebounding slightly to 468 mt in 2003. About half of the commercial landings for American eel from 1950 to 2000 were attributed to the Chesapeake Bay (Virginia=34%; Maryland=18%).

Commercial landings of American eel from Canada were of similar magnitude to U.S. landings during the period 1972-2004. Landings were fairly stable at 530 to 1000 mt for the period 1972 to 1994 but have declined from 535 mt in 1995 to 127 mt in 2004. Eel landings have also been reported by Mexico, the Dominican Republic, and Cuba, but aggregate harvests for these countries was small, less than 5% of U.S. commercial eel landings (1995-2003).

Recreational harvest of U.S. American eel ranged from < 1 mt to 71 mt between 1981 and 2004. During the recent period 1992-2004, mean harvest was estimated at 4.2 mt, c. 1% of commercial landings for the same period.

Data and Assessment

The American Eel Technical Committee examined various analytical methods for conducting the American eel stock assessment (Table 1). For most of the methods, the available data were insufficient to support an assessment at the coastwide level. Preliminary runs were made by the SASC using a surplus-production model, but these were considered "proof of concept" and not a quantitative assessment.

The primary methodology used for the American eel stock assessment, therefore, was non-quantitative, based on indices of relative abundance throughout the U.S. and Canadian portions of the species range. Although the SASC considered the relative abundance indices to be independent of each other, correlations would be expected among indices from the same basins. For example, eels must pass through the Moses-Saunders eel ladder to be counted in the Lake Ontario electrofishing survey and the Bay of Quinte trawl survey. Likewise, data from three rivers in Chesapeake Bay were used in the yellow-eel index and the same data constitute the VIMS trawl-survey index.

The data from all surveys were standardized with a Z-transformation, which results in a mean of 0 and a standard deviation of 1 for each data set and therefore allowing comparison of all data sets on the same relative scale. Multiple data sets were combined into a combined global mean by averaging the standardized indices and re-standardizing the average. The Panel determined that it was inappropriate to combine Z-transformed series of different durations. Instead the Panel recommends that multiple indices be analyzed with a Generalized Linear Model (GLM) framework. For surveys with count data, the GLM can be done as a Poisson regression with a year factor to account for common temporal patterns among the indices, and an index factor to account for the different magnitudes of the indices. Regional differences could be incorporated as an additional factor. The different indices can be weighted by sample size, inverse variance, or by other variance considerations. Examples of GLM fits are shown in Figures 3 and 4.

Fishery Dependent CPUE

Several states require the reporting of effort data from their commercial fishermen. A coastwide index of relative abundance was created using the available catch (pounds) per unit of effort (CPUE) data from the commercial eel pot fishery during the period 1992 to 2004. The states that had commercial eel pot catch and effort data and their corresponding time series are as follows: Maine (2001-2004), Massachusetts (2001-2004), Delaware (1999-2004), Maryland (1990,1992-2004), Potomac River Fisheries Commission (PRFC) (1988-2004), Virginia (1993-2004), North Carolina (1994-2004), and Florida (2004). Due to possible inaccuracies of data from North Carolina for 1994 and

1995 and only one year of CPUE data from Florida, the SASC excluded those data from the computation of the composite CPUE index.

Effort data from the eel pot fishery from each state were Z-transformed to allow for comparison of all data sets on a relative scale. The Panel did not support averaging Z-transformed indices of differing durations and recommends the use of the GLM, which is the accepted method for combining CPUE data (Hilborn and Walters 1992). An example GLM fit to the CPUE data is shown in Fig. 3.

The preliminary GLM analysis conducted by the Panel was intended only to illustrate the applicability of the GLM approach. However, it has the same qualitative pattern as the aggregate CPUE index (ASMFC 2005, Fig. 6). The eel pot fishery CPUE index was relatively high from 1993 to 1996, but dropped drastically and remained at low levels from 1997 to 1999. From 1999 to 2004, CPUE showed a positive trend. Effort was stable at relatively high levels from 1994 to 1999, but declined precipitously between the time series high in 1999 and the time series low in 2002. Estimates of effort in 2003 and 2004 remained at comparatively low levels.

Commercial CPUE data can be informative about changes in stock abundance, when properly standardized and interpreted. The panel expressed several reservations with the eel pot CPUE data. The units of effort vary among states, ranging from pot days in MD to number of licenses in MA. Do these measures reflect effective fishing effort? Does each unit of effort have comparable catchability? The catch and effort data do not come from the same source and may therefore not have a strict correspondence. Landings could be reported without corresponding effort or conversely, some effort may not report landings. Taking the ratio of two variables with errors can amplify potential errors. As fishing effort declined since 1999, CPUE could be artificially high if trap saturation occurred at higher effort levels, if less efficient units of effort were removed first, or if the remaining units of effort were concentrated in the areas of highest eel density. The panel did not reject the use of CPUE indices but felt that they needed more scrutiny, especially because CPUE appears to be increasing in the same area where trawl survey indices are decreasing (Chesapeake Bay).

Fishery Independent Surveys

Fishery independent indicators used in the assessment included glass eel indices in the South and Mid-Atlantic Bight regions and yellow eel indices from freshwater and tidal areas distributed from the Mid-Atlantic Bight region north into Canada and Lake Ontario. The yellow eel indices are of variable temporal length with the longest data set from the Gulf of St. Lawrence (Canada) commencing in 1952 to present and the shortest indices from eel ladder counts in Connecticut spanning three years (Table 2). The freshwater based indices were obtained using a broad range of sampling gears including trawl, eel ladder counts, and electrofishing. The electrofishing surveys were not specifically targeting eels. The yellow eel indices from tidal waters were obtained primarily by trawl with one from fyke nets targeting glass eels. Few of the indices represent specific length groups and in most, length sampling of the catches was not undertaken.

The freshwater indices from the North and Mid-Atlantic coastal regions were of recent and short duration. None of these indices had statistically significant linear trends in abundance (Table 2). The two groups of freshwater indices from Lake Ontario and the Gulf of St. Lawrence (Canada) covered a much longer time period, dating to 1952 from one of the rivers (Miramichi) in the Gulf of St. Lawrence and 1972 for the Bay of Quinte trawl survey in Lake Ontario. Both of these indices had statistically significant declining trends in abundance with the largest declines in the Lake Ontario indices of 11% to 22% per year. Over the more recent 1994 to 2004 time period, the declines in the Lake Ontario indices were more severe, at about 36% per year. The indices in 2004 were less than 1% of the values measured in 1994. In contrast, the Gulf of St. Lawrence indices had no statistically significant trend over the 1994 to 2004 period.

The tidal indices available for analysis were from three states in the mid-Atlantic region (Table 2). The fyke net index from New Jersey is recent and of short duration and there was no statistically significant trend. The Delaware trawl survey (not included in SASC's subset of datasets used for trend analysis) extending from 1982 to 2004 had large interannual variation in abundance but there was no statistically significant trend over the whole time period or during the shorter 1994 to 2004 period. The extensive trawl survey of the Virginia Institute of Marine Science (VIMS) in Chesapeake Bay had a statistically significant declining trend over the period 1979 to 2004 with an average rate of decline of 5% per year. Over the 1994 to 2004 period, the overall Chesapeake Bay index and the river specific indices derived from the survey showed statistically significant declines on the order of 8% to 18% per year. The river specific indices of Chesapeake Bay for 2004 are at 11% of the 1994 level whereas the overall VIMS index is at 57% of the 1994 value.

The glass eel data from the South-Atlantic (Beaufort Inlet NC) and the mid-Atlantic (Little Egg Inlet, NJ) were obtained from long-term sampling programs monitoring larval and juvenile fish abundance. Sampling methods and gears were relatively consistent over the time period. In contrast to the SASC, the Panel believed trends in arithmetic means versus presented geometric means were more representative of trends for these datasets. Although mean abundance (estimated by the Panel as arithmetic means) of glass eels was variable, there was no statistically significant trend in the abundance of glass eels at either site. Date of peak catches of glass eel has been progressively later, by about ten weeks at the New Jersey sampling site, while the date of peak density at the NC site although variable does not show a significant change over time.

The panel did not support averaging Z-transformed indices of differing durations and recommends the use of the GLM. An example GLM fit to the fishery independent data is shown in Figure 4.

Biological Reference Points / Fishing Mortality

As noted in the Terms of Reference, biological reference points were not established in the draft assessment although some proxies have been developed in ICES reports on American and European eels (ICES 2001, 2002). Some relatively simple proxies could be developed from the data used in the draft assessment, whereas others could be based on simple population models and published life history information. A longer term goal must be to estimate fishing and other sources of mortality, so that the pre-spawning mortality can be properly evaluated in the context of reference points.

Recruitment / Spawning Stock Biomass

The draft assessment contains some information about year-class strength and recruitment to the fishable stock. Glass eel surveys (bridge tow data) were available for New Jersey (1989-2003) and North Carolina (1986-2003). There is no evidence of a trend in initial year-class strength, based on samples from these two sites. The ASMFC-mandated YOY survey will provide information about year-class strength on a much broader geographic scale once a sufficiently long time series is available. Other long-term datasets such as the VIMS and Delaware trawl surveys provide information about recruitment, but the trends are difficult to interpret because information was not provided about the size or age distribution of eels collected in each survey. The surveys would be more informative if analyses were restricted to specific size ranges.

Spawning stock size is more difficult to assess because of the unique life history of the American eel. The only opportunity to directly monitor spawner escapement would be during their downstream migration as silver eels. Commercial fisheries for silver eels are reported to occur throughout their range, and sampling these fisheries could provide valuable information about trends in spawning stock size and sex ratio of adults. For American eels migrating downstream through dams, monitoring during the downstream migration is important so that the impact of turbine mortality can be assessed. Another approach for examining trends in spawning stock size would be to analyze long-term datasets using size ranges that represent fish approaching the size or age of sexual maturity.

Declines in European eel (*Anguilla anguilla*) recruitment suggest that it is extremely important to consider escapement and spawning stock size (ICES 2005). For European eels, it has been proposed that the recent period of poor recruitment may be due to spawning stock declining below a biological threshold.

Incidental Mortality

Little is known about incidental mortality, which is defined as mortality caused by anthropogenic activities other than harvest. Bycatch mortality is not known to be a concern. It has been estimated that 84% of historical habitat available to eels is now inaccessible. Dams may increase predation mortality on upstream-migrating elvers or yellow eels if they accumulate below the obstruction. Turbine-related mortality is a concern for American eels migrating downstream through dams, given estimates of turbine mortality of 18-26% per dam (ICES 2001). The draft assessment reports a range of 5-30% mortality depending on turbine type and river flow.

Sources of Information

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Tables

Table 1. Minimum data requirements of commonly used stock assessment models. Shaded cells indicate data type is not a minimum requirement for the associated model. The column on the right indicates data availability for American eel. In most instances, available data would only be available on a regional basis.

Data	Production	Delay Difference	Aggregate Matrix	VPA/Cohort	Catch-At-Age	American Eel Data
Natural Mortality						Some Estimates Published
Fishing Mortality						Not Available
Total Catch						Currently Assessed
Effort or CPUE						Currently Assessed
CAA Matrix*						Not Available
Selectivity						Not Available
Abundance						Some Estimates Published
Growth						Some Estimates Published
Fecundity						Some Estimates Published

*** Or catch-at-stage for Aggregate Matrix models**

Table 2. Summary of trend analysis of yellow eel fishery independent indices. Instantaneous rate of annual change values in bold were statistically significant. Absolute annual rates for significant values are given in parentheses.

Environment	Region	State	Location	Gear	Size (mm)	Age (years)	Years	INSTANTANEOUS RATE OF ANNUAL CHANGE[1]	P-value (Year)
FW	Lake- Ontario		Bay of Quinte, Moses Saunders	Trawl, Eel ladder	?	? 7-12	1972-2004 1994-2004	**-0.121 (-11%)** **-0.246 (-22%)** **-0.435 (-35%)** **-0.438 (-35%)**	<0.001 <0.001
	Canada, Maritimes	Gulf of St. Lawrence	Restigouche, Miramichi, Margaree	Electrofishing	?	?	1952-2004 1994-2004	**-0.042 (-34%)** 0.150	<0.001 0.15
	North	Maine	Fort Halifax	Eel ladder	80-150	2	1999 - 2004	-0.349	0.31
	North	Connecticut	Greeneville	Eel ladder	?	?	2000-2002	0.45	0.45
			Lake Whitney	Eel ladder	?	?	2001-2003	0.55	0.51
	Mid	Pennsylvania	Delaware	Electrofishing	100-200	2-3?	1999-2004	-0.095	0.37
	Mid	Maryland	Chesapeake Bay rivers	Electrofishing	?	?	1994-1997, 2000-2003	-0.057	0.43
Tidal	Mid	New Jersey	Patcong Creek	Fyke net/	?	2	2000-2004	0.493	0.43
	Mid	Delaware	Delaware River	Trawl	?	?	1982-2004 1994-2004	0.019 0.033	0.15 0.47
	Mid	Virginia[2]	York, James, Rappahannock	Trawl	>153	2-?	1994-2004	**-0.197 (-18%)**	< 0.001
	Mid	Virginia	Chesapeake Bay	Trawl	>153	2-?	1979-2003 1994-2004	**-0.052 (-5%)** **-0.076 (-7%)**	0.004 0.002

[1] The instantaneous rate of change calculated as the slope of the natural log transformed index against years (for Canada Gulf of St. Lawrence, index+0.001 was used).
[2] For the VIMS trawl survey data of 1994 to 2004 for which indices of abundance were available for the three rivers separately, the model with a common slope but different intercepts produced the lowest AIC value of all the models explored.

Figures

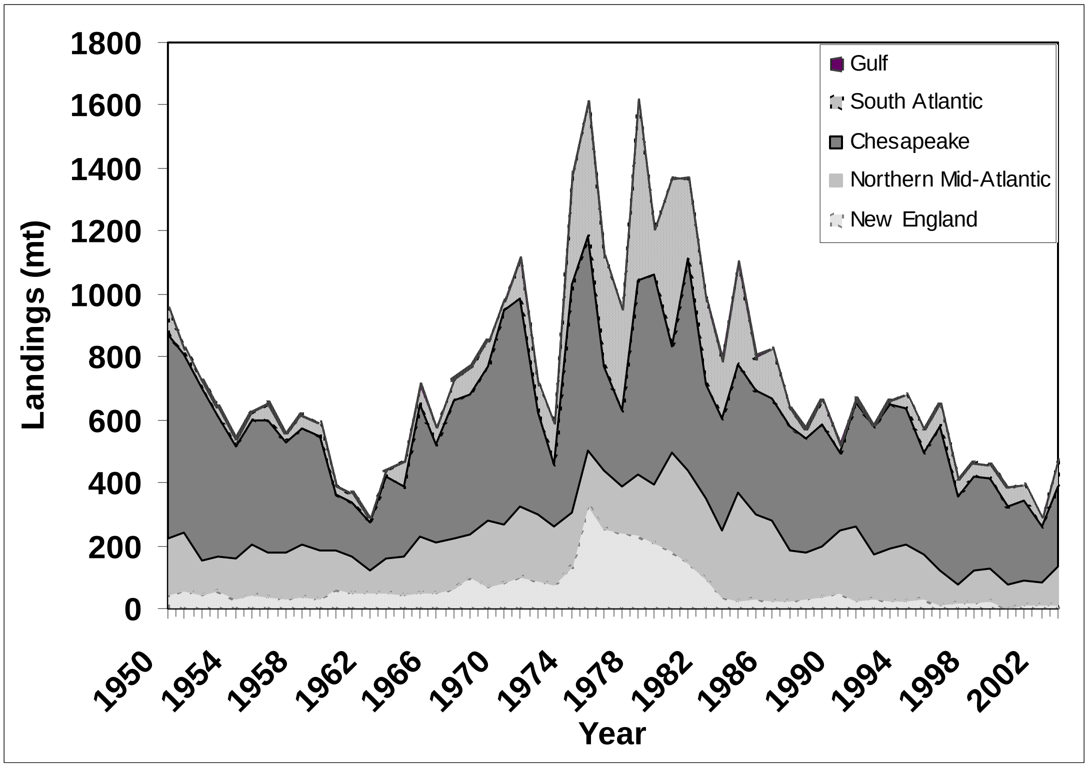

Figure 1. Total weight of American eel landed by commercial fisheries along the U.S. Atlantic and Gulf coasts by region, 1950 to 2003. New England: Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut; Mid-Atlantic: New York, New Jersey and Delaware; Chesapeake: Maryland and Virginia; South Atlantic: North Carolina, South Carolina, Georgia, Florida (East Coast and Inland waters); Gulf: Florida (West Coast), Lousiana, and Texas (no landings data for Alabama and Mississippi). (Sources: NMFS, pers. comm).

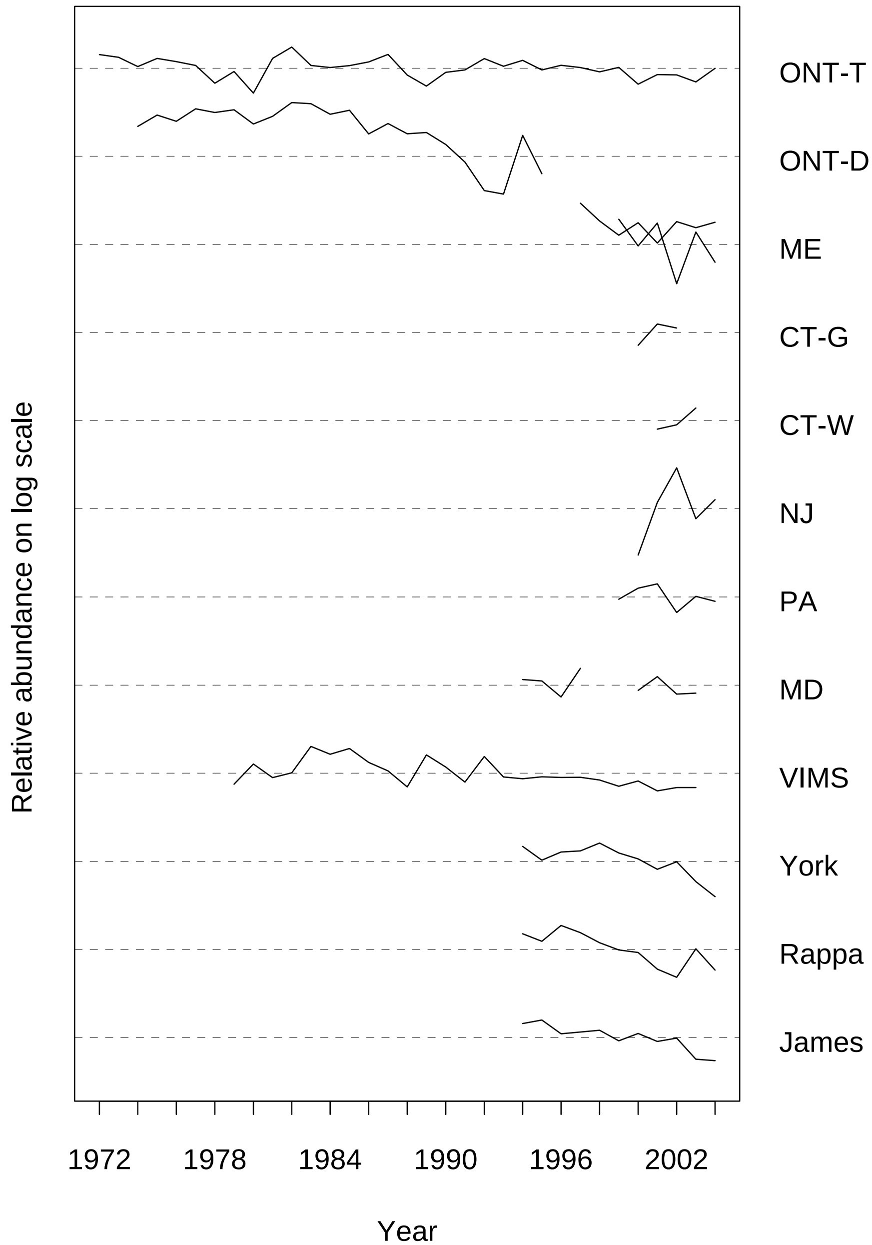

Figure 2. Relative abundance of yellow eels. Each index was $\log_{10}$ transformed and plotted relative to its mean (dashes lines). The means are separated by 2 log units (base 10). The indices are arranged geographically from north to south: ONT-T—Bay of Quinte Trawl; ONT-D—Moses-Saunders Eel Ladder; ME—Fort Halifax; CT-G—Greenville; CT-W—Lake Whitney; NJ—Patcong Creek; PA—Delaware River; MD—Chesapeake Bay; VIMS—Virginia Institute of Marine Science trawl survey; York—York River, VA; James—James River, VA; Rappa—Rappahannock River, VA.

Figure 3. Common year effects (± standard error) in the commercial CPUE indices. Four data points that resulted in the largest residuals (NC 2002 and 2003, MA 2002 and 2003) were removed to satisfy the assumption of homoscedasticity. The rug plot at the bottom of the figure indicates the number of observations each year.

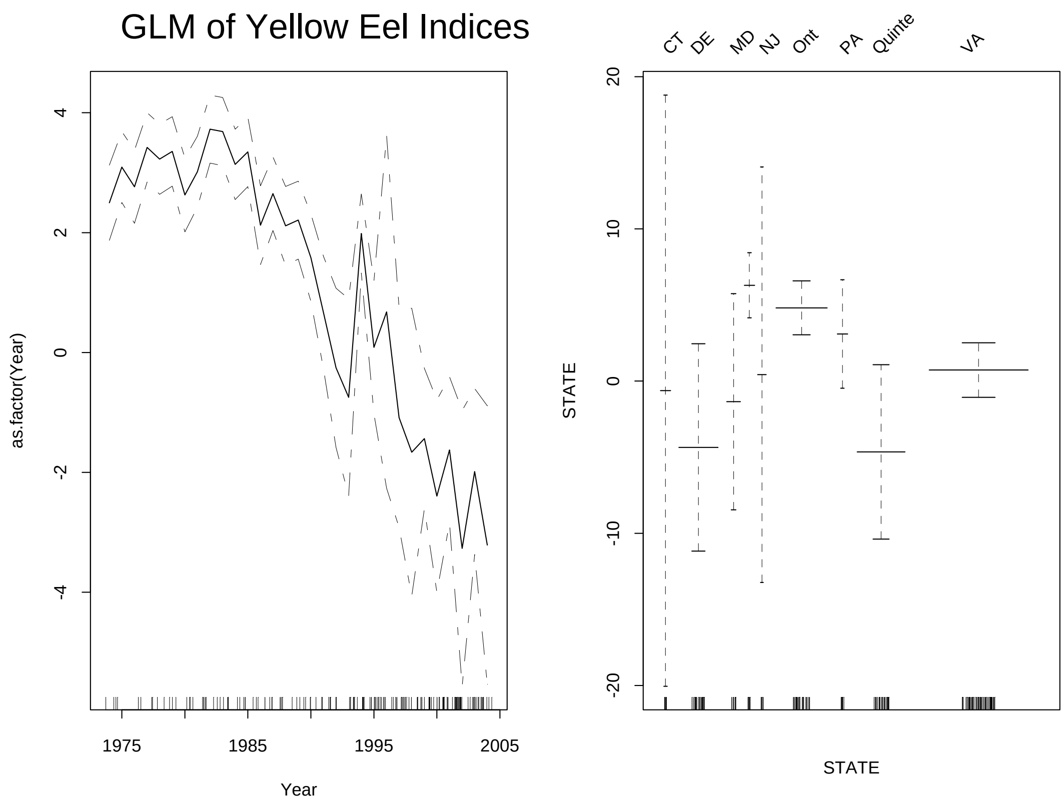

Figure 4. Generalized linear model of yellow eel indices. The left panel shows the common year effects (± standard error); the right panel shows the mean levels of each index (± standard error). The width of the horizontal bars indicates the number of observations in each index.