Atlantic States Marine Fisheries Commission

2017 American Eel Stock Assessment Update

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Sustainably Managing Atlantic Coastal Fisheries

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2017 American Eel Stock Assessment Update

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EXECUTIVE SUMMARY

The management unit for American eel under the jurisdiction of Atlantic States Marine Fisheries Commission (ASMFC or Commission) 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 varies. Glass eel fisheries are permitted in Maine and South Carolina. Yellow 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 2016, Atlantic coastwide U.S. American eel landings ranged between approximately 664,000 pounds in 1962 and 3.67 million pounds in 1979. The highest landings in the time series occurred from the mid-1970s to the early 1980s after which they declined. Since the 1990s, landings have been lower than historical landings but they have been stable in recent decades.

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 the 2012 benchmark stock assessment were updated for this report, with some noted exceptions, and most were standardized using a generalized linear model to account for changes in catchability of American eels. Regional indices were also developed for both YOY and yellow eel stages.

Trend analyses of abundance indices provided evidence of neutral or declining 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 some indices. The Mann-Kendall test detected a significant downward trend in 6 of the 22 YOY indices, 5 of the 15 yellow eel indices, 3 of the 9 regional trends, and the 30-year and 40-year yellow-phase abundance indices. The remaining surveys tested had no trend, except for two which had positive trends. The Manly meta-analysis showed a decline in at least one of the indices for both yellow and YOY life stages. For the ARIMA results, the probabilities of being less than the 25th percentile reference points in the terminal year for each of the surveys were similar to those in ASMFC 2012 and currently 3 of the 14 surveys in the analysis have a greater than 50% probability of being less than the 25th percentile reference point. Overall, the occurrence of some significant downward trends in surveys across the coast remains a cause for concern.

Reference points for determining the stock status of American eel in the U.S. in ASMFC 2012 were developed using the Depletion-Based Stock Reduction Analysis (DB-SRA) model which was not accepted for management use by the Peer Review Panel. The DB-SRA was not updated for this report because the Panel recommended it be further developed which was outside the

guidelines of a stock assessment update. Therefore neither reference points nor stock status could be determined quantitatively by this stock assessment update. Compared to the 2012 benchmark stock assessment, the ARIMA had similar results and there were more significantly downward trends in indices as indicated by the Mann-Kendall test in this update. The trend analysis and stable low landings support the conclusion that the American eel population in the assessment range is similar to five years ago and remains depleted.

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1 INTRODUCTION

The purpose of this assessment was to update the 2012 American eel (*Anguilla rostrata*) benchmark stock assessment (ASMFC 2012) with recent data from 2010-2016. No changes in structure were made to the index standardization or modeling approaches. The 2012 benchmark stock assessment and this stock assessment update for American eel was initiated by the Atlantic States Marine Fisheries Commission (ASMFC or Commission) American Eel Management Board, prepared by the ASMFC American Eel Stock Assessment Subcommittee (SAS), and reviewed and approved by the ASMFC American Eel Technical Committee (TC) as part of the interstate fisheries management process.

1.1 Fisheries Management

The ASMFC American Eel Management Board (Board) first convened in November 1995 and finalized the Interstate Fishery Management Plan (FMP) for American Eel in November 1999 (ASMFC 2000a). The goal of the FMP is to conserve and protect the American eel resource to ensure ecological stability while providing for sustainable fisheries. The FMP requires all states and jurisdictions to implement an annual young-of-year (YOY) abundance survey to monitor annual recruitment of each year's cohort (ASMFC 2000a, 2000b). In addition, the FMP requires a minimum recreational size and possession limit and a state license for recreational fishermen to sell eels. The FMP requires that states and jurisdictions maintain existing or more conservative American eel commercial fishery regulations for all life stages, including minimum size limits. Each state is responsible for implementing management measures within its jurisdiction to ensure the sustainability of its American eel population.

In August 2005, the Board directed the American Eel Plan Development Team (PDT) to initiate an addendum to establish a mandatory catch and effort monitoring program for American eel. The Board approved Addendum I at the February 2006 Board meeting.

In January 2007, the Board initiated a draft addendum with the goal of increasing escapement of silver eels to the spawning grounds. In October 2008, the Board approved Addendum II, which placed increased emphasis on improving the upstream and downstream passage of American eel. The Management Board chose to delay action on management measures in order to incorporate the results of the 2012 stock assessment.

In August 2012, the Board initiated Draft Addendum III with the goal of reducing mortality on all life stages of American eel. The addendum was initiated in response to the findings of the 2012 Benchmark stock assessment, which declared American eel stock along the US East Coast as depleted. The Management Board approved Addendum III in August 2013.

Addendum III requires states to reduce the yellow eel recreational possession limit to 25 eel/person/day, with the option to allow an exception of 50 eel/person/day for party/charter employees for bait purposes. The recreational and commercial size limit increased to a minimum of 9". Eel pots are required to be constructed with a minimum of ½" by ½" mesh size. The glass eel fishery is required to implement a maximum tolerance of 25 pigmented eels per pound of glass eel catch. The silver eel fishery is prohibited in all states from September 1st to December 31st from any gear type other than baited traps/pots or spears. The addendum also set minimum monitoring standards for states and required dealer and harvester reporting in the commercial fishery.

In October 2014, the Board approved Addendum IV. The addendum was also initiated in response to 2012 American Eel Benchmark Stock Assessment and the need to reduce mortality on all life stages. The Addendum established a coast-wide cap of 907,671 pounds of yellow eel, reduced Maine's glass eel quota to 9,688 pounds (2014 landings), and allowed for the continuation of New York's silver eel weir fishery in the Delaware River. For yellow eel fisheries, the coast-wide cap was implemented starting in the 2015 fishing year and established two management triggers: (1) if the cap is exceeded by more than 10% in a given year, or (2) the coast-wide quota is exceeded for two consecutive years regardless of the percent overage. If either one of the triggers are met then states would implement state-specific allocation based on average landings from 1998-2010 with allocation percentages derived from 2011-2013.

1.1.1 Management Unit Definition

The American eel is a catadromous species in North America that historically occurred in all major rivers from Canada through 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.

1.1.1.1 Commercial Fishery Management

1.1.1.1.1 Glass Eel / Elver Fishery

Glass eel and elver harvest along the Atlantic coast is prohibited in all states except Maine and South Carolina. In recent years, Maine was the only state reporting substantial glass eel or 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 amount of gear, type, and configuration was limited to control fishing effort. Additional measures included restrictions on allowable fishing areas, number of license holders, and a prohibition on fishing within 46 m of a dam (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 in-state 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 logbooks. 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 a fishery season was allowed for dip nets only for that one year, followed by full closure 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 prevent 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. Given the high value, poaching of glass eels and elvers is known to be a serious problem in several states, but enforcement of the regulations is limited due to the nature of the fishery (very mobile, nighttime operation, high value for product, low administrative priority). Addendum IV (ASMFC 2014) to the FMP allows approved Aquaculture Plans from states and jurisdictions to harvest up to 200 pounds of glass eel annually from within their state waters for use in domestic aquaculture activities. The American Eel Farm (AEF) in North Carolina is the only facility to have applied and been approved for domestic aquaculture, which they have done annually since 2016. Fishing did not take place in 2016 due to permitting issues in North Carolina. In 2017, a total of 0.25 pounds of glass eels were harvested of the 200 pound quota. North Carolina Division of Marine Fisheries submitted an amended plan on behalf of AEF for 2018-2020 which was approved by the Board in August 2017.

1.1.1.1.2 Yellow / Silver Eel

The yellow 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, and 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 exposure) exists for eels fished in the tidal Hudson River (from the Battery to Troy and all tributaries upstream to the first barrier), 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. The fishery in the New York portion of the Delaware River consists primarily of silver eels collected in a weir fishery. 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, Virginia, and Potomac River Fisheries Commission 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. The Potomac River Fisheries Commission has had harvester reporting since 1964, and has collected eel pot effort since 1988.

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. Landings for “other areas” reported by the state come from southern waterbodies under the jurisdiction of NCDMF. 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 et al. 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.

Current commercial fisheries regulations can be found in Table 1.

1.1.1.2 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 use as bait. Current recreational management regulations can be found in Table 2.

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 was deemed unknown by the ASMFC.

At the February 22, 2006 meeting of the Board, the American Eel Stock Assessment Subcommittee (SAS) and Technical Committee (TC) 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).

The 2012 benchmark stock assessment represented the most recent work performed by the ASMFC to ascertain stock status since 2006. Analyses and results indicated that the American eel stock had declined and that there were significant downward trends in multiple surveys across the coast. It was determined that the stock was depleted but no overfishing determination could be made based on the analyses performed. This report is an update to the 2012 benchmark stock assessment report.

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 (personal comm., Dr. John Casselman, DFO), the ASMFC requested that the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) conduct 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 coastwide 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 Environmental Science Accuracy and Reliability filed a petition to the USFWS to consider listing the American eel on the endangered species list. The proposal was based on new information that had 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).

In 2015, USFWS announced that the American eel population is stable and protection under ESA was not warranted although the agency did recommend continuing efforts to maintain healthy habitats, monitor harvest levels, and improve river passage (USFWS 2015). Conversely, the International Union for the Conservation of Nature (IUCN) listed American eel as "Endangered" on the Red List in 2014 (Jacoby et al. 2014). While this has no legal implications, it is an important metric and the Commission remains committed to closely monitoring this species and making management adjustments as necessary.

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 and die.

American eels are confronted with many environmental and human-induced stressors which affect all life stages and may reduce survival. Since all anthropogenic 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.

The following sections have been condensed and also updated with new research since the 2012 benchmark assessment report. Refer to ASMFC 2012 for more a more detailed discussion of life history.

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 broadly 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 (Avise 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 (glass or elver stage) 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. Since the 2012 assessment, a study on chemical cues was published indicating that diluted odors emitted by glass eels were detected by other glass eels in a laboratory setting and suggested coordinated inland migration (Schmucker et al. 2016). This was expanded by Galbraith et al. (2017) to suggest that cues may be life-stage specific so that one year class of glass eels moving inland may be responding to cues from the previous year class as guidance.

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, where they spawn and die.

2.4 Life History Characteristics

2.4.1 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 (1997). Since the 2012 benchmark stock assessment, the ASMFC organized an American eel otolith sample exchange. This project determined that laboratories and state agencies that age American eel along the Atlantic coast were using different processing and reading methods that resulted in a high degree of imprecision and bias across laboratories and readers (ASMFC 2017). Because of these results, the ASMFC will hold an ageing workshop for American eel in January 2018 to standardize sample preparation and reading protocols for agers.

2.4.2 Growth

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). Male maximum size is the same throughout their distribution (Jessop 2010) However, female eels reach a larger maximum size in the northern portion of their range compared to the south (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.

2.4.3 Reproduction

The sex of American eels can be determined by gross morphological examination (Vladykov 1967; Krueger and Oliveira 1997). Differentiation between sexes occurs in the yellow eel stage of American eels and maturity-at-length varies by sex and latitude (Dolan and Power 1977; Oliveira and McCleave 2000; Goodwin and Angermeier 2003; Morrison and Secor 2003; Tremblay 2009). Sex ratios by location are also variable with males found more commonly in downriver sites and females more common in upriver sites (Facey and Helfman 1985; Helfman et al. 1983; Krueger and Oliveira 1999; Oliveira and McCleave 2000; Goodwin and Angermeier 2003; Davey and Jellyman 2005) and Oliveira and McCleave (2000) found that yellow eels >400 mm and silver eels >425 mm were exclusively female. 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). 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 1998). 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.

2.4.4 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.

2.4.5 Natural Mortality

Very little is known about the natural mortality of American eels. Since eels are highly fecund (Wenner and Musick 1974; Barbin et al. 1998; 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 *Anguillicoloides crassus*. ASMFC 2012 describes each of these threats to the American eel in detail, with recent studies adding information regarding *A. crassus*. Waldt et al. (2013) found that nearly 50% of American eels in a Hudson River tributary in New York were infected during the fall of 2009. Zimmerman and Welsh (2012) confirmed the presence of *A. crassus* in the upper Potomac River watershed and found that length-at-age was lower in previously infected American eels than those uninfected, potentially reducing reproductive capabilities. Hein et al. (2014) reevaluated *A. crassus* infection in South Carolina where the American eel population has been declining since 2001 and the infection was first reported nearly 20 years ago. That study found that parasite prevalence was higher in South Carolina than in New York and Chesapeake Bay and possibly has been increasing over time. Additionally, the authors suggest that milder winters due to climate change could increase infection.

2.4.6 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 level of predation mortality or contribute to density dependent effects on growth or reproductive success. The location and number 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; Hitt et al. 2012) and could impact the total number, size distribution, and number of eggs produced from a river system (Sweka et al. 2014).

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). Habitat descriptions by life history stage can be found in Section 3 of ASMFC 2012.

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. 1984). 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).

American eel habitat associations and requirements vary by life stage. After hatching in winter and spring in the Sargasso Sea, larval American eels passively migrate to the continental shelf 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).

4 FISHERY DESCRIPTION

The American eel fishery has a long history in the U.S., and a description of the current and documented historical fisheries can be found in ASMFC 2012. A summary follows and includes any new or updated information.

4.1 Commercial Fisheries

4.1.1 Glass Eel Fishery

Glass eel fisheries along the Atlantic coast are prohibited in all states except Maine and South Carolina. Over the last seven years, there has been an increase in the demand for glass eel due to concerns over population levels of European and Japanese eels, as well as tighter restrictions on the export of European eel. Harvest, by dip net or fyke net, has increased as the average market price has risen to over $1,000 per pound with peaks exceeding $2,000 per pound. The highest value reported in Maine in the last five years was $40.38 million in 2012 for 21,611 pounds ($1,868 per pound). Since the implementation of Addendum IV (ASMFC 2014), Maine's glass eel quota has been set at 9,688 pounds (a 17.5% reduction from the 2014 quota). In 2017, preliminary landings indicate 9,282 pounds of glass eels were sold for a value of $12.08 million ($1,301 per pound).

4.1.2 Yellow Eel Fishery

Historically and currently, the majority of commercial landings come from the yellow eel fishery. Accounts of eel harvest date back to colonial times, with some commercial fishery harvest records available beginning in the late 1880s, but consistent record keeping began in 1950. After an initial decline in the 1950s, commercial yellow eel landings increased to a peak of 3.67 million pounds in 1979, declined again in the 2000s, and have exceeded one million pounds three times since 2004. Addendum IV (2014) implemented a coastwide cap of 907,671 pounds and two management triggers: (1) the coastwide cap is exceeded by more than 10% in a given year and (2) the coastwide cap is exceeded for two consecutive years, regardless of the percent over. If triggered, there is an automatic implementation of state-by-state quota as laid out in Addendum IV. In 2016, U.S. Atlantic coast preliminary yellow eel landings totaled 928,358 pounds which is above the cap although these landings are not final. Management triggers will be evaluated once landings are final. Eel pots are the typical gear used in the commercial yellow eel fishery; however, weirs, fyke nets, and other fishing methods are also employed. Although yellow eel were harvested for food historically, today's fishery sells yellow eel primarily as bait for recreational fisheries.

4.1.3 Silver Eel Fishery

Since the approval of Addendum IV (2014), silver eel fisheries are only permitted on a limited basis in the Delaware River (NY). The Delaware River eel weir fishery is restricted to nine annual permits which were initially limited to those who fished and reported landings from 2010 to 2013.

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 sport fisheries 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 U. S. caught American eels is the use of eels as bait in recreational striped bass, cobia, and catfish fisheries. 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 1981–2016 were provided by the NMFS (1981–1988; Fisheries Statistics Division, Silver Spring, MD, pers. comm.) and the United States International Trade Commission (USITC) DataWeb (1989–2016; pers. comm.). Export values were converted to 2016 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 were 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 229,000 to over 6.1 million pounds per year from 1981 through 2016 (Figure 1). Live eels comprised the majority (>50%) of exports in 1983–1988, 1993, 1999, and 2003–2005. From 2006-2011, exports of fresh and frozen eels accounted for an average of 75% of the total eel exports per year. 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. Since 2011, there have been no fresh or frozen American eel exports and 100% of the exports came from live American eel.

The value of American eel exports ranged from $2.0 to $39.6 million per year over the time series (Figure 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 through 2011 after which there were no fresh or frozen American eels exported.

The value per pound of exported American eels classified as live was above the value per pound of fresh and frozen eels (combined) throughout the time series (Figure 2). The value per pound of fresh and frozen eels ranged from $0.81 to $5.47 per pound per year from 1981 to 2016. The value per pound of fresh and frozen eels has exhibited a general decline over the time series except for one peak in 2003. The value per pound of live exports has varied over the available time series, ranging from $2.78 to $73.41 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 a review of these data by the SAS they were not considered indicative of trends in the stock as a whole and therefore were not updated for this stock assessment report. Note that fishery-dependent CPUE is almost exclusively composed of positive trips only; trip reports with zero eels caught are rare because most agencies do not require reports of zero catches. Furthermore, differences in baiting practices and bait preference vary geographically and that can confound the accuracy of commercial CPUE.

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 Information Program (MRIP) does encounter enough observations to generate catch estimates that indicate widespread and common presence as a bycatch species. Starting with 1981 estimates, the MRIP survey for all major eastern U.S. regions show higher catch estimates in the 1980s than in the 2000s on average.

There is also a subsistence component to the American eel fishery. 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. 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.

4.4 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 3). Landings reported since 1999 have been negligible and are thus confidential (R. Maxwell, LA DWF, pers. comm.). 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.

4.5 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 though 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.

4.5.1 Commercial Fisheries in Canada

For a description of American eel fisheries in Canada, refer to ASMFC 2012.

Fisheries and Oceans Canada, or the DFO, Statistical Services Unit maintains fisheries data for Canada. 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 2015 indicate a steady decline in commercial eel landings since the early 1990s, with the exception of 2012-2013 (Figure 4). Available freshwater fisheries records cover a shorter time span (1990–2015) during which time there has been a steady decline since 2000, with the exception of 2013-2014 (Figure 5). However, freshwater landings records may be less reliable than seafisheries records and it is unclear whether overlap in reporting between freshwater fisheries and seafisheries occurs.

4.5.2 Commercial Fisheries in Central and South America

Studies and reports that summarize U.S. American 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 2015 are available by country and major fishing area from the Food and Agriculture Organization (FAO) of the United Nations Fishery Global Statistics Program of the Fisheries Data, Information, and Statistics Unit (FIDI) via online tables. Mexico, the Dominican Republic, and Cuba reported a small amount of landings (primarily from in-river fisheries) from 1975-2010, although there are several missing values or years of no landings (Figure 6). There was an increase in landings, or reported landings, for 2011-2012 from Mexico and the Dominican Republic. From 2013-2015, landings remained high for the Dominican Republic but not Mexico. It is unknown whether these reports are comprehensive.

5 DATA SOURCES

For this assessment update report, the SAS updated the commercial and recreational landings through 2016. Fishery independent survey data that was used in the trend analyses in ASMFC 2012 was also updated, including state-mandated YOY surveys, non-mandated YOY surveys, yellow eel surveys, and biological data sets used in the growth analysis. Efforts were made to maintain consistency with the benchmark in terms of the data sources and treatment, but this was not always possible. Differences between the benchmark and this update are noted as appropriate.

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). During development of the benchmark assessment, not all states were able to provide this level of information, and this remains a challenge for this update.

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). 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 harvester reports (e.g., trip ticket systems or logbooks).

During 1950 to 2016, Atlantic coastwide U.S. American eel landings ranged between approximately 664,000 pounds in 1962 and 3.67 million pounds in 1979 (Figure 7). The highest landings in the time series occurred from the mid-1970s to the early 1980s. Beginning in 1984, landings begun to steadily decline. While landings since the 1990s have been lower than historical landings, they have been stable in recent decades.

Geographic regions used in the 2005 assessment (North, Mid-, and South Atlantic) exhibited differing trends and magnitudes in their eel fisheries (Figure 8). 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 coastwide landings peak in the 1970s and 1980s, 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 the 2012 assessment: Gulf of Maine, Southern New England, Hudson River, Delaware Bay/Mid-Atlantic Coast Bays, Chesapeake Bay, and the South Atlantic (Figure 9). The temporal extent to which landings could be assigned by region (i.e., divide landings within a state like Massachusetts or Maryland) could not be replicated for this update from the available commercial landings data set.

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 $40.6 million in 2012 (Figure 10). Total landings value declined again in 2014 from the large values from the previous two years but still remained high compared to the rest of the time series.

Since 1950, the majority (79%) of American eel landings were caught in pots and traps (Figure 11). Fixed nets (e.g., weirs, pound nets) accounted for about 7% of the landings. Approximately 5% of landings were caught using other gears (non-pot/trap or fixed net). About 9% of landings are reported with unknown gear type. Throughout the time series, pots and traps were the dominant gear reported for most eel landings (Figure 12).

<u>Potential Biases</u>

There are several potential biases present in the commercial data set. ACCSP validated the yellow American eel landings with each state partner, although several member states used their compliance reports rather than state data and therefore the numbers were not thoroughly validated in all cases. Additionally, Virginia and Maryland have different methods of dealing with PRFC data where Virginia includes those data and Maryland does not in their totals. As identified in ASMFC 2012, at least a portion of commercial American 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. Misreporting between conger eel, hagfish, slime eel, and American eel can occur, i.e. bycatch caught and reported from trawl gear. Despite these potential biases, the SAS felt that these landings represented the best data available and were indicative of the trend in total landings over time.

5.1.1.2 State-specific data collection

Refer to ASMFC 2012 for a description of state-specific data collection for dealer and harvester reporting. Data collection and reporting on commercial landings at the state level have changed since ASMFC 2012 due to recent addenda to the FMP and efforts by the states to improve on the accuracy of landings information. Specifically, Addendum IV (ASMFC 2014) - which stipulated the potential for state by state quota management for yellow eel if the coast wide cap is exceed by the management triggers- required all states with a yellow eel fishery to develop an implementation plan detailing the 1) current reporting structure for eels, 2) type of reporting used for monitoring quota, 3) a mechanism to account for quota overages, 4) a mechanism for quota transfers, 5) any additional management measures planned to control harvest. Table 3 indicates current reporting structure within states/jurisdictions.

5.1.2 Recreational Fisheries

5.1.2.1 Data Collection

The primary source of recreational fishery statistics for the Atlantic coast is the National Marine Fisheries Service's Marine Recreational Information Program (MRIP), formerly the Marine Recreational Fishery Statistics Survey (MRFSS) program. These programs collected 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 MRIP online data query. Catch estimates from MRIP have been available since 2004. Previous to 2004, only catch estimates from MRFSS are available. The method developed by MRIP to calibrate 1981-2003 MRFSS estimates was used in this assessment (SEDAR 2016).

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). 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 2016.

5.1.2.3 Estimates

Recreational harvest (Type A + B1) of American eels along the Atlantic coast ranged from 3,062 to 220,596 eels per year during 1981 through 2016. In terms of weight, recreational eel harvest ranged from 497 to 218,269 pounds per year during the same time period (Table 6). American eel recreational harvest demonstrated an overall decline over the available time series, with some large peaks in the mid-1980s, early 1990s, and 2010 (Figure 13). The number of American eels released alive by recreational anglers ranged from a low of 26,707 eels in 1997 to a high of 157,189 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 from 2002-2014. Both 2015-2016 indicate lower numbers of live releases.

The precision of the estimated harvest numbers, measured as proportional standard error (PSE), exceeded 50% in 29 of the 36 years for which estimates were available (Table 6). The precision of harvest weight estimates exceeded 50% in 18 of the 34 years with PSE calculations. 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 had higher precision than the harvest estimates, with PSE values exceeding 50% in 8 of the 36 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 (Table 4 and Table 5). These limited numbers are partly due to the design of the MRFSS/MRIP survey, which does not include the areas and gears assumed to be responsible for the majority of recreational fishing for American eels. As such, the recreational fishery statistics for American eels provided by MRFSS should be interpreted with caution.

The lengths reported for American eels sampled (Type A catch) ranged from 20 mm to 1,100 mm during 1981 to 2016 (Figure 14). 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. All fishery-independent surveys used in ASMFC 2012 were evaluated using a standard set of criteria (see Appendix 2 in ASMFC 2012) 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 (GLM) to account for changes in catchability of eel. Only the surveys that were used in the trend analyses in the benchmark assessment were updated in this report. Some state-mandated YOY surveys were excluded from trend analysis in ASMFC 2012 because they did not have at least 10 years of data but have been included in this update if the survey met that requirement. The same methods were used as ASMFC 2012, although differences in GLM standardization are described below.

5.2.1 Young-of-Year Abundance Surveys

5.2.1.1 Development of Indices

For a description of the coastwide mandatory state YOY and non-mandated survey methods, sampling intensity, biological sampling, and potential biases refer to ASMFC 2012 section 5.2.1.1. Annual indices of relative YOY abundance were calculated using the protocol outlined in Appendix 2 of ASMFC 2012. The YOY indices developed for ASMFC 2012 were from surveys that were sampled for at least 10 years as of 2010. For this update, three more surveys had reached the 10 year requirement: Connecticut's Ingham Hill site, Rhode Island's Hamilton Fish Ladder, and Virginia's Wareham's Pond. Conversely, three YOY indices were not updated through 2016 due to the sampling site being moved (PRFC's Clark's Millpond and South Carolina's Goose Creek) or no longer sampled (Georgia's Altamaha Canal). While these sites were not updated, they were still included in analyses and correlations. ASMFC 2012 categorized NC's Beaufort Bridgenet Ichthyoplankton Sampling Program (which ASMFC referred to as the Beaufort Inlet Ichthyoplankton Survey) as non-mandated, when it in fact serves as the state's mandated YOY survey so that has been corrected for this report. Additionally, data was only available through 2007 when it was included in analyses for this update (Figure 31). The data was later updated through 2013 but the analyses were already completed.

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, ρ, 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 $\alpha = 0.10$.

5.2.1.2 Estimates

Annual recruitment indices were computed for nineteen sites sampled as part of the ASMFC-mandate, as well as three indices that are not required by ASMFC (Table 7). 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 some sites, a stable generalized linear model could not be developed, so arithmetic mean catch per unit effort was used as an index of abundance.

Trends in the YOY indices were variable within and among survey sites (Figure 15–Figure 31). The degree of correlation between survey sites varied and all were either not significant or were significant and positively correlated (Table 8). While there is still not a lot of agreement among YOY sites, there is an improvement since ASMFC 2012. In this update, of the 22 significant relationships, all were positive. In the benchmark stock assessment, there were 13 significant relationships, ten positive and three negative. In addition, at the regional level there were 5 significant relationships between regions, all of which were positive. It should be noted that ASMFC 2012 incorrectly categorized the Beaufort Bridgenet Ichthyoplankton Sampling Program (BBISP) as non-mandated so it was not included in the correlations at that time but is included in the correlations for this report.

In the Gulf of Maine region, two YOY indices were significantly positively correlated - West Harbor Pond (Maine; Figure 15) and Lamprey River (New Hampshire; Figure 16) (Table 8). Both of these indices show low abundances in the beginning of the time series with peaks in the early 2010s. In the Southern New England region, there were two pairs of sites that were significantly positively correlated —Gilbert Stuart Dam (Rhode Island; Figure 18) and Hamilton Fish Ladder (Rhode Island; Figure 19) and Gilbert Stuart Dam (Rhode Island) and Carman's River (New York; Figure 21) (Table 8). All three of these indices show low abundances in the early and mid-2000s with small increases in the early and mid-2010s. In the Delaware Bay and Mid-Atlantic Coastal Bays and Chesapeake Bay regions, there were no significant relationships between YOY surveys (Table 8). One significant correlation was detected among the YOY indices in the South Atlantic region. The YOY indices for Goose Creek (South Carolina; Figure 32) and Guana River Dam (Florida; Figure 34) were significantly and positively correlated (Table 8). Both of these indices show a peak in recruitment in 2001 and 2005 and then a decline for the remaining years in the time series.

5.2.2 Yearling, Elver, and Yellow Eel Abundance Surveys

5.2.2.1 Development of Indices

Several surveys were developed into abundance indices for yearling, elver, and yellow American eel life stages from Connecticut to South Carolina. For a full description of these survey methods, sampling intensity, biological sampling, and potential biases refer to ASMFC 2012. Abundance indices from these surveys were standardized using the same methods as the benchmark. During the GLM standardization, there were some differences in the covariates used in the model. Table 9 summarizes the GLM model used and significant covariates. Below are some additional notes on each survey.

CTDEP Electrofishing

Elver & yellow eel index: A population estimate was derived using maximum weighted likelihood by CTDEP. The site was not sampled in 2013 and then moved to a new site for 2015-2016. Due to the change in site, the SAS decided to abbreviate this time series to 2014 (Figure 37).

NY Western Long Island Survey

Yellow eel index: A full model that predicted catch as a function of year, month, and latitude as factors was compared with nested submodels using AIC. The full model with a negative binomial error structure was selected because it produced the lowest AIC. The model was unchanged from the previous benchmark assessment, although latitude was used instead of system, and updated through 2016. The time series peaked to its highest value in 1985 and has declined since then, remaining low until the terminal year (Figure 38).

NYDEC Alosine Beach Seine Survey

Elver & yellow eel index: A full model that predicted catch as a function of year, month, river mile, water temperature, latitude, and longitude was compared with nested submodels using AIC. The model that included year, month, and river mile with a negative binomial error structure was selected because it produced the lowest AIC. The model was changed from the previous benchmark assessment, which had year, month, river mile, and water temperature as covariates. The index is variable with higher peaks in the early part of the time series and low but stable values in the later part of the time series (Figure 39).

NYDEC Striped Bass Beach Seine Survey

Elver & yellow eel index: A full model that predicted catch as a function of year, month, river mile, water temperature, latitude, and longitude was compared with nested submodels using AIC. The model that included year, month, and longitude with a negative binomial error structure was selected because it produced the lowest AIC. The model was changed from the previous benchmark assessment, which had year, month, river mile, and water temperature as covariates. The index is variable with higher peaks in the early part of the time series and declining but stable values in the later part time series. There was a notable peak in abundance in 2015 which was followed by the lowest point in the time series in 2016 (Figure 40).

HRE Monitoring Program

Yearling & older eel index: A full model that predicted catch as a function of year, month, station, river mile, tide, temperature, depth, tow volume, gear, and strata was compared with nested submodels using AIC. The model that included year, month, strata, river mile, and tow volume with a negative binomial error structure was selected because it produced the lowest AIC and good model diagnostics. The model formula for the previous benchmark assessment was the same but also included gear which was no longer significant for this update.

NYDEC provided the SAS with the HRE Monitoring Program data set through 2013. Because this data set is maintained by a utility company, the SAS submitted an additional request to HRE to obtain 2014-2016 due to data confidentiality concerns. The data set was updated through 2015, although it was received too late to be incorporated into the trend analysis and regional indices. Biologists for the HRE Monitoring Program expressed concern that the length cutoff between YOY and yearling+ was not accurate in the data set provided by NYDEC. Additionally, they were concerned that some of the covariates may not have been converted correctly. The updated data set represents the most complete and accurate data set and is included in this report despite not being used in the analyses. For the analyses and regional indices, the previous data set provided by NYDEC through 2013 was used. The GLM model for both the 1974-2013 and the 1974-2015 data sets was the same, as was the general pattern of the time series, although the scale was different (Figure 41). Abundance was highest during the early years of the time series, after which it dropped abruptly and then rebounded within the first decade. A more gradual declined followed from the mid-1980s through the early 2000s. Since then, abundance has gradually increased, but is still below levels seem in the mid-1980s.

NJDFW Striped Bass Seine Survey

Yellow eel index: A full model that predicted catch as a function of year, month, water temperature, and salinity was compared with nested submodels using AIC. The model that included year, water temperature, and salinity with a negative binomial error structure was selected. The model was unchanged from the previous benchmark assessment although salinity was not significant this time but it was retained for consistency. The index exhibited some high abundance in the early time series but otherwise a stable abundance throughout (Figure 42).

Delaware 16' Trawl Survey

Elver & yellow eel index: A full model that predicted catch as a function of year, month, surface temperature, and surface salinity was compared with nested submodels using AIC. The full model that included year, month, surface temperature, and surface salinity with a negative binomial error structure was selected. The model was unchanged from the previous benchmark assessment although surface temperature was not significant this time but it was retained for consistency. Abundance declined in the 1980s, increased in the 1990s, declined until about 2005, after which it has been relatively stable (Figure 43).

PSEG Trawl

Elver & yellow eel index: A full model that predicted catch as a function of year, month, bottom salinity, and strata was compared with nested submodels using AIC. Consistent sampling was conducted every year since 1998 so the time series was abbreviated from the previous assessment. Also, the stations have changed over time. Attempts were made to replicate the covariates from ASMFC 2012, but that model used only the months April-June when there are still consistent catches July-October. Additionally, the previous model used strata 7-9, but this update used 6-8. The model that included year, month, and bottom salinity with a negative binomial error structure was selected because it produced the lowest AIC. The model was unchanged from the previous benchmark assessment, although the months and strata used were different. The abundance index was variable in the late 1990s and early 2000s and then steady through mid-2010s. There were peaks in 2013 and 2016 (Figure 44).

Pennsylvania Area 6 Electrofishing

Elver index: A full model that predicted catch as a function of year, month, site, and tow duration was compared with nested submodels using AIC. The model that included year and site with a negative binomial error structure was selected because it produced the lowest AIC. The model was unchanged from the previous benchmark assessment. There were peaks of abundance in 2001 and 2015 and low abundance in 2002 and 2016, otherwise the index indicates steady abundance (Figure 45).

MDDNR Striped Bass Seine Survey

Yellow eel index: A full model that predicted catch as a function of year, month, and salinity was compared with nested submodels using AIC. The full model that included year, month, and salinity with a negative binomial error structure was selected because it produced the lowest AIC. The model was unchanged from the previous benchmark assessment. Abundance was high in 1965, 1975, 2003, and 2005 and low in the early 1970s, early and mid-1990s, mid-2000s, and early 2010s (Figure 46).

VIMS Juvenile Striped Bass Seine Survey

Yellow eel index: A full model that predicted catch as a function of year, month, station type, system, and salinity was compared with nested submodels using AIC. This data set was analyzed for two time periods: long (1967-2016; Figure 47) and short (1989-2016; Figure 48). The model with a negative binomial error structure was selected because it produced the lowest AIC for both long and short indices. The long model was unchanged from the previous benchmark assessment with only system as a covariate. The short model used station type whereas the benchmark assessment also had salinity as a significant covariate. Both indices are variable. The longer time series shows high abundance in 1968 and 1971, followed by low abundance and some missing values. The index is low through the late 1980s and early 1990s and then variable with some peaks in abundance in the last decade (Figure 47). The shorter time series shows a more stable abundance through time with some peaks in 1997, 2009, and 2012 and low values in 1996, 2003, 2005, and 2013 (Figure 48).

North Anna Electrofishing Survey

Elver and yellow eel index: Updated data through 2016 from this survey was not provided for this assessment and therefore the index from the benchmark was used in analyses and regional indices. The abundance index indicates low values through the 1990s to 2002. Following a missing value point in 2003, the index shows increased abundance, ending with the highest value in the terminal year of 2009 (Figure 49).

NCDMF Estuarine Trawl Survey

Elver & yellow eel index: A full model that predicted catch as a function of year, month, water temperature, salinity, dissolved oxygen, depth, latitude, longitude, and bottom type was compared with nested submodels using AIC. The model that included year, latitude, longitude, and bottom type with a negative binomial error structure was selected. The model was unchanged from the previous benchmark assessment. The abundance index shows a lot of variability with the highest values in 1990-1991 and 2011-2012 and the lowest values in 2000, 2009, 2013, and 2016 (Figure 50).

SC Electrofishing Survey

Elver & yellow eel index: A full model that predicted catch as a function of year, month, strata, water temperature, salinity, and tide was compared with nested submodels using AIC. The full model with a negative binomial error structure was selected. The model was unchanged from the previous benchmark assessment. The abundance index indicates steady abundance throughout the time series with one larger peak in 2003 (Figure 51).

Spearman's rank correlation coefficient, ρ, and the associated probability were calculated for all pairs of yellow American eel indices to assess the degree of association among the indices. Indices were considered significantly correlated at $\alpha = 0.10$. The degree of correlation between survey sites varied and all were either not significant or were significant and positively correlated (Table 10). Surveys in the Hudson River region were positively correlated with many Southern New England and other Hudson River surveys. Only the New Jersey Striped Bass Seine Survey and the Delaware trawl were positively correlated with each other in the Delaware Bay/Mid-Atlantic region. In the Chesapeake Bay region, only the MDDNR Striped Bass Seine Survey and North Anna Electrofishing survey were positively correlated while the other surveys did not have a significant relationship. The two surveys available in the South Atlantic region were not significantly correlated with each other.

6 ASSESSMENT

6.1 Coastwide Abundance Indices

Indices of coastwide 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 coastwide indices and the methods for calculating them can be found in ASMFC 2012.

6.1.1 Development of Estimates

Coastwide Recruitment

All ASMFC-mandated YOY abundance surveys and the two non-mandated YOY abundance surveys were used to assess coastwide recruitment. Two coastwide 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, coastwide index using the generalized linear modeling approach (ASMFC 2012 Appendix 2). The short-term recruitment index was based on the standardized indices developed from the ASMFC-mandated annual YOY surveys. The time period used for generating the short-term coastwide recruitment index was 2000 to 2016. The long-term recruitment index was based on the Beaufort Bridgenet Ichthyoplankton Sampling Program (referred to incorrectly as the Beaufort Inlet Ichthyoplankton Survey and miscategorized as non-mandated in ASFMC 2012) and the non-mandated HRE Monitoring Program and Little Egg 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 coastwide recruitment index was 1988 to 2013. 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.

Coastwide Yellow-Phase Abundance

The surveys used to develop the coastwide yellow-phase abundance indices were: NY Western Long Island Survey, HRE Monitoring Program, NYDEC Alosine and Striped Bass Beach Seine Surveys, New Jersey Striped Bass Seine Survey, Delaware Juvenile Finfish Trawl Survey, PSEG Trawl Survey, Pennsylvania's Area 6 Electrofishing Survey, Maryland Striped Bass Seine Survey, North Anna Electrofishing Survey, VIMS Juvenile Striped Bass Seine Survey, NCDMF Estuarine Trawl Survey, and South Carolina's Electrofishing Survey. 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.

Three indices of coastwide, 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 coastwide indices using the generalized linear modeling approach (ASMFC 2012 Appendix 2). The 40-plus-year coastwide index of yellow-phase abundance was based on the HRE Monitoring Program, MDDNR Striped Bass Seine Survey, and VIMS Juvenile Striped Bass Seine Survey (long time series) standardized indices. In ASMFC 2012, PSEG trawl was included in this index but it was omitted for this update because the time series length changed due to data concerns. Conversely, the HRE Monitoring Program survey was added since it now has enough years of data to be included in the 40-year index. The 1974–2016 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 coastwide, yellow-phase abundance index included the same survey indices as the 40-plus index as well as the NY Western Long Island Survey, NYDEC Alosine Beach Seine Survey, NYDEC Striped Bass Beach Seine, New Jersey Striped Bass Seine Survey, and Delaware Trawl 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 PSEG Trawl Survey, Pennsylvania's Area 6 Electrofishing Survey, North Anna Electrofishing Survey, NCDMF Estuarine Trawl Survey, and SC Electrofishing Survey standardized indices.

6.1.2 Estimates

Coastwide 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 region as covariates.

The short-term, coastwide recruitment index was variable (Figure 52). The index begins with low abundance and then increases to a high in 2002. Following that peak, the index declines through 2004 and then has a slight uptick and remained stable through the mid and late-2000s. Abundance increased from 2009 to the highest value in the series in 2012 and has declined slightly since then.

The long-term, coastwide index was variable, with low values in 1991 and 2010 and high values in 1988, the mid-1990s, and 2008 (Figure 53).

Coastwide Yellow-Phase Abundance

The coastwide, 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.

The 40-plus yellow-phase index for the coast began with higher abundances in the mid-1970s and a decline through the 1980s (Figure 54). Abundance has been stable since the 1990s. The time series demonstrates inter-annual variability and while values have been lower since the mid-1970s, the trend appears stable in recent decades. The 30-year coastwide index of yellow-phase American eel abundance also exhibits a decline from the beginning of the time series to the early 1990s (Figure 55). 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 no discernable trend (Figure 56). Of the three coastwide, yellow-phase abundance indices, the 20-year and 40-year indices were negatively correlated with each other but not significantly (ρ=-0.152; P=0.742). The 30-year index was positively correlated with both of the 20-year (ρ=0.383; P<0.10) and 40-year (ρ=0.493; P<0.10) indices.

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 11). 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 9).

6.2.1 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 (Table 7 and Table 9) using the generalized linear modeling approach (ASMFC 2012 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 11.

Spearman's rank correlation coefficient, ρ, 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 $\alpha = 0.10$.

6.2.2 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 state as covariates. The Chesapeake Bay's yellow eel index also included gear. The Hudson River region YOY index was based on a single recruitment index because only one such index was available for the region (Table 11). 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. There were two yellow eel abundance indices in the Southern New England region, CTDEP Electrofishing Survey and the NY Western Long Island Survey, but a regional yellow eel abundance survey was not developed due to concerns using a population estimate (CTDEP Electrofishing) and a standardized abundance index (NY Western Long Island Survey) together. Additionally, the CTDEP Electrofishing Survey had an abbreviated time series due to a year that wasn't sampled and then a change in the site location.

The regional YOY and yellow-stage indices of American eel abundance are depicted in Figure 57 and Figure 58. Both the YOY and yellow-stage regional indices are variable among years. All the YOY indices, except in the Delaware Bay and Hudson River regions, are characterized by relatively large standard errors. 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 Hudson River and Delaware Bay/Mid-Atlantic Coastal Bays indices were found to be significantly and positively correlated with Gulf of Maine indices (Table 12). Significant, positive correlations were also detected between the Delaware Bay/Mid-Atlantic Coastal Bay regional index and the Southern New England and

Hudson River YOY regional indices. The Hudson River was also positively correlated with the South Atlantic YOY regional index. There were no statistically significant correlations detected among the region-specific yellow-stage indices (Table 13). Some significant correlations were detected between the region-specific yellow-stage and lagged YOY indices (Table 14). The Hudson River yellow-stage index was significantly correlated with the Hudson River YOY index that was lagged by one, two, three, and four years. The Chesapeake Bay yellow-stage index was significantly and positively correlated with the Chesapeake Bay YOY index that was lagged by two years. The South Atlantic yellow-stage index was significantly and positively correlated with the South Atlantic YOY index that was lagged one, two, and four years.

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 the assessment. These data, updated through 2016, 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 provided a procedure for testing whether two or more nonlinear curves are coincident (i.e., not statistically different). Values were considered statistically significant at $\alpha < 0.05$.

Linear regression was used 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 $\alpha < 0.05$. The age-length relationship for American eel was also described through the von Bertalanffy model, which is given by:

$$Lt = L\infty \left[1 - e^{-K\,(t-t0)}\right]$$

where Lt 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 $t0$ is the hypothetical age at which length is zero. Model fits were first evaluated based on convergence status; models that did not successfully converge were removed from consideration for the associated dataset.

6.3.1.2 Results

The length-weight model successfully converged and parameters estimated for each of the six regions, by sex, and for all data pooled (Table 15; Figure 59). The results of the ARSS indicated that there were statistically significant differences in the length-weight relationship between at least two regions ($F_{10,\,68,276} = 293$, $P < 0.001$). However, parameter estimates were very similar in five of the six regions particularly in the Delaware Bay/ Mid Atlantic Coastal Bays, Chesapeake Bay, and South Atlantic. Parameter estimates were most different in the Southern New England region, which may be due to an extremely small sample size (N=166) and range of length-weights available in the dataset. The fit of the length-weight function to all pooled data was dominated by data from the Chesapeake Bay region, which was the source of more than 55% of the length and weight biological samples. The results of the ARSS indicated no sex specific significance between estimated length-weight parameters ($F_{2, 6,687} = 0.91$, $P = 0.40$; Figure 60).

The parameters estimated from the linear regression of length on age for the various dataset configurations are presented in Table 16. There are statistically significant differences in the age-length relation among regions based on the results of the test for coincident regressions ($F_{10, 17,402} = 754$, $P < 0.0001$). The final parameter estimates suggested distinct differences in growth patterns between the northernmost regions (Hudson River, Southern New England, Gulf of Maine) and southernmost regions (Del Bay/Mid-Atlantic Coastal Bays, Chesapeake Bay, South Atlantic) (Table 16; Figure 61). The fastest growth in length with age occurred in the Delaware Bay/Mid-Atlantic Coastal Bays region. The test for coincident regressions also detected significant differences in the age-length regressions between sexes ($F_{2, 5,932} = 1,520$, $P < 0.0001$; Figure 62). The results suggested the rate of growth in length with age is faster in females than males (Table 16; Figure 62).

Parameters were estimated from the von Bertalanffy model to further examine the age-length relationship of American eel by region and by sex (Table 17). The model failed to converge for the Southern New England region and for males. The clear differences in growth between the northernmost and southernmost regions determined from the linear regression analysis were not apparent in the parameter estimates derived from the von Bertalanffy model. However, the growth coefficient (K) was the highest in the South Atlantic region and the lowest in the Gulf of Maine.

Significant variation in length at age and a broad overlap in lengths across multiple age groups were observed in the data even within a regional analysis. Pooled data for all regions amplified these variations in length at age. These analyses confirm 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. Ageing error and uncertainty around ageing estimates may also play an additional role in the weak relationship of length and age.

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 $A_i = A_1[1+r(i\text{-}1)]$ 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 α and β are the probabilities of type 1 and type 2 errors respectively, the power of a linear trend (1 – β) assuming CV ~ 1/√*A* can be determined by satisfying the equation:

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

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

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

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 ±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 5.50. 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 0.06 to 1.00 (Table 18). 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~1⁄√A. There was very little difference in power between linear and exponential trends. The values of power presented in Table 18 can be interpreted as the probability of detecting a given linear or exponential trend of ±50% over a ten year period if it actually occurs. Many surveys decreased the median CV values with the additional years of data since ASMFC 2012 and therefore increased the power associated with that survey. These values do not reflect a retrospective power analysis and a survey with a low power value may still be capable of detecting a statistically significant trend if given enough years of data or the change over time is very large.

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 coastwide indices of relative abundance computed in this assessment. This included four new local YOY indices; Hamilton Fish Ladder, Gilbert Stuart Dam, Ingham Hill, Carman's River, HRE Monitoring Program, and

Little Egg Inlet Ichthyoplanton. There were no new yellow eel indices. Two regional indices were not analyzed because only one index in the region had been updated to 2016.

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 when the analysis was done in the last benchmark (Table 19). Of the two YOY surveys that are not ASMFC-mandated, the Little Egg Inlet had no trend and the HRE Monitoring Program had a declining trend in ASMFC 2012. In this update, six of the 22 indices showed significant negative trends. This included many of the new indices, of which 3 showed significant declining trends.

The Mann-Kendall test found statistically significant trends in six of the 15 other individual yellow eel indices evaluated; all but one of which was negative (Table 20). Since the last benchmark two significant downward trends became non-significant, while two significant upward trends also became non-significant.

Regional Indices

Of the nine regional indices, significant trends were seen in four; one positive and 3 negative (Table 21). One of the negative trends, the YOY for the South Atlantic, was not significant during the last benchmark, but is now a significantly declining trend with this update.

Coastwide Indices

The Mann-Kendall test detected two significant trends among the coastwide indices (Table 21). Both the 30-year and 40-year yellow-phase abundance indices exhibited a significant downward trend. The 40 year was not significantly declining in the last benchmark, but is with this update. The starting year of this index was 1967 in ASMFC and it is now 1974 for this update, so the loss of the beginning years may influence this declining trend.

6.4.3 Manly Analysis

A meta-analysis was conducted to determine if there was consensus among fishery-independent survey indices for a coastwide 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 ith 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 by 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 the 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 ith index. In this analysis, the number of years of survey data was used as the weight for the ith 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 though time (yellow eels: $S_1 = 115.88$, $P < 0.01$; YOY eels: $S_1 = 95.22$, $P < 0.01$; Table 22). Also, there was consensus for a decline for both life stages through time (yellow eels: $S_2 = -5.05$, $P < 0.01$; YOY eels: $S_2 = -16.03$, $P < 0.01$).

6.4.4 ARIMA

Fishery-independent surveys for American eel can be quite variable, making inferences about population trends uncertain. Time series of abundance indices can be influenced by 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 α-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 wolffish (*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*[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. The one exception to the 20 year criteria was the PSEG trawl survey which had 19 years of data included. In the previous 2012 stock assessment, the PSEG trawl survey had 38 years of data at that time, but it was truncated for this assessment update to account for methodology and sampling changes over the years.

6.4.4.2 Results

Fourteen surveys were used in ARIMA modeling (Table 23). Two surveys that were included in this assessment update that were not included in the 2012 stock assessment were the Little Egg Inlet and the Beaufort Bridgenet Ichthyoplankton surveys. These surveys were added to the ARIMA modeling because they now each had >20 years of data available.

Trends in fitted ARIMA values varied both within and among regions. In the Chesapeake Bay region, the long VIMS Juvenile Striped Bass Seine Survey for yellow eels showed a consistent increase since 2008, but the short VIMS Juvenile Striped Bass Seine Survey and the Maryland Striped Bass Seine Survey showed stable trends in recent years (Figure 63). Trends in the Delaware Bay/Mid-Atlantic region did not show any directional trends in recent years (Figure 64). Surveys in the Hudson River region generally showed continued decreasing trends except for the Hudson River Estuary Monitoring Program which has shown a consistent increase since the early 2000's (Figure 65). Both surveys in the South Atlantic region showed somewhat decreasing trends, but there was also a relatively high degree of annual variation in these surveys (Figure 66).

Overall, the probabilities of being less than the 25th percentile reference points in the terminal year (2016 in most cases) for each of the surveys were similar to those probabilities found for year 2010 (the last year of data used in the 2012 stock assessment; Table 23). This indicates relatively stable indices. One large difference between 2010 and 2016 was the NYDEC Alosine

Beach Seine survey in which the probability of being less than the 25th percentile reference point increased from 0.344 in 2010 to 0.720 in 2016. This is indicative of the continued decline of elver and yellow eels in this survey since the last stock assessment. In total, 3 of the 14 surveys included in the ARIMA modeling had greater than a 0.50 probability of being less than the 25th percentile reference point in the terminal year of the survey.

The 2012 Peer Review Panel noted that ARIMA is sensitive to the first data point in the time series and they suggested that trends be interpreted with caution, which is why this analysis is not used for developing reference points for American eel management but rather as one of the trend analyses used to draw general conclusions about the status of the stock.

6.5 Other Modeling Approaches

Several other modeling approaches were explored in ASMFC 2012 that were not updated for this report including a suite of models used by ICES (Study Leading to Informed Management of Eels or SLIME), Surplus Production Models (SPM; both age-structured and catch-free), Traffic Light Analysis (TLA), and Depletion-Based Stock Reduction Analysis (DB-SRA). The SLIME model was deemed inappropriate to the needs of the ASMFC for managing American eel. The SPMs did not find stable solutions and the TLA produced results that were difficult to interpret and therefore were not endorsed for management use by the Peer Review Panel in 2012. The Panel suggested that the TLA continue to be explored to incorporate more data, so while it could inform management decision-making in the future additional work on that model would require a peer review so it was not updated for this report. The Peer Review Panel endorsed the DB-SRA model for assessing American eel but had a number of concerns about the model (American Eel Stock Assessment Peer Review Report in ASMFC 2012). The Panel was impressed with the development of DB-SRA but ultimately were not comfortable using it to develop reference points or determine stock status without further refinements. Because further developing the DB-SRA would require a peer review for it to be used for management, the SAS did not update the model for this update report.

7 STOCK STATUS DETERMINATION

7.1 Status Determination Criteria and Current Stock Status

Reference points for determining the stock status of American eel in the U.S. in ASMFC 2012 were developed using the DB-SRA model which was not accepted for management use by the Peer Review Panel. The American Eel Technical Committee recommended that stock status was declared depleted based on trend analysis and the biomass trends estimated by the DB-SRA as recommended by the Peer Review Panel. The DB-SRA was not updated for this report because the Panel recommended it be further developed which was outside the guidelines of a stock assessment update. Therefore neither reference points nor stock status could be determined quantitatively by this stock assessment update. The trend analyses were updated and a discussion of overall trends follows in Section 8. Overall, the results in this update are very similar to the results in ASMFC 2012 and therefore the SAS and TC concluded the stock remains depleted.

8 DISCUSSION AND CONCLUSIONS

The data evaluated in this assessment provide evidence of neutral or declining abundance of American eel in the U.S in recent decades. All three trend analysis methods (Mann-Kendall, Manly, and ARIMA) detected significant declining trends in some indices over the time period examined. The Mann-Kendall test detected a significant declining trend in six of the 22 YOY indices, five of the 15 yellow eel indices, three of the nine regional trends, and the 30-year and 40-year yellow-phase abundance index. The remaining surveys tested had no trend, except for the North Anna Electrofishing and the regional Chesapeake Bay yellow eel indices which had a positive trend (although it should be noted that the North Anna Electrofishing survey was not updated from ASMFC 2012). These two surveys also had an increasing trend in ASMFC 2012, but the other two surveys that had an increasing trend in ASMFC 2012 (CTDEP Electrofishing Survey and PSEG Trawl Survey) now have no significant trend, noting that the time frame for the PSEG Trawl Survey changed since ASMFC 2012. 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. Conclusions from the Manly meta-analysis results were the same as those in ASMFC 2012.

In ASMFC 2012, the ARIMA results indicated decreasing trends in the Hudson River and South Atlantic regions. For this update, the results of the ARIMA are the same except for the HRE Monitoring Program in the Hudson River region which has been increasing in recent years. Survey indices from the Chesapeake Bay and Delaware Bay/Mid-Atlantic Coastal Bays regions showed no consistent increasing or decreasing trends in ASMFC 2012, but now the Chesapeake Bay region surveys have increasing or stable trends and the Delaware Bay exhibits no directional trends in recent years. The probabilities of being less than the 25th percentile reference points in the terminal year for each of the surveys were similar to those in ASMFC 2012 and currently 3 of the fourteen surveys in the analysis have a greater than 50% probability of being less than the 25th percentile reference point.

ASMFC 2012 concluded that significant downward trends in some surveys across the coast was cause for concern. The trend analysis results in this stock assessment update are consistent with the ASMFC 2012 results, with few exceptions. Despite downward trends in the indices, commercial yellow American eel landings have been stable in the recent decades along the Atlantic coast (U.S. and Canada) although landings still remain much lower than historical landings. Compared to ASMFC 2012, there are more significantly downward trends in indices as indicated by the Mann-Kendall test and similar results for the ARIMA. This trend analysis and stable low landings support the update conclusion that the American eel population in the assessment range is similar to five years ago and remains depleted.

9 RESEARCH RECOMMENDATIONS

The following research recommendations are based on input from the ASMFC American Eel TC and SAS during the 2012 benchmark stock assessment and many remain relevant for this update 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. Notes have been added for this report regarding work that has been addressed or initiated since ASMFC 2012.

<u>Data Collection</u>

Fisheries Catch and Effort

- **Improve accuracy of commercial catch and effort data (NOTE: Some progress was made on this recommendation through Addenda III and IV)**
  - Compare buyer reports to reported state landings* (NOTE: Initiated in NY by NYDEC)
  - Improve compliance with landings and effort reporting requirements as outlined in the ASMFC FMP for American eel (see ASMFC 2000a for specific requirements)* (NOTE: Initiated in NY by NYDEC and NJ by NJDFW)
  - 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 and initiated in NY by NYDEC)*
- Estimate catch and effort in personal-use and bait fisheries (NOTE: Initiated in NJ by NJDFW)
  - 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)*
- Estimate 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* (NOTE: Initiated in Chesapeake Bay sites (VMRC) and in NY, NJ, DE, MD by NYDEC, NJDFW, DEDFW, and MDDNR respectively)
  - 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** (see Cairns et al. 2017 for a description of the distribution of American eels from Canada to Florida)
  - Maintain and update the list of fisheries-independent surveys that have caught American eels and note the appropriate contact person for each survey* (NOTE: Work being done in NY by NYDEC and NJ by NJDFW)
  - 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* (NOTE: NYDEC began this in 2014; NJDFW collects numbers and lengths; VIMS collects numbers, lengths, weights, ages, and disease status; NCDMF collects numbers and lengths; work being done through FL FWC and a freshwater electrofishing survey)
  - 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** (NOTE: MA, MD, and NJ yellow eel survey began in 2015 by MADMF, MDDNR, and NJDFW)
  - A coastwide sampling program for yellow and silver American eels should be developed using standardized and statistically robust methodologies**
- Improve understanding of coastwide recruitment trends
  - Continue the ASMFC-mandated YOY surveys; these surveys could be particularly valuable as an early warning signal of recruitment failure* (NOTE: All states have a state-mandated YOY survey except for GA)
  - 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** (NOTE: see Pratt et al. 2014)
- 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** (NOTE: see Rypina et al 2014)
  - 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* (NOTE: Initiated in NC with a Roanoke study and in FL, work currently underway in the Chesapeake Bay through Z. Warshafsky's graduate work at VIMS, see also Zimmerman and Welsh 2012, Campbell et al. 2013, Denny et al. 2013, Waldt et al. 2013, Hein et al. 2014)
  - 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* (NOTE: work currently underway in the Chesapeake Bay through Z. Warshafsky's graduate work at VIMS, see also Zimmerman and Welsh 2012)
  - 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 (NOTE: Initiated in ME, also see Hitt et al. 2012, Gardner et al. 2013)**
  - Develop design standards for upstream passage devices for eels. The ASMFC 2011 Eel Passage Workshop (ASMFC 2013) made contributions to this goal.
  - 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** (NOTE: MADMF designed and deployed a gravity fed eel pass)

- Improve understanding of the impact of barriers on upstream and downstream movement (NOTE: Sweka et al. 2014 used an egg per recruit model to evaluate the costs/benefits to reproductive output with transport of eels upstream of hydroelectric dams and found that without downstream passage, transporting eels upstream resulted in a net loss of reproductive output.)
  - 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**
  - Use the information gained from the above evaluation and monitoring of barriers to American eel passage to develop metrics for prioritizing passage restoration projects.

- **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 freshwater habitat and water quality thresholds for American eel.

- 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* (NOTE: Data available for the Susquehanna and Shenandoah Rivers from Eyler et al. 2016 and USFWS 2012.)

- 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** (NOTE: Data available for the Delaware River through work done by the Delaware River Basin Fish and Wildlife Management Cooperative)

- Investigate best methods for reintroducing eels into a watershed; examine approaches for determining optimum density* (Note: Data available from the Roanoke Rapids and Susquehanna River through a project with Dominion Energy and USFWS-Maryland Fish and Wildlife Conservation Office, respectively)

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* (NOTE: Initiated in the Chesapeake Bay by MDDNR which has collected age information on selected tributaries since 1998)**
  - 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 (coastwide 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**

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11 TABLES

Table 1. Commercial fishery regulations for American eels as of 2016, by state. For specifics on licenses, gear restrictions, and area restrictions, please contact the individual state.

State	Min Size Limit	License/Permit	Other
ME	Glass no min size	Daily dealer reports/swipe card program; monthly harvester report of daily landings. Tribal permit system in place for some Native American groups.	Harvester license lottery system.
	Yellow 9”	Harvester/dealer license and monthly reporting. Tribal permit system in place for some Native American groups.	Seasonal closures. Gear restrictions. Weekly closures.
NH	9”	Commercial saltwater license and wholesaler license. No dealer reports. Monthly harvester reporting includes dealer information.	Gear restrictions in freshwater.
MA	9"	Commercial permit with annual catch report requirement. Registration for dealers with purchase record requirement. Dealer/harvester reporting.	Traps, pots, spears, and angling only. Mesh restrictions.
RI	9"	Commercial fishing license. Dealer/harvester reporting.	Gear restrictions.
CT	9"	Commercial license (not required for personal use). Dealer/harvester reporting.	Gear restrictions.
NY	9"	Harvester/dealer license and reporting.	Gear restrictions. Maximum limit of 14” in some rivers.
NJ	9"	License required. No dealer reports. Monthly harvester reporting includes dealer information.	Gear restrictions.
PA	NO COMMERCIAL FISHERY		
DE	6"	Harvester reporting, no dealer reporting. License required.	Commercial fishing in tidal waters only. Gear restrictions.
MD	9"	Dealer/harvester license and monthly reporting.	Prohibited in non-tidal waters. Gear restrictions. Commercial crabbers may fish 50 pots per day, must submit catch reports.
DC	NO COMMERCIAL FISHERY		
PRFC	9"	Harvester license and daily reporting due weekly. No dealer reporting.	Gear restrictions.
VA	9"	Harvester license required. Dealer/harvester monthly reporting.	Mesh size restrictions on eel pots. Seasonal closures.

Table 1. *Continued*.

State	Min Size Limit	License/Permit	Other
NC	9"	Standard Commercial Fishing License for all commercial fishing. Dealer/harvester monthly combined reports on trip ticket.	Mesh size restrictions on eel pots. Seasonal closures.
SC	Glass no min size	Fyke and dip net only permitted. Dealer/harvester monthly combined reports on trip ticket.	Max 10 individuals. Gear and area restrictions.
	Yellow 9”	Pots only permitted. Dealer/harvester monthly combined reports on trip ticket.	Gear restrictions.
GA	9"	Personal commercial fishing license and commercial fishing boat license. Dealer/harvester monthly combined reports on trip ticket.	Gear restrictions on traps and pots. Area restrictions.
FL	9”	Permits and licenses. Harvester reporting. No dealer reporting.	Gear restrictions.

Table 2. Recreational fishery regulations for American eels as of 2016, by state. For specifics on licenses, gear restrictions, and area restrictions, please contact the individual state.

State	Size Limit	Possession Limit	Other
ME	9"	25 eels/person/day	Gear restrictions. License requirement and seasonal closures (inland waters only). Bait limit of 50 eels/day for party/charter boat captain and crew.
NH	9"	25 eels/person/day	Coastal harvest permit needed if taking eels other than by angling. Gear restrictions in freshwater.
MA	9"	25 eels/person/day	Nets, Pots, traps, spears, and angling only; mesh restrictions.
RI	9"	25 eels/person/day	
CT	9"	25 eels/person/day	
NY	9”	25/eels/person/day	Maximum limit of 14” in some rivers. Bait limit of 50 eels/day for party/charter boat captain and crew.
NJ	9"	25 eels/person/day	Bait limit of 50 eels/day for party/charter boat captain and crew.
PA	9"	25 eels/person/day	Gear restrictions. Bait limit of 50 eels/day for party/charter boat captain and crew.
DE	6"	50 eels/person/day	Two pot limit/person.
MD	9"	25 eels/person/day	Gear restrictions.
DC	9"	10 eels/person/day	
PRFC	9"	25 eels/person/day	
VA	9"	25 eels/person/day	Recreational license. Two pot limit. Mandatory annual catch report. Gear restrictions. Bait limit of 50 eels/day for party/charter boat captain and crew.
NC	9"	25 eels/person/day	Gear restrictions. Non-commercial special device license. Two eel pots allowed under Recreational Commercial Gear license. Bait limit of 50 eels/day for party/charter boat captain and crew.
SC	9”	25 eels/person/day	Gear restrictions. Permits and licenses. Two pot limit
GA	9”	25 eels/person/day	
FL	9”	25 eels/person/day	Gear restrictions. Wholesale/Retail purchase exemption applies to possession limit for bait.

Table 3. Summary of current state/jurisdiction reporting structure for commercial eel landings and quota management per Addendum VI requirements.

State	Rulemaking Process	Rulemaking Timeframe	Reporting to monitor quota	Overages and Transfers	Additional Measures Planned
Maine	DMR Authority	up to 100 days	Monthly harvester. Likely to use swipe card system	Y	Possible seasons and days out by 2017
New Hampshire	Director Authority	at least 1 month	Monthly harvester	Y	None, but can if needed
Massachusetts	MF Advisory Commission	by March 2016	Weekly dealer (personal bait not counted)	Y	Close H&L gear Sept 1-Dec 31
Rhode Island	Director Authority	30 day public comment	Dealer twice a week	Y	None, but can if needed
Connecticut	DEEP Authority	10 days public notice	Monthly harvester	Y	None, but can if needed
New York	DEC Authority	6 months	Monthly harvester (river/marine) and weekly dealer (marine)	Y	Closed pot fishery on Delaware River. Need adjustment to quota through transfers or management addendum.
New Jersey	Commissioner/Council Rulemaking	3-4 months	Monthly harvester	Y	Limited entry based on 2007-2014 harvest. Possible pot maximum, and seasons. Some through notice process while others up to two years.
Delaware	Legislature (resumes in Jan 2016)	Legislature Session Jan-June	Daily harvester	Legislature	None, but can if needed
Maryland	DNR Authority	100 days or 48h with public notice authority	Daily harvester	Y	Harvester permit by 03/2016 with reporting requirement
PRFC	PRFC Authority	1-2 months	Weekly harvester	Y	None, but can if needed
Virginia	VMRC Authority	1 month	Monthly harvester with dealer check	Y	Possible seasonal closures and possession limits. Quota trigger to implement weekly/daily dealer reports.
North Carolina	NCDMF Authority	Immediate	Monthly dealer and harvester log books	Y	Proactive reporting trigger program to weekly/daily and closure at 85% of quota.
South Carolina	Legislature, but permitting authority	Permit cycle June 30	Monthly harvester and dealer	Y	Possible gear restrictions, seasons, catch limits, or closure
Georgia	Natural Resources Authority	Up to 90 days	Monthly harvester and dealer	Y	Likely close eel commercial fishery if state by state quotas are implemented
Florida	Executive Order Rulemaking	Governor-commission meets 5 times a year	Monthly harvester, weekly harvester when 50% quota is reached	Y	None, but can if needed. Issue of harvester selling to dealers outside the state and potential double counting of quota

Table 4. Numbers of American eel samples reported by the MRIP/MRFSS angler-intercept survey and at-sea headboat survey, by catch type, 1981–2016.

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		65	
2006	7	3		76	
2007	39	7		73	
2008	4	5		66	
2009	9	4		75	
2010	14	22		117	
2011	2	4		91	
2012	11	42		119	
2013	10	5		99	
2014	5	12		99	
2015	1	6		100	
2016	7	20		92	

Table 5. Numbers of American eels available for biological sampling in the MRIP/ MRFSS angler-intercept survey and at-sea headboat survey, by survey component, 1981–2016.

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	6
2008	2	3	8
2009	4	4	1
2010	6	6	2
2011	1	0	1
2012	5	5	1
2013	3	6	2
2014	1	4	0
2015	0	1	0
2016	3	4	2

Table 6. Estimates of recreational fishery harvest and released alive for American eels along the Atlantic coast, 1981–2015. The precision of each estimate, measured as proportional standard error (PSE), is also given. Estimates for 1981-2003 have been calibrated to MRIP from MRFSS.

Year	Harvest (Type A+B1)				Released Alive (Type B2)	
	Numbers	PSE[Num]	Weight (lbs)	PSE[Weight]	Numbers	PSE[Num]
1981	117,583	53.6	99,918	46.2	117,131	53.2
1982	197,724	62.6	130,815	44.3	85,001	64.6
1983	120,777	82.8	105,986	60.2	83,688	40.4
1984	81,524	54.1	78,306	47.6	49,277	60.7
1985	220,596	77.8	218,269	30.4	85,031	47.9
1986	138,583	56.6	112,388	39.7	120,993	35.4
1987	51,714	63.8	38,972	51.7	65,609	50.7
1988	85,483	52.3	41,166	32.6	104,581	52.8
1989	68,748	50.7	92,589	34.8	113,377	30.9
1990	33,324	55.9	18,239	45.8	99,998	31.0
1991	106,427	62.9	79,603	42.2	80,022	42.4
1992	42,846	70.7	2,717	28.2	55,788	48.2
1993	97,664	75.1	60,714	61.0	87,265	40.7
1994	67,999	63.1	34,420	53.1	70,089	32.3
1995	12,598	108	1,304	28.2	64,478	45.4
1996	28,149	67.4	8,765	56.9	56,131	34.3
1997	21,256	111	9,118	61.8	26,707	43.3
1998	8,543	80.6	4,625	88.0	57,803	41.8
1999	7,739	87.4	497	28.2	56,574	95.1
2000	37,084	144	18,398	92.2	48,119	52.9
2001	14,798	149			30,739	40.0
2002	7,625	74.7	812	28.2	47,952	31.8
2003	42,582	119			157,189	33.5
2004	41,286	61.4	41,191	65.2	74,653	24.6
2005	5,217	48.4	4,309	54.3	63,939	40.8
2006	19,389	53.6	15,917	49.2	99,974	42.2
2007	40,676	60.1	46,700	85.4	113,424	47.3
2008	3,062	46.0	1,245	61.4	62,625	34.5
2009	9,890	57.6	6,616	62.4	92,399	31.3
2010	129,803	78.7	31,518	64.1	90,437	28.6
2011	6,860	51.4	5,314	73.3	81,848	28.5
2012	38,493	49.0	11,999	52.1	143,868	34.1
2013	8,833	48.9	6,030	36.1	115,359	25.5
2014	5,974	47.6	7,684	61.4	148,598	53.1
2015	4,077	48.7	10,855	59.8	54,227	24.2
2016	63,946	18.8	107,480	18.0	60,589	39.6

Table 7. Summary of GLM analyses used to standardize YOY indices developed from the ASMFC-mandated and non-mandated (indicated with an * next to the survey name) recruitment surveys. Phi is the overdispersion parameter. For GLM standardized indices, the response variable was American eel catch. If a GLM wasn't applied, a nominal index was computed; nominal indices computed as ratio estimators.

Region	State	Site	Years	Gear	GLM?	Error	Predictors	Phi
Gulf of Maine	ME	West Harbor Pond	2001-2016	Irish Elver Ramp	N			
	NH	Lamprey River	2001-2016	Irish Elver Trap	Y	NB	Year+WaterTemp	1.48
	MA	Jones River	2001-2016	Sheldon Elver Trap	Y	NB	Year+Discharge	1.08
Southern New England	CT	Ingham Hill	2007-2016	Irish Elver Ramp	N			
	RI	Gilbert Stuart Dam	2000-2016	Irish Elver Ramp	Y	NB	Year+WaterTemp+WaterLevel	1.38
	RI	Hamilton Fish Ladder	2004-2016	Irish Elver Ramp	Y	NB	Year+WaterLevel	1.43
	NY	Carman's River	2000-2016	Fyke Net	Y	NB	Year+WaterTemp	1.74
Hudson River	NY	HRE Monitoring *	1974-2013	Epibenthic Sled and Tucker Trawl	Y	Delta-gamma	Year + Month + Strata + Rivermile + Volume	0.66
Delaware Bay/ Mid-Atlantic Coastal Bays	NJ	Patcong Creek	2004-2016	Fyke Net	N			
	NJ	Little Egg Inlet Ichthyoplankton *	1992-2015	Plankton Net	Y	NB	Year + Month + Flow meter + River discharge	1.07
	DE	Millsboro Dam	2000-2016	Fyke Net	Y	NB	Year+Discharge	1.76
	MD	Turville Creek	2000-2016	Irish Elver Ramp	N			
Chesapeake Bay	PRFC	Clark's Millpond	2000-2013	Irish Elver Ramp	N			
	PRFC	Gardy's Millpond	2000-2016	Irish Elver Ramp	N			
	VA	Bracken's Pond	2000-2016	Irish Elver Ramp	N			
	VA	Kamp's Millpond	2000-2016	Irish Elver Ramp	N			
	VA	Wareham's Pond	2003-2016	Irish Elver Ramp	Y	NB	Year+WaterTemp	1.31
	VA	Wormley Creek	2001-2016	Irish Elver Ramp	Y	NB	Year+WaterTemp	1.54
South Atlantic	NC	Beaufort Bridgenet Ichthyoplankton	1987-2007	Plankton Net	Y	NB	Year + Month + River discharge	1.27
	SC	Goose Creek	2000-2015	Fyke Net	Y	NB	Year+WaterTemp	1.09
	GA	Altamaha Canal	2001-2010	Fyke Net	Y	LN	Year+WaterTemp	1.11
	FL	Guana River Dam	2001-2016	Dip Net	N			

Table 8. Spearman's rank correlation between YOY indices developed from the ASMFC-mandated recruitment surveys. Values formatted in bold and italicized font are statistically significant at α < 0.10. NC's Beaufort Bridgenet Ichthyoplankton Sampling Program (BBISP) and CT's Ingham Hill indices only overlap for one year and therefore are "NA" in the table.

	Region	Gulf of Maine			Southern New England				Delaware Bay/Mid-Atl			Chesapeake Bay						South Atlantic		
Region	Survey Site	West Harbor Pond (ME)	Lamprey River (NH)	Jones River (MA)	Ingham Hill (CT)	Gilbert Stuart Dam (RI)	Hamilton Ladder (RI)	Carman's River (NY)	Patcong Creek (NJ)	Mills-boro Dam (DE)	Turville Creek (MD)	Clarks Millpond (PRFC)	Gardys Millpond (PRFC)	Brackens Pond (VA)	Kamps Millpond (VA)	Warehams Pond (VA)	Wormley Creek (VA)	BBISP (NC)	Goose Creek (SC)	Altamaha Canal (GA)
Gulf of Maine	Lamprey River (NH)	***0.532***																		
	Jones River (MA)	-0.362	-0.503																	
Southern New England	Ingham Hill (CT)	0.079	-0.224	***0.455***																
	Gilbert Stuart Dam (RI)	***0.418***	***0.476***	-0.288	0.236															
	Hamilton Fish Ladder (RI)	0.220	0.363	-0.467	-0.030	***0.505***														
	Carman's River (NY)	***0.506***	***0.535***	-0.359	0.127	***0.502***	0.319													
Delaware Bay/Mid-Atl	Patcong Creek (NJ)	0.343	***0.446***	0.032	0.183	0.332	-0.266	0.224												
	Millsboro Dam (DE)	***0.432***	***0.585***	-0.253	0.042	***0.368***	***0.434***	0.294	0.265											
	Turville Creek (MD)	0.029	-0.109	-0.203	0.176	0.157	0.049	-0.233	-0.335	0.294										
Chesapeake Bay	Clarks Millpond (PRFC)	-0.332	-0.326	0.132	0.115	-0.103	-0.462	0.118	0.009	-0.221	-0.005									
	Gardys Millpond (PRFC)	0.276	0.106	0.094	0.188	0.230	0.115	0.324	-0.091	0.211	0.002	-0.235								
	Brackens Pond (VA)	-0.179	-0.321	***0.685***	***0.564***	0.228	-0.154	-0.162	-0.029	0.032	0.235	0.208	-0.096							
	Kamps Millpond (VA)	***0.597***	0.256	-0.132	0.127	0.206	0.093	0.162	0.053	0.145	0.174	0.115	0.061	0.074						
	Warehams Pond (VA)	0.126	0.258	0.005	0.000	0.330	0.126	-0.049	0.343	-0.297	0.126	-0.511	0.077	-0.038	-0.104					
	Wormley Creek (VA)	-0.385	0.171	-0.071	-0.224	0.109	-0.005	-0.218	-0.118	0.206	0.194	0.335	-0.300	0.162	0.103	-0.291				
South Atlantic	BBISP (NC)	***0.679***	0.107	-0.286	NA	0.214	0.400	0.452	0.071	-0.452	-0.429	0.214	0.119	-0.452	***0.786***	-0.700	-0.429			
	Goose Creek (SC)	0.021	-0.271	***0.496***	0.183	-0.288	-0.112	-0.259	-0.132	-0.141	-0.379	-0.144	0.021	0.074	0.221	-0.434	0.061	0.476		
	Altamaha Canal (GA)	-0.079	0.164	0.309	0.600	-0.345	0.107	-0.212	-0.006	***0.455***	-0.067	-0.442	-0.067	0.236	0.103	0.000	0.297	-0.536	0.394	
	Guana River Dam (FL)	-0.147	-0.456	***0.491***	-0.455	-0.115	-0.280	-0.371	-0.275	-0.388	-0.094	0.085	0.100	0.203	0.215	-0.115	0.124	0.286	***0.629***	-0.200

Table 9. Summary of GLM analyses used to standardize fisheries-independent indices developed from elver and yellow eel American eel surveys. Phi is the overdispersion parameter.

Region	State	Survey	Location	Years	Gear	Life Stage(s)	GLM ?	Error	Predictors	Phi
Southern New England	CT	CTDEP Electrofishing Survey	Farmill River	2001-2014	Electrofishing	Elver & Yellow	N			
	NY	NY Western Long Island Survey	Western Long Island	1984-2016	Seine	Yellow	Y	NB	Year + Month + Lat	0.48
Hudson River	NY	HRE Monitoring Program	Hudson River	1974-2013	Epidbenthic Sled and Tucker Trawl	Yearling & older	Y	NB	Year + Gear + Month + Strata + Rivermile +Volume	1.91
	NY	NYDEC Alosine Beach Seine Survey	Hudson River	1980-2016	Seine	Elver & Yellow	Y	NB	Year + Month + Rivermile	1.23
	NY	NYDEC Striped Bass Beach Seine Survey	Hudson River	1980-2016	Seine	Elver & Yellow	Y	NB	Year + Month + Longitude	1.31
Delaware Bay/ Mid-Atlantic Coastal Bays	NJ	NJDFW Striped Bass Seine	Delaware River	1980-2016	Seine	Yellow	Y	NB	Year + Water temp + Salinity	1.02
	DE	Delaware Trawl Survey	Delaware River	1982-2016	Trawl	Elver & Yellow	Y	NB	Year + Month + Surf_Temp + Surf_Sal	2.18
	DE	PSEG Trawl Survey	Delaware River	1998-2016	Trawl	Elver & Yellow	Y	NB	Year + Month + Bot_S	1.95
	PA	Area 6 Electrofishing Survey	Delaware River	1999-2016	Electrofishing	Elver	Y	NB	Year + Site	1.16

Table 9. *Continued*.

Region	State	Survey	Location	Years	Gear	Life Stage(s)	GLM ?	Error	Predictors	Phi
Chesapeake Bay	MD	MDDNR Striped Bass Seine	Chesapeake Bay	1966-2016	Seine	Yellow	Y	NB	Year + Month + Salinity	0.95
	VA	North Anna Electrofishing Survey	North Anna River	1990-2009	Electrofishing	Elver & Yellow	Y	NB	Year+GearType+TimePeriod+Station	1.20
	VA	VIMS Juvenile Striped Bass Seine Survey - long	Lower Ches Bay & Trib	1967-2016	Seine	Yellow	Y	NB	Year + SYSTEM	1.69
	VA	VIMS Juvenile Striped Bass Seine Survey - short	Lower Ches Bay & Trib	1989-2016	Seine	Yellow	Y	NB	Year + STATION TYPE	1.38
South Atlantic	NC	NCDMF Estuarine Trawl Survey	NC waters	1989-2016	Trawl	Elver & Yellow	Y	NB	Year + Lat + Lon + Bottomtype	1.29
	SC	SC Electrofishing Survey	SC waters	2001-2016	Electrofishing	Elver & Yellow	Y	NB	Year + Strata + Water temp + Salinity + Tide Stage	1.10

Table 10. Spearman's rank correlation between yellow American eel indices. Values formatted in bold and italicized font are statistically significant at α < 0.10.

	Region	S. New England		Hudson River			Delaware Bay/Mid-Atl				Chesapeake Bay			South Atlantic
Region	Survey Site	CTDEP (CT)	W. Long Island (NY)	HRE Monitoring (NY)	NYDEC Alosine Beach Seine (NY)	NYDEC Striped Bass Beach Seine (NY)	NJDFW Striped Bass Seine (NJ)	Delaware Trawl (DE)	PSEG Trawl Survey (DE)	Area 6 Electrofishing (PA)	MDDNR Striped Bass Seine (MD)	North Anna (VA)	VIMS Juvenile Striped Bass Seine —short (VA)	NCDMF Estuarine Trawl Survey (NC)
S. New England	W. Long Island Study (NY)	-0.254												
Hudson River	HRE Monitoring (NY)	***0.406***	***0.440***											
	NYDEC Alosine Beach Seine (NY)	0.091	***0.279***	***0.284***										
	NYDEC Striped Bass Beach Seine (NY)	0.168	***0.492***	***0.726***	***0.290***									
Delaware Bay/Mid-Atl	NJDFW Striped Bass Seine (NJ)	0.147	0.129	-0.033	***0.237***	0.085								
	Delaware Trawl (DE)	-0.063	-0.162	-0.087	0.120	0.171	***0.296***							
	PSEG Trawl Survey (DE)	-0.217	-0.203	0.158	-0.275	-0.235	-0.226	0.198						
	Survey (PA)	***0.706***	0.087	***0.493***	-0.183	0.110	-0.042	-0.187	-0.028					
Chesapeake Bay	Seine (MD)	-0.007	0.105	0.047	0.131	0.184	0.099	***0.296***	0.096	-0.247				
	North Anna (VA)	***0.857***	-0.171	-0.337	0.147	-0.377	***0.575***	-0.107	0.264	***0.455***	***0.389***			
	VIMS Juvenile Striped Bass Seine —short (VA)	***0.552***	-0.077	-0.201	-0.083	0.057	-0.055	0.117	-0.175	0.115	0.139	0.072		
South Atlantic	NCDMF Estuarine Trawl Survey (NC)	0.098	0.024	***0.461***	0.111	***0.426***	-0.346	-0.098	-0.056	-0.218	-0.445	-0.491	-0.006	
	SC Electrofishing Survey (SC)	-0.217	***0.534***	-0.436	0.168	-0.238	***0.382***	***0.468***	***0.388***	-0.174	0.206	-0.167	-0.282	-0.491

Table 11. Summary of surveys used in development of region-specific indices of American eel relative abundance. Asterisks (*) denote the ASMFC-mandated recruitment surveys. A Southern New England regional yellow eel index was not developed due to concerns about the indices in that region, see section 6.2.2 for more information.

Region	Life Stage	Time Period	Survey
Gulf of Maine	YOY	2001–2016	West Harbor Pond (ME) *
			Lamprey River (NH) *
			Jones River (MA) *
	Yellow		*none available*
Southern New England	YOY	2000–2016	Gilbert Stuart Dam (RI) *
			Hamilton Fish Ladder (RI) *
			Ingham Hill (CT) *
			Carman's River (NY) *
	Yellow	2000–2012	CTDEP Electrofishing Survey (CT)
			NY Western Long Island Survey (NY)
Hudson River	YOY	1974–2013	HRE Monitoring Program (NY)
	Yellow	1980–2015	HRE Monitoring Program (NY)
			NYDEC Alosine Beach Seine Survey (NY)
			NYDEC Striped Bass Beach Seine Survey (NY)
Delaware Bay/ Mid-Atlantic Coastal Bays	YOY	2000–2016	Millsboro Dam (DE) *
			Patcong Creek (NJ) *
			Little Egg Inlet Ichthyoplankton Survey (NJ)
			Turville Creek (MD) *
	Yellow	1999–2015	NJDFW Striped Bass Seine (NJ)
			Delaware Trawl Survey (DE)
			PSEG Trawl Survey (DE)
			Area 6 Electrofishing Survey (PA)
Chesapeake Bay	YOY	2000–2016	Clark's Millpond (PRFC) *
			Gardy's Millpond (PRFC) *
			Bracken's Pond (VA) *
			Kamp's Millpond (VA) *
			Warehams Pond (VA) *
			Wormley Creek (VA) *
	Yellow	1990–2009	MDDNR Striped Bass Seine (MD)
			North Anna Electrofishing Survey (VA)
			VIMS Juvenile Striped Bass Seine Survey—short (VA)
South Atlantic	YOY	2000–2015	Beaufort Bridgenet Ichthyoplankton (NC) *
			Goose Creek (SC) *
			Altamaha Canal (GA) *
			Guana River Dam (FL) *
	Yellow	2001–2016	NCDMF Estuarine Trawl Survey (NC)
			SC Electrofishing Survey (SC)

Table 12. Spearman's rank correlation between regional YOY indices for American eel. Values formatted in *bold and italicized* font are statistically significant at α < 0.10.

	Gulf of Maine	Southern New England	Hudson River	Delaware Bay/Mid-Atlantic	Chesapeake Bay
Southern New England	0.053				
Hudson River	***0.500***	0.345			
Delaware Bay/Mid-Atlantic	***0.535***	***0.417***	***0.486***		
Chesapeake Bay	0.050	0.096	0.244	0.029	
South Atlantic	0.221	-0.285	***0.415***	-0.141	0.091

Table 13. Spearman's rank correlation between regional yellow-phase indices for American eel. Values formatted in *bold and italicized* font. None of the values are statistically significant at α < 0.10.

	Hudson River	Delaware Bay/ Mid-Atlantic Coastal Bays	Chesapeake Bay
Delaware Bay/ Mid-Atlantic Coastal Bays	-0.026		
Chesapeake Bay	-0.367	0.227	
South Atlantic	-0.372	-0.215	-0.050

Table 14. Spearman's rank correlation coefficients (ρ) and associated *P*-values from correlation of region-specific yellow-phase indices and lagged YOY indices for American eel. Values formatted in *bold and italicized* font are statistically significant at α < 0.10. There was no regional yellow eel index for Gulf of Maine or Southern New England.

Region	Yellow vs.	Lag (years)	*ρ*	*P* > |*ρ*|
Hudson River	YOY	0	0.011	0.477
		1	***0.269***	0.087
		2	***0.277***	0.085
		3	***0.476***	0.008
		4	***0.521***	0.004
Delaware Bay/ Mid-Atlantic Coastal Bays	YOY	0	0.199	0.222
		1	0.194	0.228
		2	-0.126	0.684
		3	0.039	0.446
		4	0.349	0.110
Chesapeake Bay	YOY	0	-0.370	0.861
		1	-0.091	0.612
		2	***0.734***	0.005
		3	0.137	0.328
		4	-0.024	0.536
South Atlantic	YOY	0	0.300	0.138
		1	***0.714***	0.003
		2	***0.473***	0.053
		3	0.364	0.123
		4	***0.573***	0.035

Table 15. 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 ≥ 30% of the parameter estimate.

	Subset	**n**	***a***	***b***
None	All	68,334	4.05E-7 (1.324E-8)	3.25 (0.00509)
Region	Gulf of Maine	3,420	6.49E-7 (3.574E-8)	3.17 (0.00843)
	Southern New England	166	5.10E-5 (4.10E-5*)	2.52 (0.1236)
	Hudson River	2,249	1.27E-6 (1.956E-7)	3.06 (0.0240)
	Del Bay/Mid-Atl Coastal Bays	11,270	3.48E-7 (1.972E-8)	3.26 (0.00886)
	Chesapeake Bay	38,161	3.25E-7 (1.589E-8)	3.28 (0.00757)
	South Atlantic	13,068	3.32E-7 (3.403E-8)	3.29 (0.0161)
Sex	Male	2,643	5.81E-7 (3.301E-8)	3.19 (0.00958)
	Female	4,049	6.81E-7 (4.003E-8)	3.16 (0.00912)

Table 16. 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 ≥ 30% of the parameter estimate.

Class	**Subset**	**n**	***Intercept***	***Slope***
None	All	17,414	338 (1.55)	8.77 (0.224)
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	4,815	278 (3.61)	29.4 (0.847)
	Chesapeake Bay	7,734	263 (2.85)	28.1 (0.556)
	South Atlantic	1,159	331 (9.47)	26.0 (1.92)
Sex	Male	2,423	295 (1.50)	3.39 (0.172)
	Female	3,513	358 (2.86)	7.65 (0.27)

Table 17. 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_∞ represent length in millimeters. Asterisks (*) denote standard errors that are ≥ 30% of the parameter estimate.

Class	Subset	n	L_∞	K	T_0
None	All	17,414	434 (1.78)	0.515 (0.018)	-0.34 (0.080)
Region	Gulf of Maine	2,356	1,397 (191.1)	0.022 (0.004)	-2.15 (0.254)
	Southern New England	475	*failed to converge*		
	Hudson River	875	484 (5.36)	0.230 (0.013)	0.35 (0.139*)
	Del Bay/Mid-Atl Coastal Bays	4,815	585 (26.98)	0.179 (0.027)	-2.52 (0.421)
	Chesapeake Bay	7,734	1366 (380.1)	0.030 (0.012*)	-6.84 (0.803)
	South Atlantic	1,159	569.9 (26.31)	0.263 (0.056)	-1.67 (0.623*)
Sex	Male	2,423	*failed to converge*		
	Female	3,513	668 (85.70)	0.035 (0.013*)	-20.96 (4.645)

Table 18. 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 CV	Linear trend		Exponential Trend	
					50%	-50%	50%	-50%
Gulf of Maine	YOY	YOY Survey--Jones River	MA	0.347	0.33	0.46	0.34	0.48
	YOY	YOY Survey--Lamprey River	NH	0.316	0.37	0.52	0.38	0.54
	YOY	YOY Survey - West Harbor Pond	ME	33.245	0.05	0.05	0.07	0.08
Southern New England	Elver & Yellow	CTDEP Electrofishing	CT	0.043	1	1	1	1
	Yellow	NY Western Long Island Survey	NY	1.061	0.1	0.13	0.12	0.16
	YOY	YOY Survey - Carman's River	NY	0.19	0.7	0.87	0.7	0.88
	YOY	YOY Survey - Gilbert Stuart Dam	RI	0.205	0.64	0.83	0.65	0.84
	YOY	Hamilton Fish Ladder	RI	0.205	0.64	0.83	0.65	0.84
	YOY	Ingham Hill	CT	0.455	0.23	0.32	0.24	0.35
Hudson	Elver & Yellow	NYDEC Alosine Beach Seine	NY	0.176	0.76	0.91	0.76	0.92
	Elver & Yellow	NYDEC Striped Bass Beach Seine	NY	0.231	0.56	0.74	0.56	0.76
	Yearling +	HRE Monitoring Program	NY	0.067	1	1	1	1
	YOY	HRE Monitoring Program	NY	0.111	0.98	1	0.98	1
Delaware Bay/Mid-Atlantic Coastal Bays	Elver	Area 6 Electrofishing	PA	0.182	0.73	0.9	0.74	0.9
	Elver & Yellow	Delaware Trawl Survey	DE	0.222	0.58	0.77	0.59	0.78
	Elver & Yellow	PSEG Trawl Survey	DE	0.265	0.47	0.66	0.46	0.64
	Yellow	NJ Striped Bass Seine Survey	NJ	0.501	0.21	0.28	0.22	0.31
	YOY	Little Egg Inlet Ichthyoplankton Survey	NJ	0.18	0.74	0.9	0.74	0.91
	YOY	YOY Survey--Millsboro Dam	DE	0.295	0.4	0.56	0.41	0.58
	YOY	YOY Survey--Patcong Creek	NJ	1.391	0.09	0.1	0.1	0.14
	YOY	YOY Survey--Turville Creek	MD	5.5	0.06	0.06	0.08	0.09

Table 18. *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	0.238	0.54	0.72	0.54	0.74
	Yellow	MD Striped Bass Seine Survey	MD	0.621	0.16	0.22	0.18	0.25
	Yellow	VIMS Juvenile SB Seine Survey--long	VA	0.698	0.15	0.19	0.16	0.22
	Yellow	VIMS Juvenile SB Seine Survey--short	VA	0.472	0.22	0.30	0.23	0.33
	YOY	YOY Survey--Brackens Pond	VA	0.638	0.16	0.21	0.17	0.24
	YOY	YOY Survey—Clark’s Millpond	PRFC	0.004	1.00	1.00	1.00	1.00
	YOY	YOY Survey—Gardy’s Millpond	PRFC	0.005	1.00	1.00	1.00	1.00
	YOY	YOY Survey—Kamp’s Millpond	VA	0.052	1.00	1.00	1.00	1.00
	YOY	YOY Survey--Wormley Creek	VA	0.250	0.50	0.69	0.51	0.70
	YOY	Wareham’s Pond	VA	0.246	0.51	0.70	0.52	0.71
South Atlantic	Elver & Yellow	NCDMF Estuarine Trawl Survey	NC	0.507	0.20	0.28	0.22	0.31
	Elver & Yellow	SC Electrofishing Survey	SC	0.131	0.93	0.99	0.93	0.99
	YOY	YOY Beaufort Bridgenet Ichthyo.	NC	0.216	0.60	0.79	0.61	0.80
	YOY	YOY Survey - Altamaha Canal	GA	0.320	0.36	0.50	0.37	0.53
	YOY	YOY Survey--Goose Creek	SC	0.205	0.64	0.83	0.65	0.84
	YOY	YOY Survey--Guana River Dam	FL	0.013	1.00	1.00	1.00	1.00

Table 19. Results of the Mann-Kendall trend analysis applied to YOY indices. S is the Mann-Kendall statistic, D is the Denominator, *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 < α; α = 0.05). NS = not significant. "-" indicates an index which was not available during the last benchmark but was included in the 2017 update because it now has at least 10 years of data.

Region	State	Location	Gear	Time Period	n	*T*	*D*	*S*	*P*-value	Trend 2012	Trend 2016
Gulf of Maine	ME	West Harbor Pond	Irish Elver Ramp	2001–2016	16	0.283	120	33.96	0.137	NS	NS
	NH	Lamprey River	Irish Elver Trap	2001–2016	16	0.350	120	42.00	0.065	NS	NS
	MA	Jones River	Sheldon Elver Trap	2001–2016	16	-0.533	120	-63.96	0.005	NS	↓
Southern New England	RI	Hamilton Fish Ladder	Irish Elver Ramp	2004-2016	13	0.282	78	22.00	0.200	-	NS
	RI	Gilbert Stuart Dam	Irish Elver Ramp	2000–2016	17	0.162	136	22.03	0.387	NS	NS
	CT	Ingham Hill	Irish Elver Ramp	2007-2016	10	-0.244	45	-10.98	0.371	-	NS
	NY	Carman's River	Fyke Net	2000–2016	17	0.044	136	6.00	0.840	NS	NS
	NY	HRE Monitoring	Epibenthic sled & tucker trawl	1974-2013	34	-0.422	561	-236.74	0.000	↓	↓
Delaware Bay/ Mid-Atlantic Coastal Bays	NJ	Little Egg	Plankton Net	1992-2015	24	-0.355	276	-97.98	0.016	NS	↓
	NJ	Patcong Creek	Fyke Net	2004–2016	12	0.217	120	26.04	0.260	NS	NS
	DE	Millsboro Dam	Fyke Net	2000–2016	17	0.191	136	25.98	0.303	NS	NS
	MD	Turville Creek	Irish Elver Ramp	2000–2016	17	0.176	136	23.94	0.343	NS	NS

Table 19. *Continued.*

Region	State	Location	Gear	Time Period	n	*T*	*D*	*S*	*P*-value	Trend 2012	Trend 2016
Chesapeake Bay	PRFC	Clark's Millpond	Irish Elver Ramp	2000–2016	17	-0.147	136	-19.99	0.434	NS	NS
	PRFC	Gardy's Millpond	Irish Elver Ramp	2000–2016	17	-0.191	136	-25.98	0.303	NS	NS
	VA	Warehams Pond	Irish Elver Ramp	2003-2016	13	0.308	78	24.02	0.161	-	NS
	VA	Bracken's Pond	Irish Elver Ramp	2000–2016	17	-0.324	136	-44.06	0.077	NS	NS
	VA	Kamp's Millpond	Irish Elver Ramp	2000–2016	17	-0.044	136	-6.00	0.837	NS	NS
	VA	Wormley Creek	Irish Elver Ramp	2001–2016	17	-0.100	120	-12.00	0.620	NS	NS
South Atlantic	NC	Beaufort Bridgenet Ichthyo	Plankton Net	1987-2007	21	-0.343	210	-72.03	0.032	NS	↓
	SC	Goose Creek	Fyke Net	2000–2015	16	-0.433	120	-51.96	0.022	NS	↓
	GA	Altamaha Canal	Fyke Net	2001–2010	10	-0.333	45	-14.99	0.211	NS	NS
	FL	Guana River Dam	Dip Net	2001–2016	16	-0.343	210	-72.03	0.032	NS	↓

Table 20. Results of the Mann-Kendall trend analysis applied to yellow eel indices. S is the Mann-Kendall statistic, D is the Denominator, *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 < α; α = 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 *	*T*	*D*	*S*	*P*-value	Trend 2012	Trend 2017
Southern New England	CTDEP Electrofishing Survey	Electrofishing	Elver & Yellow (50–590 mm)	2001–2014	11	0.273	66	18.018	0.244	↑	NS
	NY Western Long Island Survey	Seine	Yellow (35–770 mm)	1984–2016	32	-0.49	499.744	-244.87	0.000	↓	↓
Hudson River	HRE Monitoring Program	Epibenthic Sled and Tucker Trawl	Yearling and Older	1974–2013	39	-0.526	780	-410.28	0.000	↓	↓
	NYDEC Alosine Beach Seine	Seine	Elver & Yellow	1980–2016	36	-0.42	666	-410.28	0.000	↓	↓
	NYDEC Striped Bass Beach Seine	Seine	Elver & Yellow	1980–2016	36	-0.523	666	-279.72	0.000	↓	↓
Delaware Bay/ Mid-Atlantic Coastal Bays	NJDFW Striped Bass Seine Survey	Seine	Yellow (50–750 mm)	1980–2016	36	-0.0631	666	-42.025	0.592	NS	NS
	Delaware Trawl Survey	Trawl	Elver & Yellow (55–690 mm)	1982–2016	34	-0.153	595	-91.035	0.201	NS	NS
	PSEG Trawl Survey	Trawl	Elver & Yellow (97–602 mm)	1998–2016	18	0.158	171	27.018	0.363	↑	NS[1]
	Area 6 Electrofishing	Electrofishing	Elver	1999–2016	17	0.216	153	33.048	0.225	NS	NS
	MDDNR Striped Bass Seine Survey	Seine	Yellow (77–687 mm)	1966–2016	50	-0.111	1274.5	-141.47	0.252	NS	NS

Table 20. *Continued.*

Region	Survey	Gear	Life Stage	Time Period	n *	*T*	*D*	*S*	*P*-value	Trend 2012	Trend 2017
Chesapeake Bay	North Anna Electrofishing Survey	Electrofishing	Elver & Yellow (32–726 mm)	1990–2009	19	0.626	171	107.046	0.000	↑	↑[1]
	VIMS Juvenile Striped Bass Seine Survey—long	Seine	Yellow	1989–2016	49	0.00753	929.354	6.99803	0.951	NS	NS
	VIMS Juvenile Striped Bass Seine Survey—short	Seine	Yellow	1967–2016	27	-0.135	377.499	-50.962	0.323	↓	NS
South Atlantic	NCDMF Estuarine Trawl Survey	Trawl	Elver & Yellow (26–921 mm)	1989–2016	27	-0.296	378	-111.89	0.028	↓	↓
	SC Electrofishing Survey	Electrofishing	Elver & Yellow (44–890 mm)	2001–2016	15	-0.367	120	-44.04	0.053	↓	NS

[1] The timeframe for the PSEG trawl survey changed from 1970-2010 in ASFMC 2012 to 1998-2016 in this update report. The North Anna Electrofishing survey was not updated for this report with data from 2010-2016 and therefore the trend remains the same. Refer to Section 5.2.2. for information on survey and standardization changes.

Table 21. Results of the Mann-Kendall trend analysis applied to regional and coastwide indices of American eel abundance. S is the Mann-Kendall statistic, D is the Denominator, 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 < α; α = 0.05). NS = not significant. "-" are indices that were not updated.

Region	Life Stage	Time Period	n	*T*	*D*	*S*	*P*-value	2012 Trend	2017 Trend
Gulf of Maine	YOY	2001–2016	15	0.017	120	2.004	0.964	NS	NS
Southern New England	YOY	2000–2016	16	0.118	136	16.05	0.537	NS	NS
	Yellow	2001–2010	9			0		NS	-
Hudson River	YOY	1974–2009	35			0		↓	-
	Yellow	1980–2016	36	-0.527	665	-351	0.000	↓	↓
Delaware Bay/ Mid-Atlantic Coastal Bays	YOY	2000–2016	16	0.191	136	25.98	0.303	NS	NS
	Yellow	1999–2016	17	0.203	153	31.06	0.256	NS	NS
Chesapeake Bay	YOY	2000–2016	16	0.015	136	1.999	0.967	NS	NS
	Yellow	1990–2009	19	0.621	190	118	0.000	↑	↑
South Atlantic	YOY	2001–2015	14	-0.433	120	-52	0.022	NS	↓
	Yellow	2001–2016	15	-0.4	120	-48	0.034	↓	↓
Atlantic Coast	YOY (short-term)	2000–2016	16	0.118	136	16.05	0.537	NS	NS
	YOY (long-term)	1987–2013	26	-0.237	325	-77	0.094	NS	NS
	Yellow (40+ year)	1974–2016	42	-0.391	903	-353	0.000	NS	↓
	Yellow (30-year)	1987–2016	29	-0.333	435	-145	0.010	↓	↓
	Yellow (20-year)	1997–2016	19	-0.211	190	-40.1	0.206	NS	NS

Table 22. 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	17	0.887		
	CTDEP Electrofishing Survey	11	0.878		
	NYDEC Alosine Beach Seine	36	0.000	S_1:	115.88
	NYDEC Striped Bass Beach Seine	36	0.000	*df*:	30
	Delaware Trawl Survey	34	0.101	$P(X^2>S_1\|df)$:	<0.01
	PSEG Trawl Survey	18	0.819		
	North Anna Electrofishing Survey	19	1.000	S_2:	-5.05
	NCDMF Estuarine Trawl Survey	27	0.142	$P(Z>S_2)$:	<0.01
	SC Electrofishing Survey	16	0.026		
	HRE Monitoring	39	0.000		
	NY Western Long Island Survey	32	0.000		
	NJDFW Striped Bass Seine Survey	36	0.296		
	MD Striped Bass Seine Survey	50	0.126		
	VIMS Juvenile Striped Bass Seine --short	19	0.476		
	VIMS Juvenile Striped Bass Seine--long	49	0.838		
YOY	West Harbor Pond	16	0.932		
	Lamprey River	16	0.968		
	Jones River	13	0.003	S_1:	95.22
	Hamilton Fish Ladder	13	0.900	*df*:	42
	Gilbert Stuart Dam	17	0.807	$P(X^2>S_1\|df)$:	<0.01
	Ingham Hill	10	0.186		
	Carman's River	17	0.580	S_2:	-16.03
	HRE Monitoring	34	0.000	$P(Z>S_2)$:	<0.01
	Little Egg Inlet Ichthyoplankton Survey	24	0.008		
	Patcong Creek	12	0.870		
	Millsboro Dam	17	0.849		
	Turville Creek	17	0.829		
	Clarks Millpond	17	0.217		
	Gardys Millpond	17	0.152		
	Brackens Pond	17	0.039		
	Kamps Millpond	17	0.419		
	Wormley Creek	17	0.310		
	Beaufort Bridgenet Ichthyoplankton	21	0.016		
	Goose Creek	16	0.011		
	Altamaha Canal	10	0.106		
	Guana River Dam	16	0.016		

Table 23. Summary statistics from ARIMA model fits to American eel surveys with 20 or more years of data. $Q_{0.25}$ is the 25th percentile of the fitted values; P(<0.25) is the probability of the of the survey being below $Q_{0.25}$ in 2010 or in the terminal year with 80% confidence; r1–r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; and σ^2c is the variance of the index. P(<0.25) in 2010 is included for comparison purposes of the status of the survey from the 2012 benchmark assessment.

Region	Survey	Life Stage	Years	$Q_{0.25}$	P(<0.25) in 2010	P(<0.25) in terminal year	n	r1	r2	r3	θ	SE	σ^2_c
Hudson River	NY Western Long Island Survey	Yellow	1984 - 2016	-4.27	0.462	0.412	33	-0.26	-0.08	-0.06	0.41	0.15	0.65
	HRE Monitoring Program	YOY	1974 - 2013	-2.23	0.516	0.544	34	-0.06	-0.11	-0.29	0.78	0.14	0.28
	HRE Monitoring Program	Yearling and Older	1974 - 2013	-1.62	0.034	0.003	40	-0.14	-0.28	0.39	0.32	0.14	0.26
	NYDEC Alosine Beach Seine	Elver & Yellow	1980 - 2016	-1.33	0.344	0.72	37	-0.38	0.01	-0.06	0.66	0.13	0.25
	NYDEC Striped Bass Beach Seine	Elver & Yellow	1980 - 2016	-1.37	0.286	0.446	37	-0.08	-0.19	-0.1	0.72	0.11	0.33

Table 23. *Continued.*

Region	Survey	Life Stage	Years	$Q_{0.25}$	P(<0.25) in 2010	P(<0.25) in terminal year	n	r1	r2	r3	θ	SE	σ^2_c
Delaware Bay/Mid-Atlantic Coastal Bays	Little Egg Inlet Ichthyoplankton Survey	YOY	1992 - 2015	-0.01	0.722	0.755	24	0.03	-0.51	-0.12	0.25	0.32	0.17
	NJDFW Striped Bass Seine Survey	Yellow	1980 - 2016	-2.75	0	0	37	-0.24	-0.33	0.05	1	0.1	0.59
	Delaware Trawl Survey	Elver & Yellow	1982 - 2016	-1.98	0.479	0.242	35	-0.54	0.43	-0.28	0.54	0.14	0.41
	PSEG Trawl Survey	Elver & Yellow	1998 - 2016	-0.12	0.002	0	19	-0.85	0.7	-0.62	1	0.19	0.28
Chesapeake Bay	MD Striped Bass Seine Survey	Yellow	1966 - 2016	-2.24	0.155	0.202	51	-0.29	0.01	-0.07	0.58	0.17	1
	VIMS Juvenile SB Seine Survey - short	Yellow	1989 - 2016	-2.37	0.085	0.066	28	-0.69	0.23	0.01	1	0.13	0.33
	VIMS Juvenile SB Seine Survey - long	Yellow	1967 - 2016	-3.2	0.006	0.009	44	-0.35	-0.34	0.21	0.63	0.12	0.88
South Atlantic	Beaufort Bridgenet Ichthyoplankton	YOY	1987 - 2007	-1.12		0.454	21	-0.43	-0.12	0.1	0.74	0.17	0.52
	NCDMF Estuarine Trawl Survey	Elver & Yellow	1989 - 2016	-2.09	0.192	0.284	28	-0.28	-0.31	0.18	0.85	0.11	0.64

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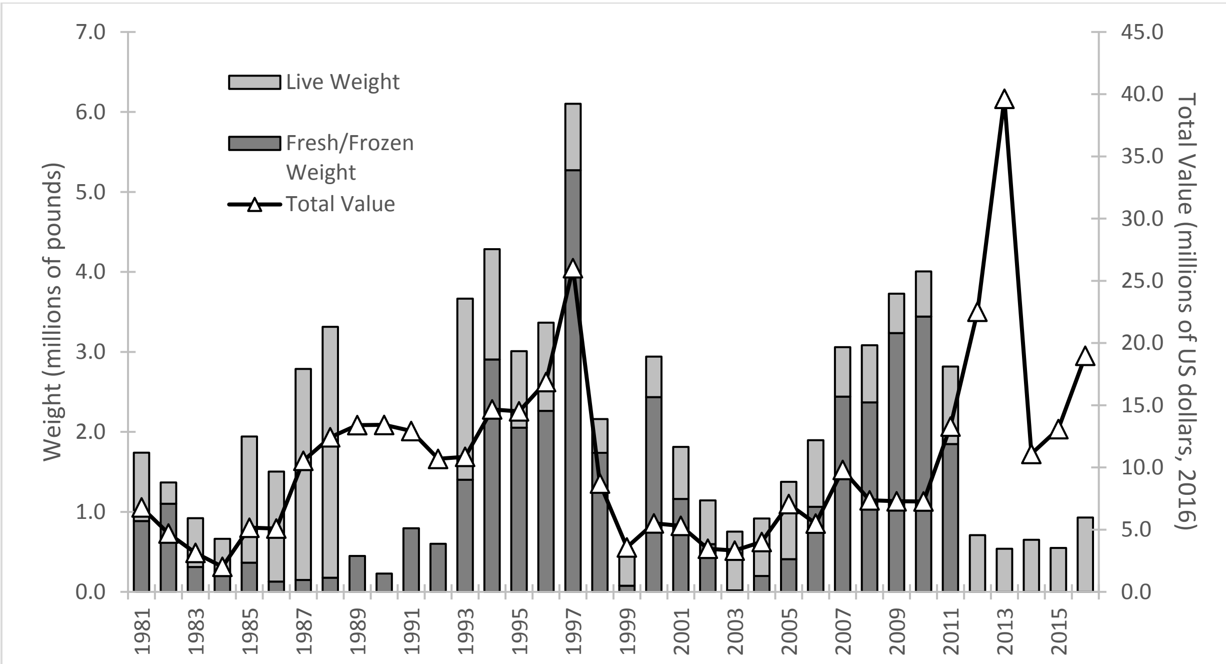


Figure 1. Annual U.S. domestic exports of American eels from districts along the Atlantic coast, 1981–2016. Note that the weights of live exports were not available for 1989 to 1992 and there were no fresh/frozen weight after 2011.

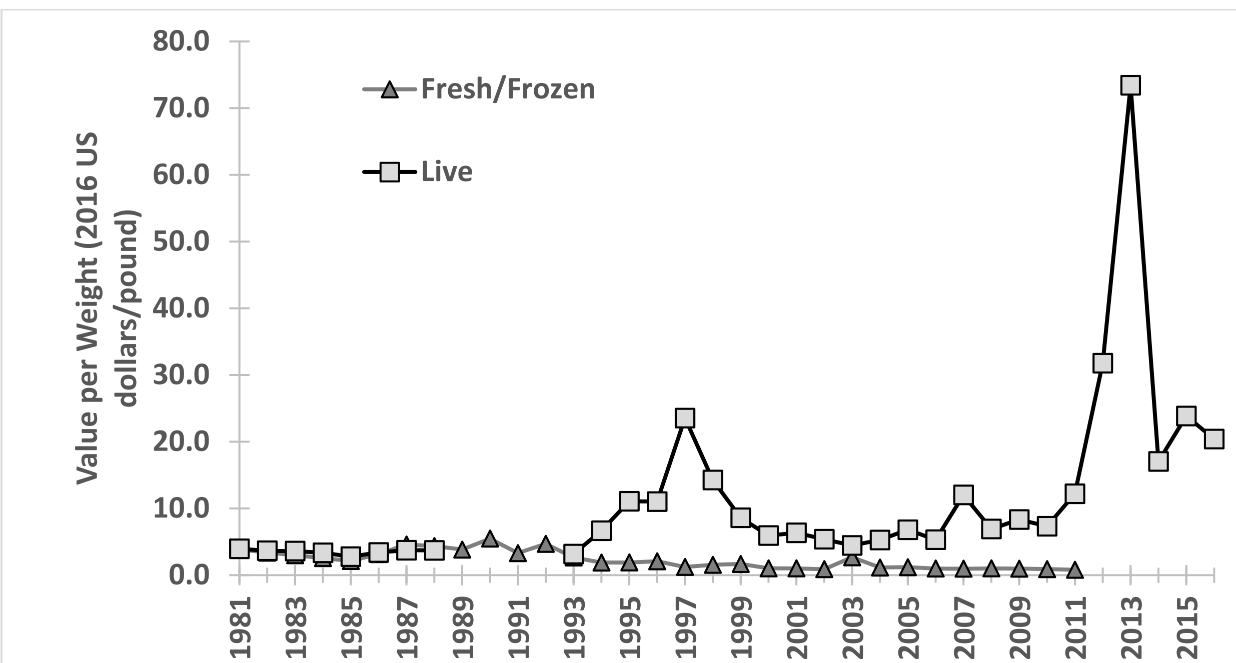


Figure 2. Value per weight of U.S. domestic exports of American eels from districts along the Atlantic Coast, 1981-2016. Note that there was no data for fresh/frozen after 2011.

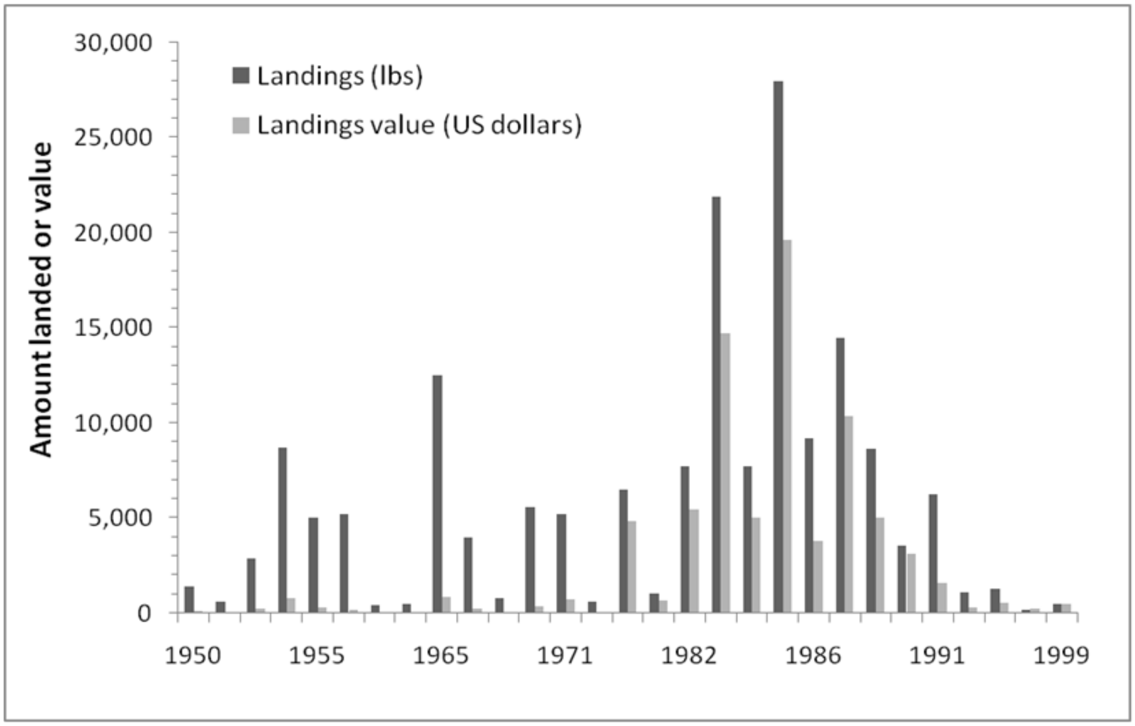


Figure 3. **Total weight and value of American eel commercial landings in the Gulf of Mexico, 1950–1999. Recent landings are confidential.**

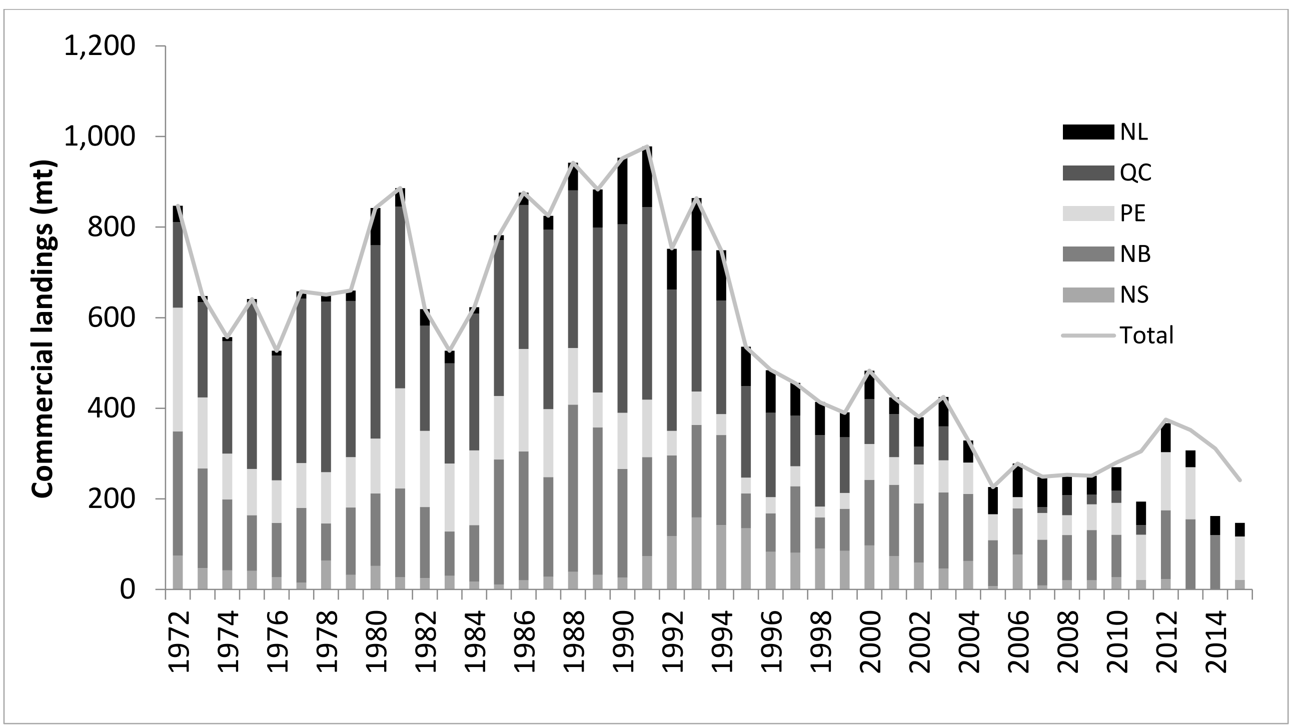


Figure 4. **Annual commercial seafisheries landings (live weight) of American eel along Canada's Atlantic Coast summarized by province, 1972–2015. In recent years, some provinces' landings have been confidential so total landings has been provided as a line.**

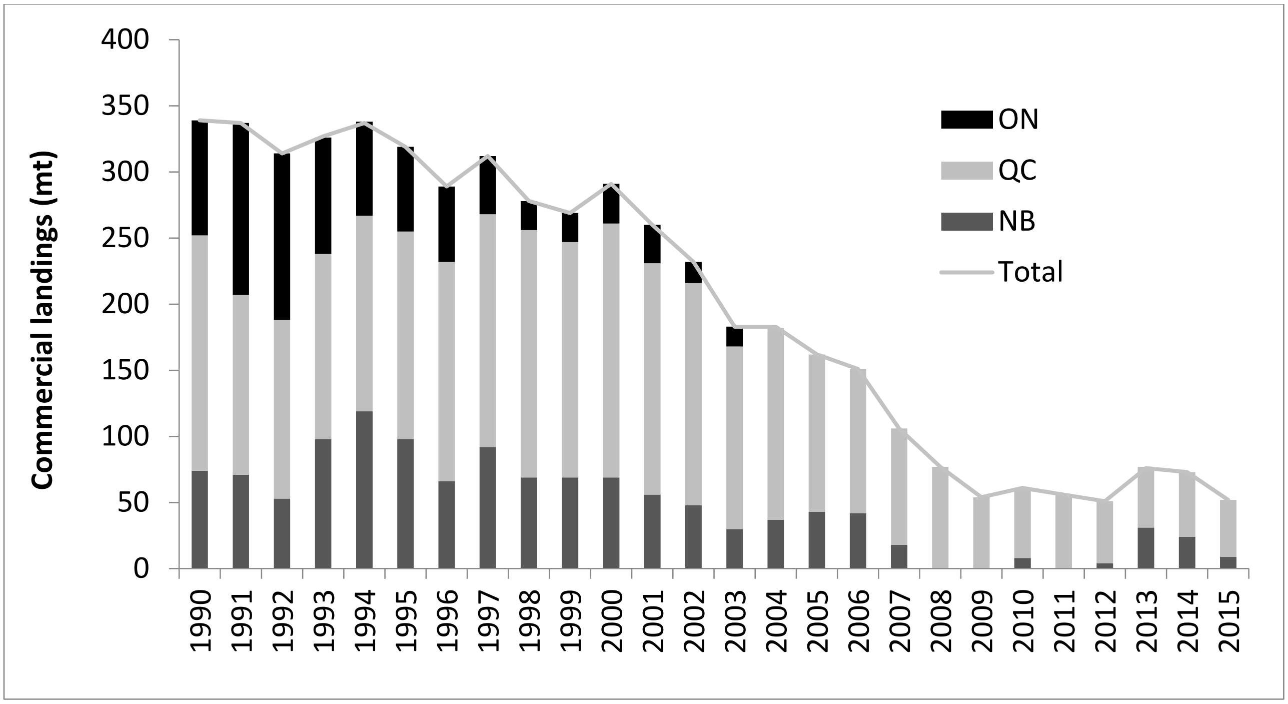


Figure 5. Annual commercial freshwater landings (live weight) of American eel along Canada's Atlantic Coast summarized by province, 1990–2015.

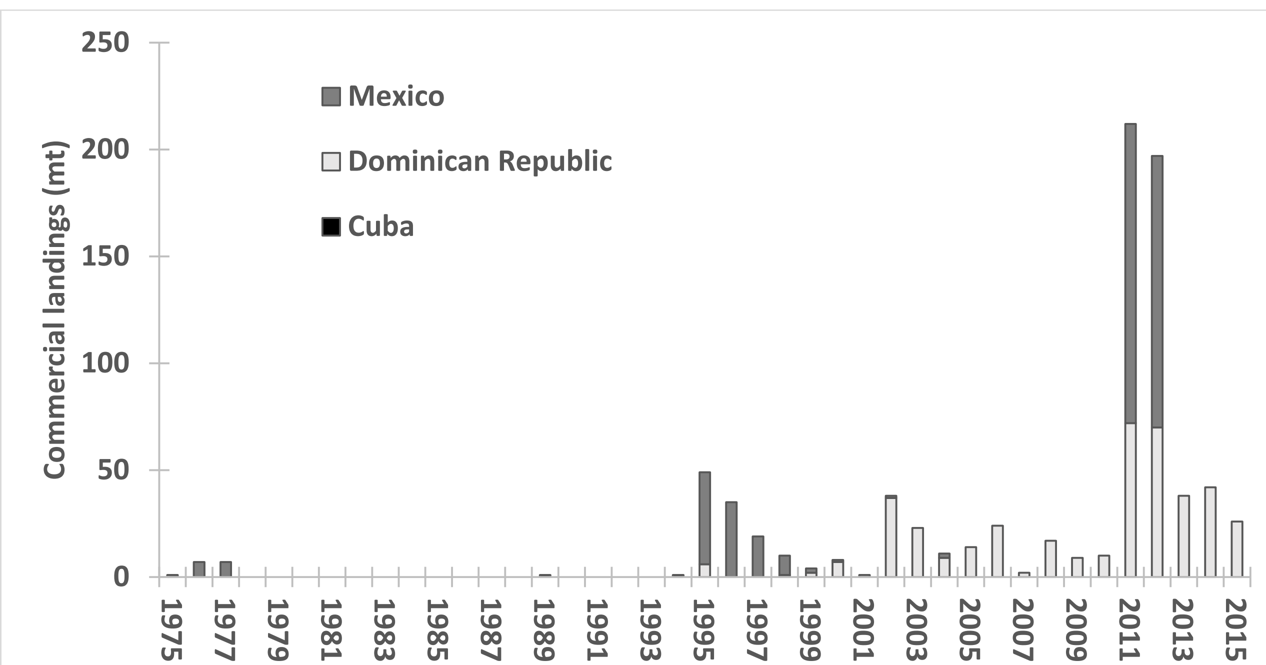


Figure 6. Annual commercial landings (live weight) of American eel reported by the FAO from Central and South America, 1975–2015. No landings were reported between 1950-1974, 1978-1988, and 1990-1993. Cuba's only reported American eel landings were 1 mt in 1989 and 1 mt in 1994.

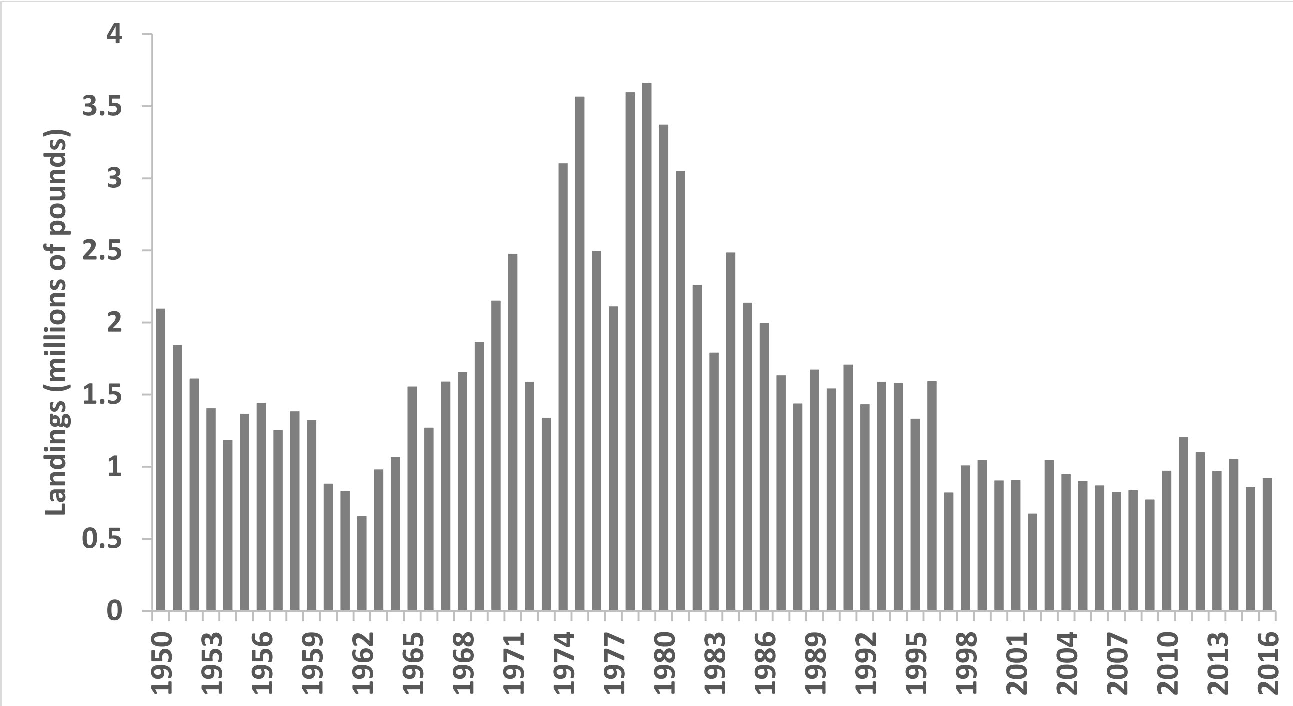


Figure 7. Total commercial landings of American eel along the U.S. Atlantic Coast, 1950–2016. Landings in 2016 are preliminary.

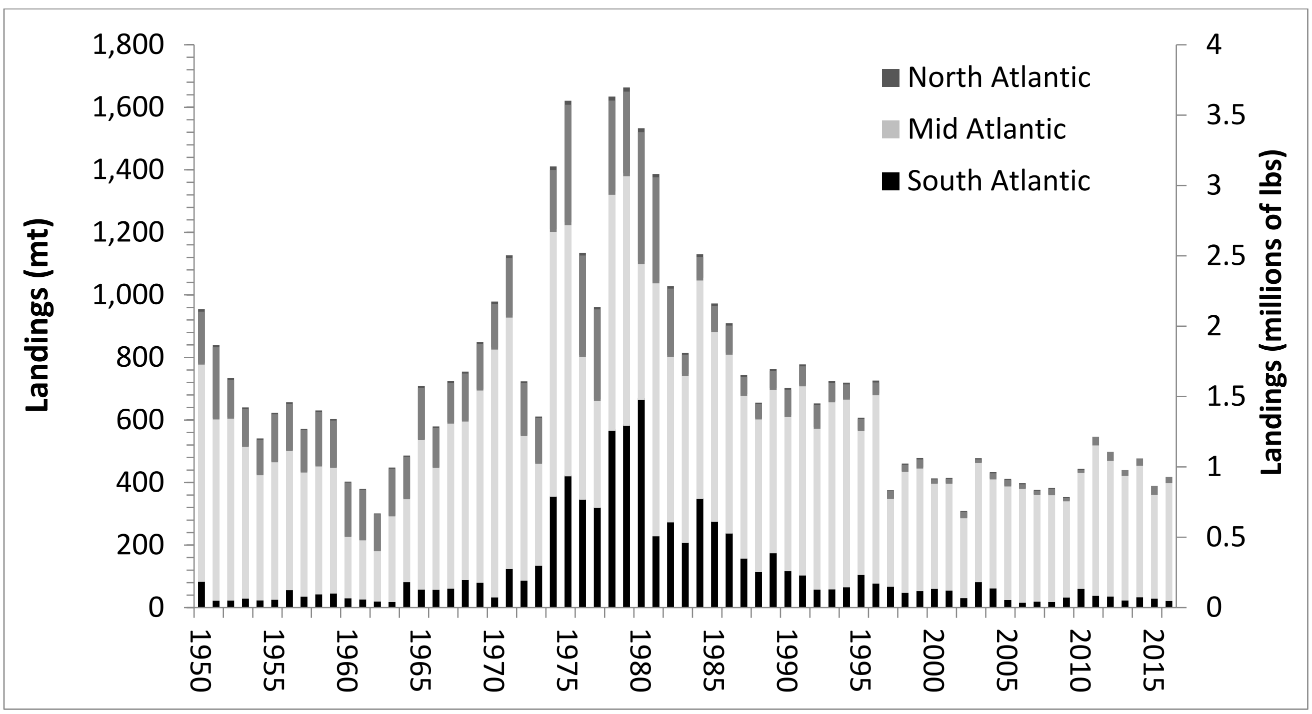


Figure 8. Total commercial landings of American eel by old geographic region along the U.S. Atlantic Coast, 1950–2016. Landings in 2016 are preliminary.

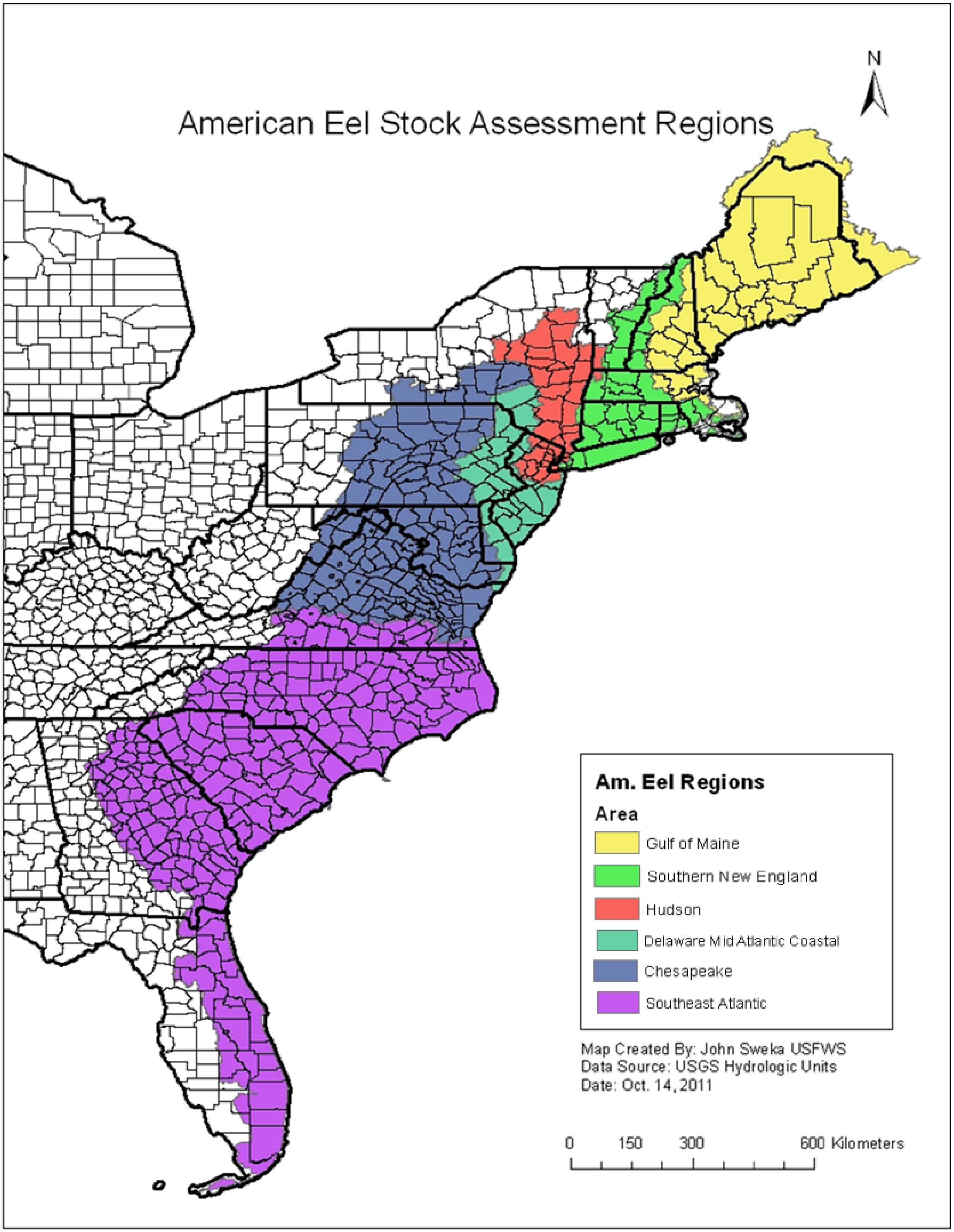


Figure 9. Watershed-based geographic regions used in the 2012 benchmark stock assessment.

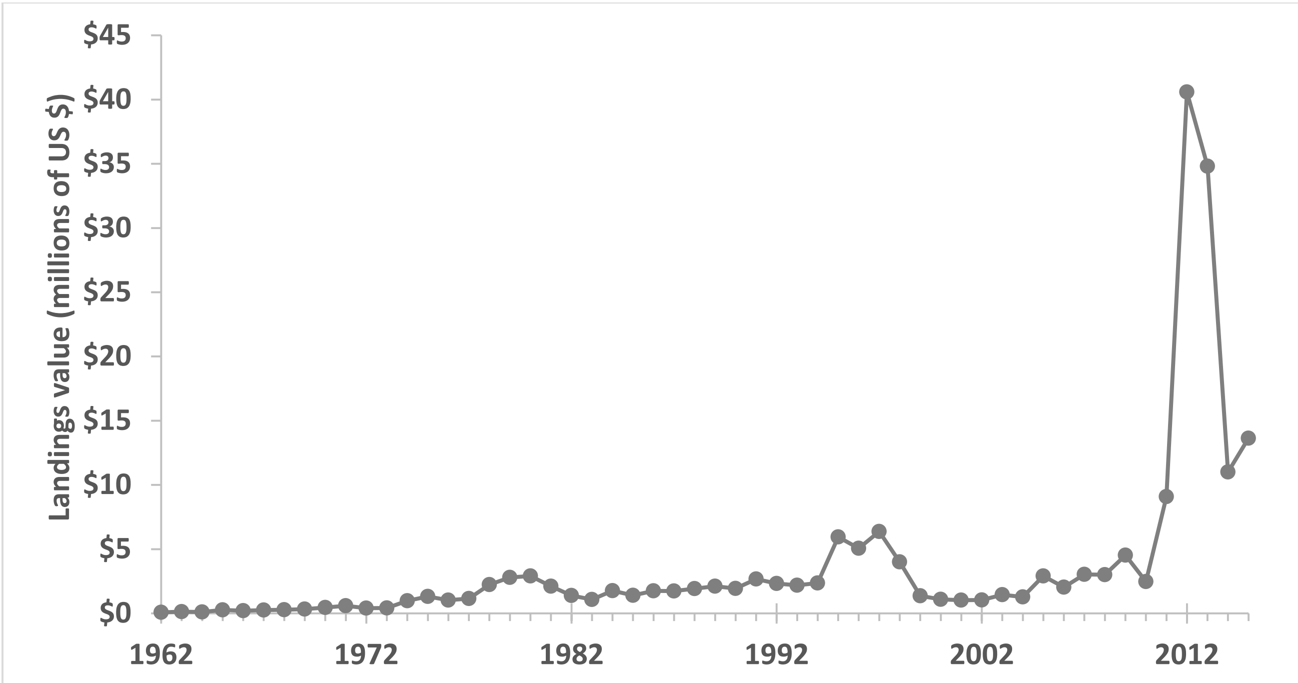


Figure 10. Estimated value of U.S. American eel landings, 1962–2015.

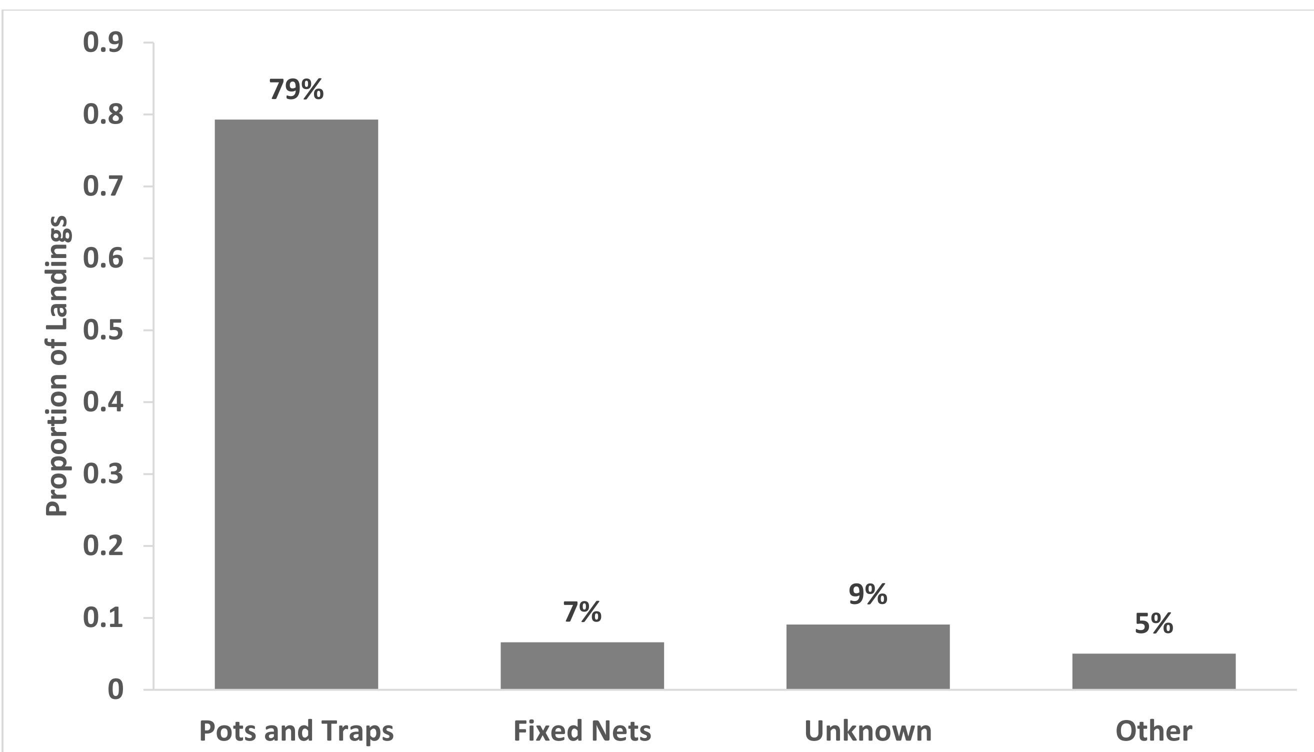


Figure 11. Proportion of Atlantic coast commercial landings by general gear type, 1950–2016.

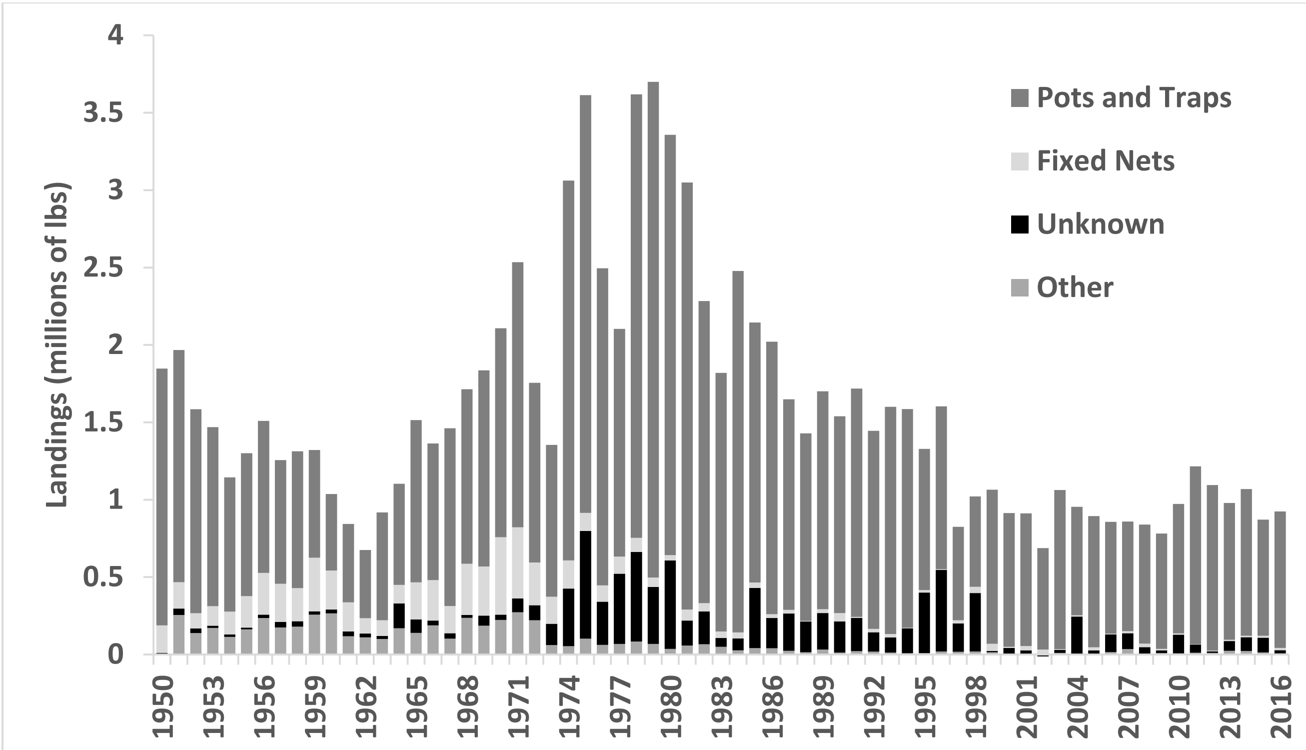


Figure 12. **Trends in the proportion of Atlantic coast commercial landings by general gear type, 1950-2016. Landings in 2016 are preliminary.**

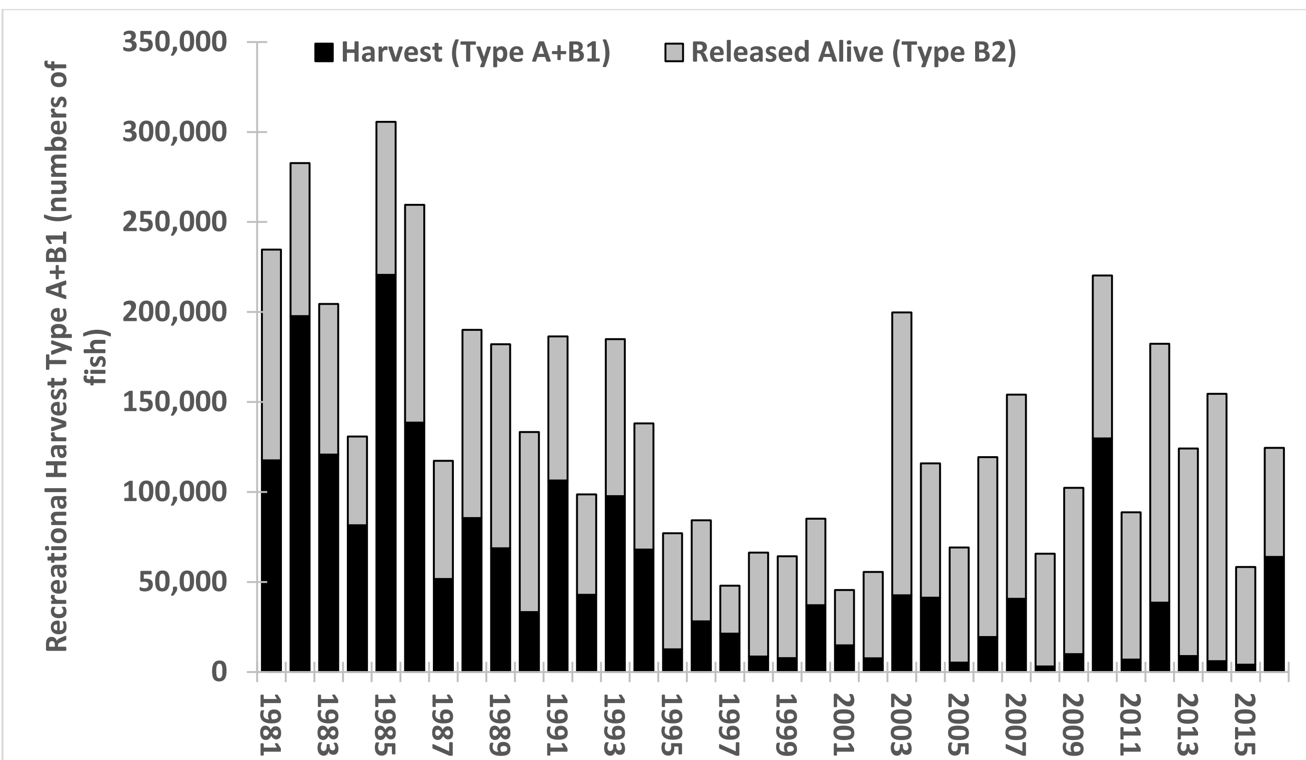


Figure 13. **Recreational harvest and releases for American eel 1981-2016. Estimates for 1981-2003 have been calibrated to MRIP from MRFSS.**

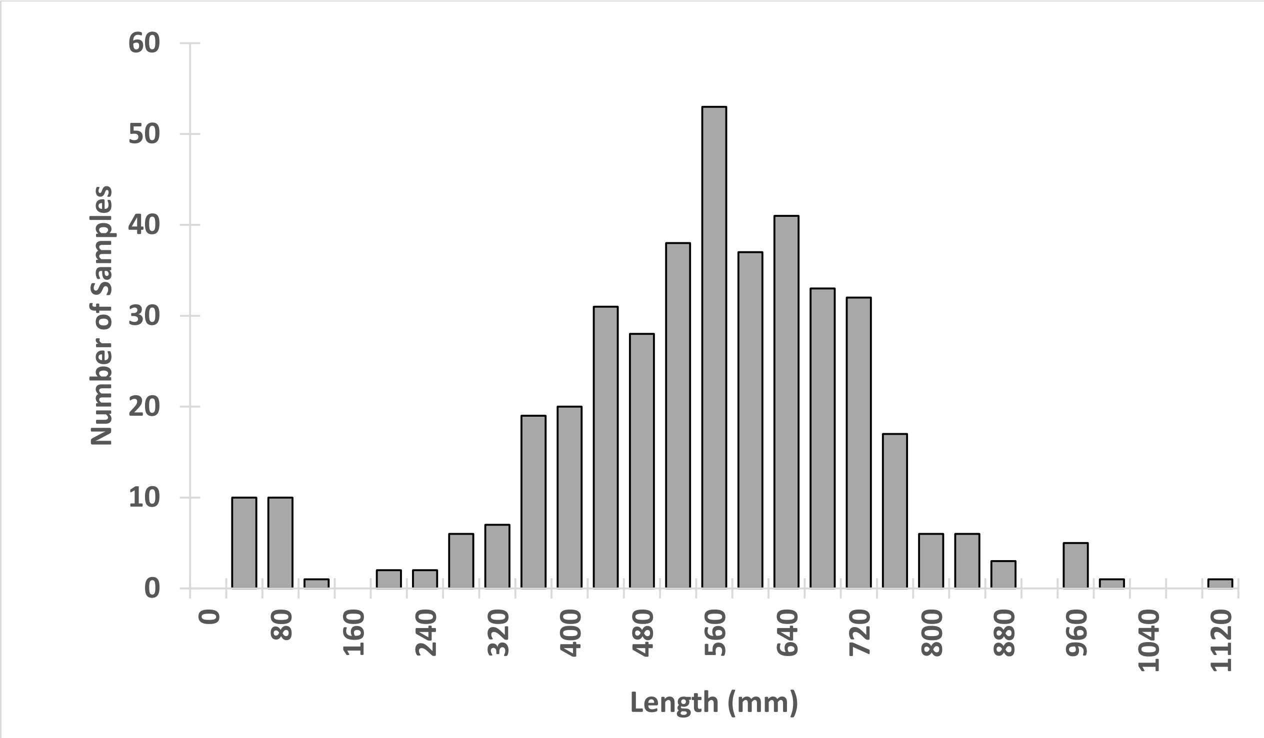


Figure 14. Length-frequency of American eels sampled by the MRFSS angler-intercept survey (Type A catch), 1981–2016. It was noted by the SAS that small lengths may represent a species misidentification.

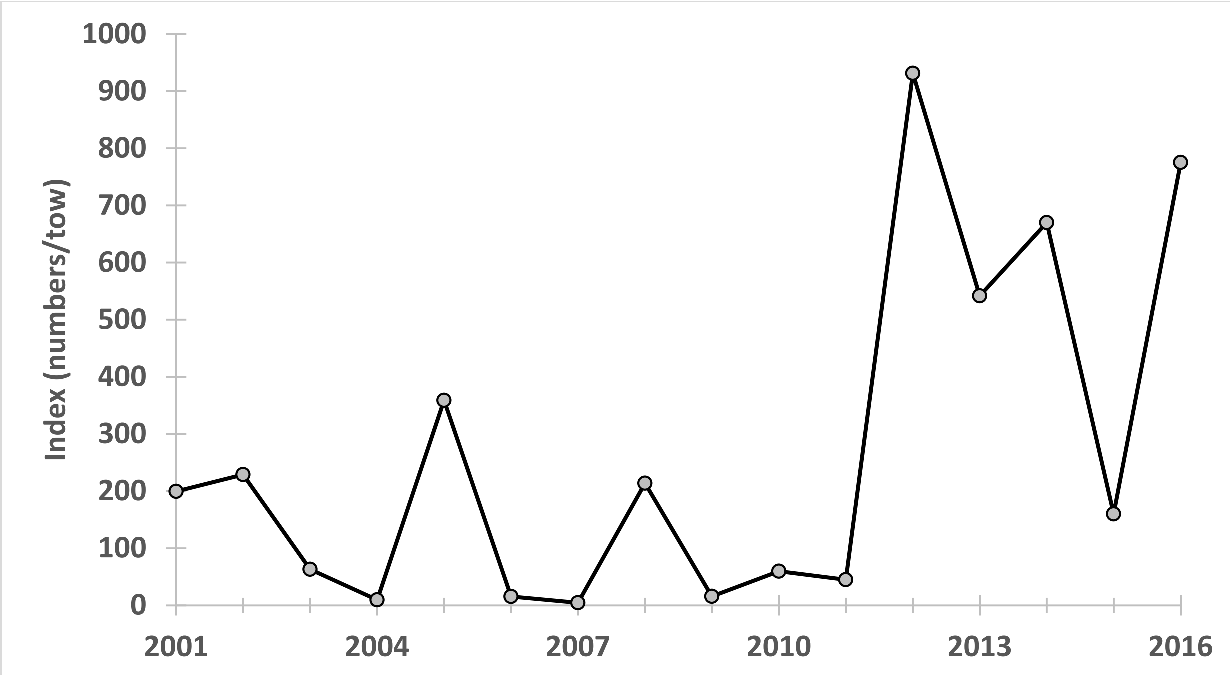


Figure 15. GLM-standardized index of abundance for YOY American eels caught by Maine's annual YOY survey in West Harbor Pond, 2001–2016. The error bars were omitted from the graph because there were several very large values. See text for more discussion on this.

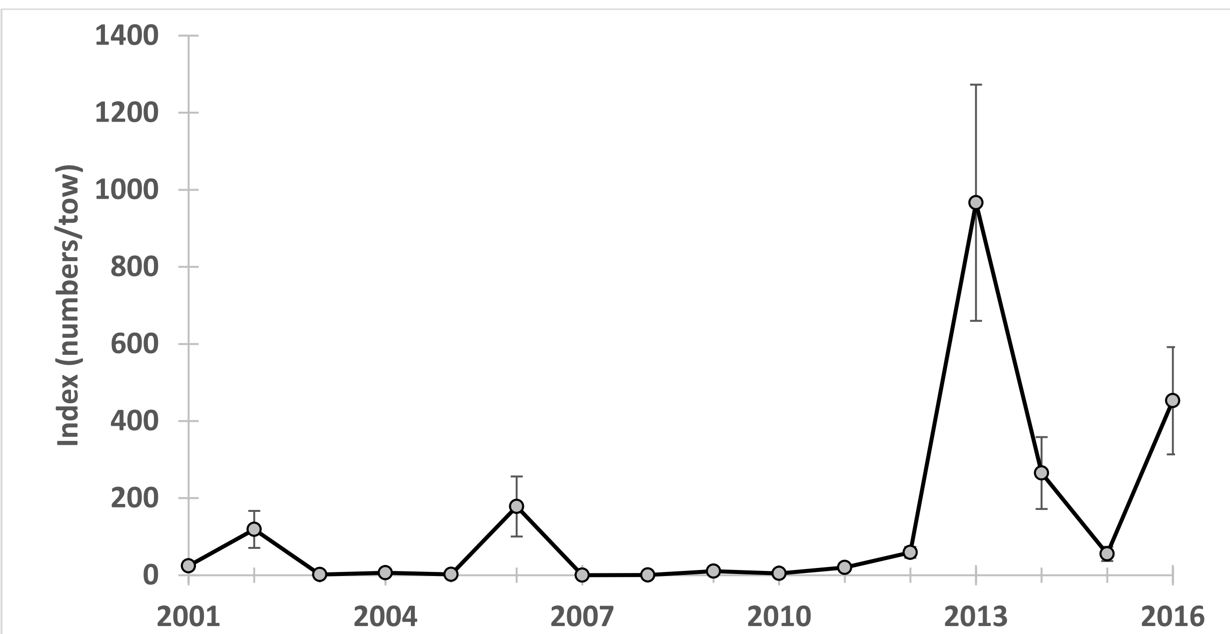


Figure 16. GLM-standardized index of abundance for YOY American eels caught by New Hampshire's annual YOY survey in the Lamprey River, 2001–2016. The error bars represent the standard errors about the estimates.

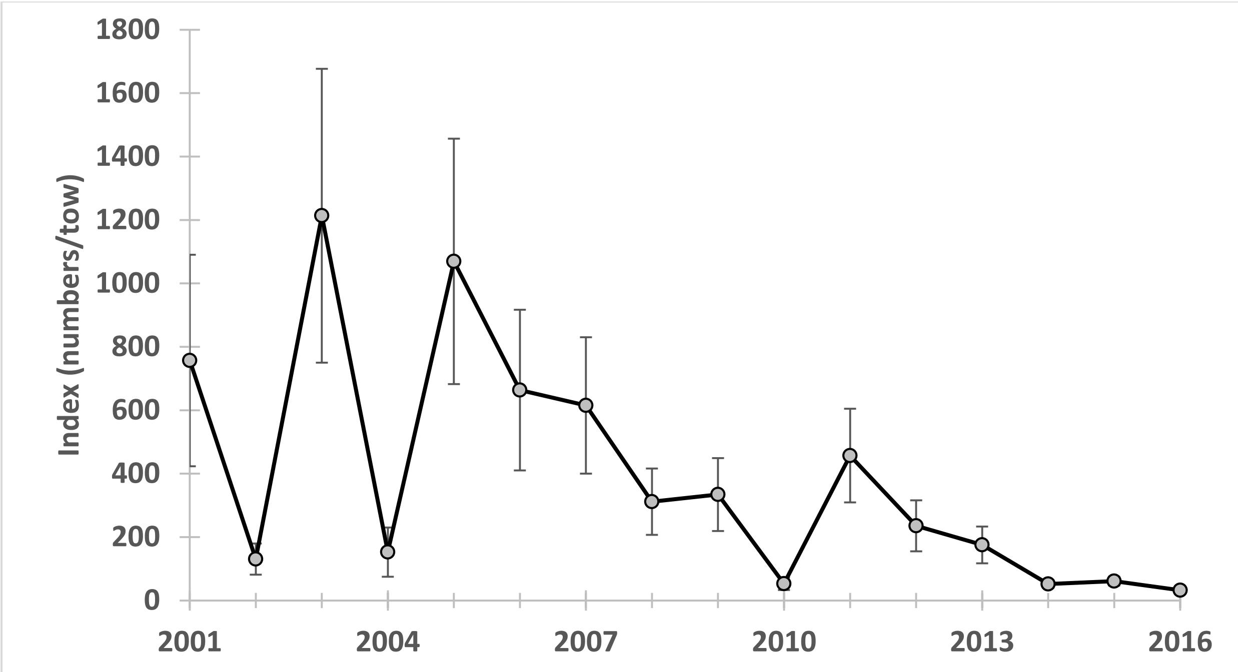


Figure 17. GLM-standardized index of abundance for YOY American eels caught by Massachusetts' annual YOY survey in the Jones River, 2001–2016. The error bars represent the standard errors about the estimates.

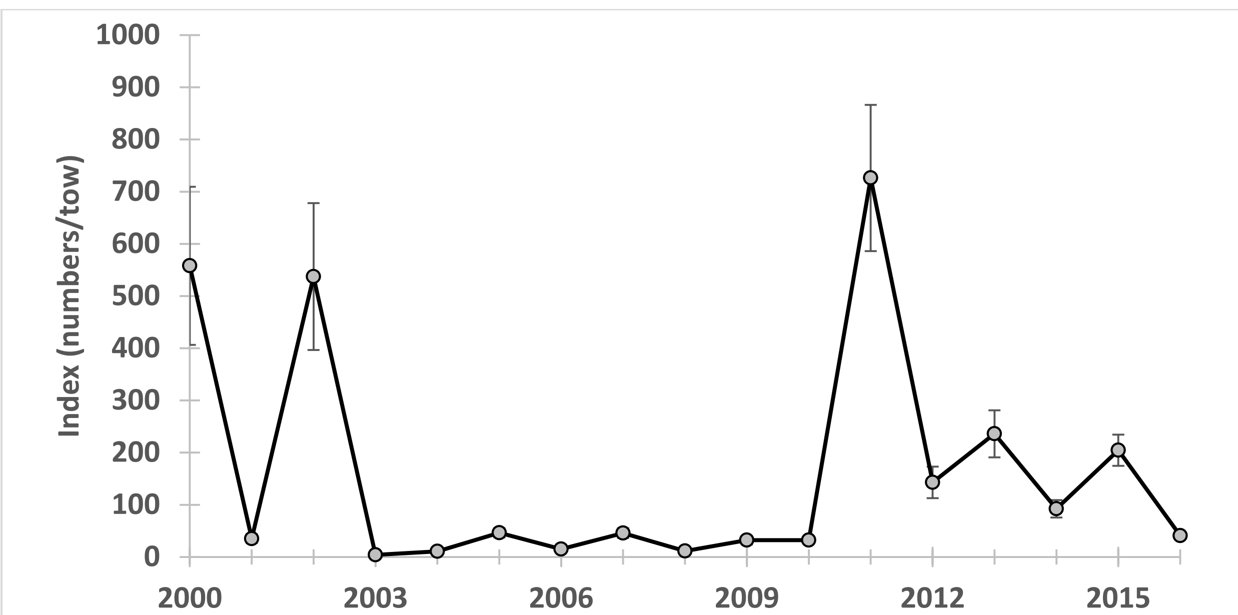


Figure 18. GLM-standardized index of abundance for American eels caught by Rhode Island's annual YOY survey near Gilbert Stuart Dam, 2000–2016. The error bars represent the standard errors about the estimates.

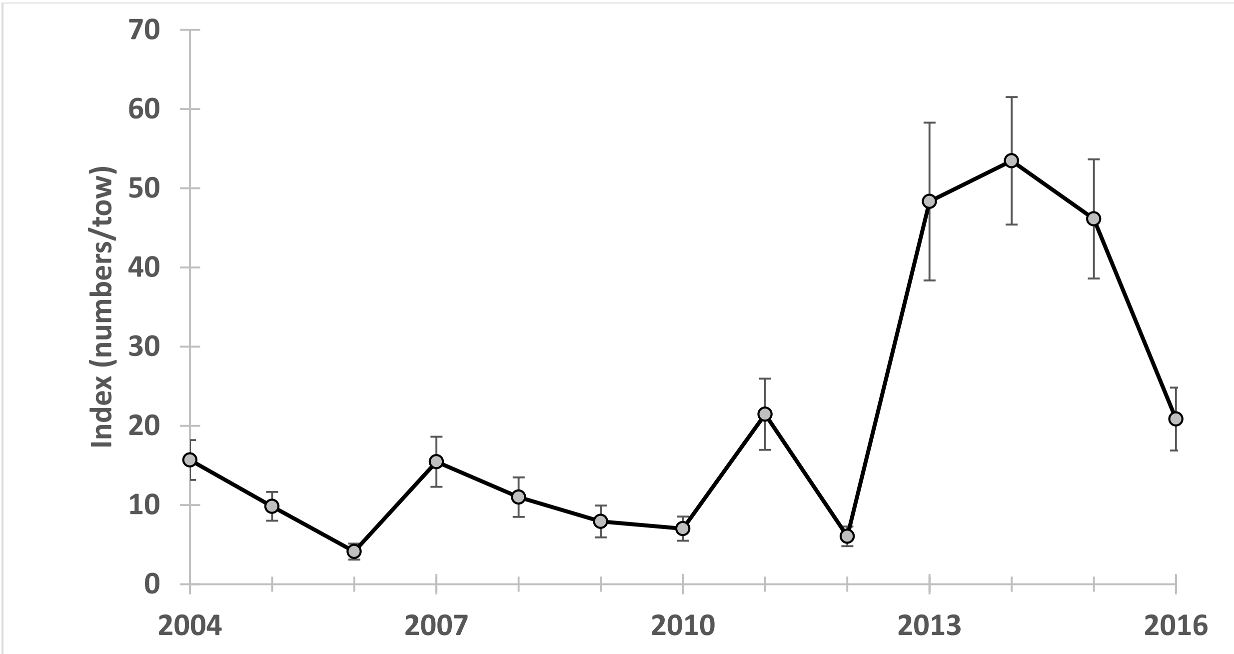


Figure 19. GLM-standardized index of abundance for American eels caught by Rhode Island's annual YOY survey at Hamilton Fish Ladder, 2004–2016. The error bars represent the standard errors about the estimates.

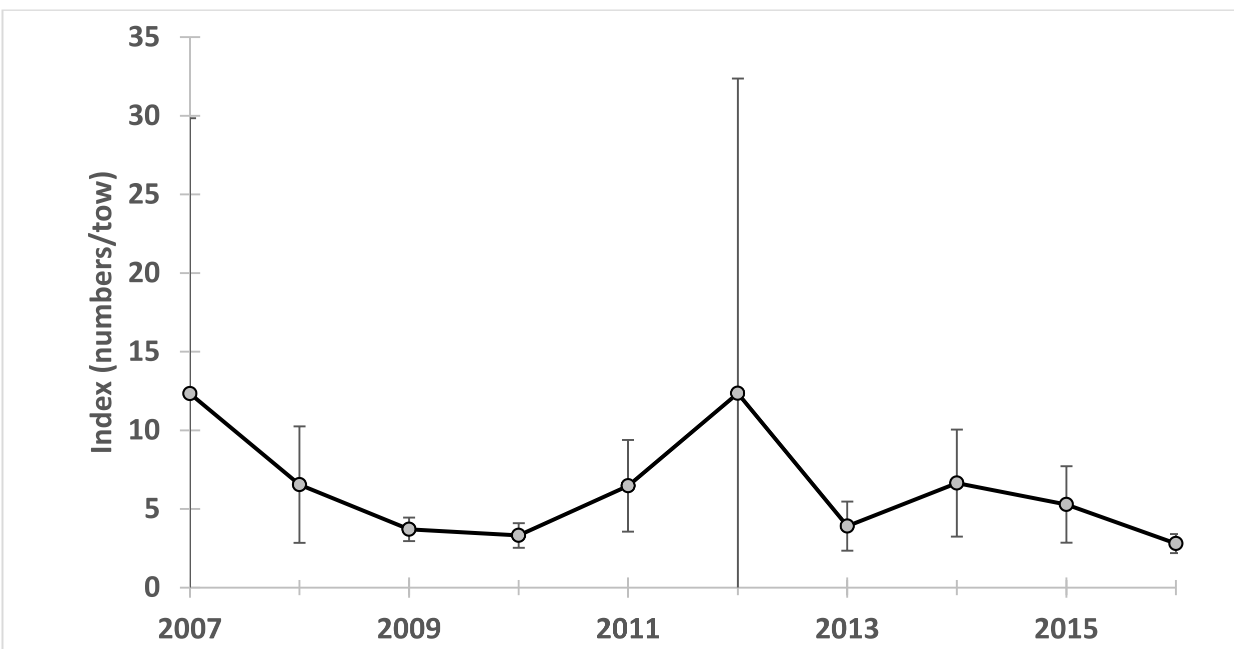


Figure 20. GLM-standardized index of abundance for American eels caught by Connecticut's annual YOY survey at Ingham Hill, 2007–2016. The error bars represent the standard errors about the estimates.

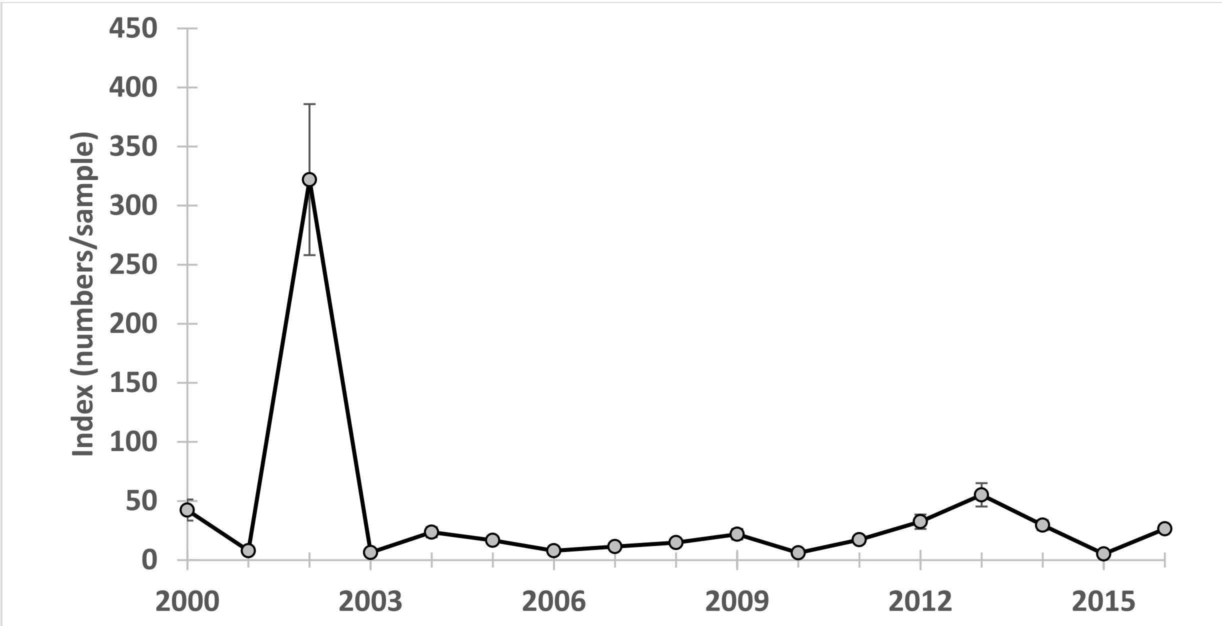


Figure 21. GLM-standardized index of abundance for American eels caught by New York's annual YOY survey in Carman's River, 2001–2016. The error bars represent the standard errors about the estimates.

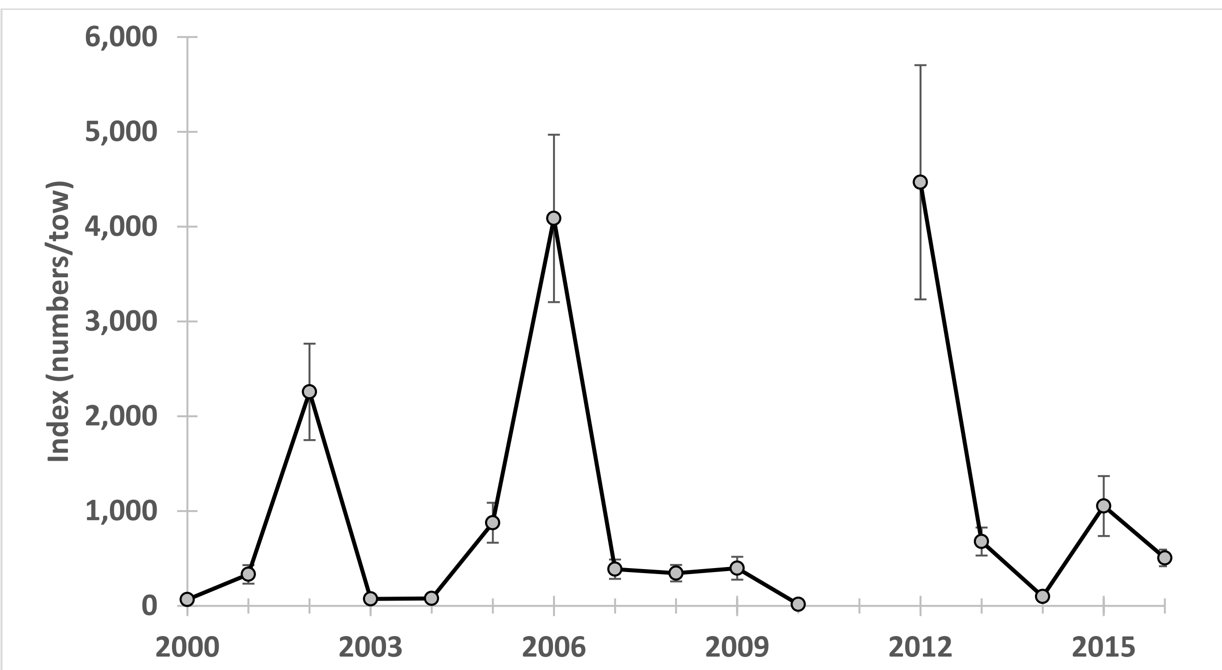


Figure 22. GLM-standardized index of abundance for YOY American eels caught by New Jersey's annual YOY survey in Patcong Creek, 2000–2016. The error bars represent the standard errors about the estimates.

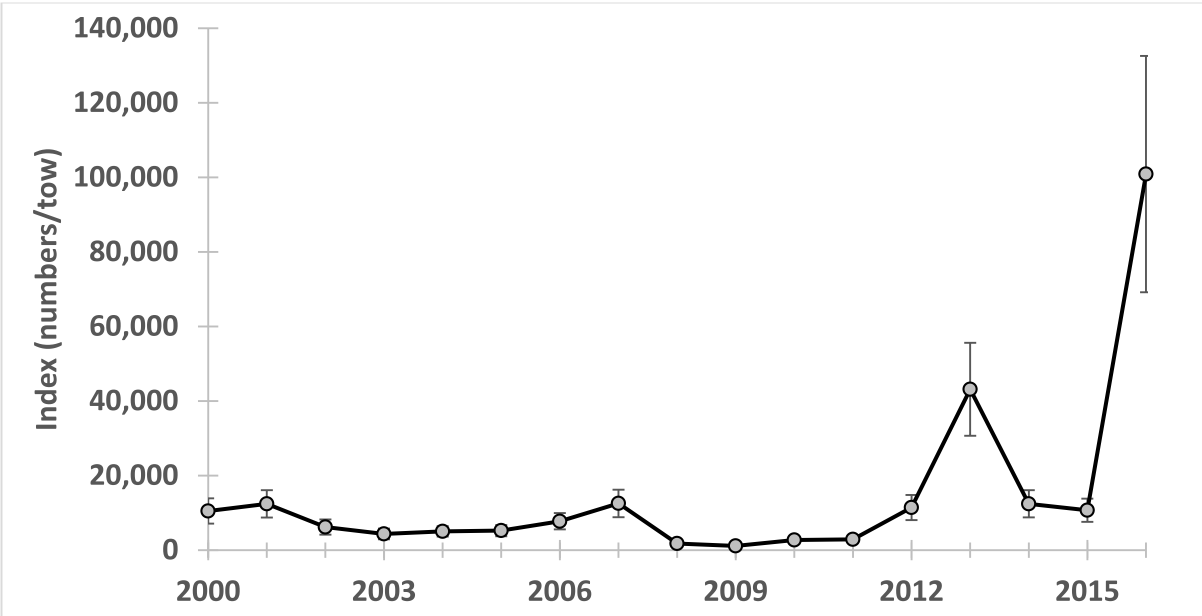


Figure 23. GLM-standardized index of abundance for American eels caught by Delaware's annual YOY survey near the Millsboro Dam, 2000–2016. The error bars represent the standard errors about the estimates.

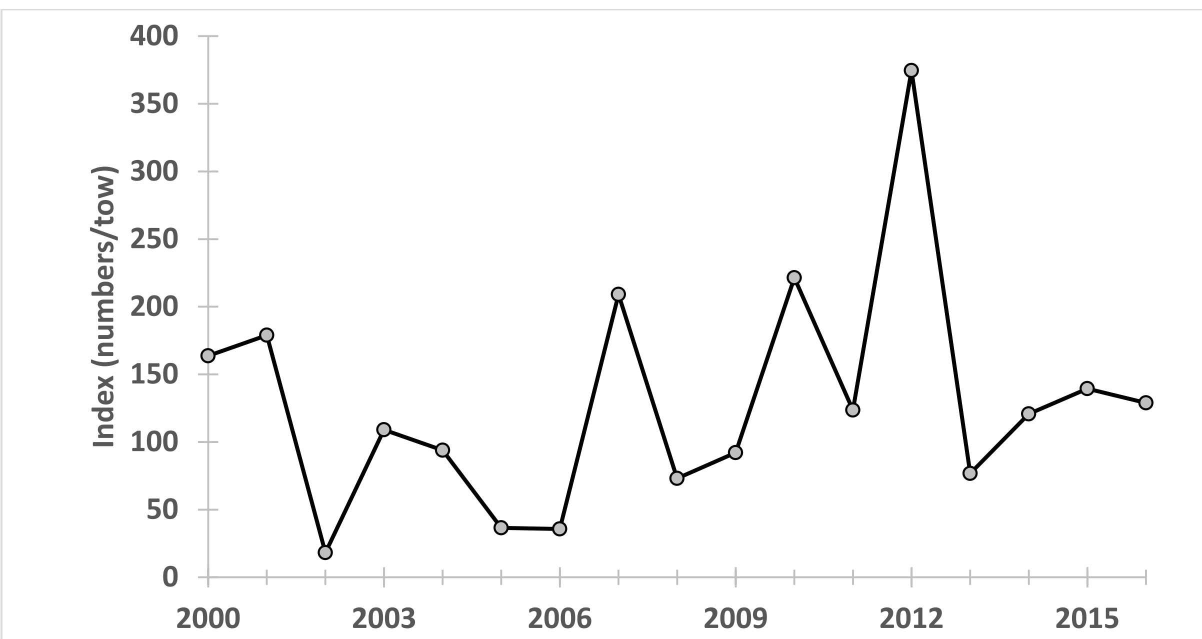


Figure 24. Annual index of abundance for American eels caught by Maryland's annual YOY survey in Turville Creek, 2000–2016. The error bars were omitted from the graph because there were several very large values. See text for more discussion.

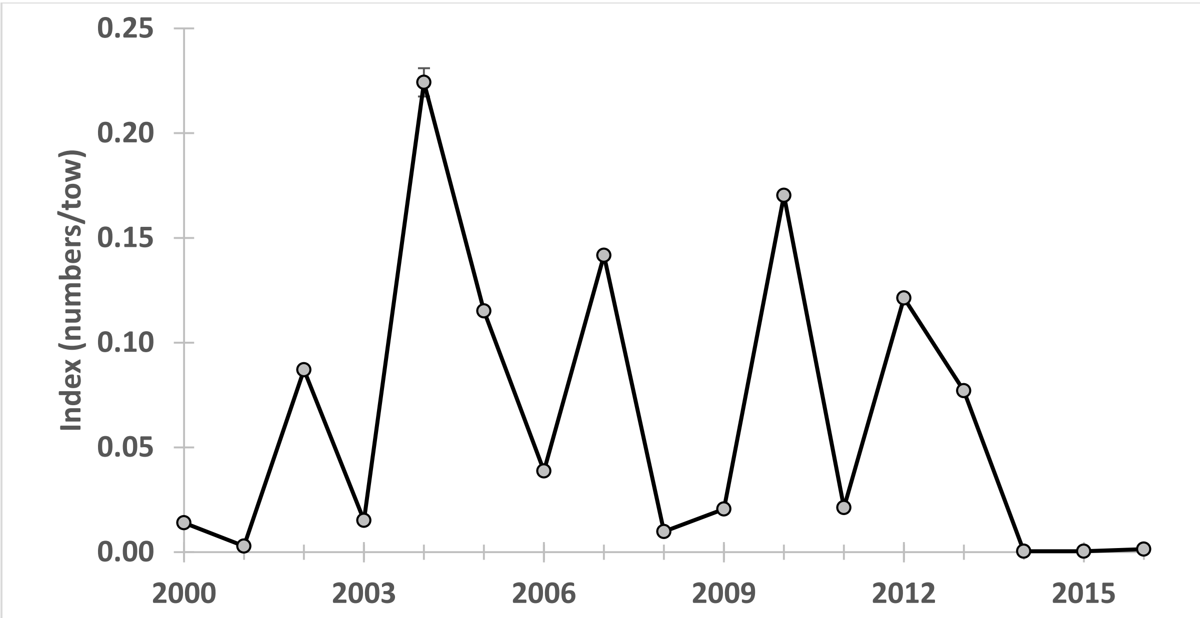


Figure 25. GLM-standardized index of abundance for American eels caught by PRFC's annual YOY survey in Clark's Millpond, 2000–2016. The error bars represent the standard errors about the estimates.

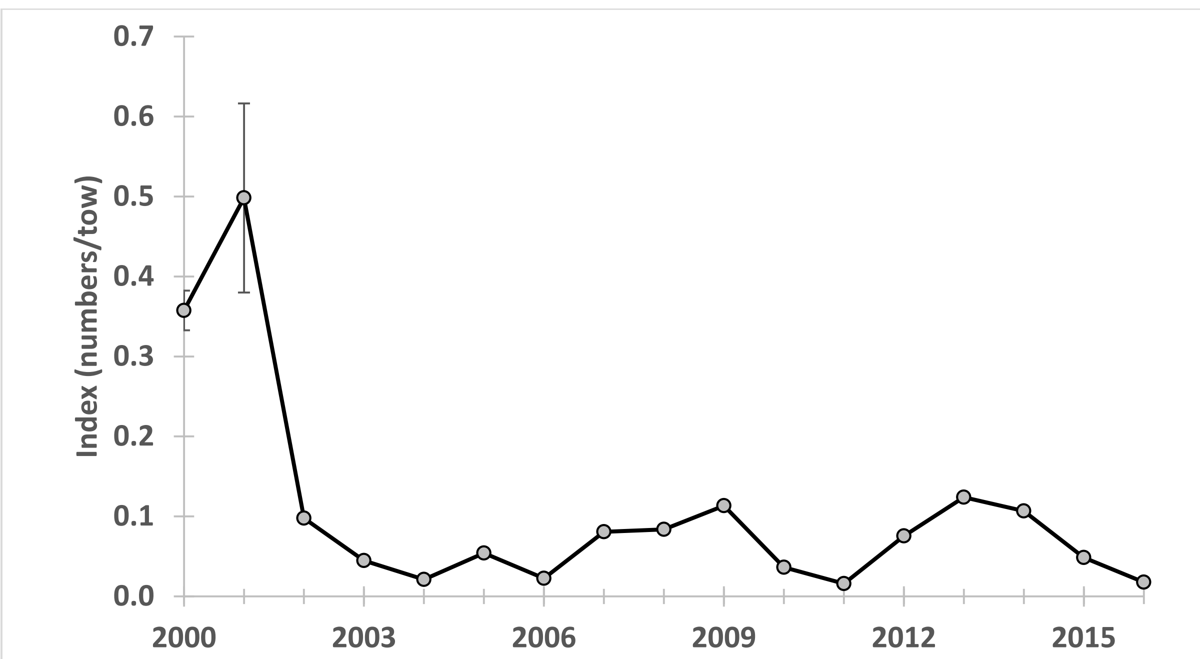


Figure 26. GLM-standardized index of abundance for American eels caught by PRFC's annual YOY survey in Gardy's Millpond, 2000–2016. The error bars represent the standard errors about the estimates.

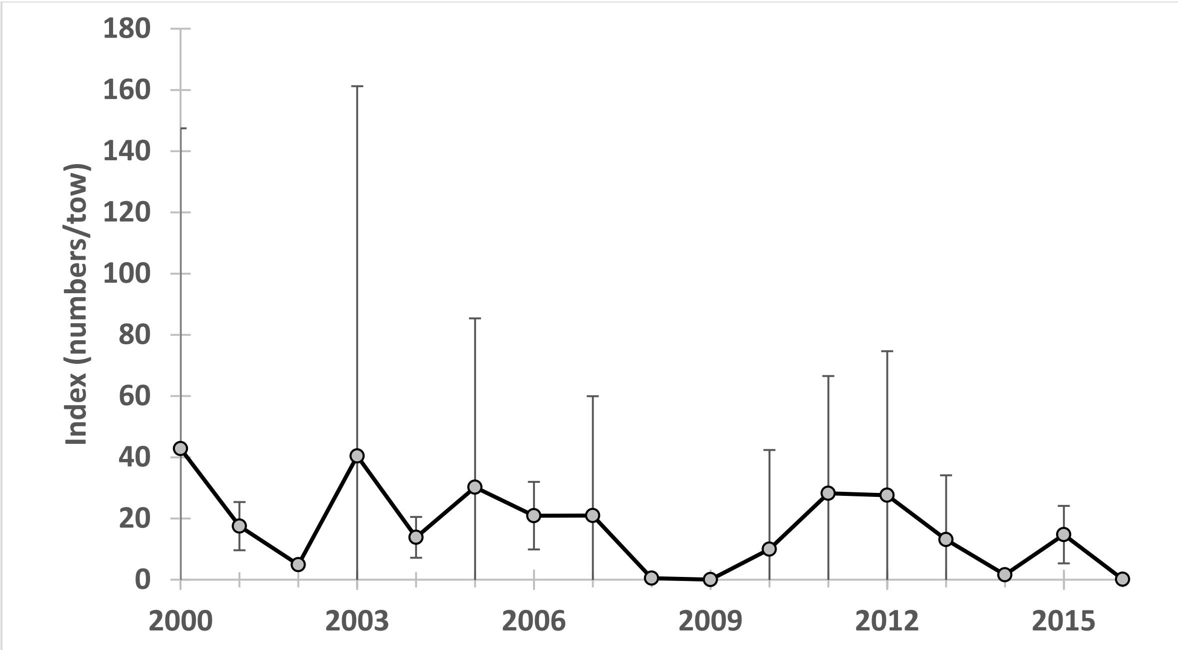


Figure 27. **Annual index of abundance for American eels caught by Virginia's annual YOY survey in Bracken's Pond, 2000–2016. The error bars represent the standard errors about the estimates.**

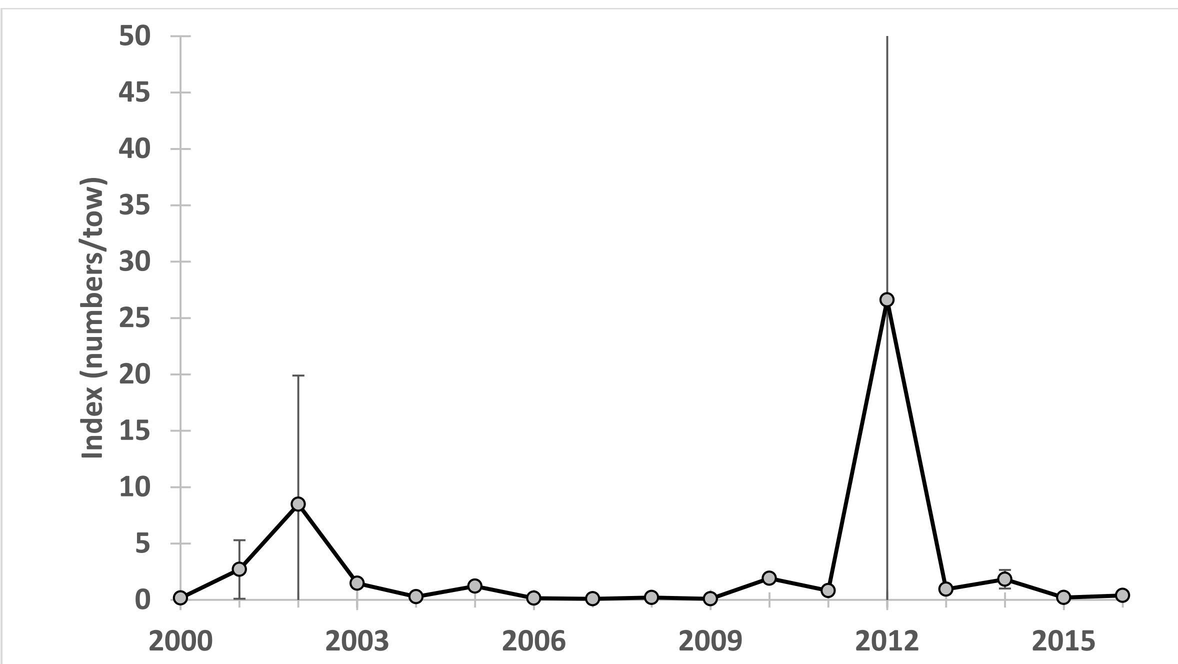


Figure 28. **GLM-standardized index of abundance for American eels caught by Virginia's annual YOY survey in Kamp's Millpond, 2000–2016. The error bars represent the standard errors about the estimates.**

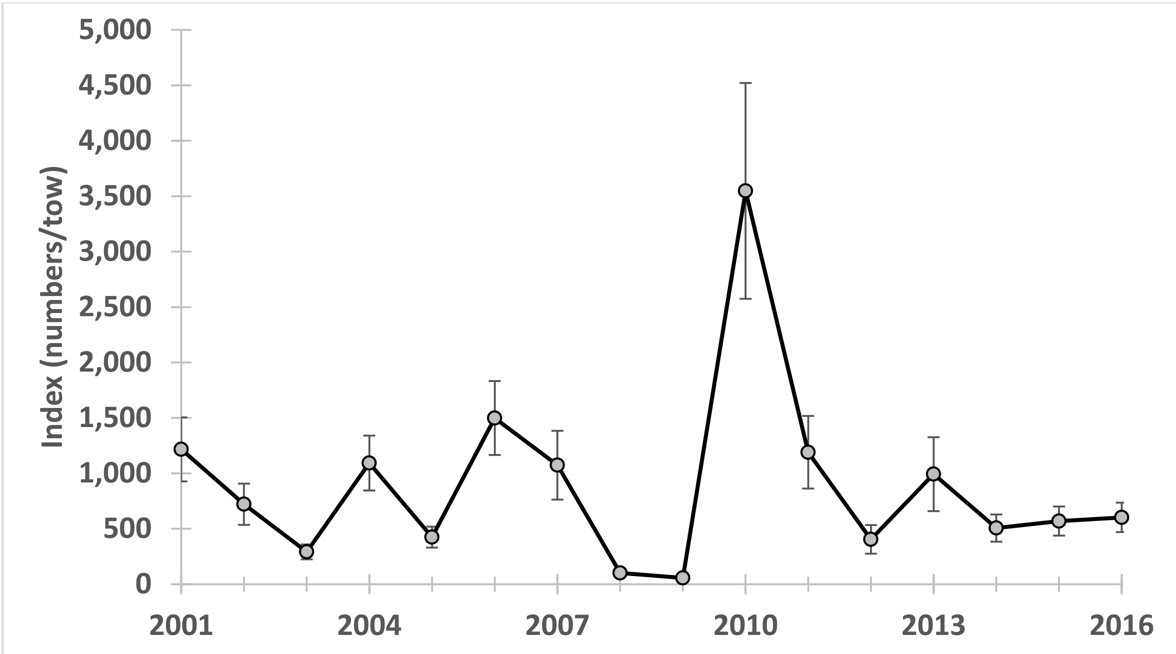


Figure 29. GLM-standardized index of abundance for American eels caught by Virginia's annual YOY survey in Wormley Creek, 2001–2016. The error bars represent the standard errors about the estimates.

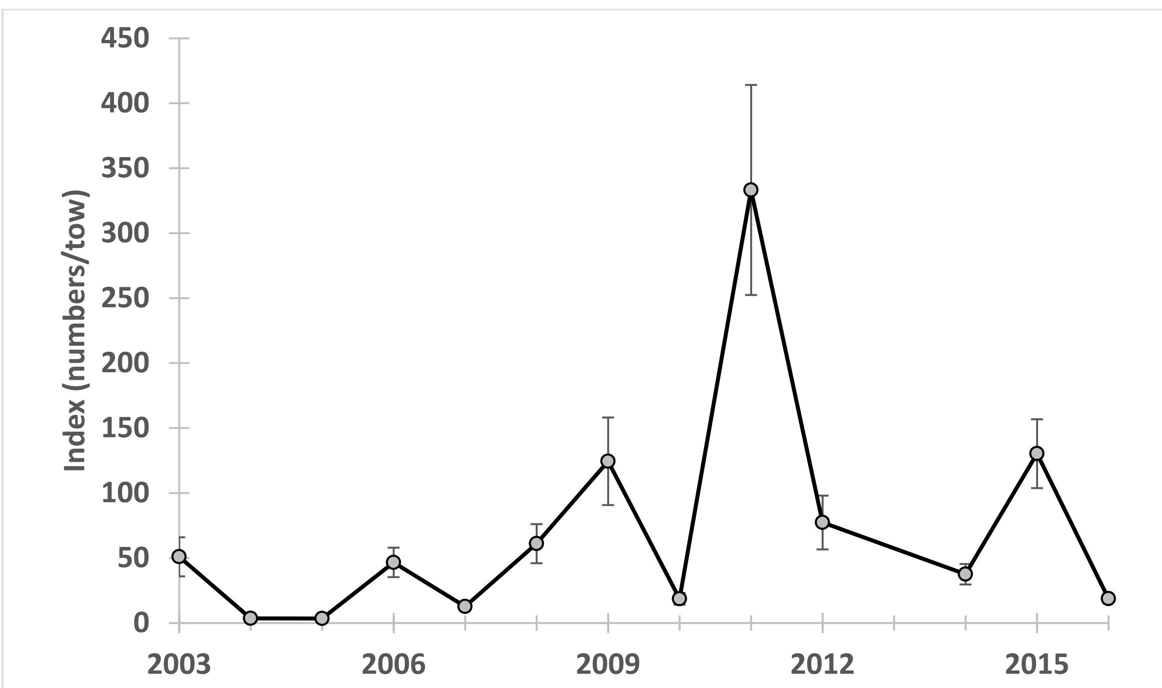


Figure 30. GLM-standardized index of abundance for American eels caught by Virginia's annual YOY survey in Wareham's Pond, 2003–2016. The error bars represent the standard errors about the estimates.

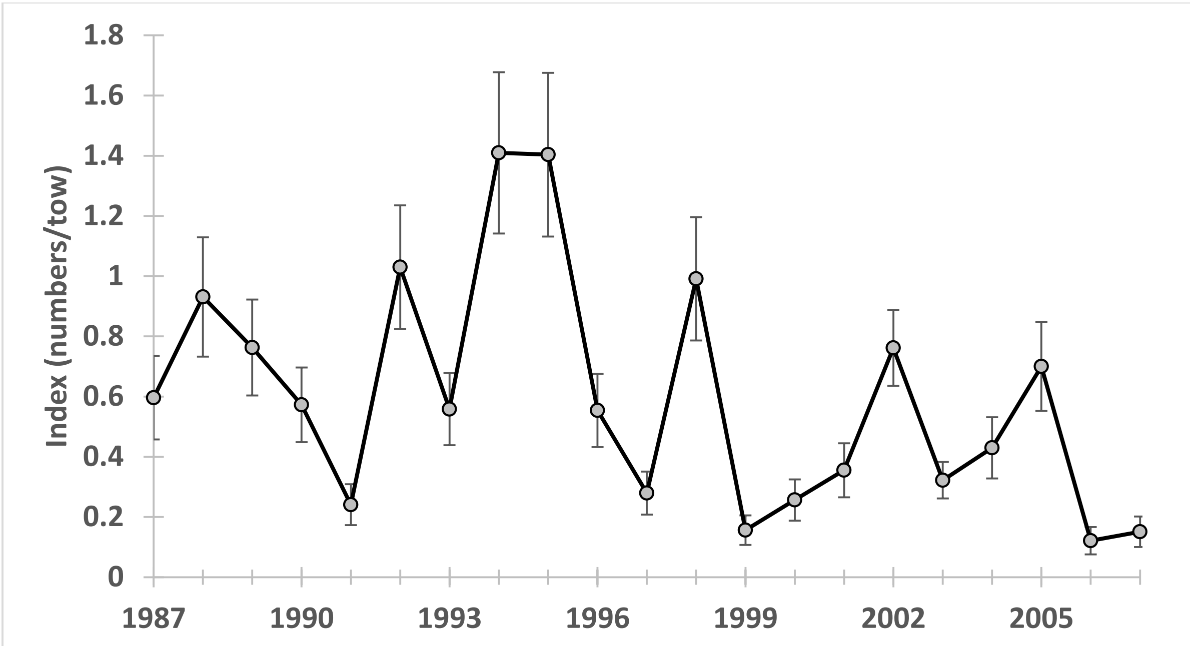


Figure 31. GLM-standardized index of abundance for YOY American eels caught by North Carolina's Beaufort Bridgenet Ichthyoplankton Sampling Program (BBISP) conducted by NOAA, 1987–2007. The error bars represent the standard errors about the estimates.

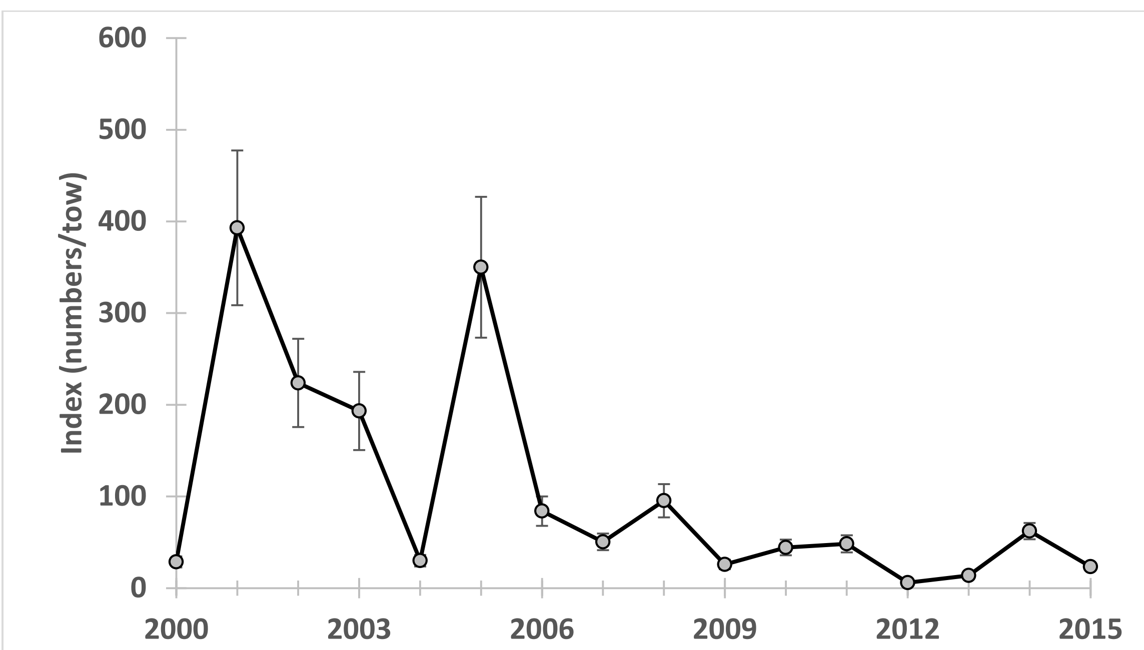


Figure 32. GLM-standardized index of abundance for American eels caught by South Carolina's annual YOY survey in Goose Creek, 2000–2015. The error bars represent the standard errors about the estimates.

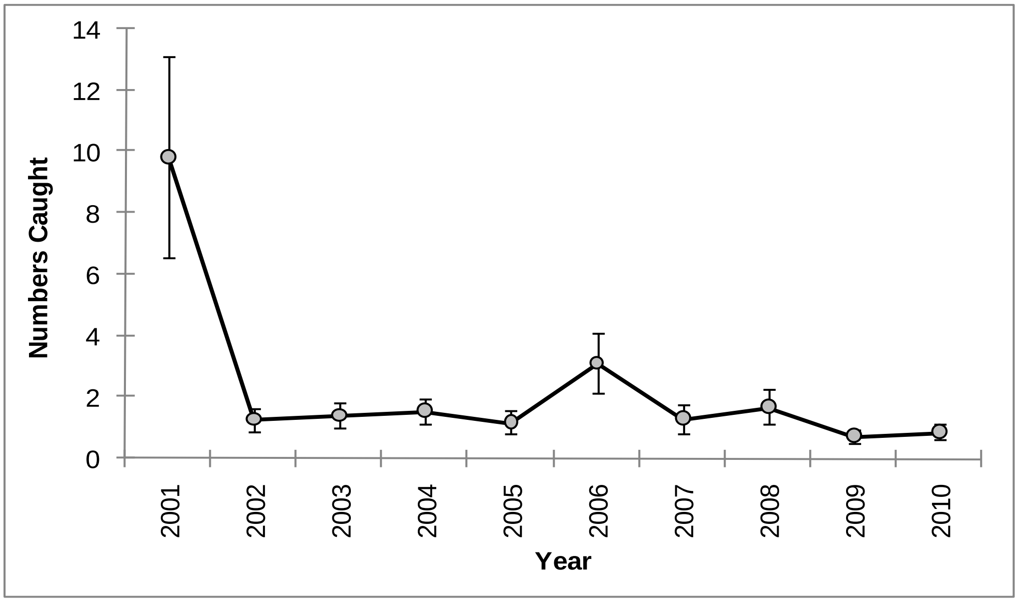


Figure 33. GLM-standardized index of abundance for American eels caught by Georgia's annual YOY survey near the Altamaha Canal, 2001–2010. The error bars represent the standard errors about the estimates. This index was not updated because the site was discontinued.

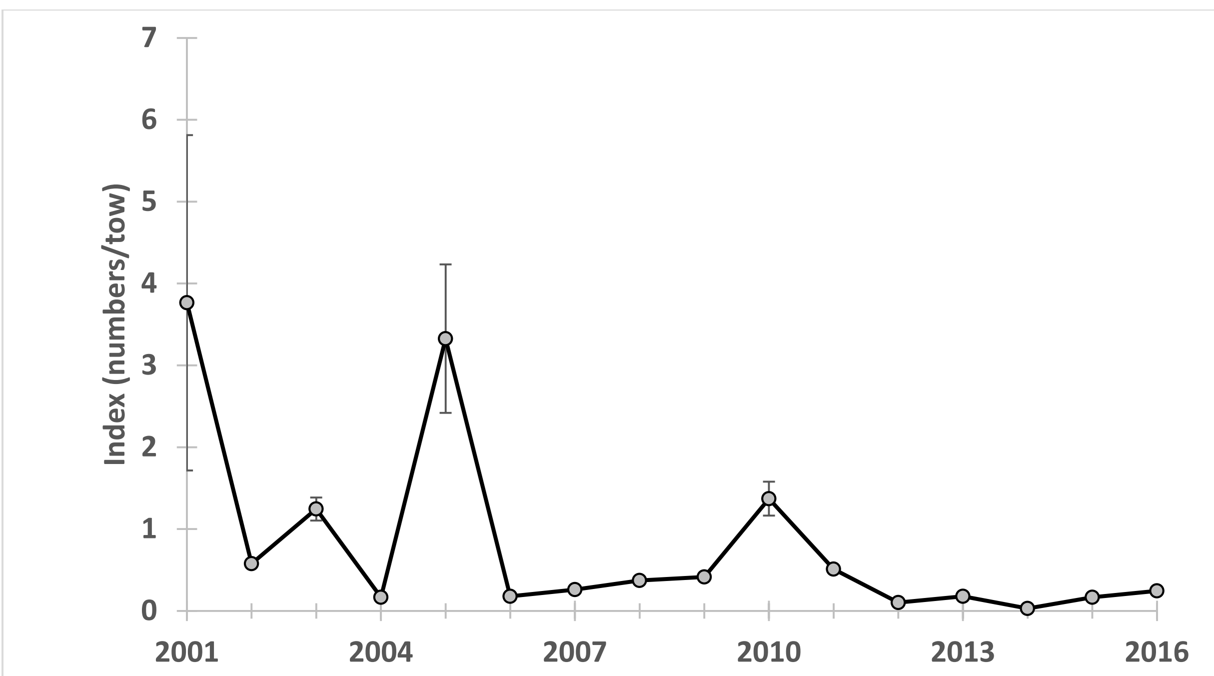


Figure 34. Annual index of abundance for American eels caught by Florida's annual YOY survey near Guana River Dam, 2001–2016. The error bars represent the standard errors about the estimates.

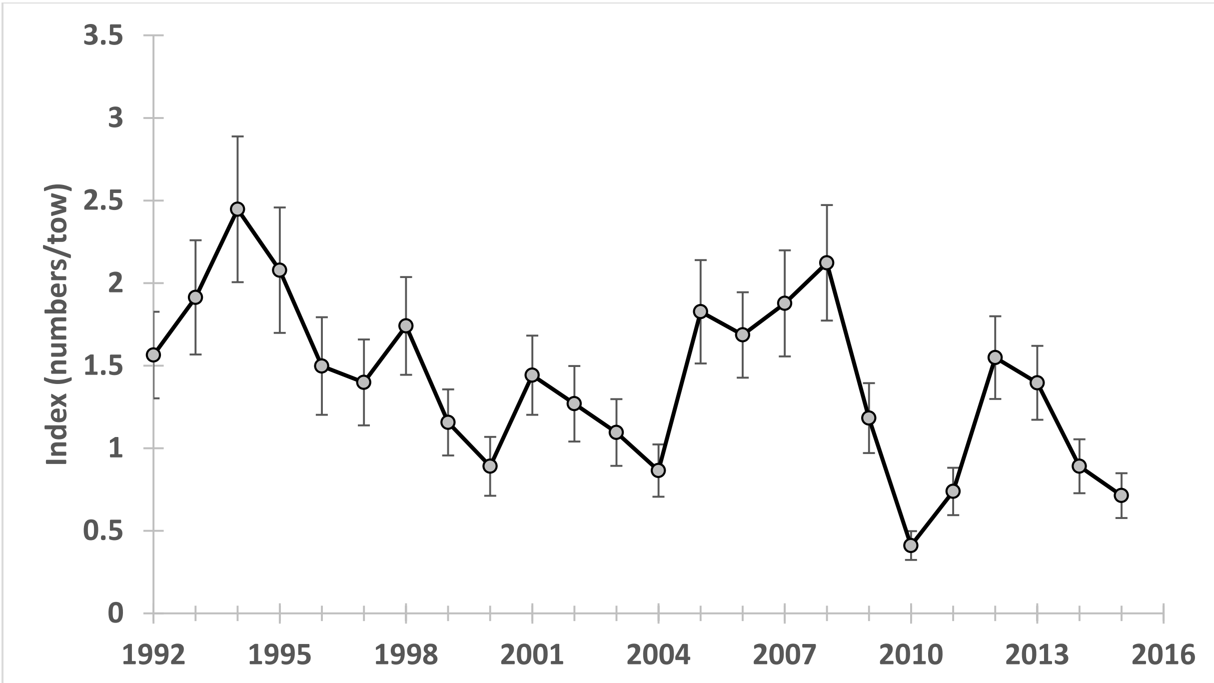


Figure 35. GLM-standardized index of abundance for YOY American eels caught by the Little Egg Inlet Ichthyoplankton Survey, 1992–2016. The error bars represent the standard errors about the estimates.

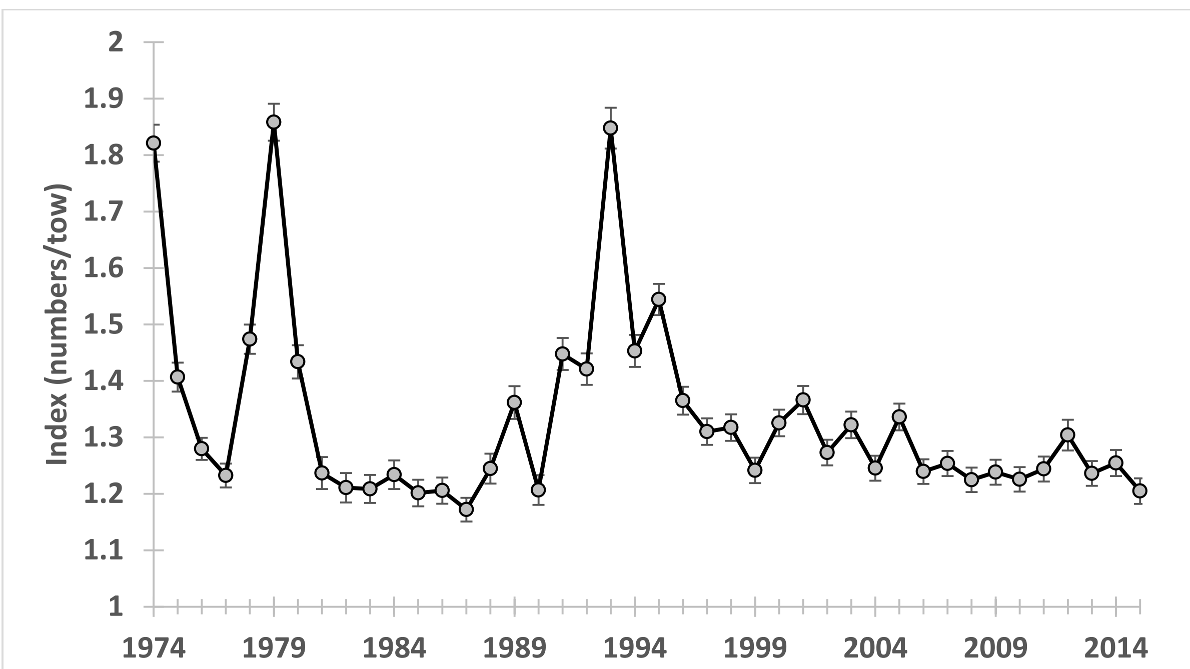


Figure 36. GLM-standardized index of abundance for YOY American eels caught by the Hudson River Estuary Monitoring Program's Ichthyoplankton Survey, 1974–2015. The error bars represent the standard errors about the estimates.

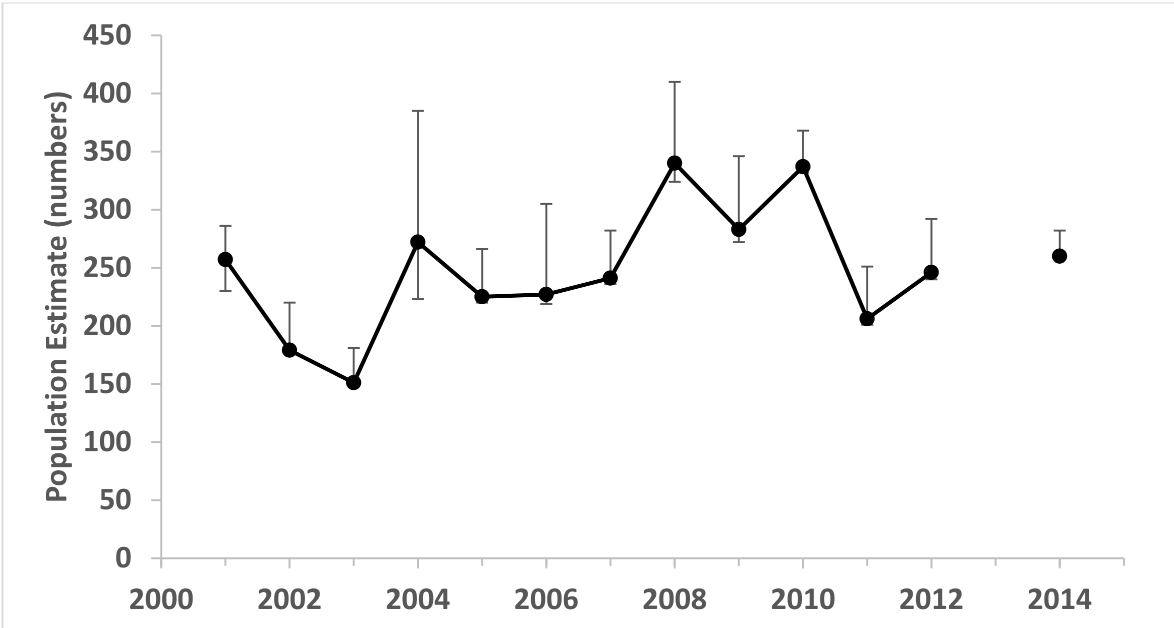


Figure 37. Annual index of abundance for American eels caught by the CTDEP Electrofishing Survey in the Farmill River, 2001–2014. The error bars represent 95% confidence intervals.

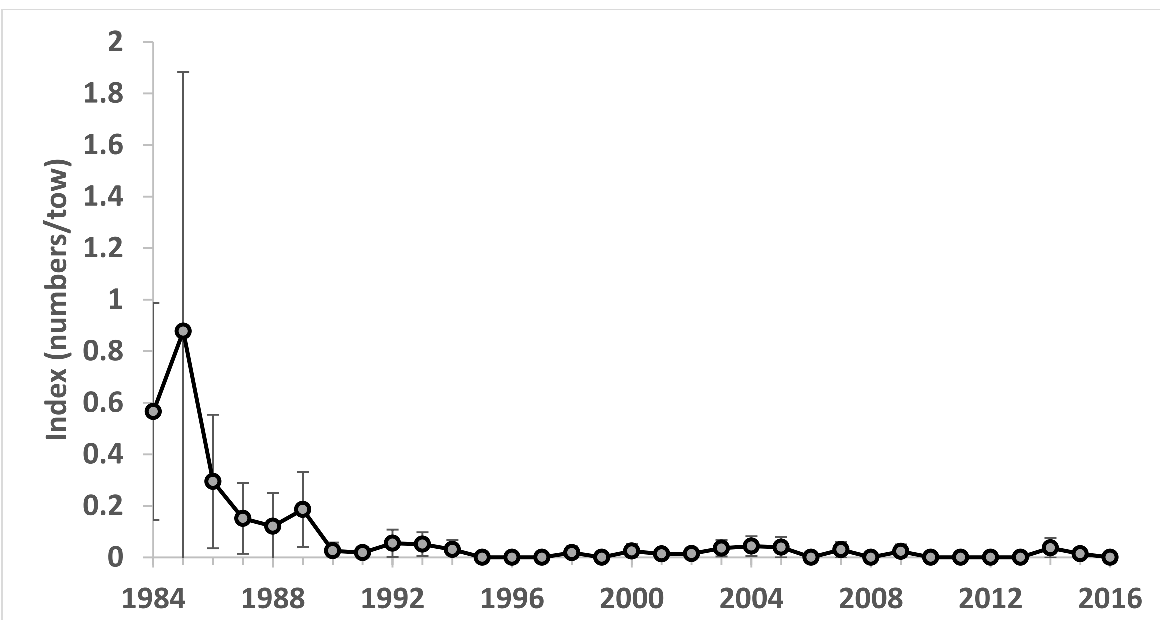


Figure 38. GLM-standardized index of abundance for American eels caught by the NY Western Long Island Survey, 1984–2016. The error bars represent the standard errors about the estimates.

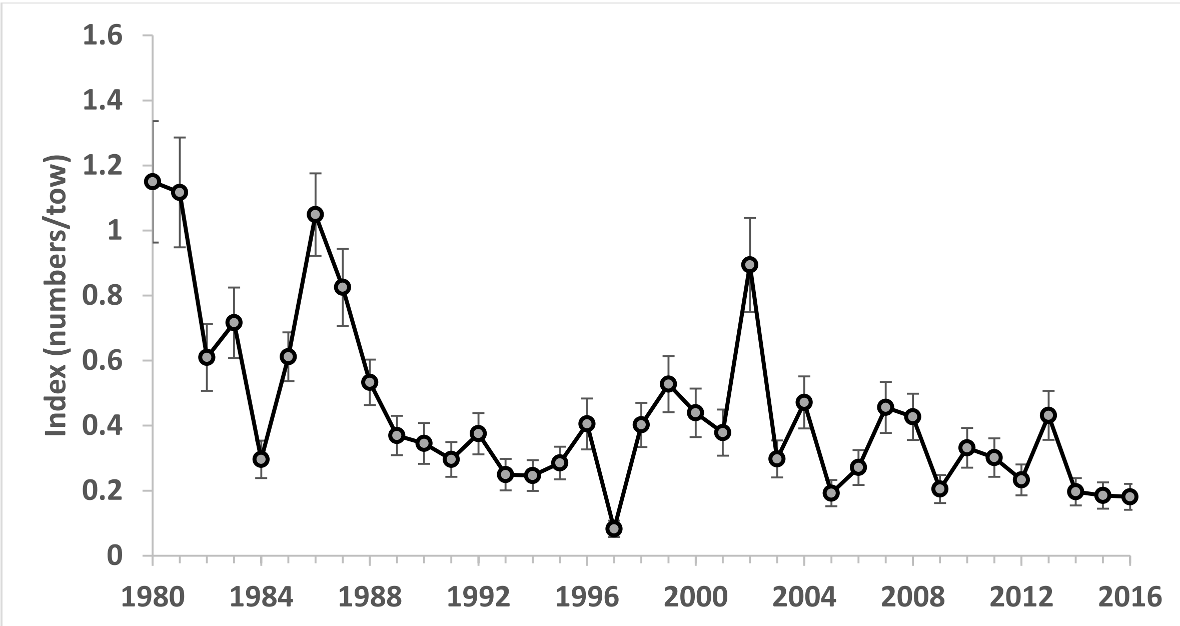


Figure 39. Annual index of abundance for American eels caught by the NYDEC Alosine Beach Seine Survey, 1980–2016. The error bars represent the standard errors about the estimates.

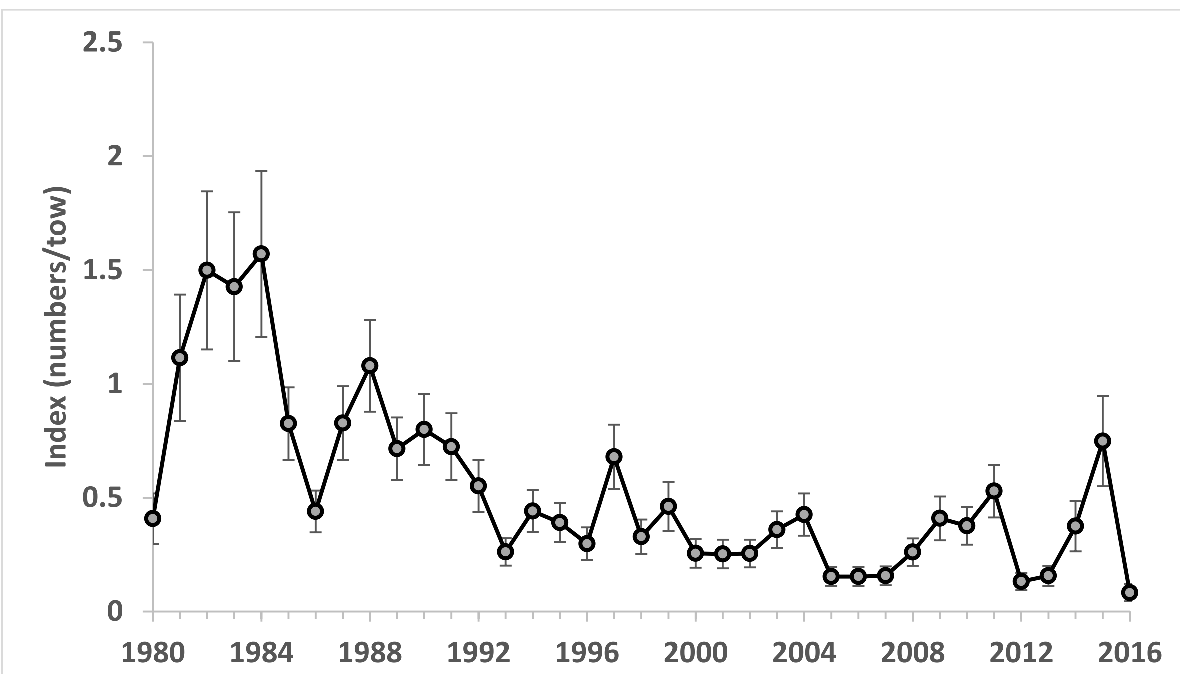


Figure 40. Annual index of abundance for American eels caught by the NYDEC Striped Bass Beach Seine Survey, 1980–2016. The error bars represent the standard errors about the estimates.

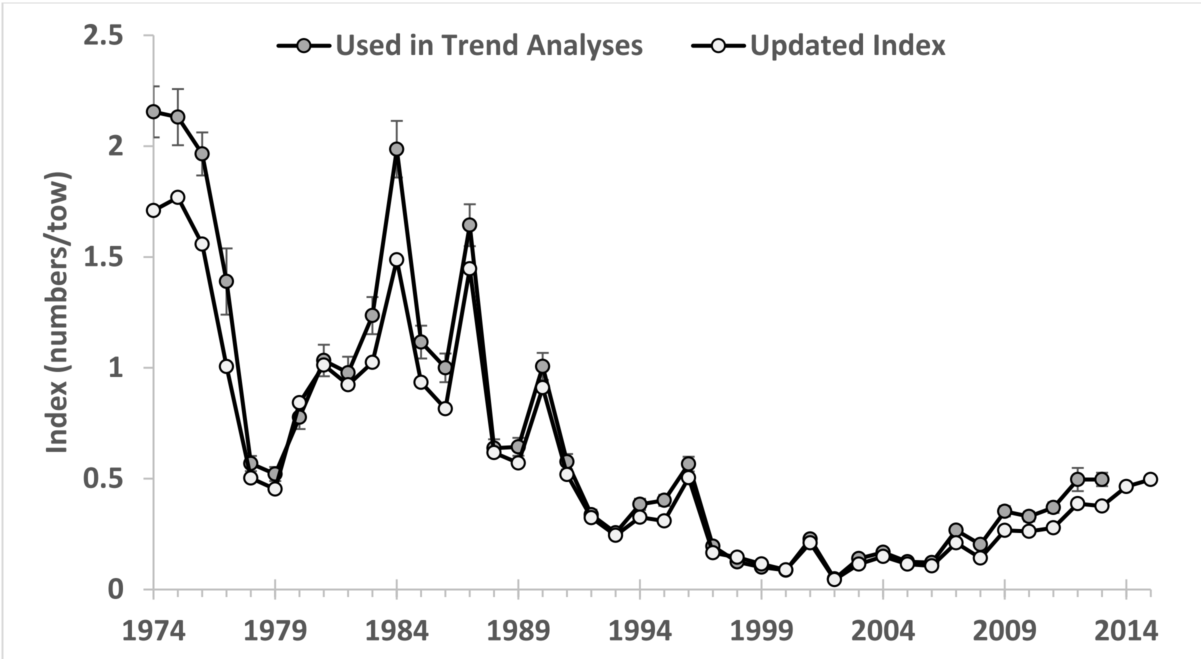


Figure 41. GLM-standardized index of abundance for yearling and older American eels caught by the HRE Monitoring Program. The error bars represent the standard errors about the estimates. Refer to section 5.2.2.1 for index discussion.

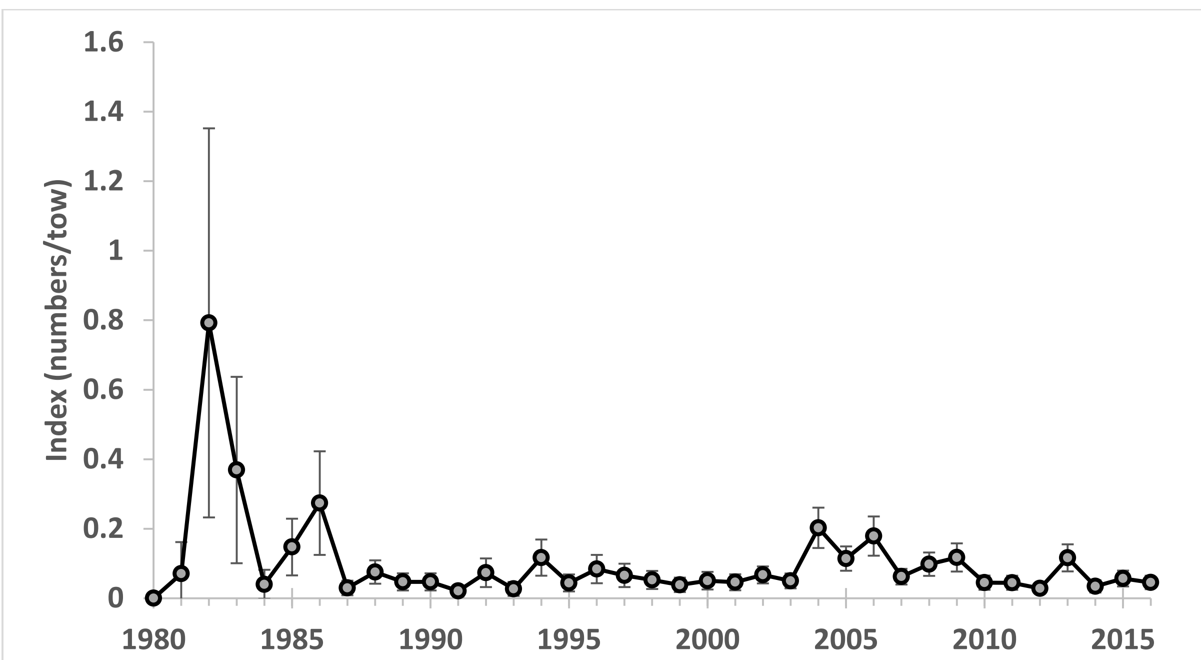


Figure 42. GLM-standardized index of abundance for American eels caught by NJDFW's Striped Bass Seine Survey, 1980–2016. The error bars represent the standard errors about the estimates.

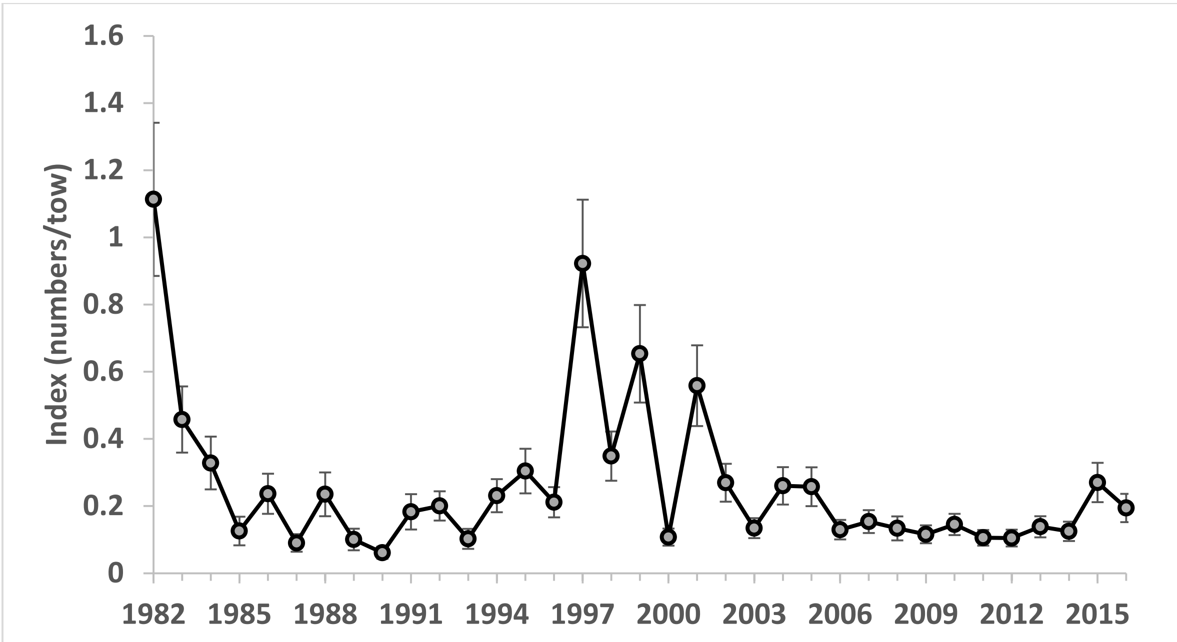


Figure 43. GLM-standardized index of abundance for American eels caught by the Delaware Trawl Survey, 1982–2016. The error bars represent the standard errors about the estimates.

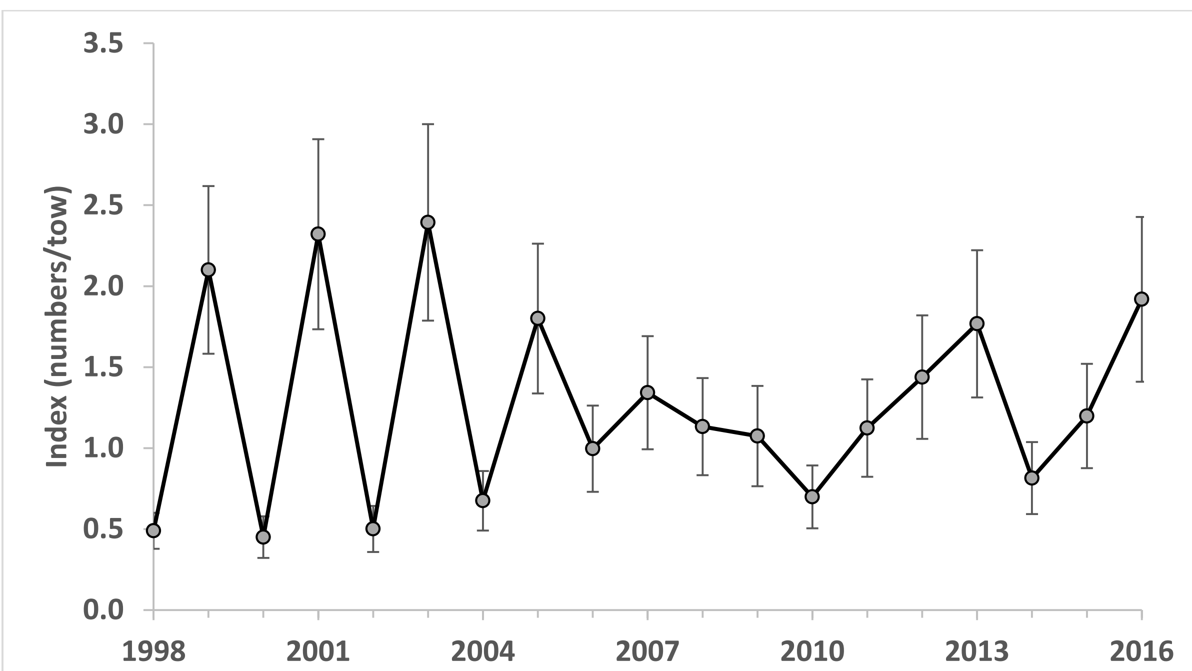


Figure 44. GLM-standardized index of abundance for American eels caught by PSEG's Trawl Survey, 1998-2016. The error bars represent the standard errors about the estimates.

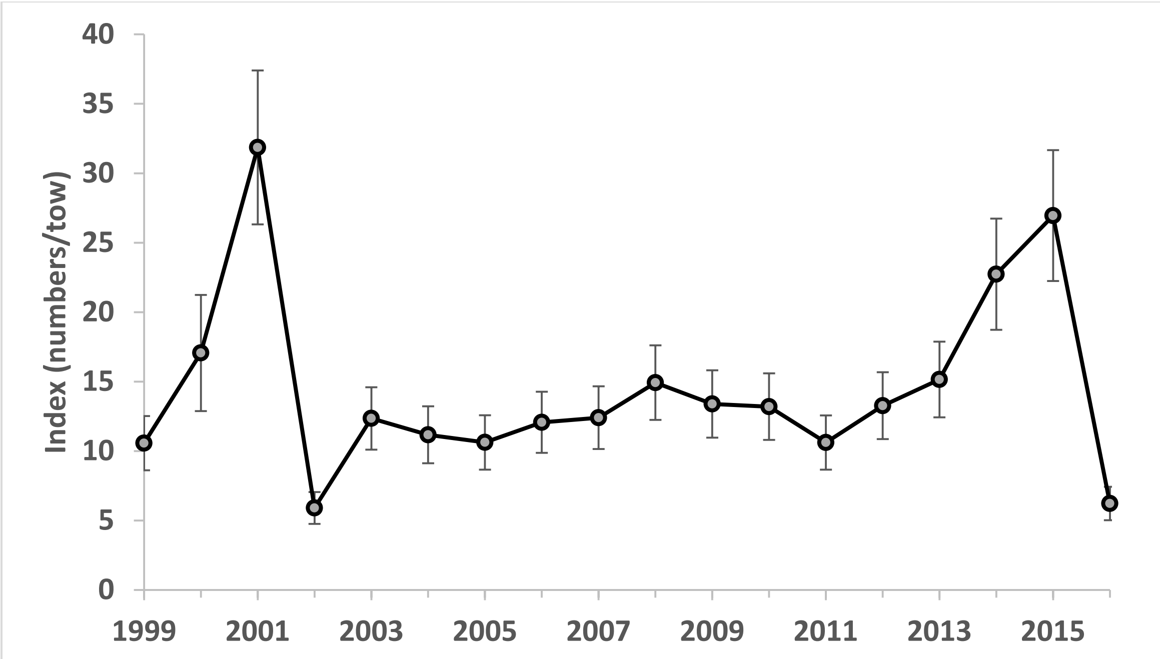


Figure 45. GLM-standardized index of abundance for American eels caught by the Area 6 Electrofishing Survey, 1999–2016. The error bars represent the standard errors about the estimates.

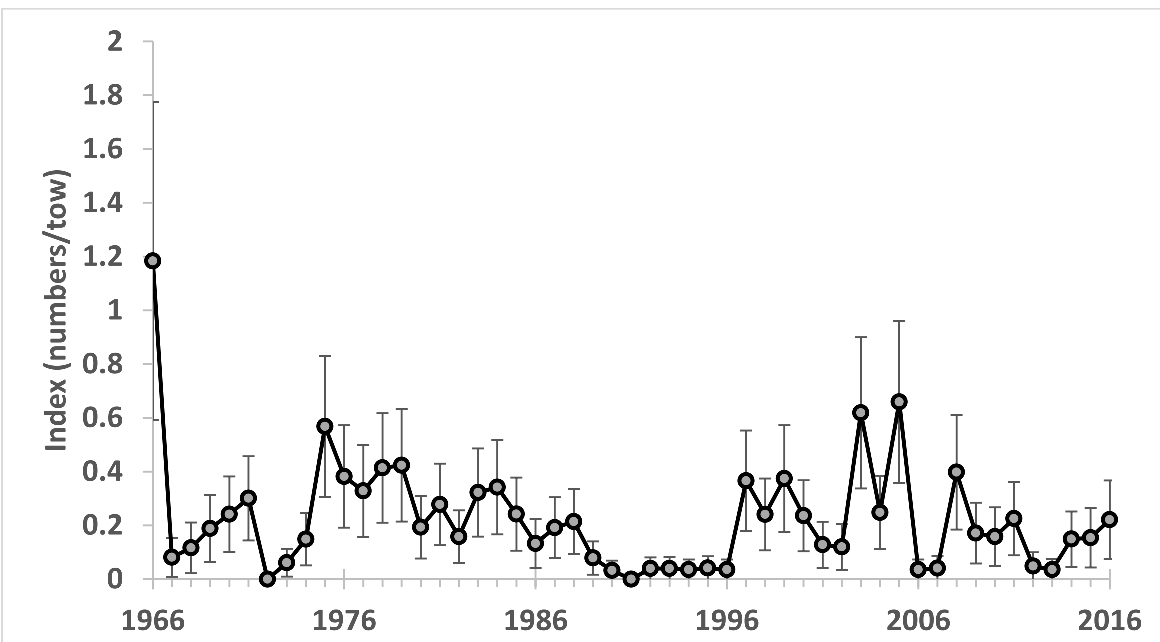


Figure 46. GLM-standardized index of abundance for American eels caught by the MDDNR Striped Bass Seine Survey, 1966–2016. The error bars represent the standard errors about the estimates.

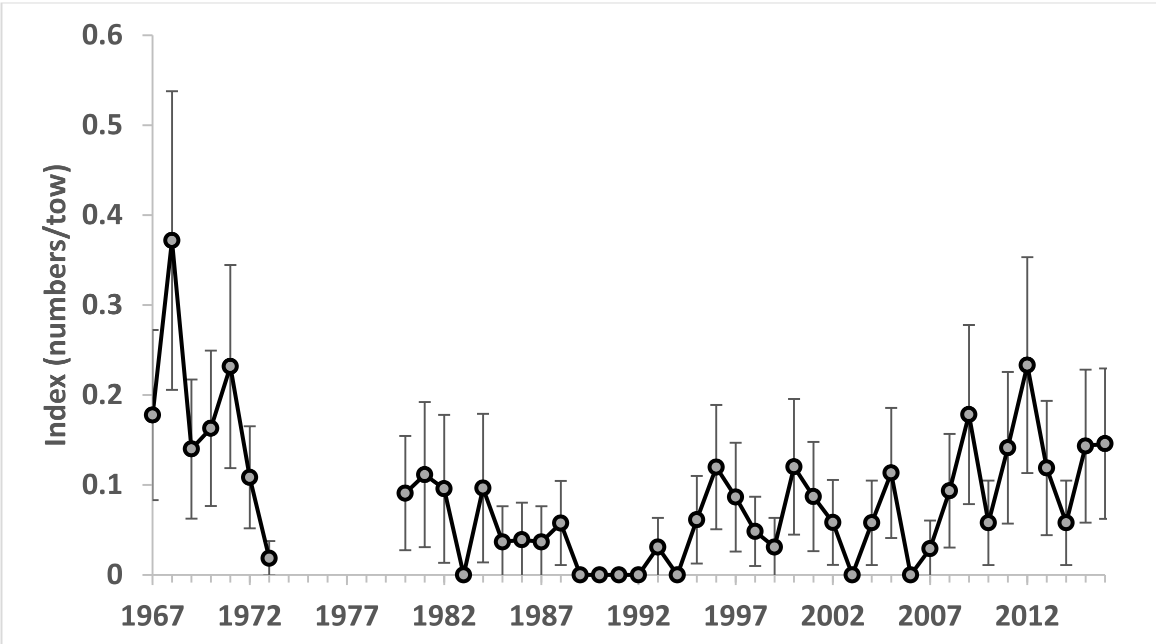


Figure 47. GLM-standardized index of abundance for American eels caught by the VIMS Juvenile Striped Bass Seine Survey, 1967–2016. The error bars represent the standard errors about the estimates.

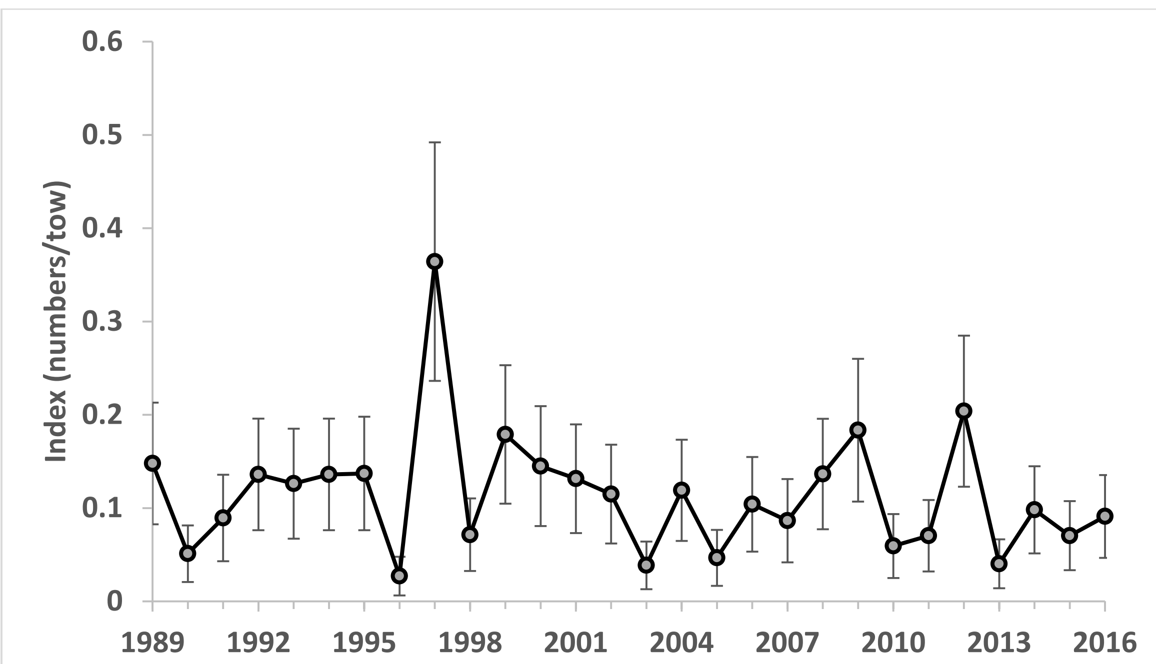


Figure 48. GLM-standardized index of abundance for American eels caught by the VIMS Juvenile Striped Bass Seine Survey, 1989–2016. The error bars represent the standard errors about the estimates.

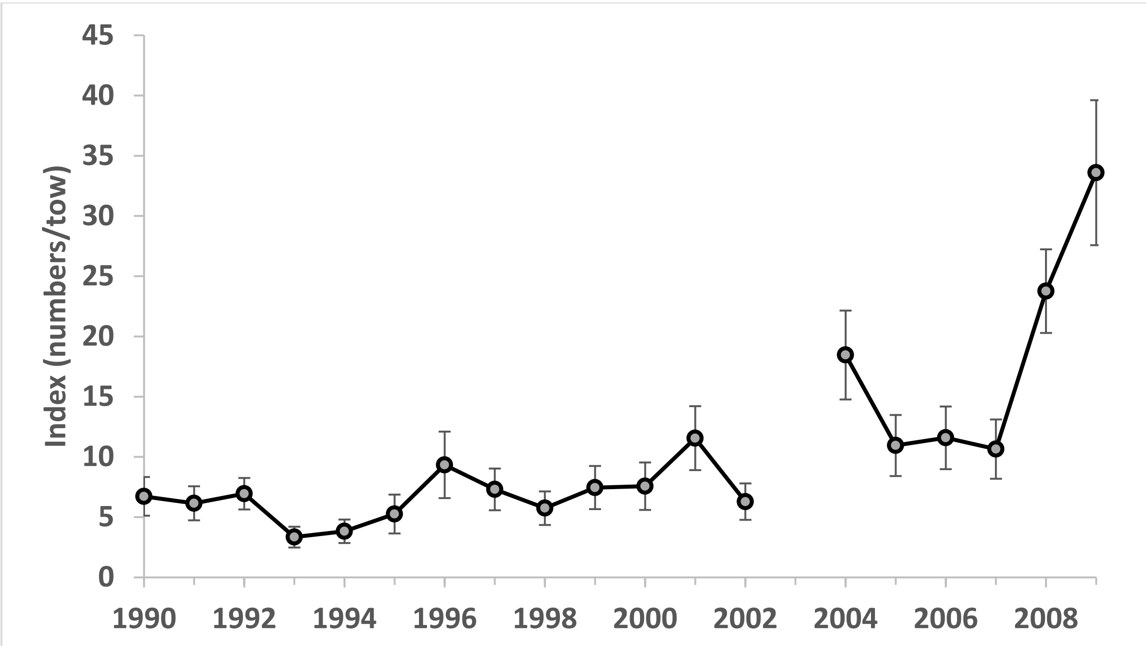


Figure 49. GLM-standardized index of abundance for American eels caught by the North Anna Electrofishing Survey, 1990–2009. The error bars represent the standard errors about the estimates.

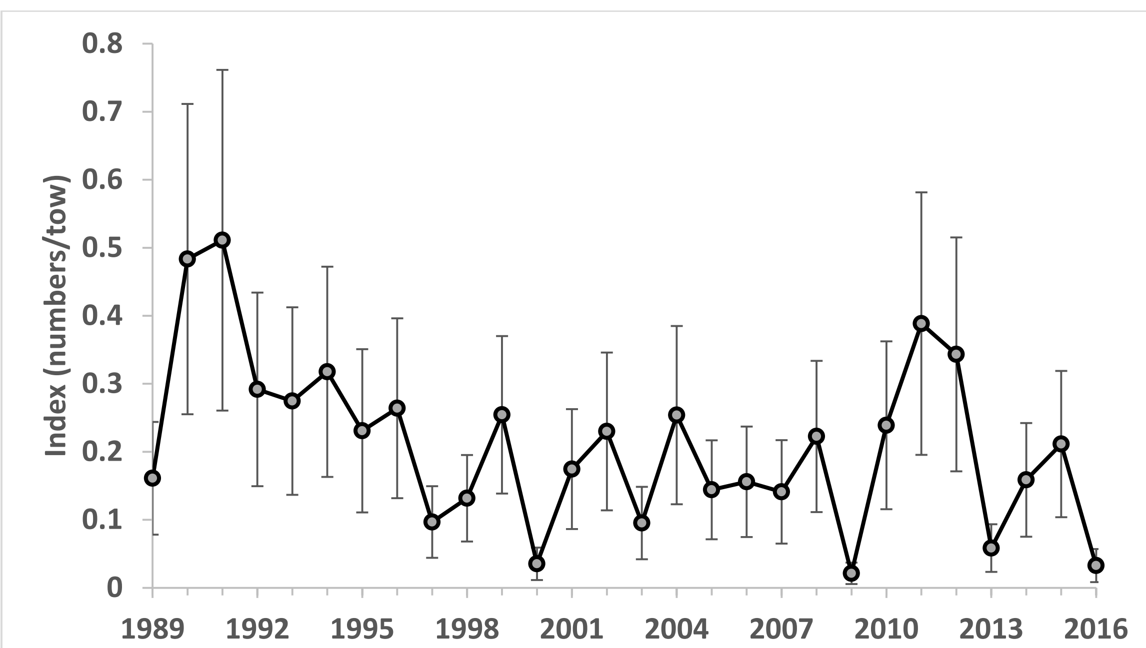


Figure 50. GLM-standardized index of abundance for American eels caught by the NCDMF Estuarine Trawl Survey, 1989–2016. The error bars represent the standard errors about the estimates.

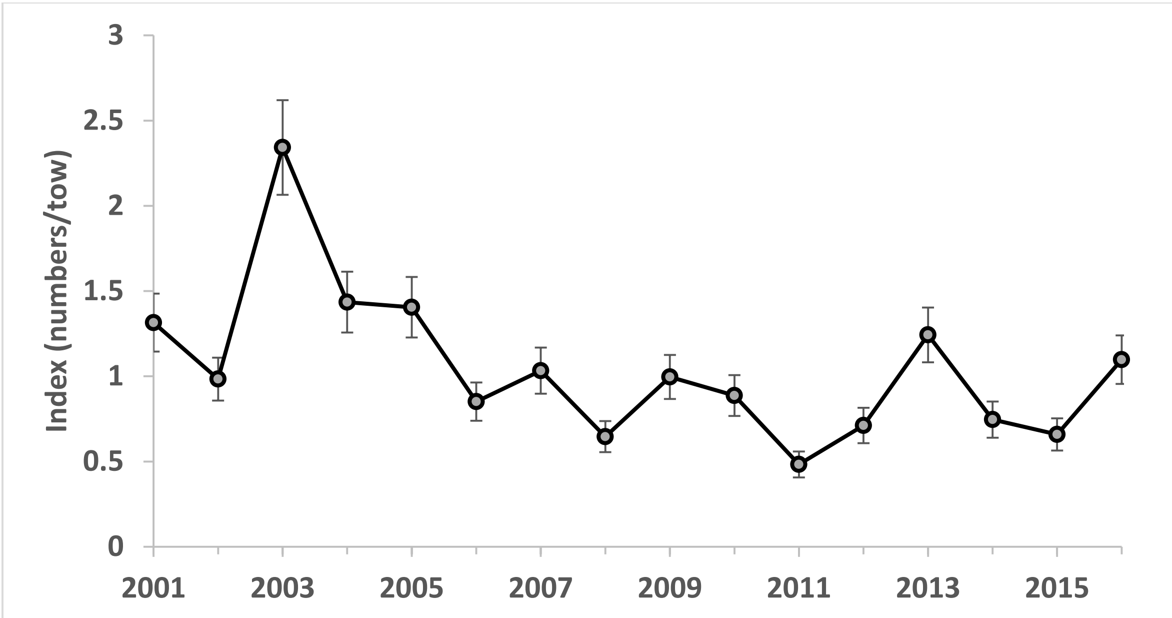


Figure 51. **GLM-standardized index of abundance for American eels caught by the SC Electrofishing Survey, 2001–2016. The error bars represent the standard errors about the estimates.**

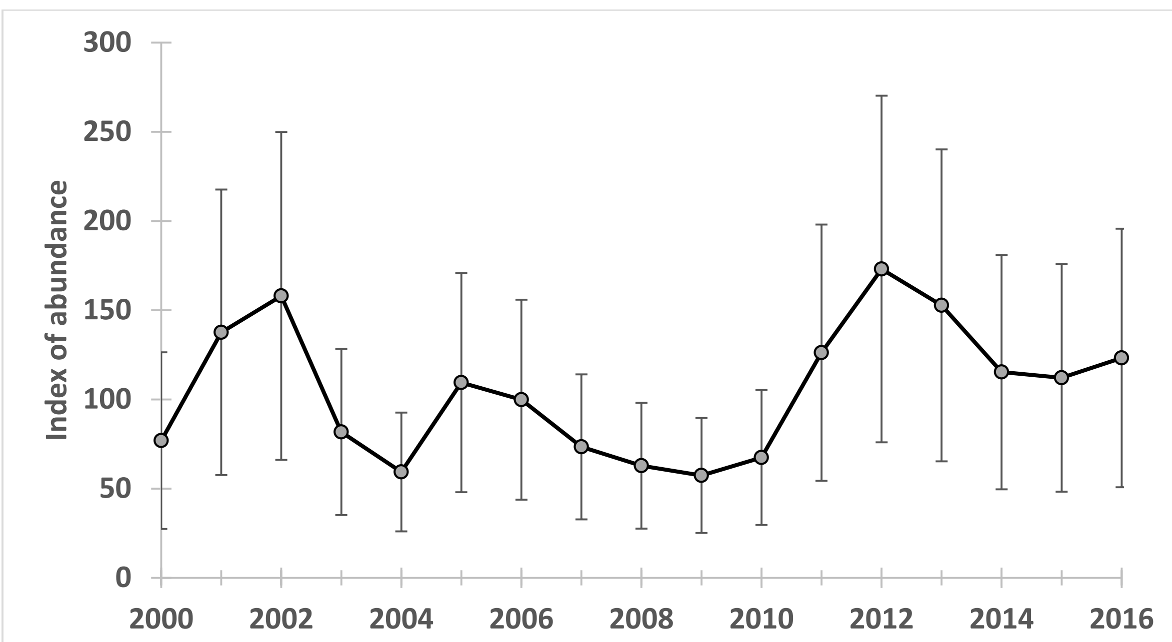


Figure 52. **GLM-standardized, short-term index of abundance for YOY American eels along the Atlantic Coast, 2000–2016. The error bars represent the standard errors about the estimates.**

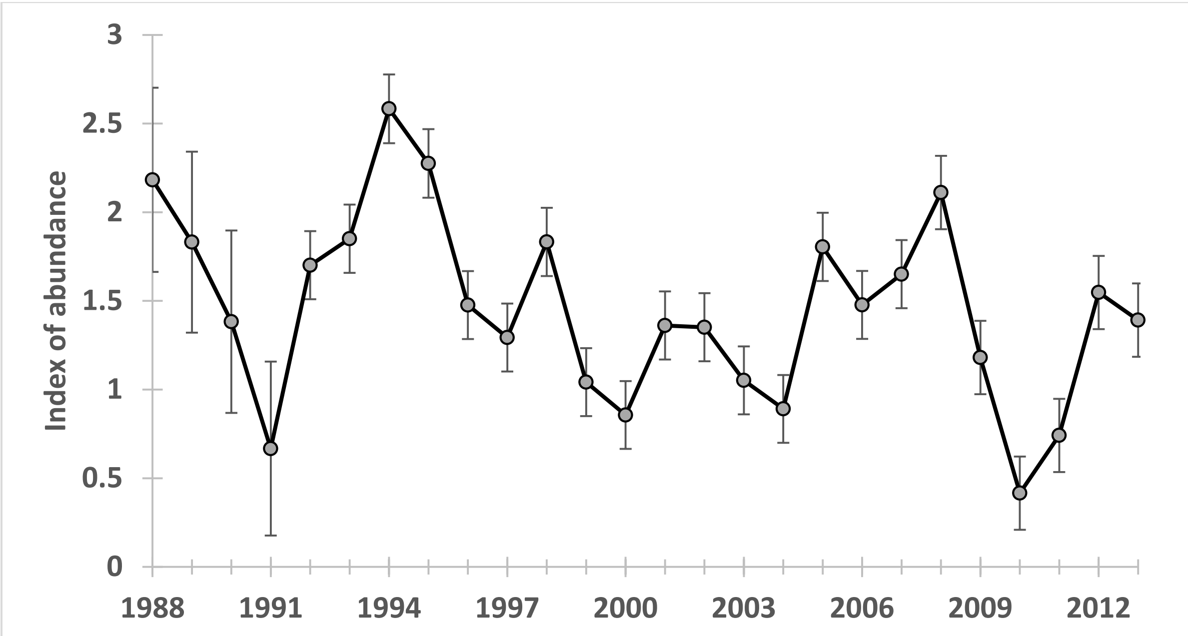


Figure 53. GLM-standardized, long-term index of abundance for YOY American eels along the Atlantic Coast, 1988–2013. The error bars represent the standard errors about the estimates.

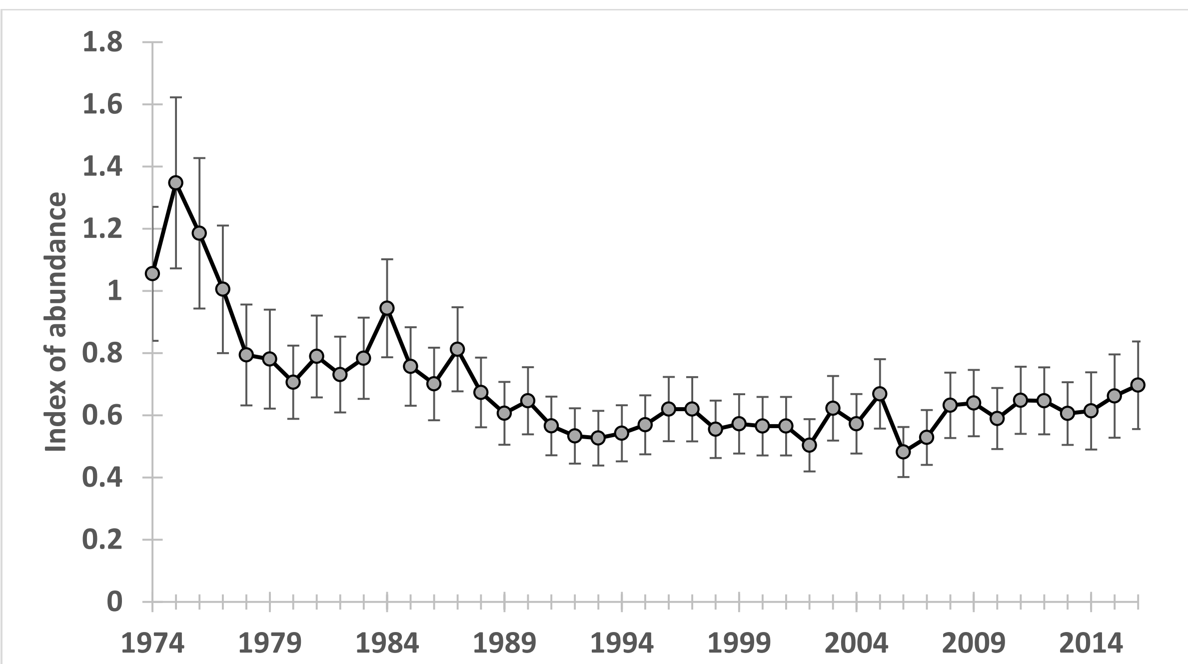


Figure 54. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1974–2016 (40-plus-year index). The error bars represent the standard errors about the estimates.

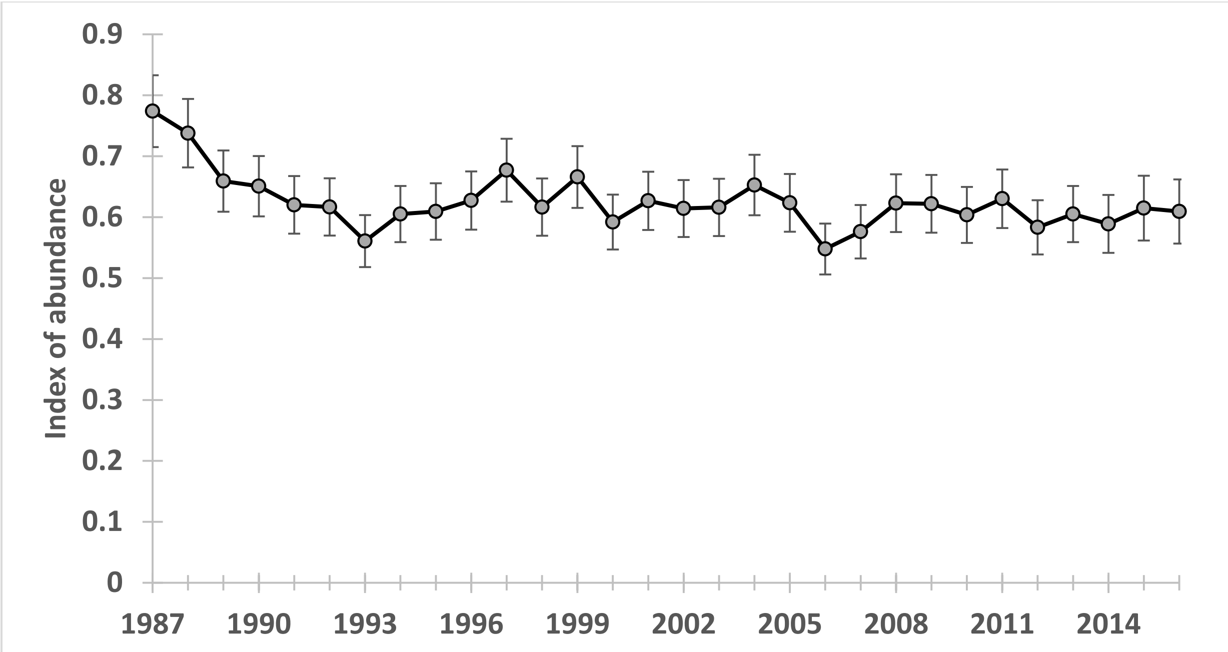


Figure 55. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1987–2016 (30-year index). The error bars represent the standard errors about the estimates.

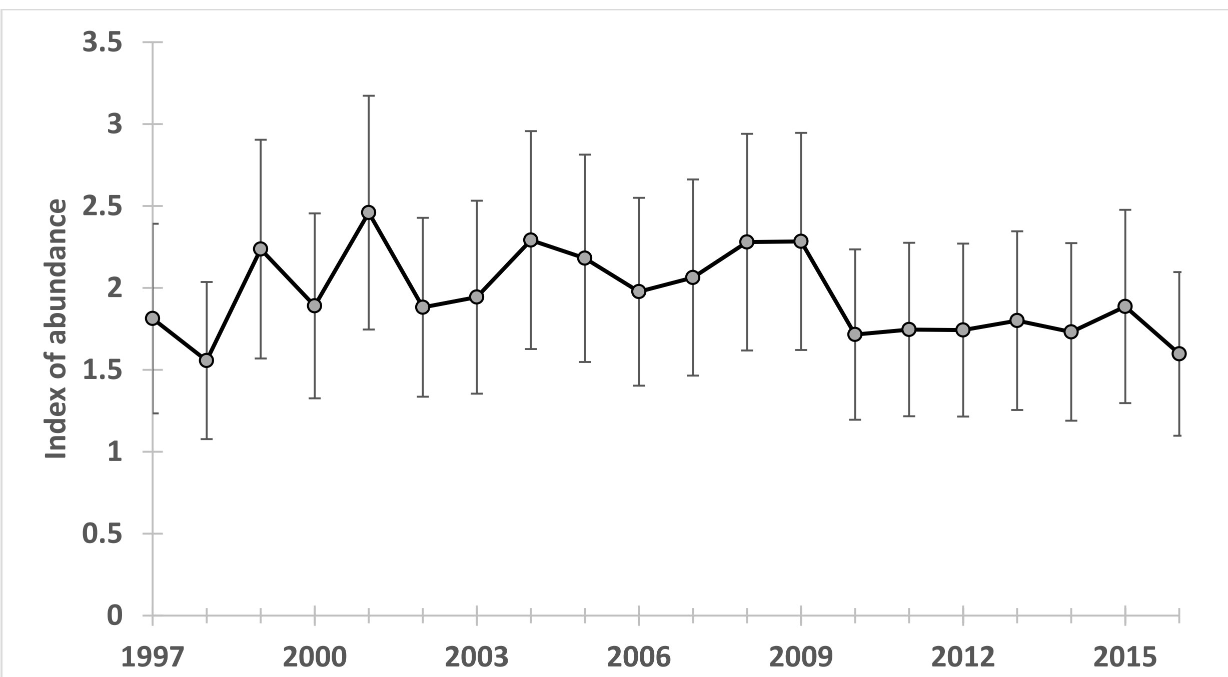


Figure 56. GLM-standardized index of abundance for yellow-phase American eels along the Atlantic Coast, 1997–2016 (20-year index). The error bars represent the standard errors about the estimates.

Figure 57. Regional indices of YOY abundance for American eels. The error bars represent the standard errors about the estimates. For the South Atlantic, the standard errors were small and do not show up on the graph.

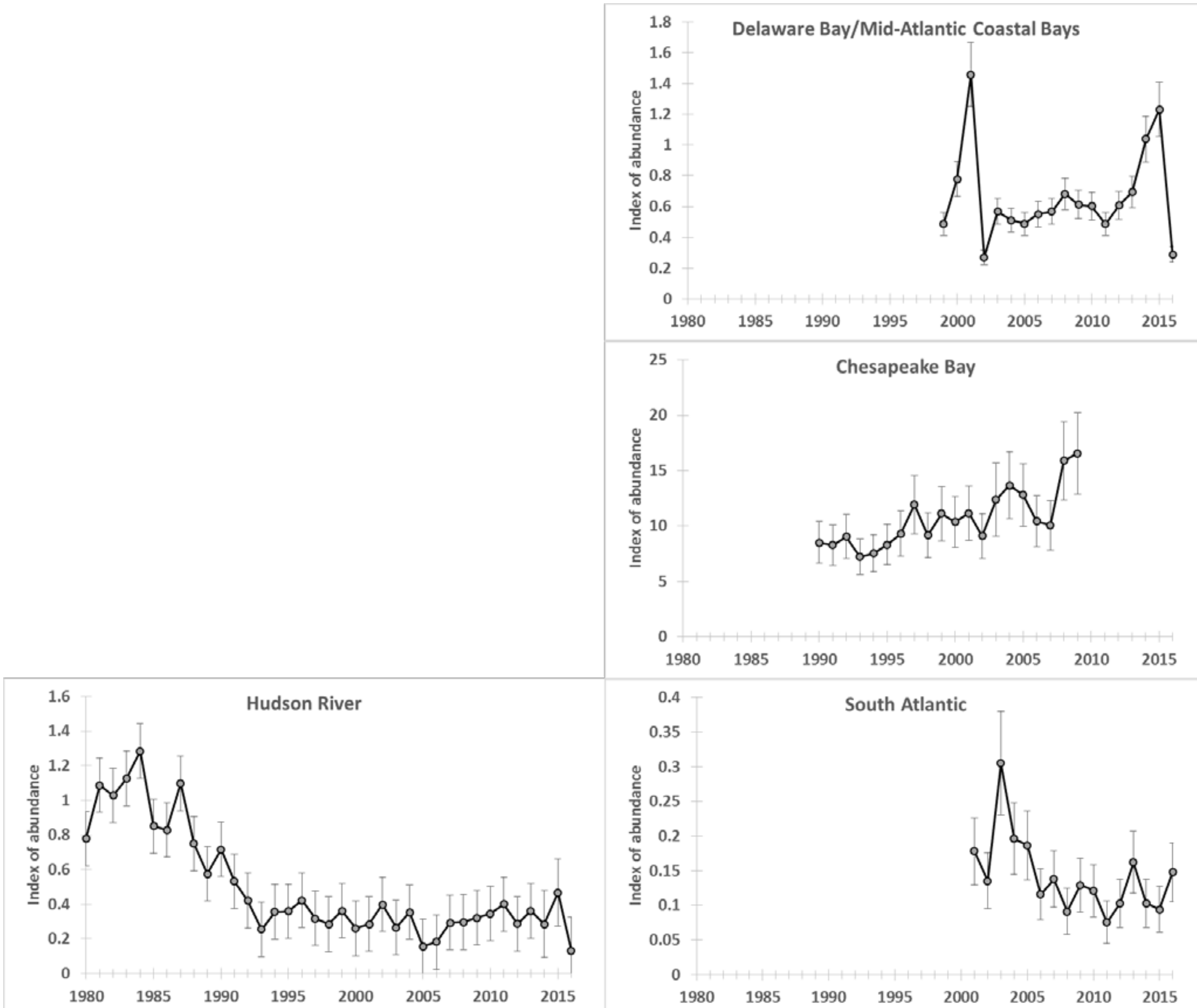


Figure 58. Regional indices of yellow-stage abundance for American eels. The error bars represent the standard errors about the estimates.

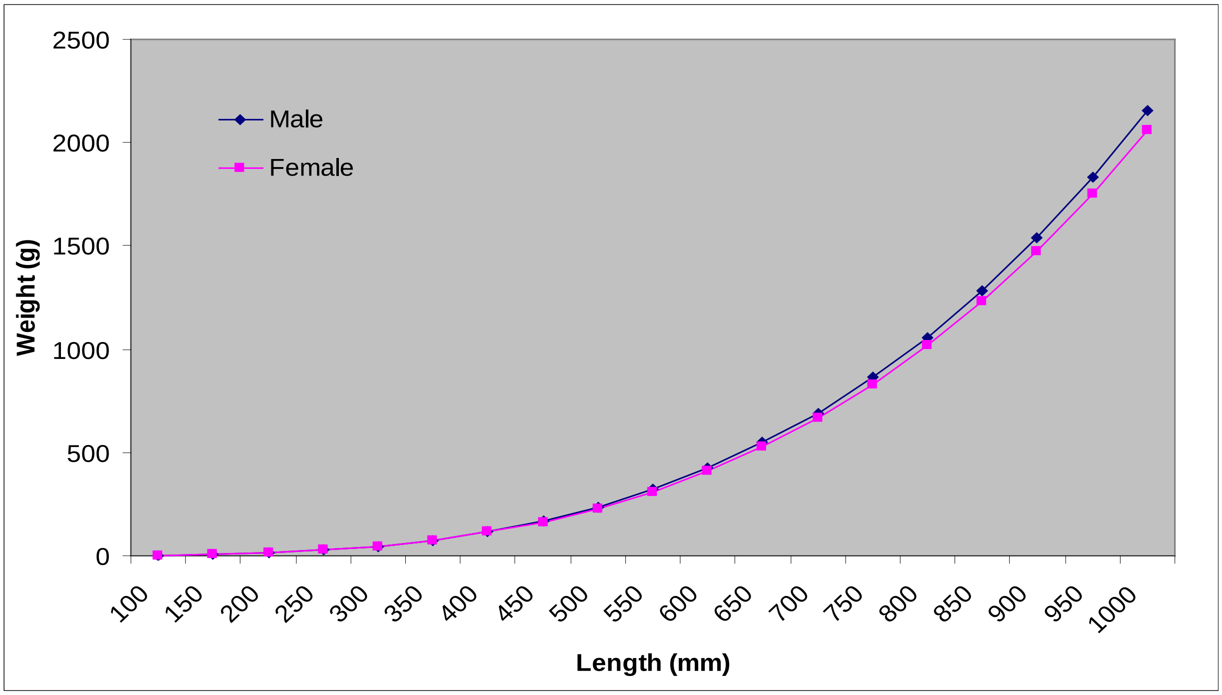


Figure 59. Predicted total length-weight relation for American eel based on available data, by sex.

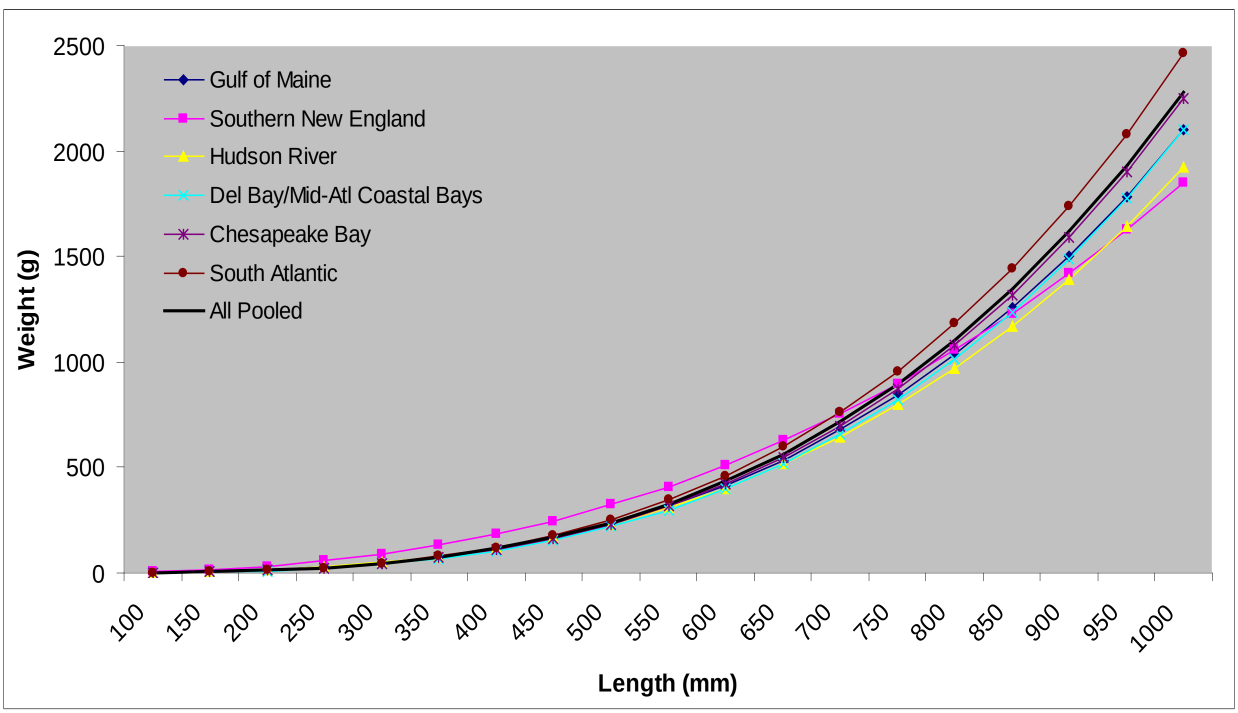


Figure 60. Predicted total length-weight relation for American eel based on available data, by region and all pooled.

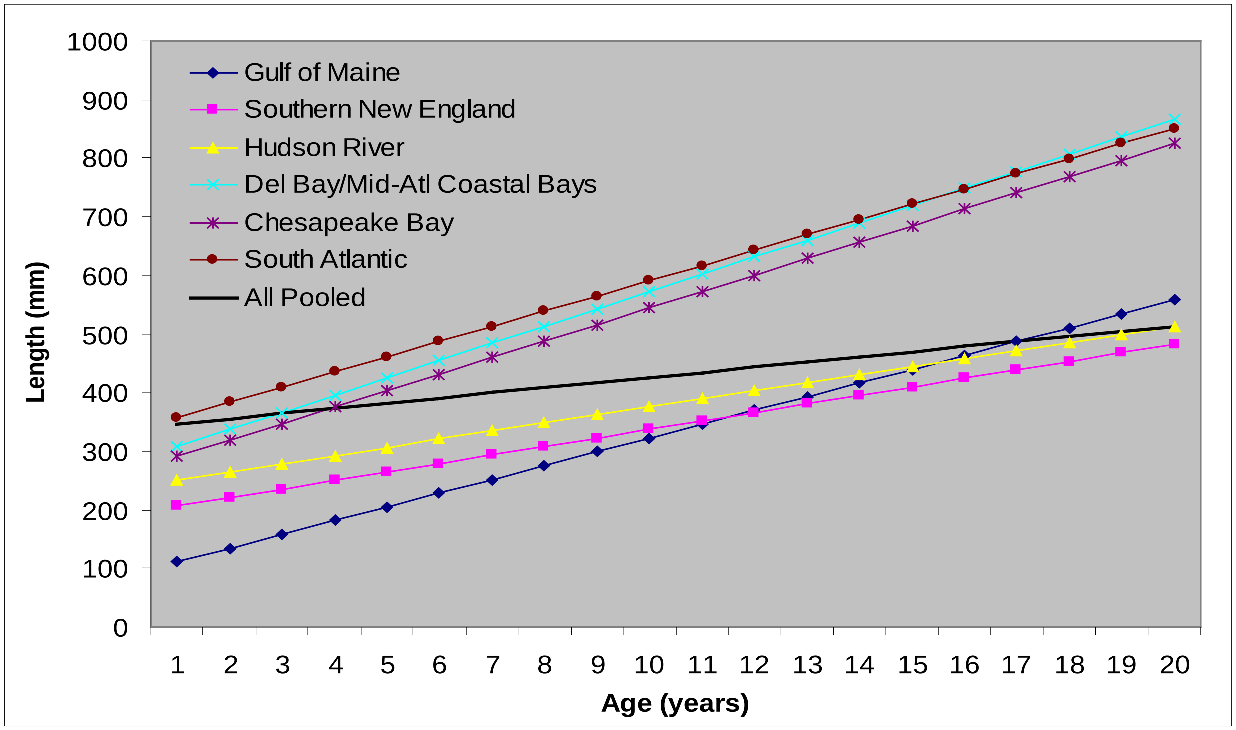


Figure 61. Predicted linear age-length relation for American eel based on available data, by region and all pooled.

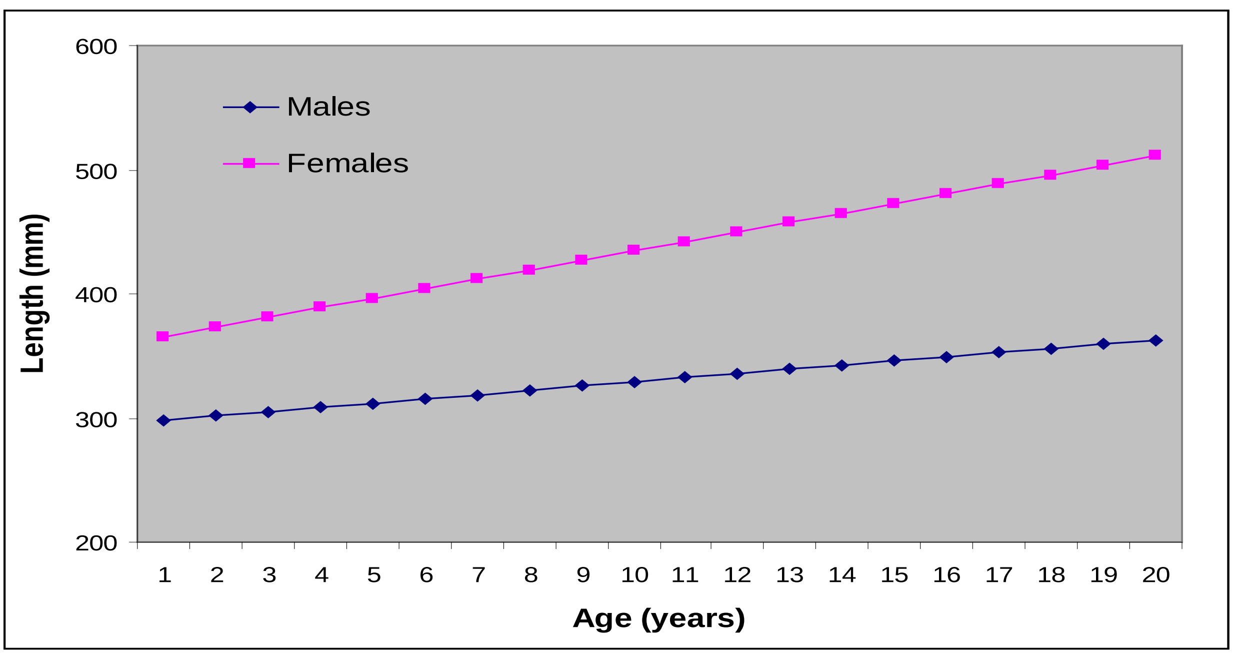


Figure 62. Predicted linear age-length relation for American eel based on available data, by sex.

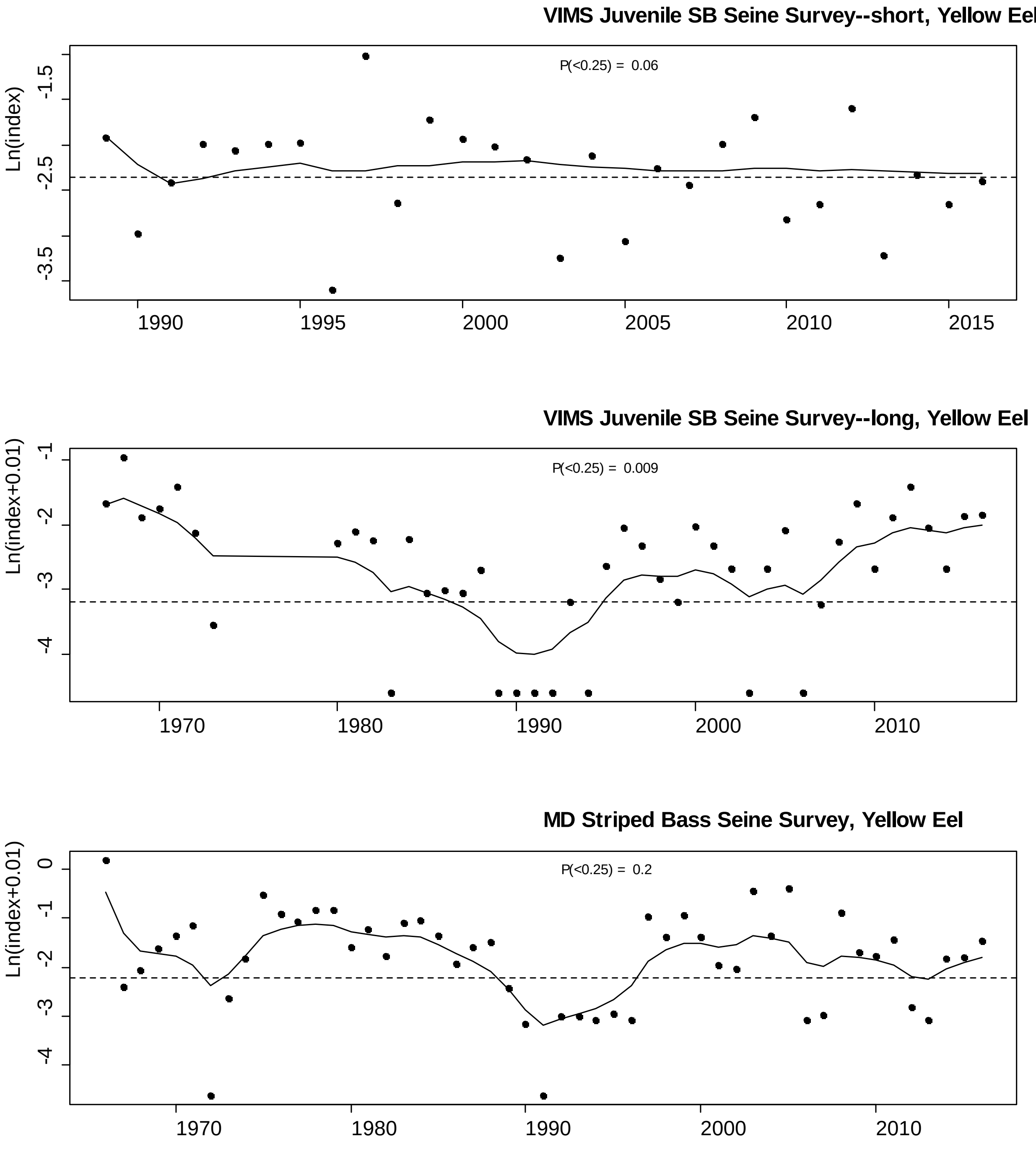


Figure 63. ARIMA model fits to American eel surveys from the Chesapeake Bay region. The dotted line represents the 25th percentile of the fitted values and *P*(<0.25) is the probability of the terminal year of the survey being less than the 25th percentile of the values.

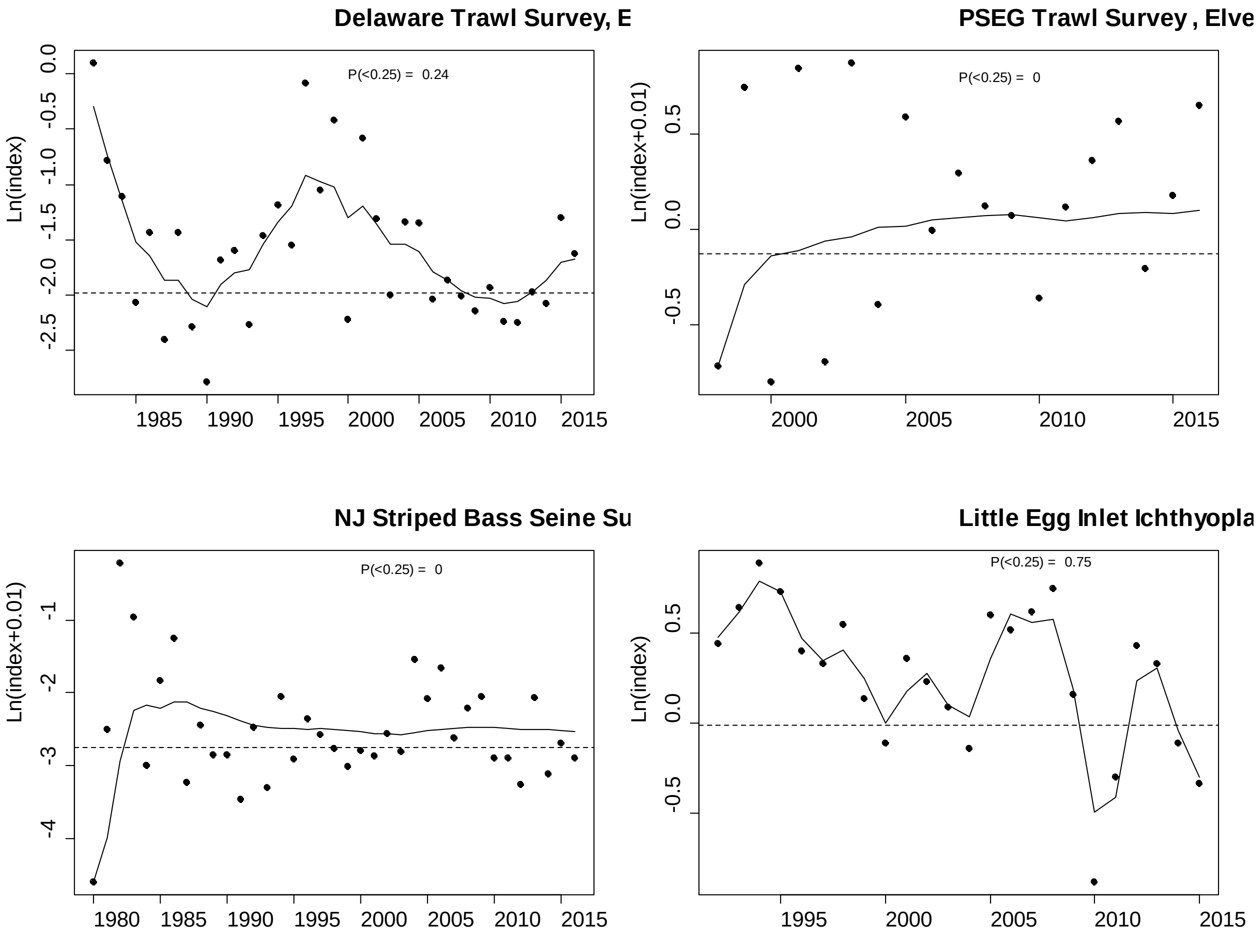


Figure 64. ARIMA model fits to American eel surveys from the Delaware Bay/Mid-Atlantic Coastal Bays region. The dotted line represents the 25th percentile of the fitted values and *P*(<0.25) is the probability of the terminal year of the survey being less than the 25th percentile of the fitted values.

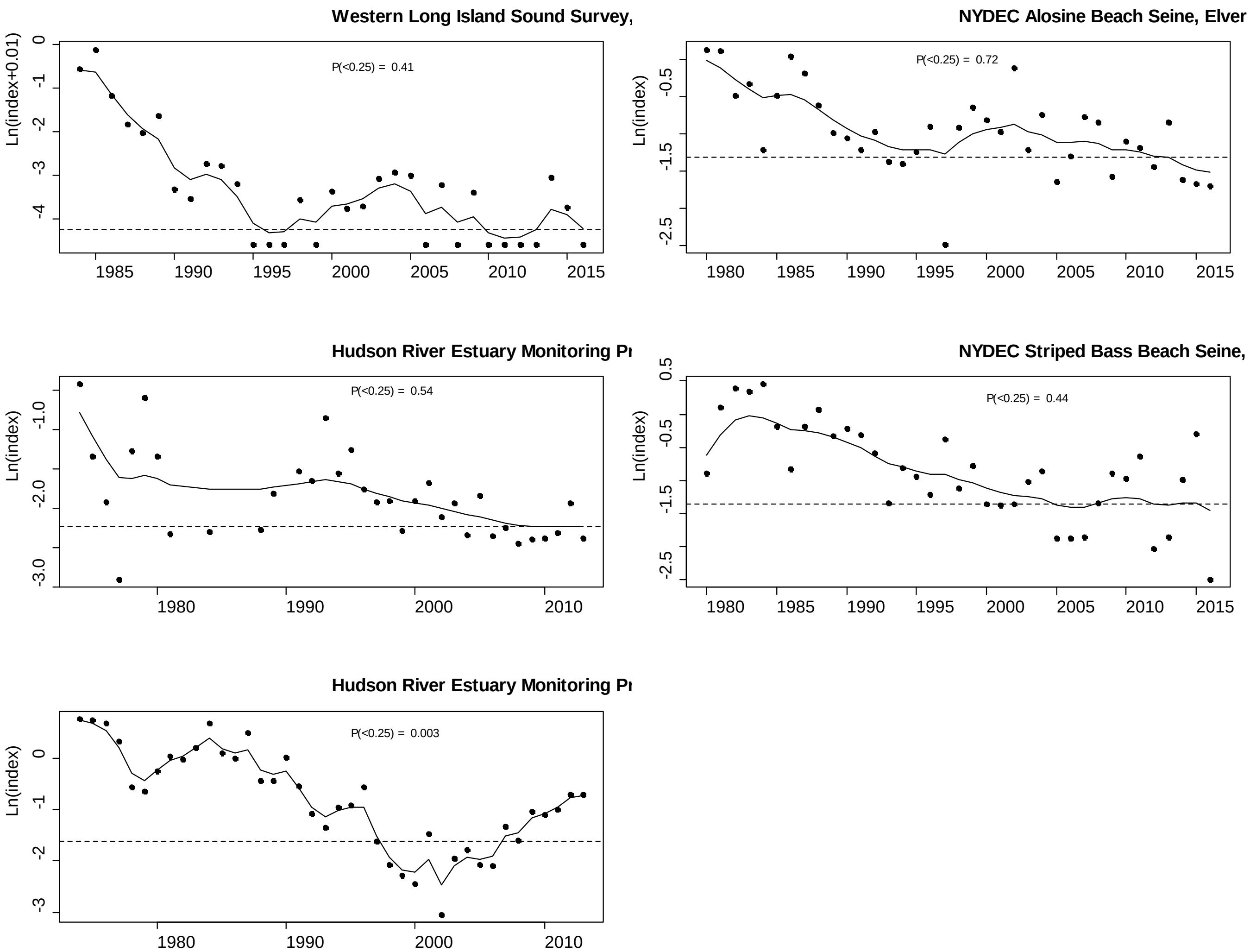
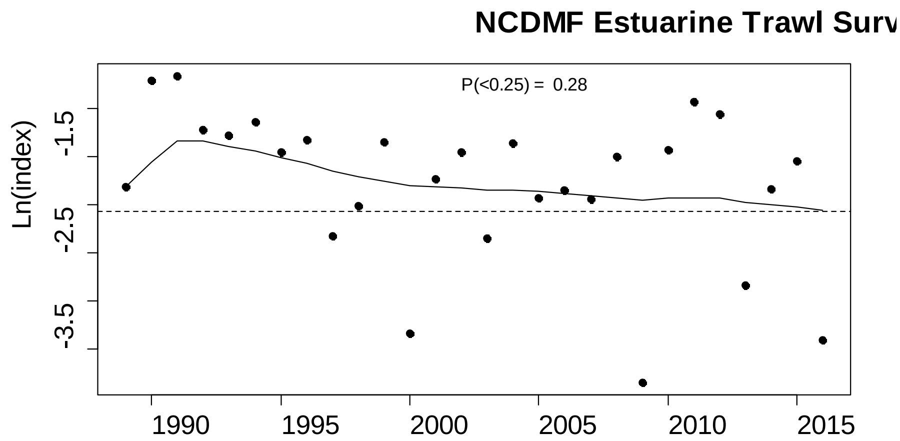


Figure 65. ARIMA model fits to American eel surveys from the Hudson River region. The dotted line represents the 25th percentile of the fitted values and *P*(<0.25) is the probability of the terminal year of the survey being less than the 25th percentile of the fitted values.



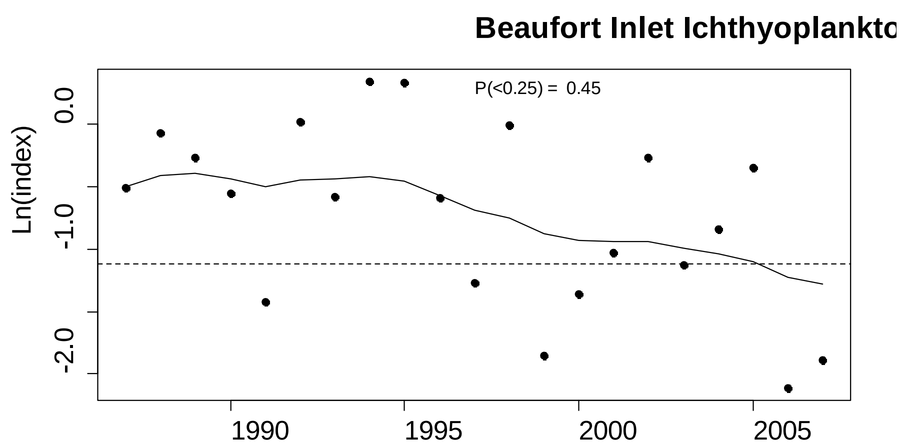


Figure 66. ARIMA model fits to American eel surveys from the South Atlantic region. The dotted line represents the 25th percentile of the fitted values and *P*(<0.25) is the probability of the terminal year of the survey being less than the 25th percentile of the fitted values.