Delaware River
Sustainable Fishing Plan for American Shad

Prepared by:

The Delaware River Basin
Fish & Wildlife Management Cooperative

Delaware Division of Fish and Wildlife • New Jersey Division of Fish and Wildlife

Pennsylvania Fish and Boat Commission • New York Division of Fish & Wildlife, Division of Marine Resources

U.S. Fish and Wildlife Service • National Marine Fisheries Service

and

Liaisons

National Park Service • The City of Philadelphia Water Department

Delaware River Basin Commission • The Nature Conservancy

For:

The Atlantic States Marine Fisheries Commission
Shad and River Herring Management Board

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Table of Contents

List of Figures

List of Tables

Executive Summary

The Atlantic States Marine Fisheries Commission's (ASMFC) Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring requires states to submit Sustainability Plans for continuance of American Shad fisheries in their jurisdictional waters. Within the Delaware River Basin, the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op) is responsible for the management of American Shad. The Co-op is seeking renewal of their Sustainable Fishing Plan of the Delaware River American Shad stock, being managed at current levels of recreational and commercial usage. The Co-op has completed a five-year update of the Sustainable Fishing Plan that was originally approved by the ASMFC in 2012 (2012 SFP). The Co-op used four indices for monitoring the Delaware River American Shad stock with associated benchmarks in the 2012 SFP. An additional index was added to this updated plan to monitor harvest on mixed stock American Shad that occur in the Delaware Bay. The Co-op judge these fisheries as sustainable while avoiding diminishing potential stock reproduction and recruitment as long as all five indices of stock condition remain within the defined benchmarks.

Currently the Delaware River American Shad stock is considered to be stable, but at low levels. Juvenile production (JAI), assessed by seine surveys in both non-tidal and tidal reaches, has varied without trend. Below average production was observed in non-tidal reaches from 1998 to 2002, but excellent year classes were observed in both JAI indices in 1996 and 2007. The 2013 JAI was the highest of the tidal reach time series, and that index has been higher than average in three of the past five years. The non-tidal JAI, however, had the second highest value in the time series in 2012, but that was followed by lower than average values from 2013-2015, including 2013 and 2015 falling below the benchmark. Measures of relative adult abundance (Smithfield Beach and Lewis haul seine) were suggestive of declining abundance in early 1990s followed by low but stable levels from 1999 to 2009. Recent evidence (since 2009) has suggested increasing abundance of adults to levels observed in the early 1990s in the Smithfield Beach survey, and three years of higher than the time-series average index values for the Lewis Haul Seine since 2009.

Commercial exploitation of the Delaware River American Shad stock is permitted by the States of New Jersey and Delaware within the Basin. Harvest occurs generally during the spring spawning migration from late February into May principally using anchored or drift gill nets. In the 2012 SFP, the Co-op acknowledged that the commercial fishery in the Delaware Bay exploited American Shad from mixed stock fisheries, along with Delaware River stock. A demarcation line from Leipsic River, DE to Gandys Beach, NJ was established, where landings in the upper estuary are considered to be 100% Delaware River American Shad stock and landings in the Bay were of mixed stock, with an estimated 40% of Delaware origin. Upon further examination of reporting regions in the State of Delaware, it was determined that the four reporting regions (River, Upper Bay, Mid Bay and Lower Bay) do not allow for landings to be divided at the Leipsic River. A new delineation point was selected for the State of Delaware

(Bowers Beach), which now assigns landings to Delaware River stock harvest for the upper three reporting regions in that state. Available tagging and genetic studies, suggest continuance of assignment of the proportion of the Delaware River stock at a similar rate as the 2012 SFP.

Fishers in New Jersey represent a small directed fishery for American Shad; whereas, landings of shad reported to the State of Delaware occur as bycatch from their concurrent Striped Bass fishery. Trends of combined landings, representative of the Delaware River stock, have been declining since 1990, with lowest levels observed in the most recent years (2008-2015), with the exception of a high harvest in 2014. The decline is most likely due to gear changes in Delaware's Striped Bass quota driven fishery and the low number of New Jersey fishers seeking American Shad.

Harvest on the mixed stock occurs in both Delaware and New Jersey in the Delaware Bay below a line from Bowers Beach, DE to Gandys Beach, NJ. A new benchmark was developed to limit expansion of the fishery on the mixed stock. Landings on the mixed stock were highest in the early 1990s and have been generally declining since that time. Landings on the mixed stock have been below the time-series mean (1985-2015) since 2006.

In addition to the Delaware Bay fisheries, a small haul seine fishery (Lewis haul seine) occurs in the Delaware River, some 15 miles above the fall line at Lambertville, NJ. This fishery exists as an eco-tourism venture with nominal harvest of shad. Trends in this fishery are highly correlated to the Smithfield Beach CPUE time-series.

Historically, a substantial recreational fishery for shad existed in the non-tidal reaches of the Delaware River; however, participation in this fishery is declining. The current recreational harvest is unknown. Most shad anglers practice catch-and-release. The mortality associated with catch-and-release of shad in the Delaware River is unknown, but considered to be minimal based on studies in the Hudson River. The recreational creel limit is currently 3 shad in the Delaware River.

In addition to harvest and natural mortality, the Co-op investigated other factors that may also impact the Delaware River stock. As part of the American Shad restoration program for the Schuylkill and Lehigh rivers, the Pennsylvania Fish and Boat Commission (PFBC) estimates the contribution of otolith-marked hatchery shad to the returning adult spawning populations in both rivers. While evidence suggests these fry stockings substantially support the runs in the Schuylkill and Lehigh rivers, the contribution to the mainstem Delaware run above their respective confluences has been minimal. Correlations between the Atlantic Multidecadal Oscillation (AMO) and indices of adult shad relative abundance from the Lewis haul seine fishery suggest a changing relationship between shad abundance and Atlantic long-term sea surface temperatures; early in the time series (1970s-1980s) there was a positive correlation; however, more recent information (1990s-2015) indicate a negative correlation. In addition, a review of the indices of abundance of Striped Bass and American Shad has determined that Striped Bass abundance is not correlated with American Shad abundance. Possible losses from oceanic commercial fisheries principally, as bycatch, have been difficult to evaluate; but, the Co-op is concerned these offshore fisheries may be having a negative impact on the Delaware River stock. Multiple water intake structures are found in the Delaware River and upper estuary that may be causing mortality on American Shad eggs, larvae, and juveniles through impingement and entrainment. The Co-op is actively commenting on water intake projects to improve protections for shad at those facilities.

The Co-op proposes five benchmarks for sustainability. The benchmarks have been set to respond to any potential decline in stock. Thus all benchmarks are viewed as conservative measures. Failure to meet any of the defined benchmarks will independently cause immediate management action. The severity of the action will be situational and proportional to the number of benchmarks exceeded. No benchmark has tripped its target level for the last two consecutive years. All benchmarks will be reviewed annually after completion of annual ASMFC Shad and River Herring compliance reports.

- **Non-tidal JAI:** Data for this index is derived from the New Jersey Division of Fish and Wildlife (NJDFW)/Co-op annual fixed station seining (1979-2007; 2012-2015) in the non-tidal Delaware River mainstem from Phillipsburg, NJ to Milford, PA. The non-tidal JAI is standardized with respect to environmental covariates using generalized linear model methodology. The benchmark is based on data from 1988-2007 and 2012-2015. Failure is defined as the occurrence of three consecutive JAI values below a value of the 25th percentile of the historical data (1988-2015), where 75% of the values are higher.

- **Tidal JAI:** Data for this index is derived from the NJDFW annual Striped Bass seining in the upper estuary. Only those stations from New Bold Island to the Delaware Memorial Bridge are included. The JAI index represents the annual geometric mean of the catch data. A benchmark was based on data from 1987 – 2015. Failure is defined as the occurrence of three consecutive JAI values below a value of 4.0 (i.e., the 25th percentile of the historical data, where 75% of the values are higher).

- **Adult CPUE:** This index is based on the annual CPUE (shad/net-ft-hr*10,000) in the PFBC gill net, egg-collection effort at Smithfield Beach. The benchmark was based on the entire dataset (1990-2015), with failure defined as the occurrence of three consecutive CPUE values below a value of 37.5 (i.e., the 25th percentile of the historical data, where 75% of the values are higher).

- **Ratio of Harvest to Smithfield Beach CPUE:** This index is calculated as a ratio of the combined commercial harvest of the Delaware River American Shad stock, in pounds, divided by relative abundance of adult survivors captured at Smithfield Beach (CPUE) divided by 100. The benchmark is based on data from 1990-2015 and failure is defined as the occurrence of three consecutive values above a value of 36.5 (i.e., the 85th percentile of historical data, where 15% of values are higher).

- **Mixed Stock Landings:** This index is calculated as the annual landings from the mixed stock fishery. It is calculated as 60% of total shad landings below the demarcation line (Bowers Beach, DE to Gandys Beach, NJ). The benchmark is based on data from 1985 – 2015 and failure is defined as the occurrence of 2 consecutive years above a value of 47,650 (i.e., the 75th percentile of historical data, where 25% of values are higher).

It is anticipated that this sustainability plan will sustain current levels of the Delaware River American Shad stock while allowing for human use of the resource. The Co-op views this plan having a five-year term beginning with its acceptance by the ASMFC.

Sustainable Fishery Plan for the Delaware River

1. Introduction

In accordance with guidelines provided in Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 2010), the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op) submitted the first American Shad Sustainable Fishing Plan (SFP) in September 2011 (DRBFWMC 2011). After review, this SFP was accepted by the Atlantic States Marine Fisheries Commission (ASMFC) Policy Board in February 2012 remaining valid for a term of five years (2012 – 2016; 2012 SFP). This document (i.e., 2017 SFP) represents a revised SFP for governing management of American Shad over the next five year term, 2017 – 2021, pending final approval by ASMFC. It is submitted jointly by the States of Delaware, New Jersey, and New York, and the Commonwealth of Pennsylvania, for management of American Shad in waters of the Delaware River Basin (Figure 1).

The 2012 SFP prescribed accomplishment of several actions to further support our understanding of sustainability of American Shad. Co-op members have successfully re-initiated the non-tidal juvenile abundance beach seining. Efforts follow the same protocols as the original survey. Ageing of shad scales has been standardized among Co-op members. Over a series of workshops, Co-op members have drafted a guidance protocol to aid in consistent interpretation of scale microstructure. Ultimately, the intent of this effort is to provide annual mortality estimates. The Co-op also conducted a thorough examination of recent tagging and genetics studies and has established a new benchmark based on harvest limits on the mixed stock of American Shad that occurs in the lower Delaware Bay during the spring fishery.

The 2012 SFP also prescribed securing additional funding for tagging programs to better delineate the mixed stock fishery. Although tagging efforts were not increased during the 2012 SFP, there are plans to conduct additional genetics studies in 2017 to further describe the genetic origin of American Shad at different locations within the estuary. These results will help the Co-op refine the proportion of landings to assign to the mixed stock based on geographic regions within the estuary.

Status updates of monitoring programs supporting the 2017 SFP and associated benchmarks will be reported in annual compliance reports to ASMFC. Annual reports are jointly submitted by the Co-op.

1.1 Request for Fishery

The Co-op desires that the Shad and River Herring Management Board consider this request to approve a Sustainable Fishery Plan for American Shad of the Delaware River Basin. This plan includes a request for approval of both recreational and commercial harvest. Accordingly, the Co-op justifies this request based on analysis of historical trends in juvenile and adult relative abundance, and commercial and recreational fishery data.

1.2 Definition of Sustainability

Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring defines a sustainable fishery as one that will not diminish potential future stock reproduction and recruitment. The Co-op proposes that reproduction and recruitment in the Delaware River American Shad stock be measured by two indices of age zero abundance to be augmented with an index of spawning stock abundance and a ratio of landings to that index of spawning stock abundance. Benchmarks have been proposed for all indices to define levels needed to avoid diminishing potential stock reproduction and recruitment. We will judge fisheries as sustainable as long as indices of stock condition remain within these benchmarks; otherwise exceedance will necessitate mandatory corrective management actions. Since the fishery in the lower Delaware Bay also harvests American Shad of other coastal stocks, an index with an associated benchmark has been established to limit harvest on non-Delaware River (mixed) stocks.

2. Stock Status

2.1 Previous Assessments

The Delaware River was included in the 1988 and 1998 ASMFC coast-wide stock assessments for American Shad (Gibson *et al*. 1988; ASMFC 1998). The 1988 Assessment utilized the Shepherd stock-recruitment model to estimate maximum sustainable yield (MSY) and maximum sustainable fishing rates (F_{msy}). That assessment estimated F_{msy} for the Delaware River to be equal to 0.795 with exploitation at MSY at 0.548. The historical fishing rate for the Delaware River stock was estimated to be F = 0.320. The 1998 Assessment utilized the Thompson-Bell yield-per-recruit model to derive an overfishing definition (F_{30}) for American Shad. Average fishing mortality from 1992 to 1996 for the Delaware River was estimated at F = 0.17, which includes out-of-basin estimates of harvest, and was considered well below the F_{30} value of F = 0.43.

The most recent stock assessment was completed in 2007 (ASFMC 2007). Findings identified more than twenty-five sources of fishery-independent and fishery-dependent data. Clearly, the Delaware River stock of American Shad declined through the 1990s and remained at low levels. The cause of the decline was not identified, nor was any explanation postulated for why the stock remained at low levels since the decline. The 2007 assessment concluded that juvenile production remained stable without any apparent trend, and did not appear to be correlated between adult abundance or returning adults in subsequent years (ASMFC 2007). The stock assessment sub-committee was unable to reach consensus on what could be considered the best scientific benchmark(s) from the available datasets (ASMFC 2007).

Substantial monitoring of the American Shad population has been accomplished in the Delaware River. Many of the indices analyzed for the ASMFC 2007 stock assessment have continued through 2015.

2.2 Stock Monitoring Programs

2.2.1 Fishery Independent Surveys

2.2.1.1 Juvenile Abundance Surveys

The New Jersey Division of Fish and Wildlife (NJDFW) conducted sampling for young-of-year (YOY) American Shad in the non-tidal Delaware River from 1979 – 2007. Sampling was conducted in non-tidal waters, to provide a juvenile abundance index (JAI) for management purposes. Beginning in 1979, only a single site, Byram (RM 157.0), was sampled. Other sites were added in later years with the addition of Trenton (RM 131.6) in 1980, Phillipsburg (RM 184.2) in 1981, Water Gap (RM 210.0) in 1983 and Milford Beach (RM 246.4) in 1988. Sampling was discontinued at the Byram site in 2002 due to heavy siltation without replacement as no suitable replacement beaches were identified. Since 1988, the Trenton, Phillipsburg, Water Gap, and Milford Beach sites were consistently annually monitored for YOY shad recruitment.

Sampling consisted of beach seining at fixed stations generally located adjacent to boat access points with suitable bottom substrates conducive to seining. A series of four seining hauls were accomplished once a month using a 300 ft (91.44 m) by 12 ft (3.6 m) bagless seine of 0.25 inch (6.3 mm) delta mesh, beginning at sunset, from August through October. Hauls occurred over the same swept area, but were separated by 30 minute intervals from the time of retrieval until the next deployment

Beginning in 2012, the Co-op reinitiated the NJDFW non-tidal beach seine survey for monitoring American Shad YOY production. The original four historic sites, Trenton, Phillipsburg, Water Gap, and Milford Beach are annually surveyed following the original NJDFW protocols. An additional site, located at Lackawaxen (RM 277), was also initiated in 2012. The intent was to provide better understanding of YOY production in the upper reaches of the Delaware River mainstem that were not traditionally surveyed by NJDFW. The Lackawaxen site, however, was discontinued after the 2014 season due to excessive submerged aquatic vegetation beds occurring in 2013 and 2014 that effectively prevented seining. The Lackawaxen site was not included in any analysis or estimation of JAI index.

The National Park Service (NPS) self-funded a one-year synoptic survey of YOY shad occurrence in the upper reaches of the Delaware River main stem, in 2015. The intent was exploratory sampling to identify potential long-term monitoring sites upstream of Port Jervis, New York (RM 254). Two sites were identified in the Delaware River main stem including Skinners Falls (RM 295) and Buckingham (RM 325). Fireman's Launch (E. Br. Del. R.) and Balls Eddy (W. Br. Del. R.) were also sampled. Young-of-year shad are known to occur in the East Branch of the Delaware River; whereas, they are generally acknowledged to be extirpated from the West Branch of the Delaware River (Sheppard 1983, Bovee *et al.* 2003). Outflows from New York City's Cannonsville Dam begin at the undammed reach of the West Branch and are manipulated to maintain a trout tailwater, which is generally colder than thermal tolerances of YOY shad.

Beach seining was accomplished following original NJDFW protocols. Bottom substrates in the upper Delaware River are best characterized as a mixture of large cobble, rock and boulders. Alternative sampling methodology, including fyke netting and visual surveys, were also investigated with limited success and will not be pursued further (Table 1). As expected, no shad were captured at the Balls Eddy site, which was discontinued after the September sampling. Few YOY shad (< 100 individuals) were caught by seining at the other three sites (Table 1). Rough bottom substrates and flow hindered seine efficiency at the Buckingham site. It was determined that long-term monitoring seining was impractical at the Buckingham site, due to perceived gear inefficiency and poor accessibility to the site. Over the tenure of the 2017 SFP, Co-op members will develop a time-series at the other two sites (i.e., Skinner's Falls and Fireman's Launch) for comparing to downriver catches. Catches from these exploratory sites will not be used in the estimation of the non-tidal JAI index in the 2017 SFP.

In the tidal Delaware River, NJDFW collected data pertaining to YOY shad during their annual Striped Bass recruitment survey. Since 1980, seining was accomplished using a 100 ft (30.48 m) by 6 ft (1.83 m) bagged seine of 1/4 inch (6.35 mm) delta mesh, during daylight hours. A series of fixed station sites were sampled twice a month June through November. November sampling was discontinued in 2016. Catches from sites were combined into two general regions. Region 2 represents sites (n = 16) from the Delaware Memorial Bridge, RM 70.9, to the Philadelphia Naval Shipyard, RM 94.4; whereas Region 3 represents sites (n = 8) from just north of the Betsy Ross Bridge, RM 105.8 to New Bold Island, RM 125.4. Data from lower Delaware Bay sites were eliminated where YOY American Shad are less likely to be encountered in higher salinity waters. In 2015, a QA/QC check was completed on all data sets from the Delaware River resulting in updates to the recruitment indices during the time-series.

Young-of-year shad lengths (i.e., fork length, FL) were measured to characterize trends in size over the time-series. A maximum of 25 individuals were measured for each haul at all non-tidal sites since 1979. Lengths from the four hauls at each non-tidal site were combined. Only lengths from 1983 to present were retained for analysis. Prior to 1983, non-tidal sites sampled and sampling frequency differed from the remainder of the time-series. Beginning in 2000, the first 30 individuals were measured at each site in the tidal reaches. Lengths from each tidal site were combined by region.

Median length frequencies for non-tidal and tidal sites, by year and month, are graphically illustrated (Figure 2). In general, for non-tidal sites, the smallest shad were collected in August, in all years. Median sizes ranged 42 mm (1996) to 69 mm FL (2013; Table 2). Exceptionally small (i.e., < 30 mm FL) YOY shad were frequent occurrences in August samples (n = 18 years). A total of 120 individuals less than 30 mm FL were captured over the time-series, principally at Milford (n = 50), Water Gap (n = 36), and Phillipsburg (n = 34) sites. Median lengths of shad caught in September varied 59 mm FL (1996) to 85 m FL (2015). While no shad less than 30 mm FL were captured at any September collections, two larger shad, 150 mm FL and 201 mm FL, were captured at Phillipsburg in 2015. The largest YOY shad were consistently caught in October, with median sizes varying 65 mm (1993) to 92 mm FL (2013). An exceptionally large individual, 203 mm FL, was captured at the Phillipsburg site in October, 2013. This shad possibly represents a 1+ age shad, straying further upriver. Conversely, two small sized shad, 17 mm FL and 29 mm FL were captured at the Trenton site in October, 2013.

Distribution of size among months collected from the tidal sites demonstrated increasing sized shad in later months (Figure 2; Table 3). Median sizes ranged from 49 mm (2003) to 68 mm FL (2006) in August; 52 mm (2007) to 73 mm FL (2006) in September; and 56 mm (2007) to 84 mm FL (2006) in October collections. A total of five exceptionally small (i.e., < 30 mm FL) sized shad including 27 mm FL and 29 mm FL shad in August, 2000, 28 mm FL shad in August 2003, 29 mm FL shad in August 2013, and 25 mm FL shad in September 2013, were collected during the time-series. No shad greater than 124 mm FL were captured at any tidal sites.

Examination of monthly median lengths determined from non-tidal catches demonstrated considerable variability among years (Figure 2). In some years, median sizes in September or October were more reflective of the previous months' smaller median size in other years. For example, the relatively small observed September median sizes in 1996 (59 mm FL) and 2003 (55 mm FL) were similar in size to typical August median sizes in other years. Observed small sized October medians in 1993 (65 mm FL) and 2003 (67 mm FL) were reflective of typical September median lengths in other years. Conversely, median sizes in August and September in some years were more reflective of latter months' larger median size in other years. Larger observed August median sizes in 2013 (69 mm FL) and 2015 (68 mm FL) were of similar sizes in other years September median sizes; and larger observed September median sizes in 2001 (76 mm FL), 2007 (75.5 mm FL), 2013 (80 mm FL), and 2015 (85 mm FL) were similar to October median sizes.

Monthly median sizes at tidal sites were inconsistent among years (Figure 2). Median sizes in 2002, 2006, 2008, and 2012 overall represented large YOY shad. Median sizes in August for these years, 64 mm FL, 68 mm FL, 66 mm FL, 64 mm FL, respectively, were larger than October median sizes in other years (Table 3). October median sizes in 2003 (62.5 mm FL), 2005 (62 mm FL), 2007 (56 mm FL), 2013 (61 mm FL), and 2014 (60 mm FL), conversely, were reflective of smaller sized YOY shad. These late season medians were of typical sizes observed in August for other years.

Latitudinal variation in sizes of YOY shad is unclear (Figure 3). In several years 2001, 2007, 2013, and 2014 the four upriver non-tidal sites had larger sized shad in most months, compared to tidal collections (i.e., Regions 2 and 3). Yet, median sizes of shad collected from Region 2 and 3 in 2002, 2003, 2006, and 2012 were larger than observed at some non-tidal sites. Considering only the four non-tidal sites, annual patterns among sites also remains unclear. Median sizes at Trenton, were typically smaller than observed at Phillipsburg, Water Gap and Milford in 2007, 2005, 2013, 2014, 2015; yet 1983, 1984, 1994, 2003, 2004, 2006 median sizes at Trenton tended to be larger shad.

Initial examination of the variability associated with measured fork lengths suggests considerable differences would be expected between observed length distributions (Tables 2 - 3; Figure 4). As an example, graphical comparison between Region 2 and Trenton mean distributions and standard errors, demonstrate limited overlap of observed length distributions among years and months, suggesting a significant difference among means between the two areas. This finding was consistent for all other comparisons among sites.

The out-migration of YOY shad in the Delaware River is poorly understood. As YOY shad increase in size at the non-tidal sites, they may preferentially out-migrate upon achieving some unknown suitable size. The relatively small differences of median sizes between September and October collections at upriver non-tidal sites might be reflective of this behavior. Alternatively, YOY shad may remain in non-tidal nursery waters until the onset of fall cold fronts, which finally forces out-migration. Sometimes, these fronts may occur prior to October sampling, possibly influencing out-migration of larger sized individuals. While the increased median size among months is suggestive of the overall year-class growth, the Delaware River represents an open population. Out-migration behaviors may be strongly influential on synoptic sampling characterized by the non-tidal sites.

The expectation of the tidal sites to have the larger sized shad was not realized. This assumes spawning occurs sooner in the calendar year at downriver locations; and hence experiences a longer growth period. Sites in the tidal waters occur primarily near the mouths of small tidal creeks or along estuarine shorelines. This close proximity to estuarine waters possibly allows out-migration to occur at smaller sizes. Additionally, gear catchability and avoidance behaviors of larger sized YOY shad in tidal sampling may influence the occurrences of larger shad. Collections are accomplished using a much smaller seine in daytime hours. Shad are visually-oriented and larger shad may preferentially escape from tidal collections; yet estuary waters are typically turbid. In contrast, non-tidal collections employ a much larger seine, in nighttime hours, which may allow increased catchability of larger YOY shad.

Both the non-tidal and tidal JAIs are reported as separate geometric means, with their respective sites combined among location and months. The historic non-tidal JAI (i.e., composed of Trenton, Phillipsburg, Water Gap, and Milford Beach sites) increased from 1980 to 1984, then fluctuated without trend through 2007, with good year class abundance reported in 1996 and 2007 (Table 4, Figure 5). Closer evaluation reveals an increasing trend from 1980 through the time-series peak in 1996. The JAI decreased from 1996 through 2002 but rebounded until the survey ended in 2007. Since the re-initiation of the survey, YOY abundance has been declining. Relative abundance observed in 2012 was of similar magnitude as some past years' peaks, ranking 9th highest overall. The 2015 estimate, however, was below the time-series average, ranking 20th overall. Comparatively the peak years, 1996 and 2007 ranked 1st and 2nd, respectively; whereas the poor years, 1998, 2002, and 2006 ranked, 28th, 30th, and 29th, respectively.

To further examine variation in the non-tidal index, the sampling sites were scrutinized for their contribution to the overall index. Table 4 shows the annual geometric mean catch per haul for the four historic, non-tidal index sites (i.e., Trenton, Phillipsburg, Water Gap, and Milford). Though variance is high, mean catches at Trenton are generally an order of magnitude lower than those at the other three sites. Table 5 displays a correlation matrix of log-transformed geometric CPUEs from each of the four non-tidal sites, the tidal index (i.e., Regions 2 and 3 combined), and a non-tidal index composed of only the Phillipsburg, Water Gap, and Milford sites. Though not significant (one tailed $p = 0.28$), Trenton has a higher correlation value with the tidal index than the index derived from the other three non-tidal sites (i.e., Phillipsburg, Water Gap, Milford).

The perceived agreement of the Trenton site to the tidal index is likely due to location. Historically, the Trenton site was included in the non-tidal JAI index; yet, this site is actually located in the tidal reach near head-of-tide (RM 133). Tidal influence is observed at the Trenton site. This is different from the other three sites, which are located in the non-tidal reaches where river flows are unidirectional. With a sampling regime where sites are sampled four times each night, a slowing or change in flow during sampling may have a large impact on fish presence and catchability. In addition, tidal fluctuations can impact water clarity and water chemistry at the site.

Co-op members will continue to sample the Trenton site as has been done in the past, but not include sample events at Trenton in either the non-tidal or tidal JAI indices. Comparison of the historic (i.e., Trenton, Phillipsburg, Water Gap, Milford) and new non-tidal (i.e., Phillipsburg, Water Gap, Milford, collectively informally referred to as the Big 3) geometric mean CPUE indices is shown in Figure 6. As the further upriver sites (i.e., Milford and Water Gap) had the biggest contributions to both non-tidal indices, the trends in the Big 3 non-tidal index are very similar to those explained above for the historic index. Co-op members will assess the non-tidal YOY shad recruitment using the Big 3 as the non-tidal JAI for the duration of the 2017 SFP.

To further standardize the non-tidal JAI in order to improve precision and accuracy, the Co-op conducted new analyses on the index to reduce variability in the index associated with collection and environmental variables. Previously, the Co-op had used a geometric mean to determine an annual value for the American Shad JAI. However, recent advances in fishery independent index standardization (e.g. ASMFC 2016) have led to indices being standardized by significant environmental covariates such as water temperature, depth, season, etc. using generalized linear models (GLM) to better account for variability in catch among years.

Inclusion of data was constrained based on two limitations. The non-tidal American Shad JAI data set extends back to 1981; however, the number of sampling events was not standardized until 1988. The survey samples American Shad at four fixed locations (Trenton, Phillipsburg, Delaware Water Gap, and Milford) with four hauls at each site from August through October. However, due to the lack of correlation of Trenton with the other non-tidal sites described above, the number of sites considered in this analysis was constrained to three locations (Phillipsburg, Delaware Water Gap, and Milford).

Model development considered explanatory variables (year, haul, ordinal day and site) to assess how they impacted catch. Ordinal day was the only variable considered continuous, and was treated as a proxy for temperature; all other variables were treated as categorical variables. Since catch was modeled for each tow, effort did not theoretically change and was excluded from the analysis. The generalized inflation factors were less than 1.5 after correcting for more than one degree of freedom suggesting that no collinearity was observed among any of the explanatory variables. Three models were compared in this analysis (Poisson, Negative binomial, and a Zero-inflated negative binomial). However, based on the dispersion or the relationship of the variance to the mean of all three candidate models (Poisson, Dispersion = 474.79; Zero-inflated negative binomial, Dispersion = 1.32) the negative binomial model (Dispersion = 1.05) was best fit to the data. After the full negative binomial model was considered, site was not found to be a statistically significant parameter impacting catch (df = 2, $p = 0.267$). However, all remaining covariates were highly significant ($p < 0.001$) when compared to the number of fish caught in each tow. Similarly, the final model was overall highly statistically significant (df = 2, $p < 0.001$). The final model chosen to standardize the non-tidal American Shad JAI in the Delaware River was defined as:

Number of Fish Caught ~ Year + Haul + Ordinal day

Annual estimates of mean number of fish caught or the new American Shad JAI, ranged from 53.67 – 420.81 with a 25th percentile of 145.90, median of 185.90 and a 75th percentile of 284.10.

We identified the relative power of the non-tidal JAI using the 'powertrend' function in the 'fishmethods' package in R. The power analysis for detecting trends in linear regression is implemented in 'powertrend' following procedures in Gerrodette (1987; 1991). Using the average annual proportional standard error (standard error/mean) from 1988-2015 of 0.23, we found that our survey can detect a 93% decrease and a 171% increase with a power ($1 - \beta$) of 0.80, i.e. our survey can detect changes in the annual JAI below 11.80 or above 456.99 over a five year period (Figure 7).

Comparison of the GM (i.e., Big 3) and GLM non-tidal JAI estimates is suggestive of similar trends (Figure 8). Both JAIs identified peak YOY production occurring in 1996, 2007, and 2012. Additionally, both indices also suggested JAI values observed in 1998, 2006 and 2013 as poor production years. One interesting difference between the two JAI indices is the reversal of relative abundances observed for 2003 to 2005. The Big 3 GM was suggestive of 2003 (78.7) and 2004 (80.0) JAIs being below long-term average of 123.4 and the 2005 (186.1) JAI being an above average year (Table 4). In contrast the 2003 (282.7) and 2004 (256.0) GLM JAI estimates were both well above the long-term average of 204.5 and the 2005 (204.6) JAI being an average production year (Table 4).

The ASMFC provides guidance on defining a JAI index and associated benchmarks. Amendment 3 to the ASMFC to the Interstate Fishery Management Plan for Shad and River Herring requires JAIs to be expressed as geometric means (GM) or area under the curve (AUC; ASMFC 2010). Confidence intervals should be provided for geometric means. For the 2017 SFP, the non-tidal JAI will be expressed both as a GM and a GLM; however, the benchmark for the non-tidal JAI will be based on the GLM analysis. The Co-op considers the GLM as providing a more robust JAI index than can be indexed by geometric means.

The tidal JAI increased from 1980 to 1988, and then varied without an apparent trend (Table 4, Figure 5). The tidal JAI also tended to be highly variable among years. Two good year-classes, 2005 and 2007, were immediately followed by two poor year classes in 2006 and 2008. After 2008, the tidal JAI was trending upwards, to an exceptional peak year-class abundance observed in 2013, ranking first over the time-series. Young-of-year production observed in 1996 also demonstrated very strong year-class abundance. Overall, the better than average year classes in 2005, 2007, 2013, and 2014 as well as favorable environmental conditions in recent years are encouraging (Table 4, Figure 5). The tidal JAI will continue to be calculated as a GM of annual catch for the duration of the 2017 SFP. The Co-op intends to conduct a similar GLM analysis on the tidal JAI to reduce variability and increase precision in that estimate.

The 2012 SFP found significant positive trends of both JAIs regressed on year and to each other. These relationships have since deteriorated. Previous relationships relied upon co-occurrences of peak year-classes, specifically 1996 and 2007. Over the last five years, since 2012, the JAIs tended to demonstrate opposite trends. For example, in 2012 the non-tidal estimate was suggestive of good production; whereas, the tidal JAI indicated poor production. The 2013 tidal JAI suggested exceptional year-class production, but the non-tidal was poor. Again in 2014, the tidal JAI decreased while the non-tidal JAI increased. This increased disparity between the two indices suggests divergence of year-class production success.

Multiple factors influence the success of YOY year-class production. Certainly, spawning success dictates total egg availability, but environmental conditions tend to heavily influence hatching success and subsequent survival of fry and juveniles. Differences between the two JAIs suggest variables such as the timing of the run, water temperatures, etc. may affect the two areas differently in a given year. Water quality in the upper estuary, particularly in the Philadelphia reach, continues to improve. Returning adults may simply be taking advantage of this improved spawning area.

Amendment 3 defines recruitment failure as occurring when three consecutive JAI values are lower than 75% of all other values in the data series (ASMFC 2010). The Co-op has adopted this definition for both the non-tidal and tidal JAI benchmarks. These are calculated as the 25th percentile, using the “quantile” function in the R package or “percentile.inc()” function in Microsoft Excel spreadsheets. The non-tidal benchmark is inclusive of those years in the GLM analysis (1988 – 2015). The tidal benchmark is based on JAI values from 1987 – 2015, rather than inclusive of the entire time-series (1980-2015). Prior to 1987, data collection was not standardized among tidal locations.

2.2.1.2 Adult Abundance Indices

Co-op members annually monitor the relative abundance of returning spawning adult shad in the Delaware River. Monitoring occurs after the commercial fishery, such that captured shad represent survivors from the fishery. This effort is currently being accomplished only at one location at Smithfield Beach (RM 218) as a gill net survey on actively spawning adults. Over the tenure of the 2012 SFP, an electrofishing survey at Raubsville, PA (RM 176) was also pursued. Electrofishing targeted adult shad migrating to upriver spawning grounds. Initiated in 2010, the intent was to investigate the possible substitution of the electrofishing effort in place of the gill net survey. This substitution was viewed as a cost savings in term of personnel resources; however, the Raubsville electrofishing monitoring was terminated in 2016. Study findings for both Smithfield Beach and Raubsville efforts are discussed in greater detail below.

2.2.1.2.1 Gill Net Survey

Collections at Smithfield Beach principally focus on capture of brood fish and subsequent strip-spawning to produce fertilized eggs in support of the Pennsylvania Fish and Boat Commission (PFBC) restoration efforts in the Schuylkill and Lehigh rivers, the largest tributaries to the Delaware River. Approximately 8 to 18 gill nets (200 feet in length by 6 ft deep) are set per night with mesh sizes ranging from 4.5 to 6.0 inches (stretch). The total number of net sets by mesh size per night depends on the previous nights' catch for maximizing female captures. Nets are anchored on the upstream end and allowed to fish parallel to shore in a concentrated array. Netting/spawning operations typically begin on Mother's Day when river flows are workable and river temperatures reach 16.0 ^{o}C. Sampling occurs Sunday through Thursday evenings and is typically terminated near the end of May or early June when egg viability decreases and/or river temperatures reach 21.0 ^{o}C for an extended period of days. Typically, the sampling period encompasses three weeks of nightly effort. Biological data collected include gender, length (total and fork), weight (excluding ovarian weight due to the strip spawning procedures), otolith age, scale age, repeat spawning marks, and chemical marks placed on the otolith during rearing. No biological data were recorded prior to 1996.

Overall, the total number of days spent gill netting varied from nine (1990 and 1992) to 21 (2001, Figure 9). Assigning a week number, based on the occurrence of January 1st as week one, sampling durations among years can be examined. Sampling principally occurred during weeks 20 through 22 (Figure 9). Yet, sampling in 1990 was completed early (i.e., weeks 18 and 19) compared to the time-series. In several years, however, sampling was extended into June, weeks 23 and 24.

Total catch at Smithfield Beach varied among years (Figure 10). Greatest total numbers of captured shad occurred in 1995 (n = 1,398), with several other early years (i.e., 1990 – 1994) in the time-series also having large total catches (> 1,000 individuals). Conversely, the lowest total catch occurred in 2006 (n = 356). Three other years, 2002 (n = 400), 2004 (n = 425), and 2009 (n = 372) also had very low total catches of shad. Observed sex ratios in any given year is dependent on the frequency of gill net mesh sizes deployed.

The frequency of stretch mesh sizes used varied among years (Figure 11). The use of 4.5 inch and 5.0 inch stretch mesh nets, tended to be principally deployed in any given year to support broodstock collections. The increased use of the 4.75 inch stretch mesh size in later years (i.e., post 2012) was due to a perceived need to increase the male to female ratio for improved egg viability. Use of large ($\geq$ 5.5 inch) stretch mesh sizes were not as commonly deployed as smaller stretch mesh sizes, due to the perceived lack of catch.

In any given year, most of the catch at Smithfield Beach principally originated from two stretch mesh sizes (Figure 12). The 5.0 inch stretch mesh typically captured 31% – 58% of all females.

The 4.5, 5.25, and 5.5 inch stretch mesh nets also caught female shad; but in lesser quantities, representing 4.8% - 20.0 %, 5.3 % – 13.7%, 0.3% - 18.0% of the female total catch, respectively. Female catch from the 5.75 and 6.0 stretch mesh nets were typically less than 10% in most years. The 4.5 inch stretch mesh typically captured 24% – 69% of all males. The 5.0 and 4.75 inch stretch mesh nets also captured some of the male total catch, 16% – 48% and 2.2% - 26.3%, respectively. The other larger stretch mesh sizes (> 5.25 inch stretch mesh) caught few (< 10%) males.

Size selectivity of gill nets introduces bias into catch characteristics (e.g., length and age distributions). This bias may preferentially capture a specific size range of shad dependent, in part, on stretch mesh size and fish body shapes. Figure 13 illustrates annual Smithfield Beach catch lengths by stretch mesh size (1999 – 2009). Median size, by stretch mesh size, does not appreciably increase among catches of shad from the small stretch mesh nets to comparatively larger stretch mesh nets. For example, median sizes of the female catches from the smallest stretch mesh nets (4.5 inch) was 534 mm TL compared to the median size of 573 mm TL of female shad caught in the 6.0 inch stretch mesh nets (Table 6). Similarly, median size of males caught in the smallest stretch mesh nets (4.5 inches) was 489 mm TL compared to 521 mm TL median size of males caught in the 5.5 inch stretch mesh nets (Table 6). Interestingly, the smallest median male size (466 mm TL), however, occurred from catches in the largest stretch mesh nets (6.0 inch; Table 7). The difference between the minimum and maximum median sizes for both genders, 39 mm and 55 mm, for females and males, respectively, does not suggest a broad distribution of lengths among the various gill net catches. In all years, for all stretch mesh sizes, a considerable overlap of size distributions occurs.

Median length frequencies varied among years for both female and male shad (Table 7; Figure 14). Female total lengths ranged from 437 mm TL (2008) to 644 mm TL (2003), with median sizes between 516 mm TL (2010) to 571 mm TL (2003). The overall size range (i.e., minimums and maximums) for females overlapped among years. Generally, males are smaller sized than females. Total lengths ranged from 398 mm TL (2005) to 615 mm TL (1996), with median sizes between 468 mm TL (2009) to 514 mm TL (2002). Length distributions for males among years also demonstrated considerable overlap.

Observed trends of annual length distributions appear to have limited relationships to the frequency of deployed gill net mesh size (Figure 14). Overlaying the frequency of gill net deployment on annual length distributions, suggests increased sizes of females were directly related to the proportion of the number of 5.0 inch mesh nets set per year. This relationship, however, was not significant (Spearman's Rank: $r = 0.246$, $p = 0.325$). Nor were observed female length frequencies significantly related to deployment frequency of all other mesh sizes. No significant relationships were found between observed male length frequencies to frequency of mesh sizes deployed, excepting for 5.5 stretch mesh (Spearman's Rank: $r = -0.718$,

$p = 0.00079$). This finding is most likely strongly influenced by the paucity of male catch in the 5.5 stretch mesh size in addition to its infrequent deployment.

Length distributions among stretch mesh sizes are influenced by several factors. During the initial days of spawning, increased body girth due to swollen gonads, tend to allow smaller sized shad being caught in large sized mesh. Then as larger fish become spent, their slimmer body girth allows larger sized shad to be caught in smaller mesh nets. Additionally, shad tend to be fragile fishes, such that they easily perish over slight interferences. Mortalities due to entanglement (i.e., lip hooks) are a common occurrence throughout the sampling periods.

A considerable time-series of Delaware River American Shad scales and otoliths have been collected from Smithfield Beach, since 1996 to present date. While these structures have been aged, due to uncertainty associated with ageing (McBride *et al*. 2005; Duffy *et al*. 2012) this information was not presented in the 2012 SFP. In recent years, Co-op members have arrived upon an agreed protocol to provide consistency of ageing scale microstructure (Appendix A). This protocol is inclusive of a reference set to aid in identifying annuli and repeat spawning marks. Co-op members will be applying this protocol to the 2015 Smithfield Beach collections and subsequent annual collections. While this protocol has not been applied to the historical ages, Co-op members have agreed inclusion of historical age distributions as necessary to fully understand the dynamics of the Delaware River shad spawning population. Co-op members intend to review the historical records to strengthen confidence of assigned interpretations.

The Delaware River American Shad spawning population is supported by few age classes (Table 8; Figure 15). Age 5 and Age 6 typically represented the majority (> 70%) of female shad, in any given year. Only in three years were these two ages not as strongly represented, including 2006 (66%), 2012 (41%), and 2014 (69%). Ages 3 and 7, typically contributed less than 1% and 10%, respectively, in any given year; yet, in 2005 (25%), 2006 (14%), 2009 (14%), 2012 (57%), and 2014 (28%), Age 7 female shad composed a greater portion of the observed ages. Ages 8 and 9 female shad were rare (<3%) occurrences. No female shad over Age 9 were observed.

Male shad were principally (> 70%) represented by Age 4 and Age 5 shad, in any given year (Table 9; Figure 14). In three years, 2011 (77%), 2013 (60%), and 2014 (41%), Age 6 male shad also contributed to a greater proportion of the observed age distribution. Age 7 male shad were also prominent in 2012 (21%) as well; whereas, in all other years, Age 7 shad were a rare occurrence (< 5%). Young (Age 3) or old (Age 8) male shad also tended to be rare (< 10%). No male shad over Age 8 were observed.

The modal progression of age classes from peak YOY production years is apparent in observed Smithfield Beach age distributions. Strong year-class production has been related to the occurrence of subsequent returning adults to Smithfield Beach. This relationship is further discussed at the end of this section.

Application of annual age-length keys provides for the estimation of mean size-at-age (Table 9; Figure 16). Graphical representation is suggestive of a downward trend for Age 4 through Age 7 for both female and male shad. Regressing mean size-at-age on year demonstrated declining trends for Age 4 (F = 8.19, df = 18, *p* = 0.010) and Age 6 (F = 5.70, df = 18, *p* = 0.028) females; but, not for Age 5 (*p* > 0.05) or Age 7 (*p* > 0.05) females. Regressions of male mean size-at-age on year were not significant for Age 4, Age 5, or Age 6, but male Age 7 mean size-at-age were significantly declining (F = 10.44, df = 9, *p* = 0.012).

Gill net selectivity can influence observed mean size-at-age; however, we believe the impact of selectivity on mean size-at-age was minimal. The majority (i.e., 74% - 99%) of the female catch originates from the combined catch of all mesh sizes ≤ 5.5 inch; whereas, the majority (88% - 98%) of the male catch is from the combined catch of 4.5 inch through 5.0 inch stretch mesh net (Figure 12). The increased use of smaller mesh nets (i.e., 4.5 and 4.75 inch stretch mesh) with a concomitant decline of larger mesh nets (i.e., > 5.0 stretch mesh) use in later years may be a causative effect to the observed declining mean size-at-age (Figure 11). A significant correlation was found between female mean size-at-Age 4 shad to the frequency use of the 4.75 stretch mesh net (Spearman's Rank: r = -0.55, *p* = 0.033). All other age classes for both female and males did not significantly correlate (Spearman's Rank: *p* > 0.05) to the frequency of use of any gill nets, regardless of stretch mesh size.

There is some evidence to suggest that mean size-at-age is declining towards smaller sized shad in two age classes. These declining trends appear to be a shift in the population, given nominal influence of gill net selectivity. In later years 2011 – 2014, older (i.e., > Age 6), and presumably larger sized shad, tended to have a greater contribution to the total catch (Figure 15). Larger sized shad would be anticipated to have a greater contribution to increased mean size-at-age. The observed declining trend is contrary to that assumption. However, the declining trend is only identifiable with any certainty (i.e., significant) to females of two age classes, Age 4 and Age 6. The lack of any significant correlation for Age 5 females, who compose a large proportion of each annual spawning run, and older Age 7 female shad, is perplexing. Nevertheless, the Co-op recognizes the significance of a declining trend in size-at-age, and will continue to monitor for similar trends in multiple year classes.

Interpretation of scale microstructure potentially provides some understanding of the occurrence of shad returning for spawning in subsequent years (Figure 17). Prior to 2014, 83 % - 97 % of females and 83 % - 98 % of males captured at Smithfield Beach were principally composed of first-time (i.e., zero repeat spawning marks) spawning shad, in any given year. Shad repeat spawning in a second year (i.e., one repeat mark), varied 2 % to 17 % for either females or males; whereas, third-time (i.e., two repeat marks) spawning shad were infrequent (0 % - 3 %). A few shad (n = 10 individuals), were identified as fourth-time (i.e., three repeat marks, female: N = 8; male n = 1) or fifth-time (i.e., four repeat marks), female: n =

1; male: n = 0) spawners. In contrast, occurrences of second-time and third-time spawners occurred more frequently in 2014 and 2015, than in past years. Second-time spawners composed 53 % and 45 % of captured shad in 2014 for female and male shad, respectively. Catch of shad in 2015 also demonstrated increased occurrences of third-time spawners (female: 18 %; male: 24 %).

The incidence of repeat spawning being consistently interpreted from scale microstructure is difficult. Historical interpretations, not being subjected to the existing Co-op ageing protocol, were most likely conservative. The increased occurrences of repeat spawning in 2014 and 2015 possibly reflect influences of discussions during the development of the Co-op ageing protocol (Appendix A). Further evaluation of the historical data set needs to be refined to provide better consistency among the Co-op members' repeat spawning assignments. Until this review occurs, Co-op members will not associate any inferences to the spawning population based on repeat spawning marks.

In an attempt to get a general sense of trends in total instantaneous mortality (Z), historical age data from shad collected at Smithfield Beach were analyzed using a Chapman-Robson bias-corrected mortality estimator described in Smith *et al.* (2012). Total mortality was calculated for females and combined sexes on an annual basis beginning in 1997. To be consistent with the methods used in the 2012 Benchmark Stock Assessment for River Herring, the age of full recruitment was the age of highest abundance and there had to be at least three ages to be included in the respective analyses (ASMFC 2012). Total mortality estimates are reported in Table 10 and Figure 18. Female Z estimates ranged from 0.81 (2006) to 2.87 (2012). Total mortality estimates for combined sexes ranged from 0.83 (2015) to 2.82 (2012). Graphical representation is suggestive of an upward trend in total mortality (Z) for both female and combined sexes of American Shad collected at Smithfield Beach (Figure 18). These data are considered preliminary, given that Co-op members have not yet confirmed the historical age dataset with the updated ageing protocols (Appendix A).

The principal operations of Smithfield Beach were for broodstock collection of field fertilized eggs in support of the PFBC Lehigh and Schuylkill rivers restoration program. Standardized (i.e., Z score + 2 transformed) annual total egg collection varied among years (Figure 19). The greatest quantity of eggs were harvested in 1990 (n = 13.4 million). Total yield declined through the 1990's to a low of 3.8 million in 2000. During the 2000's total number of eggs harvested ranged between 2.0 – 6.3 million eggs. A peak in total eggs harvested was observed in 2011 (9.9 million eggs) near levels observed in the early 1990's. Subsequently, total egg harvest declined again to recent lows (3.9 million in 2015).

Evaluation of the average number of eggs per liter offers insight into the relative size of harvested eggs (Figure 19). The peak harvest of eggs observed in 1990 resulted in an average of 35,133 eggs per liter in that year. As total harvest declined through the 1990's, the average number of eggs per liter remained relatively stable (31,395 – 39,034 eggs/L). In 1998 (10.3 million eggs) and again in 2012 (8.9 million eggs) as the total egg harvest increased, concomitantly the average number of eggs per liter (1998: 55,382 eggs/L; 2012: 77,450 eggs/L) also increased. Interestingly, during the relatively low total harvest of eggs through the 2000s (2.0 – 6.3 million eggs), the average number of eggs per liter also remained relatively low (30,543 – 62,848 eggs/L). Increased catches of females were not correlated (Spearman's Rank: $r = 0.236$, $p = 0.314$) to the average number of eggs per liter, suggesting increased availability of females is not resulting in more eggs per liter. These trends are suggestive that the relative egg size was smaller in 1998 and 2012 peak periods relative to the 1990's and the 2000's.

The total number of viable eggs is declining over the time-series (Figure 19). Viability is defined as the difference of total number of eggs collected minus the total number of unsuccessfully hatched eggs. A Spearman's Rank correlation ($r = -0.743$) suggests this declining trend is significant ($p < 0.0001$). No relationship was found between annual sex ratios to total egg viability (Spearman's Rank: $r = 0.159$, $p = 0.502$). Thus, increased or decreased frequency of male to female shad does not appear to overly influence egg viabilities.

Total egg viability and total number of eggs per liter vary throughout the spawning season (Figures 20 – 21). Comparison of total egg viability among sampling week was not suggestive of any significant trend (Kruskal-Wallis: $H = 10.491$, $p = 0.105$); however, a general trend in declining mean egg viability is observed from week 18 through week 24. The total number of eggs per liter, however, were significantly different (Kruskal-Wallis: $H = 44.733$, $p < 0.0001$) among sampling weeks, suggestive of an increasing trend (Spearman's Rank: $r = 0.928$, $p = 0.0025$). American Shad are intermittent spawners, with individual shad spawning multiple times in a single season. As the season progresses, egg size appears to decrease with variability in egg viability and fecundity also being observed through the season.

Smithfield Beach catch-per-unit-effort (CPUE) values ranged from 17.1 to 190.1 shad/net-ft-hr*10,000 (Table 11; Figure 22). Abundance peaked in the early 1990's, declined through the mid 1990's, and remained relatively stable from 1999 to 2009, but below the long-term average. In 2009, CPUE was the lowest recorded (17.1 shad/ net-ft-hr*10,000); however, this was most likely impacted by climatic factors. The exceptionally wet spring resulted in higher than average freshwater flows, reducing the efficiency of the gill nets. Cold water temperatures delayed and/or marginalized spawning behavior which would also reduce gear efficiency. Catch-per-unit-effort increased with the 2011 (72.0 shad/net-ft-hr*10,000) and 2012 (73.54 shad/net-ft-hr*10,000) estimates ranking as the sixth and fifth highest, respectively, since 1990. The most recent years, 2013 – 2015, have been slightly below the long-term average.

The utility of Smithfield Beach as a monitoring program for defining sustainability of the Delaware American Shad is critical. Yet, the primary purpose as a broodstock source for the PFBC restoration program confounds conclusive statements on observed population biological trends. Should program objectives for the PFBC restoration efforts relax; monitoring objectives need to take priority. Smithfield Beach protocols need to standardize effort in the deployment of gill net mesh size frequencies to reduce uncertainty. For example, the recording of catch by stretch mesh size will be re-initiated.

2.2.1.2.2 Electrofishing Survey

The PFBC historically (1997–2001) monitored returning adult American Shad at a fixed station (RM 176) in the vicinity of Raubsville, PA using boat electrofishing gear. These historical efforts at Raubsville focused principally in aiding assessment of hatchery restoration success in the Lehigh River (Hendricks *et al*. 2002). This survey was re-initiated in 2010 under the 2012 SFP and continued through 2016 which will be its terminal year. The intent was to allow concomitant data collection for comparison of relative annual trends at Raubsville to Smithfield Beach.

Present day sampling followed historical protocol. Sampling effort at Raubsville targets American Shad as they migrate into upriver non-tidal reaches. Separate samples were collected on the PA side (west) and the NJ side (east) of the river. The river was sampled once a week from April to May (Figure 23). Weekly sampling concluded when 15 American Shad were caught or after one hour of electrofishing, whichever came first. Electrofishing effort was not recorded during 1998. Biological data collected included gender, length (total and fork), total weight, otolith age, scale age, repeat spawning, and hatchery otolith marks.

Length frequencies of captured shad are illustrated in Figure 24. Female total lengths (mm) varied from a minimum of 427 mm TL (2014) to 624 mm TL (2013). Median sizes varied among years between 503 mm TL (1997) to 553 mm TL (2013). Female median sizes appeared to increase from 503 mm TL (1997) to 546 mm TL 2001 during the historical sampling. In later years, 2010 - 2015, female median sizes appeared to increase from 528 mm TL in 2010 to a peak in size in 2013 (553 mm TL), then decrease to 530 mm TL in 2015. Male total lengths captured at Raubsville were suggestive of a consistent trend throughout the time-series. Male total lengths varied from 389 mm TL (2012) to 584 mm TL (2015). Median sizes varied by 35 mm TL among years, 466 mm TL (1997) to 501 mm TL (2011).

Graphical comparisons of median sizes captured at Raubsville to those captured at Smithfield Beach (all mesh sizes combined) are suggestive of similar trends (Figure 25). Yet these trends for female shad are not significantly correlated (Spearman's Rank: $r = 0.587$, $p = 0.0739$). The greatest difference in female median sizes, occurred in 1997, when female shad captured at Raubsville (503 mm median size) were approximately 35 mm TL smaller than captured at Smithfield Beach (538 mm median size). Male median sizes, however, were found to be significantly correlated (Spearman's Rank: $r = 0.853$, $p = 0.0016$) between Raubsville and Smithfield Beach. Electrofishing is a non-size selective sampling methodology. These close approximations of median sizes between Raubsville and Smithfield Beach shad collections lends credence to nominal selectivity being introduced by gill nets at Smithfield Beach.

The Raubsville electrofishing CPUE was highly variable among years sampled (Table 11; Figure 26). Historical catch rates demonstrated a dramatic increase of CPUE from 1999 (13.9 shad/hr.) through 2001 (48.4 shad/hr.). After the re-initiation of the survey, in 2010 and 2011, CPUE was below the long-term average (27.5 shad/hr.); but peaked in 2012 (46.5 shad/hr.); and then dropped to the time-series low in 2015 (11.3 shad/hr.). The 2011 CPUE is an under-representation of the spawning migration. No sampling occurred during traditional peak migration weeks.

The Raubsville and Smithfield Beach relative abundance trends demonstrated different trends (Figure 27). For example, the peak relative abundance observed at Raubsville in 2001 was not observed at Smithfield Beach. While both indices demonstrated a peak in 2012, the continued declining trend through 2015 at Raubsville was not evident at Smithfield Beach. Comparison of the trends (Z score + 2 transformed) between Raubsville and Smithfield Beach demonstrated no significant correlation (Spearman's Rank, $p > 0.05$) regardless of the absence/presence of the 2011 Raubsville CPUE data.

Hendricks *et al.* (2002) demonstrated returning adult shad, originally stocked as fry in the Lehigh River, tend to have increased frequency of occurrence on the Pennsylvania side of the Delaware River main stem. These returning adult hatchery shad can orient to the Lehigh River plume within the Raubsville electrofishing survey area. Thus, captures of shad on the PA side at the Raubsville (RM 176) may be more reflective of the returning Lehigh River (RM 183) spawning run, rather than shad orienting to upriver Delaware River locations (i.e., Smithfield Beach, RM 218). No significant correlation (Spearman's Rank, $p > 0.05$) using transformed (Z score + 2 transformed) data was found between separated Raubsville electrofishing catch-effort for either Pennsylvania or New Jersey CPUEs to Smithfield Beach CPUE (Table 11).

The Raubsville electrofishing efforts, while successfully capturing shad, likely underestimated the annual shad run under historical protocols. Examination of weekly effort suggests sampling was terminated prior to the end of the migration (Figure 28). For example, CPUE estimates in 2012 and 2014 appeared to be increasing when sampling ceased. Furthermore, indices in 2010 and 2013 also appear to suggest the continuance of the spawning run, although an observed peak was evident. The early cessation of sampling at Raubsville was due to reassignment of personnel to Smithfield Beach operations. The Raubsville sampling also relies on the assumption shad migrate uniformly throughout the week. This is most likely a simplistic assumption, such that the once-a-week sampling is not an adequate representation of migration. The Raubsville electrofishing is an unsuitable substitute for Smithfield Beach. The Co-op members have terminated this survey after the 2016 sampling season.

Beginning in 2002 through present date, the Philadelphia Water Department (PWD) has maintained a robust monitoring program on the Schuylkill River. Objectives include quantifying the resurgence of key migratory species such as the American Shad, assessing the relative health and abundance of both resident and migratory fish, and evaluating the success of restoration activities with fish passage counts at the Fairmount Dam fishway. Monitoring efforts are encompassed in two programs, fish passage surveillance (refer to the Adult Fish Passage subheading) and electrofishing in tidal waters immediately downriver of Fairmount Dam in the tidal Schuylkill River.

Electrofishing catch rates (i.e., CPUE) of American Shad in the tidal Schuylkill River are illustrated in Table 11 and Figure 27. Catch-per-unit-of-effort peaked at 504.9 shad/hr and 948.0 shad/hr in two years, 2006 and 2011, respectively. The 2002 CPUE (9.7 shad/hr) represents the time-series (2002 - 2014) low; however, the electrofishing CPUE observed in 2008 (177.1 shad/hr) and 2012 (314.9 shad/hr) also represent relatively low years of abundance. No significant correlation (Spearman's Rank, $p > 0.05$) was found between the Schuylkill electrofishing and Smithfield Beach time-series CPUEs. In contrast, a significant correlation (Spearman's Rank: $r = -1.0$, $p < 0.001$) was found between the Schuylkill and Raubsville electrofishing CPUEs. This comparison, however, was limited to only four years of concurrent sampling (2010; 2012-2014). A longer-time series of concurrent years sampled for the Schuylkill and Raubsville electrofishing sites is needed to provide a more robust characterization of any correlation.

2.2.1.2.3 Adult Fish Passage

Many of the Delaware River tributaries historically contained spawning runs of American Shad. Unfortunately, with the development of the lock/canal systems throughout the Delaware River Basin, including the Lehigh and Schuylkill rivers in the early 1800s, shad became extirpated in many of these tributaries. Efforts have been undertaken to restore shad in the Lehigh and Schuylkill rivers by installation of fish ladders, and the stocked fry hatchery program. A considerable time series of fish passage monitoring exists for the Lehigh and Schuylkill rivers, but passage into many other Delaware River tributaries is unknown.

The PFBC has an extended monitoring time-series, 1995 to present, characterizing shad passage into the Lehigh River from the Delaware River. The Easton Dam (RM 0.0), situated at the confluence of the Lehigh and Delaware rivers, has a vertical slot fishway equipped with observation chamber. Video surveillance (1995 – 2012) was terminated due to the loss of grant funding support from the Interjurisdictional Fisheries Act in 2013 and reduction of personnel resources. Post 2012, total passage through the Easton Dam fishway is estimated using a predictive regression relationship between total passage and a one-day electrofishing survey, developed from concurrent years monitoring 1996 – 2012. The electrofishing survey is conducted, mid-June in two pools: the Chain Dam plunge pool (RM 3.0) and Palmer Township Riverview Park (RM 2.55).

Annual passage of shad ranged from 408 to 4,740 total shad (0.11 to 2.28 average shad/hour; Table 11; Figure 29). Peak passage was observed in 2001 (n = 4,740 shad); whereas, poor passage occurred in 2003 (n = 422), 2008 (n = 408), and 2009 (n = 425). Passage of shad through the Easton Dam fishway was not significantly correlated (Spearman's Rank, $p > 0.05$) to the Smithfield Beach CPUE. Furthermore, neither was the Easton Dam fishway passage significantly (Spearman's Rank, $p > 0.05$) related to either the combined Raubsville electrofishing CPUE or the Raubsville CPUE separated into its Pennsylvania component of catch-effort.

The Philadelphia Water Department (PWD) established a video monitoring program in 2003 to assess fish passage at the Fairmount Dam fishway (Table 11; Figure 29). The 2011 fish passage season at the Fairmount Dam fishway was a record-breaking year, with 3,366 American Shad ascending the fishway. Data from 2004–2010 suggests a similar trend in upstream fish passage between the Lehigh (Easton Dam) and Schuylkill Rivers (Fairmount Dam). Discrepancies between the two trends occurred post 2010. Shad passage at Fairmount Dam fishway peaked in 2011, but the Easton Dam fishway passage was poor (n = 558). The PWD electrofishing CPUE in the tidal Schuylkill River immediately below the Fairmount Dam was significantly correlated (Spearman's Rank: $r = 0.83$, $p = 0.005$) to total shad passage through the Fairmount Dam fishway. No significant correlation (Spearman's Rank, $p > 0.05$), however, was found between Easton and Fairmount dam fishway passages (Figure 29). Nor was passage of shad through the Fairmount Dam fishway significantly correlated (Spearman's Rank, $p > 0.05$) to Smithfield Beach CPUE.

The lack of any relationship between the Lehigh and Schuylkill rivers shad passages suggests shad runs into these rivers are independent of the Delaware River spawning run. Co-op members agreed that Easton and Fairmount fish passage was of no utility in assessing/monitoring the shad population within the Delaware River. No attempt was made to document downriver passage from the either river back into the Delaware River.

2.2.1.2.4 Comparison of JAI to adult indices

One might expect that juvenile production (i.e., recruitment) would be a function of adult stock size. Figure 30 plots the two non-tidal (Geometric Mean and GLM) and tidal JAI indices against Smithfield Beach relative abundance (a proxy for the spawning stock size). No obvious relationship exists between adult relative abundance and year class strength (juvenile production) in any given year (Figure 30). The lack of a correlation most likely is related to sampling variability, and environmental influences, especially involving early life stages.

Hattala *et al.* (2007) provide another way to validate the adult stocks with recruitment. In the 2007 American Shad stock assessment, they successfully correlated a young-of-year index with future adult spawners coming back into the Hudson River, New York. A similar comparison is possible for the Delaware River. Since 1996, American Shad from Smithfield Beach have been aged using scales and otoliths. However, it is important to note that these fish were aged with methods differing from the 2015 Aging Protocol (Appendix A). The Smithfield Beach annual index of abundance and age structures are shown in Table 12, and age specific index values are listed in Table 13. The values in Table 13 are the observed proportion-at-age multiplied by the Smithfield Beach survey abundance index. Next, the values in Table 13 are summed along the diagonal to represent year class contributions to YOY year class production. For example, in a comparison of young-of-year to an index of four to six year olds, the 1992 young-of-year index is compared to a sum of the indices for four year olds in 1996, five year olds in 1997, and six year olds in 1997. Because most fish observed are between 4 and 7 years old, we only include groupings of those ages in the correlations.

Table 14 lists the various correlations tested between the non-tidal indices and the age specific adult indices. Note the two non-tidal indexes are evaluated, each only includes the Phillipsburg, Delaware Water Gap, and Milford Beach sites (Big 3). Based on p-values and power analyses, the best correlations are between the geometric non-tidal index and the 4-6 and 4-7 year old groupings (Table 14 and Figure 31). The non-tidal GLM index does positively correlate with the age-specific adult indices; however, the relationships are not significant and have low power. Though differing in significance levels, both JAI indices positively correlate with adult indices from Smithfield Beach (Figure 31). A review of the historical age samples as well as a more robust adult index that standardizes catch rates with environmental variables and gear use, will hopefully improve the relationship between the non-tidal GLM and the age-specific adult indices.

2.2.2 Fishery Dependent Data

2.2.2.1 Commercial Fisheries

Exploitation of the Delaware River American Shad stock occurs in several fisheries within the Basin. Commercial harvest is permitted by the States of New Jersey and Delaware. These fisheries occur in tidal waters of Delaware and New Jersey using stake and anchored or drifting gill nets. Fishers principally harvest shad during the spring spawning migration from late February into May. Fishers in New Jersey represent a small directed fishery for American Shad; whereas, landings of shad reported to the State of Delaware occur as bycatch from their concurrent Striped Bass fishery.

In addition to the Delaware Estuary/Bay fisheries, a small haul seine fishery (Lewis haul seine) occurs in the Delaware River, some 15 miles above the fall line at Lambertville, NJ.

2.2.2.1.1 Lewis Haul Seine

Lewis haul seine: The Lewis haul seine is the only in-river fishery and is located at Lambertville, NJ (RM 148.7). It dates back to the late 1880's, representing a significant time-series of recorded data with catch-per-unit-effort data documented since 1925 (Table 15). The fishery has evolved from a commercial enterprise to more of an eco-tourism enterprise. To preserve this historical data series the Co-op members support the fishery with a $6,000 grant (2008-2016) to collect CPUE (catch/haul) and biological data from the catch. Contract obligations require the Lewis haul seine to fish for shad a minimum of 33 days within the traditional fishing period (mid-March through June). Required information includes dates fished, number of hauls, and total American Shad catch per haul. Gear specifications and deployment were left to the discretion of the operator of the Lewis haul seine to maintain traditional methodology, subject to in-river flow variations.

The exceptionally long time-series of CPUE data from the Lewis haul seine is a good indication of the spawning run strength in the Delaware River. Recent CPUE shows an increasing trend from the 1960's-80's followed by an overall decrease to the mid-2000's. Since the adoption of the SFP in 2012 the CPUE peaked in 2013 (26.63) with all others years in the time period being at or below the time series mean (9.89; Figure 32). Unfortunately, the Lewis haul seine may not be an ideal abundance measure since the fishery uses varying nets depending on daily environmental conditions. In addition, natural changes to the river channel in the area of the fishery may be affecting the catchability of American Shad.

The Lewis haul seine provides a separate index of the returning adult spawning population to the Delaware River. CPUE from the Smithfield Beach gill net and Lewis haul seine for 1990-2010 exhibit similar trends (Figure 33), but have diverged in recent years. The two indices are strongly correlated (Pearson product-moment: $r = 0.822$; $p < 0.001$; Figure 34).

Data on age, size and sex composition of shad captured in the Lewis haul seine fishery have been collected intermittently since 1979. Beginning in 2008, reporting of biological data (i.e., total number shad landed, length, sex, and scale samples) was mandatory as part of contractual obligations with the Co-op (Table 16). Mean fork lengths for both genders show similar changes over time with no apparent overall trend toward an increase or decrease in mean fork length (Figure 35).

2.2.2.1.2 New Jersey Commercial Fishery

Fishery Characterization and Regulations: Prior to 1998, the National Marine Fisheries Service (NMFS) estimated American Shad landings for the State of New Jersey. In 1999, the NMFS estimates were combined with voluntary logbook data from New Jersey's commercial fishers.

These landings data reported by NMFS date from the late 1800s to 2000, while extensive, are thought to be under-reported and considered inaccurate. In 2000, the State of New Jersey instituted limited entry and mandatory reporting for the American Shad commercial fishery. American shad landings reported to the State of New Jersey are separated into two reporting regions: Upper Bay/River and Lower Bay. Historically, Gandys Beach (RM 30) was the demarcation for separating the reported landings.

These mandatory logbooks allow insight into the fishery. Records indicate that the shad fishing season started as early as February 15 and ended as late as May 22. Employed mesh sizes ranges from 5 to 6 inch stretch. American Shad are primarily landed by drifting gill nets in the Upper Bay/River fishery while staked and anchored gill nets account for the majority of shad being landed in the Lower Bay.

Regulations for American Shad harvest in New Jersey include a limited entry/limited transferability license system, limitations on the amount and type of gear allowed to be fished, and gill net season and area restrictions enforced through a limited entry permitting system in the lower Delaware Bay. Specifically, these restrictions included gill nets can be deployed from February 1 to December 15, minimum stretch mesh size increases through the season, with 2.75 inches through February 29 and 3.25 inches March 1 to December 15. Net length is also limited to 2,400 feet from Feb 1 to May 15 and 1,200 feet from May 16 to December 15 (Table 17). A haul seine can also be used to harvest American Shad from November 1 to April 30. The seine must have a 2.75 inch minimum stretch mesh and maximum length of 420 feet.

<u>Fishery Participation</u>: In New Jersey, as of May 3, 2016, there were 61 permits issued (37 commercial and 24 incidental) to allow harvest of American Shad. The shad permit allows the holder to fish in any state waters where the commercial harvest of shad is allowed if the permit holder meets all other net requirements for commercial fishing in a particular area. Currently, only 47 of these permits are active, due to attrition (Table 18). Since harvest reporting became mandatory in 2000 the number of fishers landing shad in New Jersey has seen a steady decrease. From 2000 through 2006 the number of fishers landing shad averaged in the mid-twenties (range of 21-29). From 2007 through 2009 this number dropped into the mid-teens (range of 14-17), and since 2010 this number has averaged around 10 fisherman landing shad in the Delaware Bay (range of 9-13). The number of fishers landing shad in New Jersey is expected to continue to decrease as the current fishers age out of the fishery and interest in the fishery itself continues to decline.

<u>Landings</u>: Harvest of American Shad by region in New Jersey has seen a shift from historically being a predominantly Lower Bay fishery (below Gandys Beach) to an Upper Bay /River fishery. From 1985 through 2000, landings in the Lower Bay averaged 81,013 pounds, while the Upper Bay/River fishery saw average landings of 18,759 pounds of shad. Since 2001 this trend has

reversed with Lower Bay landings averaging 11,518 pounds and the Upper Bay/River fishery landing an average of 37,300 pounds of shad (Table 19, Figure 36).

Fishing Effort: Effort data for New Jersey's commercial fishery is estimated from CPUE presented in pounds per square foot of netting (Table 20). New Jersey data is partitioned to examine the Upper Bay/River CPUE as well as the Lower Bay CPUE in mixed stock areas of Delaware Bay. The overall New Jersey commercial fishery CPUE varied without trend throughout the time period with a slight decline in recent years due mainly to a lack of effort and large concentrations of Striped Bass, which NJ fishermen are not permitted to land (Figure 37). New Jersey's Upper Bay/River fishery CPUE mimics the overall trend. CPUE within the Lower Bay has actually increased in recent years with the exception of a sharp decline in 2015; however, actual effort is low. Overall effort in New Jersey has decreased more than 30 percent since 2005.

Biological Data: Length frequency data (fork length) were collected from American Shad caught during fishery independent tagging operations by gill net in lower Delaware Bay (i.e., Reed's Beach, RM 14.8; Table 21). However, data are comparable to the commercial fishery since similar gill net mesh sizes are used for this program. Fork lengths ranged from 346 mm to 615 mm and have fluctuated without trend over the course of the time series (Table 21). Sex ratios show the fishery is mostly prosecuted for females, with both the Upper Bay/River and Lower Bay fisheries averaging 80% female, but there are years when the percentage of males increased (i.e. 2010, Table 22). The State of New Jersey obtains and will continue to obtain representative samples of the commercial catch to determine gender, size, and otolith samples for age estimation as required under the ASMFC FMP.

2.2.2.1.3 Delaware Commercial Fishery

Fishery Characterization and Regulations: The Delaware commercial American Shad fishery in the Delaware River & Bay occurs during the spring spawning migration from late February through May. Landings are reported to the State of Delaware under a mandatory food fish license and are separated into four general reaches based on spatial points of reference within Delaware Bay. These areas are reported as follows: Delaware River (north of Collins Beach), Upper Bay (Collins Beach to Port Mahon), Mid Bay (Port Mahon to Bowers Beach) and Lower Bay (South of Bowers Beach; Figure 46). Almost all shad landed are in conjunction with the concurrent Striped Bass commercial season that begins February 15 and extends through May 31 in the estuary. All landings are by gill net, both anchored (fixed) and drifted. Anchor nets are used primarily in Delaware Bay; drift nets are used exclusively in the Delaware River by regulation (Table 23). There are no specific regulations that have been adopted to reduce or restrict commercial landings of American Shad in the Delaware River & Bay. Regulations governing the Striped Bass fishery have the greatest impact on the total catch of American Shad due to the presence of both species in the river and bay during the spring. Restrictions for the

Striped Bass fishery include a limited entry license system, limitations on the amount and type of gear allowed to be fished, and gill net season and area restrictions. Specifically, these restrictions included no fixed gill nets in the Delaware River north of Liston Point (RM 48) from January 1 through May 31, and not more than 200' of fixed, anchored, or staked gill net from May 10 through September in the rest of the Delaware Estuary.

Fishery Participation: Delaware has a limited entry license system for the commercial gill net fishery under their food fishing equipment permitting regulations. There is a cap of 111 gill net permits, and no new permits will be issued. Fishers may choose not to renew their permit annually, so the total number actually obtaining a permit will change annually. Fishery participation has been decreasing for multiple years and this trend is expected to continue (Table 24). Many fishers do not land any American Shad and many do not fish at all since they were allowed to transfer their individual Striped Bass quota to other licensed fishers. Furthermore, permits may be passed onto direct descendants or issued to a resident who has completed a commercial fishing apprenticeship program.

Landings: Landings are reported to the State of Delaware by geographic region; however, due to data confidentiality, landings specific to each of the four regions are not reported here. Recent review of historical landings data demonstrated the original demarcation line between Upper Bay/River fisheries and Lower Bay fisheries using Leipsic River, DE as the stated demarcation point in the 2012 SFP was unsubstantiated. Leipsic River is not a geographic reference point for landings data in the State of Delaware and the actual point used in the 2012 SFP for delineation and calculation of the Delaware River stock was Collins Beach ("Delaware River" reporting region at RM 45), about 10 miles north of Leipsic River. A new delineation point was established at Bowers Beach for the 2017 SFP, where landings in the upper three reporting regions are combined to represent Upper Bay/River landings and landings from the fourth region (south of Bowers Beach) represent Lower Bay landings. See Section 2.2.2.1.5 for further information on the adjustment of the demarcation line.

Harvest of American Shad by region in Delaware has seen a shift from historically being an Upper Bay / River fishery (above Bowers Beach) to having some landings from the Lower Bay since 2002. From 1985 through 2001 landings in the Upper Bay/River averaged 187,622 pounds while the Lower Bay had zero landings. Since 2002 landings in the Upper Bay/River have declined to an average of 30,082 pounds while the Lower Bay had an average of 10,401 pounds landed annually for the same time period (Table 25, Figure 38).

Fishing Effort: Since 1985, the data on catch, landings, and effort have been collected via logbooks. However, commercial harvesters are only required to report mesh size when landing Striped Bass. Commercial fishing effort for Delaware is measured using net yards. Net-yards were the yards of net fished on that day the landings occurred. The overall State of Delaware CPUE has declined since 1992 due to a combination of a decline in adult abundance and major changes to the way Delaware fishers prosecute the fishery (Figure 39). Shad is no longer the target species but are considered bycatch in the Striped Bass fishery. Relatively, few shad are harvested in the fishery since the larger mesh sizes used for Striped Bass allow escapement. To emphasize the decline of effort on American Shad within the Delaware Estuary, the Co-op examined effort data from the State of Delaware, expressed in yards of net fished, from 1990 to 2015 (Figure 39). Effort has decreased dramatically throughout the time series with effort peaking in the lower bay fishery in 1991 and the upper bay and river fishery in 1996.

Landings of Striped Bass in Delaware have indicated an increasing size of bass over the last decade (State of Delaware 2016). Subsequently, the mesh size of gill nets employed in the Striped Bass fishery has increased up to 7 inch stretch mesh. The majority of shad will swim through that mesh size, so catch of shad was relatively low (< 10,000 lbs) from 2009 to 2013. However, in 2014 there was an unusually large (85,794 lbs) amount of American Shad landed in Delaware. The increased catch of American Shad by Striped Bass fishers during the 2014 season is attributable to a few fishers switching to smaller gill net mesh sizes (< 7 inches) for targeting smaller Striped Bass during the 2014 season. The commercial Striped Bass fishery has a 20 inch minimum size and remains quota driven. Fishers have been known to switch to smaller mesh nets in an attempt to fill their Striped Bass quota with smaller Striped Bass. As a result, catches of American Shad increased due to their increased susceptibility to the smaller mesh nets. This shift in gear type was not representative of all fishers in 2014, nor was this pattern representative of harvest over the last ten years. Landings in 2015 were less than 2014, with a total of 21,765 pounds landed.

Biological Data: Biological data collected by the State of Delaware were gathered from New Jersey commercial fisher's landing catches from the upper Delaware Bay. The State of Delaware collects information on length (mm), weight (lbs), and sex from the commercial fisher's landings (Table 26). Scale samples have been collected from these landings, but have not yet been processed for age estimation. The Co-op members have drafted standardized ageing protocols specific to the Delaware River Basin (Appendix A). Once finalized, age and repeat spawning frequencies will be determined from commercial landing samples.

2.2.2.1.4 Determining Exploitation of the Delaware River American Shad Stock

Recent combined commercial landings (1985–2015) from the Upper Delaware Bay and River and Lower Delaware Bay are shown in Figure 40. Landings prior to 1985 are not easily partitioned between bay and river and therefore are not useful for discussions of the Delaware River stock status. State landings are considered very reliable following the implementation of mandatory reporting in 1985 in Delaware and 2000 in New Jersey. The harvest areas are delineated as river and bay based on reporting information. Upper Delaware Bay/River harvest is separated from Lower Delaware Bay harvest at a line drawn from Bowers Beach, DE to Gandys Beach, NJ.

Combined landings for Delaware and New Jersey in the upper Delaware Bay and River have declined from a peak of 425,219 pounds in 1990 to a low of 10,944 in 2010. Landings have increased slightly since 2010, with a recent peak in 2014 of 121,018 pounds (Figure 40). Combined lower Delaware Bay landings have declined from a peak of 212,749 pounds in 1990 to a low of 3,659 pounds in 2015 (Figure 40). The main causative factors of the decline in landings include regulatory action (limited entry), attrition in the fisheries, and reportedly low market value of shad, based on Delaware ex-vessel reports ($/lb = 0.40 in 2015; Figure 41), increased mesh size (7" stretch mesh) preferred by Delaware gill netters targeting larger Striped Bass, and increased abundance of Striped Bass. New Jersey gill netters who target shad complain that their nets catch Striped Bass in high numbers, yet they are not allowed to land bass; the bass damage their nets and they cut their hands on the spines and gill cover edges, so no additional effort resulting in increased landings is expected in New Jersey. Delaware gill netters report that any attempts to target shad catch large numbers of bass, and if they have already filled their Striped Bass quota, they cannot land additional Striped Bass and many will cease fishing. The overall decrease in coastal stocks of American Shad may be an additional factor to the decrease in landings of shad.

One of the main concerns of fisheries managers is potential overfishing. Determining overfishing or over-exploitation with accuracy is difficult when actual stock numbers are not measured or those estimates are considered not scientifically sound. Obtaining a ratio based on harvest and a measure of a fishery independent CPUE is one way of assessing exploitation trends. No indices of abundance, measured before harvest, exist for the Delaware River American Shad stock; therefore, we cannot estimate true relative exploitation. In the case of the Delaware River stock, the Co-op analyzed a ratio of Delaware River stock landings to the Smithfield Beach gill net CPUE since 1990.

Acceptable measures of reported commercial harvest within the Delaware Basin have only been available from Delaware since 1985 and New Jersey since 2000. Landings data have been reported since the late 1800s, but cannot be verified. Since the Smithfield Beach CPUE has been conducted since 1990, the Co-op agreed to develop a ratio of commercial harvest to CPUE for Smithfield Beach (landings/CPUE, scaled by 100) using the period from 1990-2015. The Co-op also decided to report the estimates combined and in two phases (1990-1999 and 2000-2015) to reflect the more accurate reporting from New Jersey during the 2000-2015 time period. For clarity, the 1990-1999 time period will be called the early period while data from 2000-2015 will be known as the late period.

Landings of Delaware River stock was calculated using the demarcation line from Bowers Beach, DE to Gandys Beach, NJ. Landings north of that line are assigned 100% Delaware River stock and landings south of that line are assigned 40% Delaware River stock. Delaware River stock landings ranged from a high of 510,319 pounds in 1990 to landings less than 50,000 pounds annually since 2008, with the exception of 2014 where 123,880 pounds were landed (Figure 42, Table 27). The Delaware River stock landings have varied without trend in New Jersey and have been generally declining since 1990 in Delaware.

A comparison of the commercial landings to gill net CPUE from Smithfield Beach shows a similar trend between the fishery and a measure of escapement from the upper Delaware until 2010, when lower harvest equated with higher CPUE at Smithfield Beach (Figure 43). The ratio of commercial harvest/CPUE from Smithfield Beach ranged from 14.1 to 48.4 in the early period and 2.2 to 83.0 in the late period (Figure 44, Table 28). The early time series varied without trend while the late period varied through 2004 but has declined through recent years with the exception of 2014.

It should be noted that this approach to measuring exploitation is conservative. To mimic change in actual exploitation rate, a relative exploitation rate is estimated by dividing landings by some index of stock abundance prior to the fishery. In our case, we are measuring relative abundance after the fishery occurs. That means the denominator is reduced and the relative exploitation index is biased high. The degree of bias is related to the fraction of the original population that is lost to harvest (exploitation rate or u). Bias is relatively low at low levels of exploitation, but increases as exploitation rate increases. For perspective, we created a fictitious population of fish, exploited it at different rates, and calculated actual exploitation rates based on abundance of survivors (our approach) and on abundance of the population prior to harvest (Figure 45). Results suggested low bias when actual exploitation rates were less than $u <= 0.10$, but dramatically higher bias when u exceeded 0.30. This expectation of bias was developed for the 2012 SFP and has not changed with this revision, given the Co-op's continuance of the ratio as a measure of relative exploitation.

The American Shad stock in the Delaware River is considered stable but at low levels compared to the historic population (ASMFC 2007). Juvenile production has been measured since 1980. The JAI decreased somewhat after 1996 but has increased in recent years. It is unknown why there was a decrease in numbers of returning adult American Shad within the Delaware River during the 2000s. One hypothesis is that commercial overfishing within the Delaware Estuary could be hindering stock growth. Results of the harvest to relative abundance ratio analyzed here are not consistent with that hypothesis. The harvest to relative abundance ratio has varied without trend or even decreased in recent years (Figure 44). Furthermore, the Co-op does not believe that the recreational fishery is responsible for the recent downturn in spawning stock, based on low estimated harvest in the most recent creel survey in 2002 (Volstad *et al*. 2003).

2.2.2.1.5 Commercial Landings on Mixed Stock Fisheries

Shad that inhabit the lower Delaware Bay represent multiple stocks and have been managed using a unique approach to reflect the nature of the variability of river origin. Shad harvested in the Upper Bay and Delaware River are considered to be 100% Delaware River stock while those from the lower Bay areas are mixed stock and the origin of these fish may vary annually. To help determine the proportion of mixed stock contribution to the Delaware Bay landings, the NJDFW initiated an American Shad tagging program in 1995 in Delaware Bay as part of a cooperative interstate tagging program between New York and New Jersey. Tagging was performed at Reed's Beach located in Cape May County, approximately 10 to 15 miles from ocean waters (Figure 46). This program utilizes drifting gill nets of 5.5 inch to 6 inch stretch mesh during March through May of each year.

In the program, 4,301 American Shad were tagged from 1995 to 2015 (Table 29). In recent years sampling yielded few American Shad, with fewer than 100 shad tagged annually in the past 10 years. Through May 2015, there have been 246 American Shad returns reported (5.7% of tagged fish). The tag return data indicate that shad taken in this portion of Delaware Bay are of mixed stock origin and reported recaptures ranged from the Santee River in South Carolina to the St. Lawrence River near Quebec, Canada with the majority coming from the Delaware, Hudson, and Connecticut Rivers (Table 30).

A separate study using genetic analysis was conducted in 2009 and 2010 to determine stock composition (Waldman *et al*. 2014). Stock composition was determined based on microsatellite nuclear DNA from American Shad collected in Maurice Cove, NJ (RM 21) in 2009 (n = 71) and 2010 (n = 31), and off Big Stone Beach (RM 14) in Delaware in 2010 (n = 191) (Figure 46). Stock composition estimates for 2009 and 2010 were nearly equal (50%) for Hudson River origin and Delaware River origin fish at two locations in lower Delaware Bay in a two-stock analysis. Further analysis on the 2010 samples that considered 33 baseline rivers as source rivers indicated that only 24% of the stock was of Delaware River origin.

In addition to the two recent data sources, Co-op members also evaluated two historical tagging studies (Figure 46). A study conducted by White *et al.* (1969) released tagged shad (n = 618) in 1968 off West Creek (RM 18) and Thompsons Beach (RM 19) in NJ. They reported 110 recaptures with 36% being recaptured in the Delaware Bay/River and 63% of their tags were recaptured outside of the basin. Although White *et al.* (1969) combined Delaware Bay and River into one recapture location, the proportion is similar to the 39% currently considered as Delaware River stock as determined by the more recent tagging study at Reeds Beach. A second tagging study conducted by Zarbock *et al.* (1969) tagged American Shad (n = 277) off Pickering Beach (RM 26) and Little Creek, DE (RM 27). Their study reports 26% of the 23 recapture reports were from the Delaware River/Bay. In a separate tagging effort of the same study, 81 tagged fish were released at Port Penn, DE (RM 55). Five of those fish were recaptured, with 75% of recaptures in the Delaware River/Bay. One important point to consider during these older tagging studies is that poor water quality conditions in the vicinity of Philadelphia were suggested by the authors to have impacted American Shad distribution and migration in the Delaware River and Bay during that time. Though upriver fisheries remained viable during that time period (see Lewis Haul Seine – Table 15), and one of the Delaware River recaptures in the Zarbock (1969) study was from Easton, PA, upriver of Philadelphia. Water quality conditions have improved greatly in the lower Delaware River (see Section 2.3.1) since the studies were conducted in the late 1960s.

The 2012 SFP acknowledged the occurrence of mixed shad stocks in Delaware Bay fisheries annual harvest. Delineations for assigning commercial harvest to either the mixed or Delaware River stocks was represented as a demarcation line drawn across the bay from the Leipsic River, DE (RM 34) to Gandys Beach, NJ (RM 30), as adopted from the ASMFC 2007 American Shad Stock Assessment (Figure 46). In the 2012 SFP, mark-recapture data from the NJDFW tagging program formed the basis for assigning (i.e., as a proportion) the commercial harvest to Delaware River stock. For harvest that occurred in the Bay north of the demarcation line, 100% was considered Delaware River stock. For harvest south of the demarcation line, 39% of harvest was assigned to the Delaware River stock, and the remainder was assigned as mixed stock origin shad.

For the 2017 SFP, the delineation point on the Delaware shoreline needed to be changed to better reflect how landings are reported in that state. To maintain the *status quo* with previous data reporting, the reference point would need to be changed to Collins Beach, rather than Leipsic River. Port Mahon (RM 32) is the closest Delaware reference location to Leipsic River, DE and Gandys Beach, NJ, within two River Miles from both locations. Gandys Beach has been reconfirmed by the Co-op as appropriate for the New Jersey demarcation point. In order to determine an appropriate delineation point for the Delaware River stock with respect to the four current reporting regions in Delaware, the Co-op analyzed State of Delaware landings as well as mark-recapture data and the recent genetics work of Waldman *et al.* (2014).

The majority of landings reported to the State of Delaware occur from the Delaware River and Upper Bay reporting areas in the State of Delaware (i.e., above Bowers Beach, Table 31). A reexamination of updated tag return data indicates there is limited tagging information to conclusively suggest the annual extent of the mixed stock shad into the Delaware Bay. Hudson River tagging ended in 2008, and of those tagged shad only 5 have been recaptured in Delaware Bay/River (out of 172 total recaps). Of those 5 recaptures, 4 were reported at Bowers Beach and south, while the other reported Dover as the nearest location. Based on updated (through 2015) NJDFW tagging data from the lower Bay in New Jersey, 60% of the shad in that area are from the mixed stock (Table 32). However, the tagging data from the lower Bay does not indicate how far the mixed stock travels into the Bay and River. Furthermore, tagging and subsequent recapture of shad from this program have waned over the years. Unless additional effort is committed to this tagging program, the continued poor tagging rates will remain mediocre for characterizing the extent of the mixed stocks within the Delaware River & Bay.

The recent genetics study also provided little insight into the geographic extent to which the mixed stock travels up the Delaware Bay (Waldman *et al*. 2014). The authors acknowledged the spatial and temporal constraints drawn from their conclusions, as the points of collection (Big Stone Beach, DE; Maurice Cove, NJ) were closer to the mouth of the estuary where some level of mixing would be expected and collection occurred south of the areas where the majority of commercial landings occur in Delaware. While Waldman *et al.* (2014) has provided a base line, additional annual sampling throughout the Delaware River & Bay is necessary to fully characterize the occurrences of mixed stocks.

Due to a lack of more conclusive data, the assignment of the demarcation line on the State of Delaware's shoreline among Delaware's three uppermost reporting regions was selected by the Co-op based on the limited information available. The continued use of Collins Beach (the single uppermost reporting region) as the demarcation point was unanimously agreed among Co-op members as unacceptable. Given the data deficiencies regarding the occurrence of mixed stock in the Upper Bay and Mid Bay reporting regions, the Co-op selected a new delineation point for the Delaware Shore to be located at Bowers Beach (RM 23). The justification for selecting this location was based on having genetics and tagging studies conducted in the reporting region south of Bowers Beach (Lower Bay) and that very few recaptures of Hudson River tagged American Shad were captured north of Bowers Beach in the Delaware Bay. Using the delineation proportion from the NJDFW tagging studies, all landings north of a line from Bowers Beach, DE to Gandys Beach, NJ will be considered 100% Delaware River stock. South of the demarcation line, 40% of landings will be assigned to the Delaware River stock and the remaining 60% of landings assigned to the mixed stock (Table 33).

The potential to erroneously assign commercial American Shad landings to either the Delaware or mixed stocks in the lower bay is possible. Bowers Beach represents the logbook reporting delineation just upstream (~6 miles) of the more recent tagging and genetic studies. The Co-op recognizes the potential to understate mixed stock harvest could occur. The Co-op is sensitive to the potential impacts on East Coast shad stocks should there be any increase in exploitation, especially as these stocks recover. The Co-op will continue to annually monitor landings in the lower Delaware Bay to ensure any significant increase in harvest results in increased regulatory control for keeping exploitation at current levels. The 2012 SFP did not have a mechanism to limit expansion of the Delaware Bay fisheries on the mixed stocks, but recommended that the feasibility for directly managing the mixed stock harvest be considered in the 2017 SFP. Overall, mixed stock landings have been declining since mandatory reporting was enacted by both the States of Delaware and New Jersey (Figure 47). The Co-op has proposed an additional management benchmark to explicitly manage harvest on the mixed stock under this SFP (refer to Section 3.2.3).

The Co-op recognizes the available data does not conclusively characterize the extent of the mixed stock in the Delaware Bay. In order to investigate the appropriateness of any demarcation line, the Co-op plans to conduct additional genetic analyses during the spring of 2017. Samples are anticipated to be collected from various locations within the Delaware Bay during the spring season. The 2017 sampling is envisioned as a synoptic survey to examine geographic extent of the mixed stock within the Delaware Bay. Further funding would be required to provide insight into inter-annual variation of mixed stock occurrences. As information becomes available, Co-op members anticipate petitioning ASMFC for potentially modifying the demarcation line as warranted.

2.2.2.2 Recreational Fisheries

The recreational fishery for American Shad generally occurs from late March through June of each year. The fishery is concentrated in the non-tidal reach from Trenton, New Jersey (RM 133) to Hancock, New York (RM 330). The Brandywine Creek Basin also supports a nominal recreational American Shad fishery. Typically, the lower non-tidal reach is fished earlier in the season, moving further upriver as water temperatures increase.

Participation in the recreational shad fishery fluctuates but overall, angler effort has declined from historical levels. Numerous creel surveys have been conducted since the 1960's using various sampling methodology (Marshall 1971; Lupine *et al*. 1980, 1981; Hoopes *et al.* 1983; Miller and Lupine 1987, 1996; NJDFW 1993, 2001; Volstad e*t al.* 2003; Table 34). Estimates of angler catch and harvest in 2002 (Volstad 2003) were substantially lower than reported by Miller and Lupine (1987, 1996), representing a decline of total catch by 63% and 42% since those surveys in 1986 and 1995, respectively. Similarly, the percent of harvested shad declined from 1986 (49%) to 1995 (20%) and was estimated at 19% in the 2002 survey. Angler catch rates (shad/hr), also varied among the three surveys (0.19 shad/hr, 0.25 shad/hr, 0.13 shad/hr in 1986, 1995, and 2002, respectively) with the lowest catch rate observed during the 2002 study. Inclusion of only those anglers specifically targeting American Shad during the 2002 survey however, substantially improved angler catch rate (non-tidal: 0.34 shad/hr; Volstad *et al*. 2003). No comprehensive creel survey of the Delaware River has been accomplished since 2002.

The Marine Recreational Information Program (MRIP) provides characterization of recreational American Shad harvest in the Delaware Estuary & Bay. Catch estimates are inconsistent among years and highly imprecise (Table 35). The excessively high (> 50%) percent standard error estimates (PSE) suggests total numbers of shad harvested by recreational anglers are unreliable. Co-op members agree anglers nominally fish for American Shad in the Delaware Estuary and Bay; yet, also agree the MRIP data are not representative of any shad harvest in the Delaware Estuary and Bay.

The PFBC, in collaboration with the National Park Service, jointly promoted a voluntary angler diary program (2001 – 2016) for reporting recreational angler catch (Lorantas and Myers 2003, 2005, 2007; Lorantas *et al*. 2004; Pierce and Myers 2007; Pierce and Myers 2014; NPS unpublished data). In addition, the reporting of catch was mandatory for all licensed guides operating in the Upper Delaware Scenic Recreational River (UPDE). Participation is poor (< 63 individuals) in any given year (Table 34). Most submitted logbooks originate from the licensed guides. Catch rates of shad varied among years (0.001 – 0.11 shad/hr) with the highest rate observed in 2001 thereafter declining to a relatively stable rate after 2003 (Table 34). Since 2012, however, catch rates have declined to less than 0.01 shad/hr. Harvest of shad by logbook participating anglers was typically minimal (0 – 10.9%). Prior to 2012, anglers reported 496 trips during which anglers landed shad, but anglers harvested one shad/trip from 57 trips (11%), 2 shad/trip from 19 trips (4%), 3 shad/trip from 9 trips (2%), and only 4 trips (0.8%) harvested more than 3 shad/trip. Since 2012, a total of 37 trips were reported (2012: n = 12; 2013: n = 16; 2014: n = 9) to land shad, during which anglers harvested all shad caught (Table 34).

The PFBC/NPS angler diary program is considered unrepresentative of the Delaware River recreational shad fishery. Essentially, only the licensed guides by UPDE, routinely reported trip/catch information. Anglers fishing in the river reaches within the UPDE, principally target trout occurring in the New York City water supply dam tailwater, rather than shad. Further, in most years, no information was available from participating anglers in downriver reaches (RM 133 – 303) below the UPDE, were the recreational shad fishery is principally focused. The logbook program was discontinued in 2016 due to poor participation.

The Delaware River Shad Fisherman's Association (DRSFA) represents the single largest club specifically focused on the Delaware River American Shad. Although some fish are kept to eat, the recreational fishery for shad in the Delaware River primarily practices catch-and-release (M. Topping, President, Delaware River Shad Fisherman's Association, personal communication 2016). Generally, unreported DRSFA member catch rates have been relatively consistent each year since 2012. During the peak of recent shad runs, many DRSFA members indicated 100 fish hook ups fishing in the vicinity of Easton, Pa (RM 183). Although some DRSFA members may keep as many as 6-10 fish each season (especially those that have been injured) most harvest of shad tends to be limited to a single fish. In order to protect the fish when netted, the DRSFA recommends the use of rubber nets to minimize stress to the fish when caught. The DRSFA unofficially estimates total shad caught, by club members per year since 2012, could be anywhere from a dozen to well over a 100 (M. Topping, President, Delaware River Shad Fisherman's Association, personal communication, 2016).

Recreational hooking mortality is assumed to be low in the Delaware River. A study by Millard *et al.* 2003 observed a 1.6% recreational hooking mortality of spawning American Shad caught in the Hudson River after a five day holding period. All mortality occurred for fish caught on or after May 6 when water temperatures increased to greater than 12^{o}C. No hooking mortality studies have been conducted in the Delaware River.

There is a critical need for routine comprehensive creel surveys characterizing the recreational American Shad fishery in the Delaware River Basin. Potential future surveys need to focus principally on the non-tidal reaches. Since the MRIP program does not include non-tidal reaches, resulting data from that program poorly describes the Delaware River recreational shad fishery. Volstad e*t al.* (2003), represents the most recent comprehensive creel survey (i.e., 2002) accomplished in the non-tidal Delaware River reaches. This study was jointly supported by Co-op members, but funding was on an *ad hoc* basis. It is nearly 15 years out-of-date and likely does not represent present day shad angling behaviors. Alternative available creel data since Volstad *et al.* (2003) is of limited utility and wholly inadequate to describe recreational use and harvest of American Shad. Instead, anecdotal angler reports suggest the recreational shad fishery persists principally as catch-and-release. The lack of reliable, routinely collected data on recreational use and harvest, precludes compilation of more robust stock assessments (refer to Section 8).

2.2.2.3 In-State Bycatch and Discards

There is little information on bycatch or discards of shad in any commercial fisheries within the Delaware Estuary; excepting the Delaware Bay Striped Bass fishery, which is discussed in detail in Section 2.2.2.1.3. Otherwise, American Shad has not been reported as bycatch from other commercial fisheries operating within the Delaware River Basin to either the States of New Jersey or Delaware. Neither state requires the reporting of discarded shad from any commercial fisheries within the Delaware River Basin; thus, no information is available.

2.3 Other Influences on Stock Abundance

In addition to harvest and natural mortality, other factors can also impact American Shad populations. The Co-op has identified several such influences: (1) water pollution block, (2) the Atlantic Multidecadal Oscillation which correlates with Delaware River stock indicators, (3) Striped Bass-American Shad interactions (4) potential effects from overfishing and ocean bycatch, (5) impacts of hatchery restoration, and (6) impingement and entrainment.

2.3.1 Water Pollution Block

During the late 1800s, there was evidence indicating that shad were spawning in the freshwater tidal areas of the mainstem estuary as well as several tributaries of the lower Delaware River. It was presumed that the principal spawning area was located just south of Philadelphia, in the tidal freshwater estuary, prior to 1900. The prevalence of spawning in tidewater near

Burlington was documented by the huge fishery there, as well as the hatchery effort that took place at that location (Gay 1892).

Beginning as early as the 1910s (Philadelphia 1914), and certainly prevalent by the 1940 and 1950s (Sharp 2010), heavy organic and nitrogenous biochemical oxygen demand (NBOD) loading around Philadelphia, Pennsylvania, caused severe declines in dissolved oxygen. By the 1960s, continuous dissolved oxygen data collected by the USGS (see USGS-NWIS at waterdata.usgs.gov/nwis) and modeling by the Federal Water Pollution Control Administration (FWPCA 1966) demonstrated a zone of over 30 miles of the Delaware Estuary with hypoxic and anoxic conditions that persisted, on average, for 5 months each year, beginning in late spring and extending well into the fall. Hypoxia continued to be a major factor through the 1970s and into the 1980s, whereupon point-source remediation efforts by the Delaware River Basin Commission (begun in 1967) and the Federal Clean Water Act (1972 revisions) led to both a narrowing of the spatial and temporal hypoxia window each summer/fall and an overall increase in dissolved oxygen levels, even during the worst summer conditions.

The resulting “D.O. blocks” made parts of the lower Delaware River uninhabitable for fish during the warmer months of the year (Sykes and Lehman 1957) and may have severely depressed successful out-migration of juvenile shad from the river and the tidal freshwater estuary in the fall. A remnant of the American Shad run in the Delaware River survived by migrating upstream early in the season, when water temperatures were low and flows were high, before the D.O. block set up. These fish, because of their early arrival, migrated far up the Delaware to spawn. Out-migrating juveniles survived by moving downriver late in the season during high flows and low temperatures, thus avoiding the low oxygen waters present around Philadelphia earlier in the fall. As a result of this zone of hypoxia in the tidal estuary, the majority of spawning for decades took place above the Delaware Water Gap in the non-tidal river more than 115 river miles upstream.

Environmental regulation for stricter control of discharge proved beneficial for reducing the annual D.O. blocks. By the year 2000, the goal set for the tidal estuary in 1967 for a daily average dissolved oxygen concentration of 3.5 mg/L was being attained almost without exception, although this 3.5 mg/L dissolved oxygen target was a compromise below the oxygen standards typically set under the Clean Water Act (Figure 48). Nevertheless, the restoration of dissolved oxygen in the Delaware Estuary both removed the primary migration block for shad and other migratory fishes and provided sufficient oxygen for at least the partial restoration of spawning and rearing within the formerly hypoxic zones of the estuary (Silldorff 2015). For American Shad, such restoration was demonstrated, in part, through the NJDFW tidal seine surveys which showed increasing abundance of young-of-year shad throughout the summer and fall (see Pyle 2015). In addition, ichthyoplankton surveys during 2002, 2003, and 2004, documented direct evidence and consistent presence of eggs, larvae, and juvenile American Shad within all tidal estuary zones that historically experienced hypoxia (summarized in Silldorff

2015).

American Shad can now freely pass through the urban Philadelphia corridor of the Delaware Estuary both during the spring spawning run as well as the fall out-migration period. In addition, the continued recovery of dissolved oxygen has been associated with increasing use of the tidal freshwater estuary as a key part of the overall spawning effort by American Shad in the Delaware River system.

2.3.2 Atlantic Multidecadal Oscillation (AMO)

North Atlantic sea surface temperatures have been found to exhibit long-duration oscillation for at least the last 150 years (Schlesinger and Ramankutty 1994; Enfield *et al* 2001). This includes most of the North Atlantic Ocean between the equator and Greenland. Kerr (2000) termed this oscillation the Atlantic Multidecadal Oscillation (AMO) to distinguish it from the atmospheric North Atlantic Oscillation (NAO). Models of the ocean and atmosphere that interact with each other indicate that the AMO cycle involves changes in the south-to-north circulation, including the Gulf Stream current, and overturning of water and heat in the Atlantic Ocean. When the overturning circulation decreases, the North Atlantic temperatures become cooler.

The AMO delineates cool and warm phases that may last for 20-40 years at a time and a difference of about 1°F between extremes. These changes are probably a natural climate oscillation and have been measured for at least 150 years. A positive AMO indicates a warm phase while a negative AMO indicates a cool phase. The AMO is currently in what is considered a warm phase since the mid-1990s (AMO Kaplan SST V2 data is provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/).

The AMO affects air temperatures and rainfall over much of North America including the frequency of major droughts in the Midwest and Southwest such as those during the 1930s and the 1950s. Between AMO warm and cool phases, Mississippi River outflow varies by 10% while the inflow to Lake Okeechobee, Florida varies by 40% (Enfield *et al* 2001). It is also reflected in the frequency of weak tropical storms that mature into severe Atlantic hurricanes, with at least twice as many severe hurricanes during warm phases. In the 20th century, the climate swings of the AMO have alternately camouflaged and exaggerated the effects of global warming, and made attribution of global warming more difficult to ascertain.

In an attempt to determine if there was any evidence of a relationship between the AMO and measures of the American Shad stock within the Delaware River Basin, the Co-op first compared the AMO to the Lewis haul seine CPUE (Figure 49). The Lewis haul seine represents the longest catch per unit effort within the Basin. The Co-op analyzed various portions of the

AMO dataset but determined the smoothed January to December average was the best fit for final analysis. A five-year moving average was developed for all data to decrease yearly variability. This was a similar methodology as used for the most recent ASMFC weakfish stock assessment which used a 10 year average (ASMFC 2009).

The smoothed Lewis haul seine CPUE index is calculated as a catch per haul with haul data collected back to 1925. From 1925 to 1971, the smoothed Lewis haul seine CPUE averaged less than seven fish per haul except for the brief period during 1961-1965. The Lewis haul seine CPUE increased steadily from 1972 to 1990, similar to the AMO. A quick decline ensued through 1997 with a continued steady decline until 2007. There has been a slight increase in recent years.

No correlation is evident between the Lewis haul seine CPUE and the AMO from 1925 to 1971. As noted earlier, this period also coincided with very poor water quality (i.e., dissolved oxygen pollution block) within the Delaware River. As water quality improved from the 1970s into the 1990s, the American Shad population within the Delaware River also improved. From 1972 to 1989, the smoothed Lewis haul seine CPUE correlated well with the smoothed AMO with an $R^2 = 0.7986$ (Figure 50). This correlation disintegrates during the 1990s suggesting a problem with the stock that is not related to the AMO. The Lewis haul seine to AMO analysis showed a negative correlation for the time period of 1990 to 2015 with an $R^2 = 0.7401$ (Figure 51).

Additional analyses were conducted between the AMO and the Smithfield Beach CPUE from 1990 to 2015. The first few years of this survey was associated with high catches but declined rapidly throughout the remainder of the time series until recent years. The Smithfield Beach to AMO analysis showed a negative correlation for the time period of 1990 to 2015 with an $R^2 = 0.7473$ (Figure 52). This corroborates data reported earlier from the Lewis haul seine for the same time period.

In conclusion, this analysis suggests that long-term sea surface temperature change may have an impact on abundance of American Shad within the Delaware Basin. The Lewis haul seine CPUE correlates well with the AMO during the AMO index's rise in the 1970s and 1980s but there is a disconnect that occurs during the 1990s that currently is unexplainable. Potential sources of the discontinuity include decline in adults due to overharvest; bycatch discards in ocean fisheries; increased predation from Striped Bass or other species; or other unknown interruption of the spawning runs during this time period.

2.3.3 Overfishing and Ocean Bycatch

Excessive losses to directed fishing and bycatch are often implicated as causative factors in fish stock declines. Directed commercial harvest occurs in spawning rivers on adults and until 2005, in ocean waters. Recreational harvest of American Shad generally occurs during spawning migrations. American Shad taken while fishing for other species is called bycatch and it can occur in both rivers and the ocean.

Potential impacts of recent directed ocean harvest on American Shad are more difficult to identify. Ocean harvest has been poorly quantified. Moreover, limited tagging data suggests that ocean harvest is made up of many Atlantic coast populations. Since the stock of origin is generally not known, it is very difficult to identify losses that are specific to the Delaware River stock. Some sense for relative losses on a coast-wide basis can be obtained from reported landings.   The Delaware shad population appeared to decline most precipitously during the early 1990s. Mean annual harvest for states north of North Carolina during the first half of the 1990s was 1,148,893 lbs per year from ocean waters and 413,510 lbs from in river fisheries (ASMFC 2007). Reported annual ocean harvest of American Shad from outside the 200 mile limit off of Mid-Atlantic and New England states was 310,000 lbs (Northwest Atlantic Fisheries Organization http://www.nafo.int/about/frames/about.html catch statistics for ocean waters outside of the EEZ). Recent ASMFC shad assessments have drawn conflicting conclusions about impacts of this ocean harvest. ASMFC (1998) concluded that there was no evidence that the ocean harvest was affecting coast-wide stocks. ASMFC (2007) hypothesized that coastal harvest was affecting some stocks including that in the Delaware River. Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 1999), began a phase-out of directed harvest of American Shad in state coastal waters beginning in 2000. A total ban has been in effect by U.S. Atlantic coastal states since 2005.

Incidental Ocean Harvest

Quantification of the impact of bycatch and incidental fisheries on Delaware River American Shad remains difficult. Two fishery management plans have identified alternatives to reduce catch of American Shad in their Fishery Management Plans (FMP). The Mid Atlantic Fisheries Management Council's (MAFMC) Amendment 14 of the Atlantic Mackerel, Squid and Butterfish FMP (MAFMC 2014) and the New England Fishery Management Council's (NEFMC) Amendment 5 to the Atlantic Herring FMP (NEFMC 2014) both identified shad and river herring as incidental catch in these directed fisheries and acknowledged the need to minimize catch of shad and river herring. Both of these plans, through the amendments identified above and subsequent framework adjustments:

- Implemented more effective monitoring of river herring and shad catch at sea;
- Established catch caps for river herring and shad; and
- Identified catch triggers and closure areas.

Fishery observer data is used to estimate and monitor the river herring and shad captured by Atlantic Herring and Atlantic Mackerel vessels that land more than 3mt per trip. The methodology was developed with data on river herring and shad catch (Table 36) and quotas

(Table 37) presented by the Greater Atlantic Regional Fisheries Office (GARFO) of the NOAA Fisheries.

While the data do provide us with an estimate of the incidental catch of river herring and shad in these fisheries, catch by species is not identified.   However, Amendment 14 of the Mackerel, Squid and Butterfish FMP does present species specific data by region and fleet from earlier years (Table 38). Observed annual American Shad catch between 1989 and 2010 ranged from 17mt to 104mt with an annual average of 48mt. In some years, large portions of the incidental catch were not identified to the species level. If we apply the same proportion of American Shad composition from the known catch to the unknown catch, the total estimated American Shad catch in the same time period ranged from 20mt to 139mt with an annual average of 62mt.

The proportion of known bycatch that was characterized as shad varied considerably among years, with an average proportion of annual shad catch equal to 18% and a median proportion of 13%. To get a general sense of the scale of potential shad harvest of these fisheries, the median proportion of known shad harvest between 1989 and 2010 was applied to more recent harvest years (Table 39). Unfortunately, it is impossible to determine which American Shad stock was impacted by the harvest from this mixed stock fishery.

The Co-op recommends that the Technical Expert Working Group for river herring to continue its work exploring opportunities to minimize the impacts of bycatch harvest, including developing catch caps for other fisheries as appropriate. The Co-op also recommends the continued implementation of the voluntary avoidance network and supports efforts to maximize the observer coverage in fisheries that land significant amounts of river herring as bycatch.

2.3.4 Impacts of Restoration Stocking

The PFBC has been stocking otolith-marked American Shad fry as part of their restoration program for the Delaware River Basin (Table 40). Eggs collected from Delaware River shad have been used in restoration efforts on other rivers, but since 2000, all Delaware River shad fry have been allocated to the Lehigh, and Schuylkill rivers. Occasionally, excess production was stocked back into the Delaware River at Smithfield Beach (2005 – 2008). Egg-take operations on the Delaware River have resulted in the use of an average of 756 adult shad brood fish per year, 1996 - 2015. Eggs from these shad are fertilized and transported to the PFBC's Van Dyke Anadromous Research Station where they are hatched, otolith-marked and stocked in areas above dams where fish passage projects are in place.

The contribution of hatchery-reared fry to the returning population was estimated by interpretation of oxytetracycline daily tagging patterns within the otolith microstructure

(Hendricks *et al*. 1991). The total hatchery contribution at Smithfield Beach was low ranging from 0.0 to 7.8% (Table 41), suggesting that hatchery-reared fry are not a significant component of the Smithfield Beach catch. The PFBC restoration program focuses shad fry stockings within the Lehigh and Schuylkill river main stems. Both the Lehigh River (RM 183) and Schuylkill River (RM 92) connect to the Delaware River main stem well downriver of Smithfield Beach (RM 218). Presumably shad impressed with the water quality signatures of either tributary would not likely occur further upriver at Smithfield Beach; rather, preferring homing to their natal source. The poor catches of marked shad at Smithfield Beach suggest straying is not a frequent occurrence. In addition, below the confluence of the Lehigh River with the Delaware River, Hendricks *et al.* (2002) demonstrated the occurrence of hatchery stocked shad in the Raubsville (RM 176) collections. Hatchery origin fish favored the west side of the river, presumably homing to the Lehigh River where they were stocked as fry. Contributions of hatchery shad to the catch at Raubsville varied 0.0 – 11%, among years.

Limited success has occurred in returning a self-sustaining spawning shad run to either the Lehigh or Schuylkill rivers by the PFBC American Shad restoration program. Greatest success has been achieved within the Lehigh River. The percentage of wild shad within the lower three miles of river (i.e., between the Easton, RM 0.0 and Chain, RM 3.0 dams) has increased since monitoring began in 1996. Initially the wild component of the Lehigh River spawning run was relatively poor, with the majority of the run composed of hatchery stocked shad. From 1996 – 2001, the wild component varied 2.0 – 9.4%, averaging 6.3%; the wild component increased slightly from 11.0 to 19.4% in 2002 and 2004, respectively (averaging 15%). By 2005-2015 the wild component varied between 26.3 – 67.7% (averaging 42.5%). The wild component was best represented in 2015, composing over two-thirds of the Lehigh River spawning run. Thus, over the years, the wild component has been increasing; yet, the hatchery component remains integral to the Lehigh River spawning run.

Returning shad into the Schuylkill River are mostly originating from hatchery stocked shad fry (Table 41). Hatchery origin shad composed 91%-100% of the annual returning run 2007 – 2010. In those years, wild shad (i.e., unmarked otoliths) composed < 10%. Yet, catches of shad during 2011 – 2014 were suggestive of an improved the wild component (i.e., 12% – 16% of the spawning run. But, wild shad were not observed in the 2015 catch (i.e., 0% contribution). Without maintenance hatchery shad fry stockings into the Schuylkill River, any anticipated annual returning shad spawning run would be very poor.

Self-sustaining spawning runs in to the Lehigh and Schuylkill rivers have not materialized after 31 years of restoration efforts. It is the conclusion of PFBC, American Shad passage into the Lehigh River is inefficient and inadequate to support the restoration of a self-sustaining population. The Lehigh River shad spawning runs remain well below the original expectations of successfully annually passing 165,000 – 465,000 wild shad (PFBC 1988). The observed peak passage in 2001 (n = 4,470) represents 0.9% - 2.7% of PFBC's restoration goal. Furthermore, 4.0% (n = 179) of the 2001 spawning run were determined to be of wild origin, representing less than 0.1% of the original restoration goal. Even in 2015, when the wild contribution was the greatest (i.e., 67.7%), the wild component remained less than 0.1% of the original restoration goal. This also assumes the wild shad caught from the Lehigh River, were indeed homing to the Lehigh and not straying from the Delaware River. The termination of the PFBC restoration program of the Lehigh River would undoubtedly severely reduce the Lehigh River spawning run size. Thus, the continued operation of the fishways would only provide, at best, a nominal dedicated spawning run into the Lehigh River.

To describe potential alternatives for improved shad passage into the Lehigh River, in 2012, PFBC in partnership with the Wildlands Conservancy and American Rivers/NOAA Community Grant Program, supported a feasibility study to investigate a suite of engineering options. Study findings suggested improvements of shad passage were best accomplished by full dam removal of the Easton and/or Chain dams (KCI Technologies Inc. 2013). Several key limitations were identified including, the need for pumping of water to support the flooding of both the Lehigh and Delaware canals, potentially negatively impacting various existing bridges and sewage pipelines (i.e. requiring additional support and/or armoring), and various user groups dependent on present day pools maintained by the existing dams. Achieving improved passage requires considerable focused cooperation between dam owners, user groups, and stakeholders, as well as utility owners in the vicinity of the structures. Any improvement is dependent on the willingness of the owners (i.e., Easton Dam owned by PA Dept. Conservation and Natural Resources; Chain Dam owned by the City of Easton) being in agreement to advance modifications. To date, the owners have not expressed interest in pursuing dam removal.

Similarly, annual spawning runs of American Shad into the Schuylkill River have been disappointing. The original restoration goal of an annual run size of 300,000 – 850,000 wild shad (PFBC 1988) has not been realized. Typically, observed runs remain less than 0.1% of this goal at Fairmount Dam fishway passage (Table 11; Figure 29). Modifications to the fishway have been accomplished for improving passage (i.e., 2008); however, returning runs continue to be poor. The invasive Flathead Catfish has severely impacted successful passage of shad and river herring. These large predators reside within the various pools of the fishway and have been observed to prey on passing shad and herring. Removal of the catfish was accomplished on several occasions, but other catfish immediately took up residence in the fishway, making catfish removal efforts ineffective.

Success for restoring American Shad to their once natal waters of the Lehigh and Schuylkill rivers appears bleak. The traditional hatchery methodology used for restoration in either tributary is not sufficient for generating a run size of the magnitude originally envisioned. Yet without maintenance fry shad stockings, any future spawning run into either tributary would most likely be nominal. The PFBC will continue maintenance shad fry stockings to continue annual spawning runs in both tributaries. Yet, PFBC will also investigate the feasibility of alternative methodology for possibly increasing the magnitude of annual hatchery stockings.

2.3.5 Impingement and Entrainment

Nearly 10 percent of Americans rely on the waters of the Delaware River Basin for drinking and industrial use (DRBC 1998). Power generating facilities, refineries, and other industries rely on withdrawal of surface water from the Delaware River to cool their industrial processes, with most industrial water withdrawals requiring continuous once-through use of water. This results in the suction of fish and other aquatic organisms into the industrial water intake structures where they either become trapped against the intake screens (impingement-I) or actually get taken further into the cooling system (entrainment-E). Both I&E can result in the death of fish and other organisms. Larger individuals become impinged and smaller organisms such as eggs and larvae become entrained. Impingement does not necessarily result in 100% mortality of affected organisms, but entrainment is considered 100% lethal to fish eggs and larvae. When fish spawn in spring and early summer in the Delaware River, the resulting eggs and larvae are vulnerable to entrainment; as fish grow larger during the balance of the year, they become susceptible to impingement. Therefore, losses to I&E are ongoing throughout the calendar year.

There are several large water intake systems at energy projects on the Delaware River. Recent estimates of impingement and entrainment (I&E) rates at water intake systems for American Shad in the Delaware River indicate that individual projects can entrain millions of American Shad eggs and larvae annually, and impinge tens of thousands of juveniles (Table 42). In a river system with numerous intake facilities that occur in spawning and nursery grounds for American Shad, the cumulative impacts to the population could be substantial.

To put the American Shad impingement rates into perspective, the Pennsylvania State Fish Hatcheries annually released 474,271 fry, on average, into the Delaware River Basin (Table 40). Considering additional mortality between the fry and juvenile stage, from various projects with intakes, impingement rates are likely far greater than resource agency stocking efforts to protect and restore American Shad to the Delaware River. Impingement data for other important fisheries suggest that impacts may be occurring on Striped Bass and Weakfish populations, reducing the number of fish that would later be available for recreational and commercial fishing. Recent estimates derived by staff from the Delaware Department of Natural Resources and Environmental Control, Division of Fish & Wildlife (DFW) suggest that losses of early life stages of Striped Bass at the Project translate into losses of Adult Equivalents that rivals or even exceeds current commercial and recreational harvest in Delaware (Ed Hale, DFW, pers. comm.). Losses of large numbers of forage species also reduce the food resources available in the river, further impacting fish communities in the Delaware River.

Recognizing the considerable I&E losses on the Delaware River Basin shad populations (and other fishes), routine quantification of I&E shad losses would provide for better estimation of anthropogenic mortality. Co-op members also agree improved best management practices to eliminate or reduce I&E losses would be prudent. Current available data preclude annual estimation of mortality by these facilities. We concede data collection/reporting and improved technologies place an additional monetary burden on operators with water intakes, but the paucity of information hinders development of a more robust stock assessment of Delaware River Basin shad populations.

3. Sustainable Fishery Benchmarks and Management Actions

The Co-op proposes a series of relative indices for monitoring trends in the American Shad population in the Delaware River. The benchmarks were derived to allow the existing fishery to continue. The benchmarks have been set to respond to any potential decline in stock. Thus all benchmarks are viewed as conservative measures. The benchmark measures for maintaining sustainability are in order of their importance as follows:

1. Non-tidal JAI index
2. Tidal JAI index
3. Smithfield Beach adult CPUE survey
4. Commercial harvest to Smithfield Beach relative abundance ratio
5. Mixed stock landings

3.1 Benchmarks

3.1.1 Non-tidal JAI index

This JAI is based on annual catch data standardized by environmental covariates using GLM methodology. Only data originating from Phillipsburg, Delaware Water Gap, and Milford Beach are included in the JAI. The benchmark was based on data from years 1988-2015 (Table 4, Figure 53). Failure is defined as the occurrence of three consecutive JAI values below a value of the 25th percentile where 75% of the values are higher from the reference period (1988-2015). Exceeding the benchmark will trigger management action. The period of 1988 to 2015 was selected as these years encompass the years when sampling methodology was consistently applied to all sampling stations included in the JAI calculations; however no sampling occurred at any non-tidal station between 2008 and 2011. The non-tidal JAI fell below this target most recently in 2013 and 2015.

3.1.2 Tidal JAI index

This JAI is based on annual geometric means of the catch data from stations near Trenton to Delaware Memorial Bridge. The benchmark was based on data from years 1987-2015 (Table 4, Figure 54). Failure is defined as the occurrence of three consecutive JAI values below a value of 4.00 (i.e., the 25th percentile where 75% of the values are higher). Exceeding the benchmark will trigger management action. The period of 1987 to 2015 was selected as these encompass the years when sampling methodology was consistent among stations. The tidal JAI has been at or above this target since 2009.

3.1.3 Smithfield Beach CPUE Index

This index is based on the annual CPUE (shad/net-ft-hr*10,000) in the PFBC egg-collection effort at Smithfield Beach and represents the entire data series available from 1990 through 2015 (Figure 55, Table 28). This index represents a fishery-independent measure of the spawning run success as survivors after the fishery. The benchmark is defined as the 25th percentile of the time-series where 75% of values are higher. Failure is defined as the occurrence of three consecutive CPUE values below the benchmark value of 37.5. Exceeding the benchmark will trigger management action. The index has been higher than the benchmark since 2010.

3.1.4 Ratio of Commercial Harvest to Smithfield Beach Relative Abundance Index

This index is defined as the ratio of survivors after the fishery as indexed by the Smithfield Beach gill net CPUE divided by the total Delaware River stock landed by commercial fishers as reported to the States of New Jersey and Delaware. It is based on data from 1990-2015 (Figure 56, Table 28). The benchmark is defined as the 85th percentile of the time-series where 15% of values are higher. Failure is defined as the occurrence of three consecutive values above a value of 36.5. Exceeding the benchmark will trigger management action. The ratio estimate exceeded the benchmark four times in 1993, 1996, 2001, and 2004 for the entire time-series. This index is particularly appealing since it is sensitive to changes in both harvest and abundance (CPUE).

3.1.5 Mixed Stock Landings

This index is defined as the total pounds landed from the mixed stock, which consists of 60% of the landings south of a demarcation line from Bowers Beach, DE to Gandys Beach, NJ. The index was based on data from 1985-2015 (Figure 57, Table 33). The benchmark is defined as the 75th percentile of the time-series where 25% of values are higher. Failure is defined as the occurrence of 2 consecutive values above a value of 47,650 lbs. Exceeding the benchmark will trigger management action. This index provides additional harvest protections for American

Shad stocks with origins outside of the Delaware River, some of which have closed commercial fisheries. This index has been below the benchmark since 2006.

3.2 Management Actions

All management actions are subject to the severity and frequency of the breach of the established benchmarks. For instance, if the Smithfield Beach CPUE falls below the benchmark for three consecutive years but the JAI is increasing and appears in no danger of doing the same, the action taken will be less severe than if the JAI was decreasing and in jeopardy of falling below its own benchmark. If both indices were to exceed the benchmarks simultaneously, swift action such as a harvest closure may be justified. Additional and more severe management action may be taken in time if one or more indices continue to fall below the benchmark after the initial management action. The Co-op will review these benchmarks annually to determine if management action is necessary, and if so, to detail appropriate management based on the options below.

There are many restrictions already in place for the commercial fishery that limit participation. These include limited entry, seasons, and gear restrictions throughout the Delaware Bay. The recreational fishery is limited to three fish in all areas, excepting Delaware jurisdictional waters where the recreational shad fishery is nominal. The following options regarding breach of the Delaware River benchmarks may require amending current regulations.

A) If the non-tidal or tidal JAI benchmark is exceeded:

Option 1: closure of commercial fishery; recreational catch and release only

Option 2: reduce commercial fishery by 50% through gear restrictions, seasons, trip limits, or quota reduction; reduce recreational fishery to 1 fish bag limit

Option 3: reduce commercial fishery by 25% through gear restrictions, seasons, trip limits, or quota reduction; reduce recreational fishery to 2 fish bag limit

B) If the Smithfield Beach adult CPUE benchmark is exceeded:

Option 1: closure of commercial fishery; recreational catch and release only

Option 2: reduce commercial fishery by 50% through gear restrictions, seasons, trip limits, or quota reduction; reduce recreational fishery to 1 fish bag limit

Option 3: reduce commercial fishery by 25% through gear restrictions, seasons, trip limits, or quota reduction; reduce recreational fishery to 2 fish bag limit

C) If both the tidal JAI and Smithfield Beach adult benchmarks are exceeded:

Option 1: closure of commercial fishery; recreational catch and release only

Option 2: reduce commercial fishery by 50% through gear restrictions, seasons, trip limits, or quota reduction; reduce recreational fishery to 1 fish bag limit

D) If the harvest to Smithfield Beach adult CPUE ratio benchmark is exceeded:

Option 1: closure of commercial fishery; recreational catch and release only

Option 2: reduce commercial fishery by 50% through gear restrictions, seasons, trip limits, or quota reduction; reduce recreational fishery to 1 fish bag limit

Option 3: reduce commercial fishery by 25% through gear restrictions, seasons, trip limits, or quota reduction; reduce recreational fishery to 2 fish bag limit

E) If the mixed stock landings benchmark is exceeded:

Option 1: gill nets with stretch mesh greater than or equal to 4 inches and less than 7 inches will be prohibited below the mixed stock demarcation line during February 1st through May 31st. Harvest of American Shad as bycatch (American Shad $\leq$ 50% of harvest by weight) is still permissible below the demarcation line from Bowers Beach, DE to Gandys Beach, NJ

During the implementation of the 2012 SFP, indices for the four sustainable fishery benchmarks (tidal and non-tidal JAI, Smithfield Beach CPUE, and the ratio of commercial harvest to Smithfield Beach) stayed above or below their specified benchmark levels for the specified time periods, therefore no management action was implemented during the 2012 SFP.

3.3 Benchmark Summary

Index	Benchmark Value	Years of Index for Benchmark	Benchmark Level	Management Trigger	Data Values
Non-Tidal JAI (GLM of Big 3)	145.9*	1988-2015	25^{th} percentile	3 consecutive years below benchmark	Table 4, Figure 53
Tidal JAI (GM)	4.00	1987-2015	25^{th} percentile	3 consecutive years below benchmark	Table 4, Figure 54
Smithfield Beach CPUE Index	37.5	1990-2015	25^{th} percentile	3 consecutive years below benchmark	Table 11, Figure 55
Ratio of Comm. Harvest to Smithfield Beach	36.5	1990-2015	85^{th} percentile	3 consecutive years above benchmark	Table 28, Figure 56
Mixed Stock Landings	47,650	1985-2015	75^{th} percentile	2 consecutive years above benchmark	Table 33, Figure 57

*This value may change slightly each year based on re-analysis of data using the GLM.

4. Proposed Time Frame for Implementation

The Co-op proposes that this plan be re-evaluated on a five-year cycle. The tenure for the 2017 SFP is expected to cover the period 2017 through 2021. Thereafter the next planned update should be initiated in 2020. All datasets will be updated annually for assessing the exceeding of any benchmarks requiring immediate management action. The mixed stock benchmark will be reevaluated upon completion of the 2017 genetics study to determine the extent that the mixed stock travels into the Delaware Bay, or at such time when new data are available. All sustainability benchmarks will be reviewed annually after completion of annual ASMFC compliance reports.

The Co-op views the 2017 SFP as a working document. Over the tenure of the 2017 SFP, Co-op members will continue investigations of recommended actions herein and/or as new opportunities become available. Petitions arising to ASMFC for updating the 2017 SFP may be initiated prior 2020.

5. Future Monitoring Programs

5.1 Fishery Independent

5.1.1 Juvenile Abundance Indices

The tidal beach seine program conducted by NJDFW will continue indefinitely, given its importance to their Striped Bass monitoring requirements.

The non-tidal seine program will continue through a collaborative effort during the duration of this SFP (2017-2021). The index will be generated from catches from Phillipsburg, Water Gap, and Milford. The inclusion of Trenton and the upper freshwater sites in the East Branch to the index will be reevaluated for the next SFP update. The continuance of this program is dependent on the collaboration among Co-op members ability to commit personnel resources without dedicated budgeted funding.

5.1.2 Adult Stock Monitoring

Spawning stock

The PFBC will continue to fully support the fishery independent survey at Smithfield Beach (gill net survey) for, at a minimum, the next five years (2017-2021). The objective is to obtain biological data on the spawning stock as well as an index of relative abundance. Additionally, all caught shad will be strip spawned in support of the PFBC American Shad restoration program for the Lehigh and Schuylkill rivers.

Total mortality

Due to the uncertainty associated with ageing of shad scales and otoliths, confidence in ageing is low. The Co-op will not use mortality estimates as targets for managing the Delaware River stock. However, scale and otoliths will continue to be collected and the Co-op will re-evaluate the use of mortality estimates as shad ageing techniques improve.

Co-op members will focus on finalizing the Delaware River specific ageing protocols. Inclusive of this effort are the scheduling/assignment for production ageing of scale microstructures for future collection and the considerable backlog of historical collections; reaffirming interpretation of repeat spawning marks; and evaluation of otolith microstructures.

Hatchery evaluation

Otoliths of all hatchery-reared American Shad larvae stocked by PFBC into the Delaware River Basin are marked with oxytetracycline to distinguish hatchery-reared shad from wild, naturally-produced shad (Hendricks *et al*. 1991). Since 1987, larvae were marked with unique tagging patterns accomplished by multiple marks produced by immersions 3 or 4 days apart.

Determinations of origin are interpreted from the presence of florescent tagging patterns in the otolith microstructure. Hatchery contribution is determined for specimens collected in the Schuylkill and Lehigh rivers above the first dam and in the Delaware River at Smithfield Beach. The proportion of hatchery fish present in juvenile or adult population will continue to be monitored as per ASMFC Amendment 3.

5.2 Fishery Dependent

5.2.1 Commercial Fishery

The States of Delaware and New Jersey will conduct fishery dependent surveys as required by ASMFC Amendment 3. Landings by geographic location will be noted to determine the extent of harvest on the mixed stock fishery.

5.2.2 Recreational Fishery

Comprehensive angler use and harvest surveys are monetarily prohibitive. The NPS/PFBC angler logbooks are considered unreliable by Co-op members for characterizing the recreational shad fishery. Without dedicated funding, Co-op members are unable to support a comprehensive creel survey. Co-op members anticipate no quantifiable source of data will be available for documenting angler use and harvest over the tenure of the SFP.

6. Fishery Management Program

6.1 Commercial Fishery

Delaware: The State of Delaware has no regulations that have been specifically adopted to reduce or restrict the landings of American Shad in the Delaware Estuary. However, there are regulations that apply to the commercial fishery in general that limit commercial fishing. Additionally, we have introduced measures to control for the expansion of landings in the lower bay. Existing regulation affecting the Striped Bass fishery will remain the same, such as limited entry, limitations on the amount of gear and annual mandatory commercial catch reports. Area and gear restrictions will remain the same (see Section 2.2).

New Jersey: New Jersey waters are open to gill netting for the majority of the year but the current directed commercial fishery for American Shad occurs primarily during March through April of each year depending on environmental conditions. New Jersey regulations are listed in Table 17. Limited entry is in place; permits are not gear specific. All permits are currently non-transferable except to immediate family members.

Pennsylvania and New York: Both Pennsylvania and New York do not permit the commercial harvest of American Shad within the Delaware River Basin.

6.2 Recreational Fishery

Within the jurisdictional waters of New Jersey, New York, and Pennsylvania for the Delaware River main stem, all impose a three shad daily possession limit with no size limit or closed season. The State of Delaware continues with a ten fish/day, combined American and Hickory shad, with no size limit or closed season. Little effort is expended by recreational anglers for American Shad in Delaware waters with no reported harvest.

The Lehigh and Schuylkill rivers represent the two largest tributaries to the Delaware River, draining 3,529.7 km^2 and 4,951.2 km^2, respectively. Both of these tributaries in their entirety are contained within Pennsylvania. Beginning January 1, 2013, regulations were modified to reflect recreational catch and release only and prohibited commercial harvest of American Shad.

Bycatch and Discards

New Jersey and Delaware do not require mandatory reporting of bycatch and discards in their commercial fisheries. In the recreational fishery many anglers are practicing catch-and-release, there are no plans to regulate this other than with possession limits which are already in place.

7. Data Needs for Improved Characterization of the Delaware River American Shad Population

To some extent American Shad remain an enigma for the Delaware River Basin as well as coast-wide. While current knowledge has provided insight into the returning adult spawning run, YOY production and recreational/commercial exploitation, we essentially have a very limited knowledge of landscape-scale and temporal variation of shad within the Basin similar to other basins along the Atlantic Coast.

To conduct a data rich stock assessment for American Shad in the Delaware River Basin, additional data collection is necessary. Information collected annually from our commercial and recreational fishery sectors both within the Delaware River/Bay and other estuary systems could be used to model fishing mortality (F) and spawning stock biomass (SSB) of Delaware River origin fish using a Statistical Catch at Age model (SCAA). Using a SCAA we would be able to estimate the abundance at age, age specific selectivity, fishing mortality (F) and catchability (q) for each year.

7.1 Existing Data

The following data sources are currently available to be used in a stock assessment. These data will continue to be collected through their respective surveys so that they continue to be available for future assessments. The resultant time-series support trend analysis from which professional judgments for associated management benchmarks are enacted.

- Commercial landings (pounds landed, CPUE as are reported to the states of New Jersey and Delaware)
- Age and repeat spawn structure of adult spawners (result of the aging sub-committee)
- Index(ices) of adult abundance (CPUEs from Smithfield Beach and Lewis Haul Seine)
- Index(ices) of YOY abundance (CPUE from beach seining at tidal and non-tidal sites)
- Coefficient of Variation for Indices

7.2 Estimated Parameters from Existing Data Sources

The following data can be estimated from currently available data provided in section 8.1.

Age determination among Co-op members is considered preliminary, as draft protocols continue to be further refined. One obstacle to full Co-op support of age-based modeling is consistent and dedicated personnel for scale/otolith processing and age interpretation. The Ageing Protocol in Appendix A is the first step toward consistency going forward.

- Age specific Natural Mortality (M)
- Proportion Mature at Age (result of the ageing sub-committee)

7.3 Required Data for Fully Supporting a Data Rich Stock Assessment

The following data are not currently being collected or are being collected on a limited basis without sufficient sample sizes to provide for adequate analysis. Collection of these data on an annual basis is necessary to conduct a more data rich stock assessment.

- Commercial age at length
- Commercial weights at age
- Commercial bycatch (numbers)
- Commercial discards (numbers)
- Commercial discard mortality rate
- Commercial bycatch size and age structure (inland, estuaries and ocean fisheries – by NMFS statistical area and fishery)
- Recreational landings (numbers) by state
- Recreational bycatch (numbers) by state
- Recreational discards (numbers) by state
- Recreational discard mortality rate

- Recreational age at length
- Recreational weights at age
- Index(ices) of Age 1 abundance
- Percent stock composition within the Delaware Bay/Estuary at points along an estuarine gradient

7.4 Additional Data Needs

In addition to the data required for a more data-rich stock assessment, additional data are necessary to better understand the Delaware River Basin American Shad stocks.

7.4.1 Proportion of Mixed Stock Fishery

Tagging and genetics studies have indicated that some portion of the American Shad captured in the Delaware Bay are spawning stock from other Atlantic Coast Rivers. A multi-year, robust genetic or tagging study within the entire expanse of the bay will best provide a delineation point for mixed stock circulation in the bay, above which the majority of fish are solely Delaware River Stock. In addition, better reporting of capture location for the Delaware River/Bay commercial harvest occurs is necessary to better characterize the impact of the fishery on the Delaware River stock as well as stock of other Atlantic Coast rivers.

- Delineation point for mixed stock
- Location of capture of commercial harvest

7.4.2 Weight and Size Characterization at Different Collection Points

Length and age may differ depending on collection location and gear type used in the basin. Understanding differences in the population demographics by location and gear can inform management decisions on protecting or exploiting different portions of the American Shad population.

- Compare length frequency for different collection sources (i.e. Lewis Haul Seine, tagging, commercial catch)
- Prespawn weights for adult American Shad

7.4.3 Improve Existing Data Collection and Benchmark Evaluation

Currently, samples are taken from American Shad to generate age data. The Co-op has been working on standardizing ageing techniques between the basin states to produce a more rigorous and reliable ageing data set. Those techniques have been finalized (Appendix A) and need to be implemented. In addition, the Co-op has conducted some analysis looking at the power of our current benchmarks to detect changes in the American Shad population. An evaluation of the non-tidal JAI has indicated that the current benchmark is adequate, but the survey has low power to detect change in the population. The power analysis should be conducted on other benchmarks as well to determine our ability to detect change in our other surveys used as the basis for the Sustainable Fishing Plan. Co-op members have expanded the non-tidal fixed station YOY beach seine survey to include two sites located in the upper Delaware River Basin (i.e., Skinners Falls and Fireman's Launch). The intent is to allow examination of YOY production in reaches not historically surveyed. Support for this effort remains on an *ad hoc* basis. The Co-op needs to secure long-term commitment for the continuance of surveying these sites.

- Finalize ageing techniques and data
- Tidal JAI power analysis to evaluate benchmark
- Standardization of Smithfield Beach CPUE and power analysis of the time-series
- Investigate benefits/losses to transitioning the non-tidal beach seine survey from fixed station sampling into a more rigorous survey design such as a stratified random design, for example
- Secure expansion of the non-tidal YOY sampling to include the upper Delaware non-tidal reaches

7.4.4 Additional Fishery-Independent Monitoring Programs

Reliance of characterizing the adult shad spawning run singly upon Smithfield Beach as representative of the entire Delaware River Basin is a poor assumption. Sampling on a larger geographic scale is needed to better characterize the variation of spawning adult population in the Basin. Returning spawning adult shad appear to be utilizing the upper Delaware Estuary reaches as spawning grounds, as water quality continues to improve. Without an adult monitoring program in the upper Delaware Estuary, validation of the tidal JAI will remain intangible. Similarly, shad are known to spawn in the upper Delaware Basin, yet, this has not been suitably quantified.

- Investigate the feasibility for initiating a fishery-independent annual monitoring of returning shad in the upper Delaware River Basin and Delaware Estuary/Bay
- Investigate the feasibility for initiating telemetry studies to characterize adult spawning behavior and residency to particular locales

7.4.5 Characterize Loss from Non-traditional Fishery Harvest sources

Losses of shad from the Delaware River population beyond either recreational or commercial harvest occur. Impingement and entrainment from various water intakes are known to be considerable sources of mortality. Yet available data quantifying this loss is not consistently reported.

- Collaborate with regulatory agencies for improving reporting rates of I&E losses of shad
- Investigate the feasibility for initiating a survey to quantify density of eggs and larvae of American Shad in the Delaware River to better quantify impacts of specific water intake

structures and inform mitigation measures at intake structures that have a substantial impact on shad populations

7.4.6 Multi-species Management

Understanding how different species of predators and prey interact is an important component to managing fish stocks. American Shad are prey species for a suite of inshore and offshore predators. Shad also share resources with other prey species. Better management of American Shad stocks can occur if we consider other species that interact with or depend upon American Shad.

- Pursue other data sources for potentially relating interactions between various predators and resource competitors.

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9. Figures

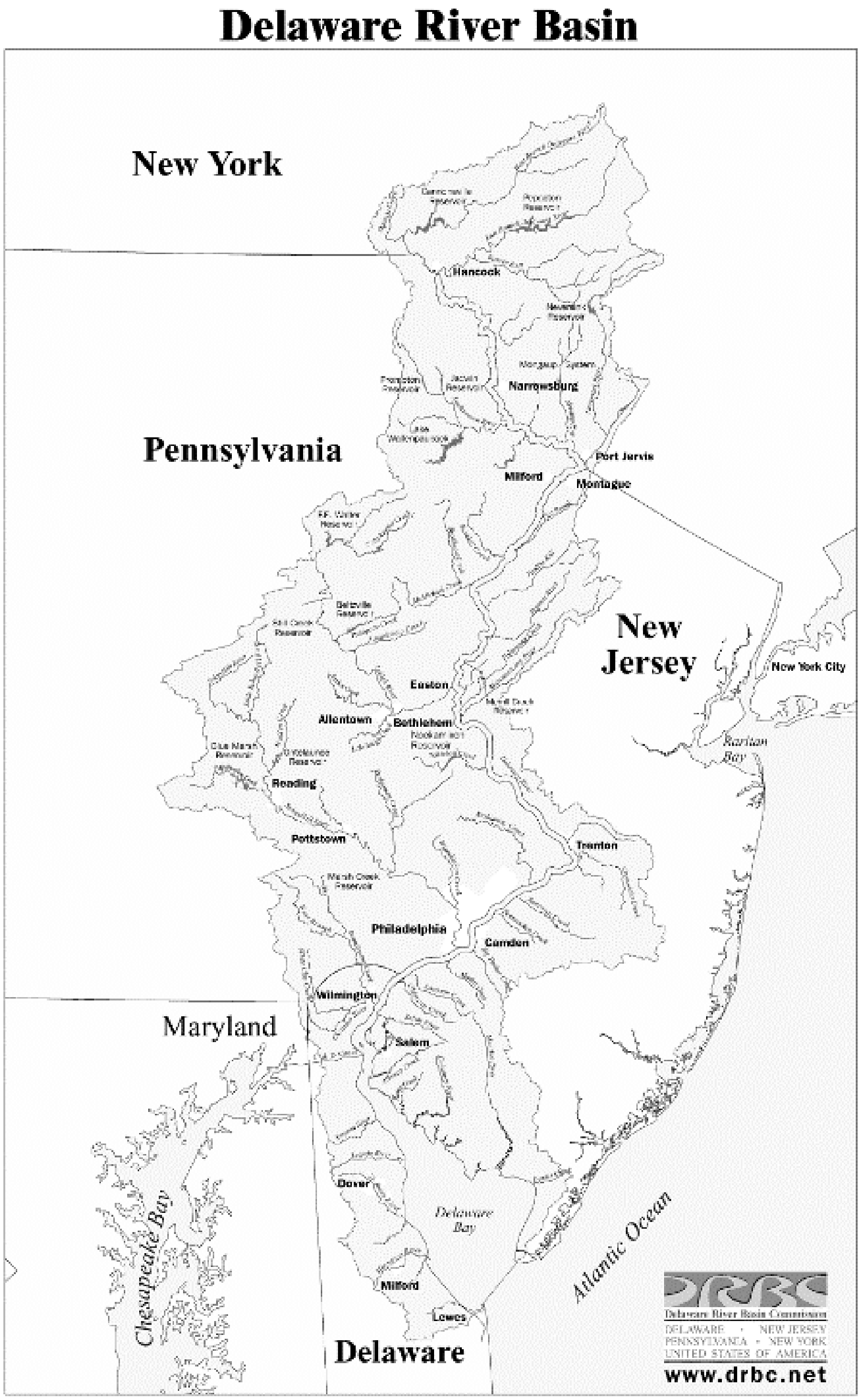


Figure 1. The Delaware River watershed.

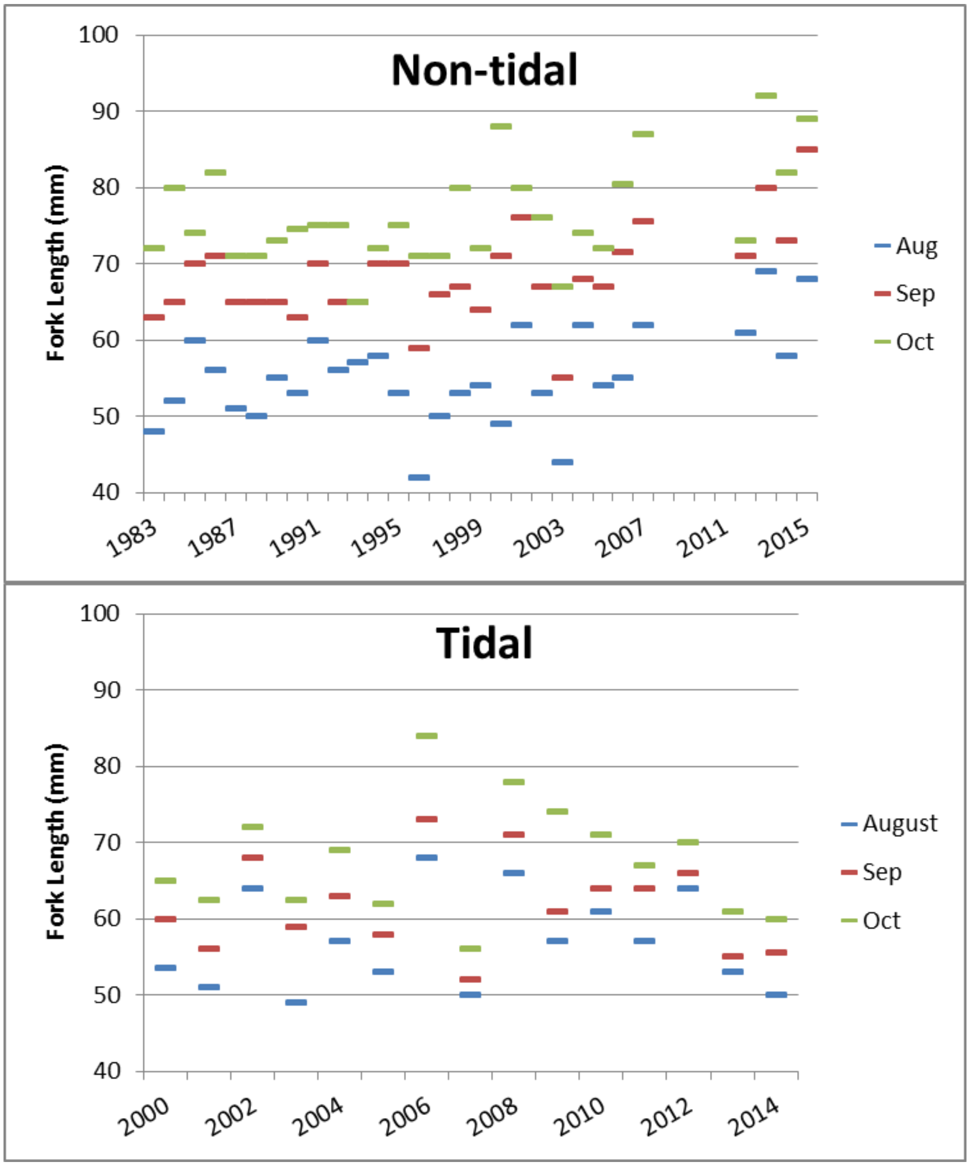


Figure 2. Distribution of YOY American Shad median fork lengths by month for the non-tidal and tidal beach seining. Medians are inclusive of those fork lengths collected from the traditional non-tidal sites: Trenton, Phillipsburg, Delaware Water Gap and Milford Beach.

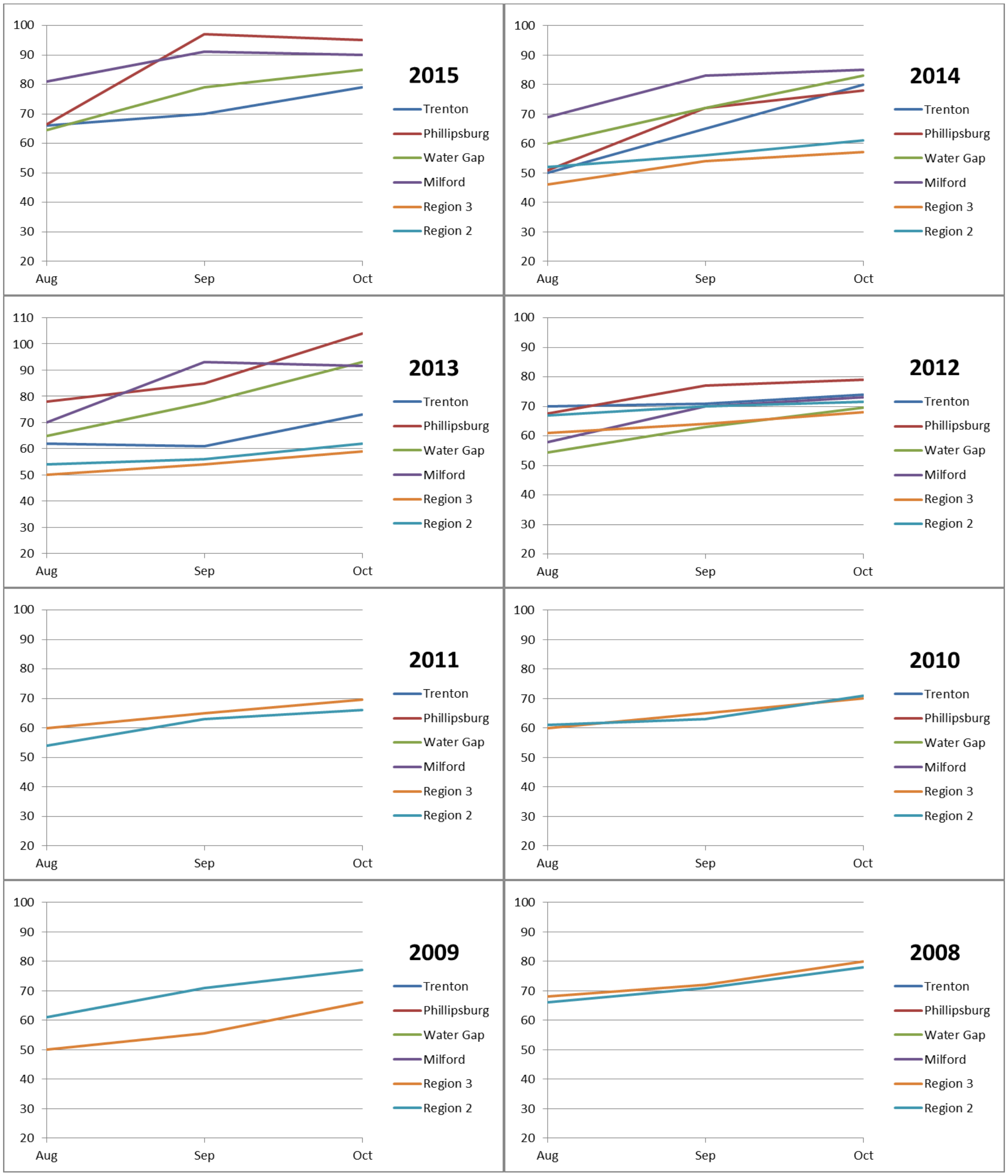
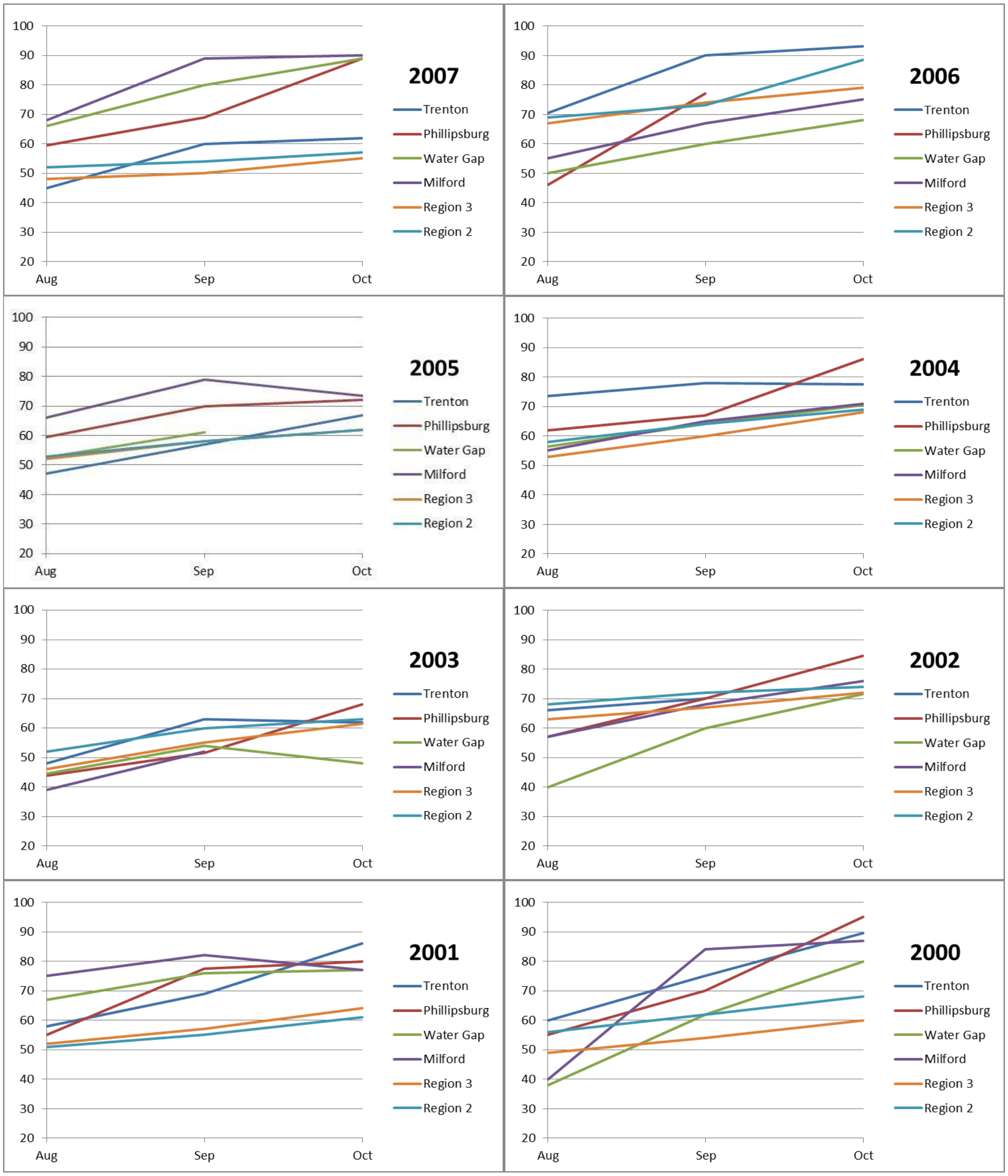


Figure 3. Distribution of YOY median fork lengths, by month and location, for the non-tidal and tidal beach seining.



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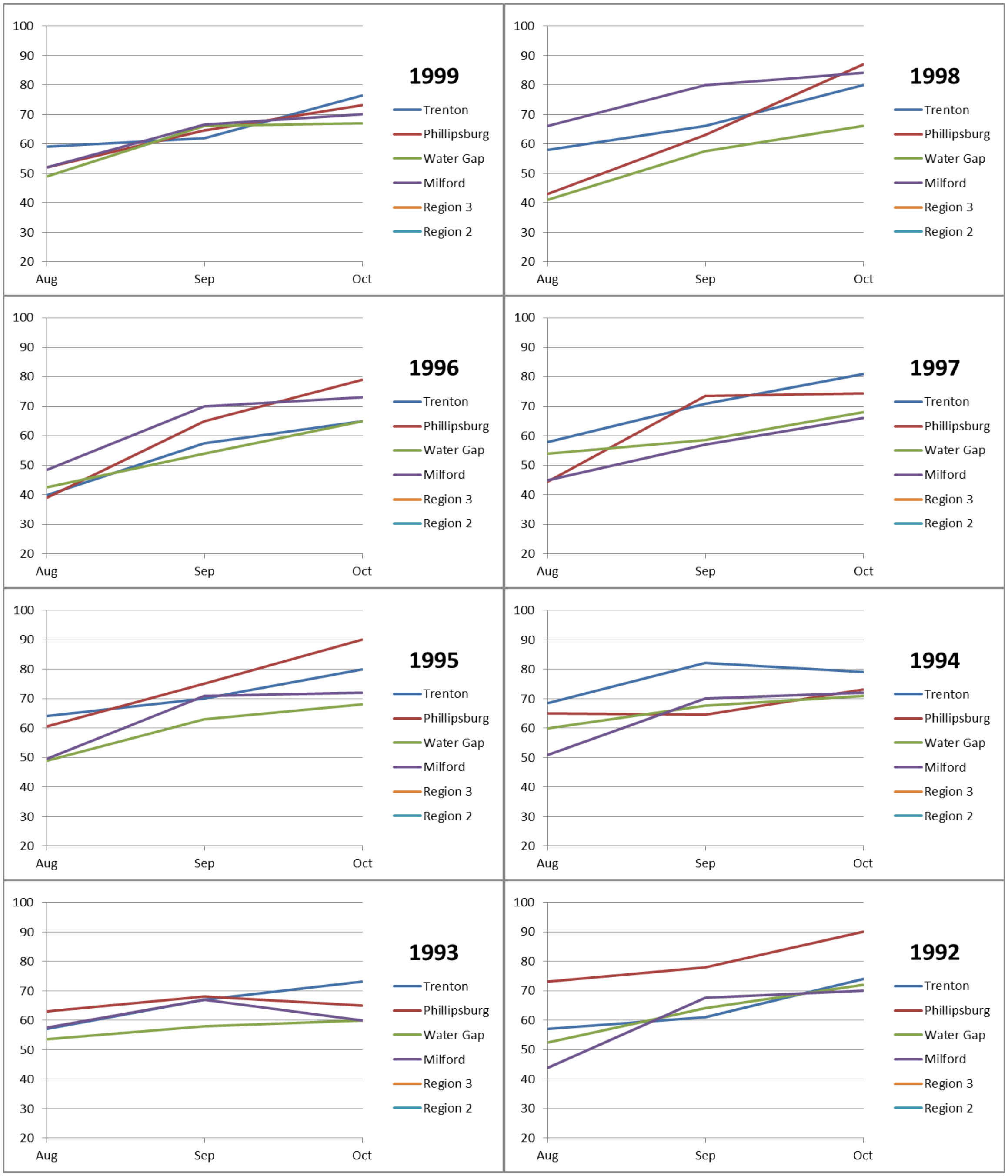

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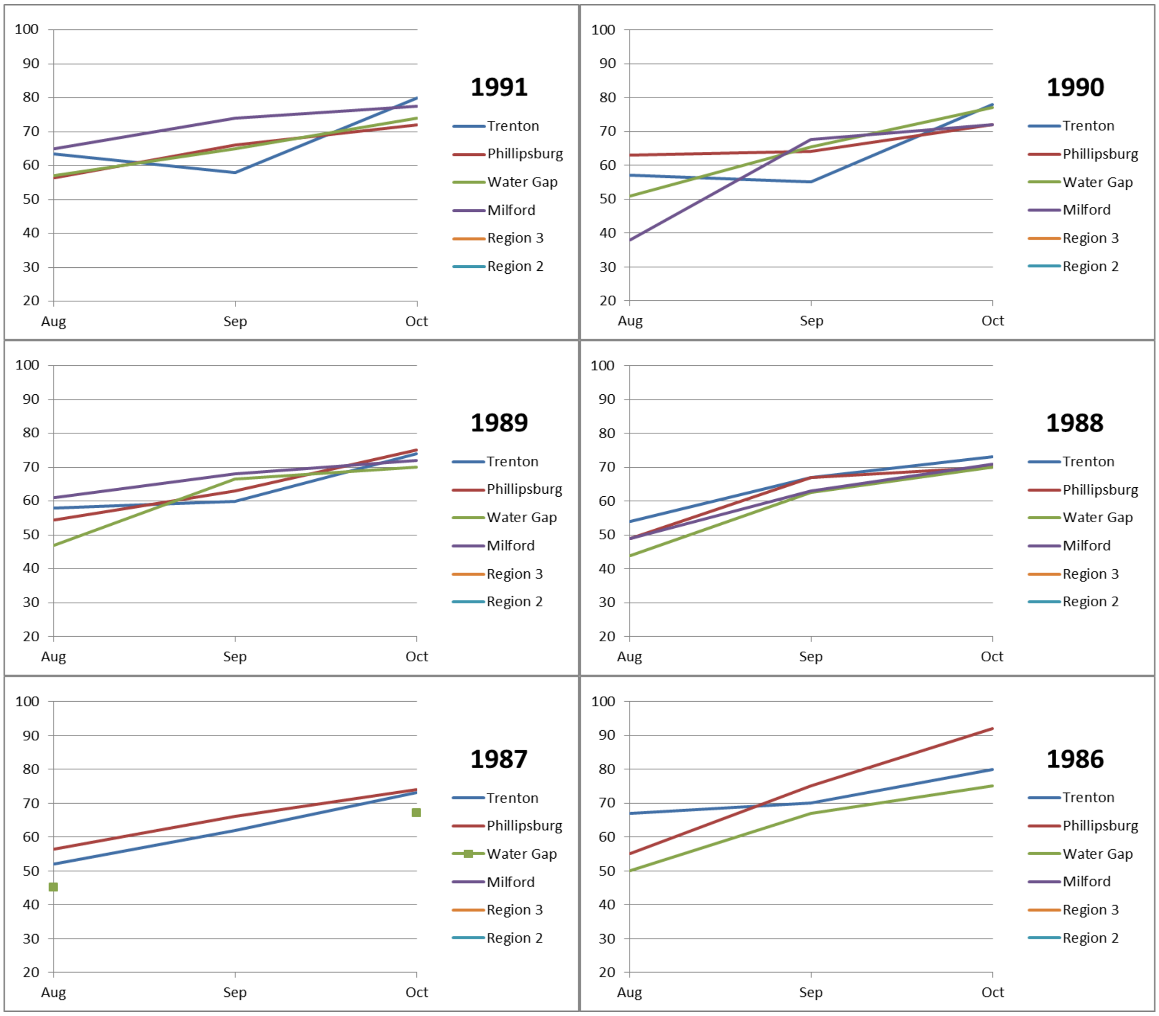

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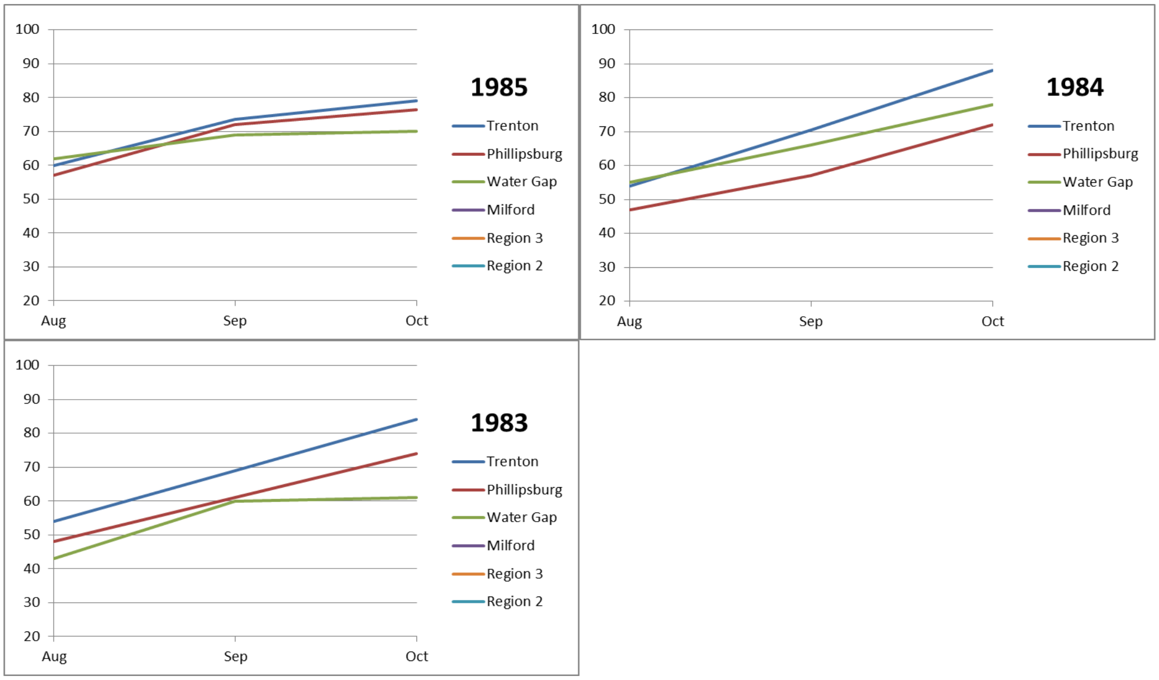

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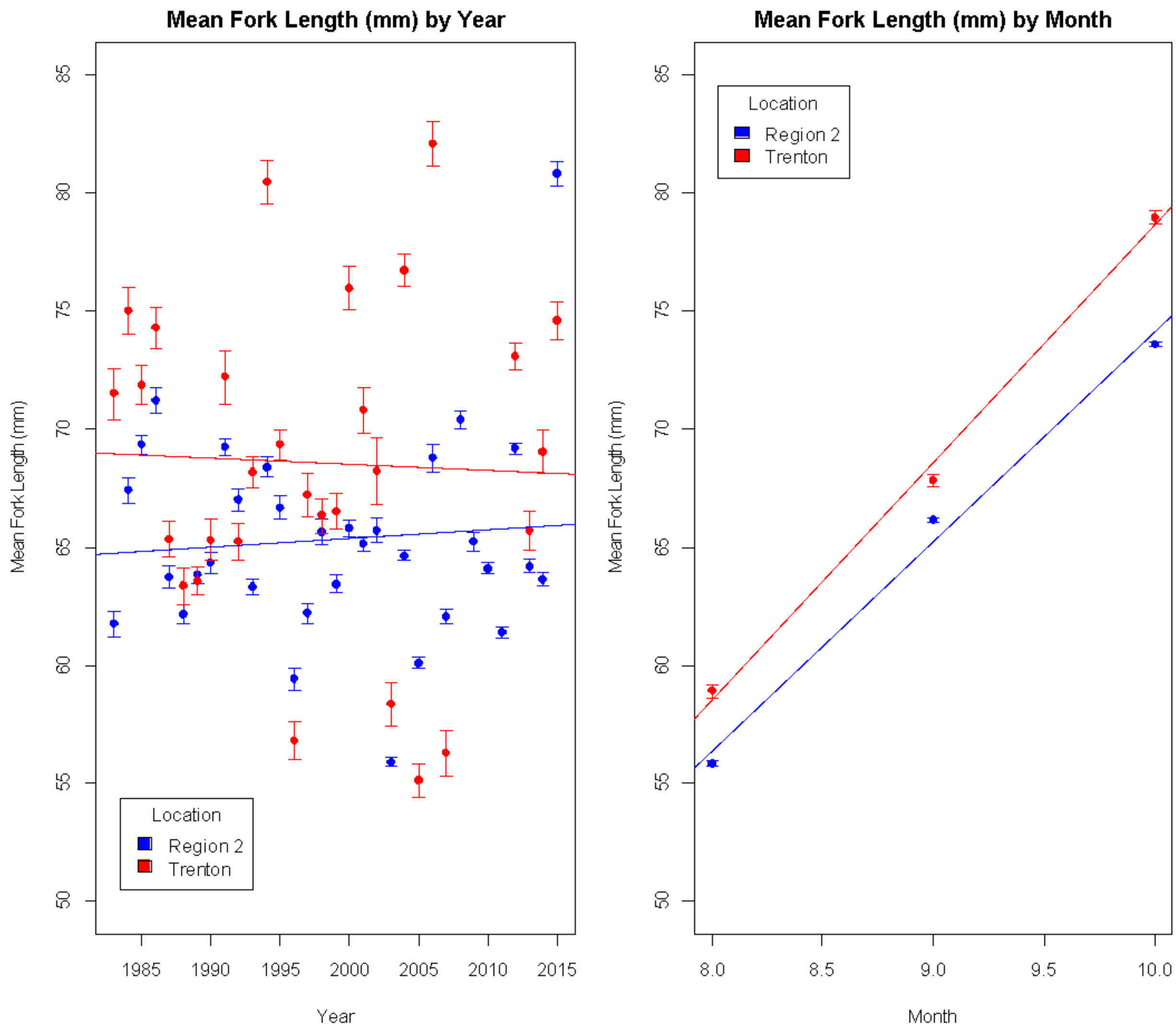


Figure 4. Comparison of YOY shad fork lengths between the upper estuary (Region 2) and Trenton sites.

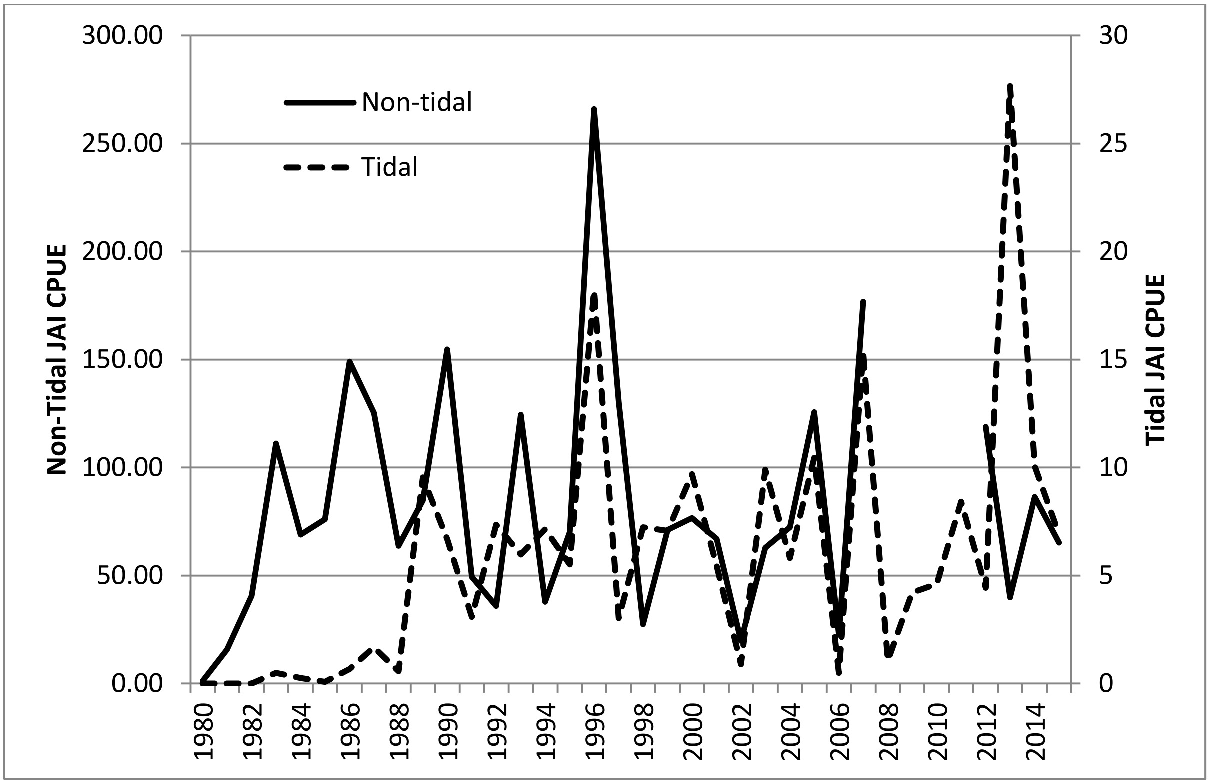


Figure 5. Non-tidal (based on the four historic sites Trenton, Phillipsburg, Delaware Water Gap and Milford Beach) and tidal Delaware River American Shad JAIs both expressed as Geometric means: 1980 – 2015.

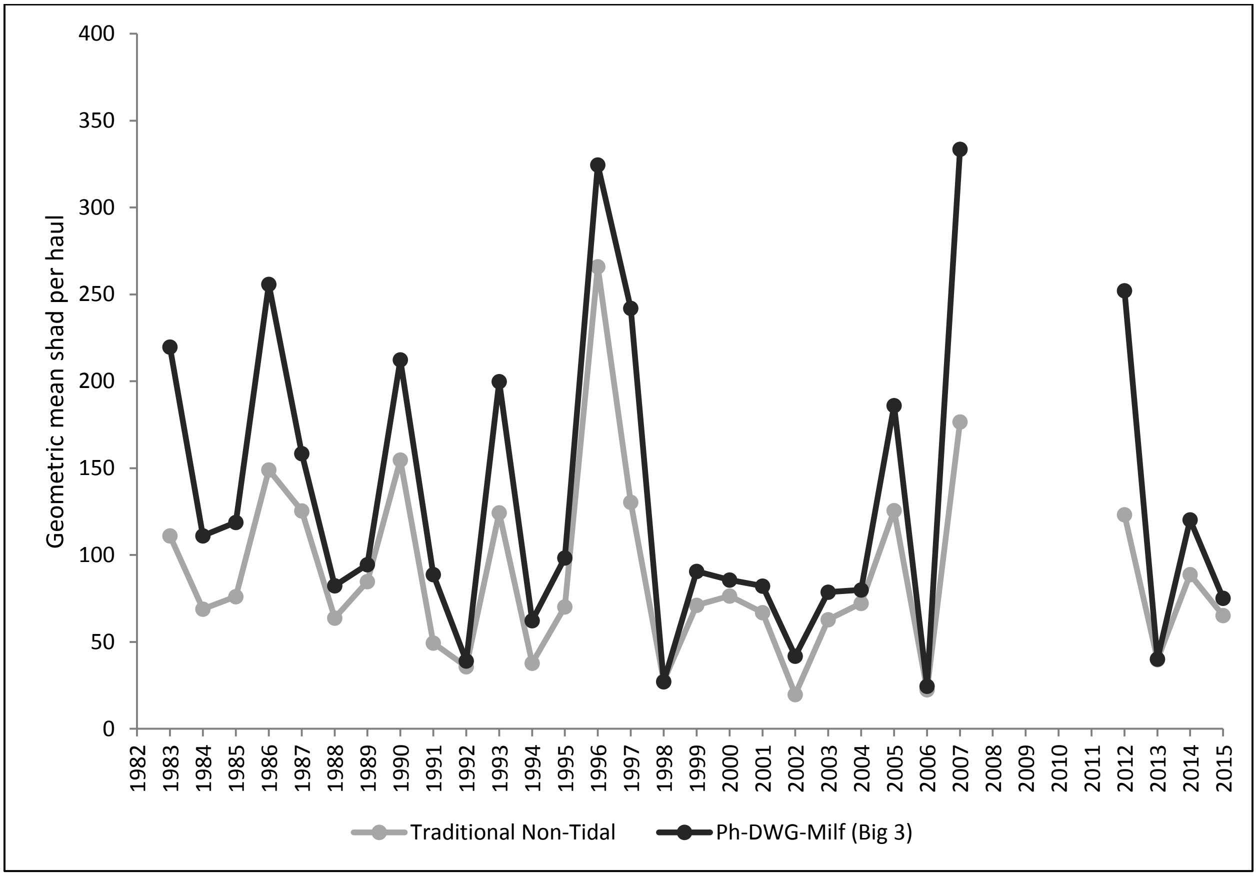


Figure 6. Geometric means for the non-tidal JAI from the traditional (i.e., Trenton, Phillipsburg, Delaware Water Gap and Milford Beach) and new non-tidal (i.e., Phillipsburg, Delaware Water Gap and Milford Beach, collectively informally referred to as the Big 3) sampling sites.

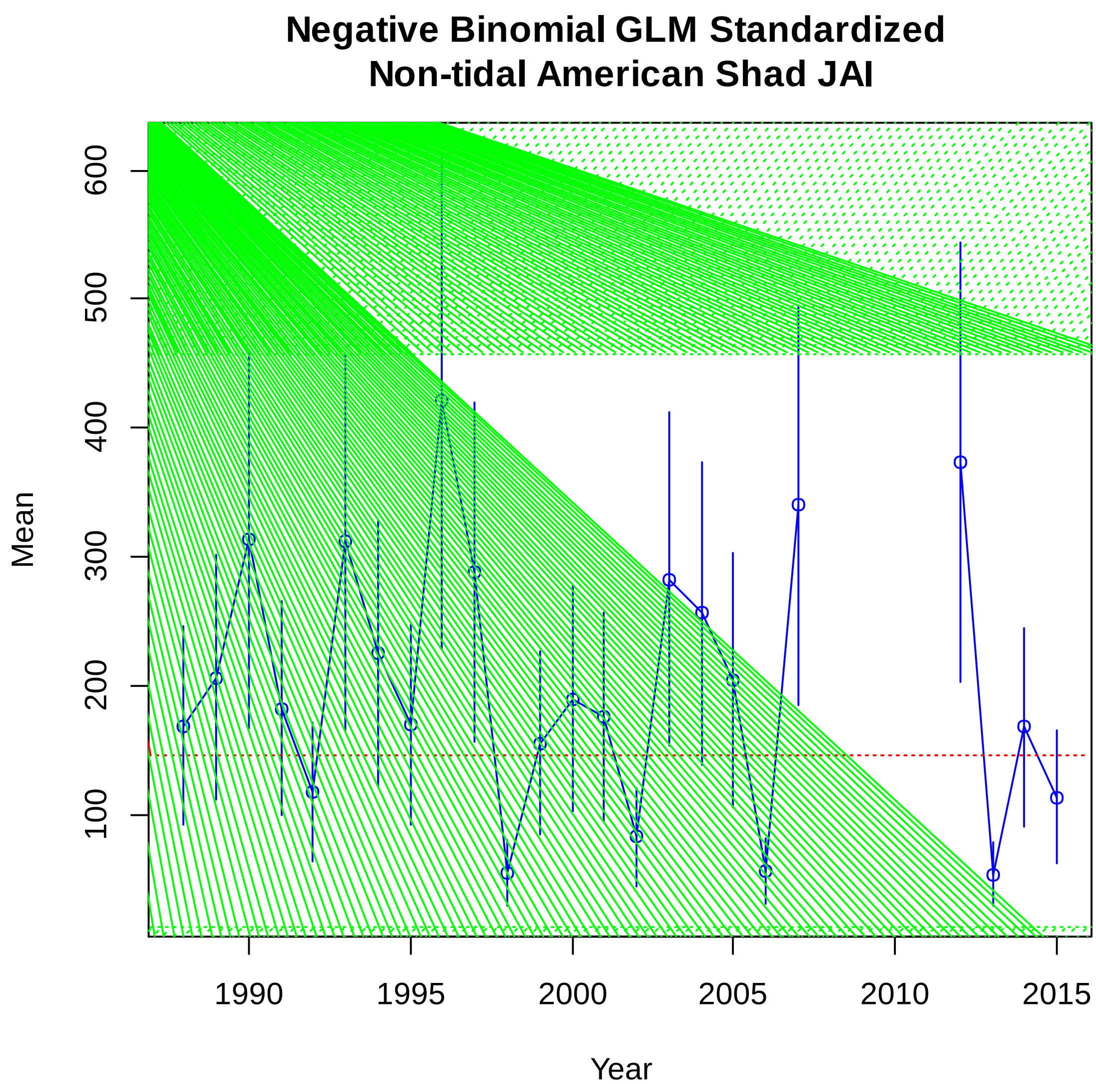


Figure 7. The Delaware River non-tidal American Shad JAI (GLM) with 25th percentile benchmark (red dotted line) from 1988 – 2015 with 95 % confidence intervals. The green boxes represent our survey detectability over a five year period with power = 0.80. Only the Big 3 non-tidal sites (i.e. Phillipsburg, Delaware Water Gap and Milford Beach) were inclusive in this analysis.

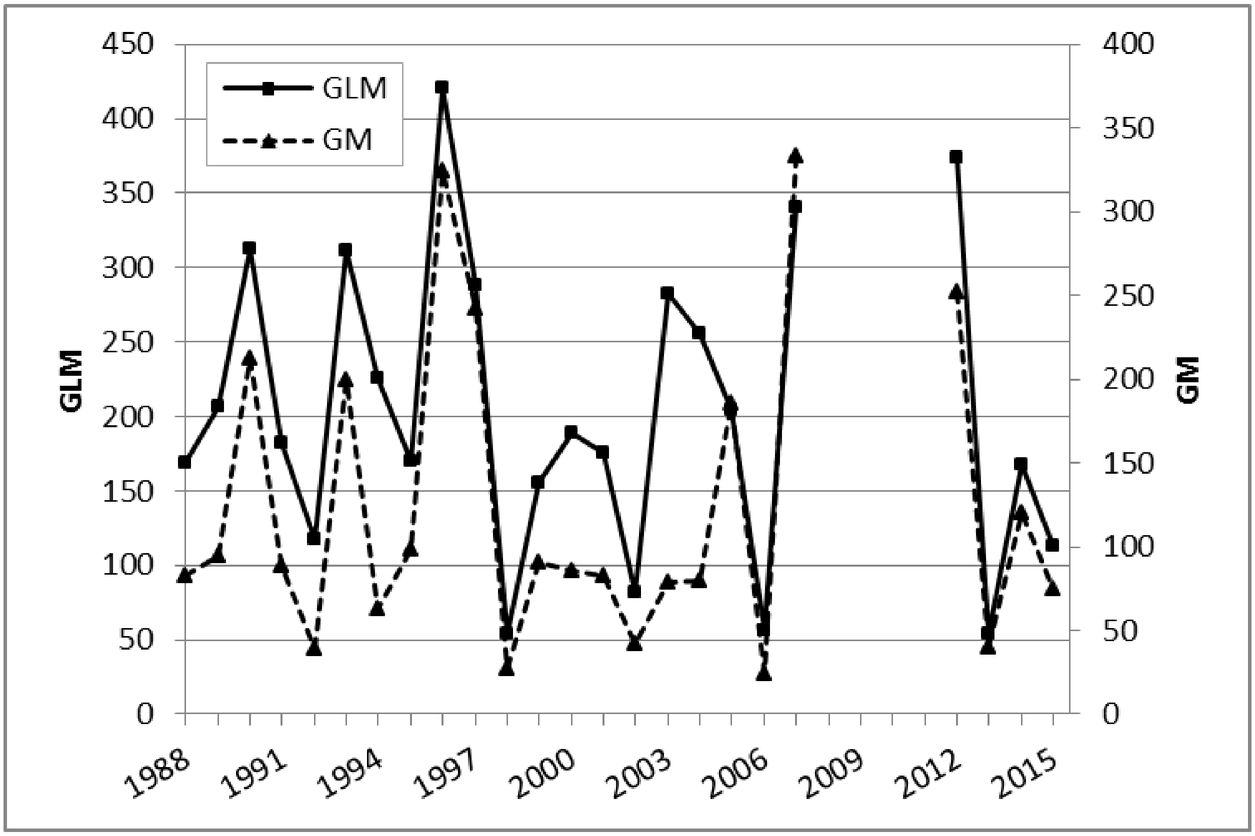


Figure 8. Comparison of non-tidal JAI as represented by geometric mean (GM) and generalized linear model (GLM) from Phillipsburg, Delaware Water Gap, and Milford Beach from 1988 to 2015.

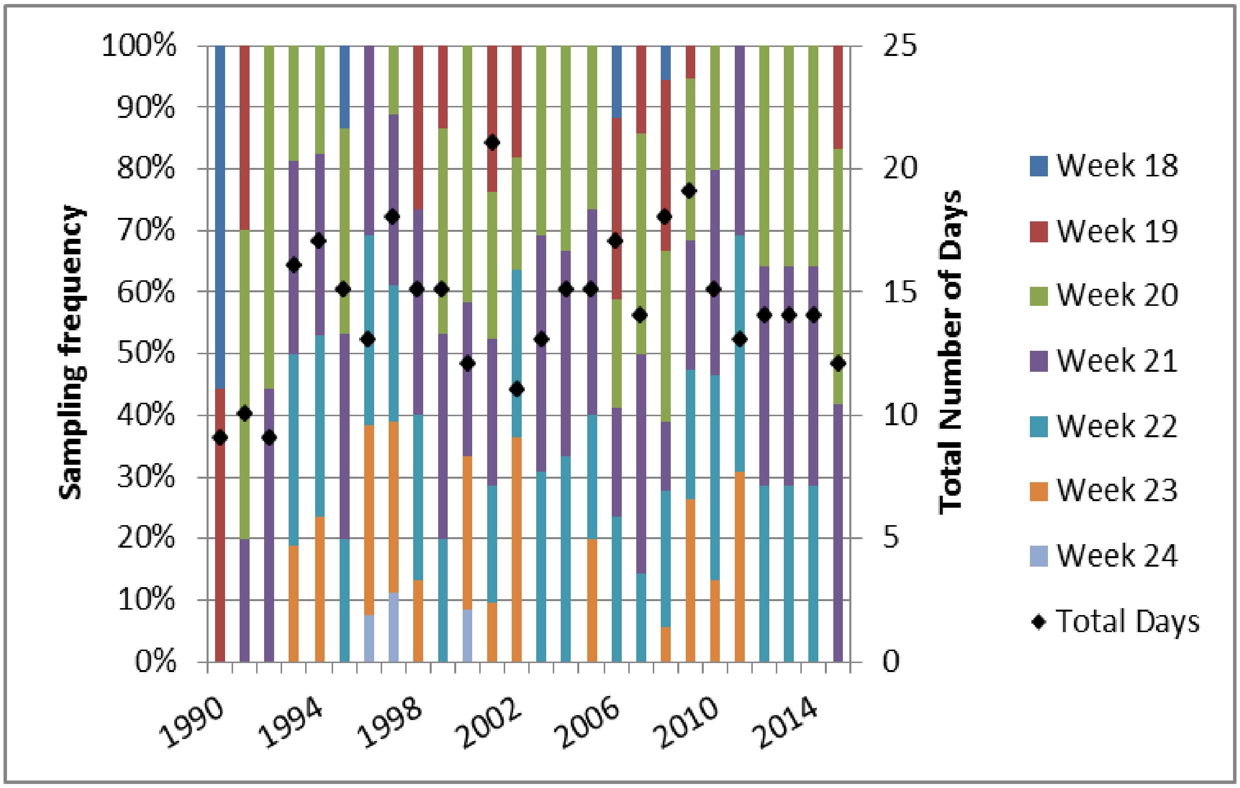


Figure 9. Sampling frequency and total number of days for gill netting American Shad at Smithfield Beach.

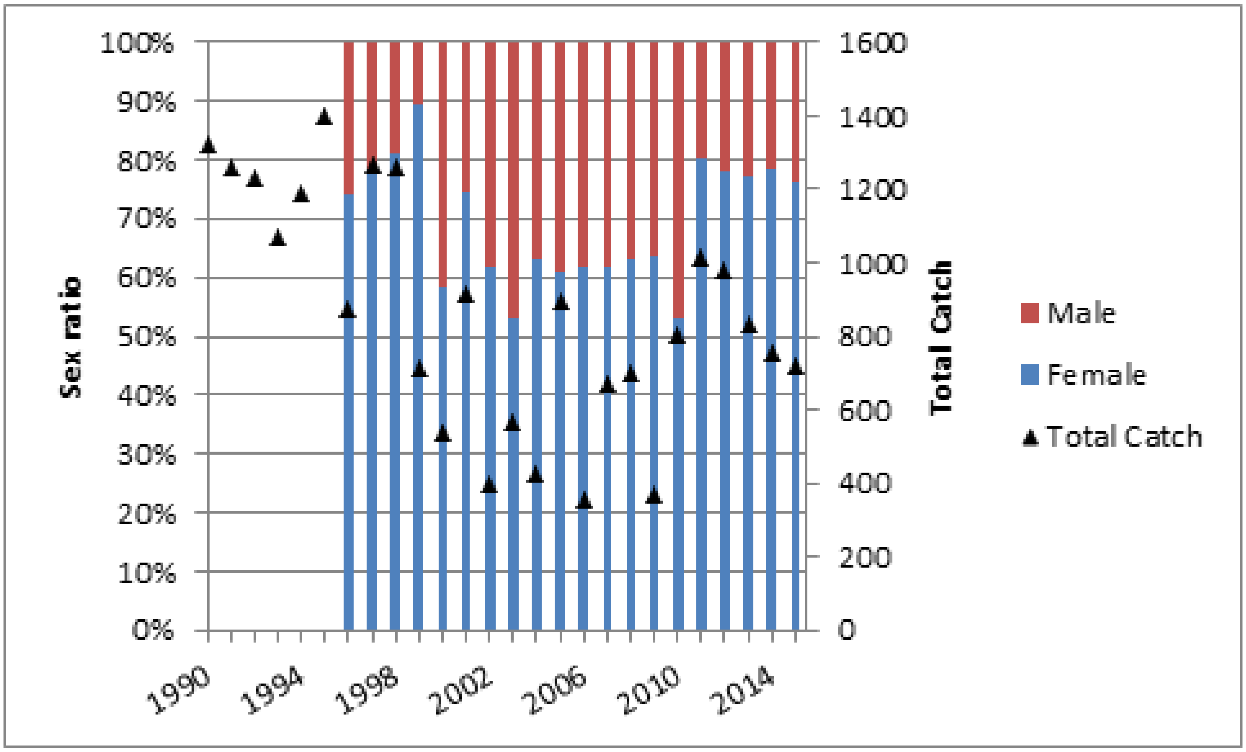


Figure 10. Total catch of American Shad at Smithfield Beach, by gender. No biological data were recorded prior to 1996. Observed sex ratio is dependent on the frequency of mesh sizes deployed in any given year.

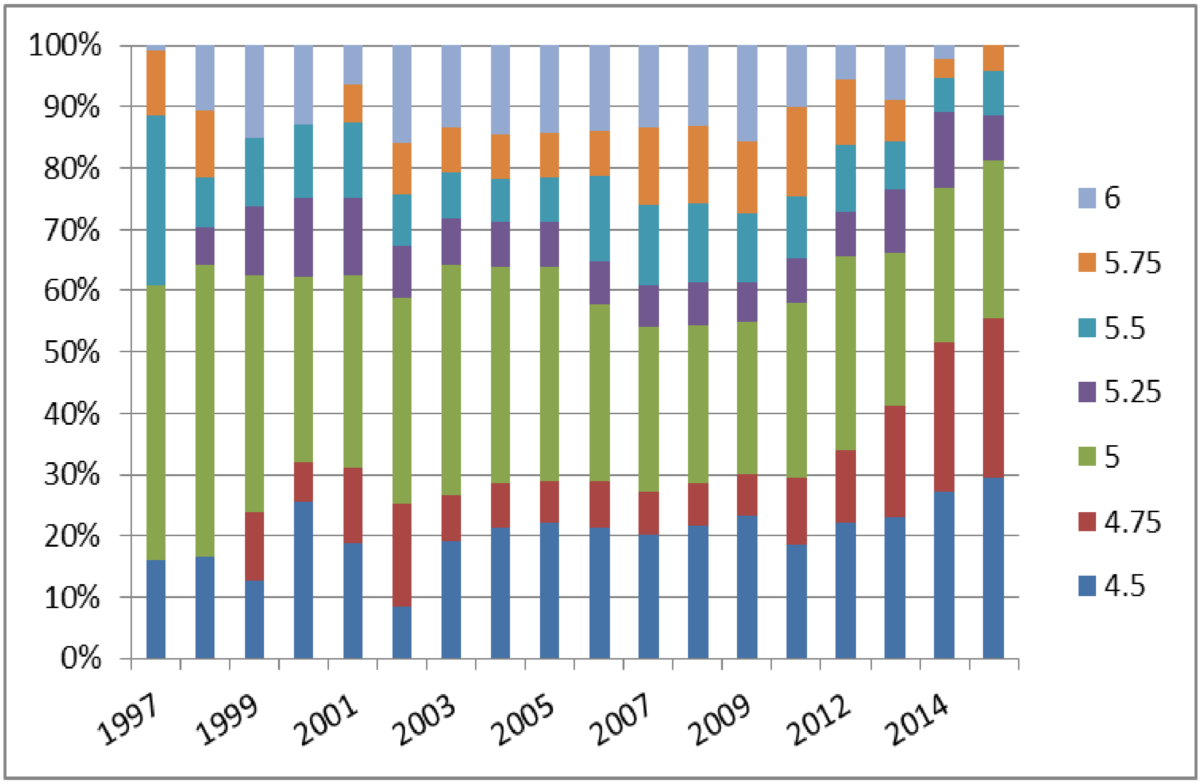
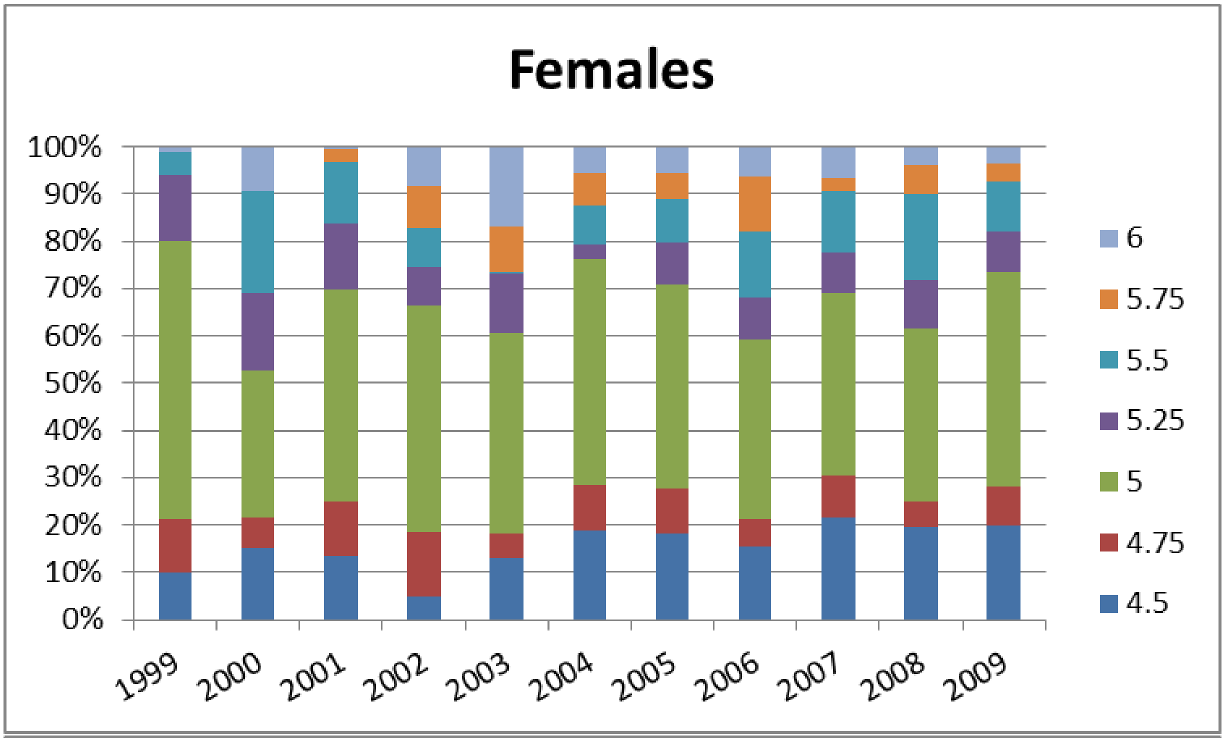


Figure 11. Percent frequency of gill net deployment of stretch mesh sizes (stretch inches) at Smithfield Beach.



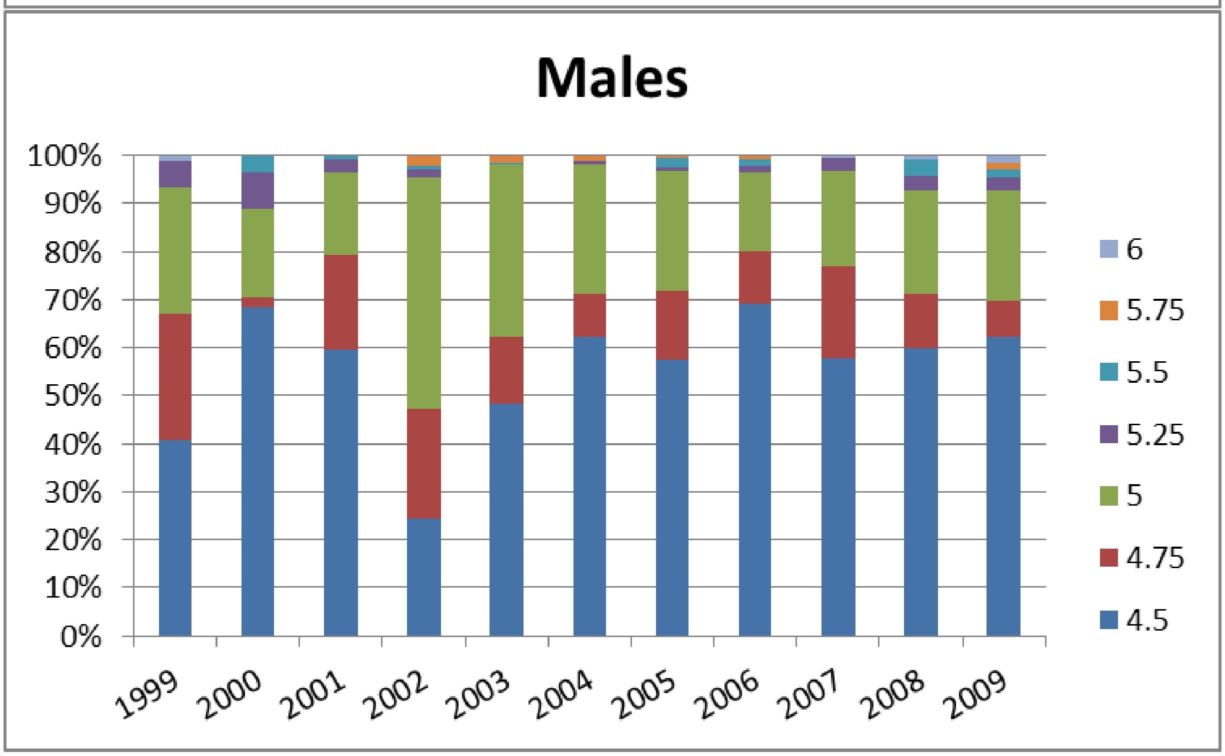


Figure 12. Percent of annual total catch of shad at Smithfield Beach for each mesh size (stretch inches) deployed, by year. Catch was only reported by mesh size 1999 through 2009.

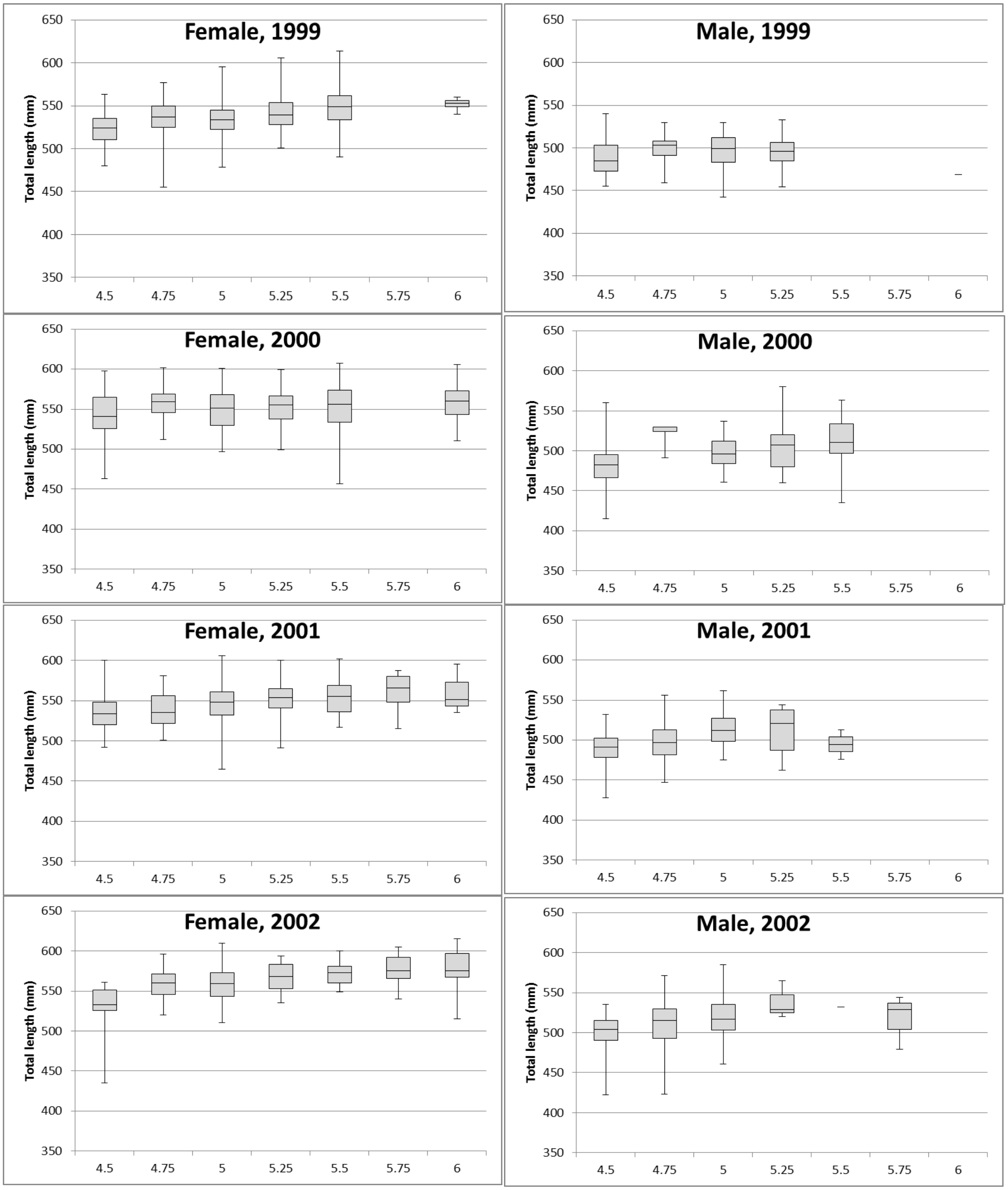
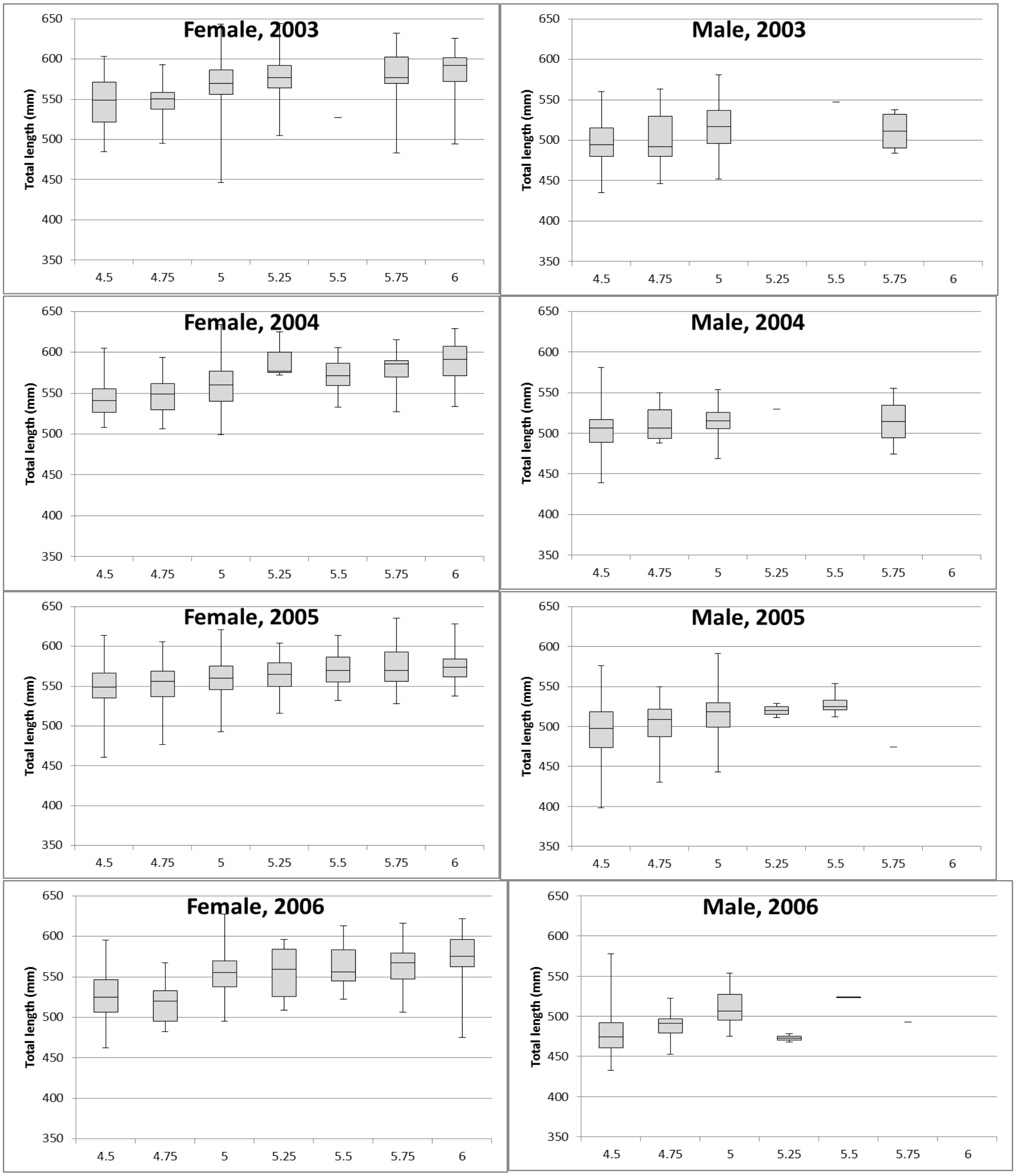


Figure 13. Total length distributions of shad caught at Smithfield Beach by mesh size (stretch inches). Whiskers represent minimum and maximum values; the box represents 25th and 75th percentiles, and the line median sizes.



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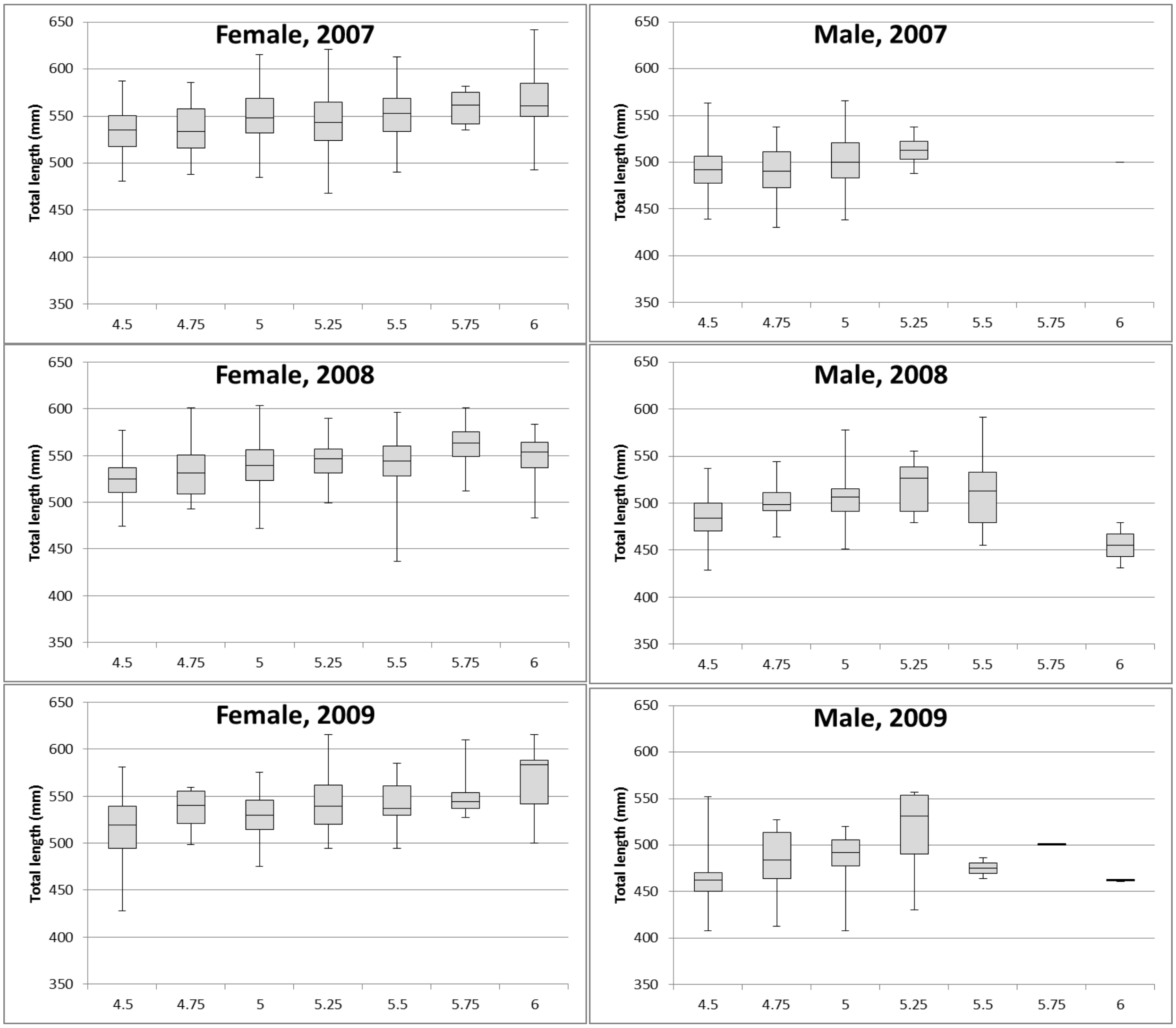

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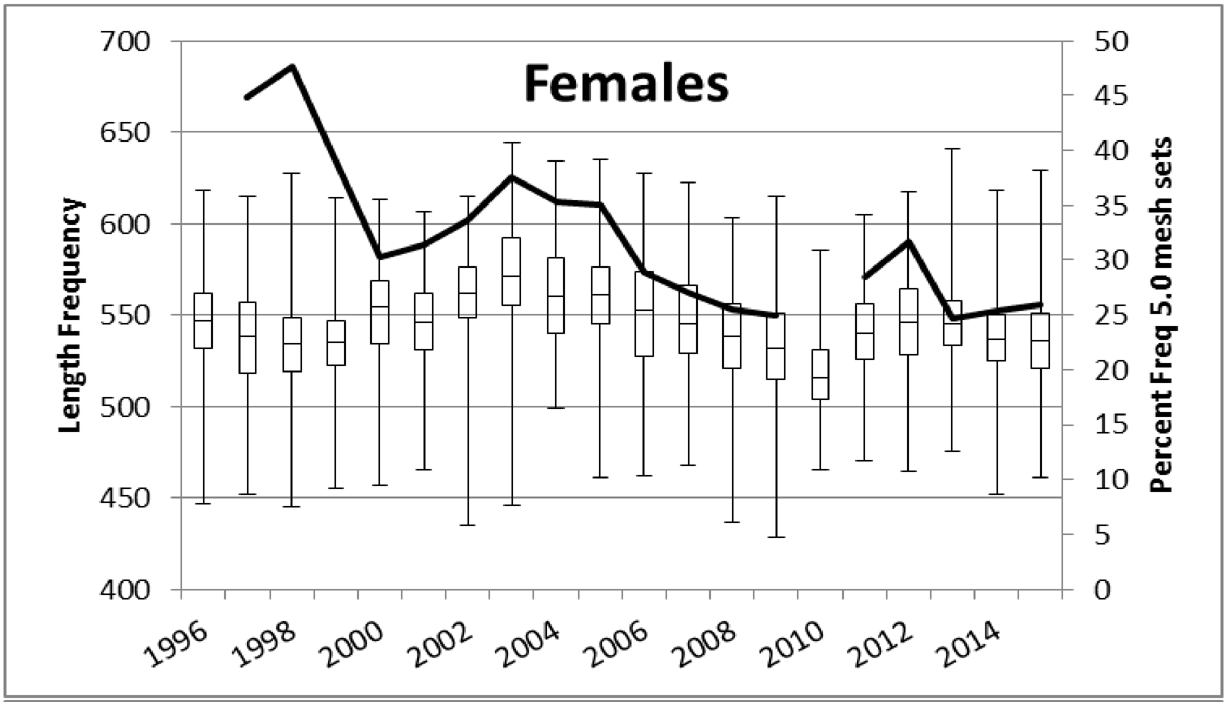


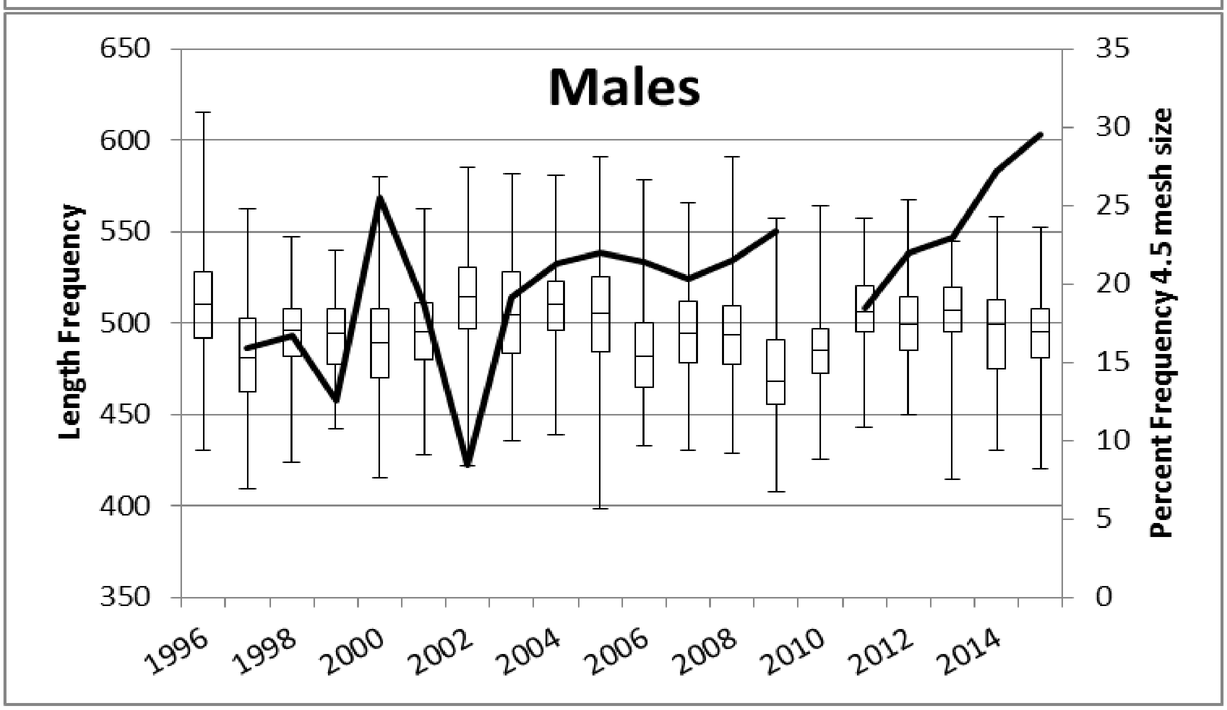


Figure 14. Total length distributions of female and male American Shad overlaid by the frequency of deployment of 5.0 inch (females only) and 4.5 inch (males only) mesh sizes, by year. Whiskers represent minimum and maximum values; the boxes representing 25th, 50th and 75th percentiles.

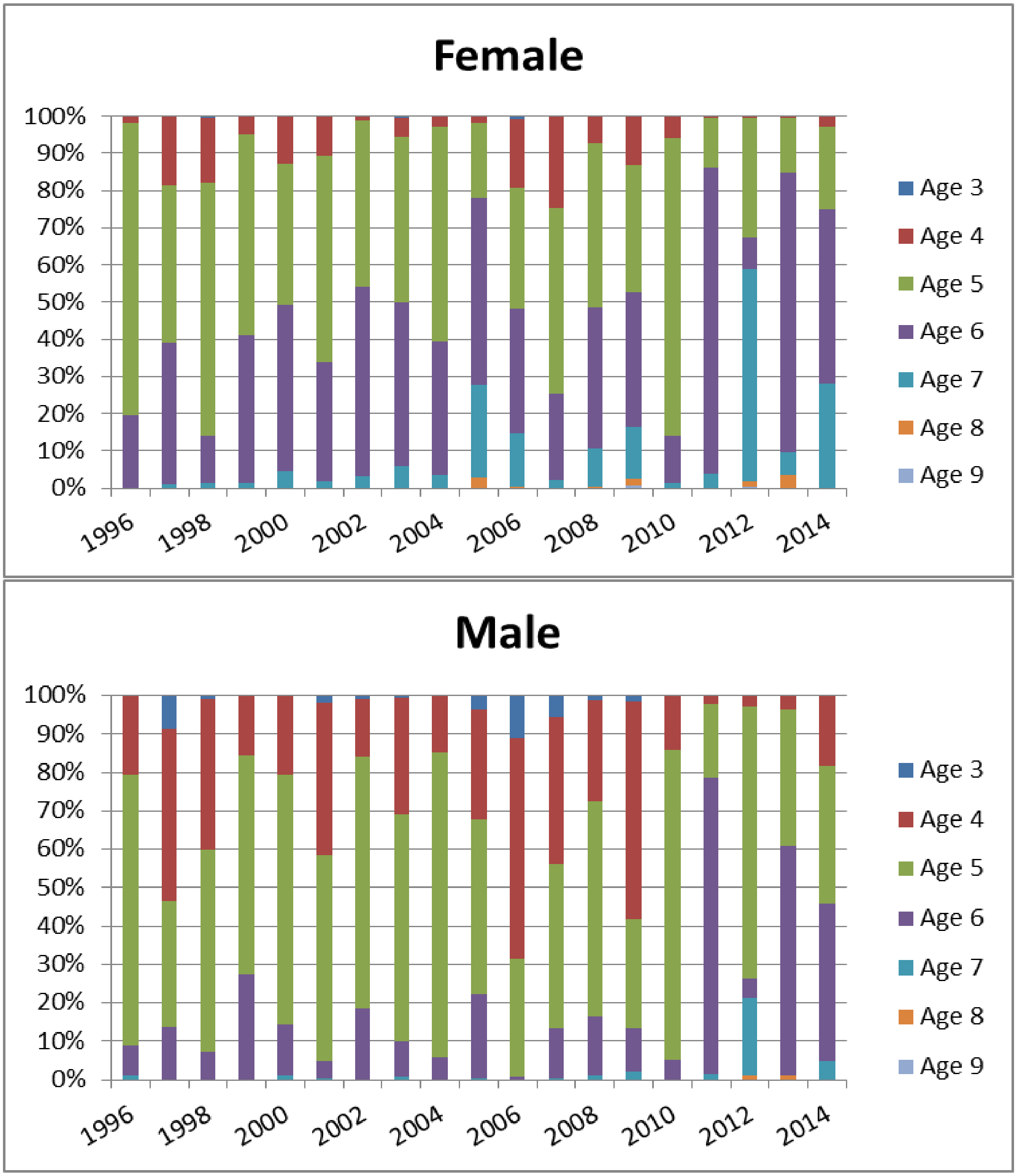


Figure 15. Distribution of age for female and male American Shad captured at Smithfield Beach. No biological information was collected prior to 1996. Assigned ages do not represent the combined agreement of Co-op members as per the Co-op's Ageing Protocol (Appendix A).

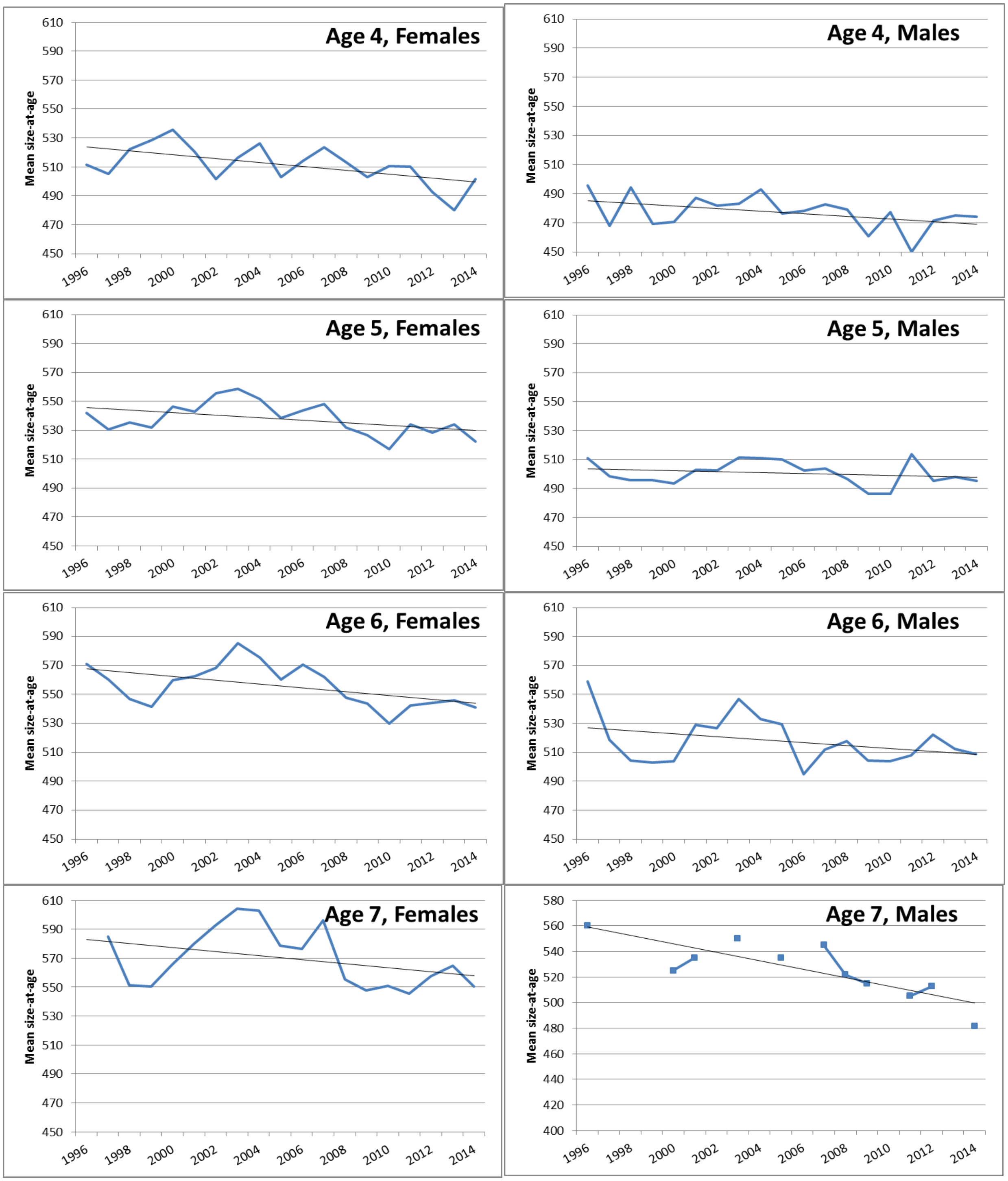


Figure 16. Mean size-at-age (mm TL) for female and male American Shad collected from Smithfield Beach, by age class.

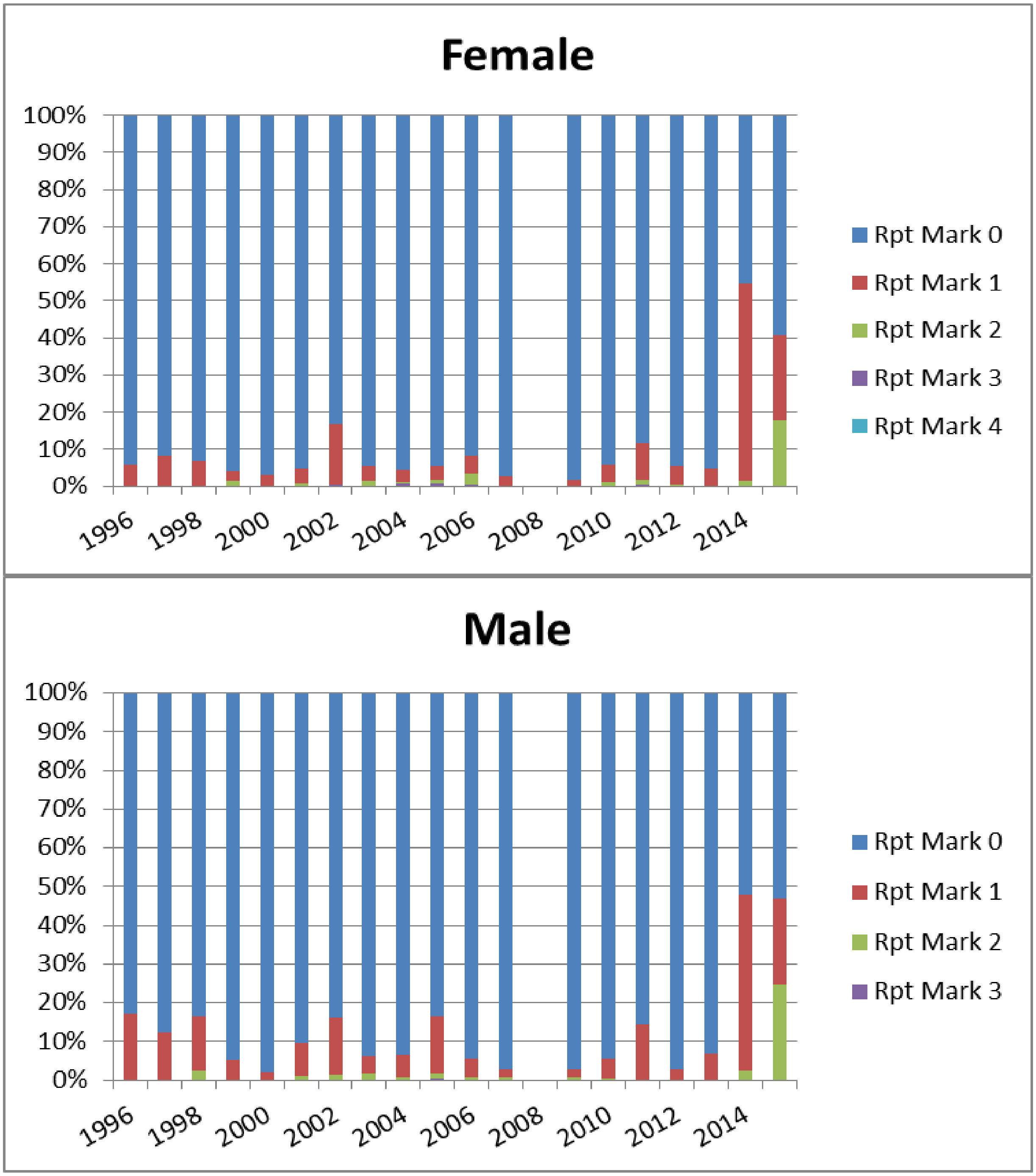


Figure 17. Percent frequency of repeat spawning marks as identified from scale microstructure from shad collected at Smithfield Beach. Scales collected during 2008 have not been processed.

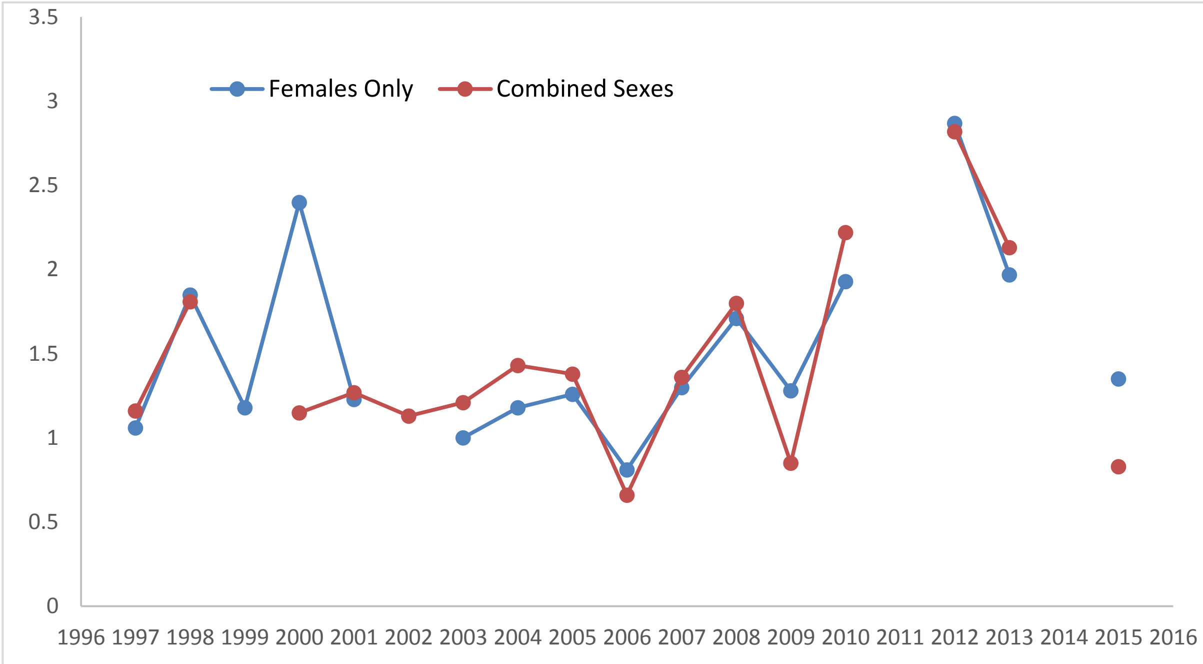


Figure 18. Chapman-Robson bias-corrected total instantaneous mortality (Z) estimates derived from American Shad collected at Smithfield Beach.

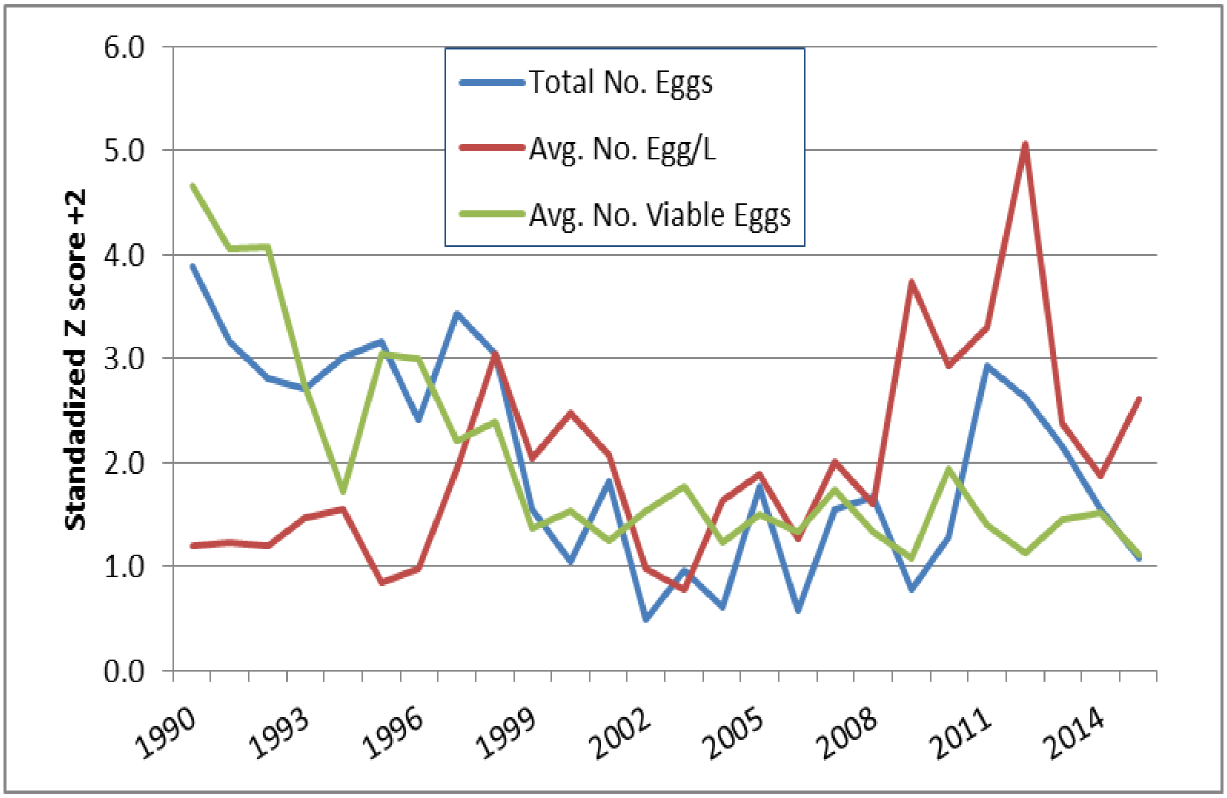


Figure 19. Annual egg harvest characteristics at Smithfield Beach.

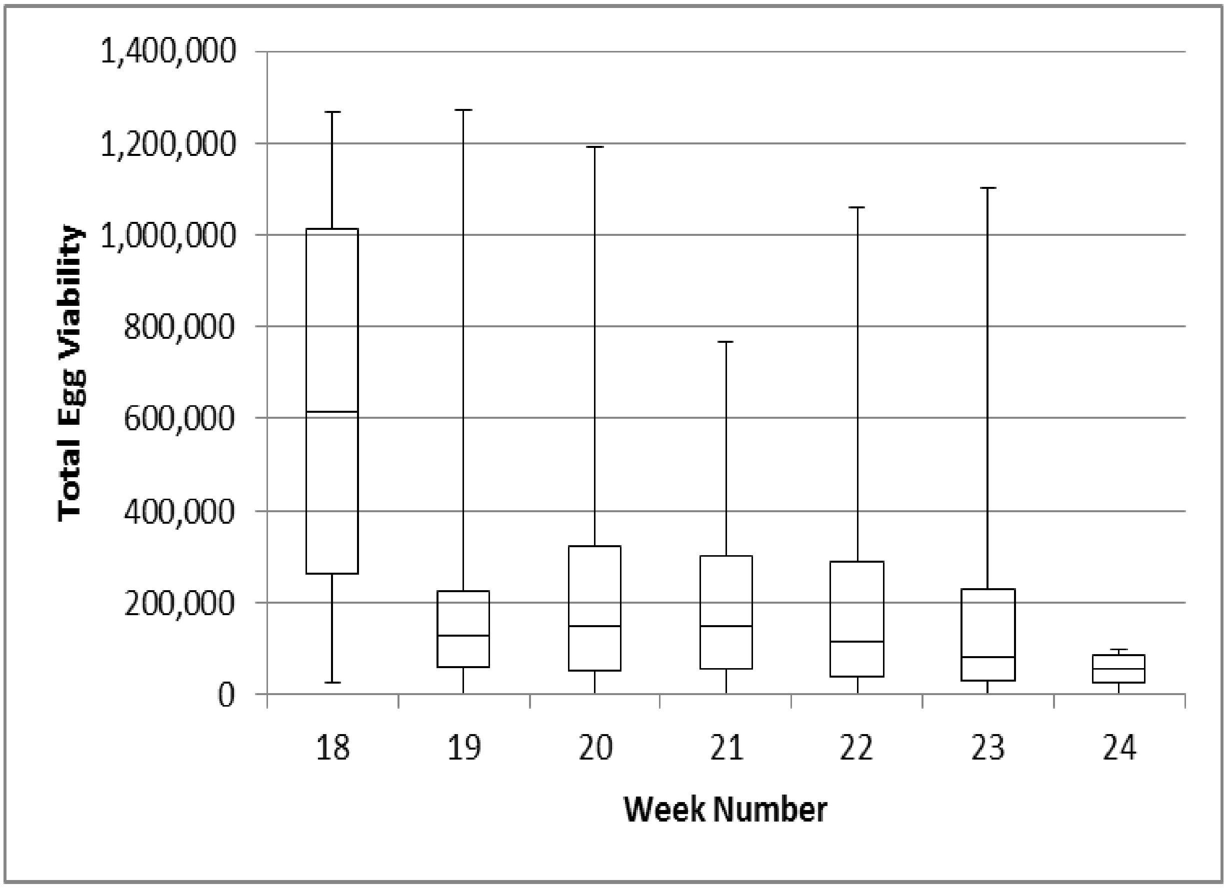


Figure 20. Quartile and median distribution for total egg viability by sampling week, harvested from Smithfield Beach. Whiskers represent minimum and maximum values; the box represents 25th and 75th percentiles; and horizontile line within the box as the median.

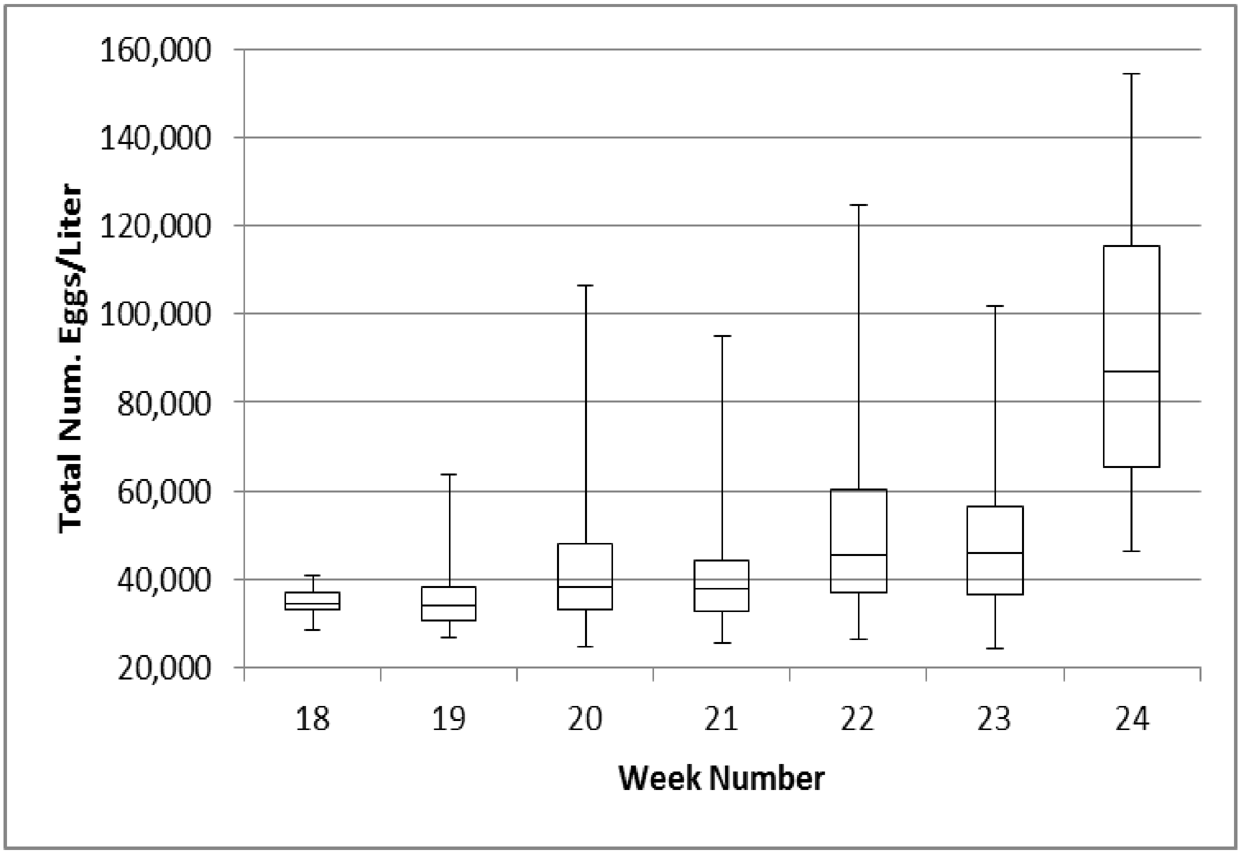


Figure 21. Quartile and median distribution for total number of eggs per liter by sampling week, harvested from Smithfield Beach. Whiskers represent minimum and maximum values; the box represents 25th and 75th percentiles; and horizontile line within the box as the median.

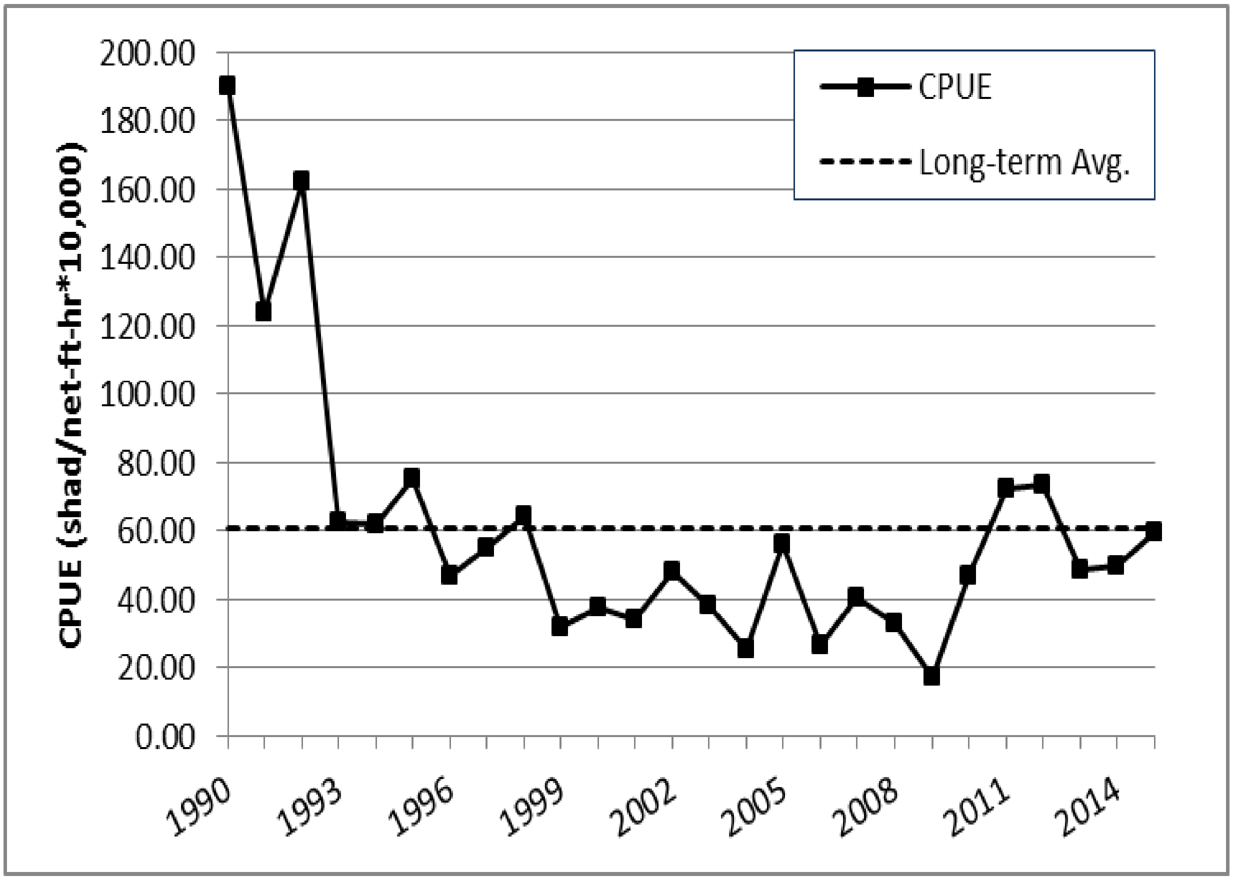


Figure 22. CPUE for American Shad collected from the Delaware River at Smithfield Beach (RM 218) by gill net (shad/net-ft-hr * 10,000).

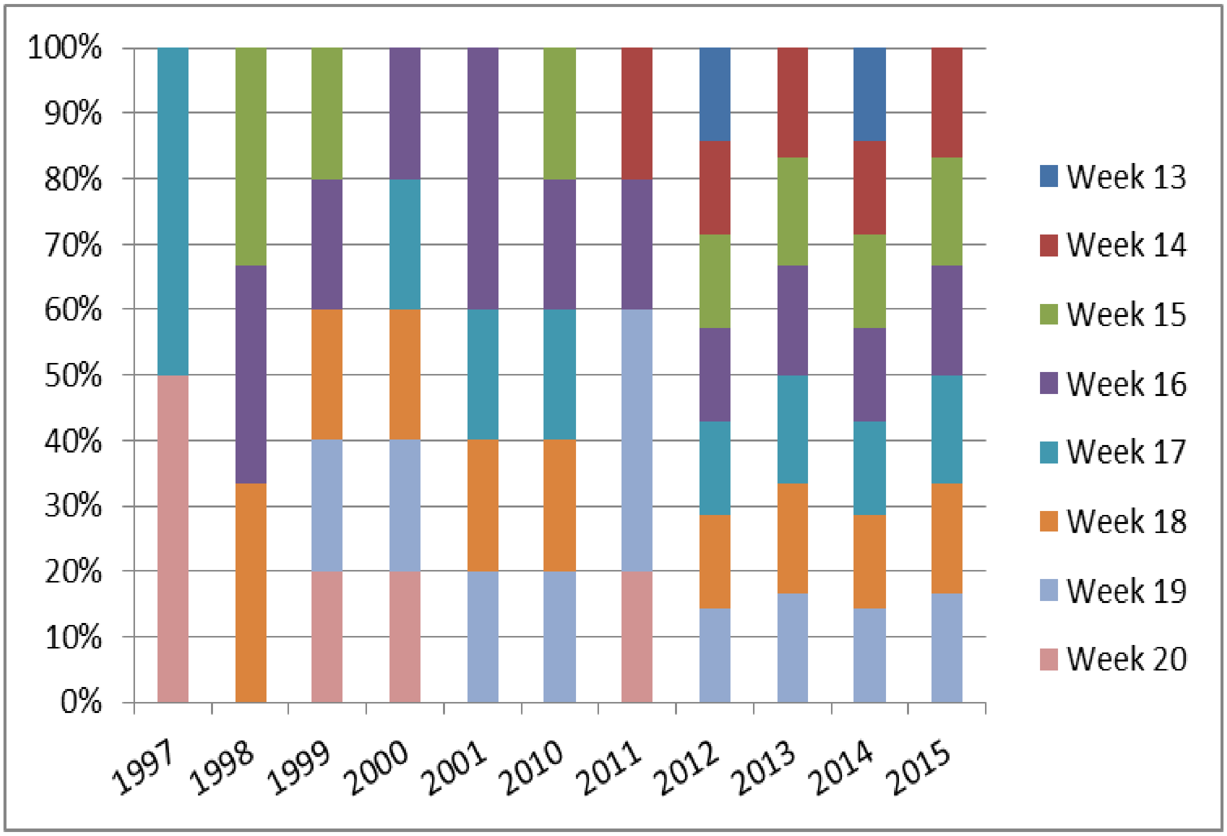


Figure 23. Electrofishing sampling frequency at Raubsville (RM 176) for American Shad as they migrate upriver. Week number is defined as the occurrence of January 1st as week one.

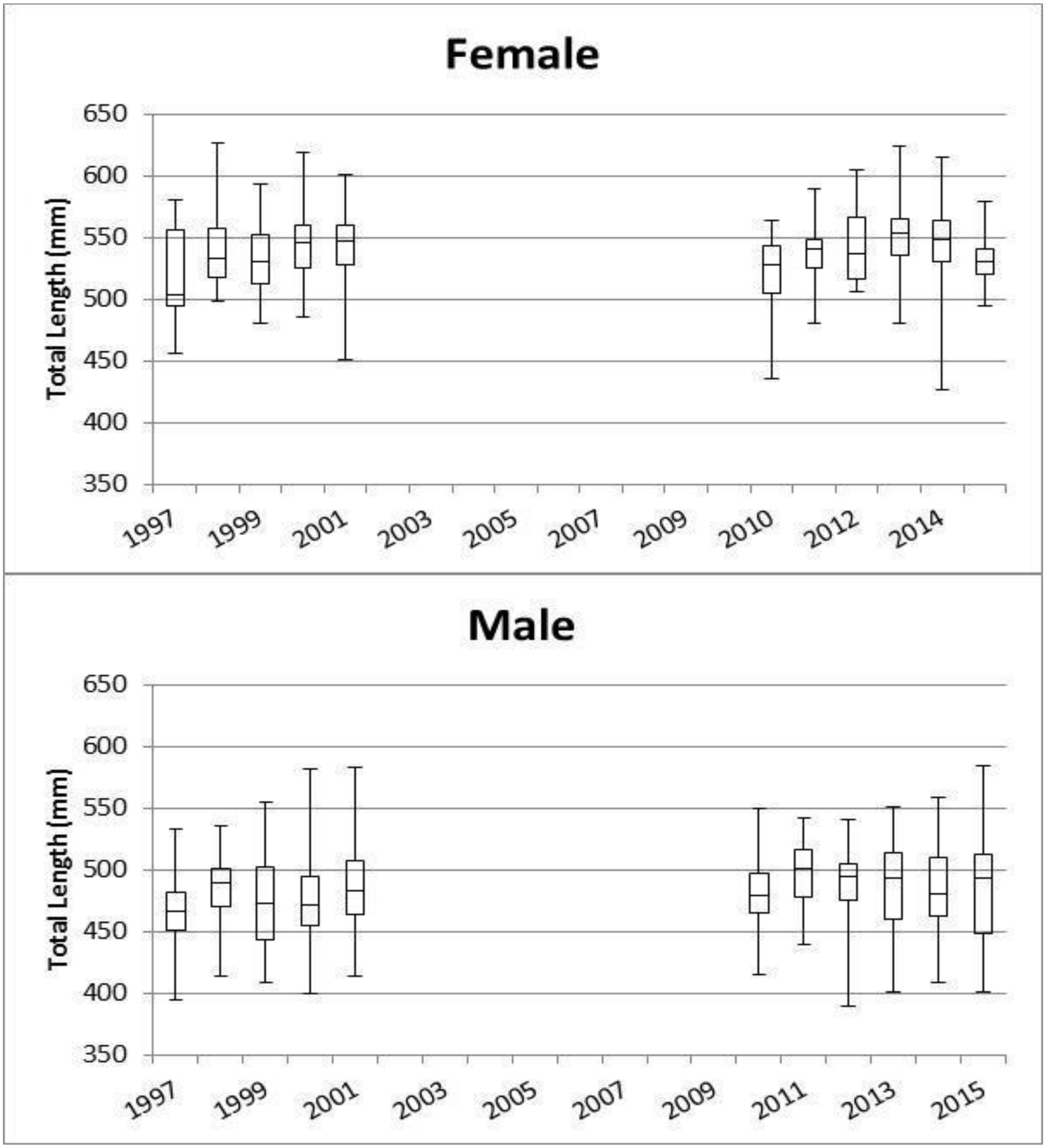
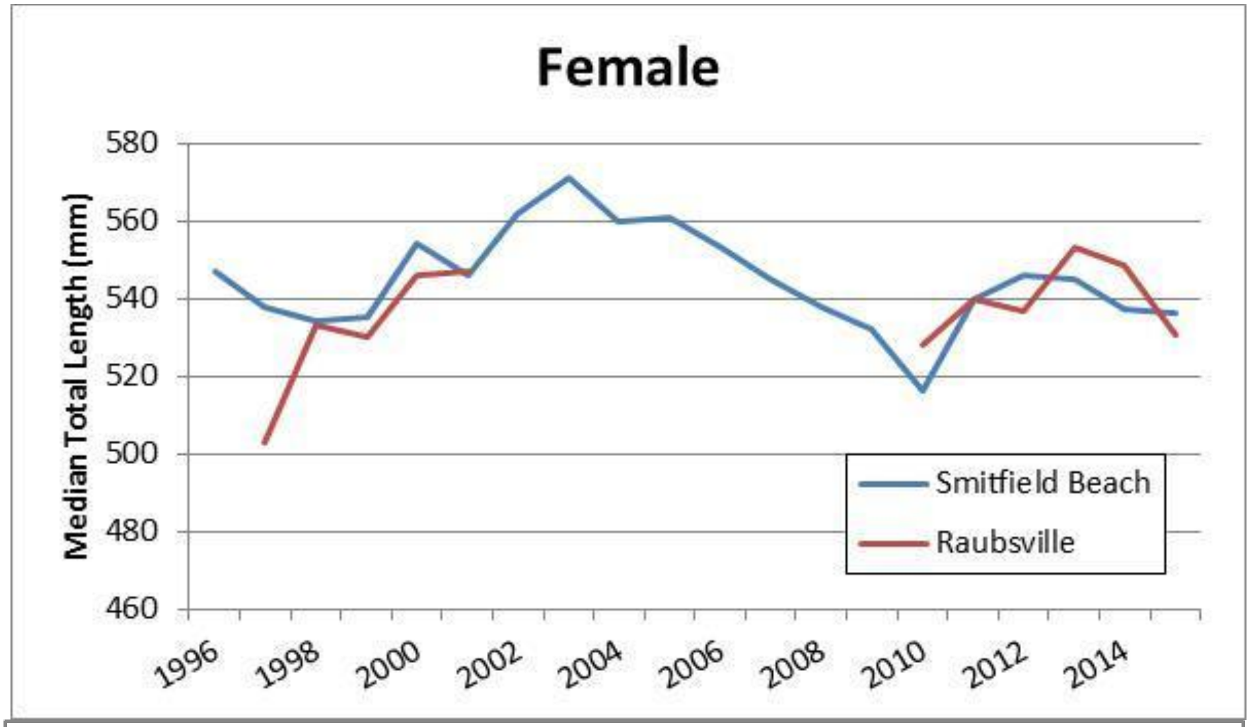


Figure 24. Length frequencies of shad collected at Raubsville (1997-2001; 2010-2015). The boxes represent the lower box 25th, 50th and 75th percentiles. Whiskers are the minimum and maximum lengths.



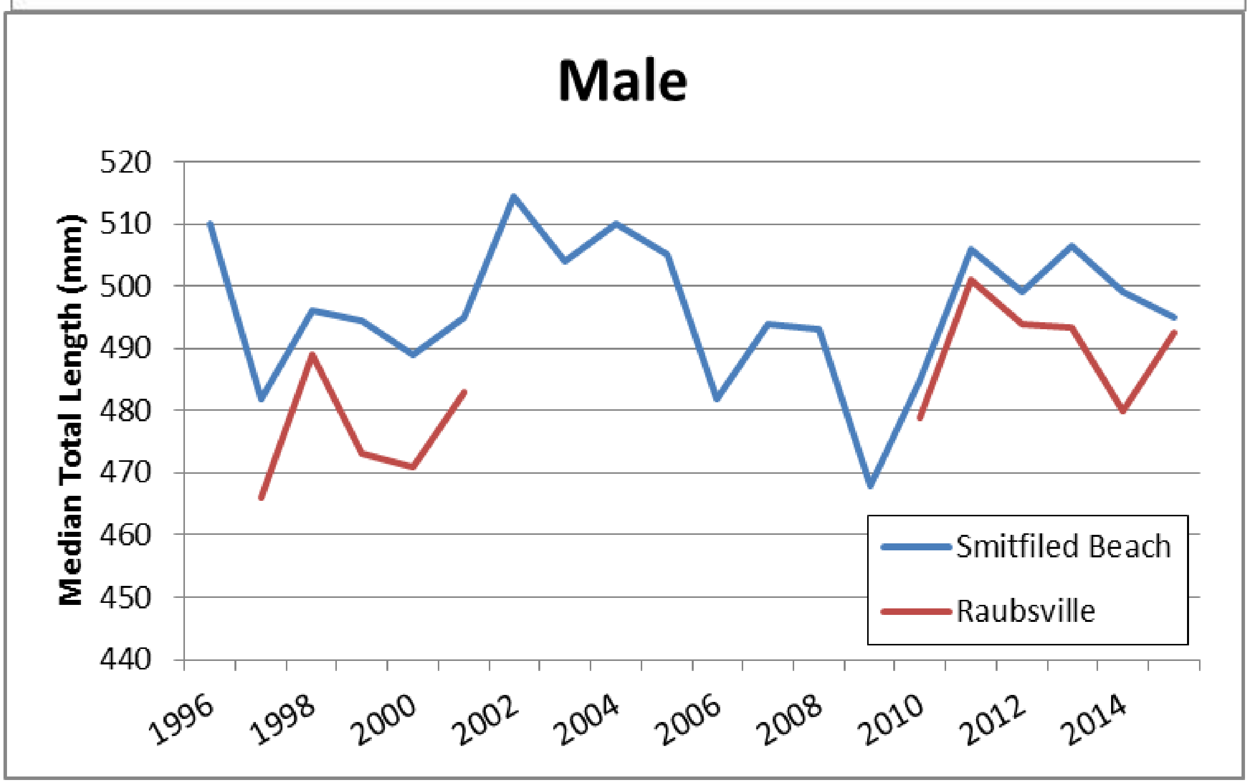


Figure 25. Median sizes (mm TL) of American Shad collected from Smithfield Beach (all mesh sizes combined) and Raubsville.

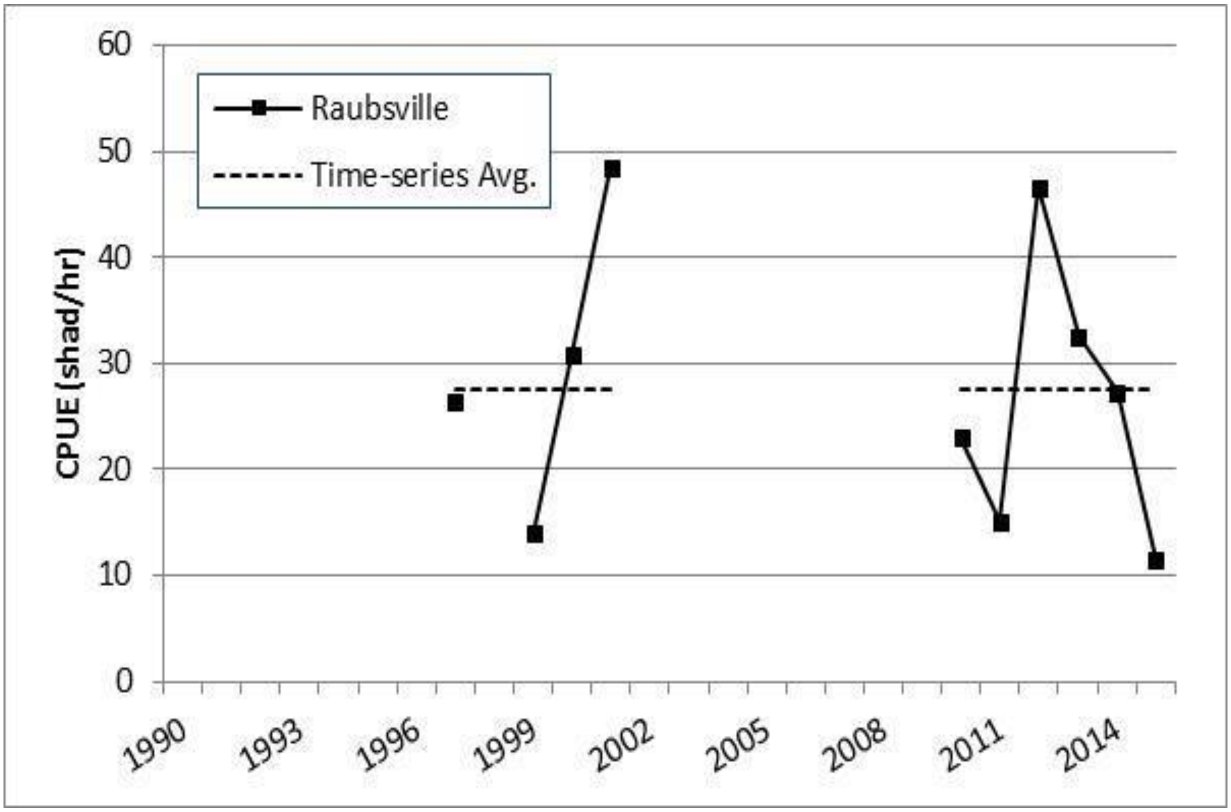


Figure 26. Raubsville electrofishing CPUE of American Shad.

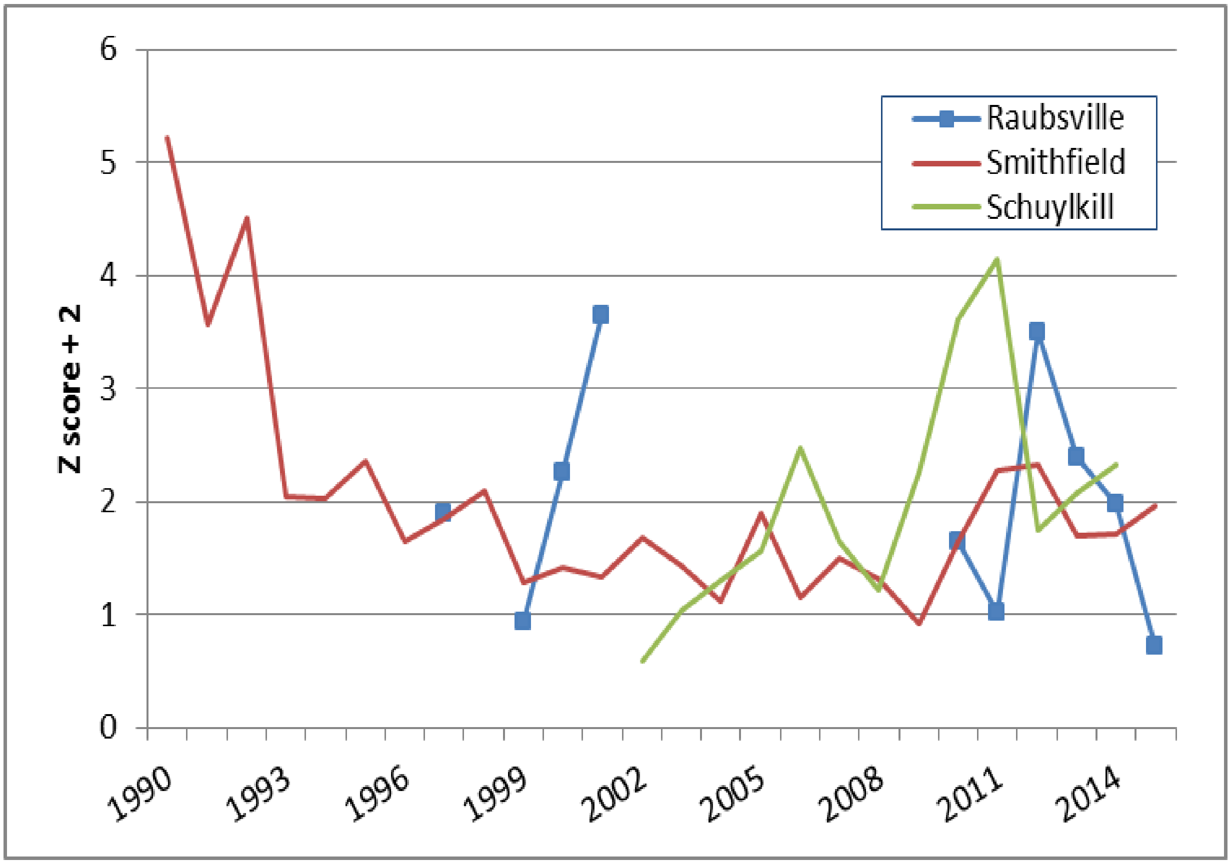


Figure 27. Comparison of CPUEs from monitoring programs at Smithfield Beach (i.e., gill netting) and Raubsville (i.e., electrofishing) on the main stem Delaware River; and CPUE from the tidal main stem of the Schuylkill River (i.e., electrofishing). Indices are represented as standardized Z scores plus two.

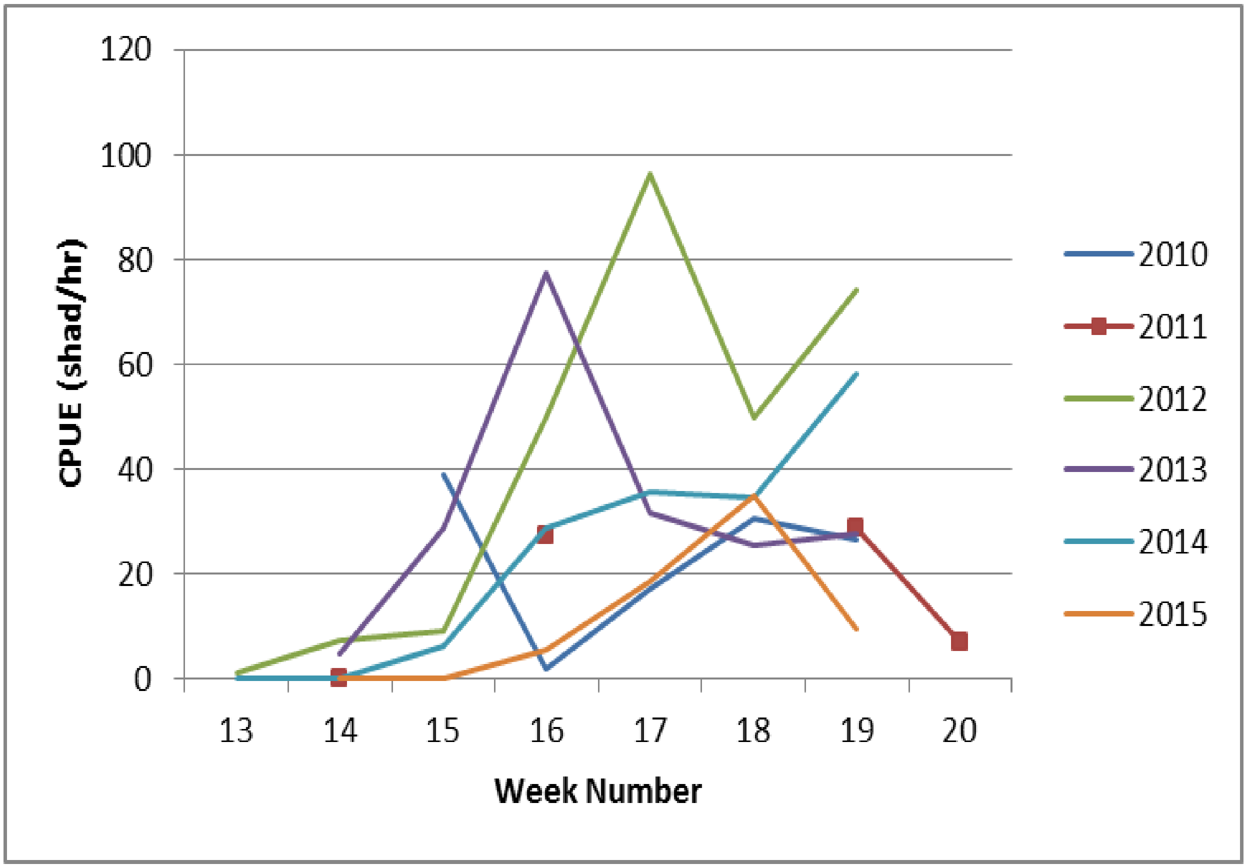


Figure 28. Weekly electrofishing CPUE estimates from the Raubsville monitoring. Week number is defined as the occurrence of January 1st as week one.

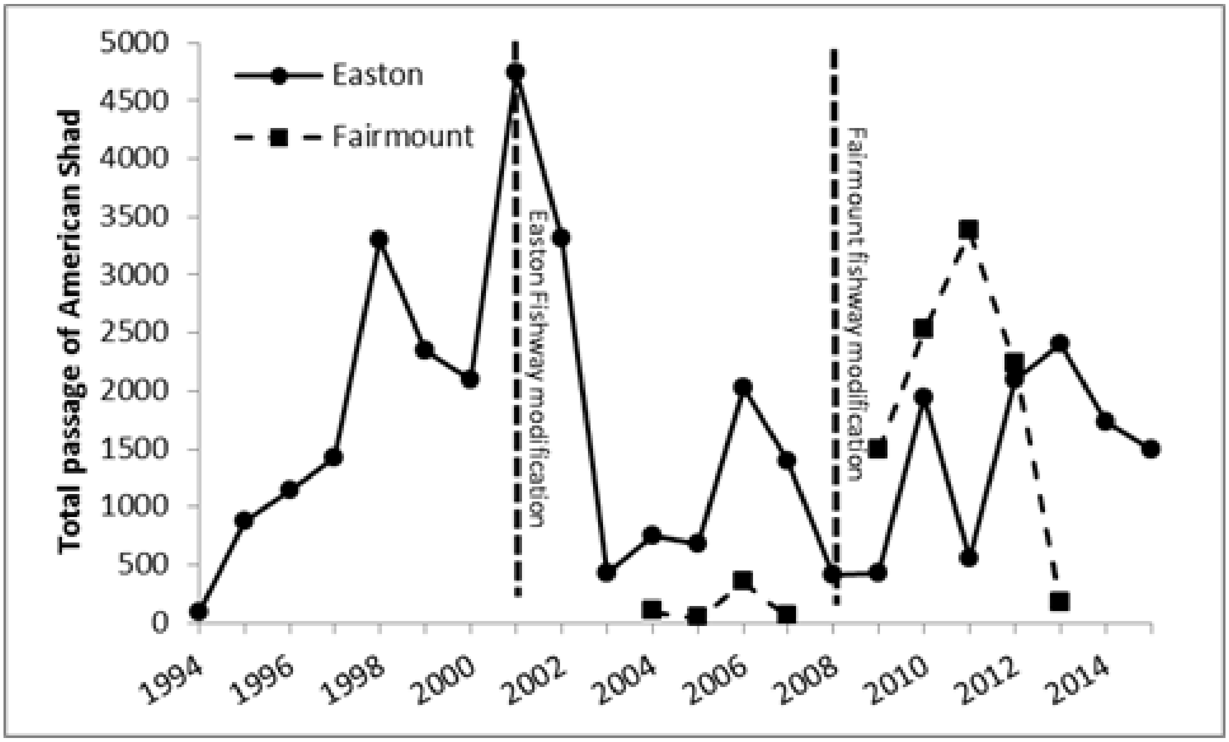


Figure 29. Upstream fish passage trends for the Lehigh (Easton Dam) and Schuylkill (Fairmount Dam) rivers. A predictive regression based on electrofishing CPUE was substituted for video surveillance beginning in 2013 for estimating total passage into the Lehigh River.

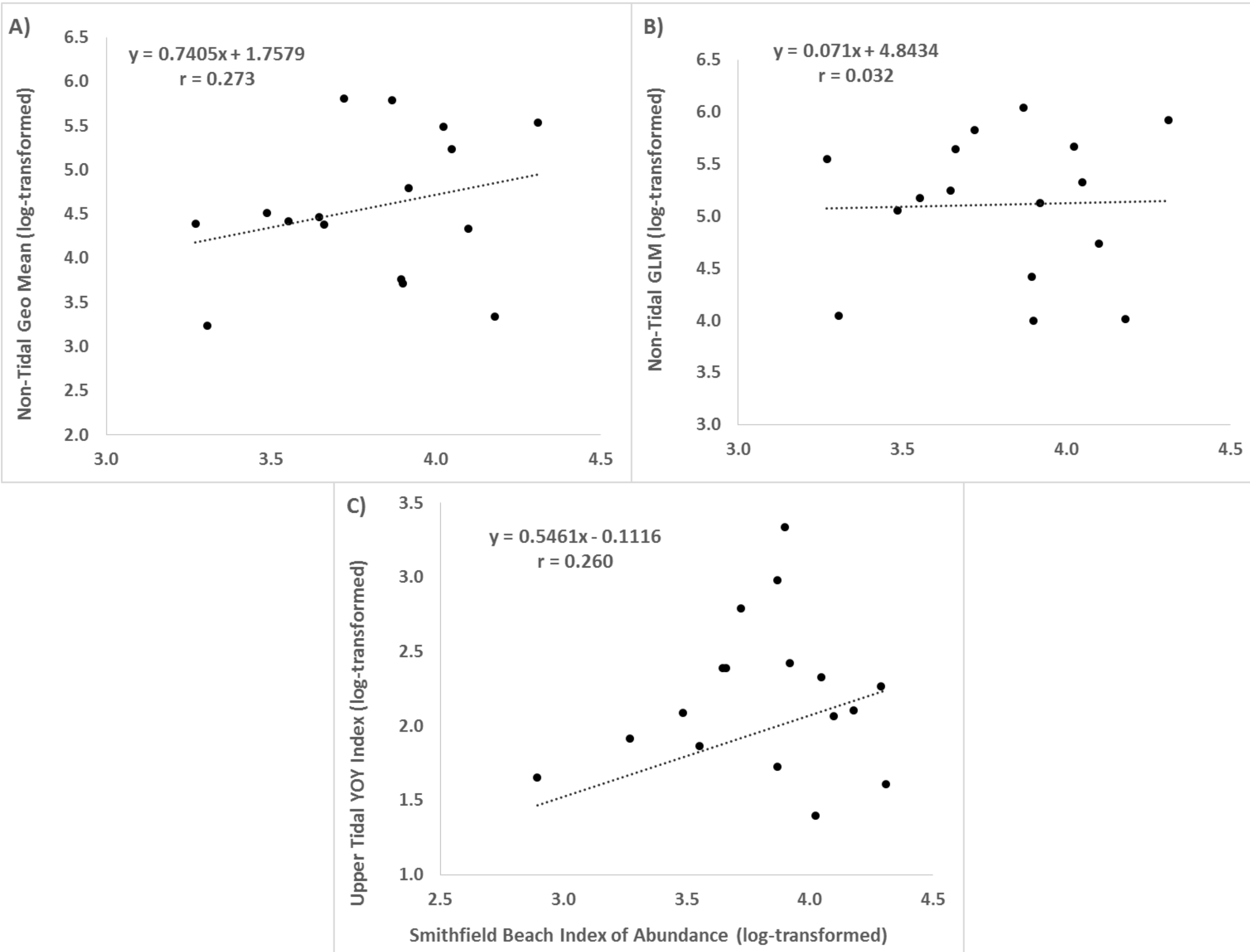


Figure 30. Correlations between the JAI indices (A – Non-tidal geometric mean; B – Non-tidal GLM; C – Tidal geometric mean) vs the Smithfield Beach Adult Index. All values are log-transformed.

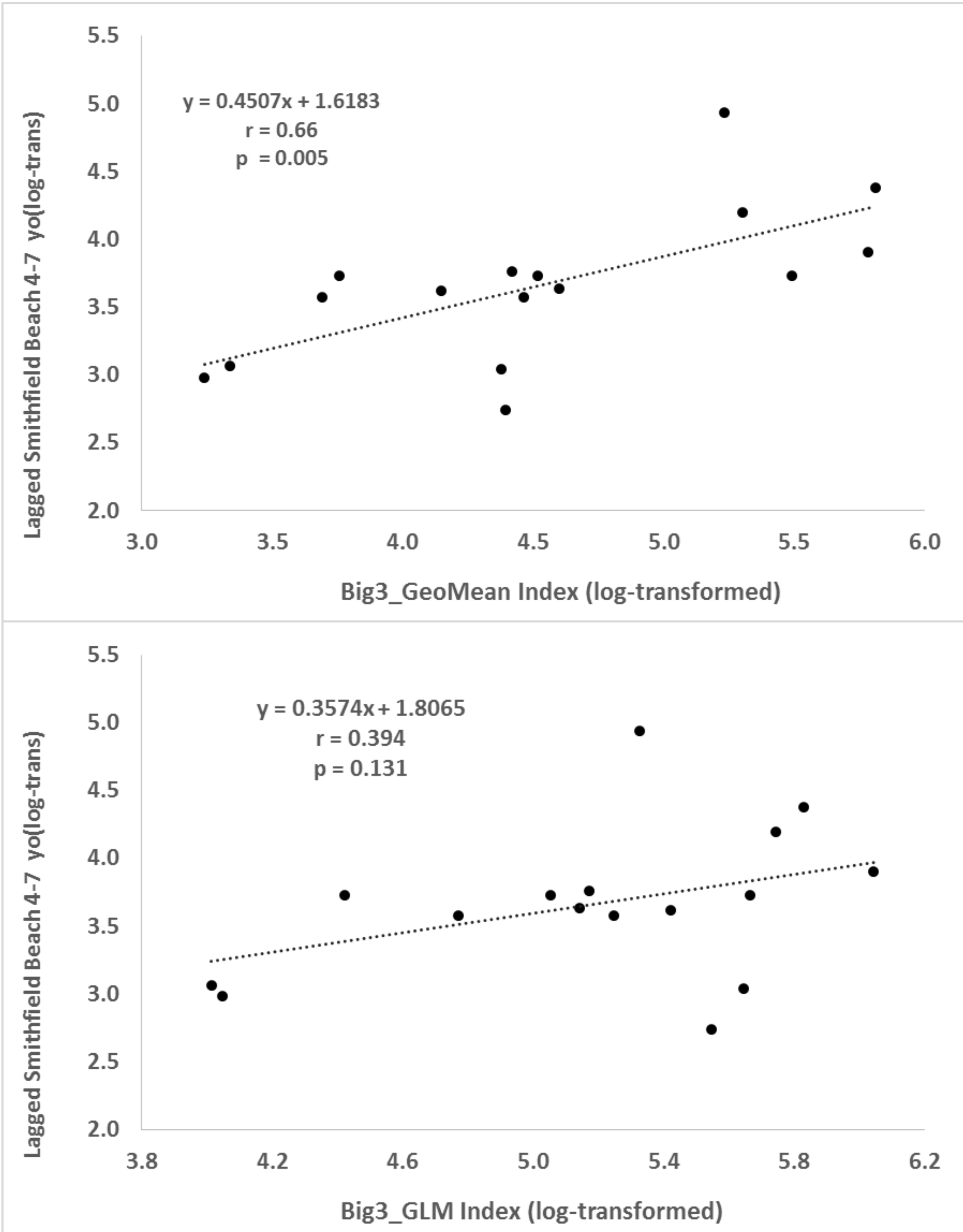


Figure 31. Correlations between the two non-tidal JAI indices vs the lagged Age 4-7 Index calculated from the Smithfield Beach Index. All values are log-transformed.

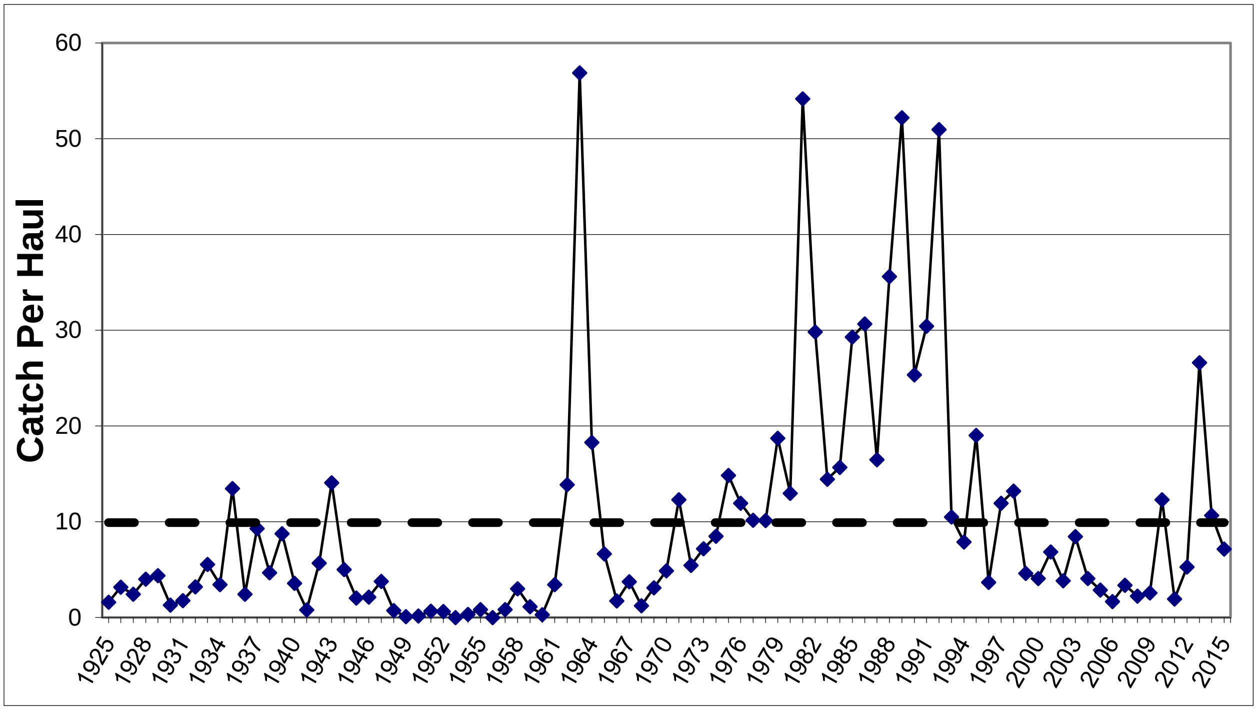


Figure 32. Lewis haul seine CPUE (shad/haul), 1925-2015. Dashed line represents the time series average.

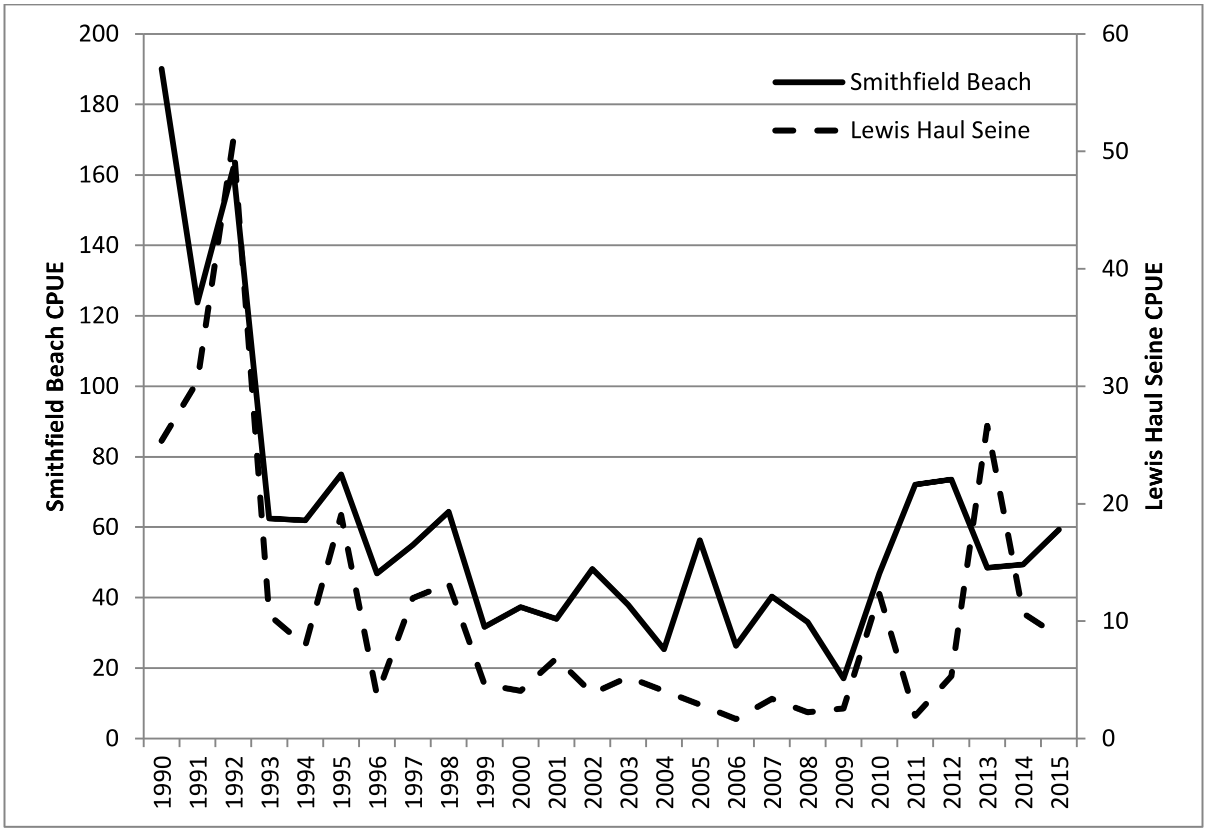


Figure 33. Trends in relative abundance as estimated from Smithfield Beach (shad/net-ft-hr*10,000) and Lewis haul seine (shad/haul), 1990-2015.

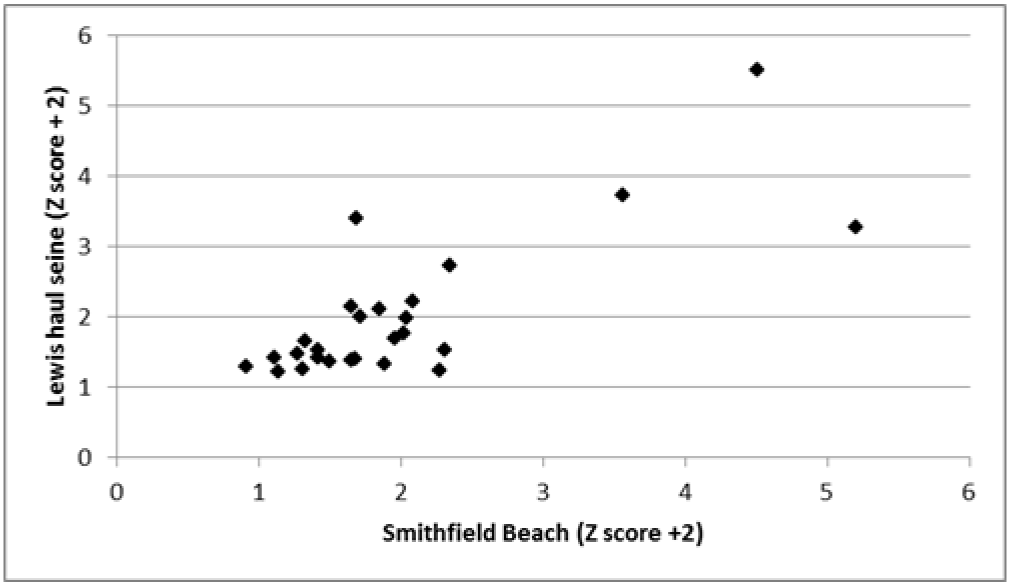


Figure 34. Correlation between Smithfield Beach and Lewis haul seine, 1990-2015.

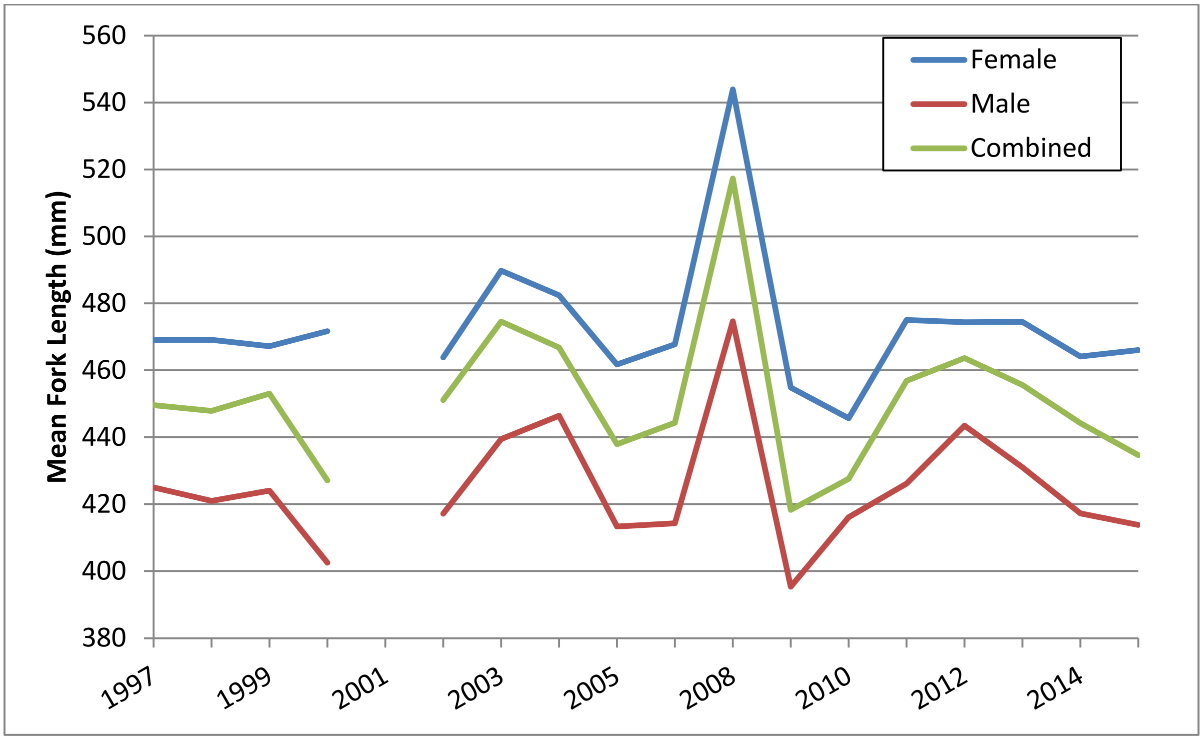


Figure 35. Mean fork lengths of male and female American Shad collected in the Lewis haul seine from 1997-2015.

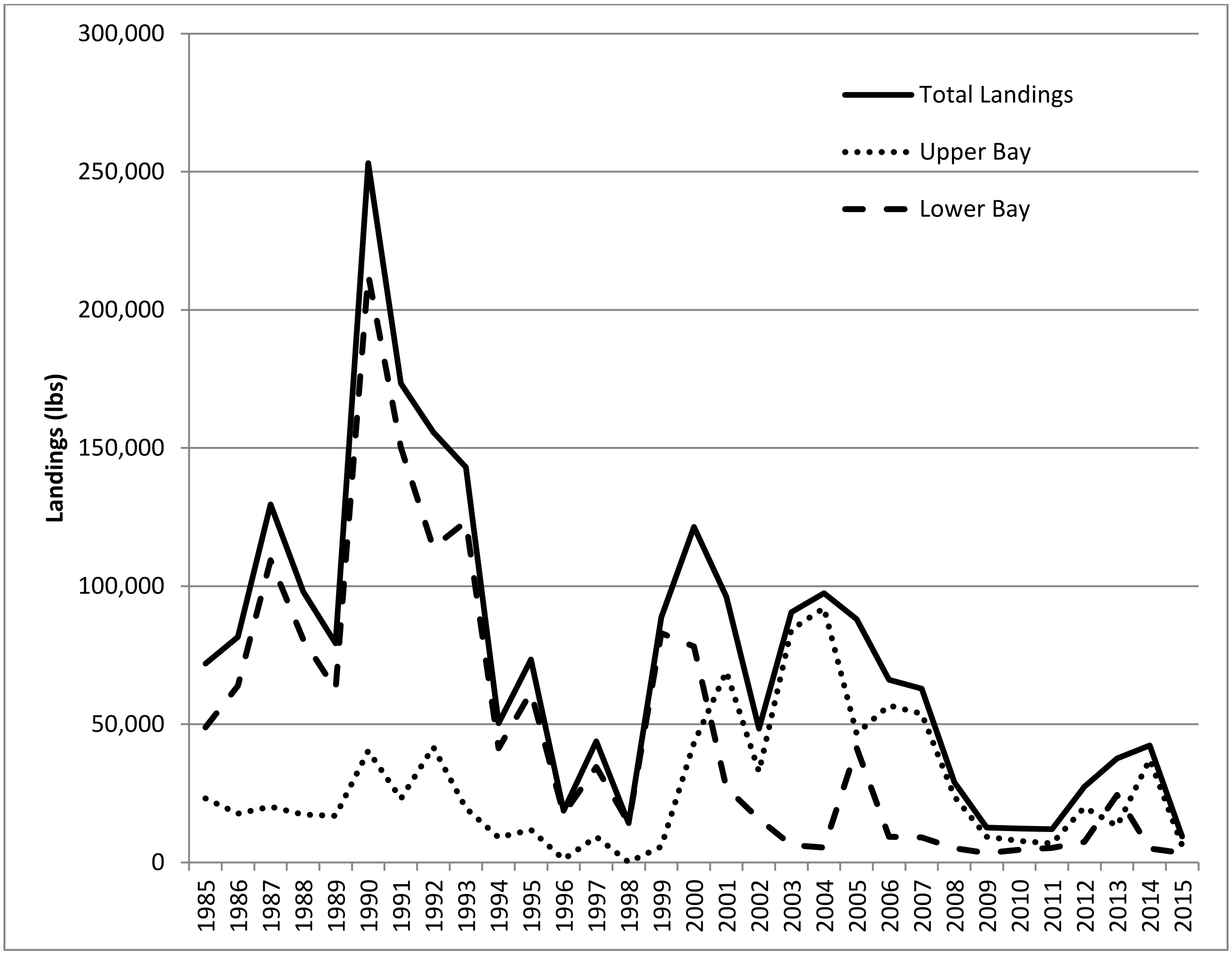


Figure 36. American Shad landings in the State of New Jersey separated into Upper Bay/River (north of Gandys Beach) and Lower Bay (south of Gandys Beach), reporting regions.

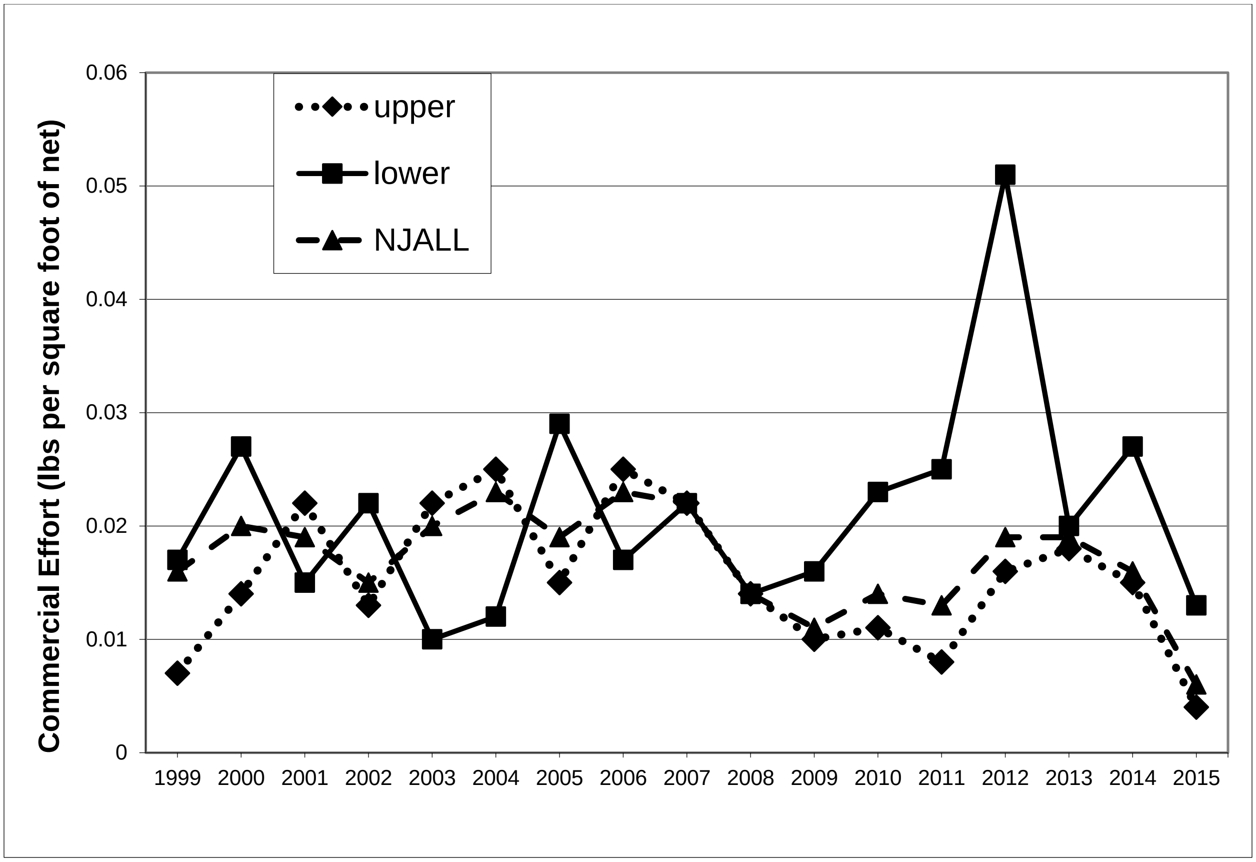


Figure 37. New Jersey commercial American Shad CPUE from 2000-2015. Effort is separated into Upper Bay/River (north of Gandys Beach) and Lower Bay (south of Gandys Beach), reporting regions.

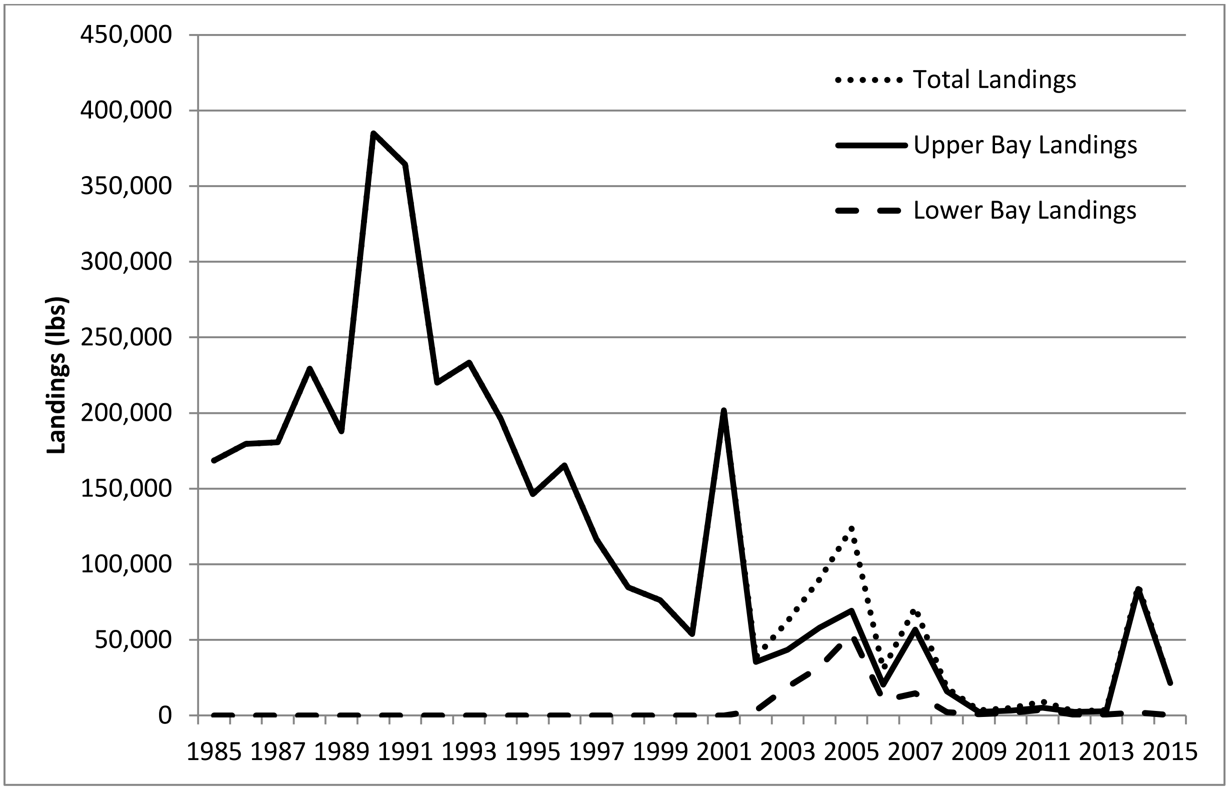


Figure 38. American Shad landings in the State of Delaware separated into upper bay (north of Bowers Beach) and lower bay (south of Bowers Beach), reporting regions.

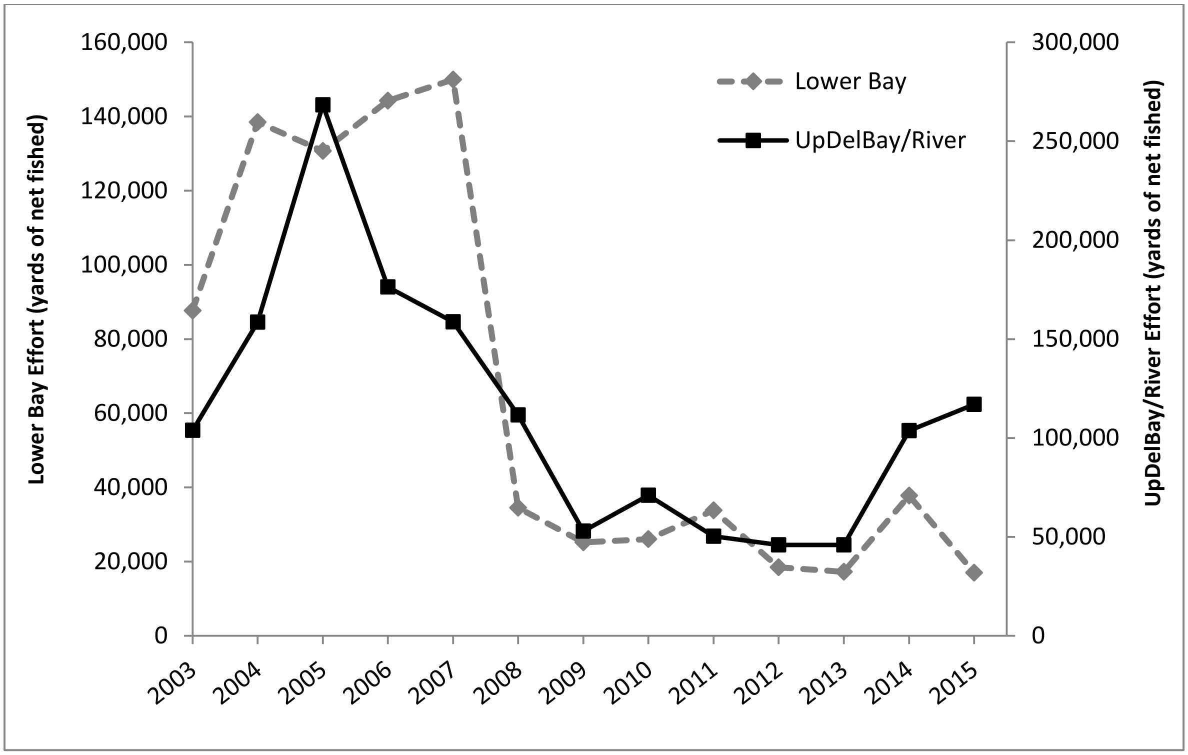


Figure 39. State of Delaware commercial fishery effort in yards of net fished for the Delaware River and Bay (1990-2015). Effort was separated into upper bay (north of Bowers Beach) and lower bay (south of Bowers Beach), reporting regions.

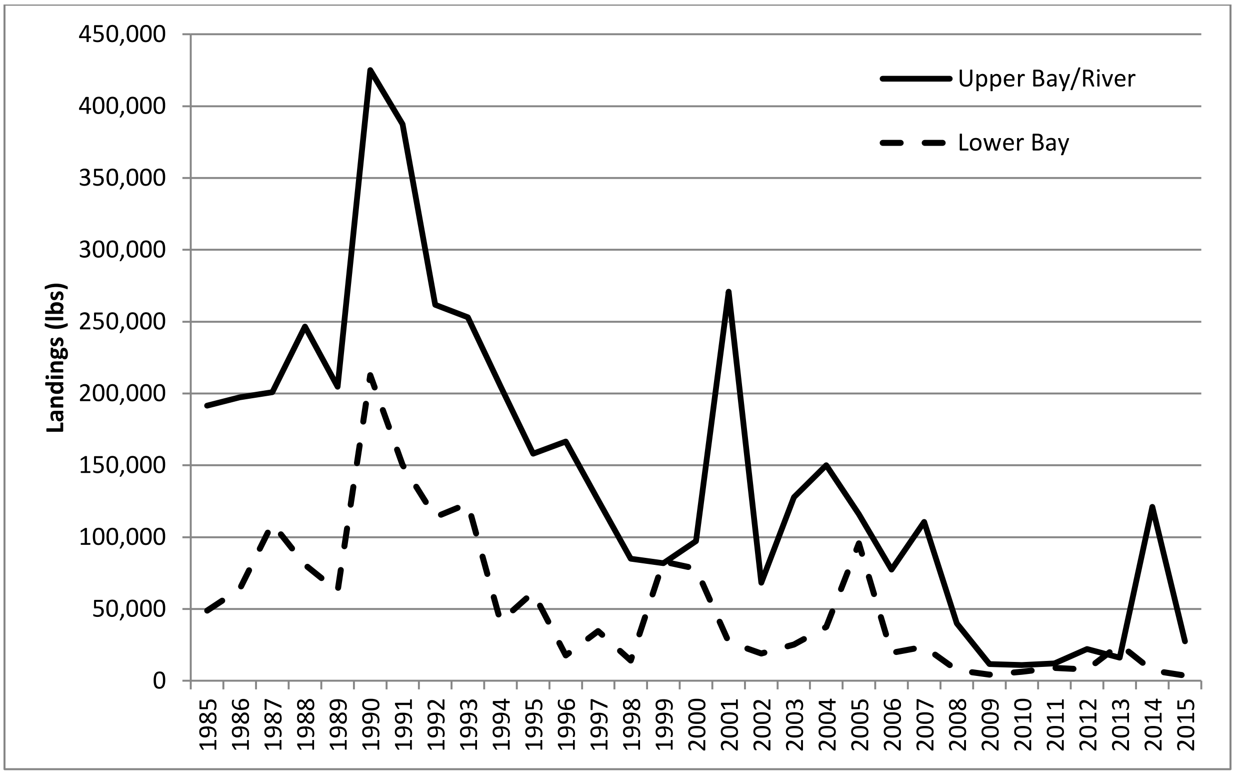


Figure 40. Combined landings for American Shad commercial harvest for the states of Delaware and New Jersey: 1985-2015. The Upper Bay / River is defined by those landings occurring above the Bowers Beach, DE to Gandys Beach, NJ. Lower Bay is defined by those landings occurring below that line.

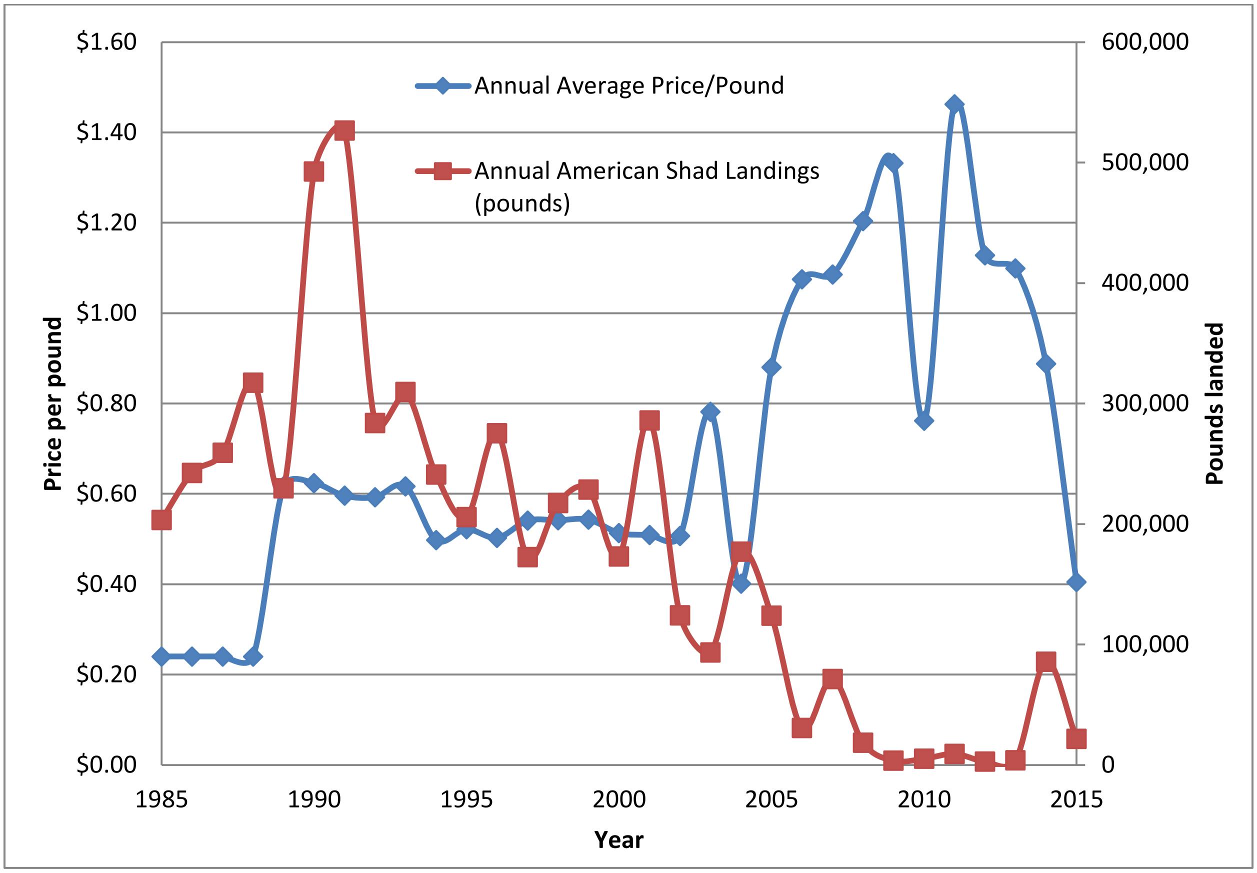


Figure 41. Pounds landed and market value for American Shad landed in the State of Delaware from 1985-2015.

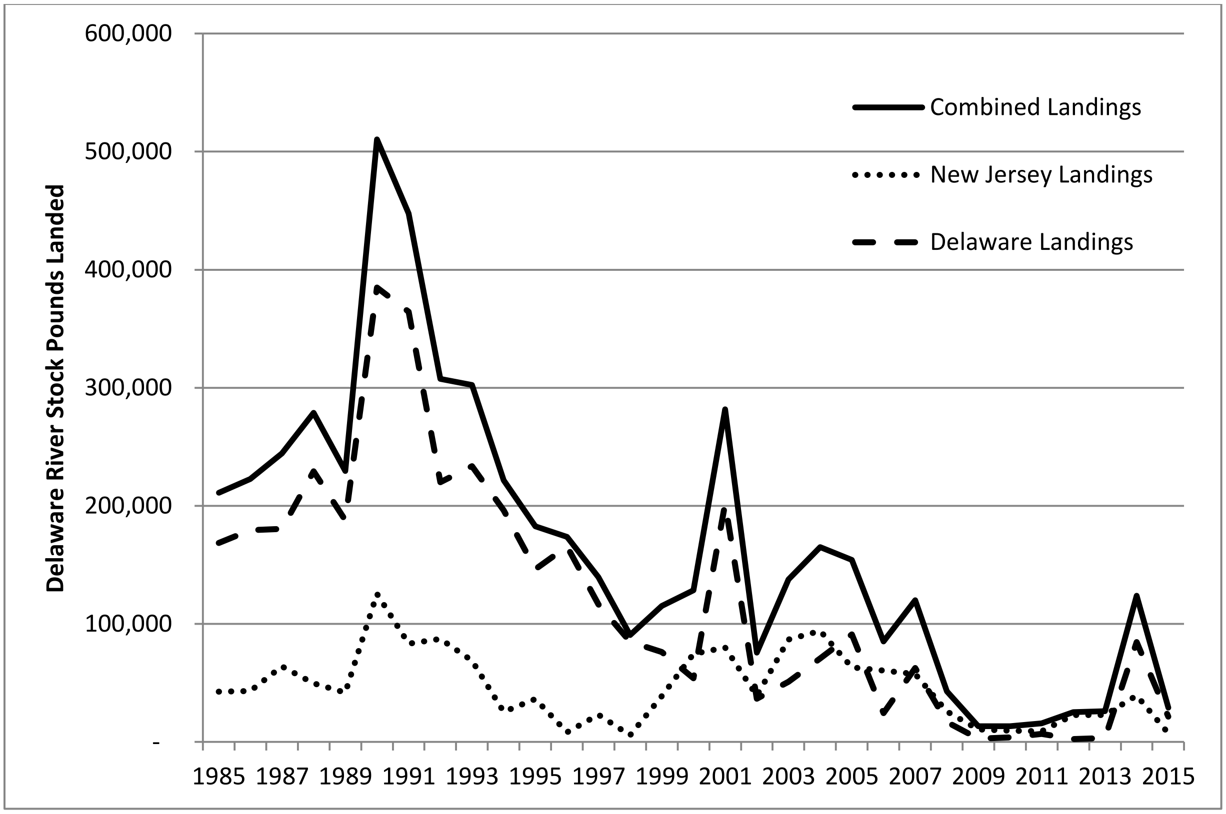


Figure 42. Pounds of Delaware River stock American Shad landed in the Delaware Bay.

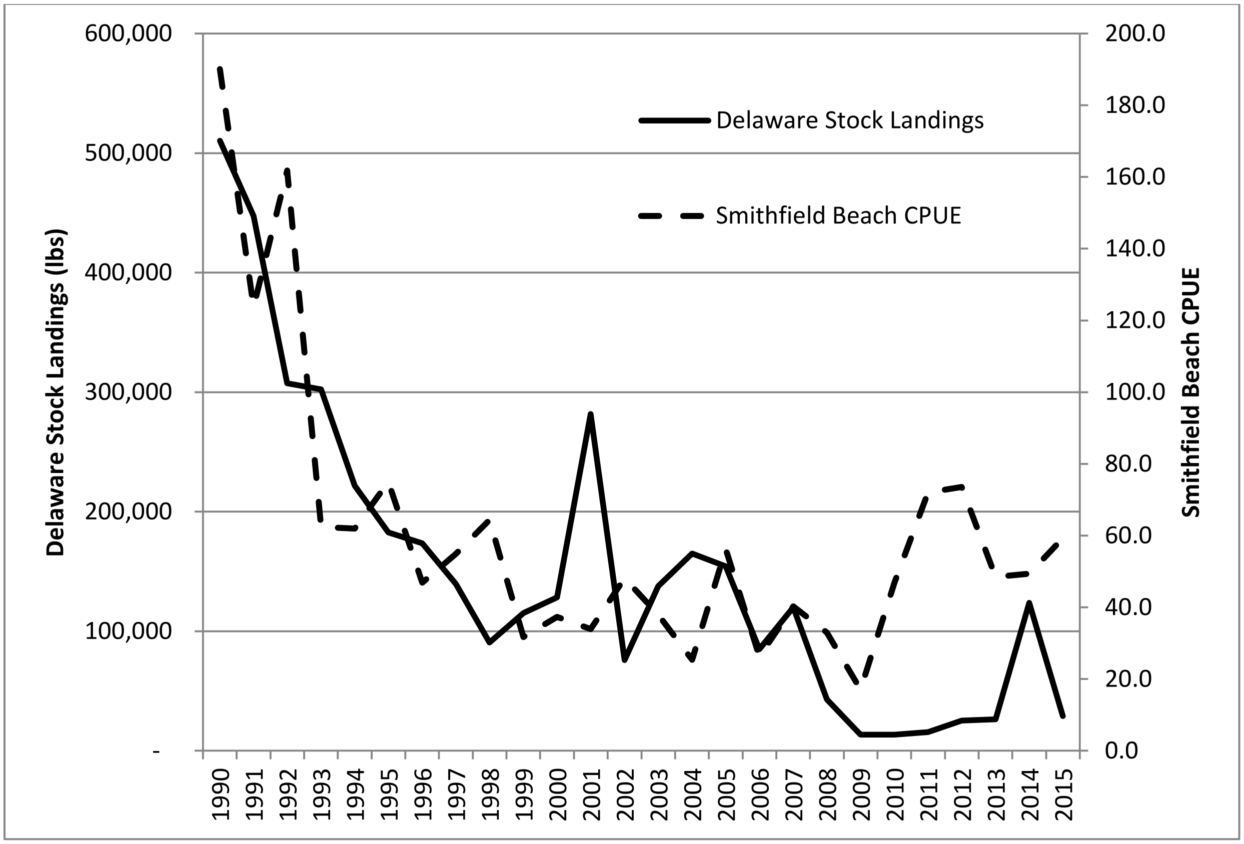


Figure 43. Comparison of trends between Delaware River stock landings and Smithfield Beach CPUE.

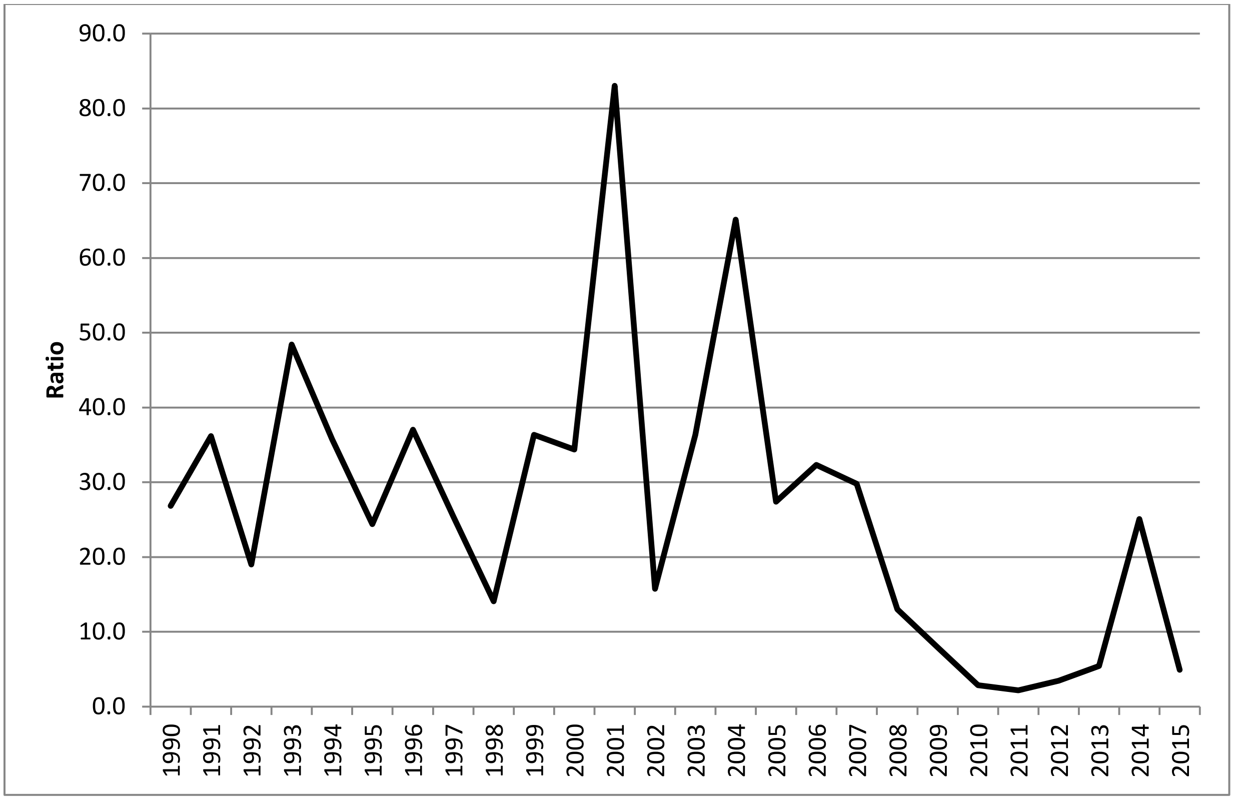


Figure 44. Ratio of Delaware River stock landings divided by Smithfield Beach CPUE (divided by 100). Early Period (NMFS estimations) is defined as 1990-1999, Late Period (mandatory reporting) is defined as 2000-2015.

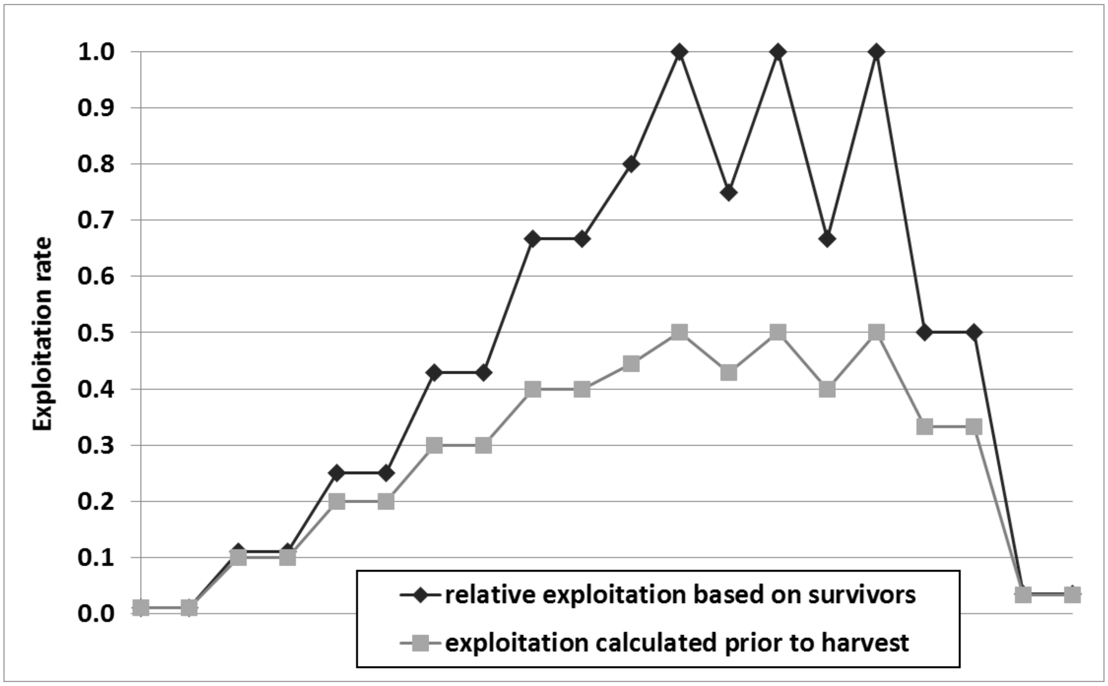


Figure 45. Comparison of exploitation rates based on the population prior to harvest (pop) and on survivors following harvest (survivors).

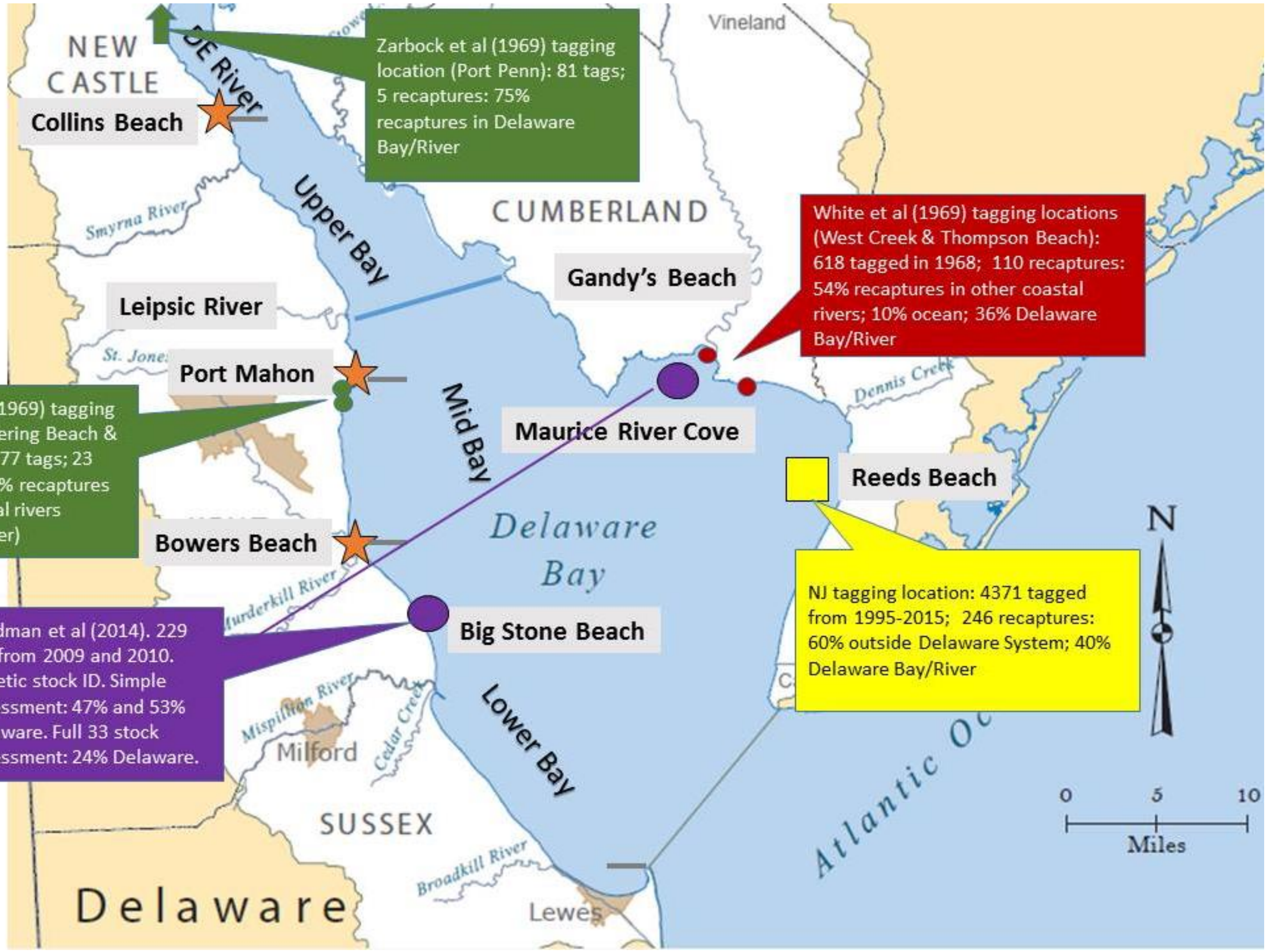


Figure 46. Map of the lower Delaware River and Bay, delineating harvest reporting regions for Delaware (orange), location of recent tag releases (yellow), location of historic tag releases (red and green), location of genetics studies (purple) and delineation line listed in 2012 SFP (blue).

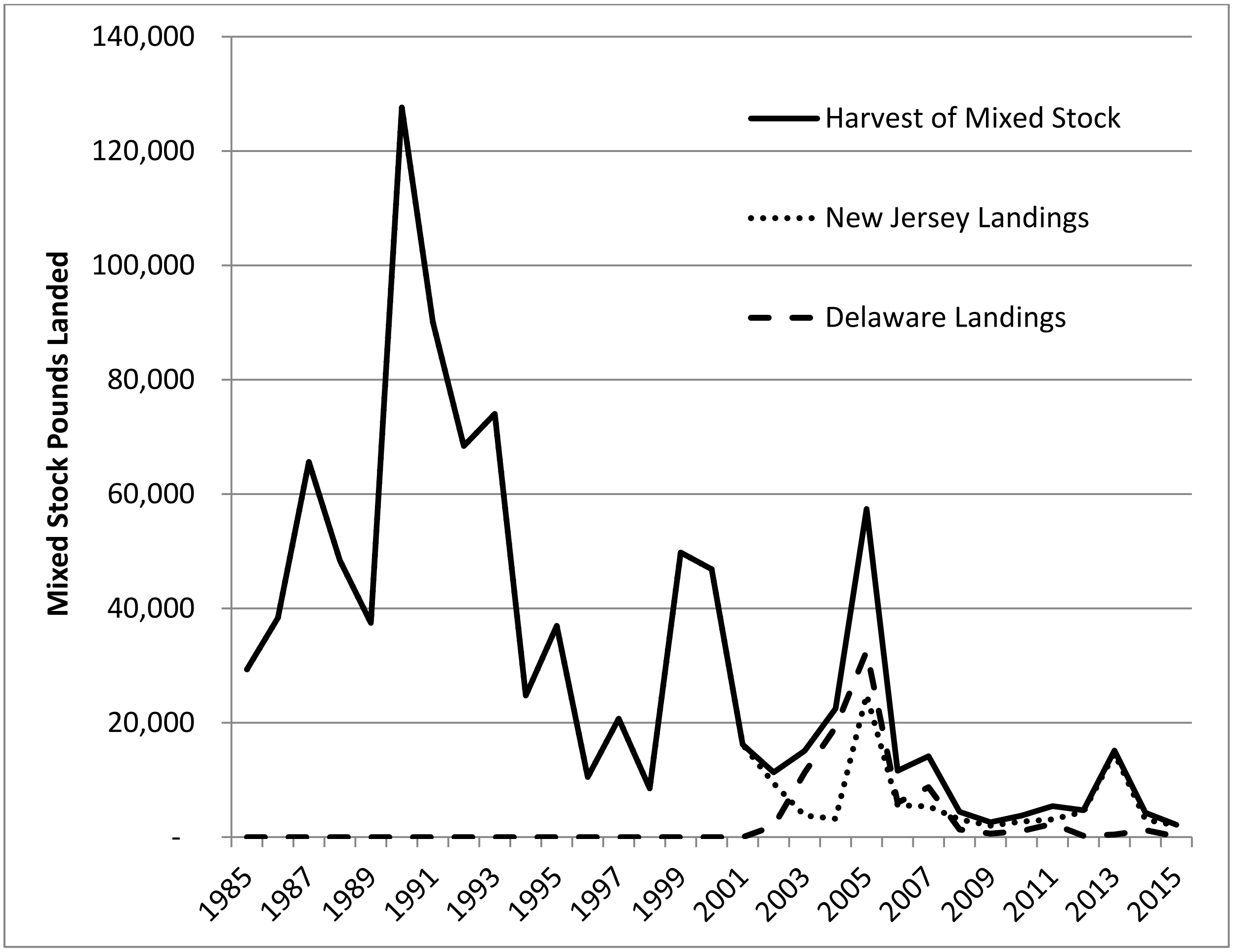


Figure 47. Pounds of mixed stock American Shad landed in the Delaware Bay. New Jersey represented 100% of the landings from 1985 to 2001.

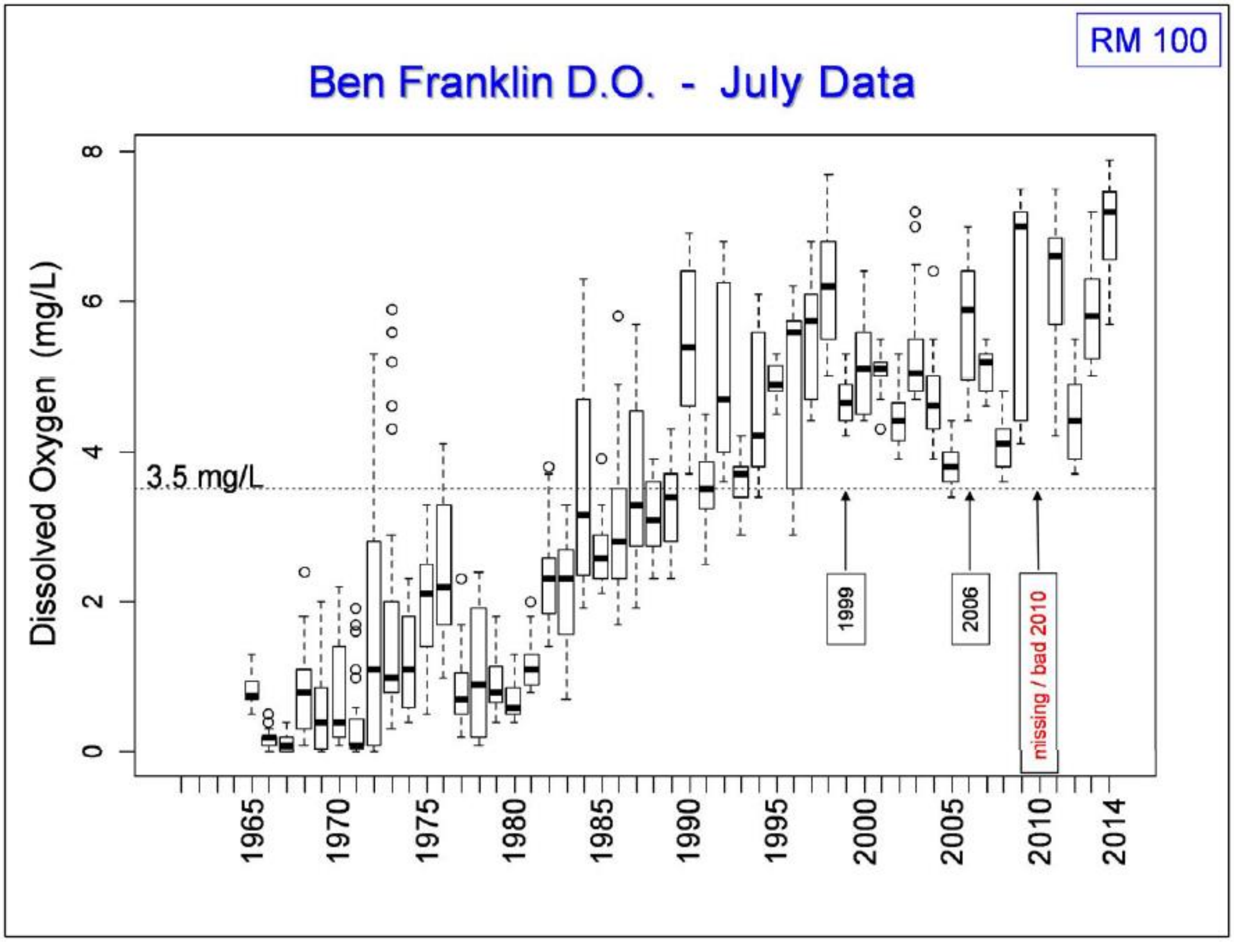


Figure 48. Box and whisker plot of dissolved oxygen concentrations during July, 1965-2014 at the Ben Franklin Bridge (RM 100). Data available at *waterdata.usgs.gov.*

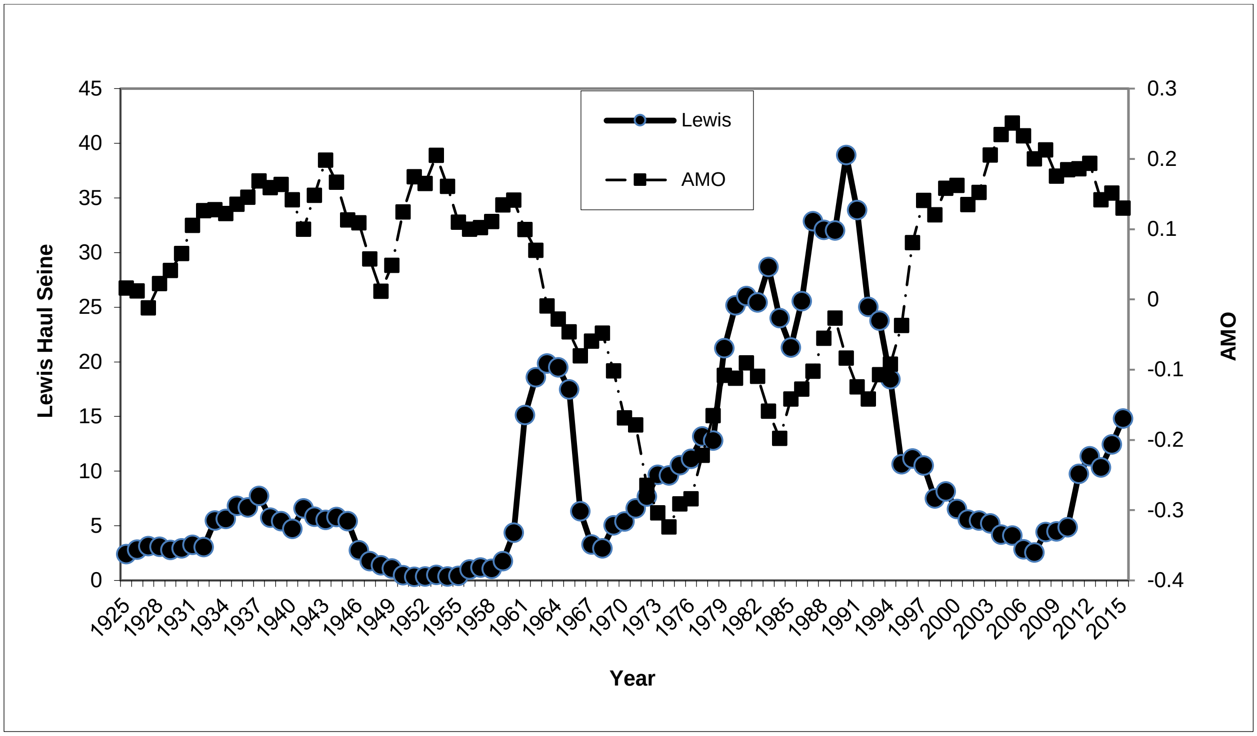


Figure 49. Five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Lewis haul seine CPUE: 1925 - 2015.

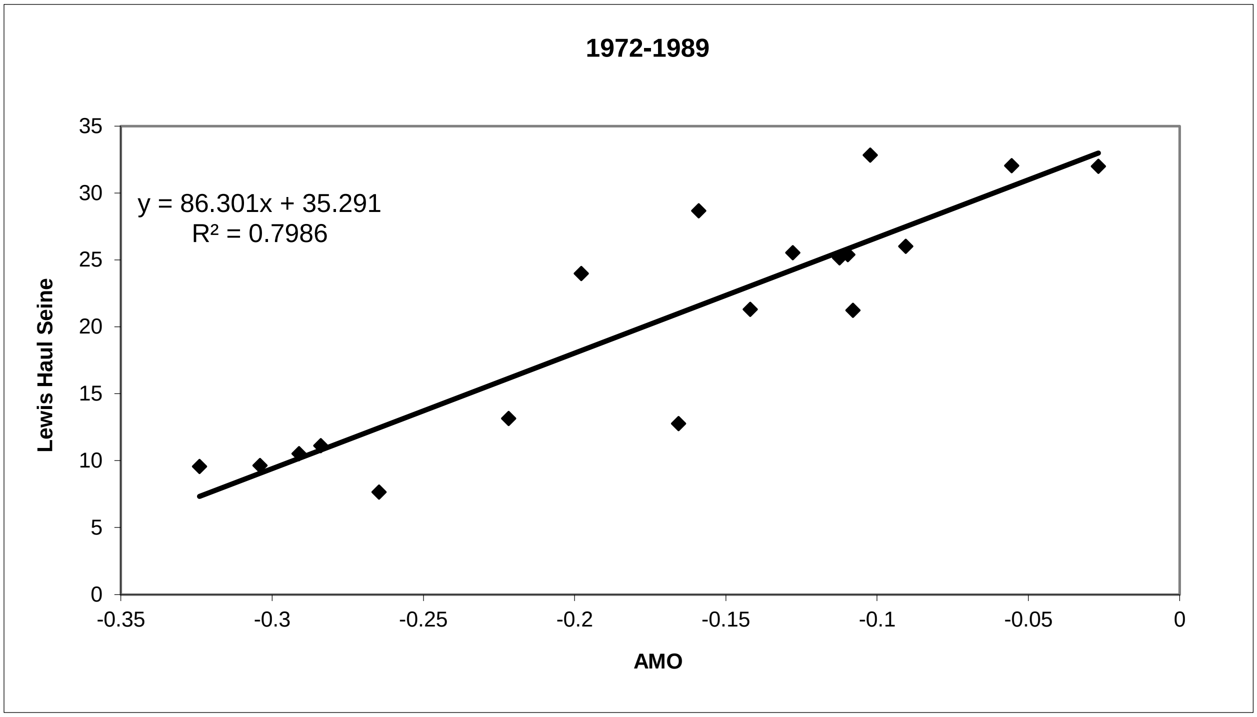


Figure 50. Scatter plot of the five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Lewis haul seine CPUE: 1972 - 1989.

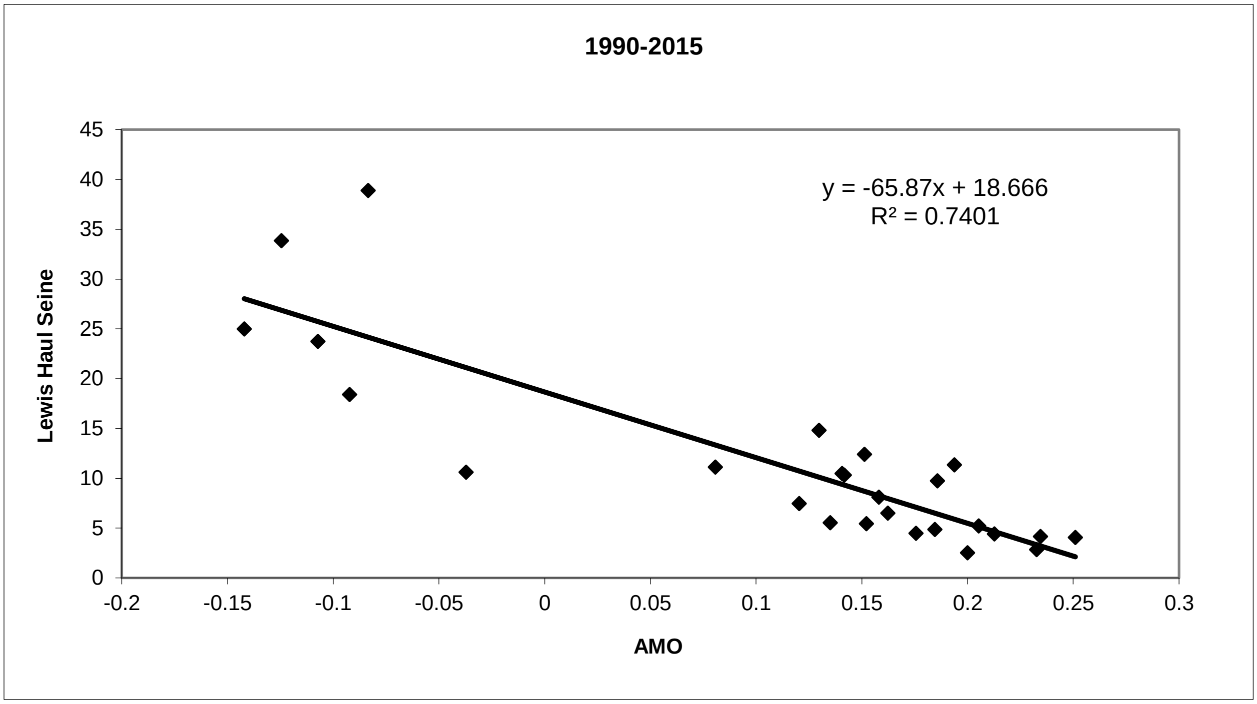


Figure 51. Scatter plot of the five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Lewis haul seine CPUE: 1990 - 2015.

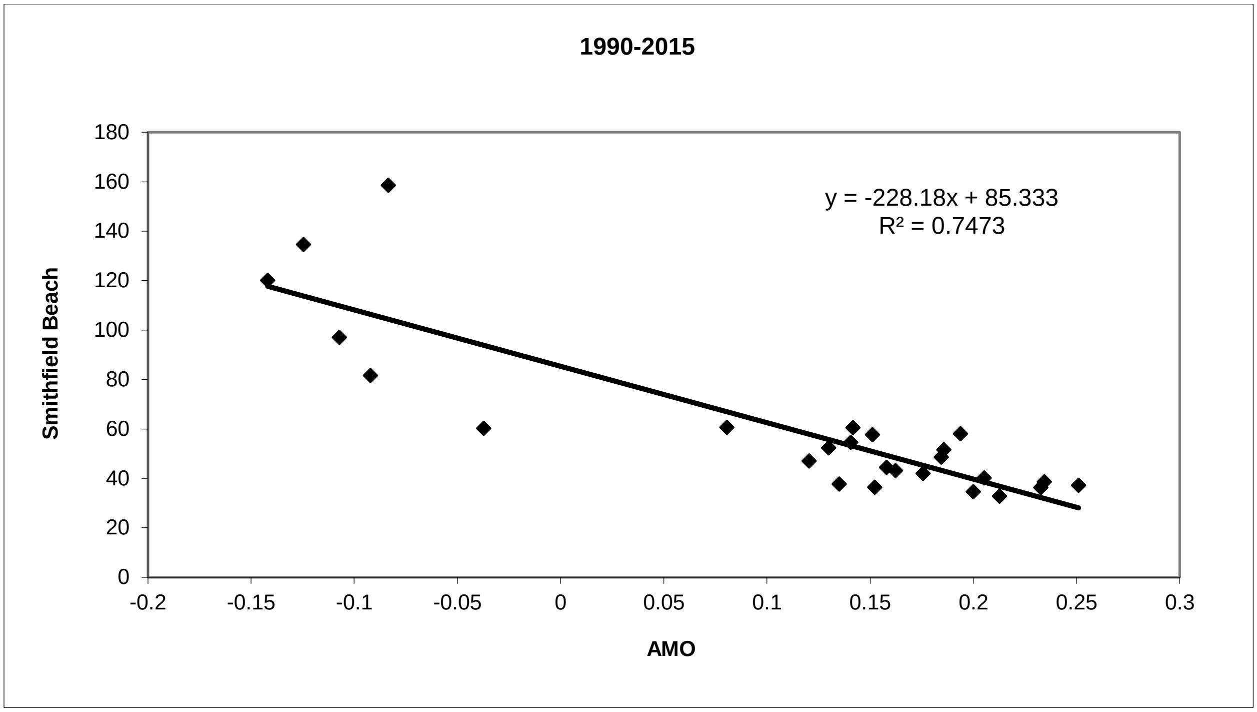


Figure 52. Scatter plot of the five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Smithfield Beach CPUE: 1990 - 2015.

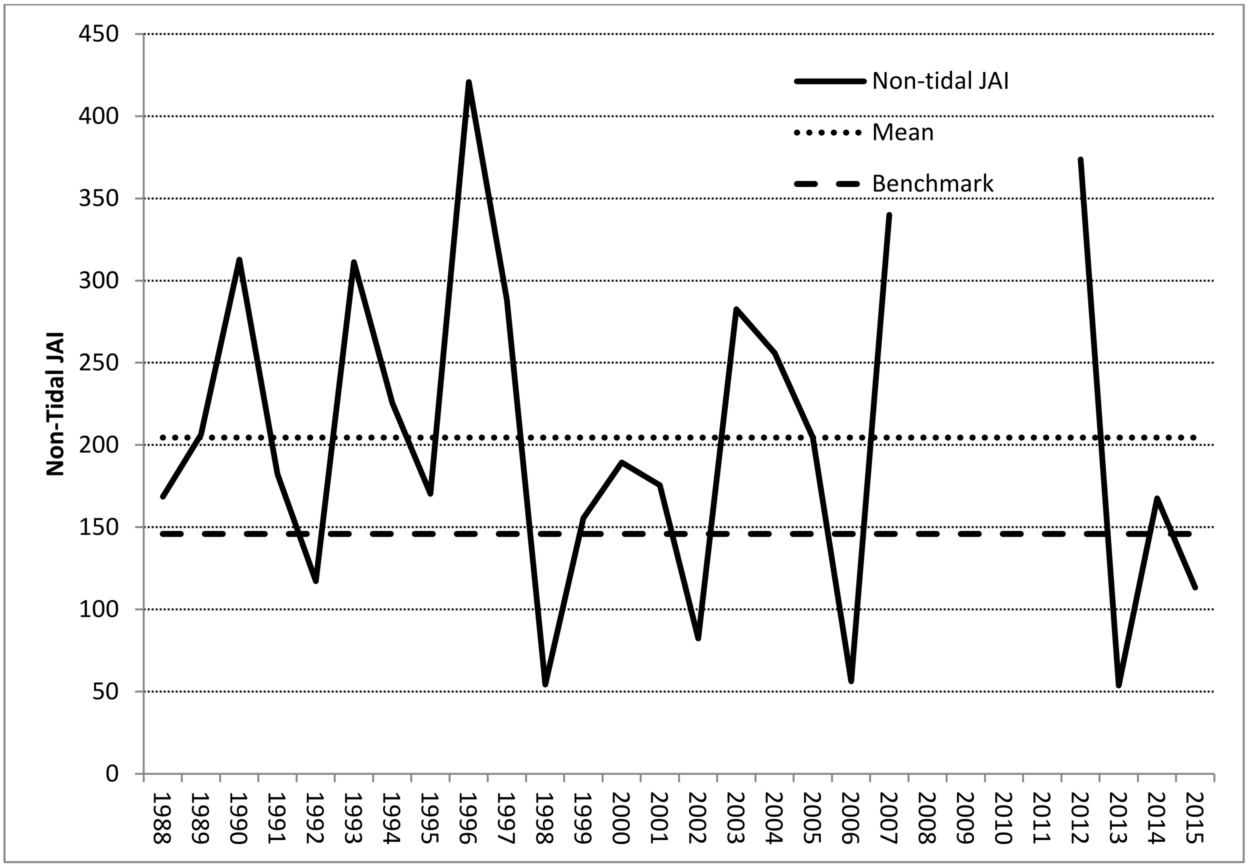


Figure 53. The Delaware River non-tidal American Shad JAI (GLM) with a 25th percentile benchmark: 1987 – 2015. The GLM estimates are based on catches only from the Big 3 sites (i.e., Phillipsburg, Delaware Water Gap and Milford Beach). Note that the benchmark value may change annually based on updated GLM analysis.

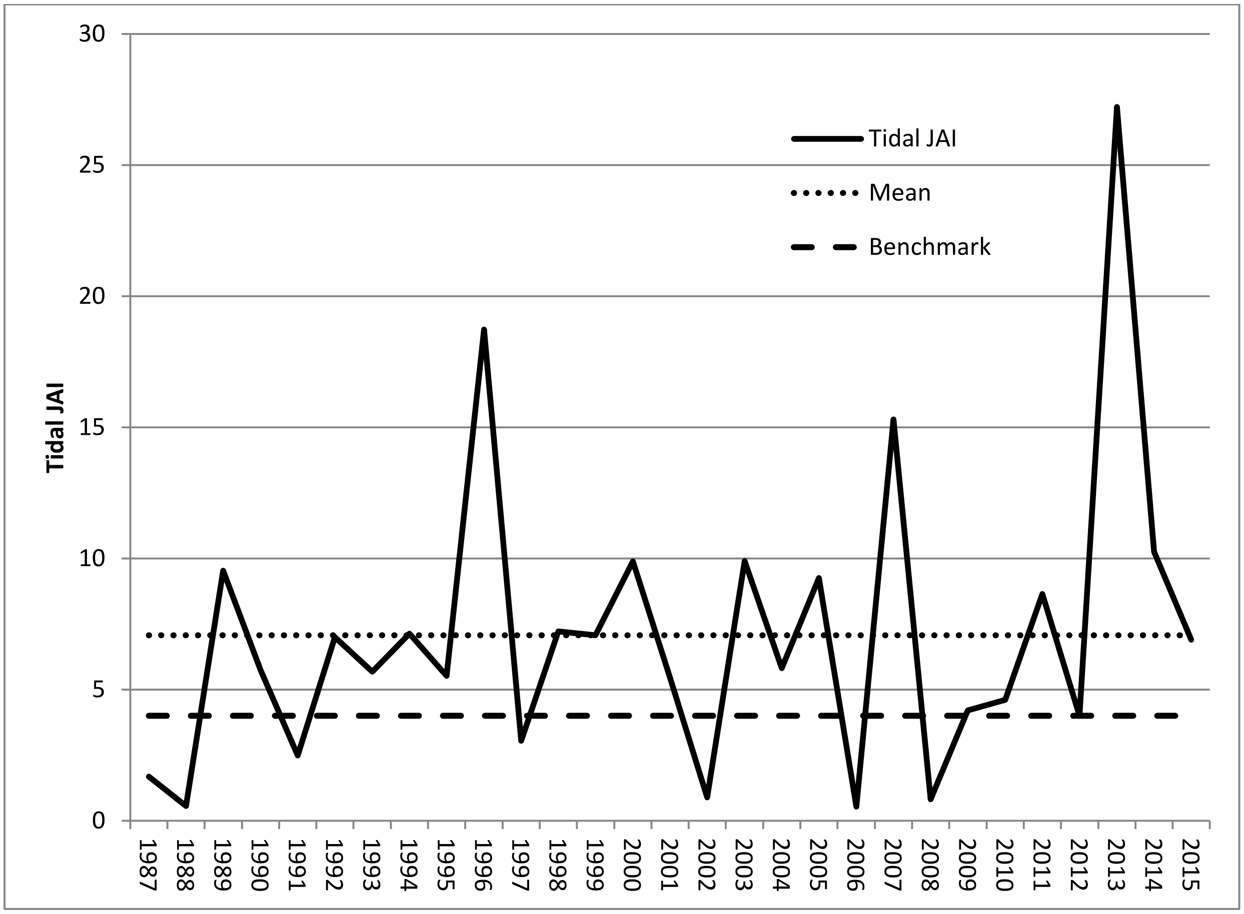


Figure 54. The Delaware River tidal American Shad JAI (GM) with a 25th percentile benchmark: 1987 – 2015. The GM values are based on catches from Region 2 and 3 of the NJDFW tidal seine sites.

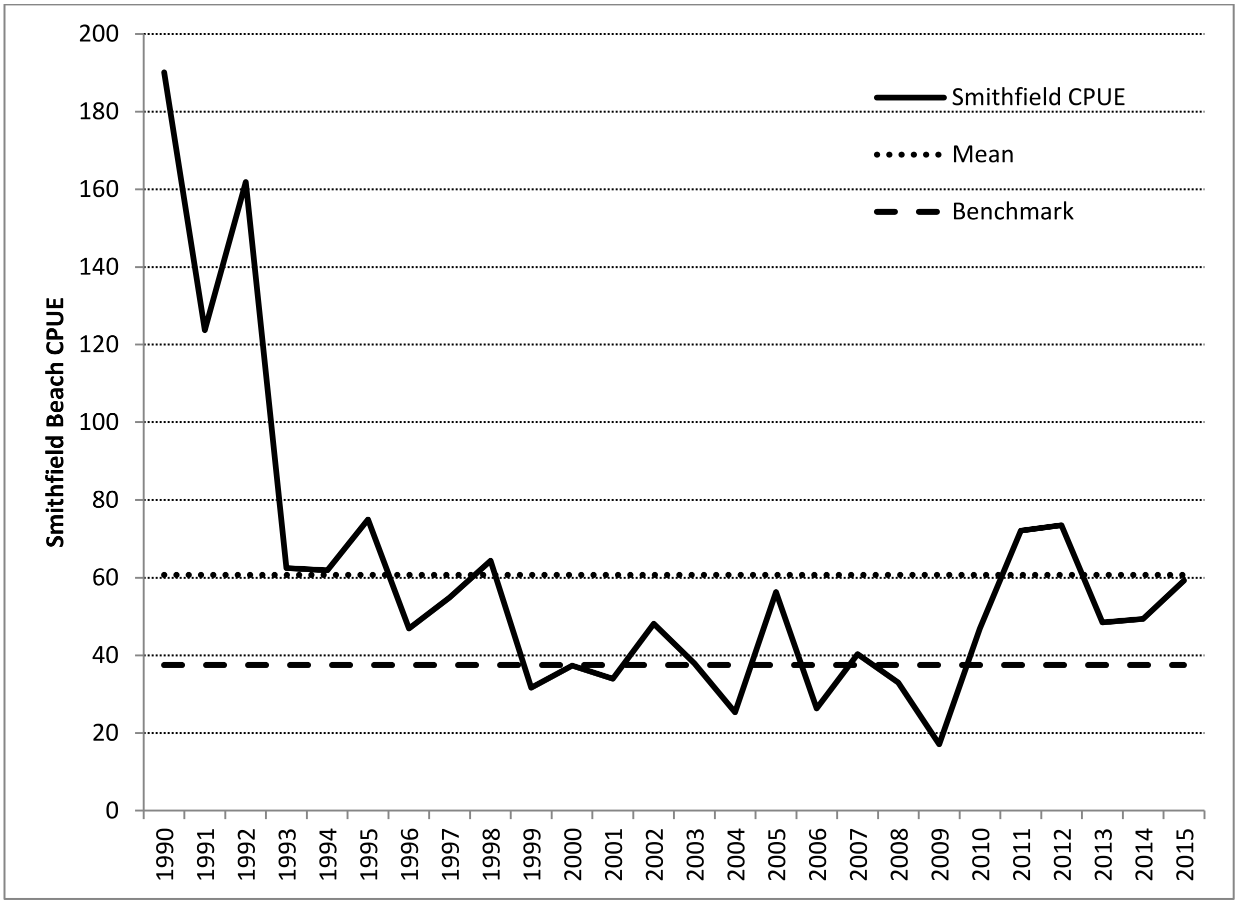


Figure 55. The Delaware River spawning adult American Shad index at Smithfield Beach (RM 218) with a 25th percentile benchmark: 1990 – 2015.

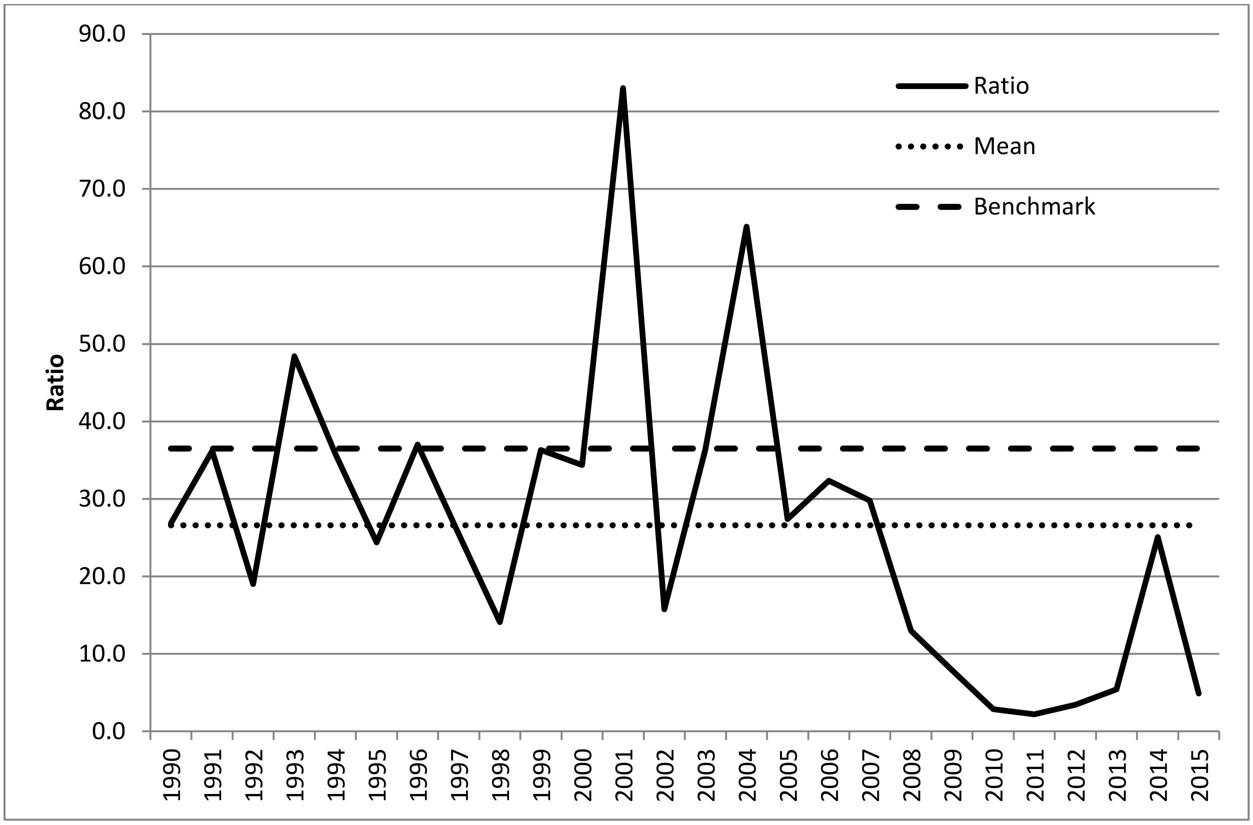


Figure 56. Ratio of Delaware River stock landings divided by Smithfield Beach CPUE (divided by 100) with an 85th percentile benchmark: 1990-2015.

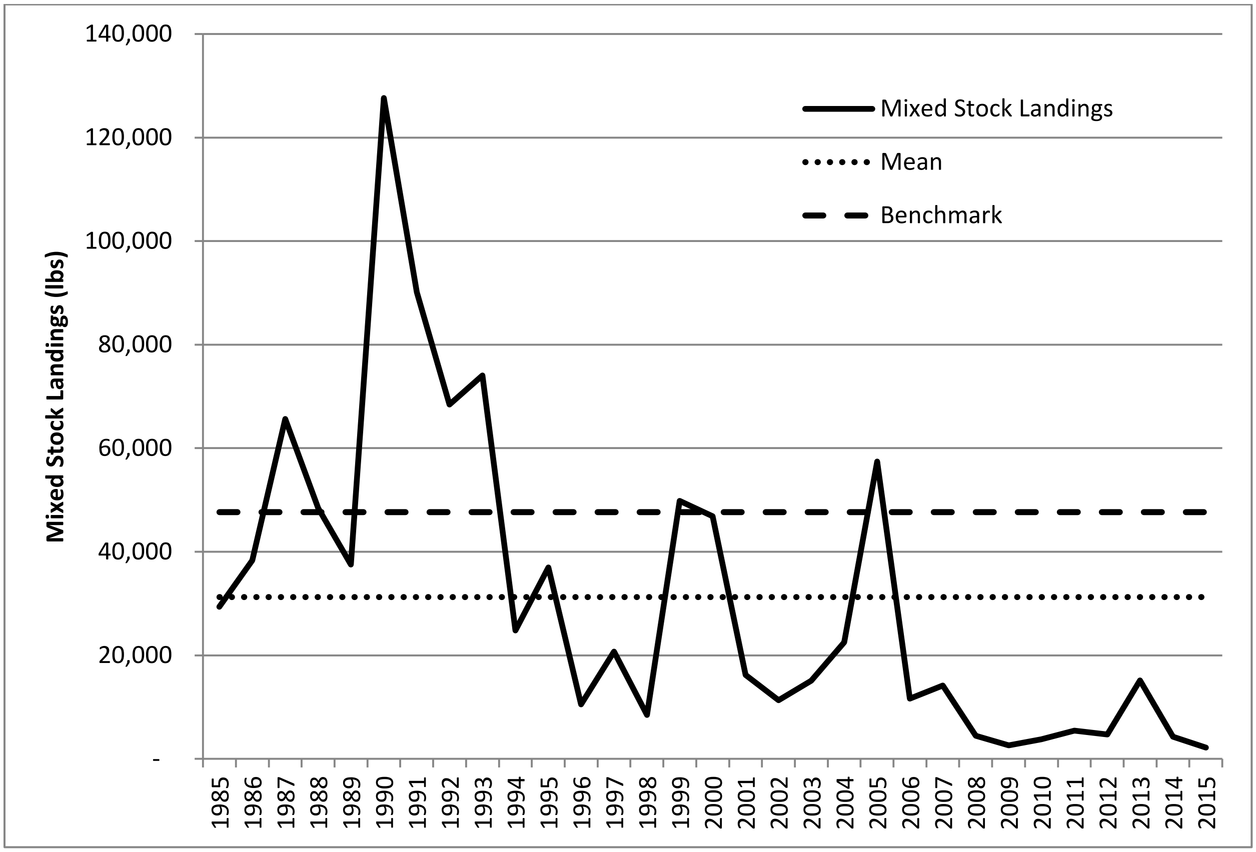


Figure 57. Landings in the Delaware Bay from the mixed stock fishery with a 75th percentile benchmark: 1990-2015.

10. Tables

Table 1. Total catch (N) of YOY American Shad collected during the 2015 synoptic exploratory surveys in the upper Delaware River.

		Fyke		Beach seine			
Site	Visual	Upper	Lower	Haul 1	Haul 2	Haul 3	Haul 4
	July						
Skinners Falls	0	N/A	N/A	47	95	9	4
Buckingham	N/A	N/A	N/A	0	0	0	0
Balls Eddy	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fireman's Launch	0	N/A	N/A	0	0	0	0
	August						
Skinners Falls	100+	0	0	2	9	29	21
Buckingham	0	0	0	N/A	N/A	N/A	N/A
Balls Eddy	0	0	0	0	0	0	0
Fireman's Launch	0	0	0	0	0	0	0
	September						
Skinners Falls	100+	N/A	N/A	0	1	13	14
Buckingham	N/A	N/A	N/A	0	1	0	0
Balls Eddy	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fireman's Launch	0	N/A	N/A	0	8	0	3
	October						
Skinners Falls	N/A	N/A	N/A	6	4	1	1
Buckingham	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Balls Eddy	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fireman's Launch	N/A	N/A	N/A	0	3	1	2

Table 2. Descriptive statistics of fork lengths (mm) collected from non-tidal beach seine sites, by month and year. Data are inclusive of lengths collected at the traditional non-tidal sites: Trenton, Phillipsburg, Delaware Water Gap and Milford Beach.

Year	N	Min.	25th Quart.	50th Quart.	75th Quart.	Max.	Avg.	Std.
August								
1983	266	30	41.25	48	55	86	49.1	10.0
1984	229	29	46	52	58	80	52.5	10.6
1985	259	32	54	60	68	96	61.7	11.6
1986	250	34	49	56	65	103	57.8	12.2
1987	249	33	46	51	57	77	52.2	8.7
1988	361	32	45	50	56	115	52.1	11.2
1989	375	28	48	55	62	94	55.5	10.6
1990	385	20	45	53	63	85	53.7	13.2
1991	294	42	55	60	67	90	61.3	8.3
1992	274	27	48	56	68	85	57.3	13.3
1993	398	37	52	57	65.75	94	59.0	10.2
1994	240	29	48.75	58	67	88	58.0	12.3
1995	349	29	46	53	63	86	53.8	11.3
1996	400	23	36	42	54	91	45.3	13.1
1997	375	27	44	50	58	89	51.2	11.3
1998	310	26	41.25	53	63	87	52.2	14.6
1999	366	28	45	54	62	80	53.5	10.6
2000	356	20	39.75	49	63.25	101	53.0	17.9
2001	346	36	54.25	62	71	89	62.9	12.1
2002	251	25	40	53	61.5	84	51.4	12.7
2003	399	22	38	44	50.5	90	45.1	10.9
2004	395	30	53	62	74	112	63.3	15.8
2005	398	32	47	54	64	84	56.3	11.1
2006	318	25	45	55	65	97	56.1	14.6
2007	374	29	50	62	69	93	60.9	13.8
2012	298	36	53.25	61	68	93	60.9	10.0
2013	347	27	58	69	81	105	68.8	15.0
2014	311	32	50	58	66	101	58.8	13.0
2015	355	22	60.5	68	78	101	68.7	13.1

Table 2. Cont.

Year	N	Min.	25th Quart.	50th Quart.	75th Quart.	Max.	Avg.	Std.
September								
1983	256	46	57	63	70	103	64.2	9.4
1984	254	44	60	65	73	96	66.4	10.4
1985	235	47	66	70	75	112	71.6	9.2
1986	267	45	65	71	77	107	71.7	10.2
1987	194	47	59	65	75	106	67.6	11.8
1988	393	45	59	65	72	100	66.3	10.6
1989	334	44	59.25	65	71	87	65.1	7.8
1990	351	39	55	63	72	101	64.7	12.2
1991	234	50	65	70	75	97	70.1	8.5
1992	298	45	60	65	74	100	66.9	10.2
1993	335	42	58	65	72	94	65.5	9.8
1994	325	40	62	70	78	125	70.4	11.7
1995	306	50	65	70	75	96	70.3	9.1
1996	355	37	54	59	68	91	61.7	11.0
1997	331	39	57	66	74	117	66.3	12.4
1998	327	31	58	67	76.5	95	67.2	12.1
1999	376	46	60	64	70	101	65.7	8.7
2000	345	41	62	71	81	118	71.5	12.7
2001	330	49	68	76	84	103	76.2	10.7
2002	208	38	60	67	73.25	93	66.7	10.1
2003	377	30	46	55	65	97	56.5	13.7
2004	401	40	61	68	75	110	68.5	11.8
2005	369	47	59	67	75	101	67.8	11.2
2006	332	34	59	71.5	87	105	72.3	16.1
2007	352	40	65.75	75.5	85	110	75.4	13.8
2012	360	47	65	71	76.25	106	71.2	10.1
2013	296	42	64	80	92	119	78.2	16.2
2014	380	37	65	73	82.25	128	74.4	13.7
2015	362	37	75	85	96	201	85.6	16.6

Table 2. Cont.

Year	N	Min.	25th Quart.	50th Quart.	75th Quart.	Max.	Avg.	Std.
October								
1983	242	48	61	72	83	110	73.0	13.2
1984	299	48	73	80	87	110	79.6	9.9
1985	252	57	69	74	80	95	75.0	7.9
1986	255	61	75	82	90	130	83.9	11.3
1987	261	55	67	71	76	95	71.8	7.3
1988	229	53	65	71	75	96	70.8	7.2
1989	332	50	67	73	76.25	92	71.9	7.5
1990	368	47	68	74.5	82	132	75.0	11.2
1991	339	55	70	75	80	116	75.5	8.5
1992	271	48	69	75	82	110	76.8	12.0
1993	323	48	58	65	73	99	66.2	10.2
1994	323	48	69	72	78	114	74.0	8.9
1995	315	52	69	75	85	113	77.4	11.6
1996	399	52	64	71	78.5	113	71.5	9.3
1997	302	52	64	71	78	104	71.3	9.5
1998	272	54	70.75	80	87	113	79.1	11.3
1999	291	55	68	72	76.5	124	73.1	9.6
2000	297	51	80	88	95	127	87.6	12.0
2001	379	60	74	80	85	116	80.2	9.3
2002	276	54	70	76	81	105	77.0	9.6
2003	122	43	62	67	72.75	100	67.5	9.1
2004	128	55	69.75	74	79.25	105	74.9	9.2
2005	200	51	66.75	72	76.25	101	72.0	7.7
2006	178	48	71.25	80.5	89	115	80.4	12.7
2007	343	50	81	87	92	110	85.1	10.6
2012	313	60	70	73	77	100	73.9	6.7
2013	309	17	84	92	104	203	92.5	17.1
2014	400	45	76	82	88	125	81.9	9.3
2015	339	53	81	89	96	124	88.1	10.7

Table 3. Descriptive statistics of fork lengths (mm) collected from tidal beach seine sites, by month and year.

Year	N	Min.	25th Quart.	50th Quart.	75th Quart.	Max.	Avg.	Std.
August								
2000	654	27	48	53.5	58.75	71	52.7	8.1
2001	559	35	48	51	55	74	52.0	6.3
2002	127	45	58.5	64	67.5	74	62.4	6.7
2003	1889	28	46	49	54	80	50.1	6.4
2004	858	37	53	57	61	83	56.4	6.6
2005	927	38	50	53	55	74	52.8	4.2
2006	70	58	65	68	71.75	83	68.3	4.5
2007	1093	34	48	50	54	67	50.6	4.7
2008	95	44	62	66	69	81	65.3	6.3
2009	684	31	50	57	63	78	56.2	9.0
2010	609	41	56	61	65	77	60.7	6.2
2011	655	32	52	57	62	77	57.1	7.1
2012	362	43	58	64	69	85	63.1	7.9
2013	1134	29	49	53	56	70	52.5	5.6
2014	881	32	45	50	54	86	50.1	6.4
September								
2000	581	40	54	60	65	90	59.6	7.5
2001	492	40	53	56	60	78	56.6	5.9
2002	143	51	64.5	68	71	91	67.7	6.3
2003	942	43	55	59	63	83	59.5	5.6
2004	399	48	60	63	67	90	63.2	5.7
2005	550	43	55	58	61	99	58.2	5.3
2006	56	63	71	73	78	124	74.7	8.4
2007	851	40	50	52	55	67	52.5	4.2
2008	163	57	68	71	75	83	70.9	5.1
2009	325	37	53	61	70	90	61.7	11.0
2010	415	46	60	64	69	83	63.8	6.6
2011	466	45	60	64	67	82	63.6	5.8
2012	465	49	62	66	70	90	66.0	6.5
2013	1085	25	52	55	59	79	55.4	5.5
2014	610	40	52	55.5	60	80	55.4	5.9

Table 3. Cont.

Year	N	Min.	25th Quart.	50th Quart.	75th Quart.	Max.	Avg.	Std.
October								
2000	507	49	60.5	65	70	95	65.5	6.7
2001	248	50	59	62.5	69	94	64.3	7.5
2002	70	57	68	72	75	82	71.4	4.6
2003	382	51	60	62.5	66	82	62.9	4.9
2004	416	54	66	69	72	83	68.8	4.8
2005	433	45	59	62	65	102	62.6	5.4
2006	73	59	78	84	89	95	82.9	7.7
2007	485	43	53	56	60	84	56.6	5.5
2008	75	65	74	78	81	92	77.6	5.3
2009	130	57	68	74	80	99	74.1	8.0
2010	340	57	67	71	74	87	70.6	5.2
2011	398	49	63	67	71	81	67.0	5.7
2012	402	53	67	70	74	88	70.6	5.4
2013	918	47	58	61	64	117	61.2	5.5
2014	547	35	56	60	64	85	60.1	6.4

Table 4. Juvenile tidal and non-tidal abundance indices for Delaware River American Shad. Historic sites include Trenton, Phillipsburg, Delaware Water Gap and Milford Beach. The Big 3 sites include Phillipsburg, Delaware Water Gap and Milford Beach. GM = geometric mean; GLM = generalized linear model mean.

Year	Trenton (GM)	Phillipsburg (GM)	Del. Water Gap (GM)	Milford (GM)	Non-tidal (GM) (Historic)	Non-tidal (GM) (Big 3)	Non-tidal (GLM) (Big 3)	Tidal (GM)
1980	1.15				1.15			0
1981	2.95	74.4			15.80			0
1982	30.4	56.8			40.62			0
1983	31.8	443.6	137.4		111.19	219.7		0.48
1984	27.3	200.5	64.4		68.87	111.0		0.23
1985	30.9	121.6	116.1		76.09	118.8		0.06
1986	22.8	215.5	303.5		149.12	255.8		0.67
1987	83.6	160.7	154.6		125.39	158.5		1.68
1988	29.3	25.6	178.0	121.1	63.74	82.4	168.63	0.56
1989	61.0	32.7	256.3	99.3	84.73	94.5	206.37	9.54
1990	72.4	143.4	670.0	102.9	154.74	212.4	312.81	5.74
1991	7.9	48.2	106.6	136.1	49.43	88.9	182.33	2.49
1992	27.1	67.1	60.2	15.2	35.86	39.2	117.23	7.00
1993	32.1	155.2	387.3	137.1	124.41	199.8	311.26	5.68
1994	8.0	39.2	154.5	39.7	37.85	62.4	225.59	7.13
1995	25.1	89.1	94.9	112.7	70.14	98.4	170.20	5.52
1996	146.3	209.8	646.7	251.5	265.95	324.4	420.81	18.73
1997	16.6	273.0	265.2	195.9	130.4	242.1	288.24	3.05
1998	28.5	13.8	50.4	28.3	27.46	27.1	54.31	7.22
1999	34.2	160.9	94.9	48.5	71.13	90.6	155.41	7.07
2000	54.9	153.9	157.1	27.1	76.57	85.8	189.38	9.89
2001	29.5	209.4	56.4	58.5	66.95	82.2	175.53	5.45
2002	1.4	47.2	59.8	25.9	19.78	41.9	82.25	0.89
2003	31.7	245.2	25.9	75.4	62.78	78.7	282.66	9.90
2004	53.4	65.2	63.6	123.4	72.34	80.0	255.90	5.81
2005	43.7	125.2	411.6	162.8	125.64	186.1	204.56	9.26

Table 4. Cont.

Year	Trenton (GM)	Phillips-burg (GM)	Del. Water Gap (GM)	Milford (GM)	Non-tidal (GM) (Historic)	Non-tidal (GM) (Big 3)	Non-tidal (GLM) (Big 3)	Tidal (GM)
2006	17.4	8.7	39.8	41.3	22.53	24.5	56.29	0.53
2007	25.7	288.7	553.6	231.9	176.75	333.5	339.97	15.30
2008								0.82
2009								4.21
2010								4.61
2011								8.64
2012	11.1	267.6	428.9	139.6	118.91	252.2	373.71	4.00
2013	39.3	51.6	26.1	48.0	39.90	40.2	53.67	27.22
2014	36.3	108.8	144.6	109.9	86.42	120.3	167.51	10.26
2015	42.9	99.9	45.3	95.9	66.08	75.2	113.17	6.9
2006-2015 Average	28.8	137.6	206.4	111.1	85.10	141.0	184.05	8.25
Long-term Average	34.6	135.6	198.4	101.2	87.00	132.0	204.49	7.07
Time Series	1980-2015	1981-2015	1983-2015	1988-2015	1980-2015	1983-2015	1988-2015	1987-2015

Table 5. Correlation matrix of geometric CPUEs (log-transformed).

	Trenton	Phillipsburg	Del. Water Gap	Milford
Phillipsburg	0.26	-	0.44	0.46
Del. Water Gap	0.25	0.44	-	0.63
Milford	0.30	0.46	0.63	-
Phillipsburg/Del. Water Gap / Milford	***0.33***	0.78	0.85	0.83
Tidal	***0.48***	0.38	0.13	0.13

Table 6. Distribution of American Shad total lengths (mm) caught at Smithfield Beach by stretch mesh size, all years combined (1999-2009).

Mesh	count	min	25th	50th	75th	max	avg	std
Female								
4.5	659	428	517	534	552	614	535	27.4
4.75	392	455	525	544	560	606	542	24.8
5	1899	446	530	547	566	643	548	26.0
5.25	473	468	535	552	570	644	553	25.9
5.5	471	437	536	556	573.5	614	556	25.3
5.75	191	483	550.5	571	586.5	635	569	26.8
6	222	475	554	573	591	629	571	29.7
Male								
4.5	1264	398	470	489	507	581	489	26.8
4.75	309	413	484	499	518	571	500	26.4
5	555	408	493	510	526	591	509	25.2
5.25	54	430	488	511.5	530.75	580	510	31.2
5.5	33	435	500	521	532	591	516	33.5
5.75	13	474	484	500	530	555	507	28.3
6	6	431	461.5	466	476.5	500	467	22.7

Table 7. Total length (mm) distribution of American Shad collected at Smithfield Beach separated by gender and year.

Year	count	min	25th	50th	75th	max	avg	std
Female								
1996	643	447	532	547	562	618	546.7	25.39
1997	996	452	518	538	557	615	536.9	29.68
1998	1022	445	519	534	548	627	534.4	23.25
1999	638	455	522	535	547	614	535.0	19.99
2000	316	457	534	554	569	613	551.2	25.70
2001	685	465	531	546	562	606	546.5	22.40
2002	248	435	548	562	576	615	561.8	23.47
2003	299	446	555	571	592	644	569.6	31.32
2004	269	499	540	560	581	634	560.2	27.02
2005	545	461	545	561	576	635	559.9	25.74
2006	220	462	527	553	574	627	550.9	33.02
2007	414	468	529	545	566	622	545.9	27.41
2008	440	437	521	538	556	603	538.8	26.12
2009	236	428	515	532	551	615	532.8	28.64
2010	427	465	504	516	531	585	517.7	20.63
2011	811	470	526	540	556	605	540.4	21.02
2012	762	464	528	546	564	617	545.8	25.89
2013	645	475	533	545	558	641	545.1	19.85
2014	593	452	525	537	550	618	536.8	23.98
2015	547	461	520.5	536	551	629	536.2	23.84

Table 7. Cont.

Year	count	min	25th	50th	75th	max	avg	std
Male								
1996	220	430	491.75	510	528	615	510.8	31.16
1997	273	409	462	481	503	562	482.8	27.72
1998	235	424	482	496	507.5	547	494.9	19.77
1999	76	442	477	494.5	507.5	540	493.0	21.34
2000	225	415	470	489	508	580	488.9	26.29
2001	233	428	480	495	511	562	495.8	22.25
2002	154	422	497	514.5	530	585	512.1	26.30
2003	257	435	483	504	528	582	504.9	29.86
2004	156	439	495.75	510	523	581	508.7	21.65
2005	351	398	484	505	525	591	501.6	31.27
2006	136	433	464.75	482	500	578	483.4	25.43
2007	255	430	478	494	511.5	566	494.4	24.04
2008	257	429	477	493	509	591	494.1	25.56
2009	136	408	455.75	468	491.25	557	472.8	28.01
2010	380	425	472.75	485	497	564	485.0	18.44
2011	200	443	494.75	506	520	557	506.9	20.32
2012	216	450	485	499	514	567	499.6	21.35
2013	190	414	495	506.5	519.75	545	505.1	20.38
2014	162	430	475	499	512.75	558	494.6	26.01
2015	172	420	480.75	495	507.25	552	492.5	22.14

Table 8. Percent frequency of American Shad ages interpreted from scale microstructures collected at Smithfield Beach. No biological information was collected prior to 1996. Assigned ages do not represent the combined agreement of Co-op members as per the Co-op's Ageing Protocol (Appendix A). Scale ages for 2015 are unavailable as they are still being processed by Co-op members.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10
Female										
1996	0.0	0.0	0.0	1.9	78.7	19.5	0.0	0.0	0.0	0.0
1997	0.0	0.0	0.0	18.6	42.3	38.3	0.9	0.0	0.0	0.0
1998	0.0	0.0	0.6	17.3	67.9	12.9	1.3	0.0	0.0	0.0
1999	0.0	0.0	0.0	5.0	53.9	39.7	1.4	0.0	0.0	0.0
2000	0.0	0.0	0.0	12.7	38.1	44.8	4.4	0.0	0.0	0.0
2001	0.0	0.0	0.0	10.6	55.6	32.1	1.8	0.0	0.0	0.0
2002	0.0	0.0	0.0	1.2	44.8	50.8	3.2	0.0	0.0	0.0
2003	0.0	0.0	0.3	5.4	44.5	44.1	5.7	0.0	0.0	0.0
2004	0.0	0.0	0.0	3.0	57.6	36.1	3.3	0.0	0.0	0.0
2005	0.0	0.0	0.0	1.7	20.3	50.1	25.0	2.9	0.0	0.0
2006	0.0	0.0	0.9	18.4	32.3	33.6	14.3	0.5	0.0	0.0
2007	0.0	0.0	0.0	24.7	50.1	23.0	2.2	0.0	0.0	0.0
2008	0.0	0.0	0.0	7.3	44.0	38.1	10.1	0.5	0.0	0.0
2009	0.0	0.0	0.0	13.1	34.2	36.3	13.9	1.7	0.8	0.0
2010	0.0	0.0	0.0	5.9	80.1	12.6	1.2	0.2	0.0	0.0
2011	0.0	0.0	0.0	0.5	13.3	82.6	3.7	0.0	0.0	0.0
2012	0.0	0.0	0.0	0.5	32.0	8.8	57.0	1.3	0.4	0.0
2013	0.0	0.0	0.0	0.3	14.7	75.5	5.9	3.6	0.0	0.0
2014	0.0	0.0	0.0	3.0	22.1	46.7	28.2	0.0	0.0	0.0

Table 8. Cont.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10
Male										
1996	0.0	0.0	0.0	20.6	70.4	8.1	0.9	0.0	0.0	0.0
1997	0.0	0.0	8.8	44.7	33.0	13.6	0.0	0.0	0.0	0.0
1998	0.0	0.0	0.8	39.4	52.5	7.2	0.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	15.6	57.1	27.3	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	20.5	65.2	13.4	0.9	0.0	0.0	0.0
2001	0.0	0.0	1.7	39.9	53.6	4.3	0.4	0.0	0.0	0.0
2002	0.0	0.0	0.7	15.2	65.6	18.5	0.0	0.0	0.0	0.0
2003	0.0	0.0	0.4	30.4	59.2	9.2	0.8	0.0	0.0	0.0
2004	0.0	0.0	0.0	14.7	79.5	5.8	0.0	0.0	0.0	0.0
2005	0.0	0.0	3.7	28.6	45.3	22.1	0.3	0.0	0.0	0.0
2006	0.0	0.0	11.0	57.4	30.9	0.7	0.0	0.0	0.0	0.0
2007	0.0	0.0	5.5	38.3	43.0	12.9	0.4	0.0	0.0	0.0
2008	0.0	0.0	1.2	26.4	55.9	15.4	1.2	0.0	0.0	0.0
2009	0.0	0.0	1.5	56.6	28.7	11.0	2.2	0.0	0.0	0.0
2010	0.0	0.0	0.0	14.2	80.5	5.3	0.0	0.0	0.0	0.0
2011	0.0	0.0	0.0	2.0	19.4	77.1	1.5	0.0	0.0	0.0
2012	0.0	0.0	0.0	2.8	70.7	5.1	20.5	0.9	0.0	0.0
2013	0.0	0.0	0.0	3.7	35.3	60.0	0.0	1.1	0.0	0.0
2014	0.0	0.0	0.0	18.4	35.6	41.1	4.9	0.0	0.0	0.0

Table 9. Mean size-at-age for female and male American Shad caught at Smithfield Beach.

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9
Female							
1996		512	542	571			
1997		505	531	560	585		
1998	565	522	536	547	551		
1999		528	532	541	551		
2000		536	546	560	566		
2001		521	543	562	580		
2002		502	555	569	593		
2003	445	516	558	586	604		
2004		526	551	576	603		
2005		503	538	560	579	597	
2006	495	514	544	571	577	595	
2007		524	548	562	596		
2008		513	532	548	555	560	
2009		503	527	544	548	548	560
2010		511	517	530	551	555	
2011		510	534	542	546		
2012		493	528	544	558	562	565
2013		480	534	546	565	560	
2014		502	522	541	550		

Table 9. Cont

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9
Male							
1996		496	511	559	560		
1997	458	468	498	519			
1998	465	494	496	504			
1999		469	496	503			
2000		471	493	504	525		
2001	450	487	503	529	535		
2002	425	482	502	527			
2003	435	483	511	547	550		
2004		493	511	533			
2005	443	476	510	529	535		
2006	464	478	502	495			
2007	470	483	504	512	545		
2008	452	479	497	518	522		
2009	420	461	487	504	515		
2010		477	486	504			
2011		450	514	508	505		
2012		472	496	522	513	535	
2013		475	498	512		505	
2014		474	496	509	481		

Table 10. Chapman-Robson bias-corrected Z estimates for American Shad collected at Smithfield Beach.

	Females Only		Combined Sexes	
	Z	SE	Z	SE
1997	1.06	0.06	1.16	0.534
1998	1.85	0.15	1.81	0.2
1999	1.18	0.506	*	*
2000	2.4	0.174	1.15	0.435
2001	1.23	0.423	1.27	0.382
2002	*	*	1.13	0.533
2003	1	0.5	1.21	0.321
2004	1.18	0.397	1.43	0.278
2005	1.26	0.312	1.38	0.25
2006	0.81	0.323	0.66	0.206
2007	1.3	0.348	1.36	0.313
2008	1.71	0.225	1.8	0.234
2009	1.28	0.155	0.85	0.216
2010	1.93	0.068	2.22	0.063
2011	*	*	*	*
2012	2.87	1.256	2.82	0.982
2013	1.97	0.476	2.13	0.553
2014	*	*	*	*
2015	1.35	0.21	0.83	0.286

* denotes insufficient number of age classes (less than three)

Table 11. Annual indices of American Shad from long-term monitoring program time-series. Smithfield Beach (Smithfield) and Raubsville occur on the Delaware River main stem, representing relative abundances (i.e., CPUE) from gill netting (shad/net-ft-hr *10,000) and electrofishing (shad/hr) efforts, respectively. The Raubsville CPUE is reported as a total and separated into PA and NJ CPUEs. Total passage is also reported for the Lehigh and Schuylkill rivers from fishway monitoring at the Easton and Fairmount dams, respectively. An electrofishing (shad/hr) survey is also accomplished in the tidal Schuylkill River immediately below the Fairmount Dam.

		Raubsville					
Year	Smithfield	Total	PA	NJ	Lehigh	Schuylkill	
	CPUE	CPUE	CPUE	CPUE	N	N	CPUE
1990	190.09						
1991	123.72						
1992	161.84						
1993	62.44						
1994	61.93				87		
1995	75.00				873		
1996	46.88				1141		
1997	54.89	26.32			1428		
1998	64.34				3293		
1999	31.69	13.96			2346		
2000	37.36	30.88	24.33	39.81	2094		
2001	33.93	48.48	40.05	78.41	4740		
2002	48.13				3314		9.72
2003	37.93				422		128.92
2004	25.34				754	91	197.20
2005	56.28				675	41	265.74
2006	26.31				2023	345	504.96
2007	40.31				1397	56	287.10
2008	33.01				408		177.09
2009	17.07				425	1485	449.67
2010	46.88	22.99	28.21	21.36	1935	2521	806.03
2011	72.08	15.06			558	3366	948.02
2012	73.54	46.59	35.87	55.36	2096	2227	314.90
2013	48.45	32.53	32.05	44.05	2364*	166	401.38
2014	49.38	27.24	24.67	51.19	1682*		468.55
2015	59.28	11.38	13.12	12.45	1430*		
* Total passage is estimated from electrofishing CPUE upriver in the Lehigh River.							

Table 12. Ages and relative abundance index for Smithfield Beach (sexes combined).

	Ages								Total	Relative
	2	3	4	5	6	7	8	9	aged	abundance
1996	0	1	8	42	26	12	4	0	93	46.88
1997	0	3	23	22	18	8	0	0	74	54.89
1998	0	1	25	114	46	15	9	0	210	64.34
1999	0	1	55	94	53	2	0	0	205	31.69
2000	0	4	42	122	114	48	7	0	337	37.36
2001	0	4	141	365	194	32	7	0	743	33.93
2002	0	2	21	115	175	46	12	1	372	48.13
2003	0	4	102	132	214	64	6	1	523	37.93
2004	0	2	48	199	99	64	6	0	418	25.34
2005	0	10	143	340	247	30	7	1	778	56.28
2006	0	2	81	146	72	45	3	0	349	26.31
2007	0	3	54	318	315	32	10	2	734	40.31
2008	0	1	65	212	304	68	3	0	653	33.01
2009	0	2	91	105	121	36	5	0	360	17.07
2010	0	0	45	656	73	9	2	0	785	46.88
2011	0	0	7	45	329	10	0	0	391	72.08
2012	0	0	4	165	29	180	6	2	386	73.54
2013	0	0	12	97	305	21	18	0	453	48.45
2014	0	0	77	111	168	132	1	0	489	49.38

Table 13. Smithfield Beach index at Age. Calculated by multiplying annual relative abundance index by the annual relative proportion of observed age class.

	Index at age - sexes combined			
	4	5	6	7
1996	4.03	21.17	13.11	6.05
1997	17.06	16.32	13.35	5.93
1998	7.66	34.93	14.09	4.60
1999	8.50	14.53	8.19	0.31
2000	4.66	13.52	12.64	5.32
2001	6.44	16.67	8.86	1.46
2002	2.72	14.88	22.64	5.95
2003	7.40	9.57	15.52	4.64
2004	2.91	12.06	6.00	3.88
2005	10.34	24.60	17.87	2.17
2006	6.11	11.01	5.43	3.39
2007	2.97	17.46	17.30	1.76
2008	3.29	10.72	15.37	3.44
2009	4.31	4.98	5.74	1.71
2010	2.69	39.18	4.36	0.54
2011	1.29	8.30	60.65	1.84
2012	0.76	31.44	5.53	34.29
2013	1.28	10.37	32.62	2.25
2014	7.78	11.21	16.96	13.33

Diagonal shading represents year classes

Table 14. Correlation values for non-tidal JAI indices vs lagged Smithfield Beach age class indices. Big 3 represents catches from the non-tidal Phillipsburg, Delaware Water Gap and Milford Beach seine sites.

	Pearson				Spearman			Power analysis n=16 sig.level=.05	
Correlation	r	t	df	p-value	r	s	p-value	Pearson	Spearman
Big3_GeoMean vs 4-5 yo	0.586	2.70	14	0.017	0.538	314	0.034	0.70	0.61
Big3_GeoMean vs 4-6 yo	0.646	3.17	14	0.007	0.659	232	0.007	0.81	0.83
Big3_GeoMean vs 4-7 yo	**0.660**	**3.29**	**14**	**0.005**	**0.753**	**168**	**0.001**	**0.83**	**0.95**
Big3_GLM vs 4-5 yo	0.394	1.60	14	0.131	0.350	440	0.180	0.34	0.27
Big3_GLM vs 4-6 yo	0.402	1.64	14	0.122	0.438	382	0.091	0.35	0.41
Big3_GLM vs 4-7 yo	**0.394**	**1.60**	**14**	**0.131**	**0.441**	**380**	**0.089**	**0.34**	**0.42**

Table 15. Lewis haul seine catch-per-unit effort (CPUE – catch per haul) for American Shad in the Delaware River from 1925 to 2015.

Year	CPUE	Year	CPUE	Year	CPUE
1925	1.62	1961	3.46	1997	11.96
1926	3.18	1962	13.89	1998	13.20
1927	2.43	1963	56.90	1999	4.60
1928	4.00	1964	18.29	2000	4.07
1929	4.39	1965	6.65	2001	6.84
1930	1.30	1966	1.75	2002	3.85
1931	1.77	1967	3.74	2003	5.23
1932	3.20	1968	1.22	2004	4.07
1933	5.54	1969	3.10	2005	2.89
1934	3.45	1970	4.88	2006	1.66
1935	13.47	1971	12.30	2007	3.38
1936	2.43	1972	5.44	2008	2.24
1937	9.29	1973	7.19	2009	2.57
1938	4.68	1974	8.51	2010	12.31
1939	8.77	1975	14.85	2011	1.93
1940	3.59	1976	11.95	2012	5.30
1941	0.80	1977	10.18	2013	26.63
1942	5.68	1978	10.13	2014	10.67
1943	14.07	1979	18.72	2015	8.68
1944	5.02	1980	12.97		
1945	2.05	1981	54.17		
1946	2.15	1982	29.83		
1947	3.79	1983	14.44	Time Series Average	9.89
1948	0.73	1984	15.68		
1949	0.09	1985	29.30	2006-2015 Average	7.54
1950	0.18	1986	30.67		
1951	0.66	1987	16.49		
1952	0.63	1988	35.62		
1953	0.00	1989	52.20		
1954	0.35	1990	25.35		
1955	0.84	1991	30.42		
1956	0.00	1992	50.96		
1957	0.83	1993	10.52		
1958	3.00	1994	7.90		
1959	1.13	1995	19.05		
1960	0.32	1996	3.67		

Table 16. Biological data collected by the Lewis haul seine fishery from their annual catches of American Shad at Lambertville, NJ as contracted by the Co-op. The count is not reflective of the total number caught, only those subsampled. Age was estimated from scale microstructure and was not determined for 2009 and 2015.

		Fork Length (mm)			Age		
Year	N	Min	Max	Avg	Min	Max	Avg
Female							
2008	48	469	602	543.9	4	7	5.5
2009	34	395	560	454.9			
2010	112	395	500	445.7	4	7	5.4
2011	27	410	518	475.1	4	7	5.5
2012	94	40	560	474.4	4	8	5.6
2013	237	410	575	474.5	4	7	5.3
2014	141	323	530	464.2	4	7	5.3
2015	98	154	558	466.1			

Male							
2008	30	377	539	474.7	3	6	4.8
2009	54	110	460	395.4			
2010	176	340	479	416.1	3	7	5.0
2011	16	383	490	426.2	3	6	5.1
2012	50	400	497	443.5	4	7	5.1
2013	182	346	485	431.0	3	6	4.5
2014	104	320	490	417.2	3	6	4.4
2015	147	276	485	413.8			

Table 17. New Jersey commercial fishing regulations for 2015.

System	Season	Gear Limits	Mandatory Reporting	Other Restrictions
Delaware Bay & River	Gill nets: Feb 1-Dec 15 ----------------- Haul Seine: Nov 1-Apr 30	Stretch mesh min.: 2.75” Feb 1-Feb 29 *3.25” Mar 1-Dec 15 Length: 2400’ Feb 12-May 15 1200’ May 16-Dec 15 --- 2.75" min. stretch mesh, max length 420'	YES	Limited entry; gear restrictions in defined areas

*except with special permit

Table 18. Number of permits issued to New Jersey fishermen and number reporting landings annually in the Delaware Bay 2000-2015.

Year	Total Permits Issued	Active Permits	Permits Reporting Landings
2000	-	-	28
2001	-	-	29
2002	-	-	21
2003	-	-	24
2004	-	-	24
2005	-	-	24
2006	-	-	25
2007	-	-	17
2008	-	-	14
2009	-	-	16
2012	83	51	11
2013	61	47	13
2014	61	47	11
2015	61	47	9

Table 19. Commercial landings in the state of New Jersey. Upper and lower bay landings are delineated by harvest occurring north and south of Gandys Beach, NJ.

Year	Total Landings (lbs)	Upper Bay Landings (lbs)	Lower Bay Landings (lbs)
1985	72,000	23,100	48,900
1986	81,600	17,700	63,900
1987	129,600	20,200	109,400
1988	98,000	17,300	80,700
1989	79,300	16,800	62,500
1990	253,113	40,364	212,749
1991	173,301	23,092	150,209
1992	155,800	41,765	114,035
1993	142,980	19,552	123,428
1994	50,371	9,066	41,305
1995	73,432	11,811	61,621
1996	18,663	1,100	17,563
1997	43,799	9,250	34,549
1998	14,255	75	14,180
1999	88,706	5,670	83,036
2000	121,431	43,299	78,132
2001	96,138	69,098	27,040
2002	48,417	32,746	15,671
2003	90,520	84,198	6,322
2004	97,458	92,073	5,385
2005	87,984	46,543	41,441
2006	66,154	56,847	9,307
2007	62,828	53,818	9,010
2008	29,034	23,877	5,157
2009	12,645	9,264	3,381
2010	12,220	7,721	4,499
2011	12,054	6,855	5,199
2012	27,368	19,923	7,445
2013	37,659	13,204	24,455
2014	42,378	37,319	5,059
2015	9,418	6,013	3,405

Table 20. New Jersey's gill net effort data for the American Shad commercial fishery.

Year	No. of Fishermen			No. of Man-days			Square Feet of Net			Pounds Harvested			Pounds/Square Foot		
	Upper Bay	Lower Bay	Comb.	Upper Bay	Lower Bay	Comb.	Upper Bay	Lower Bay	Comb.	Upper Bay	Lower Bay	Comb.	Upper Bay	Lower Bay	Comb.
2012	8	3	11	44	38	82	1,338,500	117,600	1,456,100	19,923	7,445	27,368	0.016	0.051	0.019
2013	9	4	13	54	55	109	1,369,040	654,000	2,023,040	13,204	24,455	37,659	0.018	0.020	0.019
2014	3	8	11	82	34	116	2,458,400	186,480	2,644,880	37,319	5,059	42,378	0.015	0.027	0.016
2015	7	2	9	52	38	90	1,357,200	256,000	1,613,400	6,013	3,405	9,418	0.004	0.013	0.006

Table 21. Fork length of American Shad captured in New Jersey's tagging gill net surveys.

Year	Number	Mean Fork Length (mm)			Range	Std. Dev.	Stretch Mesh (inches)
		Male	Female	Sexes Combined			
1995	107			483.70	405-605	30.8	5.5-6
1996	294			467.70	384-567	33.6	4.5-6
1997	500			448.40	346-600	34.1	5-6
1998	554			460.40	383-605	28.5	5-6
1999	753			465.10	375-563	26.2	5-5.75
2000	425			455.90	382-547	25.2	5-6
2001	663			474.10	396-615	29.6	5-6
2002	273	452.80	483.10	476.80	375-573	32.9	5-6
2003	170	451.40	477.40	472.20	401-538	27.1	5-6
2004	51	447.50	497.40	489.60	414-575	38.7	5-6.5
2005	220	445.20	477.50	470.60	402-586	36.7	5-6.5
2006	73	453.60	484.00	480.30	406-584	37.3	5.5
2007	42	444.50	478.20	476.60	426-571	32.9	5.5-6.5
2008	0						
2009	11	423.30	477.90	455.00	387-523	46.0	5-6
2010	85	430.90	457.90	447.10	366-518	32.3	5-6
2011	17	444.71	489.58	473.05	425-538	34.0	5-6
2012	18	435.67	485.67	477.33	459-515	26.7	5-6
2013	17		481.32	481.32	443-507	16.7	5.5-6
2014	18	444.25	485.77	476.11	395-525	33.6	5.5-6
2015	10	457.00	481.20	469.10	437-500	11.0	5.5-6

Table 22. Sex composition of New Jersey's commercial gill net shad landings: 1996–2015.

Year	Female (%)	Male (%)
1999	82.6	17.4
2000	86.0	14.0
2001	83.8	16.2
2002	69.4	30.6
2003	80.3	19.7
2004	77.9	22.1
2005	73.9	26.1
2006	79.5	20.5
2007	80.6	19.4
2008	77.5	22.5
2009	80.4	19.6
2010	67.2	32.8
2011	76.4	23.6
2012	85.6	14.4
2013	87.4	12.6
2014	90.7	9.3
2015	84.9	15.1
AVG	**80.2**	**19.8**

Table 23. Delaware's gill net effort for the American Shad commercial fishery. Upper and lower bay landings are delineated by harvest occurring north and south of Bowers Beach, DE.

Year	No. of Fishermen				No. Vessel Trips				Net Yards Fished				Pounds Harvested				Pounds/Net Yard			
	Upper Bay/River Anchor	Upper Bay/River Drift	Lower Bay Anchor	Lower Bay Drift	Upper Bay/River Anchor	Upper Bay/River Drift	Lower Bay Anchor	Lower Bay Drift	Upper Bay/River Anchor	Upper Bay/River Drift	Lower Bay Anchor	Lower Bay Drift	Upper Bay/River Anchor	Upper Bay/River Drift	Lower Bay Anchor	Lower Bay Drift	Upper Bay/River Anchor	Upper Bay/River Drift	Lower Bay Anchor	Lower Bay Drift
2003	18	12	8	2	271	85	117	4	71,145	32,743	85,100	2,500	38,290	5,161	18,742	118	0.54	0.16	0.22	0.05
2004	19	13	9	3	348	76	186	21	125,140	33,300	121,040	17,400	53,779	4,221	31,242	851	0.43	0.13	0.26	0.05
2005	23	23	4	3	302	270	107	69	138,440	129,900	68,310	62,400	46,377	22,961	35,114	19,113	0.33	0.18	0.51	0.31
2006	26	12	8	7	308	121	154	37	117,325	59,050	107,820	36,400	18,265	2,211	8,814	1,235	0.16	0.04	0.08	0.03
2007	23	17	6	8	270	114	135	67	117,540	41,100	99,275	50700	49,668	7,157	10,402	4,211	0.42	0.17	0.10	0.08
2008	22	15	3	6	212	108	5	49	65,689	45,870	3,800	30,675	13,930	2,137	34	2,232	0.21	0.05	0.01	0.07
2009	19	14	2	6	99	38	5	22	30,352	22,450	5,000	20,200	2,032	404	92	918	0.07	0.02	0.02	0.05
2010	13	12	1	4	85	54	12	24	40,800	30,250	3,050	23,000	1,529	1,694	409	1,387	0.04	0.06	0.13	0.06
2011	17	10	1	5	98	50	13	33	30,830	19,400	5,200	28,600	3,531	1,721	1,159	2,722	0.11	0.09	0.22	0.10
2012	10	7	0	6	63	45	0	28	21,850	24,050	0	18,400	1,216	1,095	0	429	0.06	0.05	0.00	0.02
2013	10	9	0	3	45	63	0	18	14,900	31,000	0	17,200	778	1,715	0	784	0.05	0.06	0.00	0.05
2014	11	4	1	5	173	13	1	44	97,435	6,300	1,000	36,800	83,400	299	2	2,093	0.86	0.05	0.00	0.06
2015	11	4	0	4	143	27	0	20	96,500	20,380	0	17,000	21,091	420	0	254	0.22	0.02	0.00	0.01

Table 24. Number of permits issued to Delaware fishermen and number reporting American Shad landings annually.

Year	Total Permits Issued	Active Permits	Permits Reporting Landings
2000	110	84	56
2001	111	75	53
2002	108	72	46
2003	110	70	41
2004	110	66	44
2005	111	67	52
2006	111	63	45
2007	111	59	41
2008	111	56	38
2009	111	60	35
2010	111	56	29
2011	111	56	30
2012	111	59	20
2013	111	54	20
2014	111	52	19
2015	111	51	19

Table 25. Commercial landings in the state of Delaware. Upper and lower bay landings are delineated by harvest occurring north and south of Bowers Beach, DE.

Year	Total Landings (lbs)	Upper Bay Landings (lbs)	Lower Bay Landings (lbs)
1985	168,483	168,483	0
1986	179,511	179,511	0
1987	180,582	180,582	0
1988	229,302	229,302	0
1989	187,787	187,787	0
1990	384,855	384,855	0
1991	364,385	364,385	0
1992	220,014	220,014	0
1993	233,449	233,449	0
1994	196,140	196,140	0
1995	146,328	146,328	0
1996	165,474	165,474	0
1997	116,516	116,516	0
1998	84,813	84,813	0
1999	76,222	76,222	0
2000	53,887	53,887	0
2001	201,834	201,834	0
2002	38,710	35,466	3,244
2003	62,422	43,562	18,860
2004	90,093	58,000	32,093
2005	123,610	69,383	54,227
2006	30,525	20,476	10,049
2007	71,438	56,825	14,613
2008	18,339	16,067	2,272
2009	3,446	2,436	1,010
2010	5,019	3,223	1,796
2011	9,133	5,252	3,881
2012	2,740	2,311	429
2013	3,732	2,943	789
2014	85,794	83,699	2,095
2015	21,765	21,511	254

Table 26. The State of Delaware summary of biological data collected from New Jersey commercial fishers: 1999-2015.

Year	Number	Mean TL (mm)	Mean WT (lbs)
1999	370	510	4.8
2000	250	506	N/A
2001	250	521	3.5
2002	189	517	N/A
2003	186	528	4.0
2004	37	548	4.6
2005	190	539	4.6
2006	294	523	5.3
2007	245	512	4.9
2008	N/A	N/A	N/A
2009	N/A	N/A	N/A
2010	150	510	N/A
2011	335	534	4.3
2012	432	541	4.2
2013	251	533	3.5
2014	270	473	3.0
2015	299	507	2.8

Table 27. Landings of Delaware River stock of American Shad from 1985-2015. Delaware River stock consists of 100% of upper bay landings and 40% of lower bay landings from Delaware and New Jersey combined. Landings are separated relative to the Bowers Beach, DE to Gandys Beach, NJ line.

Year	Upper Bay Landings Combined (lbs)	Lower Bay Landings Combined (lbs)	Total Delaware River Stock Landings (lbs)	Delaware River Stock Landings in New Jersey	Delaware River Stock Landings in Delaware
1985	191,583	48,900	211,143	20%	80%
1986	197,211	63,900	222,771	19%	81%
1987	200,782	109,400	244,542	26%	74%
1988	246,602	80,700	278,882	18%	82%
1989	204,587	62,500	229,587	18%	82%
1990	425,219	212,749	510,319	25%	75%
1991	387,477	150,209	447,561	19%	81%
1992	261,779	114,035	307,393	28%	72%
1993	253,001	123,428	302,372	23%	77%
1994	205,206	41,305	221,728	12%	88%
1995	158,139	61,621	182,787	20%	80%
1996	166,574	17,563	173,599	5%	95%
1997	125,766	34,549	139,586	17%	83%
1998	84,888	14,180	90,560	6%	94%
1999	81,892	83,036	115,106	34%	66%
2000	97,186	78,132	128,439	58%	42%
2001	270,932	27,040	281,748	28%	72%
2002	68,212	18,915	75,778	51%	49%
2003	127,760	25,182	137,833	63%	37%
2004	150,073	37,478	165,064	57%	43%
2005	115,926	95,668	154,193	41%	59%
2006	77,323	19,356	85,065	71%	29%
2007	110,643	23,623	120,092	48%	52%
2008	39,944	7,429	42,916	60%	40%
2009	11,700	4,391	13,456	79%	21%
2010	10,944	6,295	13,462	71%	29%
2011	12,107	9,080	15,739	57%	43%
2012	22,234	7,874	25,384	90%	10%
2013	16,147	25,244	26,245	88%	12%

Table 27. Cont.

Year	Upper Bay Landings Combined (lbs)	Lower Bay Landings Combined (lbs)	Total Delaware River Stock Landings (lbs)	Delaware River Stock Landings in New Jersey	Delaware River Stock Landings in Delaware
2014	121,018	7,154	123,880	32%	68%
2015	27,524	3,659	28,988	25%	75%

Table 28. Delaware Stock landings, Smithfield Beach CPUE and the Ratio of the landings divided by Smithfield CPUE divided by 100.

Year	Delaware Stock Landings	Smithfield Beach CPUE	Ratio
1990	510,319	190.1	26.8
1991	447,561	123.7	36.2
1992	307,393	161.8	19.0
1993	302,372	62.4	48.4
1994	221,728	61.9	35.8
1995	182,787	75.0	24.4
1996	173,599	46.9	37.0
1997	139,586	54.9	25.4
1998	90,560	64.3	14.1
1999	115,106	31.7	36.3
2000	128,439	37.4	34.4
2001	281,748	33.9	83.0
2002	75,778	48.1	15.7
2003	137,833	37.9	36.3
2004	165,064	25.3	65.1
2005	154,193	56.3	27.4
2006	85,065	26.3	32.3
2007	120,092	40.3	29.8
2008	42,916	33.0	13.0
2009	13,456	17.1	7.9
2010	13,462	46.9	2.9
2011	15,739	72.1	2.2
2012	25,384	73.5	3.5
2013	26,245	48.5	5.4
2014	123,880	49.4	25.1
2015	28,988	59.3	4.9
2006-2015 Average	49,523	46.6	12.7
1990-2015 Average	151,127	60.7	26.6

Table 29. American Shad tag returns, by year, from fish tagged in Delaware Bay: 1995-2015.

Year	American Shad Tagged	Recaptures
1995	107	10
1996	294	14
1997	500	36
1998	554	38
1999	753	46
2000	425	32
2001	663	35
2002	273	15
2003	170	7
2004	51	0
2005	220	9
2006	73	2
2007	42	1
2008	0	0
2009	11	1
2010	85	3
2011	17	0
2012	18	0
2013	17	0
2014	18	2
2015	10	1

Table 30. Recaptures of American Shad tagged and released in the Delaware Bay.

Recapture Location	Number of Reports	Percent of Reports
St. Lawrence River, Quebec	1	0.4
New Brunswick, Canada	3	1.2
Shubenacadie River, Nova Scotia	1	0.4
Atlantic Ocean and Rivers, RI	3	1.2
Connecticut River	40	16.3
Hudson River	43	17.5
Atlantic Ocean, NY	2	0.8
Atlantic Ocean, NJ	38	15.4
Delaware Bay/River	98	39.8
Atlantic Ocean, DE	4	1.6
Atlantic Ocean, MD	2	0.8
Atlantic Ocean, VA	1	0.4
Chesapeake Bay and Tribs	7	2.8
Atlantic Ocean and Rivers, NC	2	0.8
Santee River, SC	1	0.4

Table 31. Commercial landings (pounds) of American Shad reported to the State of Delaware, with the harvest that occurred at Mid Bay and above (Bowers Beach to the Delaware state line), Upper Bay and above (Port Mahon to the Delaware state line), and Lower Bay (Bowers Beach to the mouth of Delaware Bay).

	Pounds Landed				Percent of Landings		
Year	Total Landings	Upper Bay and North	Mid-Bay and North	Lower Bay	Upper Bay and North	Mid-Bay and North	Lower Bay
1985	168,483	168,483	168,483	0	100	100	0
1986	179,511	179,511	179,511	0	100	100	0
1987	180,582	180,582	180,582	0	100	100	0
1988	229,302	229,302	229,302	0	100	100	0
1989	187,787	187,787	187,787	0	100	100	0
1990	384,855	384,855	384,855	0	100	100	0
1991	364,385	364,385	364,385	0	100	100	0
1992	220,014	220,014	220,014	0	100	100	0
1993	233,449	233,449	233,449	0	100	100	0
1994	196,140	196,140	196,140	0	100	100	0
1995	146,328	146,328	146,328	0	100	100	0
1996	165,474	165,474	165,474	0	100	100	0
1997	116,516	116,516	116,516	0	100	100	0
1998	84,813	84,813	84,813	0	100	100	0
1999	76,222	76,222	76,222	0	100	100	0
2000	53,887	53,887	53,887	0	100	100	0
2001	201,834	201,834	201,834	0	100	100	0
2002	38,710	34,832	35,466	3,244	90	92	8
2003	62,422	37,397	43,562	18,860	60	70	30
2004	90,093	41,732	58,000	32,093	46	64	36
2005	123,610	45,572	69,383	54,227	37	56	44
2006	30,525	16,516	20,476	10,049	54	67	33
2007	71,438	52,748	56,825	14,613	74	80	20
2008	18,339	12,793	16,067	2,272	70	88	12
2009	3,446	1,385	2,436	1,010	40	71	29
2010	5,019	1,204	3,223	1,796	24	64	36
2011	9,133	3,005	5,252	3,881	33	58	42
2012	2,740	1,605	2,311	429	59	84	16
2013	3,732	1,685	2,943	789	45	79	21
2014	85,794	14,708	83,699	2,095	17	98	2
2015	21,765	19,484	21,511	254	90	99	1

Table 32. Recapture locations of Hudson River and Delaware Bay tagged American Shad from 1995-2015.

	Tagging Location	
	Hudson River	Delaware Bay
Total Recaptured	172	246
Number of Hudson River Tagged Recaptures	151	43
Percent of Hudson River Tagged Recaptures	87.8%	17.5%
Number of Delaware Bay Tagged Recaptures	5	98
Percent of Delaware Bay Tagged Recaptures	2.9%	39.8%
Number of Tagged Shad Recaptured outside of Delaware Bay or Hudson	16	105
Percent of Tagged Shad Recaptured outside of Delaware Bay or Hudson	9.3%	42.7%
Recaptures in Delaware River/Bay		
Number North of Leipsic/Gandys Line	0	63
Percent North of Leipsic/Gandys Line	0.0%	25.6%
Number North of Bowers/Gandys Line	1	65
Percent North of Bowers/Gandys Line	0.6%	26.4%
Number South of Bowers/Gandys Line	4	23
Percent South of Bowers/Gandys Line	2.3%	9.4%
Number from Unk. Delaware Bay/River Location	0	10
Percent from Unk. Delaware Bay/River Location	0.0%	4.1%

Table 33. Total American Shad landings (pounds) by state and reporting region and the assignments of landings to Delaware River and mixed stock fisheries.

Year	Total Landings	New Jersey Upper Bay Landings	New Jersey Lower Bay Landings	Delaware Upper Bay Landings	Delaware Lower Bay Landings	Harvest North of Demarcation	Harvest South of Demarcation	Harvest of Delaware Stock	Harvest of Mixed Stock
1985	240,483	23,100	48,900	168,483	0	191,583	48,900	211,143	29,340
1986	261,111	17,700	63,900	179,511	0	197,211	63,900	222,771	38,340
1987	310,182	20,200	109,400	180,582	0	200,782	109,400	244,542	65,640
1988	327,302	17,300	80,700	229,302	0	246,602	80,700	278,882	48,420
1989	267,087	16,800	62,500	187,787	0	204,587	62,500	229,587	37,500
1990	637,968	40,364	212,749	384,855	0	425,219	212,749	510,319	127,649
1991	537,686	23,092	150,209	364,385	0	387,477	150,209	447,561	90,125
1992	375,814	41,765	114,035	220,014	0	261,779	114,035	307,393	68,421
1993	376,429	19,552	123,428	233,449	0	253,001	123,428	302,372	74,057
1994	246,511	9,066	41,305	196,140	0	205,206	41,305	221,728	24,783
1995	219,760	11,811	61,621	146,328	0	158,139	61,621	182,787	36,973
1996	184,137	1,100	17,563	165,474	0	166,574	17,563	173,599	10,538
1997	160,315	9,250	34,549	116,516	0	125,766	34,549	139,586	20,729
1998	99,068	75	14,180	84,813	0	84,888	14,180	90,560	8,508
1999	164,928	5,670	83,036	76,222	0	81,892	83,036	115,106	49,822
2000	175,318	43,299	78,132	53,887	0	97,186	78,132	128,439	46,879
2001	297,972	69,098	27,040	201,834	0	270,932	27,040	281,748	16,224
2002	87,127	32,746	15,671	35,466	3,244	68,212	18,915	75,778	11,349
2003	152,942	84,198	6,322	43,562	18,860	127,760	25,182	137,833	15,109

Table 33. Cont.

Year	Total Landings	New Jersey Upper Bay Landings	New Jersey Lower Bay Landings	Delaware Upper Bay Landings	Delaware Lower Bay Landings	Harvest North of Demarcation	Harvest South of Demarcation	Harvest of Delaware Stock	Harvest of Mixed Stock
2004	187,551	92,073	5,385	58,000	32,093	150,073	37,478	165,064	22,487
2005	211,594	46,543	41,441	69,383	54,227	115,926	95,668	154,193	57,401
2006	96,679	56,847	9,307	20,476	10,049	77,323	19,356	85,065	11,614
2007	134,266	53,818	9,010	56,825	14,613	110,643	23,623	120,092	14,174
2008	47,373	23,877	5,157	16,067	2,272	39,944	7,429	42,916	4,457
2009	16,091	9,264	3,381	2,436	1,010	11,700	4,391	13,456	2,635
2010	17,239	7,721	4,499	3,223	1,796	10,944	6,295	13,462	3,777
2011	21,187	6,855	5,199	5,252	3,881	12,107	9,080	15,739	5,448
2012	30,108	19,923	7,445	2,311	429	22,234	7,874	25,384	4,724
2013	41,391	13,204	24,455	2,943	789	16,147	25,244	26,245	15,146
2014	128,172	37,319	5,059	83,699	2,095	121,018	7,154	123,880	4,292
2015	31,183	6,013	3,405	21,511	254	27,524	3,659	28,988	2,195
2006-2015 Average	56,369	23,484	7,692	21,474	3,719	44,958	11,411	49,523	6,846
Time Series Average	196,289	27,730	47,387	116,475	4,697	144,206	52,084	165,039	31,250

Table 34. Recreational catch in the Delaware River by various investigators. Upper Delaware River: the non-tidal reach upriver of Port Jervis, New York (RM 253.6); non-tidal: above head-of-tide at Trenton, New Jersey (RM 133.4); tidal: below head-of-tide; and Delaware River: boundary waters of Eastern Pennsylvania.

Year	River reach	No. anglers	Total catch	Total Harvest	Catch rate (shad/hr)
Marshall (1971)					
1971	Non-tidal		25,204		
Lupine et al (1980)					
1980			7,386		0.47
Lupine et al (1981)					
1981			12,767		0.67
Hoopes et al. (1983)					
1982	Upper Del. River		37,323	31,725	
Miller and Lupine (1988)					
1986	Non-tidal	65,690	56,320	27,471	0.19
NJDEP (1993)					
1992			46,780	5,146	1.10
Miller and Lupine (1996)					
1995	Non-tidal		83,141	16,628	0.25
NJDFW (2001)					
2000					0.77
Volstad et al. (2003)					
2002	Non-tidal		34,091	6,312	0.13
2002	Tidal		1,190	315	0.008
PFBC/NPS Angler Diary					
2001	Del. R.	62	1,375	81	0.11
2002	Del. R.	52	708	67	0.06
2003	Del. R.	50	345	24	0.03
2004	Del. R.	45	330	36	0.03
2005	Del. R.	42	330	12	0.03
2006	Del. R.	35	35	0	0.01
2007	Del. R.	41	359	16	0.05
2008	Del. R.	33	207	14	0.02
2009	Del. R.	36	569	6	0.10
2010	Del. R.	30	216	14	0.04
2011	Del. R.	34	112	2	0.02
2012	Del. R.	14	19	19	0.002
2013	Del. R.	23	46	46	0.004
2014	Del. R.	9	13	13	0.001

Table 35. Recreational harvest of American Shad in the Delaware Estuary & Bay, as estimated by the Marine Recreational Information Reporting program. Total harvest reflected the estimated numbers of fish taken, per year. The Proportional standard error (PSE) express the standard error of an estimate as a percentage of the estimate and is a measure of precision. A PSE value greater than 50 indicates a very imprecise estimate.

	Delaware		New Jersey	
Year	Total Harvest	PSE	Total Harvest	PSE
1989			0	
1990				
1991	0			
1992	0			
1993				
1994	2,018	57.1	9,871	59.5
1995				
1996				
1997			2,242	100.0
1998				
1999	760	76.1		
2000			0	
2001			14,383	64.1
2002	2,068	61.7		
2003	3,577	100.0		
2004	0			
2005	0			
2006	0			
2007	0			
2008	0			
2009			0	
2010	1,724	103.3	7,678	99.0
2011	3,194	101.9		
2012			4,110	99.7
2013	0			

Table 36. River herring and shad catch by Atlantic Mackerel and Atlantic herring vessels, 2014 - 2015. Data summarized by NMFS from vessels via the Vessel Monitoring System (VMS), the Vessel Trip Report System (VTR), Dealer Reports, and the Northeast Fisheries Observer Program.

Estimated river herring/shad catch (mt)	**2014**	**2015**
Atlantic mackerel vessels	6.42	12.87
Atlantic herring vessels - ALL	N/A	176.5
Atlantic herring: GOM Mid-water trawl	N/A	11.1
Atlantic herring: Cape Cod Mid-water trawl	N/A	0.7
Atlantic herring: Southern New England bottom trawl	N/A	100.7
Atlantic herring: Southern New England mid-water trawl	N/A	64

Table 37. River herring and shad quotas for Atlantic Mackerel and Atlantic herring vessels, 2014-2015, and anticipated quota for Atlantic herring vessels 2016-2018.

Annual harvest cap for river herring/shad (mt)	**2014**	**2015**	**2016-18 (proposed)**
Atlantic mackerel vessels	236	89	82
Atlantic herring vessels - ALL	312	312	361
Atlantic herring: GOM Mid-water trawl	86	86	76.7
Atlantic herring: Cape Cod Mid-water trawl	13	13	32.4
Atlantic herring: Southern New England bottom trawl	89	89	122.3
Atlantic herring: Southern New England mid-water trawl	124	124	129.6

Table 38. Species-specific total annual incidental catch (mt) across all fleets and regions. Midwater trawl estimates were only included beginning in 2005. Modified from Amendment 14 of the Atlantic Mackerel, squid and butterfish Fishery Management Plan for the Mid Atlantic Fishery Management Council.

Year	Alewife Catch (mt)	American Shad Catch (mt)	Blueback Herring Catch (mt)	Herring Unk. Catch (mt)	Hickory Shad Catch (mt)	Total Catch (mt)	Total identified catch (mt)	Proportion of known catch that is American Shad	Estimated unknown catch that is American Shad (mt)	Total estimated American Shad catch (mt)
1989	20.4	58.9	19.6	7.1	0.0	106.0	98.9	0.60	4.2	63.1
1990	55.3	25.8	78.9	331.3	0.0	491.4	160.1	0.16	53.4	79.2
1991	68.2	104.3	115.4	110.5	39.4	437.7	327.3	0.32	35.2	139.5
1992	30.6	79.8	458.2	387.5	0.0	956.1	568.5	0.14	54.4	134.2
1993	40.5	51.0	210.6	18.6	0.0	320.6	302.0	0.17	3.1	54.1
1994	5.5	70.3	40.2	9.8	0.2	126.0	116.2	0.61	5.9	76.2
1995	6.4	17.2	213.5	51.9	0.0	288.9	237.1	0.07	3.8	20.9
1996	482.0	40.0	1803.4	28.7	26.6	2380.8	2352.1	0.02	0.5	40.5
1997	41.3	37.0	982.0	67.6	18.3	1146.2	1078.6	0.03	2.3	39.3
1998	80.9	55.3	49.3	0.4	39.2	225.1	224.7	0.25	0.1	55.4
1999	3.9	15.7	206.7	128.8	56.8	411.8	283.0	0.06	7.2	22.9

Table 38. Cont.

Year	Alewife Catch (mt)	American Shad Catch (mt)	Blueback Herring Catch (mt)	Herring Unk. Catch (mt)	Hickory Shad Catch (mt)	Total Catch (mt)	Total identified catch (mt)	Proportion of known catch that is American Shad	Estimated unknown catch that is American Shad (mt)	Total estimated American Shad catch (mt)
2000	28.4	74.4	55.5	22.0	0.1	180.2	158.3	0.47	10.3	84.7
2001	93.0	61.9	120.1	2.1	80.6	357.8	355.7	0.17	0.4	62.3
2002	2.7	24.1	173.2	76.5	1.4	277.9	201.4	0.12	9.1	33.2
2003	248.4	21.4	332.5	15.3	14.3	631.9	616.6	0.03	0.5	21.9
2004	99.7	18.2	81.5	176.7	35.0	411.2	234.5	0.08	13.7	31.8
2005	347.4	78.2	220.0	7.2	19.4	672.3	665.1	0.12	0.8	79.1
2006	57.6	29.3	187.5	232.0	13.4	519.8	287.7	0.10	23.6	52.9
2007	484.0	55.1	180.1	105.3	4.8	829.3	724.0	0.08	8.0	63.1
2008	145.0	52.4	526.6	328.0	7.8	1059.8	731.8	0.07	23.5	75.9
2009	158.7	59.5	202.0	180.1	10.9	611.2	431.1	0.14	24.9	84.4
2010	118.5	46.1	125.0	86.5	1.1	377.3	290.8	0.16	13.7	59.8

Table 39. Estimated American Shad harvest (mt), based on median rate of known shad bycatch 1989-2010 applied to actual harvest in 2014-2015.

Estimated American Shad catch (mt)	**2014**	**2015**
Atlantic mackerel vessels	0.83	1.67
Atlantic herring vessels - ALL	N/A	22.9
Atlantic herring: GOM Mid-water trawl	N/A	1.44
Atlantic herring: Cape Cod Mid-water trawl	N/A	0.09
Atlantic herring: Southern New England bottom trawl	N/A	13.09
Atlantic herring: Southern New England mid-water trawl	N/A	8.32

Table 40. Number of American Shad fry stocked in the Delaware River Basin.

Year	Delaware	Lehigh	Schuylkill
1985		600,000	251,980
1986		549,880	246,400
1987		489,980	194,575
1988		340,400	
1989		2,087,700	316,810
1990		793,000	285,100
1991		793,000	75,000
1992		353,000	3,000
1993		789,600	
1994		642,200	
1995		1,044,000	
1996		993,000	
1997		1,247,000	
1998		948,000	
1999		501,000	410,000
2000		447,900	535,990
2001		675,625	490,901
2002		85,025	2,000
2003		783,013	1,000,448
2004		366,414	521,583
2005	169,802	668,792	545,459
2006	52,782	293,083	253,729
2007	47,587	276,000	540,655
2008	158,151	696,785	486,774
2009		210,584	161,938
2010		347,522	380,000
2011		473,366	643,361
2012		301,112	200,429
2013		402,089	338,084
2014		584,730	439,136
2015		247,649	198,855

Table 41. Hatchery contribution for adult American Shad collected from the Delaware River (Smithfield Beach and Raubsville), the Lehigh River, and the Schuylkill River.

Location Gear	Smithfield Beach gill net		Raubsville electro.		Lehigh R electro.		Schuylkill R electro.	
Year	N	Percent	N	Percent	N	Percent	N	Percent
1997	88	0.00%	No collections		No collections			
1998	234	3.80%	No collections		No collections			
1999	208	0.00%	8	5.30%	104	91.00%		
2000	330	3.00%	14	10.90%	99	91.00%		
2001	198	4.00%	12	8.30%	103	92.00%		
2002	378	1.10%	No collections		99	89.00%		
2003	245	7.80%	No collections		No collections			
2004	414	1.20%	No collections		60	80.00%		
2005	776	0.50%	No collections		13	62.00%		
2006	350	1.40%	No collections		55	73.00%		
2007	746	2.80%	No collections		40	58.00%	22	91.6%
2008	667	1.00%	No collections		41	51.00%	28	100%
2009	367	1.10%	No collections		27	63.00%	24	96.0%
2010	470	0.20%	1	0.90%	96	67.00%	25	100%
2011	409	0.50%	0	0.00%	16	56.00%	22	88.0%
2012	412	1.00%	80	2.50%	62	42.60%	21	84.0%
2013	454	0.20%	146	2.70%	76	73.70%	25	84.0%
2014	488	1.40%	129	3.10%	80	58.80%	25	88.0%
2015	Not Examined		62	0.0%	62	32.3%	4	100 %

Table 42. American Shad impingement and entrainment data for selected water intake structures for power generation facilities on the Delaware River and major tributaries.

		During Study		Annual Estimates	
Power Generation Facility	Years of Data Collection	Number Entrained	Number Impinged	Number Entrained	Number Impinged
Cromby Phoenixville, PA*	2005/2006	0	47	0	716
Delaware City Refinery New Castle, DE	1998/2000	Not reported	417	Not reported	Not reported
Eddystone Eddystone, PA	2005/2006	76	95	2,044,000	657
Edge Moor Wilmington, DE	1999/2001	43	3,684	Not reported	Not reported
Fairless Hills Fairless Hills, PA	2005/2006	170	0	892,422	0
Salem Salem, NJ	2002/2004	0	Not reported	0	88,189
Schuylkill Philadelphia, PA	2005/2006	0	6	0	398
Trainer Refinery Trainer, PA	2001	12,716,936	0	Not reported	Not reported

*Cromby is located on the Schuylkill River which currently has very limited American Shad upstream passage. Impingement occurs on hatchery stocked individuals at this time.

Appendix A: Delaware River American Shad (*Alosa sapidissima*) Ageing Protocol

Delaware River American Shad (*Alosa sapidissima*) **Ageing Protocol**

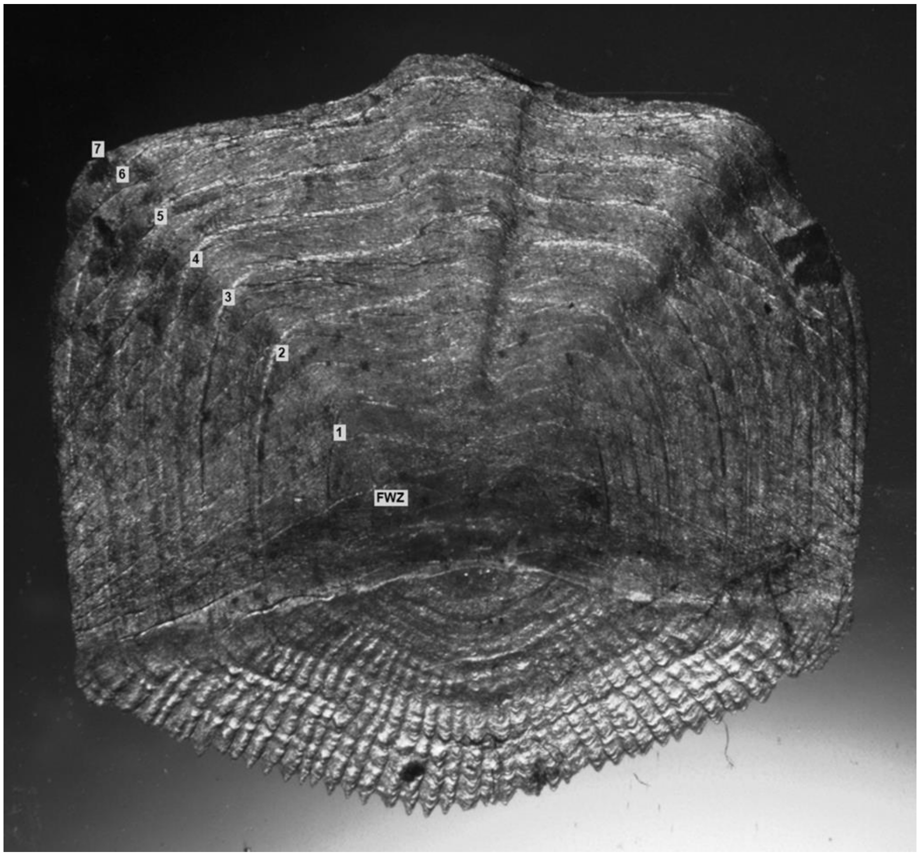
Prepared by:

The Delaware River Basin Fish & Wildlife Management Cooperative

Delaware Division of Fish and Wildlife • New Jersey Division of Fish and Wildlife

Pennsylvania Fish and Boat Commission • New York Division of Fish, Wildlife & Marine Resources

U.S. Fish and Wildlife Service • National Marine Fisheries Service



December 15, 2014

Table of Contents

I. Introduction

American Shad (*Alosa sapidissima*), an anadromous fish, return to their natal freshwaters in the spring for spawning. Eggs, fry and young-of-the-year (YOY) juveniles develop in freshwater during summer. Juveniles subsequently emigrate to estuarine/oceanic waters in fall. Adults reside in the coastal waters of the eastern Atlantic Ocean, seasonally migrating up/down the coastline. Indigenous to the Delaware River basin, shad are considered iteroparous spawners, meaning many individual adults perish after spawning; whereas, other adults survive, returning to oceanic waters until migrating into freshwater again in following year(s) for spawning. Yearling shad, however, are known to reside in estuarine waters.

American Shad are critical for maintaining the ecological and cultural integrity of coastal river systems. Returning adults and subsequent eggs, fry, and juveniles are a vital forage basis for a plethora of aquatic and terrestrial predators and scavengers, throughout the early spring through late fall. American Shad are also a desired gamefish and contribute significantly to the cultural and recreational values of the Delaware River fisheries. Thus, supporting a solid self-sustaining population of American Shad translates into a robust forage basis and fisheries opportunities for river systems.

Within the Delaware River, management of American Shad is a joint effort among the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op), under the direction of the Atlantic States Marine Fisheries Commission (ASMFC). In February 2012, the ASMFC accepted the Co-op's American Shad Sustainability Plan (SFP). Population benchmarks and management actions are detailed in the SFP for the sustainability of the Delaware River American Shad population and fisheries.

The SFP identified the need for developing age-based benchmarks. Prior to the SFP, ageing American Shad scales and otoliths were accomplished on an *ad hoc* basis. Most scale/otolith (>1,000 annually) collections were accomplished by the Pennsylvania Fish and Boat Commission (PFBC) at Smithfield Beach (RM 218) and/or Raubsville (RM 176). Both sites are located well above head-of-tide at Trenton Falls (RM 133). Scales from these sites tend to be heavily damaged due to reabsorption/erosion of scale edge material. It is believed, shad reabsorbed scale material to support the energetic cost associated with their upstream migration into freshwater, in some cases over 200 miles upriver to Hancock, New York (RM 330), and then be able to successfully reproduce. The New Jersey Division of Fish and Wildlife (NJDFW) also annually collects samples from the lower Delaware

Estuary; and the Delaware Department of Natural Resources and Environmental Control (DNREC) annually purchases scale samples from shad bycatch in the Delaware Estuary Striped Bass fishery. Each agency individually collected and aged their samples, with little inter-agency discussion of ageing protocols or quality controls.

The interpretation of scale microstructure is an arduous task. Historically, ageing protocols were largely reliant on methods described by Cating (1956). Annuli of a particular age, Ages 1 - 3, were identified by counting transverse grooves above the base line. Each annulus was assigned based on the counts. For example, Age 2 was defined to be between approximately 8 – 11 (average 10) transverse grooves. McBride *et al*. (2005), and Duffy *et al*. (2012,) questioned the validity of ageing American shad by scales, suggesting annuli were not related to transverse groove counts. The inconclusiveness of ageing shad scales in the Delaware River prevented inclusion of age-based benchmarks in the 2007 ASMFC American shad stock assessment (ASMFC 2007). Since 2007, scales and otoliths have been annually collected by Co-op members and aged (*ad hoc* basis), but remained unused for management purposes.

Concomitantly, PFBC was ageing American shad otoliths. Known-age shad were derived from chemical marking (OTC) daily tagging patterns in fry otoliths, which were then stocked in the Lehigh and Schuylkill rivers, tributaries to the Delaware River. Returning adult shad were harvested and origin and year-of-release was determined by the presence of the daily tagging pattern. Daily tagging patterns required grinding the otolith to view the core; whereas, ageing was accomplished by viewing the whole otolith. Known-age was the simple subtraction of year-at-capture minus year-of-release. Yet, known-age otoliths, gave no indication of which otolith microstructures were true annuli versus false/double bands. Ambiguity in correctly identifying true otolith annuli and how to assign Age 1 resulted in readers' under- or over-estimating the known-age, typically by a single year. Furthermore, repeat spawning cannot be ascertained from otoliths, only from scales. Poor agreement was also found between estimates of age derived by scales to known-age totals. Hence, the utility of otoliths for ageing Delaware River American shad has limited success or acceptance.

Since the implementation of the SFP, the Co-op has begun revisiting ageing Delaware River American shad scales. The goal was to determine if Co-op members could consistently age American shad via scales under a single agreed upon set of protocols. In September 2012, an initial two-day ageing workshop was held (Hancock, New York) by Co-op members. Scales and otoliths were viewed by the collective group, with extensive discussions on how each agency identified and aged scales and otoliths. Personnel were in general agreement on interpreting various scale microstructures; assignment of Age 1 was quickly identified as problematic among agencies. A review of otoliths also quickly revealed similar problematic issues. Co-op members decided to focus on pursuing scales for determining shad ages. A follow up ageing workshop was held a year later (September 2013 at Hancock, New York) were scales and protocols were further discussed.

An outcome of the second ageing workshop was a blind test set of scales and initial set of ageing protocols. The intent of the blind test set was to provide a measure of agreement between agency personnel. Only date, location-of-capture and scales were included. Scales were randomly selected by size class from four locations: Smithfield Beach (n = 25), Raubsville (n = 25), Lambertville (n = 25), and upper Delaware Estuary (n = 25). Personnel with various levels of experience ageing American shad scales then derived ages and frequency of repeat spawning marks for each scale. Agencies were allowed to age the scales using their own preferred methods, but all readers would age the same scale samples.

Comparison of age assignments among readers were analyzed using a standard precision template developed by NOAA's Northeast Fisheries Science Center. Templates can be found at http://www.nefsc.noaa.gov/fbp/age-prec/. Precision was evaluated by examination of the mean coefficient of variation (CV), percent agreement and the Bowker's test of symmetry. Ageing laboratories around the world view a measure of mean CV of 5% or less to be acceptable (Compana (2001). Mean CV's of the blind test set ranged from 3.66% and 21.14%. Percent agreement ranged from 76% agreement to 4 % agreement. Readers from within the same agency consistently had the lowest CV's and highest percent agreement. Readers with minimal experience ageing shad scales consistently had the highest CV's and lowest percent agreement when compared to all readers regardless of experience. Therefore, age determinations of inexperienced readers must be interpreted with caution. Co-op members agreed that the differences between experienced readers from various agencies were in the identification of the first annulus, resulting in a one year discrepancy of assigned ages.

Based on the blind test results, Co-op members held a third ageing workshop, December 2014 at New Paltz, New York. The intent was for Co-op members familiar with American shad scale ageing to develop an agreed upon reference set of scales. A reference set would aid in uniformity of identifying scale structures, possibly increasing consistency of age derivations. Differences in scale microstructure interpretations were discussed including, identification characteristics and assignment of annuli, identification of the first annulus and repeat spawning marks. A total of 50 specimens were accepted as reference scales. In order to assess the suitability of the reference set, the Co-op sought third party confirmation from the Massachusetts Division of Marine Fisheries ageing lab in Gloucester, MA. The reference set was independently examined by the Massachusetts ageing lab. Results of their age determinations were compared to the Co-op ages using a standard precision template as described above. Percent agreement was 73.6% with a CV of 3.65%. These values fall within the accepted ranges for precision. A final result of the December 2014 workshop is an agreed reference set and updating of the informal ageing protocol, for Co-op member use.

The goal for these workshops (and future workshops) is to train and re-train Co-op members in interpreting American shad scale microstructures. Specific objectives are to: (1) develop and use a standard ageing protocol for assisting Co-op members to consistently interpret American shad scale microstructure for age and repeat spawning marks; (2) provide the mechanism for production ageing of Delaware River American shad scales; and (3) provide a mechanism for developing total mortality estimates usable as benchmarks in an American shad SFP.

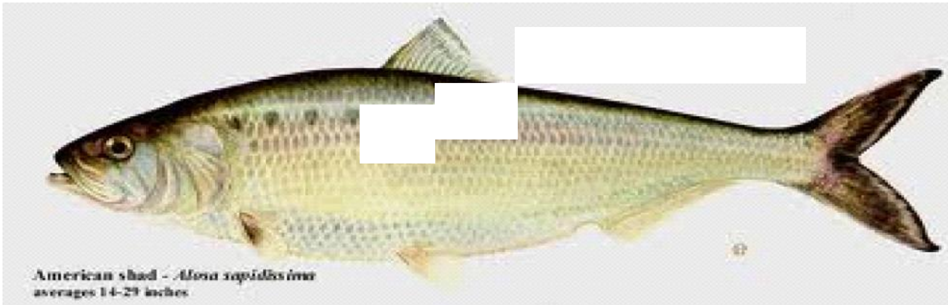
II. Scale Sample Collection

- Each fish is given its own unique sample ID (river, year, and fish number)
- Total Length (mm), fork length (mm), weight (g), sex (male or female), stage of maturity (gravid, ripe/running/ spent), capture date and sample ID number are recorded on scale envelopes and data sheet.
    - Total length (mm) is the distance between the tip of the mouth (when closed) to the tip of the caudal fin (when gently compressed).
    - Fork Length (mm) is the distance between the tip of the mouth (when closed) to the center of the caudal fin (the bottom of the "V")
    - The illustration demonstrates total and fork length. Note the picture has the mouth open. The line is placed when the mouth is assumed to be when closed.

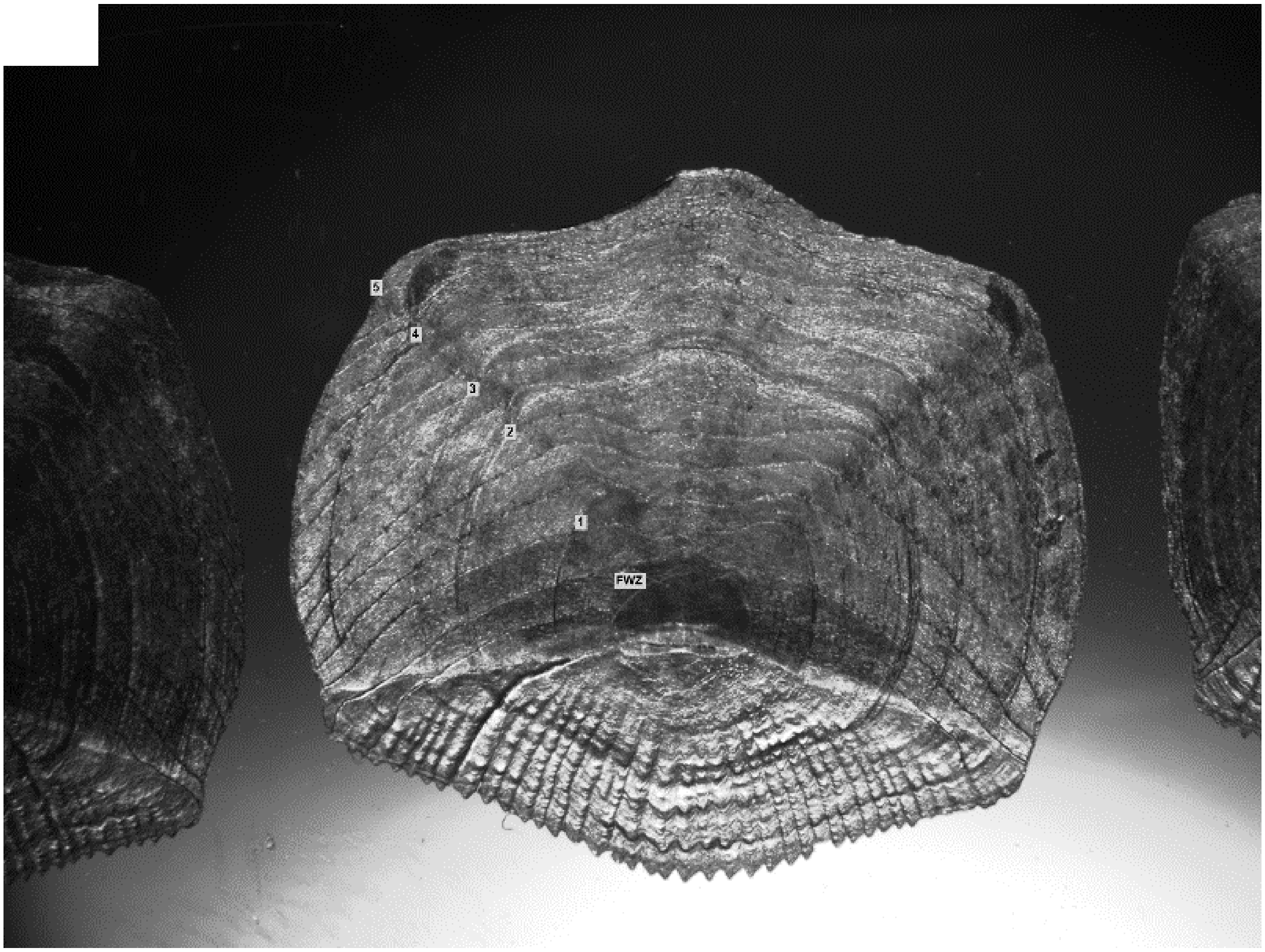
- Scales are collected just ventral of the dorsal fin
    - Before removal use a knife to remove the slime coat and any dirt from the area scales are to be removed on the carcass.

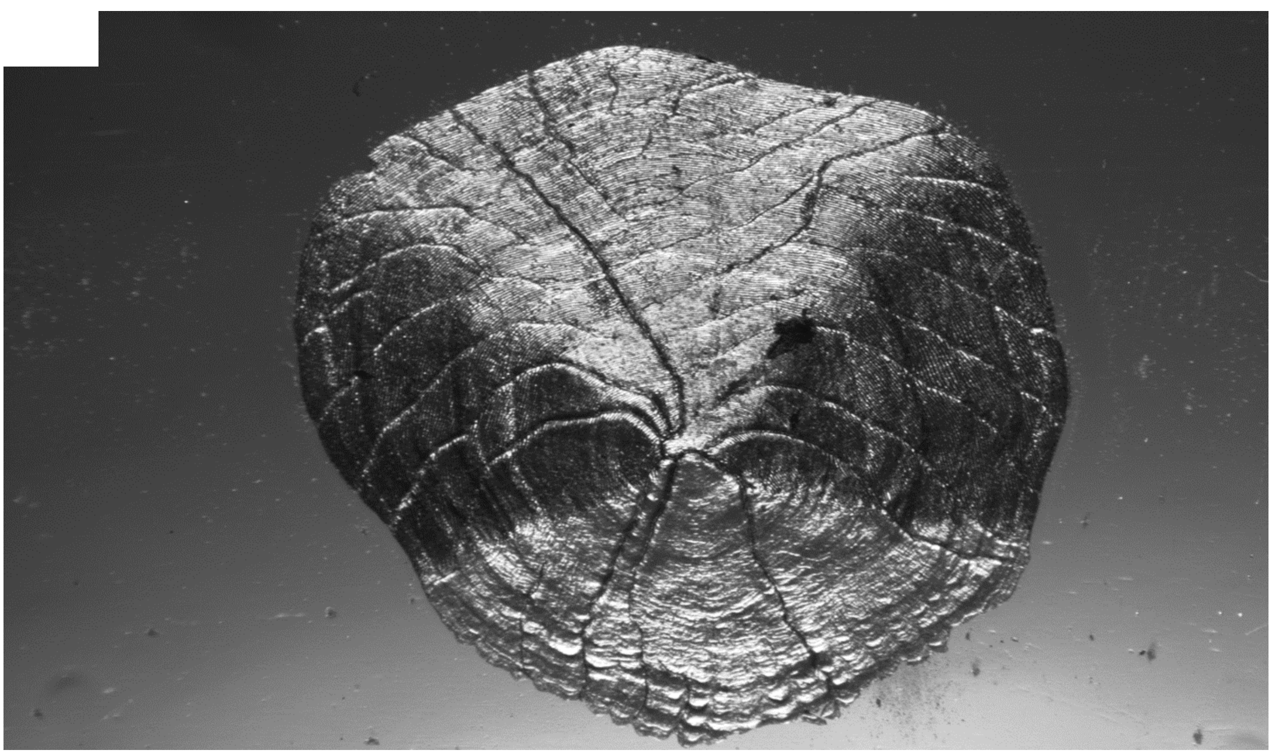
- Ensure the knife is also free of any dirt, slime and previous fish scales.

- Scales taken near the dorsal fin, high up on the fish back tend to be more circular and not conducive for age determination. These are to be avoided.



- Remove approximately 20 or more scales and place into an envelope with the corresponding sample ID number.
- Scales are to look like rounded squares (A), not oblong (B) (See pictures below).


5
4
3
2
1
FWZ



III. Scale Preparation and Mounting

- Scales must be cleaned before age assignment
- Scales should be directly read
- To reduce unnecessary handling, a cursory visual inspection of each scale to be cleaned/mounted should be able to identify regenerated scales (Figure 1). Any regenerated scale should **NOT** be mounted or used for age interpretation.

A. Preferred Cleaning Method

- Make up a Pancreatin solution 500mL water with 3.5g Pancreatin. Place on a stir plate and let mix for approx. 10 mins.
- After initial 10 minute stir, reduce the speed of the stir plate to low and allow to continue to mix slowly.
- Select approximately 10 "good" scales, (i.e., avoid regenerated scales) and place into a centrifuge tube (one sample per centrifuge tube).
- Then fill each centrifuge tube with 15-20mL of Pancreatin solution then place in a sonicator.
- Each batch will contain 10 samples, sonicate for 15mins.
- Remove samples from sonicator and empty scales into a fine mesh strainer on sample at a time.
- Wipe, rinse and dry scales. Make sure scales are dry; any moisture between slides will cause distortion when viewing the scales under magnification.
- Either immediately mount (preferred) or store in a folded piece of paper in the original scale envelope.

B. Alternative Cleaning Method

- Minimally, scales need to be thoroughly soaked to loosen adhered tissue using a solution of liquid detergent and water
- Gently wipe, rinse and dry scales.
  - o After soaking, rubbing the scales between fingers will move most of the debris, and then gently blot with paper towels.
- Either immediately mount (preferred) or store in a folded piece of paper in the original scale envelope.

C. Mounting

- It is critical that scales are completely dry
- Reading directly off the scales eliminates difficulties inherent in less than quality impressions. Interpretations of age from scale impressions, however, are generally as dependable as the direct procedure, but tend to require greater processing time

Direct viewing

- Scales can be viewed directly in either a digital computer system or microfiche.
  - o If possible directly viewed scales can be mounted between two glass slides tapping the ends together and labeling one with the corresponding sample ID number.
    - ▪ Multiple scales from the same shad specimen should be mounted between the slides. A minimum of three scales need to be mounted. More should be mounted if space on the slide is available.
    - ▪ Glass mounted scales are typically stored separately in plastic sleeves in a three-ring binder
  - o If viewing with a microfiche, typically, mounting between glass slides is impractical, due to limited focus
    - In this case, a series of cleaned scale(s) can be placed on the microfiche bottom plate
    - A minimum of three scales from the sample need to be on the viewing plate
    - Any scales not mounted are stored in the original scale packet

Impressions

- Historically, impressions of scales were taken and viewed under a microfiche. Age is interpreted from the impression rather than directly from the scale. This procedure has fallen into disfavor and is presented here as a historical reference. This procedure uses the “rough” side of the scale to form an impression in acetate under heat and pressure. The ridge/valleys of the scale are then reflected in the pressed acetate
- Pressing scales requires the use of a Carver heated 12 ton press (Model 2112), two aluminum base plates (6in x 6in), two pieces of thin cardboard (cereal box material), two polished stainless steel impression plates (6inx6in), and one piece of acetate (6in x 6 in).
  - o Pressing involves creating a “sandwich”. The acetate is to be oriented between the stainless steel plates (polished side towards acetate) and then the thin cardboard (to protect the stainless steel plates) and then Aluminum base plates.
  - o Any scratches in the stainless steel plates are pressed into the acetate. Hence the use of the cardboard to reduce this possibility.
  - o Prior to loading the press the heating plate should be set at 100 degrees Celsius
- Acetate is to be scored to produce 10-1in x 3 in segments
- Acetate sheets need to be cut to the shape of the stainless steel pressing plates. These sheets can hold multiple scale samples, thus the order of sample number is to be written as the acetate is prepared
- Create the bottom of the “sandwich” by placing the base plate on the table, followed by the cardboard, then stainless steel plate (polished side up towards the acetate), then the scored acetate.
- A series (minimum of three per specimen), cleaned, <u>dry</u> scales are placed on the acetate. Usually 5-8 scales can be mounted per specimen.
  - o **IMPORTANT:** Scales have a “smooth” side and a “rough” side. Scales must be oriented “rough” side facing down onto the acetate in order for a proper impression. The scales can be examined using tweezers or fingernails to determine the “rough” side.

- Once all scales are loaded on the acetate, carefully complete the “Sandwich” with the remaining stainless steel plate (polished side down towards the acetate), then the cardboard, then the remaining base plate.
- Carefully, place the “sandwich” in the press
- Once the “sandwich” is in the press the hydraulic pump should be set at 5000 psi and allowed to bake (@ 100 ^{o}C) for 5 minutes
- After 5 minutes, using leather gloves, remove the plates from the press and allow to cool for approximately 10 minutes.
- Once cooled, the acetate can be removed and cut into individual sections
- Assign proper identification to each piece as it is cut from the acetate and place into corresponding scale envelope
    - Acetate should be marked with the specimen ID
    - These may also be stored separately from the scale envelope, such as slide trays to reduce scratches and/or unnecessary bending.

IV. Scale Interpretation

A. Magnification

- A consistent magnification should be set for all scale samples. Increased magnification (i.e., zooming in) to highlight a specific area of the scales, should only be used to identify edge structure.
    - For instance, increased magnification may help determine a repeat spawning mark
- Typically, a broader view of the scale (as opposed to focusing in on specific points) tends to provide better consistency of identifying scale structures (Figure 2).
    - Magnification should be set to view the scale in its entirety on the display screen. Readers should not need to continuously adjust magnification or scale position on the screen to identify scale structure.

B. Scale orientation

- Scale orientation on a view screen is generally individual reader preference. Yet, general convention of most readers is to orient the scale with the anterior portion to the top of the viewing screen (Figure 2).
    - The anterior potion of the scale is the embedded portion of the scale in the fishes’ skin. This portion of the scale has varying contrasts, but generally looks flat/smooth.
    - The posterior portion of the scale is exposed to the elements. This portion of the scale appears as rows of “teeth” and has a rough appearance. Annuli typically appear as dark bands. Typically readers orient the posterior portion to the bottom of the viewing screen.
    - The dorsal side is towards the back/top of the shad closest to the dorsal fin of the fish. On the viewing screen, if the anterior portion of the scale is oriented to the top of the screen, then the dorsal side is to the readers’ right.

- o The ventral side is towards the belly of the fish. On the viewing screen, if the anterior portion of the scale is oriented to the top of the viewing screen, then the ventral side is to the readers' left.

C. Identifying regenerated scales

- Regenerated scales represent replacement of lost scales (Figure 1). They are easily identified by their "chaotic" appearance in the scale focus, lacking any organized structures. These scales are formed by extreme rapid growth to ensure protection of exposed skin.
  - o Regenerated scales are not to be used for age determination or repeat spawning marks.
  - o Regenerated scales formed at a younger age generally have a relatively smaller disruption of scale structure, than scales lost at an older age. Occasionally, the periphery of a regenerated scale, however, may illustrate consistent ageing structures that may only help clarifying difficult structures on other scales and not be used in age/repeat spawning mark assignments.

D. Identifying the base line

- The baseline is the separation between the posterior (portion of the scale exposed) from the anterior (portion embedded in the fish skin) of the scale. This is typically viewed as a heavy groove across most of the scale, running between the dorsal and ventral sides (Figure 2).

E. Identifying transverse grooves

- Transverse grooves appear as thin dark lines crossing the entire scale (Figure 2).
- Generally, transverse grooves are oriented dorsal to ventral sides for the scales. They are typically parallel with the base line.

F. Identifying the freshwater zone

- The freshwater zone (FWZ) is typically the first dark area near the scale focus that travels through both anterior and posterior portions of the scale and indicates the time spent in the freshwater portion of the estuary before entering saltwater. It is NOT the first annulus (Figure 3).
  - o Usually, but not always, the FWZ may appear as a concentric ring in both the anterior and posterior portions of the scale (Figure 3)
  - o On rare occasions, double banding may be associated with the FWZ in the posterior portion of the scale (Figure 3).

G. Identifying annuli

- An annulus (annuli – plural) is identified as a smooth band that MUST be visible through both the anterior AND posterior portion of the scale (Figure 4).
  - o Annuli appear as concentric rings for multiple ages. In the anterior portion, they have a slight convex shape on the dorsal and ventral sides.

        - Readers should be able to trace annuli on all sides (anterior, posterior, dorsal and ventral) of the scale.
    - Frequently, annuli can appear to be a “broad” or “wide” band (Figure 5), rather than a concise line.
    - Increasing/decreasing contrasting light may improve identification of annuli. If using a microfiche, colored acetate may be used to change contrasting lighting.
    - Along the sides of the scale (ventral and dorsal), annuli are generally perpendicular to transverse grooves.
- Each scale should be viewed for annuli from several different focal views to confirm annuli are visible around the scale (Figure 6).
    - Annuli are easier to determine in the anterior portion of the scale, but can become obscured with false annuli and/or double banding.
    - When reading the anterior portion of the scale, typically readers orient the scale with the anterior portion of the scale to the top of the viewing screen, such that anterior is “up” and posterior is “down” relative to its projection.
    - Readers typically, look at the anterior portion first reading from the middle of the scale, either “up” to the left or right. Annuli are then traced into the posterior and through the “peak” of the anterior portion of the scale.
    - Reader may also start on the outside edge and work towards the middle as well.
- The first annulus (i.e., Age 1) is typically not readily apparent or “strong” (Figure 7). Meaning when viewing the scale, readers’ typically interpret the first readily apparent mark as Age 2.
    - Age 1 is usually in close proximity to the FWZ, but on occasion may be relatively distant from the FWZ. Usually, the dark FWZ is followed by a slightly lighter shade. The Age 1 annulus generally resides in this lighter shade.
    - Occasionally the Age 1 annulus is very apparent (Figure 4). When this occurs, recognizing its relative positioning to the FWZ and Age 2 annulus will help identify Age 1 annulus in other specimens’ scales.
- The second annulus (Age 2) is typically easily identified (Figure 7). It tends to be a strong mark (i.e., high contrast) in the anterior portion of the scale, easily traced into the posterior.
    - The relative position of Age 2 annulus can be variable, appearing closer to Age 3 than Age 1 annuli or vice versa.
    - Usually the Age 1 annulus is difficult to readily identify. Thus, readers typically use the inner most annulus that is readily apparent as the Age 2 annulus.
        - Once Age 2 is assigned, readers can usually find Age 1 and FWZ, using the posterior portion of the scale if both are weakly defined in the anterior.
- The appearance of Age 3 annulus or older annuli tend to be similar to Age 2 annulus.
    - The distance (or “spacing”) between annuli can be variable. Spacing may conform to traditional theory: greatest distances between the younger annuli (i.e., Age 1, 2, and 3); and smaller distances between the older annuli (Figure 7). Yet, in some shad, the just the opposite has been observed. (Figure 8).
- Severe scale erosion on the edge in the current year or previous years (i.e., repeat spawning) may eliminate previous years’ annulus or multiple annuli structures.
    - In cases of severe erosion, the very tip “peak” of the anterior portion and/or the posterior portion of the scale are the only remaining areas of the scale for identifying annuli (Figure 9).

    - Edge erosion is typically greater on the dorsal and ventral sides relative to the anterior and posterior edges where edge erosion is relatively less.
    - One common feature aiding identification of lost annuli on the dorsal/ventral edges is the "Y" effect (Figure 10).
        - When tracing annuli along in the anterior edge, annuli appear to converge near the corners of the anterior edges into a single band along the dorsal/ventral edges, then separate into separate bands, just below the base line in the posterior portion of the scale. This convergence/separation visually looks like the letter "Y". If viewing the scale with the anterior portion of the scale oriented to the top of the viewing screen, the "Y" effect in the posterior is upside-down.
        - In the case of multiple years being lost on the dorsal/ventral edges, multiple annuli in the anterior/posterior will appear to converge/separate.
- Occasionally, a high contrasting band occurs almost directly on the outer edge (Figure 11). Conventional thought is: shad form annuli during the spring spawning run in May. Thus, the appearance of this annuli right at the edge of the scale may be the start of the year-of-capture's annulus. Without confirmation of the timing of annuli formation, however, this mark is not counted as an age, using the scale edge as the year-of-capture annulus.
- The outer edge of the scale is counted as an annulus, if specimen is collected in early spring.
    - The convention of counting the outer edge as annulus originates in Cating (1953).
- False annuli appear similar to annuli in the anterior portion of the scale, BUT do not cross the base line into the posterior portion of the scale (Figure 12). This is the key characteristic for distinguishing false annuli from annuli.
    - False annuli tend to be dark, concise, concentric lines in the anterior portion.
    - False annuli commonly appear as "double banding" (Figure 13).
    - False annuli can have relatively greater separation (i.e., spacing) from annuli.
- Double banding are false annuli (Figure 13). Their appearance is similar to a false annuli, typically a dark, concise, concentric line in the anterior portion, but they are typically in close proximity (i.e., little separation/spacing) from an annuli. Hence, the annuli and the false annuli are collectively referred to as a double band.
    - It is not uncommon to have multiple false annuli between annuli.

H. Identifying repeat spawning marks (SPM).
- The presence of a repeat spawning mark(s) is interpreted as the returning individual shad has spawned in previous year(s). Repeat spawning marks are created by the loss of scale material along the outer edge, and in subsequent years new scale material is deposited beyond the original damaged edge; resulting in non-uniformity appearance to the scale microstructure. This is most pronounced along the dorsal and ventral sides.
    - Multiple repeat spawning marks may be illustrated for a shad, indicating it has returned to its natal waters in multiple years.
    - A scale interpreted as having a single repeat spawning mark, suggest the shad has spawned twice: once in a previous year, and currently in the year-of-capture.
    - First-time spawners do not have any repeat spawning marks - their first spawning event is the year-of-capture.

- Scale erosion is generally greater on the dorsal and ventral sides of the scale relative to less erosion on the anterior and posterior edges. Sever cases of lost edge material may include more than one annuli either partially or wholly eliminating annulus(i) from the dorsal and ventral sides.
- Spawning marks are identified as annuli with breaks, fractures, jagged (jiggety) bands (Figure 14) as opposed to non-spawning mark annuli that have smooth band formation (Figure 7).
  - Typically female shad return to natal waters at Age 4 or Age 5; Male shad return at Age 3 or 4. Thus, repeat spawning marks can be expected to begin to occur at these ages.
    - Precocious shad have been known to return earlier and or yearling shad are known to reside in estuarine waters. These behaviors may result in a repeat spawning mark type mark at young ages. Given the inability to differentiate between spawning and residency in estuarine waters, any disruptions of smooth annuli are to be interpreted as repeat spawning marks.
  - Sever erosion of edge material may eliminate multiple annuli
    - In the corners of the anterior, annuli will appear to converge into a single band along the dorsal and ventral edges, then separate into distinct bands in the posterior. This is called a "Y" effect (Figure 10). The convergence of annuli visually appears as the letter "Y" (assuming the scale is oriented with the anterior portion to the top of the viewing screen). In the posterior, the "Y" will be upside-down.
    - Cating (1956) also describes a "Y' effect. Although, Cating (1956) did not label the microstructure as a "Y".
  - A "pocket" or "bell" (Figure 15) may be evident on the base line, suggestive of repeat spawning mark(s). This structure is when erosion on the base line forms a strong concave edge.
    - "Y" effects may be distinguishable below the pocket.
    - Subsequent growth may camouflage a pocket in previous years.
  - Breaks in transverse grooves across an annulus can be an indication of a repeat spawning mark and should be considered but is not a required criterion for determining a repeat spawning mark (Figure 16).
  - Repeat spawning marks must be present on both ventral/dorsal sides and must be present over most of the annulus on either side.
  - Repeat spawning marks observed at Smithfield Beach tend to be straight ("flat line") opposed to following the scale edge contour (Figure 17).
- Skipped spawning occurs. Meaning shad spawn, survive and return to the ocean, but do not return for spawning in the following year (Figure 18).

I. Assignment of age and repeat spawning marks
   - View several scales (minimum of three) prior to age assignment to identify <u>consistent</u> scale markings among all scales. Dissimilar scales should be removed from age analysis, possibly eliminating the entire sample.
     - Patterns in annuli formations often become apparent to the reader after viewing many specimens when production ageing. Recognizing patterns will develop with the readers' experience. Recognizing patterns will also aid in with consistency of ageing the scales.

        - For instance, the distances (i.e., spacing) between annuli tend to be the same among shad in a given year. Exceptional differences in distances between annuli (great or small) tend to be found similar among annuli.
    - All scales mounted or a minimum of three scales per specimen should be reviewed/assessed for age. Identified annuli should be apparent in the majority of the scales reviewed per specimen.
- Final age assignment is based on the derived age from the majority of the scales of an individual specimen.
    - Ageing of shad should be accomplished without any knowledge of other biological information (i.e., length, weight, gender, etc.) that could unduly influence age assessments.
    - Age is the total number of concentric identified annuli plus the scale edge, which is counted as an annulus (Figures 4 and 7).
    - The Delaware River American Shad tend to be a "young" population. Typically most of the returning spawning adults are ages 4 to 6. In exceptional year classes, older shad, ages 7 to 9 have been observed, but more as a rarity.
- Frequency of repeat spawning assignment is the total number of repeat spawning marks observed in the majority of mounted scales
    - The scale edge is not interpreted as a repeat spawning mark. Thus, if no SPMs are identified within the scale from previous years (i.e., the shad is a first-time spawner), then the repeat spawning mark is assigned a value of zero (0).
    - In instances of sever erosion and subsequent loss of multiple annuli, this sample should be discarded for assignment of repeat spawning marks.
    - Frequency of repeat spawning marks in Delaware River American Shad tends to be low. First-time spawners have been observed at age 8 and as young as age 3. Most Delaware River shad are first-time spawners, meaning no SPMs are evident. The year-of-capture is the first-time they are returning to spawn. Second-time spawners are uncommon, meaning only one SPM is evident in the scale microstructure. Two and three SPMs are a rarity.
- First impressions are important. When viewing a scale, get an overall impression of the scale prior to attempting to identify specific annuli/spawning marks. Then through the process of identifying specific annuli/repeat spawning marks attempt to rectify with the first impression.
- Occasionally, first impressions of scales suggest structures are difficult to readily identify. Rather than attempting to work through the scale, instead pass over to a different scale from the same specimen. Not all scales are as easily interpreted. Structures on one scale may be difficult to identify, but are readily apparent on another scale from the same specimen.

V. Reference Set

A. Utility

- The goal of the reference set is to keep all readers of Delaware River American Shad scales as consistent as possible.

    - Actual scales (slide mounted and impressed) are archived by the Pennsylvania Fish and Boat Commission.
    - Picture references (labeled (Appendix A) and un-labeled (Appendix B) pictures) are available on the Co-op ftp site or compact disk. Please contact Daryl Pierce, Pennsylvania Fish and Boat Commission, dapierce@pa.gov, 570 – 588 - 6388 for access.
- A reference set of agreed upon scale ages and repeat spawning marks has been defined by Co-op members.
    - The initial reference set (n = 50) was derived in December 2014 workshop, by members from NYDEC, DNREC, and PFBC. This set was evaluated by the Massachusetts Division of Marine Fisheries resulting in acceptable standards of precision.
    - Scale samples will be added or deleted in future ageing workshops.
    - The frequency of updating the reference set will be on an "as needed" basis, by Co-op member consensus.
    - If possible, third party confirmation will be sought for all reference set additions.
    - Unique specimen identifiers will be assigned to all reference samples. Only location and date captured are to be included with any reference samples. No biological data (i.e., length, weight, gender, etc.) is permissible.
- Prior to production ageing, readers will re-familiarize themselves with interpreting shad scales using the reference set.
    - Readers will attempt to assess age/repeat spawning frequency on the unmarked reference set.
    - Derived ages can then be compared to the agreed upon age/repeat spawning frequencies.
    - Differences greater than a CV 5% would indicate the reader should spend more time familiarizing themselves with scale structure identification.

B. Individual scale descriptions
- Listed below are individual scales in the reference set. Information included is the year-of-capture (all in May), date (month/year) accepted into the reference set, Location-of-capture, Specimen ID, age, total number of repeat spawning marks (SPM), and specific commentary for highlighting particular scale characteristics.
    - Pictures are organized by Specimen ID.
    - Accompanying pictures of each specimen are available in Appendix A with identifying microstructures labeled. Appendix A allows for training for recognizing microstructures.
    - Appendix B is the same picture of each specimen in Appendix A, but microstructures remain unlabeled. Appendix B allows a reader to "test" their consistency of scale interpretation, prior to production ageing.
        - When "testing" using Appendix B, the reader should allow sufficient time (i.e., a few days) to pass prior to testing, avoiding associating Specimen ID ages from Appendix A to the unlabeled scale.

Reference American shad scale set (ver. Dec 2014, original set)						
Year-of-capture	Accepted	Location	Specimen ID	Age	SPM	Comments
2012	Dec 2014	known age	3046	7	0	
2012	Dec 2014	known age	3130	7	0	Went conservative with SPM; age 6 is eroded away
2012	Dec 2014	known age	3134	7	2	
2012	Dec 2014	known age	3405	6	0	
2012	Dec 2014	known age	5034	5	0	
2012	Dec 2014	known age	5043	5	0	
2012	Dec 2014	known age	5136	3	0	
2012	Dec 2014	Raubsville	12-R-1	5	0	Very weak annulus at age 3
2012	Dec 2014	Raubsville	12-R-2	4	0	
2012	Dec 2014	Raubsville	12-R-3	5	0	
2012	Dec 2014	Raubsville	12-R-5	5	0	
2012	Dec 2014	Raubsville	12-R-8	5	0	
2012	Dec 2014	Raubsville	12-R-11	4	0	
2012	Dec 2014	Raubsville	12-R-15	5	0	
2012	Dec 2014	Raubsville	12-R-16	5	0	
2012	Dec 2014	Raubsville	12-R-18	5	0	
2012	Dec 2014	Raubsville	12-R-19	5	1	
2012	Dec 2014	Raubsville	12-R-20	5	1	Good example of straight edge erosion
2012	Dec 2014	Raubsville	12-R-21	5	0	
2012	Dec 2014	Raubsville	12-R-22	7	0	

2012	Dec 2014	Raubsville	12-R-23	7	1	
2012	Dec 2014	Raubsville	12-R-24	5	0	Good example of atypical band width
2012	Dec 2014	Raubsville	12-R-25	7	0	Beautiful scale, supermodel style
2012	Dec 2014	Smithfield	12-S-1	8	1	Skip spawn: Spawn mark (SPM) at 6, no SPM at 7; 7 close to edge, but crosses the baseline in both spots. Tough to see last annulus on microfiche
2012	Dec 2014	Smithfield	12-S-2	7	1	Supermodel
2012	Dec 2014	Smithfield	12-S-3	5	0	
2012	Dec 2014	Smithfield	12-S-4	5	0	False annulus between year 2 and 3 (cannot follow it all the way around)
2012	Dec 2014	Smithfield	12-S-6	6	0	
2012	Dec 2014	Smithfield	12-S-7	5	0	Good example where 1st annulus is pretty far from freshwater zone. False check between 3 & 4
2012	Dec 2014	Smithfield	12-S-8	5	0	Went conservative on spawn mark (on left side of many scales, but not right side)
2012	Dec 2014	Smithfield	12-S-9	6	0	High uncertainty scale, good example of an annulus being eroded away (age 5)
2012	Dec 2014	Smithfield	12-S-11	5	0	
2012	Dec 2014	Smithfield	12-S-12	5	1	
2012	Dec 2014	Smithfield	12-S-13	7	1	
Reference American shad scale set (ver. Dec 2014, original set)						
Year-of-capture	Accepted	Location	Specimen ID	Age	SPM	Comments
2012	Dec 2014	Smithfield	12-S-14	5	0	
2012	Dec 2014	Smithfield	12-S-15	8	0	

2012	Dec 2014	Smithfield	12-S-16	6	0	
2012	Dec 2014	Smithfield	12-S-18	6	0	Three looks strongest above baseline, but 2 strongest below. 5 eroded on both edges but mostly on the right side
2012	Dec 2014	Smithfield	12-S-19	7	0	False band on outside, near edge. Not calling it an annulus
2012	Dec 2014	Smithfield	12-S-20	6	0	Contentious spawn mark, not on all scales; weak 2 above baseline
2012	Dec 2014	Smithfield	12-S-21	7	0	
2012	Dec 2014	Smithfield	12-S-23	7	1	Nice picture for potential SPM, go to fiche for best view of SPMs
2012	Dec 2014	Smithfield	12-S-24	7	1	Double banding at age 5
2012	Dec 2014	upper bay	12-UB-1	5	0	
2012	Dec 2014	upper bay	12-UB-2	5	0	Good example of double banding, especially at age 2
2012	Dec 2014	upper bay	12-UB-5	5	0	Tough read, scale clarity a little poor
2012	Dec 2014	upper bay	12-UB-8	6	0	
2012	Dec 2014	upper bay	12-UB-10	5	1	Good example of jiggety spawn mark
2012	Dec 2014	upper bay	12-UB-12	9	4	Middle scale is the best, 8 SPM eats into 7 annulus. Weakish 3
2012	Dec 2014	upper bay	12-UB-14	7	1	Weak 5
2012	Dec 2014	upper bay	12-UB-16	7	3	Crazy one, looks like there is a SPM at age 3, then skip spawn at 4
2012	Dec 2014	upper bay	12-UB-18	5	0	
2012	Dec 2014	upper bay	12-UB-20	6	0	The toughest part of this one is determining first annulus

VI. Production Ageing

- Ageing will be done by at least one experienced reader from each of the Co-op member states. The Co-op will facilitate distributing the samples between state agencies.
- Criterion(a) for acceptance of ages/repeat spawning marks

- Comparison of age and repeat spawning mark assignments among readers will be analyzed using a standard precision template developed by NOAA's Northeast Fisheries Science Center. Templates can be found at http://www.nefsc.noaa.gov/fbp/age-prec/. Precision will be evaluated by examination of the mean coefficient of variation (CV), percent agreement and the Bowker's test of symmetry. Ageing laboratories around the world view a measure of mean CV of 5% or less to be acceptable (Compana (2001). Production ageing results with a mean CV of greater than 5% will be rejected and not used to calculated mortality estimates.

- The Co-op will attempt to age the entire sample; however, if sample sizes become too large to analyze in a timely manner, we will take a random subsample of 10 fish per length bin (Coggins et al. 2013).

VII. Calculation of total mortality (Z)

- Total mortality (Z) estimates will be calculated using a bias-correction Chapman and Robson (1960) mortality estimator described in Smith et al., 2012.

$$Z = log_e\,(\,1 + \underline{T} - T_C - \frac{1}{N}) - \frac{(N-1)(N-2}{N[N(\underline{T} - T_C) + 1][N + N(\underline{T} - T_C) - 1]}$$

where:

$\underline{T}$ is the mean age of fish in the sample greater than or equal to age T_C

T_C is age of full recruitment

N is the sample size of fish greater than or equal to age T_C

VIII. References

ASMFC. (Atlantic States Marine Fisheries Commission). 2007. American shad stock assessment report 07-01. Washington, D.C. USA.

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IX. Glossary

Annuli (plural)/Annulus (singular) – A concentric ring that can be traced through the anterior and posterior portions of the scale. These bands are typically lighter in contrast relative to growth areas. They may occur as tight concise lines and/or wide broad lines in the anterior portion of the scale.

Anterior portion – This is the portion of the scale that remains embedded in the fish's skin. This portion of the scale has varying contrasts, but generally looks smooth. Typically, readers orient the anterior portion of the scale to the top of the viewing screen.

Band – A general term referencing a concise line giving the appearance being concentric on the scale. These may potentially be annulus(i) or false annulus(i).

Banding – A general term for collectively referring to multiple bands.

Base line – The base line separates the anterior from the posterior portions of the scale. It typically appears as a dark heavy band running between the ventral and dorsal scale edges.

Dorsal side – This is the edge of the scale that is oriented to the dorsal fin of the fish. On the viewing screen, if the anterior portion of the scale is oriented to the top of the screen, then the dorsal side is to the readers' right.

Double band – These are false annuli that appear as dark bands in the anterior portion of the scale, but are typically not present in the posterior portion. Usually there is little separation (i.e., spacing/distance) between the annuli and a second band. Collectively the annuli and the false annulus are called a double band.

False annulus(i) – These are structures that appear as dark bands in the anterior portion of the scale, but are not present in the posterior portion. False annuli can be in close proximity of the annuli (i.e., double band), or well separated from other annuli. Speculation on potential causes for false annuli formation may be related to growth changes, available food/starvation, diet shifts, etc.

Flat line – Refers to a repeat spawning mark appearing as a straight edge along the dorsal and ventral sides. This mark is formed by scale erosion in previous years spawning, when the scale is evenly eroded, forming a very straight line. As with any erosion, flat lines may have eroded past multiple annuli. Occurrences of "Y" effects are usually associated with a flat line.

Focus – This represents the center of the scales growth. The focus is the center of the freshwater zone located on the base line, halfway between the dorsal and ventral sides. Typically, the anterior portion of the scale is relatively larger (~ two-thirds) than the posterior portion of the scale. Thus, the focus is not in the physical center of the scale.

Fresh water zone (FWZ) – This appears as a concentric small dark area in the middle of the scale just above the base line.

Jiggety – Refers to the ragged appearance of an annulus. Scale erosion occurs as shad return to freshwater for spawning. The erosion of the scale edge is not uniform, leaving a "ragged", "fragmented", or "jagged" edge. Subsequent scale growth deposits material on the scale edge, but does not reform a uniform edge of the erosion from the previous edge. Erosion of the scale margins are most pronounced on the ventral and dorsal edges.

Peak – references the very anterior most part of the scale.

Pocket/Bell – At the base line, scale erosion on the ventral and dorsal edges often erode in a concave shape.

Posterior portion – This is the portion of the scale exposed to the elements. This portion of the scale appears as rows of "teeth" and has a rough appearance. Annuli typically appear as dark bands. Typically readers orient the posterior portion to the bottom of the viewing screen.

Repeat spawning mark/Spawning mark/SPM – This is an annulus(i) that appears jiggety suggesting the individual shad spawned at that age. Each annulus identified as a SPM, is cumulatively counted. A repeat spawner is a shad that is returning to its natal water for the second-time (or more). For example, the presence of one SPM indicated the shad spawned once in a previous year, and has returned again in a following year (i.e., year-of-capture). SPMs are most easily identified on the dorsal and ventral sides of the scale. Occasionally an exceptionally disruptive SPM (erosion) will also be evident in the anterior. Scale erosion may eliminate multiple annuli, in such cases, a SPM is referring to a single event of the oldest annulus, since all previous scale material (annulus(i) and SPMs) may have been lost. Skip spawners are those shad demonstrating a SPM, then appear not to spawn in the following year (i.e., the annulus is a smooth band, not jiggety), then returning again in a future year to spawn again.

Strong/Weak – This is a descriptive term for characterizing how apparent an annulus is on the scale. Well defined annuli that immediately jump out to the reader are "strong". They are easily identified throughout the scale. Annuli that are difficult to immediately pin point are "weak" or not readily apparent to the reader. The annuli may not be traceable throughout the entire scale, such that sections of the annuli are not discernable in various portions of the scale.

Ventral side – This is the edge of the scale that is oriented to the belly of the fish. On the viewing screen, if the anterior portion of the scale is oriented to the top of the viewing screen, then the ventral side is to the readers' left.

Y effect - When tracing annuli along in the anterior edge, annuli appear to converge near the corners of the anterior edges into a single band along the dorsal/ventral edges, then separate into separate bands, just below the base line in the posterior portion of the scale. This convergence/separation visually looks like the letter “Y”. If viewing the scale with the anterior portion of the scale oriented to the top of the viewing screen, the “Y” effect in the posterior is upside-down.