Delaware River
Sustainable Fishing Plan for American Shad

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For:

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

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Executive Summary

The Atlantic States Marine Fisheries Commission (ASMFC) has required all states to submit Sustainability Plans for American shad fisheries by Aug 1, 2011 or be forced to close them by January 1, 2013 as per Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring. 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 sustainability of the Delaware River American shad stock at current levels of recreational and commercial usage. Through extensive data review and analysis, the Co-op has identified several indices for monitoring the Delaware stock with associated benchmarks. The Co-op judge these fisheries as sustainable while avoiding diminishing potential stock reproduction and recruitment as long as indices of stock condition remain within the defined benchmarks.

Currently the Delaware shad stock is considered to be stable, but at low levels. Recent data is suggestive of an increasing trend. 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 areas from 1998 to 2004, but excellent year classes were observed in both JAI indices in 2005 and 2007. The 2011 JAI was the 7th highest of the tidal reach time series. 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 (2011) has suggested increasing abundance of adults to levels observed in the early 1990s.

The New Jersey Division of Fish and Wildlife (NJDFW), monitors JAI in both the non-tidal and upper estuary reaches, but the non-tidal JAI was discontinued in 2008 as a cost cutting measure. Although the tidal JAI does provide an indication of American shad production within the Delaware River Basin, differences in the two indices indicates that variables such as the timing of the run, water temperatures, etc. may affect the two areas differently in a given year. Concern has been expressed that the correlation between the two JAI indices relies too heavily on occurrences of peak year classes; such that the tidal JAI may not be sensitive to poor year classes observed in the non-tidal reaches. Currently, the Co-op lacks funding to resume sampling for the non-tidal index. Securing funding for this important index is under discussion by Co-op members.

Exploitation of the Delaware shad stock occurs in several fisheries within the Basin. Commercial harvest is permitted by New Jersey and Delaware, generally during the spring spawning migration from late February into May. These fisheries occur in tidal waters of Delaware and New Jersey using anchored or drift gill nets. Landings in the upper estuary are considered to be 100% Delaware shad stock; whereas, landings in the Bay are of mixed stock, with an estimated 39% of Delaware origin. 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 shad stock, have been declining since 1990, with lowest levels

observed in the most recent years (2008-2010). The decline is most likely due to gear changes in DE's striped bass quota driven fishery and the low number of NJ fishers seeking American shad.

In addition to the lower Delaware River and 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. The recreational creel limit is currently 3 shad above the Commodore Barry Bridge and 6 shad below the bridge.

In addition to harvest and natural mortality, the Co-op investigated other factors that may also impact the Delaware shad 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 relationship between shad abundance and Atlantic long-term sea surface temperatures; however, there is a disconnect that has occurred since the 1992 that currently is in debate. In addition, a strong inverse correlation has been identified between adult shad abundance in the Delaware River and coastal striped bass abundance. Possible losses from oceanic commercial fisheries principally, as bycatch, have been difficult to evaluate; but, this issue is becoming more of a priority to those agencies responsible for governing offshore fisheries.

The Co-op proposes four 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 compliance reports.

- **Non-tidal JAI:** Data for this index is derived from the NJDFW annual fixed station seining (1979-2007) in the non-tidal Delaware River mainstem from Trenton, NJ to Milford, Pa. The benchmark is based on data from 1987-2007. Failure is defined as the occurrence of three consecutive JAI values below a value of 49.43 (i.e., the 25th percentile of the historical data, 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. The shad benchmark includes only those stations from Trenton to the Delaware Memorial Bridge, and is based on data from 1987 – 2010. Failure is defined as the occurrence of three consecutive JAI values below a value of 2.83 (i.e., the 25th percentile of the historical data, where 75% of the values are higher).

- **Adult CPUE:** This benchmark is based on the annual CPUE (shad/net-ft-hr*10,000) in the PFBC gill net, egg-collection effort at Smithfield Beach. This benchmark was based on the entire dataset (1990-2011), with failure defined as the occurrence of three consecutive CPUE values below a value of 34.79 (i.e., the 25th percentile of the historical data, where 75% of the values are higher).

- **Ratio of Harvest to Smithfield Beach CPUE:** This benchmark is calculated as a ratio of the combined commercial harvest of the Delaware shad stock from the river and bay in pounds divided by relative abundance of adult survivors captured at Smithfield Beach (CPUE). Delaware stock, lower Bay landing are calculated as 39% of the total lower bay landings. The benchmark is based on data from 1990-2010 and failure is defined as the occurrence of three consecutive values above a value of 27.79 (i.e., the 85th percentile of historical data, where 15% of values are higher).

In addition to the above benchmarks, the Co-op identified several other datasets warranting further monitoring as collaborating evidence of the Delaware shad stock trends. The intent was to provide an additional measure of stock performance; however, the Co-op does not propose these as defined benchmarks for management action, given various associated extraneous caveats and assumptions. Auxiliary data sets include: (1) Lewis haul seine adult relative abundance (catch/haul), (2) ratio of harvest to Lewis haul seine relative abundance, (3) commercial effort, (4) harvest of shad from mixed stocks in the Delaware Bay, and (5) commercial exploitation. The Co-op will pursue investigations of assumptions and data needs for these auxiliary datasets.

It is anticipated that this sustainability plan will permit growth of the Delaware 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) submits the following Sustainable Fishing Plan. 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).

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.

2. Current 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 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 2011.

2.2 Stock Monitoring Programs

2.2.1 Fishery Independent Surveys

Juvenile Abundance Surveys

The New Jersey Division of Fish and Wildlife (NJDFW) conducted juvenile abundance monitoring for American shad in the non-tidal Delaware River from 1979-2007 to provide a juvenile abundance index (JAI) for management purposes. In non-tidal waters, where the majority of spawning takes place, a beach seine monitoring program for juvenile American shad was conducted during August through October at representative stations (Trenton, Byram, Phillipsburg, Delaware Water Gap, and Milford, Pa, Figure 2). Beginning in 1979, only a single station, Byram, was sampled. Other sites were added in later years with the addition of Trenton in 1980, Phillipsburg in 1981, Water Gap in 1983 and Milford, Pa in 1987. Sampling was discontinued at the Byram station in 2002 due to heavy siltation. This station was eliminated from the program since a suitable replacement beach was not located. Because this station is no longer used in the calculation of the index, the entire time-series was recalculated by eliminating this station from the analysis.

In the tidal Delaware River, NJDFW collected data during their annual striped bass recruitment survey from Trenton to Artificial Island during August through October, 1980 – present date. This index was recalculated to eliminate stations in waters of higher salinity where American shad are less likely to be encountered. The actual assessed sampling range is from Trenton to the Delaware Memorial Bridge. In 2010, a quality check was completed on all data sets from the Delaware River resulting in updates to the recruitment indices during the time series.

Both JAIs are reported as geometric means. The non-tidal JAI increased from 1980 to 1984, then fluctuated without trend through 2007, with good year class abundance reported in 1996 and 2007 (Table 1, Figure 2). 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. The geometric mean per haul for the time series was calculated as 83.12. Cohorts with poor recruitment are thought to be due to poor environmental conditions, such as 2002 and 2006. Recent strong year classes in 2005 and 2007, as well as favorable environmental conditions in recent years, are encouraging.

The tidal JAI increased from 1980 to 1988, then varied without an apparent trend excepting a strong peak observed in 1996 (Table 1, Figure 2). The geometric mean per haul for the time series was calculated as 4.85. The preliminary 2011 index (7.99) was the 7th highest of the time series. The tidal JAI has become highly variable in recent years with two very good year classes (2005 and 2007) and two very poor year classes (2006 and 2008). Overall, recent strong year classes in 2003, 2005, 2007 and 2011, as well as favorable environmental conditions in recent years, are encouraging (Table 1, Figure 2).

Both the tidal and non-tidal YOY indices show a significant positive trend through time. The tidal index was regressed on year, and a very highly significant regression was found, ($F = 6.88$, $P = 0.0138$, $R^2 = 19\%$). The slope of the regression was 0.22, meaning that on average, the index increased by 0.22 per year. For the non-tidal index, the regression on year was also highly significant ($F = 9.14$, $P = 0.0056$, $R^2 = 26\%$). The slope was 1.037, meaning the index increased by that amount per year on average. The coefficient of determination (R^2) was not high for either regression, indicating that other (environmental) factors also influenced the variation of the index.

The Delaware non-tidal and tidal indices correlated well (Pearson product-moment $r = 0.793$, $P < 0.001$) from 1994 to 2007, leading to a proposal to discontinue the non-tidal JAI survey as a cost cutting measure. The Technical Committee approved the proposal in January 2008 and the non-tidal JAI survey was therefore eliminated. Although the tidal JAI does provide an indication of American shad production within the Delaware River Basin, differences in the two indices indicates that variables such as the timing of the run, water temperatures, etc. may affect the two areas differently in a given year. For example, the non-tidal JAI was suggestive of a seven year period (1998–2004) when juvenile production was below the long-term mean. During the same time period, the tidal JAI was suggestive of average juvenile production. Concern has been expressed that the correlation between the two JAI indices relies too heavily on occurrences of peak year classes; such that the tidal JAI may not be sensitive to poor year classes observed in the non-tidal reaches. Without a representative index of juvenile production in the non-tidal reaches, prolonged occurrences of poor recruitment in the primary spawning grounds may not be detected. The Co-op is currently attempting to secure funding for re-instituting the non-tidal JAI (Section 6.1.1).

Adult Abundance Indices

The Pennsylvania Fish and Boat Commission (PFBC) annually monitors the relative abundance of returning spawning adult shad in the Delaware River. This effort has and is currently being accomplished in two separate surveys: a gill net survey at Smithfield Beach (RM 218.0) and an electro-fishing survey at Raubsville (RM 178.5).

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 PFBC restoration efforts in the Schuylkill and Lehigh rivers, the largest tributaries to the Delaware River. Gill net gear is used for shad capture and efficiently provides the largest sample for strip-spawning and biological data. Approximately 8 to 18 gill nets (200 feet in length) are set per night with mesh sizes ranging from 4.5 to 6.0 inches (stretch). 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 16C. The project is performed on 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 21.1C. 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 hatchery otolith marks.

Catch-per-unit-effort (CPUE) values ranged from 17.1 to 190.1 shad/net-ft-hr*10,000 (Figure 3). Abundance peaked in the early 1990's, declined through the mid 1990's, and remained relatively stable from 1999 to 2009 (mean = 35.1 shad/ net-ft-hr*10,000). 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 flows, reducing the efficiency of the gill nets. Cold water temperatures delayed and/or marginalized spawning behavior which would also reduce gear efficiency. In the last two years, CPUE increased with the 2011 CPUE estimate (72.0 shad/net-ft-hr*10,000) ranking as the fifth highest since 1990. High flows during the 2011 collections may have adversely impacted CPUE, which could have been higher than measured. Angler catches, as reported on an internet message board (http://woofish.homestead.com/shad.html) were good in 2009, better in 2010, and exceptional in 2011.

Electrofishing Survey

The PFBC historically (1997–2001) monitored returning adult American shad at a fixed station (RM 178.5) in the vicinity of Raubsville, Pa using electro-fishing gear. This survey was re-initiated in 2010 and continues to date. Separate samples were collected on the PA side (west) and the NJ side (east) of the river. The river was sampled four to five times from April to May with one electro-fishing event per week. Sampling events were terminated when 15 American shad were caught or after one hour of electro-fishing, whichever came first. Biological data collected included gender, length (total and fork), total weight, otolith age, scale age, repeat spawning, and hatchery otolith marks.

Preliminary correlations (Pearson product-moment analysis) of this data series to other datasets, i.e., Smithfield Beach gill net and Lewis haul seine CPUE, have demonstrated a strong correlation and excellent potential of the Raubsville electro-fishing survey for utility as a relative index of abundance for adult shad. Therefore, in consensus with other Basin states, PFBC has tentatively agreed to continue the Raubsville sampling and re-evaluate its utility after five consecutive years of data have been collected.

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 in the Lehigh and Schuylkill rivers in the early 1800s, shad became extirpated in these tributaries. Efforts have been undertaken to restore shad in the Lehigh and Schuylkill rivers by installation of fish ladders, stocking of OTC tagged fry, and on-going feasibility studies of dam removal. 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. Passage of shad into the Lehigh and Schuylkill rivers occurs via fishways outfitted with observation rooms enabling monitoring of passage using and video surveillance equipment. Monitoring occurs 24 hours a day, 7 days a week using time-lapsed photography. Passage is monitored only during the spawning migration, typically from April 1st through July 1st. Shad passage is enumerated by staff review of video tape.

Since 1995, the PFBC has been monitoring 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. Annual passage of shad ranged from 408 to 4,740 total shad (0.11 to 2.28 average shad/hour; Figure 4). Passage of shad through the Easton fishway was not significantly correlated (Pearson product-moment, $P > 0.05$) to either the Smithfield Beach or Raubsville CPUE. This lack of any relationship suggests that the shad run into the Lehigh River is independent of the Delaware River spawning run. Co-op members agreed that Easton 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 Lehigh River back into the Delaware River.

Between 2002 and 2011, the Philadelphia Water Department (PWD) maintained a robust monitoring program on the Schuylkill River, quantifying the resurgence of key migratory species including 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. A video monitoring program was established in 2003 to assess fish passage at the fishway (Figure 4). The 2010 fish passage season at the Fairmount Fishway was a record-breaking year, with 2,521 American shad ascending the fishway. This number was the highest ever recorded and more than seven times greater than passage numbers prior to the renovations in 2008 (Figure 4). Data from 2004–2010 suggests a similar trend in upstream fish passage between the Lehigh (Easton Dam) and Schuylkill Rivers (Fairmount Dam); but no significant correlation (Pearson product-moment, $P > 0.05$) was found (Figure 4). Since hatchery contribution is high in both these stocks (96% for the Schuylkill and 74% for the Lehigh), this may be related to annual variations in hatchery production and similar environmental conditions at stocking. The positive trend in both rivers is encouraging. Passage of shad through the Fairmount fishway was not significantly correlated (Pearson product-moment, $P > 0.05$) to Smithfield Beach CPUE.

Comparison of JAI to adult indices

One might expect that juvenile production (i.e., recruitment) would be a function of adult stock size. Figure 5 plots both the non-tidal and tidal JAI indices (i.e., recruitment) against Smithfield Beach relative abundance (a proxy for the spawning stock size). No obvious relationship appears to exist between adult relative abundance and year class strength (juvenile production) (Figure 5). Thus, production of young-of-year shad does not appear to be related to adult stock size. The lack of a correlation most likely is related to environmental influences and sampling variability. Future work is planned to examine the JAI-Adult relationship with multivariate statistics, including the influence of environmental variables.

Shad from the Delaware River Basin have been aged using scales and otoliths. The Co-op initially used all available data, including estimation of ages from scales and otoliths, knowing that there are limitations and controversy attached to ageing techniques which produced the data sets. Exploratory correlations (Pearson product-moment analysis) between adult CPUE , partitioned by age and summed to represent year class contributions to YOY year class production, as measured by the non-tidal JAI, yielded a positive slope, but an insignificant correlation (Pearson product-moment $r = 0.431$, $P > 0.05$; Figure 6). Recent findings have determined that the ageing of scales from Delaware River American shad cannot be substantiated (McBride *et al*. 2005). Otolith ageing has been validated using known age specimens from the Lehigh and Delaware Rivers (Duffy et al., in review). Without confidence in the scale ageing technique (Cating 1953), the frequency of repeat spawning from scale microstructure also cannot be determined with confidence. The Co-op agreed that alternative methods (e.g., otolith ageing) are preferable to assess ages of the Delaware River stock.

2.2.2 Fishery Dependent Data

Commercial fisheries

Exploitation of the Delaware shad stock occurs in several fisheries within the Basin. Commercial harvest is permitted by New Jersey and Delaware, generally during the spring spawning migration from late February into May. These fisheries occur in tidal waters of Delaware and New Jersey using anchored or drift gill nets. 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 lower Delaware River and 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.

Total catch, landings, and effort

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. 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 (2008-2012) 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. Unfortunately, this 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. Recent CPUE shows an increasing trend from the 1960's-80's followed by an overall decrease to the mid-2000's (Figure 7).

CPUE from the Smithfield Beach gill net and Lewis haul seine for 1990-2010 exhibit similar trends (Figure 8) and are strongly correlated (Pearson product-moment: $r = 0.866$; $P < 0.001$;Figure 9).

New Jersey commercial fishery: 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.

In New Jersey, as of June 20, 2011, there were 86 permits issued (46 commercial and 40 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 76 of these permits are active, due to attrition, while only 10 fishers landed shad in the Delaware Estuary during 2010.

Since 2000, the data on catch, landings, and effort have been collected via mandatory logbooks through the limited entry program and will continue to be used to assess stock status. Records indicate that the shad fishing season started as early as February 15 and ended as late as May 22. Data collected from the logbooks show that the mesh size in the Delaware Bay fishery ranges from 5 to 6 inch stretch.

Delaware commercial fishery: Delaware has a limited entry system for commercial gill net fishers. In recent years only handful of fishers has reported landings of shad, which is currently a bycatch in the directed striped bass fishery. Because striped bass fishers have been targeting larger bass over the last decade, the mesh size of gill nets has increased up to 7 inch stretch mesh. The large majority of shad will swim through that mesh size, so bycatch of shad has declined drastically.

Delaware fishers have explained that they have a small striped bass quota which is often filled quickly. If they then try to fish for shad, striped bass fill their nets. They are difficult to pick out of the nets because of their spines and sharp gill covers, which can cut fishers' hands and the nets are damaged by the bass catch. Striped bass are currently at unprecedented levels of abundance in the River and Bay. Clark and Kahn (2009) reported that catch per trip of striped bass in Delaware's spring gill net fishery increased by 3000% to 6000% between 1987 and 2002-2003, based on at-sea samples of gill net catches. The result of the high abundance of striped bass together with the limited striped bass quota is that fishing for shad is impractical, according to numerous commercial fishers.

The spring striped bass season runs from February 15th through May 31st. Gill nets used in February and May are restricted to drift nets; either anchored or drift nets are allowed during other times. Shad have been landed as early as February, but peak in April. Delaware fishers are required to pull their nets during the first week in May as a conservation measure for weakfish, but very few shad are still in the estuary at that time.

Combined State landings

Recent commercial landings (1985–2010) from the Delaware River and Bay are shown in Figure 10 and Table 2. 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 from Delaware since 1985 and New Jersey since 2000. Reported landings for both states are presented for comparison. The harvest areas are delineated as river and bay based on information on the fisheries gathered throughout the years. Delaware River harvest is separated from Delaware Bay harvest at a line drawn from the mouth of the Leipsic River, DE to Gandy's Point, NJ (Figure 11).

Shad harvested in the Delaware River are considered to be 100% Delaware stock while those from the Bay areas are mixed stock and the origin of these fish may vary annually. In 1995, NJDFW initiated American shad tagging 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. American shad are caught as bycatch in NJ's striped bass tagging program. This program utilizes drifting gill nets during February through May of each year. In recent years, bass have been very abundant in the sampling with few American shad being caught. Over the past five to seven years fewer than 100 shad were caught and tagged annually.

A total of 4,239 American shad were tagged from 1995 to 2011 (Table 3). Through May 2011, there have been 246 American shad returns reported (5.8% of tagged fish). The tag return data indicate that shad taken in this portion of Delaware Bay are of mixed stock origin. Reported recaptures of American shad tagged in Delaware Bay ranged from the Santee River in South Carolina to the St. Lawrence River near Quebec, Canada (Table 4).

The proportion of out-of-basin (non-Delaware River stock) shad present throughout the Bay and River undoubtedly changes annually and most likely decreases as one moves up the Bay and into the River. Analysis completed for the 2007 ASMFC Stock Assessment estimated that 39% of shad caught in lower Delaware Bay were of Delaware River stock origin. Other stocks with significant tag returns included the Hudson River (17%) and Connecticut River (15%).

Delaware stock commercial landings have declined since 1990 for a variety of reasons including a decline in the stock, increased abundance of striped bass, reduced efforts of Delaware fishers and attrition in the New Jersey fishery as fishers retire from the business. Furthermore, because striped bass fishers have been targeting larger bass over the last decade, the mesh size of gill nets has increased up to 7 inch stretch mesh. The large majority of shad will swim through that mesh size, so bycatch of shad has declined drastically. 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 (Figure 10).

Fishery biological data: size, sex and age composition

Lewis haul seine: 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. 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 12).

New Jersey: Length frequency data (total length) was collected from American shad caught during fishery independent tagging operations by gill net in lower Delaware Bay. However, data are comparable to the commercial fishery since similar gill net mesh sizes are used for this program (Figure 13a). Sex ratios show the fishery is mostly prosecuted for females but there are years when the percentage of males increased (Table 5). 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.

Delaware: Length, scales for age determination and weight data by sex was collected from American shad caught by commercial fishers in Delaware Bay from 1999 through 2010, except a few years (Figure 13b). The same data was collected from commercial fishers in the Delaware River beginning in 1997. In the last few years, extremely low landings in Delaware have eliminated this source of data. In 2011, Delaware Division of Fish and Wildlife was aided by the NJDFW in contacting New Jersey commercial fishers to obtain samples from their landings in the River and Upper Bay, and data was collected from several hundred fish.

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). Typically, the lower non-tidal reach is fished earlier in the season, moving further upriver as waters warm up.

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 6). 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).

The PFBC, in collaboration with the National Park Service, jointly promotes a voluntary angler diary program (2001 – present) for reporting recreational angler catch (Lorantas and Myers 2003, 2005, 2007; Lorantas et al. 2004; Pierce and Myers 2007). In addition, the reporting of catch is mandatory for all licensed guides operating in the Upper Delaware Scenic Recreational River. Catch rates of shad varied among years (0.01 – 0.11 shad/hr) with the highest rate observed in 2001 thereafter declining to a relatively stable rate after 2003 (Table 6). Harvest of shad by logbook anglers was minimal (0 – 10.9%) in any given year. 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.

In-State Bycatch and Discards

There is little information on bycatch or discards of shad in any commercial fisheries within the Delaware Estuary, although it is known that male shad are discarded when they are no longer profitable to commercial fishermen. Some shad (male and female) are also discarded during the striped bass fishery in Delaware for the same reason. As previously discussed, fishers in the lower Bay area may harvest shad from other river systems but as the fish move further up the Bay, the more likely fishers are to be harvesting Delaware River stock.

The recreational fishery for shad in the Delaware River principally practices catch-and-release (R. Marks, Delaware River Shad Fisherman's Association, personal communication). There have been at least two studies which estimated catch and release mortality in the Susquehanna River (Lukacovic 1998; reference point mileage: Conowingo Dam RM 10) and Hudson River (Millard *et al.* 2003, tidal influenced). These studies estimated catch and release mortality at less than 2 percent. The Co-op considers mortality due to recreational angling to be of minimal impact despite the long migrations necessary for the Delaware River American shad population. It should be noted that the shad in the non-tidal Delaware River experience long migrations and the inherent energy expenditure is presumed to be greater for these shad as compared to those in the previous studies, thus the expected catch and release mortalities may or may not be similar. The tidal influence of the Delaware River terminates near Trenton, NJ at RM 133, therefore the shad must traverse another 207 miles of river without the aid of the tide to assist the shad in its spawning migration.

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 7). 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). Since 1985, egg-take operations on the Delaware River have resulted in the use of an average of 765 adult shad brood fish per year. 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 or are planned.

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 8) suggesting that hatchery-reared fry are not a significant component of the Smithfield Beach catch. In contrast, electrofishing between Easton and Chain Dams showed that an average of 74% of captures were hatchery fish. At the Fairmount Dam on the Schuylkill River, about 96% of the fish returning to spawn are of hatchery origin. 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 collections. Hatchery origin fish favored the west side of the river, presumably homing to the Lehigh River where they were stocked as fry.

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 Multi-decadal Oscillation which correlates with Delaware River stock indicators, (3) striped bass-American shad interaction which shows that American shad commercial harvest in the lower Bay negatively correlates with the recreational catch of striped bass, and (4) potential effects from overfishing and ocean bycatch.

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 as well as several tributaries of the lower Delaware River. It was presumed that the principal spawning area was located just south of Philadelphia 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). During the 1940s and 1950s, heavy organic loading around Philadelphia, Pennsylvania caused severe declines in dissolved oxygen (D.O.). The ensuing "D.O. blocks" made parts of the lower Delaware River uninhabitable for fish during the warmer months of the year (Sykes and Lehman 1957). 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. Pollution continued to be a major factor until passage of the Federal Clean Water Act in 1972. This Act was instrumental in the elimination of the "pollution block" in the region around Philadelphia (Figure 14). By 1973, the majority of spawning took place above the Delaware Water Gap more than 115 river miles upstream. American shad can now freely pass through this area during the spring spawning run as well as the fall out-migration. Recent observations indicate that shad spawning has returned to the tidal areas of the Delaware.

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 the 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 15). 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 16). 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 2010 with an $R^2 = 0.7811$ (Figure 17).

Additional analysis was conducted between the AMO and the Smithfield Beach CPUE for 1990 to 2010. 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 2010 with an R^2 = 0.7771 (Figure 18). This corroborates data reported earlier from the Lewis haul seine for the same time period.

In conclusion, this analysis provides evidence 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 Striped Bass vs. American shad

To investigate the hypothesis that striped bass have had a negative impact on American shad abundance in the Delaware River, correlation analysis was conducted between the Lewis haul seine index of adult shad abundance and an index of striped bass abundance in Delaware state waters, using the National Marine Fisheries Service's Marine Recreational Fisheries Statistics Survey (MRFSS; Figure 19a). The Lewis haul seine index was used as a proxy of the Delaware shad stock, given its longer timer-series to 1981 when the MRFSS survey was initiated and high correlation with the Smithfield Beach relative abundance index.

The contrast in the abundance of striped bass over this period is particularly large in the Delaware. Abundance was extremely low in the 1980s, but dramatically increased through the 1990s, being declared fully restored in 1998 by the Atlantic States Marine Fisheries Commission. Prior to resurgence in the 1980s, the Delaware River stock was considered extinct by some writers. Clark and Kahn (2009) demonstrated that catch per trip in the Delaware spring gill net fishery in the Delaware Bay and River increased by 3000% to 6000% between 1987 and 2002-2003.

Conversely, trends in American shad abundance, as implied by the Lewis haul seine are essentially the opposite of striped bass population trends. The shad population within the Delaware River, while variable, tended to be at higher levels during the 1980s and early 1990s, prior to record lows observed after 1999. Striped bass total catch per recreational trip for the state of Delaware had a highly significant negative correlation with the Lewis haul seine index (Figure 19b; Pearson's $r = -0.76$, $P << 0.01$).

2.3.4 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.

We evaluated potential impacts of recent directed in-river commercial harvest of Delaware American shad by comparing losses estimated by the hind cast method discussed in Section 5.2 to relative abundance of the spawning stock as measured by catch per haul (CPH) in the Lewis haul seine fishery. Hind cast estimates were available from 1985 through 2010. For visual comparison, data were normalized by dividing each value by the mean of the time series. Results did not show a spike in harvest followed by a decline in stock size that would have suggested that directed harvest was excessive (Figure 20). In fact, the harvest and the stock index both declined during the time-series and were significantly correlated (r = 0.66, P = 0.0002). It would appear that in-river directed harvest declined as did the shad population. We did not evaluate impacts of recreational harvest on Delaware River American shad because data were too sparse for meaningful analyses. However, as discussed above, recreational harvest has generally been lower than reported commercial landings and much lower than the hind cast estimates of commercial losses.

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 impact 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. Directed harvest of American shad in state coastal waters has been banned by US Atlantic Coastal states since 2005.

Possible effects of bycatch losses in ocean commercial fisheries on Delaware River American shad are much more difficult to evaluate. Not only are bycatch losses poorly documented, but as with ocean harvest, stock of origin is generally not known. American shad appear to be a rare or poorly reported event in available fisheries observer data obtained by the National Marine Fisheries Service Observer Program. For example, NFSC (2009) reported that only 2,918 kg of American shad were observed during 10,108 observer days on a range of commercial fishing trips in northeastern ocean waters from July 2007 through June 2008. However, 405,881 kg of unidentified herring were landed during this time period which was tentatively identified as shad. NFSC (2011) estimated a mean of 385,000 lbs of American shad were landed in ocean fisheries for squid, mackerel, and butterfish in 1991 through 1995. Becker (2010a and 2010b) reported on monitoring of landings from the commercial Atlantic herring fishery at processing facilities from Cape May, NJ through Prospect Harbor, ME. From January through December 2010, he examined 46 samples and observed 171 kg of American shad in 58,783 kg of landed bycatch. Most shad observed in these fisheries were immature fish. Few data are available from onboard observers on bycatch of shad in near-shore or estuarine fisheries of the Northeast. Based on reports by fishermen, few American shad have been taken by Northeastern commercial fishermen in recent years (ASMFC 2007, 2008, 2009). However, differentiating among Alosines in commercial catches is questionable. Both Amendment 14 of the Squid, Butterfish Plan, Mid-Atlantic Fishery Management Council and Amendment 5 to the Atlantic herring plan of the New England Fishery Management Council will begin to address bycatch issues in the ocean.

3 Sustainable Fishery Benchmarks

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. Harvest to Smithfield Beach relative abundance ratio

3.1 Juvenile Benchmarks

3.1.1 Non-tidal JAI index

The benchmark was based on data from years 1987-2007 (Table 1, Figure 21) and failure is defined as the occurrence of three consecutive JAI values below a value of 49.43 (i.e., the 25th percentile where 75% of the values are higher). Exceeding the benchmark will trigger management action. The period of 1987 to 2007 was selected because sampling methodology was more consistent, with representative stations throughout the middle and lower reaches of the River.

Sampling to generate this index was discontinued in 2008. Currently, the Co-op is unable to accomplish sampling for this index pending securing funding for field activities (Section 6.1.1).

3.1.2 Tidal JAI index

The benchmark was based on data from years 1987-2010 (Table 1, Figure 22) and failure is defined as the occurrence of three consecutive JAI values below a value of 2.83 (i.e., the 25th percentile where 75% of the values are higher). Exceeding the benchmark will trigger management action. The period of 1987 to 2010 was selected as these encompass the years when sampling methodology and catches of shad were more consistent. The tidal JAI has been above this target for the past three years. The preliminary 2011 data was not incorporated into the benchmark time period since the JAI may change slightly when data proofing is finalized.

3.2 Adult Benchmarks

3.2.1 Smithfield Beach CPUE Index

This benchmark 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 2011 (Figure 23, Table 1). Failure is defined as the occurrence of three consecutive CPUE values below a value of 34.79 (i.e., the 25^{th} percentile where 75% of values are higher). Exceeding the benchmark will trigger management action. The 2010 index was above the target and the 2011 CPUE is estimated to be higher than that of 2010.

3.2.2 Ratio of commercial harvest to Smithfield Beach relative abundance index

One of the main concerns of fisheries managers is potential overfishing of a particular species. 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 shad stock, the Co-op analyzed a ratio of Delaware 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 has 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 1990-2010. The Co-op also decided to report the estimates combined and in two phases (1990-1999 and 2000-2010) to reflect the more accurate reporting from New Jersey during the 2000-2010 time period. For clarity, the 1990-1999 time period will be called the early period while data from 2000-2010 will be known as the late period.

To develop these estimates, an understanding of American shad migration patterns and fisheries within Delaware Bay must be considered (see Adult monitoring programs above). Based on New Jersey's mark/recapture information, American shad in the lower Bay are of mixed stock origin with returns from Canada to South Carolina. It is estimated that 39% of landings from the lower portion of the Delaware Bay are of Delaware stock origin. The 39% figure was developed from the number of recaptures reported during 1995-2011 within the Delaware Bay and River. This is considered a conservative estimate since some of these recaptures were taken in areas of mixed stock congregations and may have actually been from other stocks. All shad harvested within the tidal Delaware River and upper Bay (Figure 10) are considered to be Delaware stock. Total estimates of Delaware stock harvest were developed by combining reported Delaware landings (river) plus the reported New Jersey landings (river) and 39% of the combined Delaware (bay) and New Jersey (bay) landings from mixed stock fisheries (Table 2).

The Co-op has agreed to use the ratio of commercial harvest/CPUE from Smithfield Beach as a means to determine if management intervention is warranted to insure stock sustainability. These ratios ranged from 6.78 to 26.69 in the early period and 2.66 to 52.48 in the late period (Table 2; Figure 24). The early time series varied without trend while the late period varied through 2004 but has decreased through recent years. The benchmark was based on data from 1990-2010 (Table 2; Figure 23) and failure is defined as the occurrence of three consecutive values above a value of 27.79 (i.e., the 85^{th} percentile where 15% of the values are higher). Exceeding the benchmark will trigger management action. During the early period, the ratio estimate did not exceed the benchmark. During the late period, the benchmark was exceeded three times (2001, 2003 and 2004). This index is particularly appealing since it is sensitive to changes in both harvest and abundance (CPUE).

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 25). Results suggested low bias when actual exploitation rates were less than u <= 0.10, but dramatically higher bias when u exceeded 0.30.

The American shad stock in the Delaware River is considered stable but at low levels compared to the historic population. 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. 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 (2002).

4 Proposed Time Frame for achievement

The Co-op proposes that this plan be re-evaluated on a five-year cycle. All datasets will be updated annually for assessing the exceeding of any benchmarks requiring immediate management action. All sustainability benchmarks will be reviewed annually after completion of annual ASMFC compliance reports.

5 Adaptive management

5.1 Benchmarks

All management actions are subject to the severity of the breach. 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. The Co-op will review these benchmarks annually to determine if management action is necessary, and if yes, 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 most areas and will be so in all waters once this plan is fully enacted. One of the following options regarding breach of the Delaware River benchmarks are based on amending the 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

5.2 Auxiliary Data

The Co-op has recognized several datasets that warrant monitoring as collaborating evidence to support the identified sustainability benchmarks: 1) the Lewis haul seine as a fishery dependent index of adult spawning population; 2) the harvest to Lewis haul seine relative abundance ratio; 3) estimates of commercial effort; 4) the harvest of shad from mixed stocks in the Delaware Bay; and 5) commercial exploitation (u) as derived from a scaled up Smithfield Beach relative abundance.

Lewis haul seine: The Lewis haul seine provides a separate index of the returning adult spawning population to the Delaware River (Figure 7). Given the greater uncertainty of catchability in the Lewis haul seine fishery, the Co-op does not desire to overstate sustainability targets with this index. Yet, the observed strong correlation between the Smithfield Beach and Lewis haul seine CPUEs suggest these indices are complementary and can offer two viewpoints on the status of the Delaware River shad population (Figure 8).

Harvest to Lewis haul seine relative abundance ratio: As with the calculation of the harvest/Smithfield Beach relative abundance ratio, the Co-op derived a similar ratio using the Lewis haul seine dataset. While the Lewis haul seine dataset is extensive, the Co-op decided to restrict the ratio estimator to the same time–series (1990-2010) as Smithfield Beach. The ratio was calculated as the landings/CPUE, scaled by 1000. These the estimates were calculated as combined and in two phases (1990-1999 and 2000-2010) to reflect the more accurate reporting from New Jersey during the 2000 to 2010 time period. Estimates of relative exploitation based on the Lewis haul seine relative abundance ranged from 2.33 to 21.42 in the early period and 5.93 to 43.84 in the late period (Table 2; Figure 26).

The Co-op decided to use the harvest to Lewis haul seine CPUE ratio as ancillary data to the four benchmarks due to the inconsistent nature of the Lewis haul seine which implements varying nets pending environmental conditions. There has also been a concern raised regarding possible changes to the channel in the area of the fishery which may have changed catchability of American shad. If a distinct increase in this ratio occurs over time, technical review will ensue.

Commercial effort: Commercial fishing effort for Delaware is calculated from the mandatory monthly landings data using net yards as the indicator of measure. Net-yards were the yards of net fished on that day the landings occurred. The Delaware CPUE estimate of the Delaware River drift-net fishery was developed to determine a time period when shad catches were typically the greatest. The CPUE from this time period was then used to determine possible trends in stock abundance.

Effort data for New Jersey's commercial fishery is estimated from mandatory logbooks, which started in 2000 and CPUE is presented in pounds per square foot of netting. New Jersey data is partitioned to examine the in-river CPUE as well as the CPUE in mixed stock areas of Delaware Bay.

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 27). Shad is no longer the target species but are considered bycatch in the striped bass fishery. 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 2010 (Figure 28). Effort has decreased dramatically throughout the time series with effort peaking in the bay fishery in 1991 and the river fishery in 1996.

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 within the river (Figure 29). New Jersey's river fishery CPUE mimics the overall trend. CPUE within the Bay has actually increased in recent years; however, actual effort is low. Overall effort in New Jersey has decreased more than 30 percent since 2005. The New Jersey river fishery CPUE shows a similar trend to the Delaware River CPUE in recent years (Figure 30).

Delaware Bay landings: Landings in the Delaware Bay present a unique situation. Ongoing tagging studies conducted by the NJDFW in the lower eastern Bay off Reed's Beach, New Jersey, approximately fifteen miles north of Cape May Point (Section 2.2.2) indicate that American shad landings from this portion of Delaware Bay are a mixture of East Coast stocks (Tables 3-4). Shad recaptures have occurred in various locations from South Carolina to Canada, with the majority coming from the Delaware, Hudson and Connecticut Rivers.

The actual landings for the Delaware Bay have declined from a peak of 581,805 pounds in 1990 to a low of 6,730 pounds in 2009 (Figure 31). Landings in 2010 were also low (9,371 lbs). No expansion of the Delaware Bay fishery is expected in the near future, specifically for the 2011 season based on communication with fishers in this area. The main causative factors of the decline include regulatory action (limited entry), attrition in the fisheries, low market value of shad, increased mesh size (7" stretch mesh) used 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. 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. The overall decrease in coastal stocks of American shad may be an additional factor to the decrease in landings of shad.

There is concern whether the results of the tagging efforts off Reeds Beach are indicative of the mixed stock shad landed by commercial fishers within the Delaware Bay. One theory is that as shad swim north in late winter and early spring, they must navigate across the mouth of Delaware Bay. If they swim slightly too far to the west, which could be made more likely by strong tidal flows into the Bay and warmer water temperatures within the Bay, they will arrive in the Bay just to the west of Cape May. Since tidal exchange with the ocean is occurring, it may take them some time to orient themselves to exit the Bay and continue north along the coast.

In an effort to determine stock composition, Delaware and New Jersey provided samples for a Hudson River Foundation genetic study in 2009 and 2010. These fish were caught in several locations within Delaware Bay, including Delaware commercial landings from the western side of the Bay, and from New Jersey landings off Reeds Beach and the Maurice River Cove area. Stock composition will be determined based on microsatellite nuclear DNA. The analysis should be completed during the winter of 2012 (J. Waldman pers. comm.). Until this analysis is completed, the extent of stock mixing in commercial landings will be unclear.

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 immediate increased regulatory control for keeping exploitation at current levels to protect other East coast stocks. However, pending outcomes of the genetic analysis for defining the extent of the mixed stock composition of commercial landings, a plan will be developed to constrain expansion of this fishery. Although a specific benchmark has not been developed at this time, it is anticipated Co-op members will develop a more comprehensive approach once the additional information is available. Current regulations include limited entry and gear restrictions, which have limited access to the fishery and limited harvest to individual fishers. However, the Co-op will work to define specific management actions such as gear restrictions, mesh size restrictions, closed areas, closed seasons or individual quotas which can be implemented if landings exceed a threshold level.

Discussion points and analysis for consideration within the timeframe of this plan will include:

- A more detailed analysis of existing tagging data to determine migration patterns of recaptured fish within season. This may allow the Co-op to develop closed seasons when non-Delaware Basin stocks are more prevalent.

- A more thorough analysis of mixed stock landings and effort will be undertaken including exact areas of the Bay where landings occur. The Co-op can also estimate harvest levels of stocks based on recapture percentages, as demonstrated in Table 9.
- NJ and DE management staff will consult with the fishing industry and State Management Councils to determine appropriate benchmarks for the commercial mixed stock fishery. This will be completed within three years, reviewed by the Co-op and the finalized benchmark(s) incorporated into this plan.
- Funding is needed to support a more robust tagging program in the Delaware Bay for determination of the mixed stock component of Delaware Bay landings. Consideration may be given to expanding tagging to the DE side of the Bay for complementing efforts in NJ waters to determine if stock percentages are the same throughout the Bay. Portions of the Bay fishery are prosecuted further up the Bay than where the NJ tag program is conducted.

Exploitation: This section presents work done towards the goal of estimating the exploitation rate from the commercial fishery conducted in New Jersey and Delaware. In order to evaluate the impact of the fishery and possibly move in the future toward biological reference points, estimates of exploitation rate and the instantaneous fishing mortality rate are needed. Estimation of one will allow conversion to the other. In previous decades, the Co-op supported two general methods of estimating the number of shad in the River every spring: tag-recapture methods 1976-1977; 1979-1983; 1992 (Schaefer Estimation, 1976–1992, NJDFW 1993, 2001) and hydroacoustic methods, alternative estimates 1995-1996; 2000-2007 (Barnes-Williams Environmental Consultants 1992, 1995, 1996, 1998, 1999, 2000, 2001; P.A.C.E. Environmental Services 2002, 2003, 2004, 2005). Our current best estimate of relative abundance is the Smithfield Beach index of catch per unit effort, which began in 1990. Prior to 1990, we have the Lewis haul seine catch per haul index. A plot of these two indices for 1990-2010 shows similar trends (Figures 8-9). The correlation between these two indices is highly significant (Pearson product-moment: $r = 0.866$; $P < 0.001$). This suggests that we can consider the Lewis haul seine index to be a proxy for the Smithfield Beach index prior to 1990.

If we plot the Lewis haul seine index with the Schaffer tag-recapture estimates, we see another very tight correlation (Spearman's Rank; $r_S = 0.83$, $n = 17$, $P < 0.01$) (Figure 32). This suggests that both the Lewis haul seine index and the Schaffer estimates are tracking the stock size fairly well, since the correlation of the two is extremely high, and the probability that the match is due to chance alone is very small. Yet estimation of population size in prior years using hydroacoustic methodology (alternative estimates), do not appear correlated with the Smithfield Beach index except for the last four years (Figure 33).

Estimation of the American shad run size requires the scaling up of the observed relative index. Given the tight correlation between the Lewis haul seine and Smithfield beach indices and the uncertainty of shad catchability in the Lewis haul seine, the Co-op decided to initially focus on Smithfield Beach index. The Smithfield Beach relative index was scaled to an estimate of absolute abundance using a scalar (Schaefer estimate)/ (Smithfield index) derived from Schaffer estimates. Only a single year, 1992, was a Schaeffer estimate conducted concurrently with the

Smithfield Beach index. This scalar was then multiplied by all Smithfield Beach index values to get absolute population estimates for all years (Figure 34). These run size estimates were in very close agreement with the run size estimates from the hydroacoustic estimates (alternative estimates) during the last four years (2004-2007).

Estimation of the commercial exploitation rate and the instantaneous fishing mortality exerted by the combined New Jersey and Delaware fisheries can now be calculated based on the run size estimates. Corrections to the commercial harvest were required to estimate landings prior to the implementation of mandatory reporting by New Jersey (2000). Previous landings were developed by the National Marine Fisheries Service, but that agency did not seem to have good estimates from the River and Upper Delaware Bay, where much of the New Jersey fishery occurred. We used the ratio of New Jersey river landings to the bay landings in Delaware for the period 2000-2003, after the New Jersey mandatory reporting went into effect, but before Delaware shad landings declined due to a shift to larger mesh nets that catch few shad. The average of this ratio for the four years was then applied to the period before 2000 by multiplying the Delaware Bay landings by this ratio, producing a higher set of New Jersey landings for this period (Figure 35). The resulting estimates of annual instantaneous fishing mortality average $F = 0.15$ from 1990 to 2010, and have declined in recent years. A value of $F = 0.15$ is a low rate of fishing mortality (Figure 36). Exploitation of the total Delaware stock was estimated to vary between 1.3% and 28.5%, during the time period with a long-term average of 13.7% (Figure 37). It should be noted that this mortality rate only applies to in-river fisheries and does not account for mortality caused by the historical directed ocean fishery or the historic and current ocean bycatch losses.

6 Future Monitoring Programs

6.1 Fishery Independent

6.1.1 Juvenile abundance indices

The tidal beach seine program conducted by NJDFW will continue, given its importance to their striped bass monitoring requirements.

The Co-op would like to reinstitute the upper river non-tidal JAI index that was discontinued in 2008 by the NJDFW. A look at the period of 1999 to 2005 lends emphasis to the Co-op's concerns over lack of juvenile abundance sampling within the non-tidal section of the Delaware River. During that period, two year classes were considered to be below the sustainability benchmark while five others were at or slightly higher than the benchmark. During that same period, the tidal JAI was below its benchmark only once and well above it for the majority of those years. The consensus of the Co-op is that it is critical to renew the non-tidal survey as part of this sustainability plan, given the perceived variability of juvenile production within the entire Basin.

The Co-op is discussing possible options to re-initiate the non-tidal JAI. In the spirit of moving forward with the Delaware River Basin Sustainability Plan, the Co-op proposes retaining the non-tidal JAI benchmark as discussed above with the caveat of its use pending secured funding.

6.1.2 Adult stock monitoring

Spawning stock

The two fishery independent surveys at Smithfield Beach (gill net survey) and at Raubsville (electro-fishing) will continue for, at minimum, the next five years. The objective is to obtain biological data on the spawning stock as well as a relative abundance.

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 shad 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.

Upriver and downriver passage efficiencies

Access into tributary waters from the Delaware River mainstem is problematic. The two largest tributaries to the Delaware River Basin, the Lehigh River (RM 186) and Schuylkill River (RM 92.5), have several low head dams with various fishway designs. Furthermore, the Delaware Canal along Pennsylvania from Easton, Pa to Bristol, Pa and the Delaware & Raritan Canal from Bulls Island, NJ to Trenton, NJ restrict access to some tributaries in Pennsylvania and New Jersey; whereas other tributaries (e.g., Tohickon Creek, Cooks Creek and Frya Run in Pennsylvania) retain their direct connection to the Delaware River mainstem.

The PFBC, with the support from PA Department of Conservation and Natural Resources and the City of Easton, has received a grant from American Rivers/NOAA Community Grant Program to fund a feasibility study for improving fish passage at the two lowermost dams on the Lehigh River (i.e., Easton (RM 0.0) and Chain (RM 3.0) dams). This proposal was fully funded ($75,000 from Am. Rivers; and an additional $75,000 non-federal matched fund from Palmerton Resource Damage Settlement) in the spring of 2011. The PFBC anticipates the study's findings to provide future guidance on its shad restoration program in the Lehigh River. The study is expected to be completed no later than end of summer 2013.

Hatchery evaluation

Otoliths of all hatchery-reared American shad larvae stocked by PFBC into the Delaware River Basin are marked with tetracycline 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 and Raubsville. The proportion of hatchery fish present in juvenile or adult population will continue to be monitored as per ASMFC Amendment 3.

6.2 Fishery Dependent

6.2.1 Commercial fishery

The States of Delaware and New Jersey will conduct fishery dependent surveys as required by ASMFC Amendment 3.

6.2.2 Recreational fishery

Comprehensive angler use and harvest surveys are monetarily prohibitive. As an alternative, the Co-op intends to utilize the PFBC/NPS angler logbook survey as a measure of recreational angling on the Delaware River stock. To provide a more comprehensive understanding of angler catches the Co-op has solicited the Delaware River Shad Fisherman's Association (DRSFA) to participate in the logbook survey. The DRSFA organization represents the single largest sportsmen's group dedicated to fishing for American shad in the Basin states.

Angler information will also be gathered from a long standing annual American shad harvest tournament. The "Forks of the Delaware Tournament" is located in Easton Pa., lasts for multiple days in mid-May, and traditionally draws sizable angler participation. Unfortunately, historical information from this tournament is sporadic. To improve data gathering, the PFBC requires a special activities permit for any tournament with participation over ten anglers. A condition for this permit is the mandatory reporting of tournament catch. Tournament directors are required to electronically submit catch information (total number of participating anglers, total hours fished, total number of fishes checked in by species, total number of fishes released) for the tournament, but not on a per angler basis.

The Marine Recreational Information Program (MRIP) will be reviewed for pertinent angler catch data for the Delaware River Basin. However this program does not extend to anglers above head-of-tide, where the shad fishery is principally focused.

7.0 Fishery Management Program

7.1 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. As described above, 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 restriction will remain the same (Table 10).

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 10. 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.

7.2 Recreational fishery

Above the Commodore Barry Bridge (82.9 km downstream from the head-of-tide in Trenton), both, New Jersey and Pennsylvania currently have an American shad creel limit of three shad per day. Below the Commodore Barry Bridge, the six shad/day limit still applies, but very little recreational fishing for shad occurs in this tidal zone. In the joint New York/ Pennsylvania reaches of the upper Delaware River, the creel limit is three per day. 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.

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, under the stewardship of the Pennsylvania Fish and Boat Commission. The Lehigh River is managed under the Lehigh River Fisheries Management Plan adopted in May 2007 (Arnold and Pierce 2007; http://www.fishandboat.com/LehighRiverPlan.htm). Current regulations allow for a one shad daily creel, no minimum size in both rivers, including all their respective tributaries, starting at the Easton Dam (RM 0.0) on the Lehigh River and Interstate 95 Bridge on the Schuylkill River (RM 0.5). Both rivers are stocked with hatchery reared fry annually to support PFBC's restoration efforts, with a goal of generating self-sustaining spawning populations. Given PFBC's ongoing restoration program for these rivers, by definition, the American shad populations within the Lehigh and Schuylkill rivers are considered recovering stocks. As such, the PFBC intends to modify current regulations to reflect recreational catch and release only and prohibit any commercial harvest by Jan 1, 2013 for the Lehigh and Schuylkill basins. The Lehigh River Management Plan has been submitted to the ASMFC in fulfillment of the required Implementation (Recovery) Plan.

7.3 Bycatch and Discards

New Jersey and DE will require data on bycatch and discard in commercial fisheries in state waters in their mandatory reports. In the recreational fishery many anglers are practicing catch-and-release, there are no plans to regulate this other than with creel limits which are already in place.

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Figure 1. The Delaware River watershed.

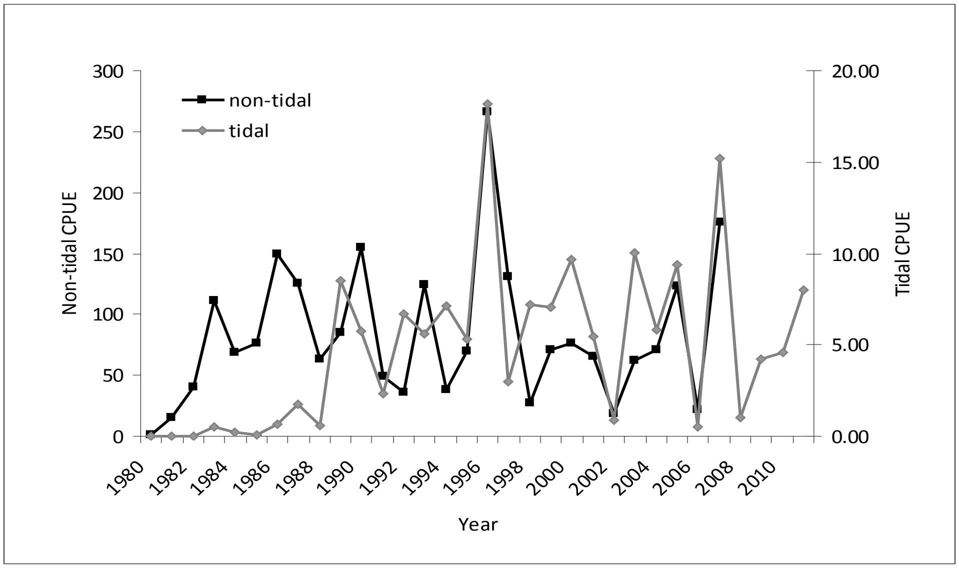

Figure 2. Non-tidal and tidal Delaware River American shad JAI (Geometric mean): 1980 – 2011. Data for 2011 is preliminary.

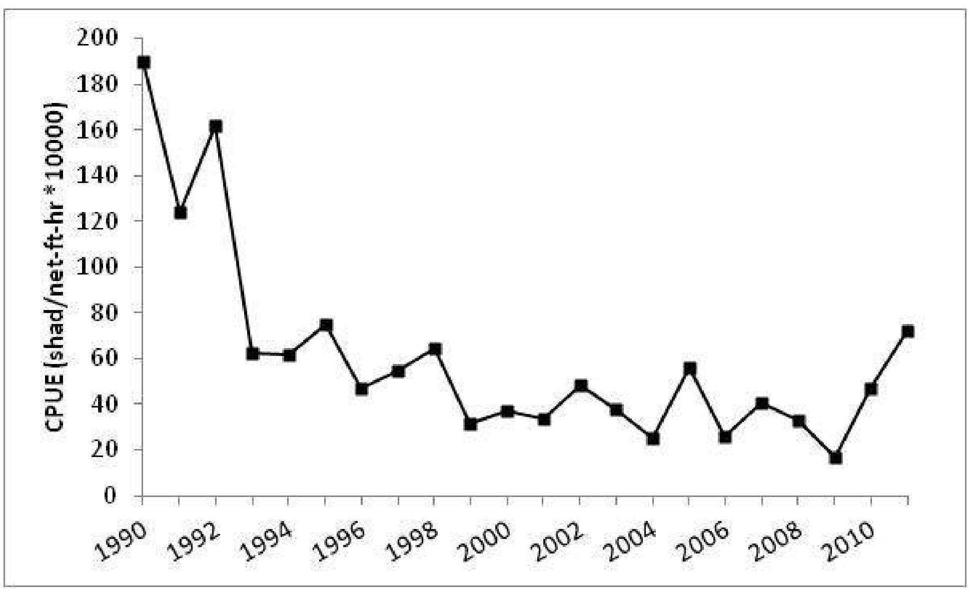

Figure 3. CPUE for American shad collected from the Delaware River at Smithfield Beach (RM 218) by gill net (shad/net-ft-hr * 10,000).

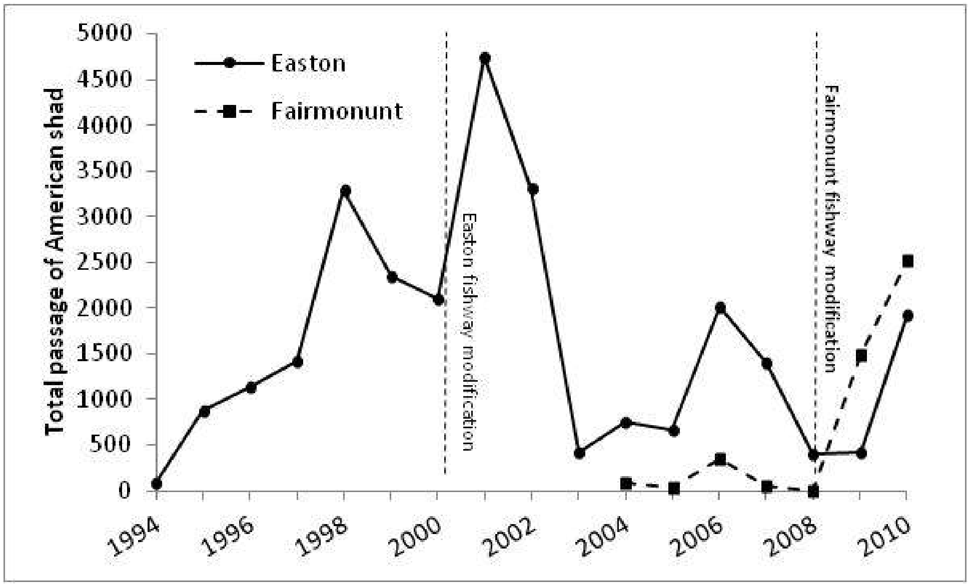

Figure 4. Upstream fish passage trends for the Lehigh (Easton Dam) and Schuylkill (Fairmount Dam) rivers.

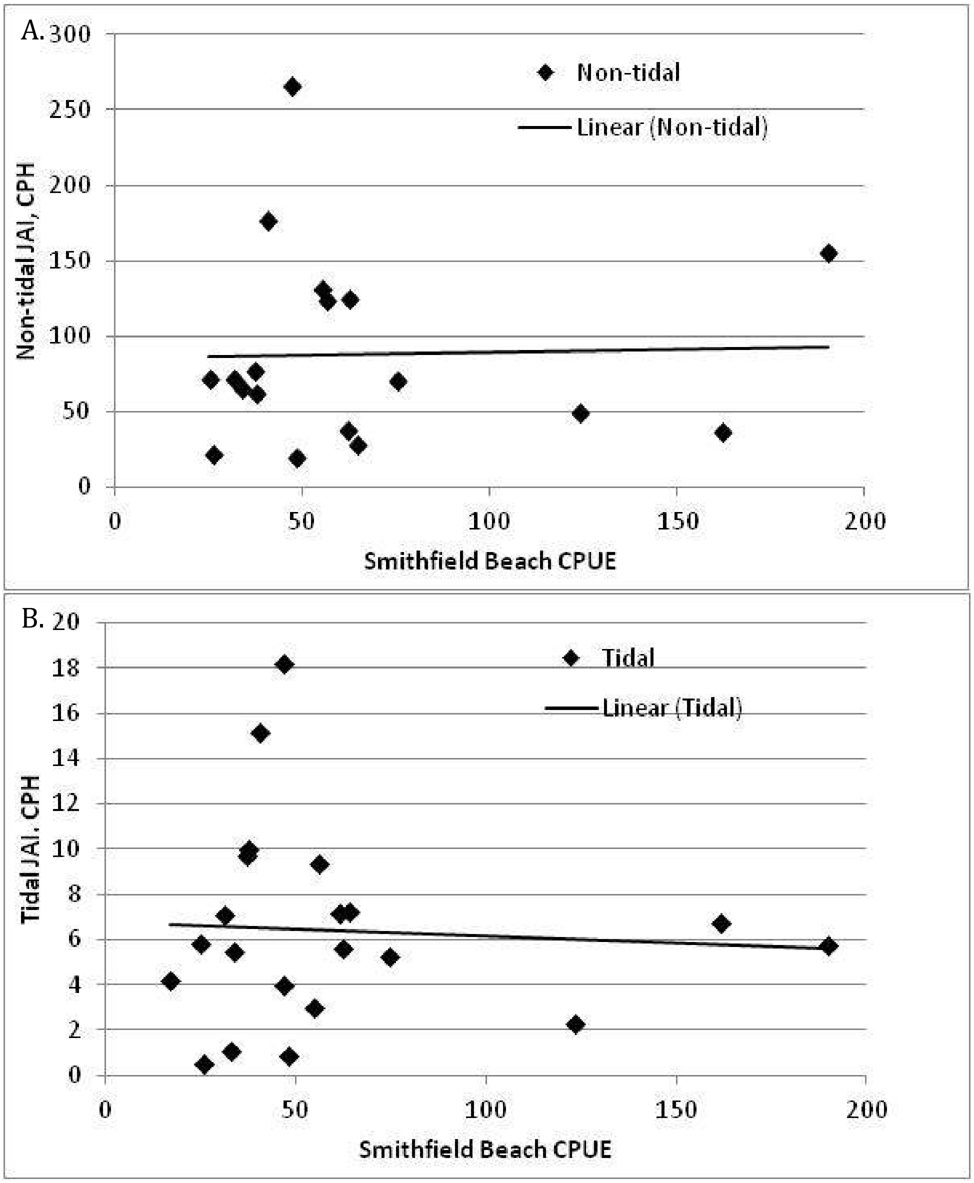

Figure 5. Scatter plots of the non-tidal (A) and tidal (B) JAIs to adult relative abundance as indexed at Smithfield Beach.

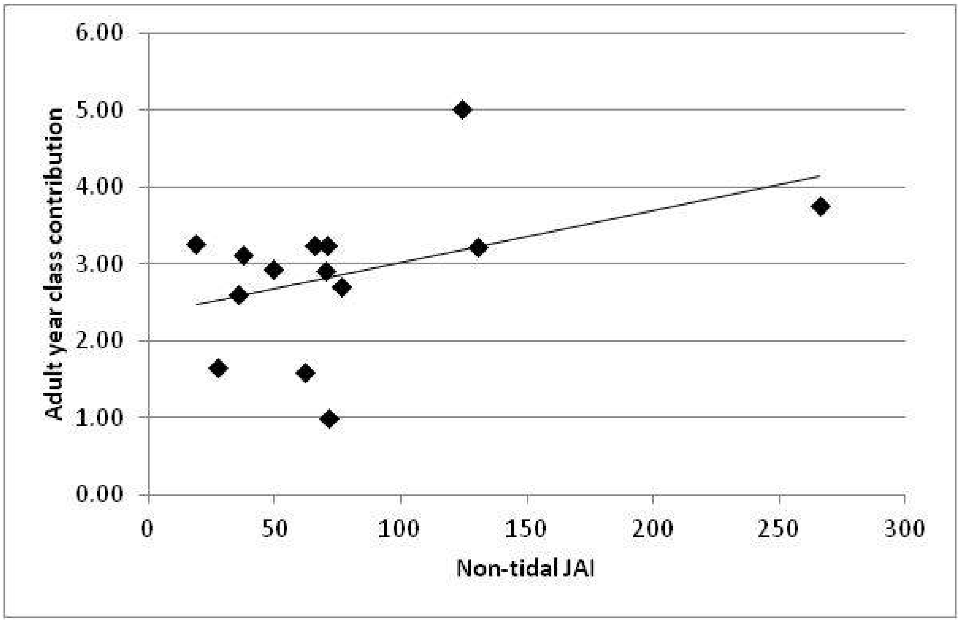

Figure 6. Correlation between spawning adult year class CPUE partitioned by year class contributions at Smithfield Beach to non-tidal JAI index.

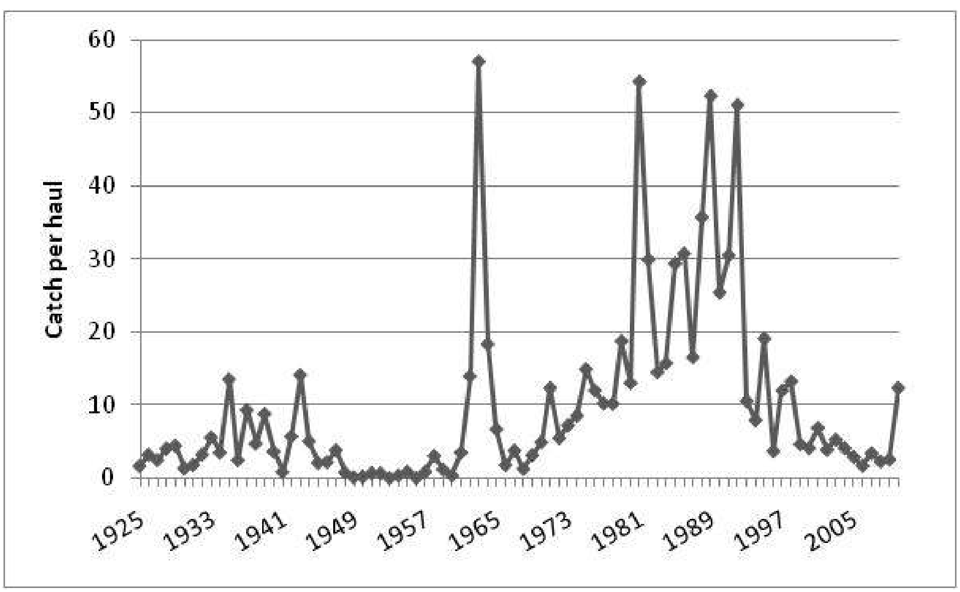

Figure 7. Lewis haul seine CPUE (shad/haul), 1925-2010.

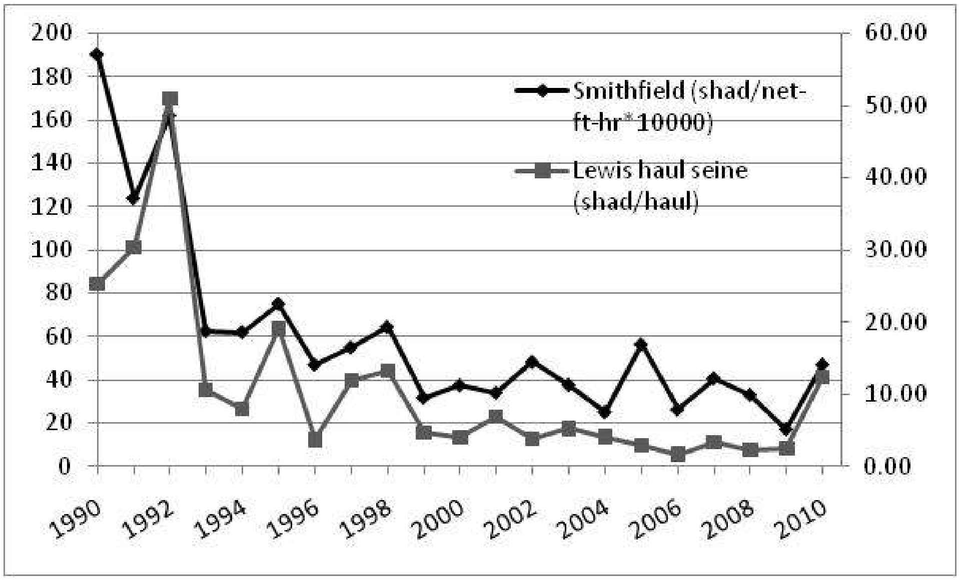

Figure 8. Trends in relative abundance as estimated from Smithfield Beach and Lewis haul seine, 1990-2010.

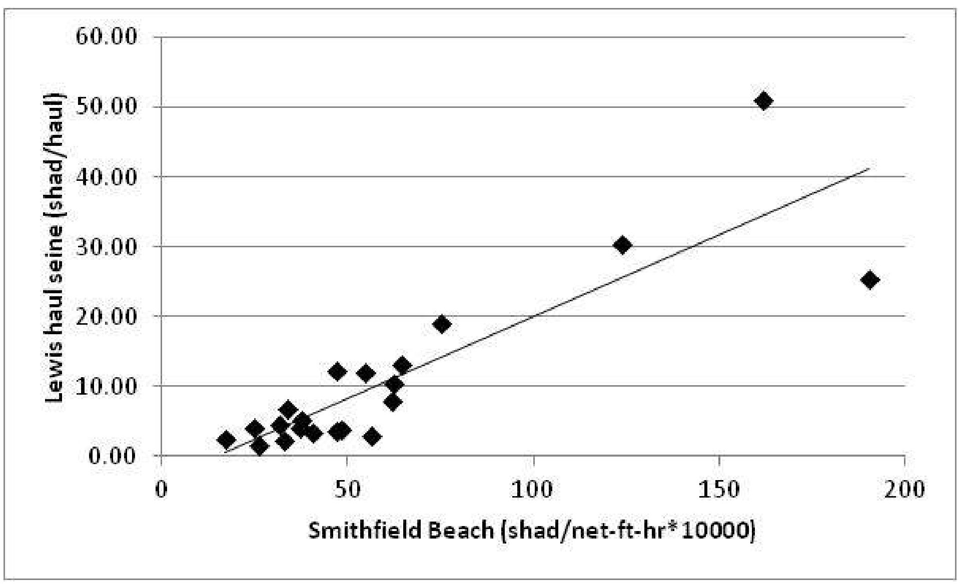

Figure 9. Correlation between Smithfield Beach and Lewis haul seine, 1990-2010.

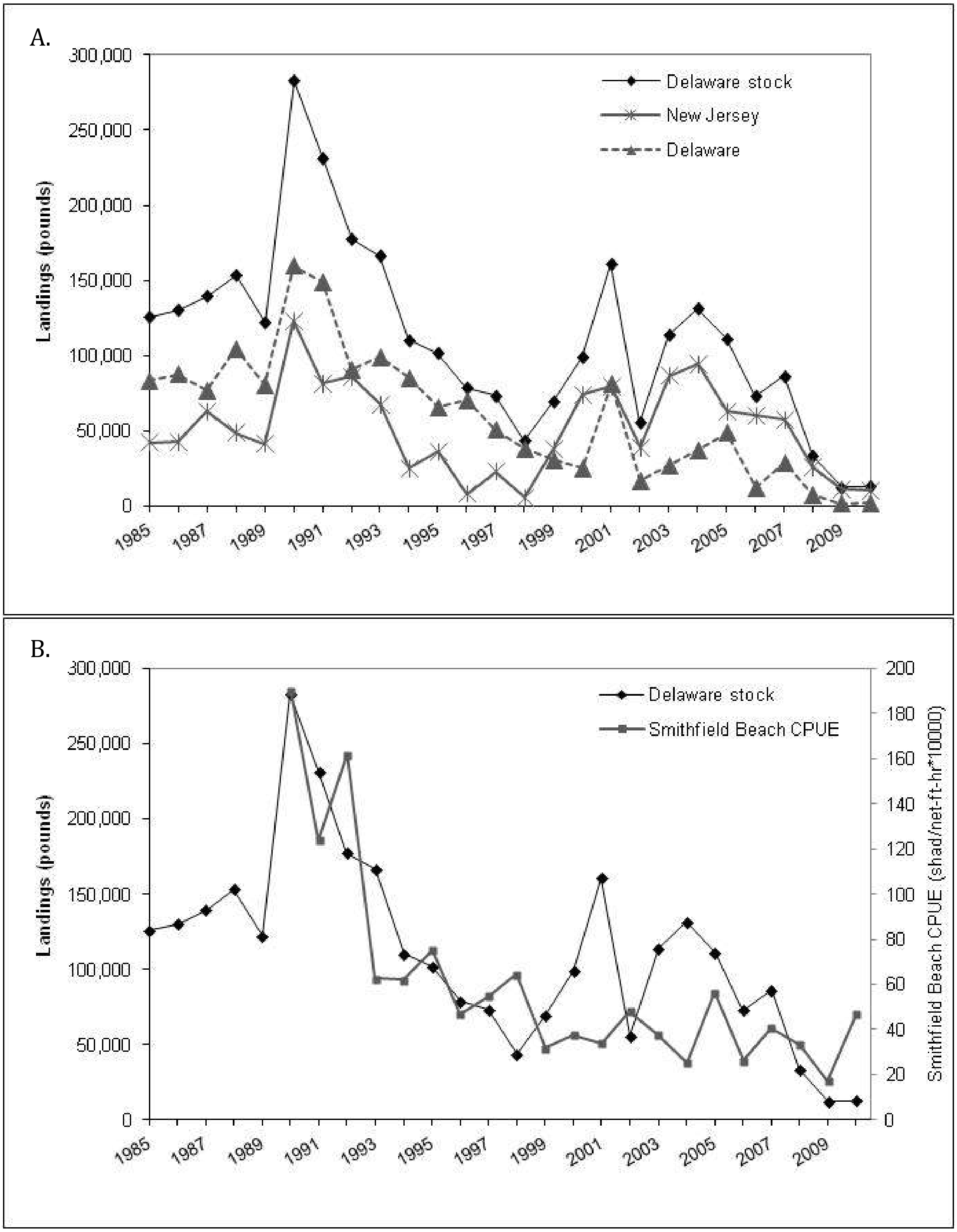

Figure 10. Commercial landings of American shad from New Jersey, Delaware and the combined Delaware stock (A); and the Delaware stock to Smithfield Beach CPUE (B).

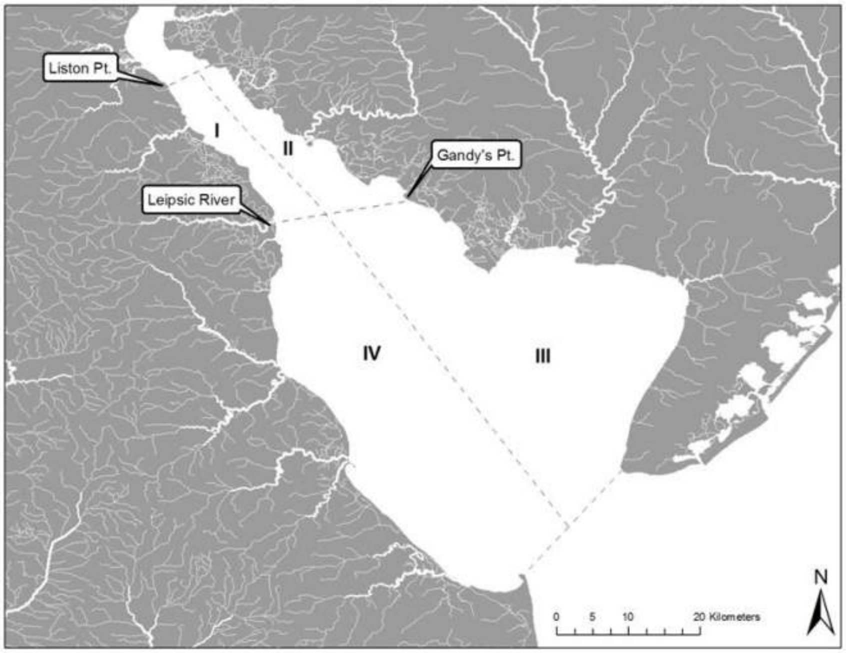

Figure 11. Map of illustrating general regions of commercial landings for River (I and II) and Bay (II and IV) reporting.

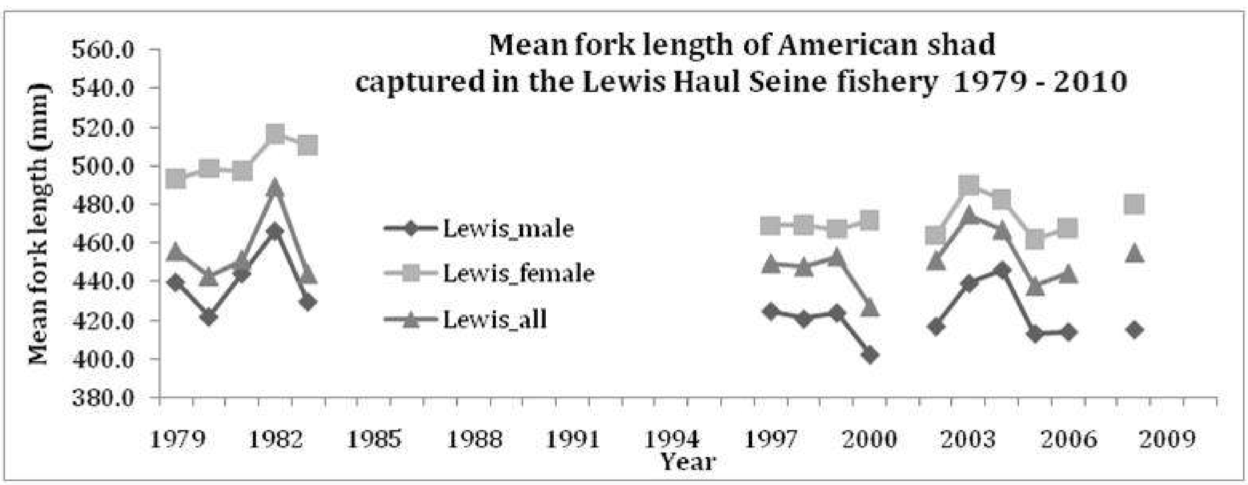

Figure 12. Mean fork length of male and female American shad captured in the Lewis haul seine fishery between 1997 and 2010.

A.

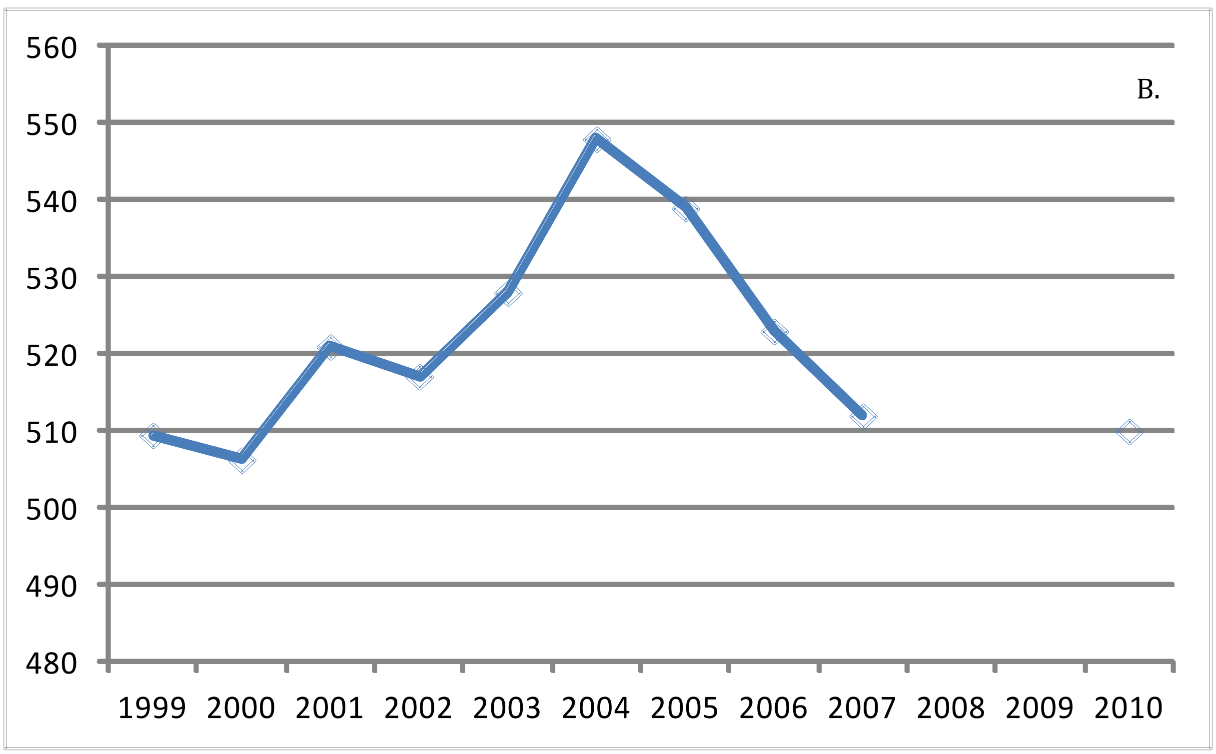

Figure 13. Length frequency of shad from A) New Jersey's Delaware Bay fisheries independent sampling at Reed's Point for American shad using gill net similar to commercial mesh sizes, length frequencies (sexes combined): 1997-2010; and B) State of Delaware commercial fishers American shad mean lengths from all locations sampled in the Delaware River and Bay, sexes combined, 1999-2010. No samples were obtained by Delaware in 2008 and 2009.

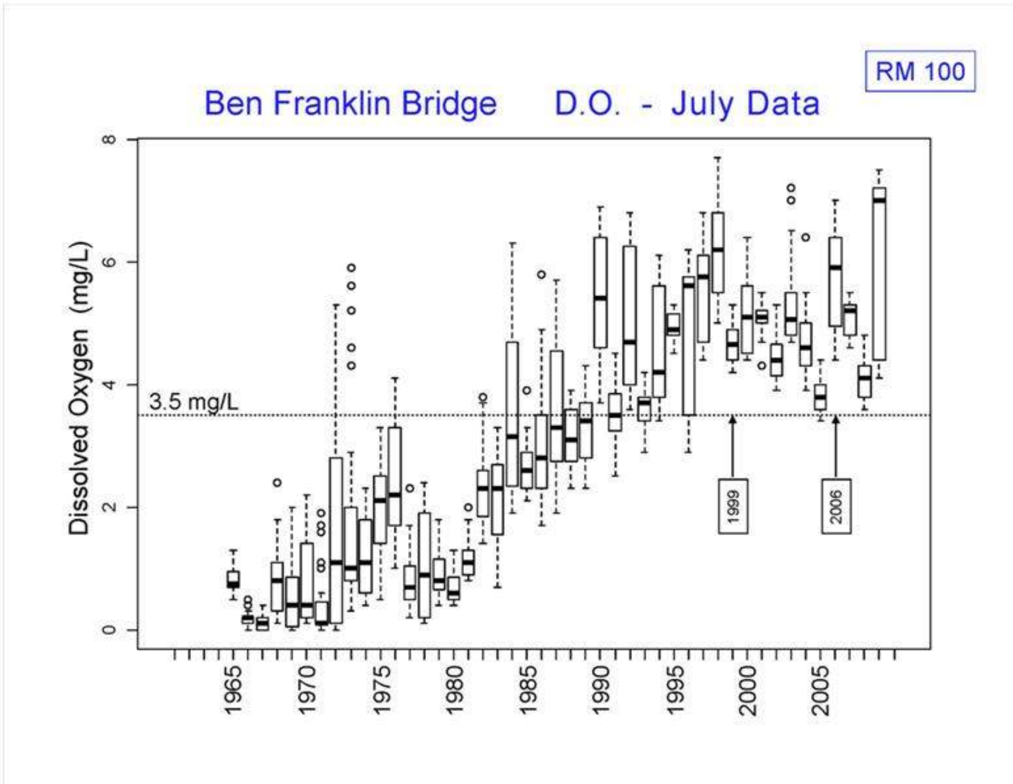

Figure 14. Box and whisker plot of dissolved oxygen concentrations during July, 1965-2009 at the Ben Franklin Bridge (RM 100). Data and graph provided by the Delaware River Basin Commission (DRBC).

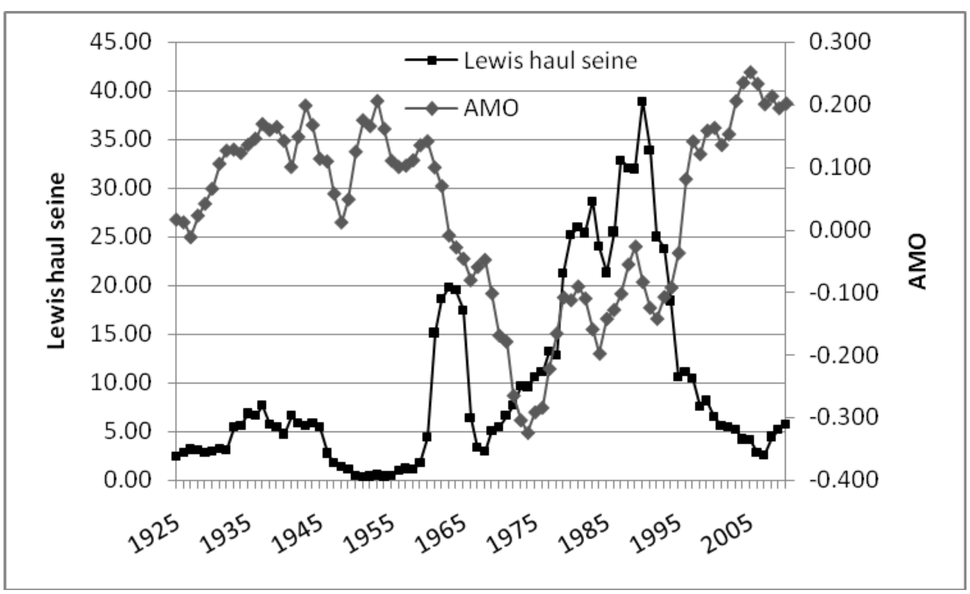

Figure 15. Five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Lewis haul seine CPUE: 1925 - 2010.

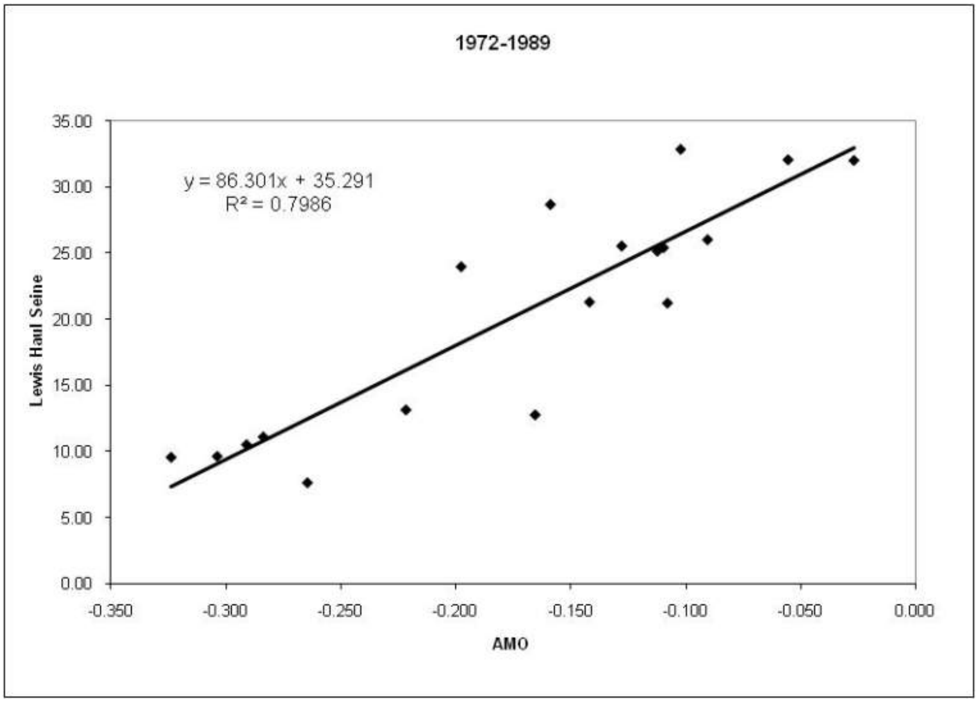

Figure 16. Scatter plot of the five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Lewis haul seine CPUE: 1972 - 1989.

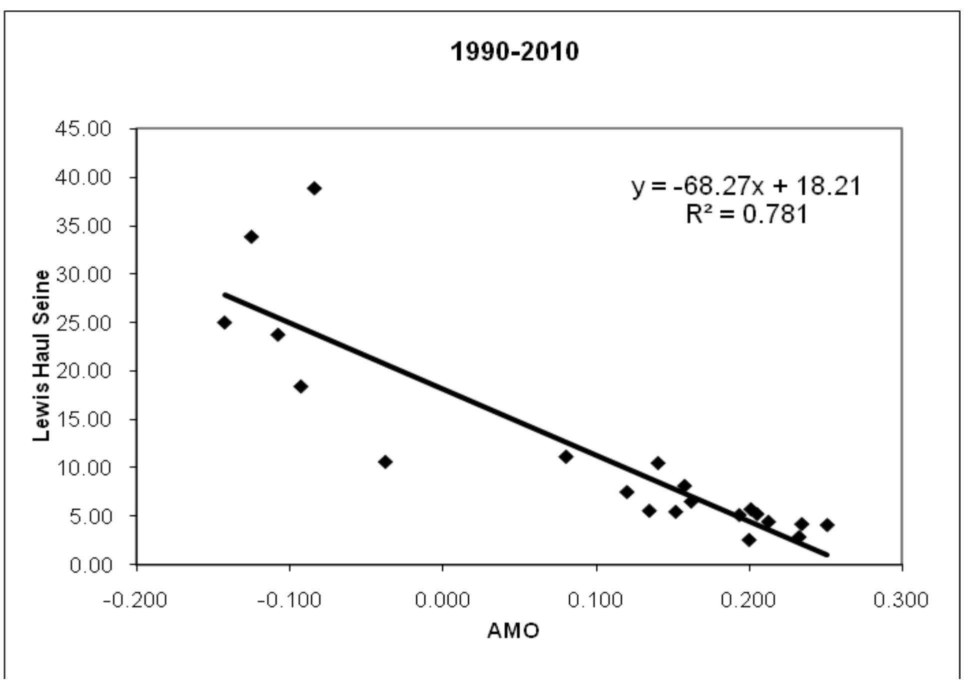

Figure 17. Scatter plot of the five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Lewis haul seine CPUE: 1990 - 2010.

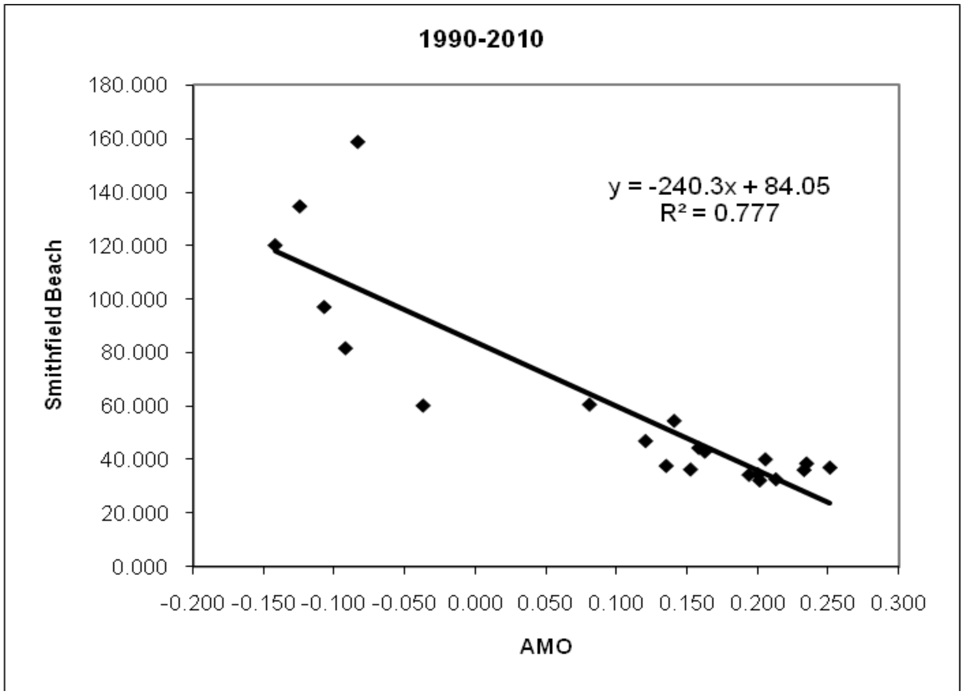

Figure 18. Scatter plot of the five-year smoothed Atlantic Multidecadal Oscillation (AMO) compared to five-year smoothed Smithfield Beach CPUE: 1990 - 2010.

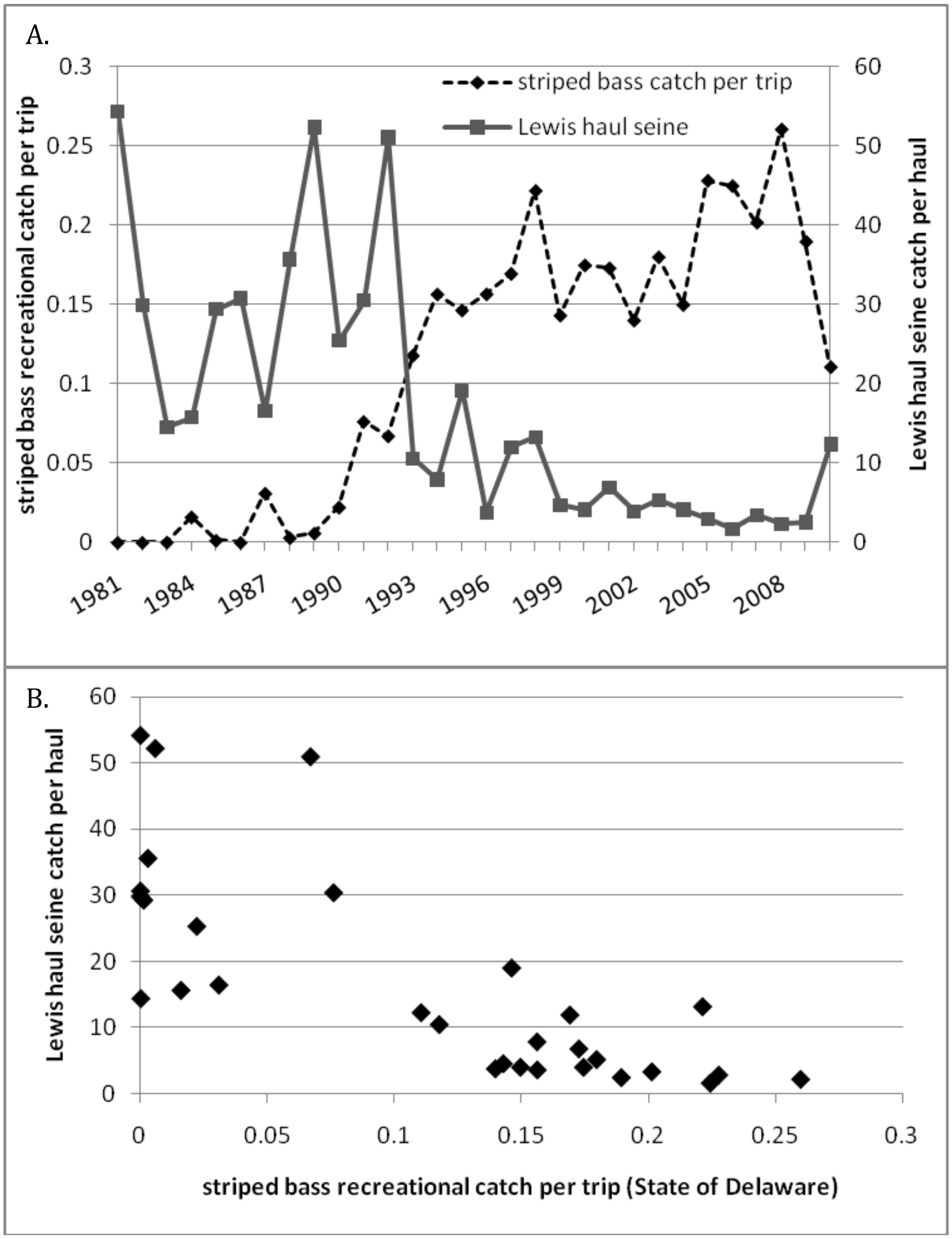

Figure 19. Adult shad abundance as estimated by the Lewis haul seine catch-per-haul from 1981 through 2010 plotted with an index of striped bass relative abundance in Delaware waters (MRFSS recreational total catch per trip; A) and associated scatter plot. (B)

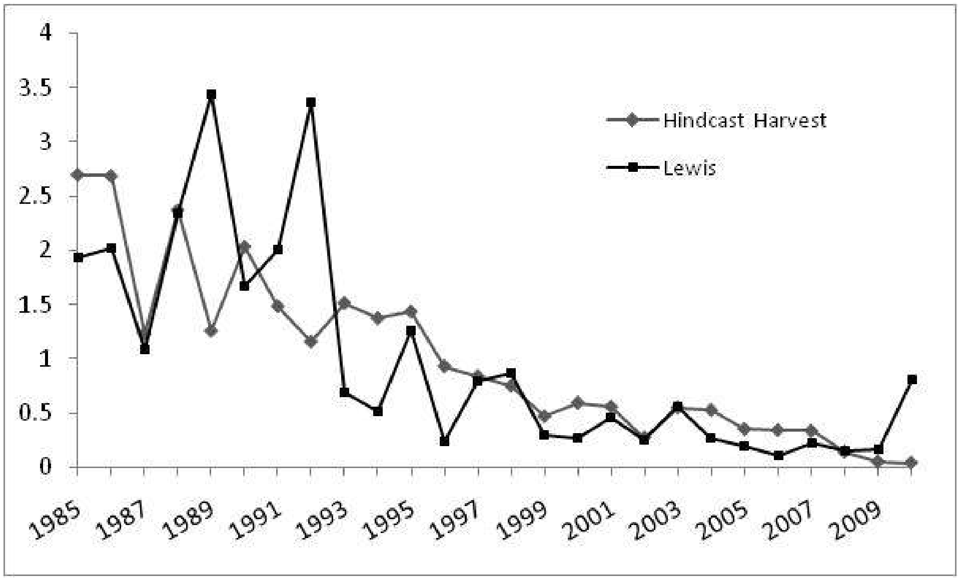

Figure 20. Normalized estimated harvest in numbers of American shad from the Delaware stock and relative abundance of surviving mature American shad in the Lewis haul seine fishery at Lambertville, NJ.

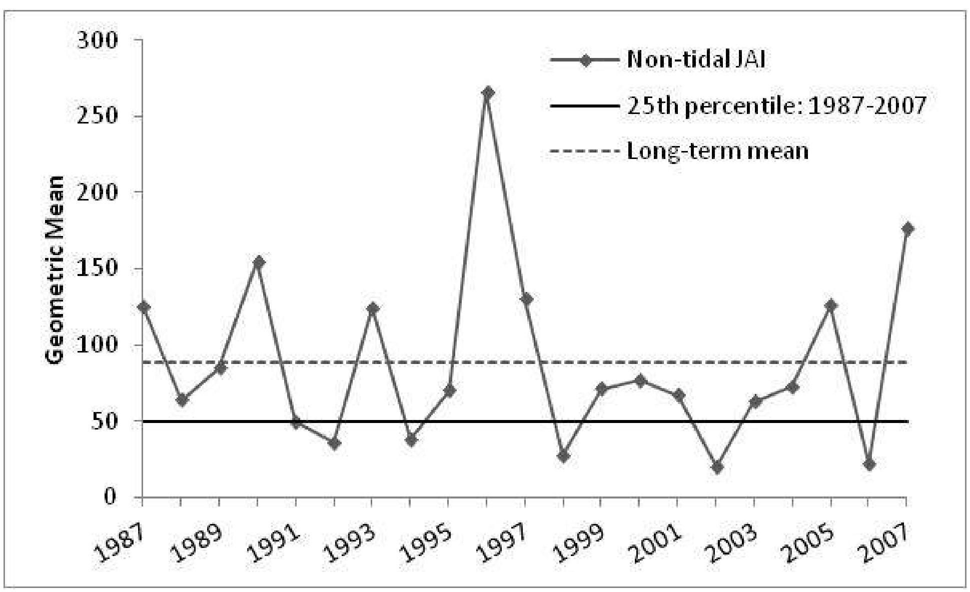

Figure 21. The Delaware River non-tidal American shad JAI with 25th percentile benchmark: 1987 – 2007.

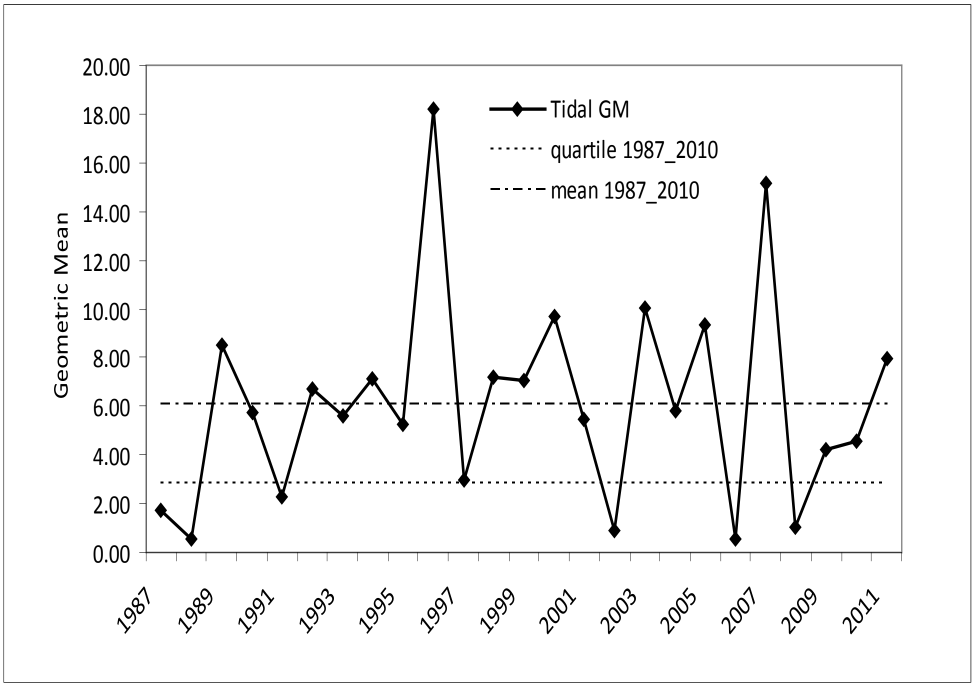

Figure 22. The Delaware River tidal American shad JAI with 25th percentile benchmark: 1987 – 2011. The geometric mean JAI for 2011 was not included in the benchmark calculation and is considered preliminary.

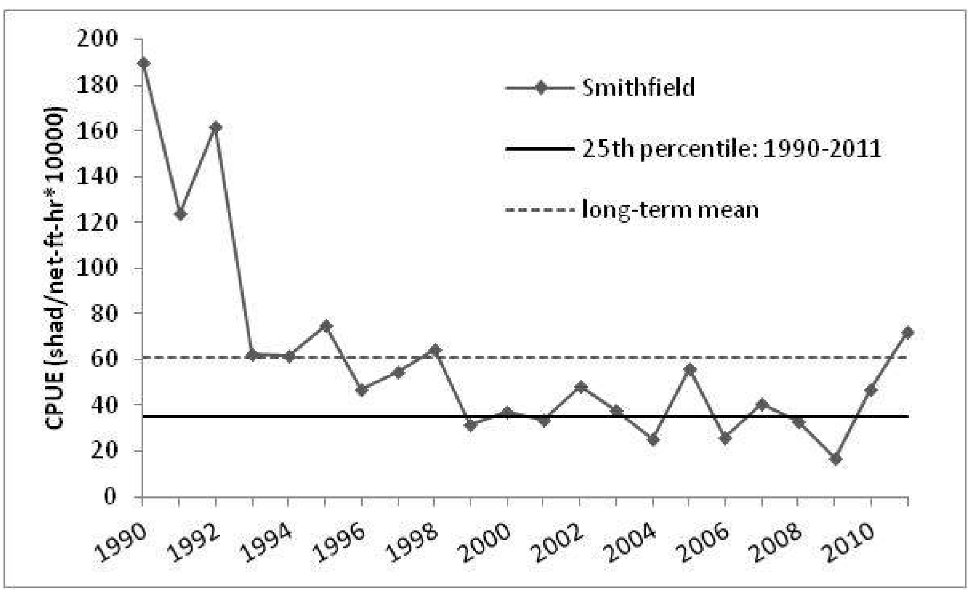

Figure 23. The Delaware River spawning adult American shad index at Smithfield Beach (RM 218) with 25th percentile benchmark: 1990 – 2011.

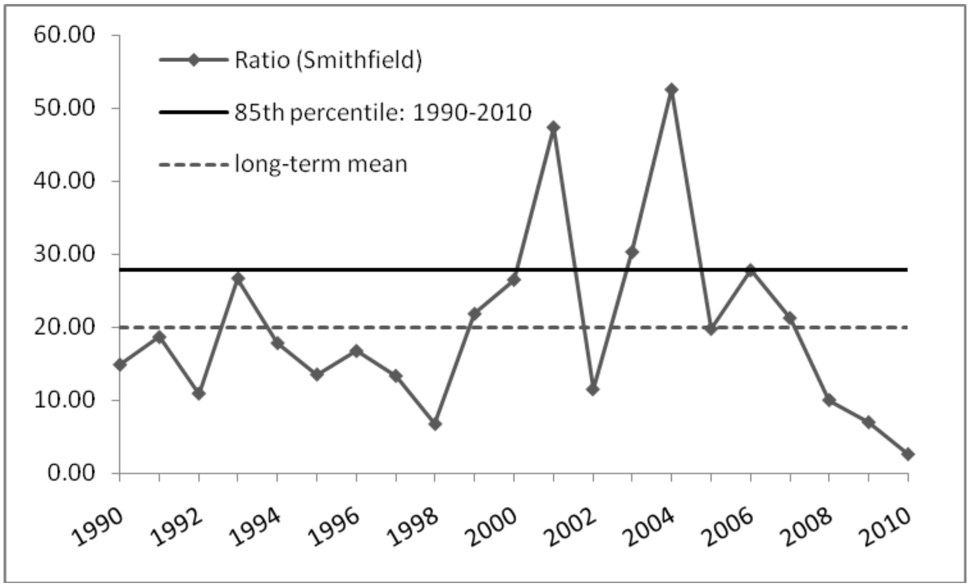

Figure 24. Ratio of harvest to Smithfield Beach relative abundance with 85th percentile benchmark: 1990-2010.

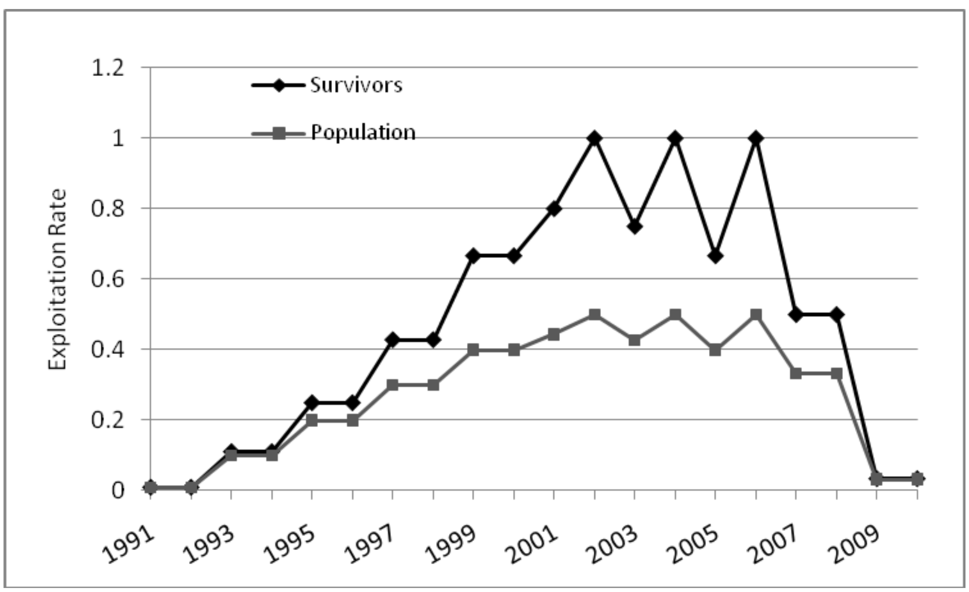

Figure 25. Comparison of exploitation rates based on the population prior to harvest (pop) and on survivors following harvest (survivors).

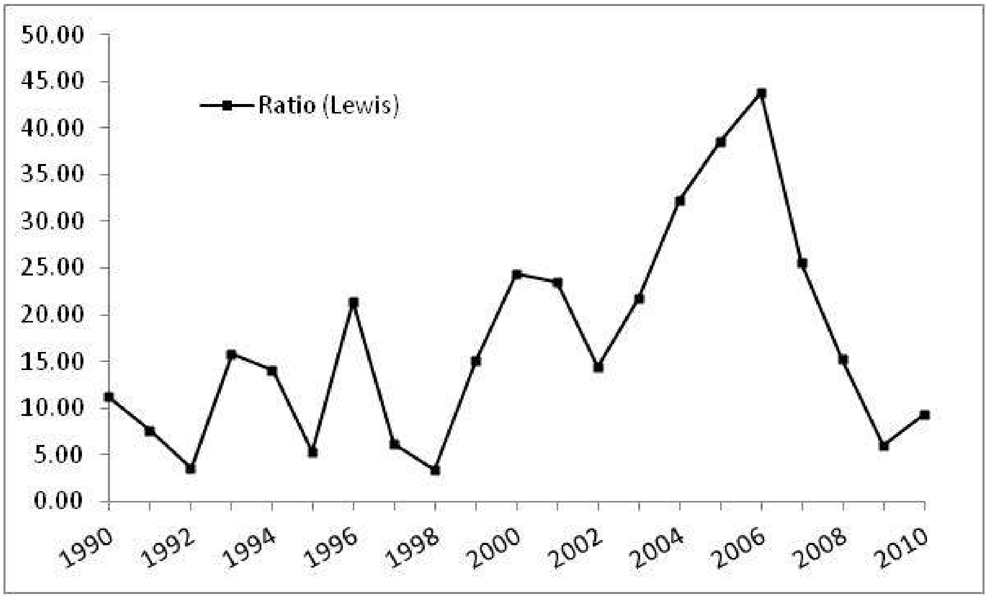

Figure 26. Ratio of harvest to Lewis haul seine relative abundance.

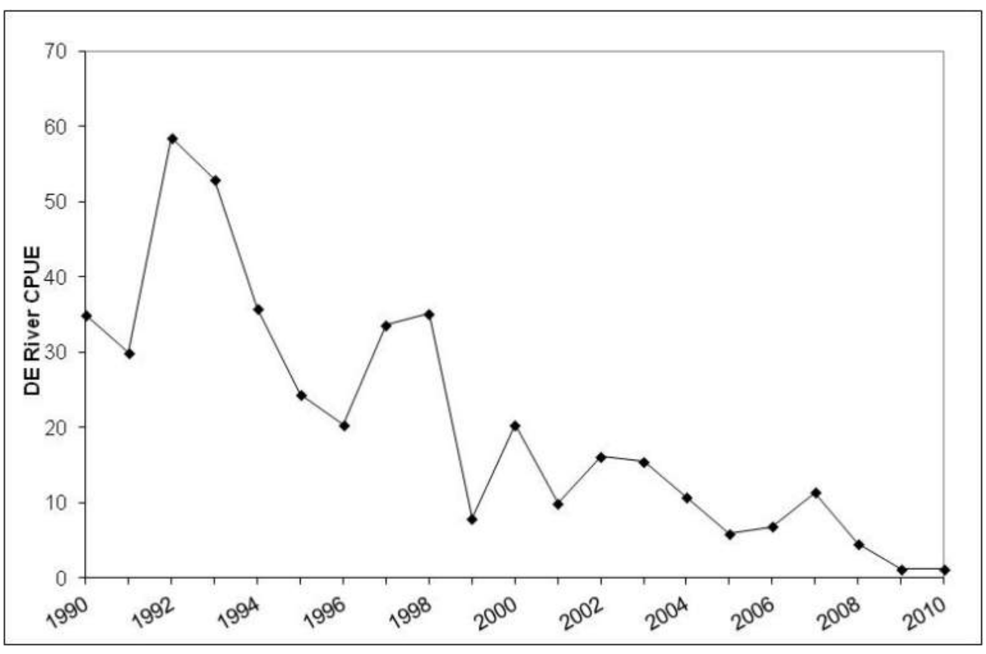

Figure 27. State of Delaware commercial American shad CPUE for the Delaware River.

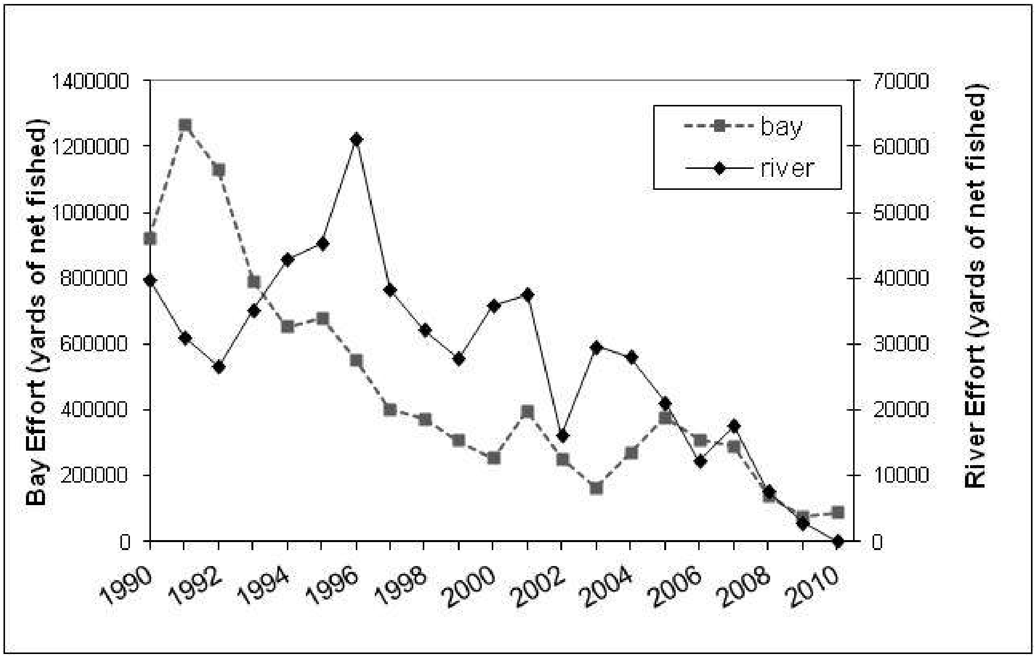

Figure 28. State of Delaware **c**ommercial fishery effort in yards of net fished for the Delaware River and Bay (1990-2010).

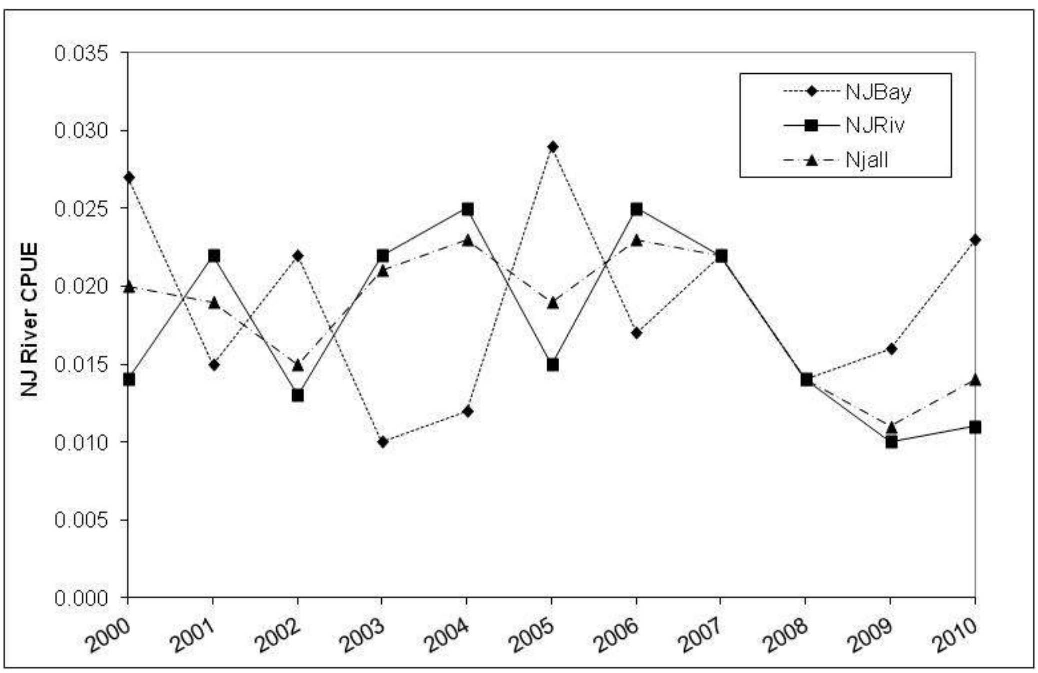

Figure 29. New Jersey commercial American shad CPUE from 2000-2010.

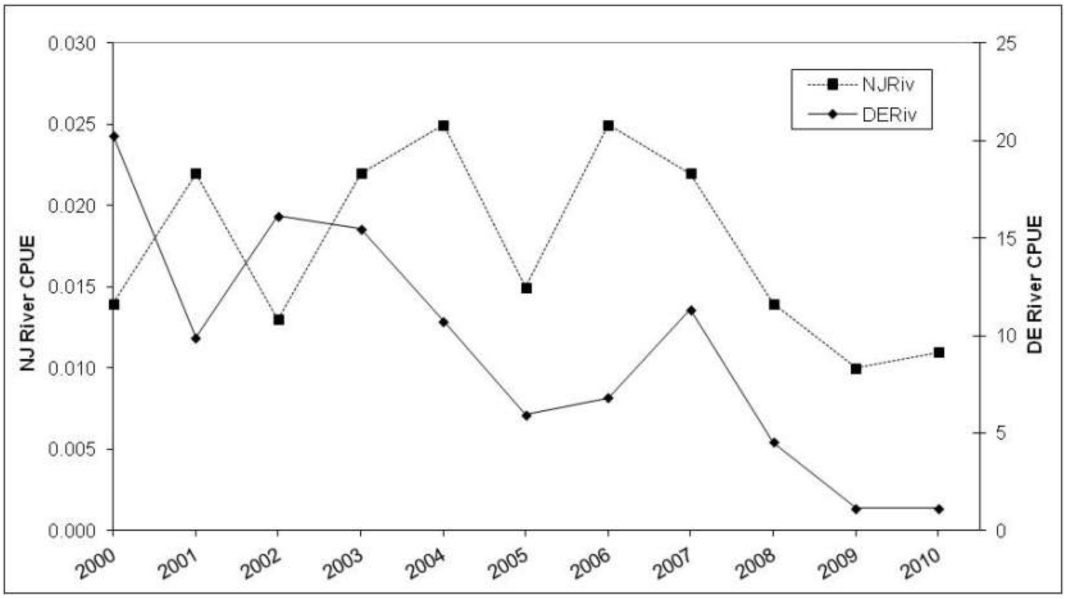

Figure 30. New Jersey and Delaware trends in commercial American shad CPUE from 2000-2010.

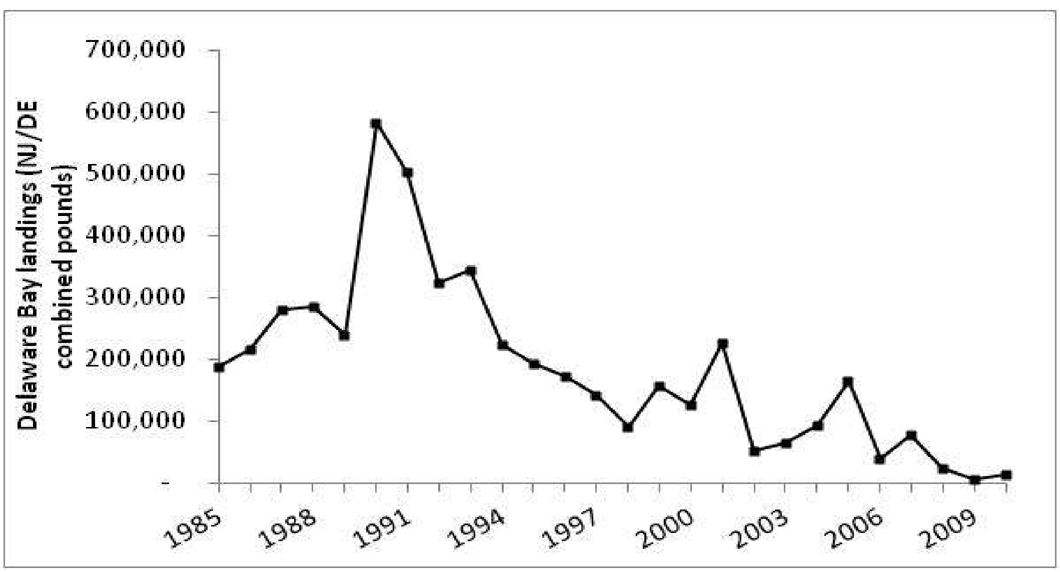

Figure 31. Combined Delaware Bay landings (pounds) of the mixed stock from New Jersey and Delaware, 1985 – 2010.

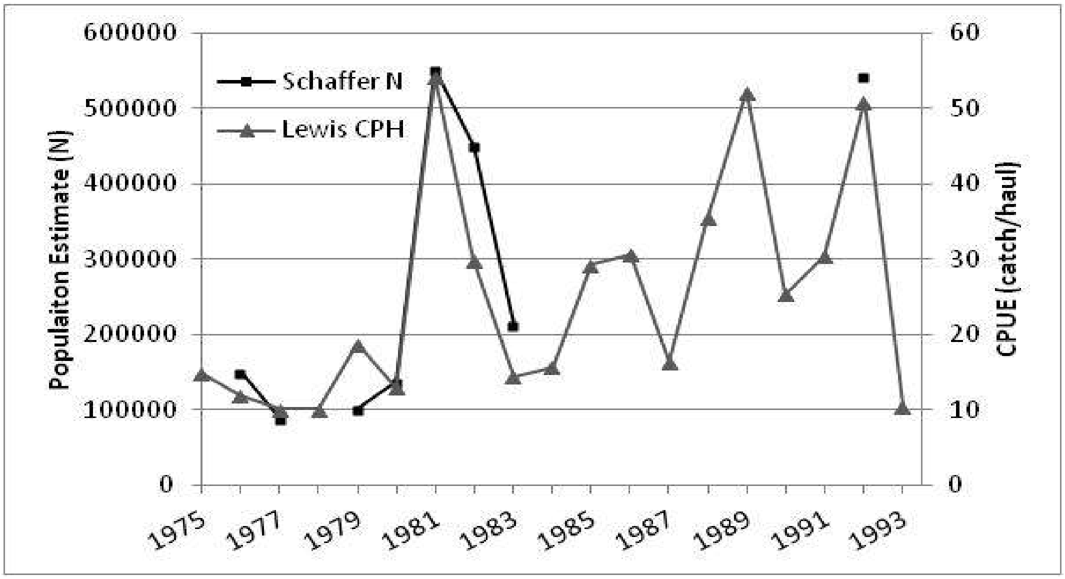

Figure 32. Schaefer tag-recapture estimates of stock size and the Lewis haul seine index of relative abundance, 1976 – 1992.

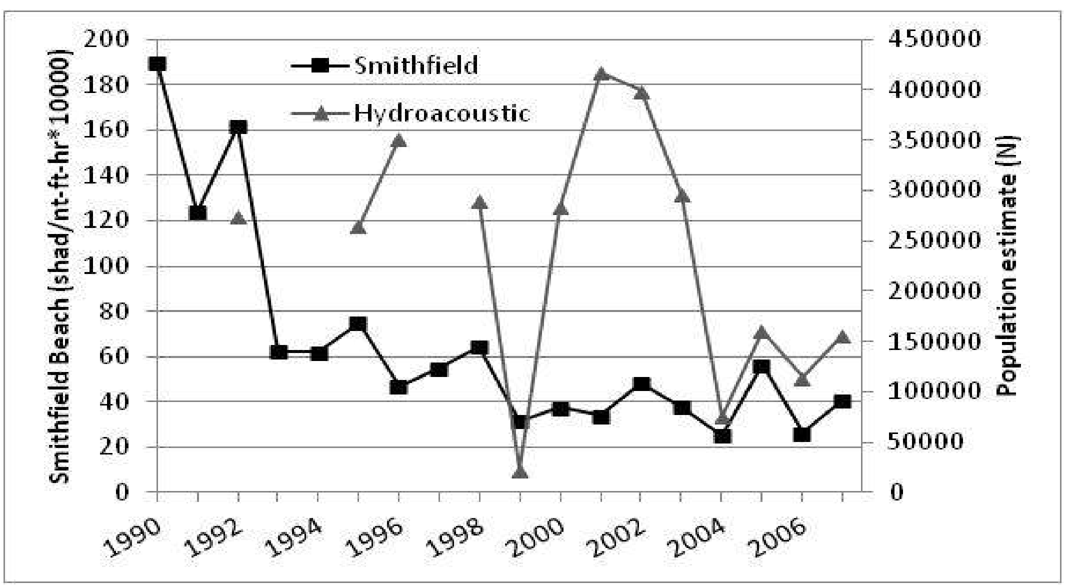

Figure 33. Estimates of absolute abundance from the hydroacoustic (alternate method) and the Smithfield Beach relative abundance.

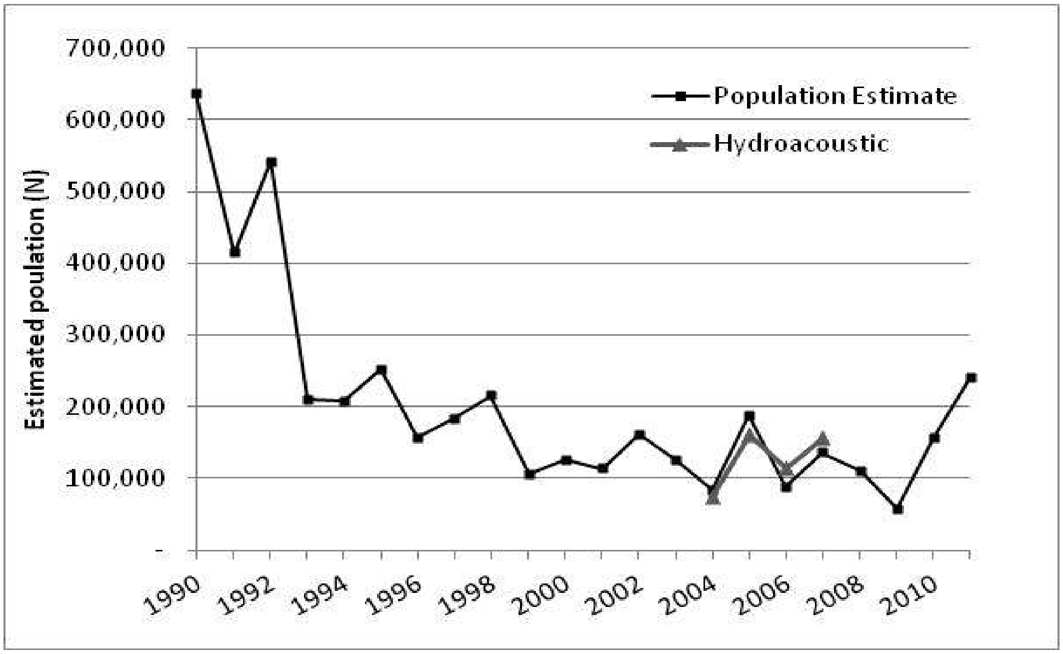

Figure 34. Absolute run size estimates for 1990 – 2011 based on the Smithfield Beach index as scaled up by use of the 1992 Schaefer estimate of run size. Estimates of run size from the hydroacoustic alternative method are also plotted for 2004-2007.

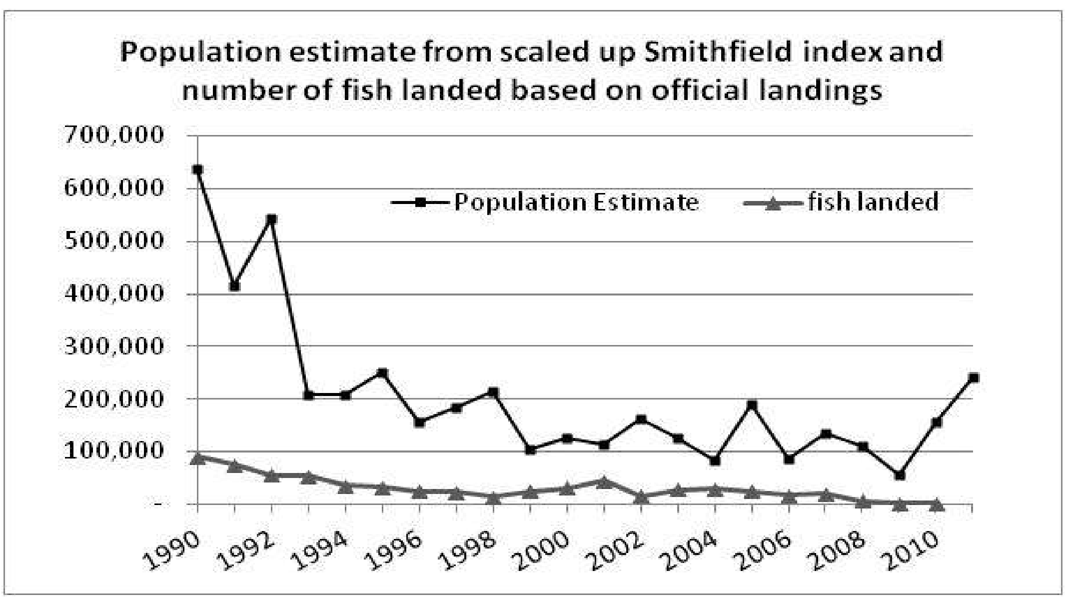

Figure 35. Landings in numbers of shad landed plotted with the run size estimated from the scaled up Smithfield Beach index.

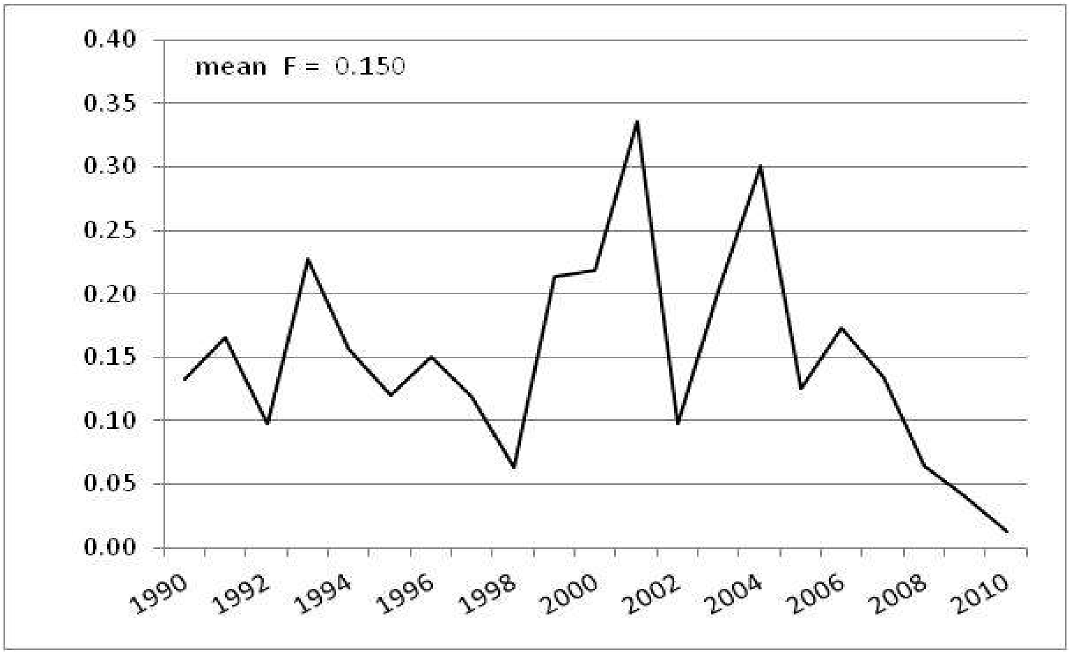

Figure 36. The time series of estimated instantaneous fishing mortality from the combined commercial fisheries of New Jersey and Delaware for the period 1990-2010.

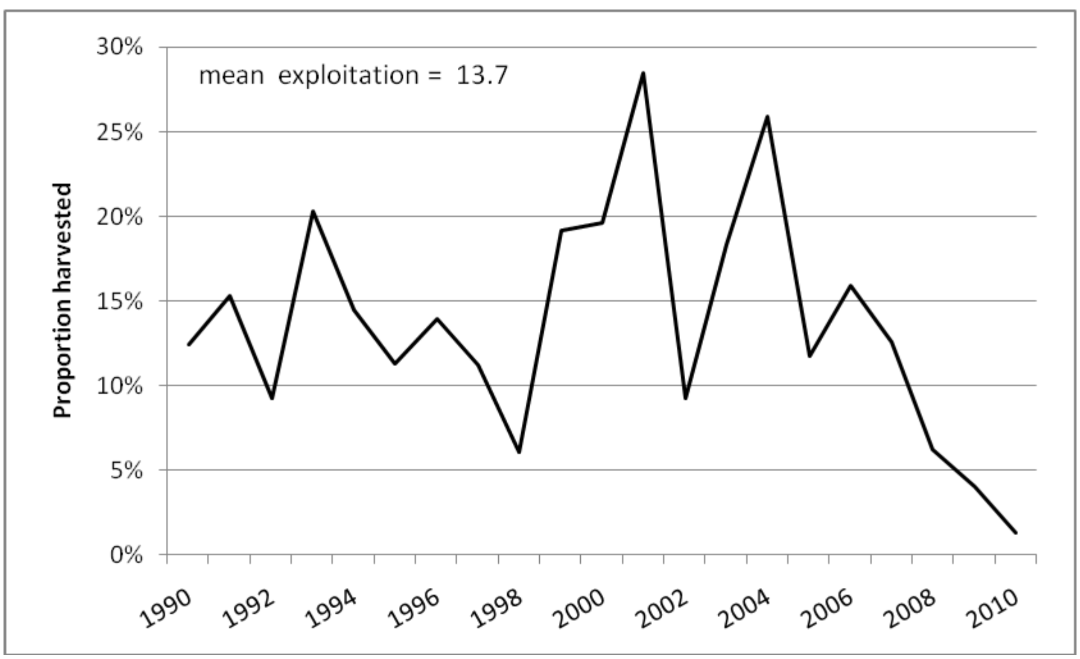

Figure 37. Estimation of the percentage of exploitation of the Delaware stock by commercial fishers as derived from the scaled Smithfield Beach relative abundance index, 1990-2009.

Table 1. Abundance indices for Delaware River American shad.

Year	Juvenile Indices		Adult Indices	
	Upper Non-tidal	Lower Tidal	Smithfield Beach CPUE	Lewis haul seine CPUE
1925				1.62
1926				3.18
1927				2.43
1928				4.00
1929				4.39
1930				1.30
1931				1.77
1932				3.20
1933				5.54
1934				3.45
1935				13.47
1936				2.43
1937				9.29
1938				4.68
1939				8.77
1940				3.59
1941				0.80
1942				5.68
1943				14.07
1944				5.02
1945				2.05
1946				2.15
1947				3.79
1948				0.73
1949				0.09
1950				0.18
1951				0.66
1952				0.63
1953				0.00
1954				0.35
1955				0.84
1956				0.00
1957				0.83
1958				3.00
1959				1.13
1960				0.32
1961				3.46
1962				13.89

	Juvenile Indices		Adult Indices	
Year	Upper Non-tidal	Lower Tidal	Smithfield Beach CPUE	Lewis haul seine CPUE
1963				56.90
1964				18.29
1965				6.65
1966				1.75
1967				3.74
1968				1.22
1969				3.10
1970				4.88
1971				12.30
1972				5.44
1973				7.19
1974				8.51
1975				14.85
1976				11.95
1977				10.18
1978				10.13
1979				18.72
1980	1.15	0		12.97
1981	15.8	0		54.17
1982	40.62	0		29.83
1983	111.19	0.49		14.44
1984	68.87	0.25		15.68
1985	76.09	0.08		29.30
1986	149.12	0.67		30.67
1987	125.39	1.71		16.49
1988	63.74	0.56		35.62
1989	84.73	8.49		52.20
1990	154.74	5.72	190.09	25.35
1991	49.43	2.29	123.72	30.42
1992	35.86	6.72	161.84	50.96
1993	124.41	5.61	62.44	10.52
1994	37.85	7.14	61.93	7.90
1995	70.14	5.28	75.00	19.05
1996	265.95	18.21	46.88	3.67
1997	130.4	3.01	54.89	11.96
1998	27.46	7.21	64.34	13.20
1999	71.13	7.07	31.60	4.60
2000	76.57	9.69	37.36	4.07
2001	65.5	5.45	33.94	6.84
2002	18.9	0.89	48.14	3.85

Year	Juvenile Indices: Upper Non-tidal	Juvenile Indices: Lower Tidal	Adult Indices: Smithfield Beach CPUE	Adult Indices: Lewis haul seine CPUE
2003	61.9	10.01	37.59	5.23
2004	71.3	5.81	24.99	4.07
2005	123.7	9.38	56.28	2.89
2006	21.8	0.53	26.17	1.66
2007	175.9	15.17	40.57	3.38
2008	-	1.05	33.01	2.24
2009	-	4.21	17.07	2.57
2010	-	4.58	46.88	12.31
2011	-	7.99	72.00	
Long-term Mean	88.78	6.07	61.22	
Benchmark quartile	49.43	2.83	34.79	
Period used	1987-2007	1987-2010	1990-2011	

Table 2. Commercial landings of American shad in the Delaware River Basin and estimates of the ratio of the combined Delaware stock harvest to Smithfield Beach and Lewis haul seine relative abundance. Light shading = early period; dark shading = late period.

	River			Bay			Delaware Stock			Smithfield	Lewis
	NJ	DE	Comb	NJ	DE	Comb	NJ	DE	Comb	Ratio	Ratio
1975			0	5,611		5,611	2,188	0	2,188		
1976			0	18,780		18,780	7,324	0	7,324		
1977			0	29,578		29,578	11,535	0	11,535		
1978			0	31,438		31,438	12,261	0	12,261		
1979			0	17,499		17,499	6,825	0	6,825		
1980	25,000		25,000	50,600		50,600	44,734	0	44,734		
1981	30,000		30,000	67,600		67,600	56,364	0	56,364		
1982	1,100		1,100	132,900		132,900	52,931	0	52,931		
1983	4,300		4,300	49,300		49,300	23,527	0	23,527		
1984	7,400		7,400	41,900		41,900	23,741	0	23,741		
1985	23,100	29,297	52,397	48,900	139,186	188,086	42,171	83,580	125,751		4.29
1986	17,700	28,622	46,322	63,900	150,889	214,789	42,621	87,469	130,090		4.24
1987	20,200	10,265	30,465	109,400	169,954	279,354	62,866	76,547	139,413		8.46
1988	17,300	24,413	41,713	80,700	204,889	285,589	48,773	104,320	153,093		4.30
1989	16,800	12,249	29,049	62,500	175,538	238,038	41,175	80,709	121,884		2.33
1990	40,364	15,798	56,162	212,749	369,056	581,805	123,336	159,730	283,066	14.89	11.17
1991	23,092	11,715	34,807	150,209	352,670	502,879	81,674	149,256	230,930	18.67	7.59
1992	41,765	9,247	51,012	114,035	209,757	323,792	86,239	91,052	177,291	10.95	3.48
1993	19,552	13,008	32,560	123,428	220,395	343,823	67,689	98,962	166,651	26.69	15.85
1994	9,066	14,347	23,413	41,305	181,793	223,098	25,175	85,246	110,421	17.83	13.98
1995	11,811	14,293	26,104	61,621	132,030	193,651	35,843	65,785	101,628	13.55	5.34
1996	1,100	10,095	11,195	17,563	155,140	172,703	7,950	70,600	78,549	16.76	21.42
1997	9,250	8,473	17,723	34,549	108,043	142,592	22,724	50,610	73,334	13.36	6.13
1998	75	8,047	8,122	14,180	76,766	90,946	5,605	37,986	43,591	6.78	3.30
1999	5,670	2,055	7,725	83,036	74,129	157,165	38,054	30,965	69,019	21.84	14.99
2000	43,299	6,867	50,166	78,132	47,010	125,142	73,770	25,201	98,971	26.49	24.34
2001	69,098	3,677	72,775	27,040	198,152	225,192	79,644	80,956	160,600	47.32	23.47
2002	32,746	2,510	35,256	15,671	36,200	51,871	38,858	16,628	55,486	11.53	14.43

2003	84,198	4,748	88,946	6,322	57,628	63,950	86,664	27,223	113,887	30.30	21.77
2004	92,073	3,015	95,088	5,385	87,078	92,463	94,173	36,975	131,149	52.48	32.19
2005	46,543	677	47,220	41,441	122,933	164,374	62,705	48,621	111,326	19.78	38.54
2006	56,847	576	57,423	9,307	29,949	39,256	60,477	12,256	72,733	27.80	43.84
2007	53,818	1,816	55,634	9,010	69,622	78,632	57,332	28,969	86,300	21.27	25.53
2008	23,877	260	24,137	5,157	18,073	23,230	25,888	7,308	33,197	10.06	15.20
2009	9,589	97	9,686	3,381	3,349	6,730	10,908	1,403	12,311	7.02	5.93
2010	8,699	121	8,820	4,499	4,872	9,371	10,454	2,021	12,475	2.66	9.34

Table 3. American shad tag returns, by year, from fish tagged in Delaware Bay: 1995-2011.

Year	No. Tag	Recaptures
1995	107	10
1996	294	14
1997	508	36
1998	554	38
1999	753	46
2000	425	32
2001	663	35
2002	274	15
2003	170	7
2004	51	0
2005	220	9
2006	71	2
2007	42	1
2008	0	0
2009	11	1
2010	85	3
2011	11	0
Total	4,239	246

Table 4. American shad tag returns, by area, from fish tagged in Delaware Bay: 1995-2011.

Recapture Area	Number	Proportion
Delaware River	69	28.1%
Hudson	43	17.5%
Connecticut	38	15.5%
NJ Ocean	38	15.5%
Delaware Bay	30	12.2%
Ches/Susq	8	3.3%
Ocean DE - NC	7	2.9%
Ocean NY - RI	5	2.0%
Canada	5	2.0%
Pawcatuck	1	0.4%
Cape Fear	1	0.4%
Santee	1	0.4%
Total	246	

Table 5. Sex composition of New Jersey's commercial gill net shad landings: 1996–2010.

	Delaware Bay		Coastal	
Year	% female	% male	% female	% male
1996	-	-	84.1	15.9
1997	-	-	82.8	17.2
1998	-	-	81.4	18.6
1999	82.6	17.4	81.9	18.1
2000	86	14	69	31
2001	83.8	16.2	70.8	29.2
2002	69.4	30.6	71.4	28.6
2003	80.3	19.7	61	39
2004	77.9	22.1	71.3	28.7
2005	73.9	26.1	98.9	1
2006	79.5	20.5	73.3	26.7
2007	80.6	19.4	96.6	3.6
2008	77.5	22.5	91.7	8.3
2009	80.4	19.6	84	16
2010	67.2	32.8	75.5	24.5
AVG	**78.3**	**21.7**	**79.6**	**20.4**

Table 6. 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

Table 7. Number of American shad larvae stocked in the Delaware River Basin.

Year	**Delaware**	**Schuylkill**	**Lehigh**
1985		251,980	600,000
1986		246,400	549,880
1987		194,575	490,730
1988			340,400
1989		316,810	833,170
1990		285,100	2,087,700
1991		75,000	793,000
1992		3,000	353,000
1993			789,600
1994			642,200
1995			1,044,000
1996			993,000
1997			1,247,000
1998			948,000
1999		410,000	501,000
2000		535,990	447,390
2001		490,901	675,625
2002		2,000	85,025
2003		1,000,448	783,013
2004		421,583	366,414
2005	169,802	545,459	668,792
2006	52,782	253,729	293,083
2007	47,587	540,655	281,884
2008	158,151	486,774	696,785
2009		161,938	210,584
2010		380,000	347,522
Total	428,322	6,602,341	17,068,797

Table 8. Hatchery contribution for adult American shad collected from the Delaware River (Smithfield Beach and Raubsville), the Lehigh River and the Schuylkill River.

	Percent exhibiting hatchery mark							
	Delaware River							
	Smithfield Beach		Raubsville		Lehigh River		Schuylkill River	
Year	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
1997	0%	88	-	-	-	-	-	-
1998	4%	234	-	-	-	-	-	-
1999	0%	208	5%	150	91%	104	-	-
2000	3%	330	11%	129	91%	99	-	-
2001	4%	198	8%	144	92%	103	-	-
2002	1%	378	1%	109	89%	99	-	-
2003	8%	245	-	-	-	-	100%	25
2004	1%	414	-	-	80%	60	90%	21
2005	1%	776	-	-	62%	13	92%	25
2006	1%	350	-	-	73%	55	100%	19
2007	3%	746	-	-	58%	40	91%	23
2008	1%	667	-	-	51%	41	100%	28
2009	1%	367	-	-	63%	27	96%	25
2010	0%	470	-	-	67%	96	100%	25
Mean	2%		6%		74%		96%	

Table 9. Total number of mixed stock American shad landed from Delaware Bay from 2008-2010, the average number landed annually, the proportion of tag-recaptures recovered in various rivers, and the numbers of shad from each spawning stock, on average, landed in Delaware Bay.

Year	Total Number of shad landed	
2008	4,718	
2009	1,367	
2010	1,903	
average	2,663	
Spawning stock	Proportion of recaptures	Number per spawning stock
Delaware	0.39	1,038.52
Hudson	0.175	466.00
Connecticut	0.155	412.74
Che/Sus	0.033	87.87
Pawcatuck	0.004	10.65

Table 10. New Jersey and Delaware regulations for the harvest of American shad (current as of 2010) in the Delaware River and Bay.

State	Season	Gear Limits	Mandatory reporting	Other Restrictions
NJ: Delaware Bay & River	Gill nets: Feb 1-Dec 15	-2.75" min. stretch mesh Feb 1-Feb 29; * 3.25" min. stretch Mar 1-Dec 15 (*special permit required) -length: 2400" Feb 12-May 15, 1200' May 16-Dec 15	Yes	Limited entry; gear restrictions in defined areas
	Haul Seine:Nov 1-Apr 30	2.75" min. stretch mesh, max length 420'		
DE: Delaware Bay & River	See gear limits	- Del River: Jan 1-May 31 no fixed gill nets - Del River: Not more thatn 200 ft gill net Jun to Dec - Striped bass spawning area closed to all gillnets Apr 1 to May 31 - Del Bay No fixed gill nets May 10 to Sep 30	Yes	