Status and Trends of Hudson River Fish Populations and Communities Since the 1970s: Evaluation of Evidence Concerning Impacts of Cooling Water Withdrawals

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Introduction

The purpose of this paper is to summarize our views concerning the status of fish populations and communities of the Hudson River estuary, and whether those populations and communities reasonably can be said to have changed since the mid-1970s as a result of operation of the Bowline Point, Indian Point, and Roseton generating stations ("stations). Our concern is with impacts as defined by biologists, using established definitions and standards of ecology and resource management. The paper does not address any of the regulatory issues currently being addressed through the SPDES process, and specifically does not address either (1) the regulatory definition of "Adverse Environmental Impact" (AEI) under section 316(b) of the Clean Water Act, or (2) Best Technology Available (BTA) for minimizing AEI. We have not conducted an independent analysis of the supporting data used in the preparation of the generators' Draft Environmental Impact Assessment (DEIS). We have, however, reviewed both the DEIS and the comments on the DEIS prepared by ESSA and Pisces. We requested and received updated abundance indices through 2000. Our conclusions are based on our evaluation of all three reports, as augmented by the updates.

Rationale for focusing on population- and community-level impacts

Our interpretation of the data is premised on a view that populations and communities are the proper focus for evaluating impacts of cooling water withdrawals on the Hudson River estuary. The reason for this is that all individual organisms have finite life spans; only populations and communities persist through time. As long as key populations are relatively stable, the mix of species present remains relatively constant, and important functional relationships continue, the river can be said to be healthy and can continue to persist in spite of the deaths of individuals. There are ample precedents for a focus on populations and communities. For instance, EPA's Guidelines for Ecological Risk Assessment (EPA 1998, section 3.3.1.1) identify "ecological relevance" as a key criterion for selecting specific entities to be evaluated in risk assessments. Examples of relevant entities discussed by EPA include individual species, functional groups of species, and communities. A focus on populations and communities is also fundamental to natural resource management. The Magnuson-Stevens Fishery Conservation Act, for example, focuses on maintenance of sustainable yields from exploited populations. In fact, even the concept of "sustainable yield" implicitly focuses on populations and communities, because only populations and communities are persistent and therefore "sustainable."

A population and community-based approach is fully consistent with the approach taken in the studies that supported the 1980 Hudson River Settlement Agreement (HRSA). These studies, which expressly focused on populations and communities, are fully documented in the peer-reviewed scientific literature (Barnthouse et al. 1988) and are widely regarded as a classic study in environmental impact assessment.

A population and community-oriented framework for impact assessment made sense in 1980, and from a scientific perspective it still makes sense today. However, the information base to support population and community assessments vastly exceeds the information available at the time of the settlement. Models were the principal technical approach used in 1980 in large part because long-term monitoring data did not exist. An extraordinarily extensive data set is now available for use in impact assessment. Techniques for modeling impacts of fishing and power plant mortality on fish populations have also advanced greatly since 1980; these models provide additional insights into the potential impacts of cooling water withdrawals.

Hypotheses concerning expected impacts of cooling water withdrawals on fish populations and communities

Estuarine environments are highly variable. Moreover, land use changes, pollution abatement, harvest restrictions, invasions by exotic species, climate change, and many other factors that potentially influence fish populations and communities have occurred in the lower Hudson River valley since the 1970s. Under these circumstances, simply documenting the types and magnitudes of changes that have occurred is insufficient to fully evaluate the presence or absence of changes related to cooling-water withdrawals. Specific hypotheses concerning the expected impacts of cooling-water withdrawals (termed "risk hypotheses" in EPA's Guidelines for Ecological Risk Assessment) are useful for distinguishing between changes that could have been caused by cooling-water withdrawals and changes that are most likely related to other causes.

Entrainment and impingement by once-through cooling systems can result in mortality of early life stages of fish and other aquatic organisms. If the magnitude of this mortality were high enough, and if this mortality persisted over a long period of years, then the following types of adverse changes in populations and communities might be expected:

- **Continued, long-term declines in the abundance of susceptible populations.** Such declines would result where entrainment and impingement mortality rates exceed the replacement capacity of the affected populations. Such declines would be most likely to occur in species that (1) are highly susceptible to entrainment or impingement (because of their life history and spatial distribution), (2) are also subject to other sources of mortality, especially harvesting, and (3) have an inherently low capacity to sustain additional mortality. Declines related to cooling-water withdrawals should approximately coincide with the startup of the three stations (possibly with a lag time of several years).

- **Reduction in species richness or diversity.** Species richness (as measured by the number of species present in a community) and species diversity (as measured by various numerical indices that consider both the number and the relative abundance of species present in a community) are among the most widely accepted indicators of adverse community-level effects (Rapport et al. 1985, Gotelli and Graves 1996). Declines in species richness and diversity can be caused by a wide variety of stressors, through a wide variety of mechanisms. If cooling-water withdrawals were reducing species richness or diversity, then declines in these indicators should be observable over time, although the declines would not necessarily coincide in time with the startup of the stations. Any such declines could be localized within the immediate vicinity of the stations, or could be estuary-wide. Because changes in species richness and diversity are nonspecific indicators of stress, additional information on spatiotemporal patterns of hypothetical causes is usually needed to interpret any changes that are observed.

- **Change in the balance of predator and prey species.** If cooling-water withdrawals were reducing the abundance of predator populations (e.g., striped bass) within the estuary, then the abundance of prey populations (e.g., bay anchovy) would be expected to increase. Conversely, if cooling-water withdrawals were reducing the abundance of forage species such as bay anchovy, then the abundance of predators could decline even if those predators are not themselves vulnerable to entrainment or impingement. Because the dominant predator and prey species in the estuary are migratory and widely distributed, any such changes would be expected to be estuary-wide.

Changes consistent with one or more of the above hypotheses could be related to cooling-water withdrawals over the past 25 years of operation of the stations. Changes inconsistent with these hypotheses (e.g., of a type not expected to result from mortality to early life stages of fish, or occurring at times or locations inconsistent with the expected effects of cooling water withdrawals) likely are related to other causes.

Evaluation of impact hypotheses using results from 25 years of monitoring

The data presented in the DEIS indicate that changes that most fisheries biologists would view as "adverse" have not occurred. Further, changes that have occurred appear to be inconsistent with the impact hypotheses discussed above and, therefore, are not reasonably attributable to the stations.

Trends in population abundance

It would be laborious and probably not very meaningful to attempt to summarize trends in the abundance of all 17 of the target species evaluated in the DEIS for this brief analysis. For determining whether cooling-water withdrawals have affected fish populations, it should be sufficient to evaluate those for which station-related mortality, measured in terms of the CMR, is the highest. These populations are striped bass, white perch, Atlantic tomcod, American shad, blueback herring, alewife, bay anchovy, and spottail shiner.

Striped bass

This species is, among all of the species present in the lower estuary, perhaps the most vulnerable to cooling-water withdrawals. The spawning grounds of Hudson River striped bass are located primarily north of the Hudson Highlands. Striped bass are pelagic spawners, and the early life stages of striped bass are also pelagic. Striped bass eggs, larvae, and juveniles are subject to tidal transport and are susceptible to entrainment at all three stations. Estimated CMRs for striped bass are consistently among the highest of all of the species evaluated in the DEIS. In addition to entrainment and impingement, the Hudson River striped bass population is also affected by harvesting. Moreover, as a top predator, station impacts on lower trophic levels (e.g., bay anchovy and other forage fish) would be expected to translate into reduced striped bass production.

If entrainment and impingement were adversely affecting the Hudson River striped bass population either directly, through reduced abundance of young fish, or indirectly, through a reduction in prey availability, then a decline in the abundance of these fish should be observable over the 27 years of available data. Figure 1 shows trends in four indices of striped bass year-class strength, each derived from a different data set. The four sets of indices are highly consistent and show that there has been no trend in striped bass recruitment since the initiation of the utility and NYSDEC monitoring programs.At the same time, the abundance of adult striped bass and of early striped bass life stages has greatly increased. The increase was, biologists agree, caused by harvest restrictions imposed beginning in the mid 1980s. Reduced fishing mortality increased the annual survival rate of adult striped bass, resulting in a rapid buildup of the adult population after 1980. The increased spawning stock is now producing far more eggs and larvae per year than were produced in the 1970s, although the production of young-of-the-year fish has been stable. Meanwhile, cooling-water withdrawals have occurred at a relatively constant rate (as measured by the CMR) throughout a quarter-century.

One might argue that without power plants the population growth would have been even greater. However, the constancy of year-class strength, even as egg production has greatly increased, supports a conclusion that an additional increase in larval abundance (as would have occurred had there been no entrainment) would not have translated into an increase in abundance of young-of-the-year striped bass.

White perch

White perch are similar to striped bass with respect to life history and vulnerability to cooling-water withdrawals, except that (1) spawning occurs further up-river, (2) white perch juveniles are more evenly dispersed throughout the river than are striped bass, and (3) adult white perch are nonmigratory and much smaller in size, so they remain vulnerable to impingement throughout their life spans. However, in spite of the lifetime vulnerability of white perch to impingement, entrainment is still the prevalent station-related source of mortality to this species (average CMR of 17.5% for entrainment, as compared to 2.2% for impingement).

Trends in the abundance of white perch juveniles and yearlings indicate an apparent decline from 1979 through 1996, however, data for the years 1998 through 2000, which were provided to us by the generators, suggest that the white perch population may have stabilized. The abundance of juvenile and one-year-old white perch appears to have increased since 1996, with an especially strong year class being produced in 1999. As noted in the DEIS, the spatial distribution of white perch within the estuary appears to have shifted, with the decline in juvenile and yearling abundance being much greater in the lower estuary (regions 1-5) than in the upper estuary (regions 6-12). The DEIS discusses possible explanations for these changes (predation by striped bass in the lower estuary; changes in submerged aquatic vegetation in the upper estuary). Although no definitive conclusions appear possible at this time, there is no apparent reason why cooling-water withdrawals should have affected white perch but not striped bass. Estimated CMRs for these two species are similar. White perch are more widely distributed throughout the estuary and make greater use of tributaries. Thus, they should be less vulnerable to entrainment and impingement than striped bass. White perch are not heavily exploited, so that this species should be less vulnerable to effects of additional mortality due to entrainment and impingement than should striped bass. During the period in which the abundance of juvenile and yearling white perch was declining, the abundance of post yolk-sac larvae (PYSL, Figure 2) did *not* decline, indicating that the annual reproductive output of the population was never reduced.

Atlantic tomcod

Atlantic tomcod is unique among the fish species of the Hudson River estuary in that it is adapted to cold climates, and the Hudson River population is the southernmost spawning population of this species. Spawning occurs during winter, primarily between West Point and Poughkeepsie. Atlantic tomcod larvae and juveniles are found primarily in the lower estuary, between Yonkers and Cornwall. Because the Hudson River is at the southern end of the range of Atlantic tomcod, this population may be especially sensitive to climatic fluctuations, especially high summer temperatures. Growth rates in juvenile Atlantic tomcod have been shown to decline when water temperatures rise above 55°F and to stop when they exceed 71°F, a temperature that is exceeded annually in the Hudson River.

Data for evaluating trends in the abundance of Atlantic tomcod are available both from the utilities' ichthyoplankton survey, which samples larval and juvenile tomcod, and from an Atlantic tomcod mark-recapture program that samples 1-year old and 2-year old fish. Annual abundance values from these three data sets (from Table V-21 of the DEIS) are plotted in Figure 3. As noted in the DEIS, the design of the mark-recapture program changed after 1979 and age-1 and age-2 population estimates for 1979 and earlier may not be fully comparable to estimates for later years. Although correlations between the larval/juvenile index and the mark-recapture indices are low, all three indices show a decline only after 1989.

The Atlantic tomcod is a short-lived species, with a generation time of 1-2 years. If entrainment and impingement were adversely affecting the Hudson River Atlantic tomcod, then a decline in abundance should have been evident within a few years after the startup of the stations. The recent decline in abundance of this species, however, did not begin until about 1990. Changes in cooling water withdrawal rates that could explain such an abrupt decline did not occur during this period. As noted in the DEIS, warmer summer or winter water temperatures, among other factors, could influence Atlantic tomcod populations. However, a detailed evaluation of these factors has not been performed.

American shad

American shad spawn in the uppermost regions of the estuary, and early life stages of this species are found primarily in the upper estuary above Poughkeepsie. Juvenile American shad are present in the vicinity of the stations primarily in the fall, during emigration from the river. After emigration, American shad remain at sea until they become sexually mature and return to spawn, at an age of 3-6 years.

Juvenile abundance indices for American shad show limited evidence of a downward trend in recent years. Figure 4 shows trends of the two available indices of juvenile abundance, derived from the utility and NYSDEC beach seine data sets (from Table V-25 of the DEIS). Both indices indicate that strong year classes were produced in 1986, 1989, and 1990, and that relatively weak year classes were produced in 1984 and 1995. Data for 1998-2000, available only for the utility index, indicate that the 1998 and 2000 year classes were also weak.

Other information indicates that the decline in abundance of American shad is coastwide, and is likely due to overfishing. According to the Atlantic States Marine Fisheries Commission (ASMFC 1998a) shad abundance has declined greatly since the end of World War II.. Although fishing mortality within the Hudson River itself has apparently declined since 1984, this decline has been offset by an increase in mortality due to the Atlantic coastal intercept fishery.

Blueback herring and alewife

These two species need to be considered together for purposes of evaluating impacts of cooling-water withdrawals, because the early life stages of these species are indistinguishable.

Figure 5 shows abundance trends for both species for the years 1979 through 2000. Figure 5 shows that the two species have tended to vary together, with strong year classes being produced in 1980, 1985, 1987, and 1996, and weak year classes being produced in 1983, 1986, and from 1993 through 1995. The only years when divergent changes in abundances occurred were 1980 and 1999, when strong alewife and weak blueback herring year classes were produced. Year-class abundance in both species appeared to decline from the late 1980s through the mid 1990s. Otherwise no trends are apparent for either species.

Coastwide populations of both blueback herring and alewife were severely depleted by overfishing during the 1960s and 1970s. Harvesting has been severely restricted, but coastwide populations of both species have remained depressed (ASMFC 1998b). Damming of tributaries is believed to have substantially reduced the available spawning and nursery habitat for both, but especially for blueback herring. There is no evidence of a long-term decline in either species that would be consistent with expected impacts of cooling water withdrawals.

Bay anchovy and spottail shiner

Bay anchovy and spottail shiner are both forage species, meaning that they are small fish that serve as prey for larger, predatory fish. Bay anchovy is the principal forage species in the lower estuary. For this reason, impacts on bay anchovy could indirectly affect predators such as striped bass and bluefish. Spottail shiner is abundant primarily in the upper estuary. Impacts on this species could indirectly affect predators such as striped bass and largemouth bass.

Figure 6 plots time trends in juvenile abundance for both species. No trend in abundance of spottail shiner is evident; however, the abundance of bay anchovy appears to have declined between 1995 and 2000. This recent, abrupt decline is inconsistent with the expected effects of cooling-water withdrawals and is likely related to other causes.

Trends in species richness and diversity

As documented in the DEIS, changes in species richness and diversity have been observed in the Hudson River estuary. Trends in species richness and diversity have varied between life stages, with the number and diversity of ichthyoplankton species increasing slightly and the number and diversity of juvenile and older fish decreasing slightly over the period from 1974 through 1997. The decline in richness and diversity of juvenile and older fish has resulted primarily from a small reduction in the numbers of freshwater species present, especially in the upper estuary (Regions 6-12). These species should be less susceptible to entrainment and impingement than the marine, diadromous and estuarine species (e.g., striped bass, bay anchovy, white perch, and blueback herring) that dominate the lower estuary (Regions 1-5). The causal mechanism through which cooling-water withdrawals could reduce species richness in a component of the community that is not highly susceptible is unclear. It is possible, as stated in the DEIS, that habitat changes, such as regrowth of water-chestnut beds, have reduced the quality of littoral habitat present in the freshwater zone of the estuary, and thus reduced the ability of this habitat to support freshwater species. Regardless of the specific causes, the observed changes are well within the range of natural variability that would be expected in an estuarine environment and are unlikely to be related to cooling-water withdrawals.

Predator-prey balance

If cooling-water withdrawals were substantially depleting prey populations in the estuary, then predators that depend on those prey populations could also decline in abundance. If, on the other hand, cooling water withdrawals were depleting predator populations, then prey populations could increase because of reduced predation. These types of changes have not been observed in the Hudson River estuary. Major prey species such as bay anchovy, spottail shiner, and juvenile blueback herring have been stable over most of this period. The principal predator species, striped bass, has also been stable. Disruption of predator-prey balance in the estuary clearly has not occurred.

<u>Strength of evidence supporting conclusions regarding lack of adverse changes potentially related to cooling-water withdrawals</u>

The data sets on which the above conclusions are based are unprecedented in our experience. Independent data sets, ranging between 10 and 25 years in duration, include:

- Utilities' Longitudinal River Ichthyoplankton survey
- Utilities' Fall Shoals Survey
- Utilities' Beach Seine Survey
- NYSDEC juvenile beach seine survey
- Utilities' mark-recapture surveys of striped bass and Atlantic tomcod

Like all biological data sets, the data provided by each of the above survey programs is subject to a variety of sources of unquantifiable uncertainties and potential biases. However, where comparisons are possible, the results provided by these surveys are consistent. The consistency of these results is a strong indication that the data sets are providing valid information concerning trends in the abundance of Hudson River fish populations.

At least with respect to striped bass, the conclusions evident from our evaluation of the DEIS are supported by coast-wide assessments performed by federal and interstate resource management organizations. Data summarized in the Stock Assessment Review Committee (SARC) report for 1998 (NMFS 1998a) show that the total coastwide biomass of spawning Atlantic striped bass in 1996 was more than ten times as high as in 1982 (NMFS 1998a, Figure C11). Although the contribution of Hudson River striped bass to the growth of the coastal population has not been quantified, data summarized in Tables C17 and C18 of the SARC report show that the abundance of juvenile and 1-year-old striped bass in the Hudson River fluctuated without a discernable trend between 1981 and 1996. The SARC report utilized many of the same data (e.g., the utility and NYSDEC beach seine indices) that were used in the DEIS, indicating that the review committee believed these data to be valid indicators of the status of the Hudson River striped bass population. An updated assessment (ASMFC 2000) showed a slight decline in coastal spawning stock size, but continued stability in the abundance of juvenile striped bass produced by the Hudson River population.

<u>The validity of spawner-recruit analyses as supporting lines of evidence</u>

We firmly believe that the extraordinary long-term database on population and community trends in the Hudson River provides the strongest evidence concerning the ecological significance of cooling-water withdrawals by Hudson River power plants. However, the population modeling results discussed in the DEIS provide valuable supporting evidence.

Spawner-recruit analyses such as the striped bass, American shad, and Atlantic tomcod models presented in the DEIS (and critiqued by ESSA and Pisces) have been especially controversial components of impact assessments performed for Hudson River power plants. Such models have been used both in pre-HRSA assessments and in the DEIS to demonstrate the existence of density-dependent population regulation in Hudson River fish populations and to quantify the impacts of power plants on the long-term abundance of those populations. As shown by Christensen and Goodyear (1988) and by Fletcher and Deriso (1988), the data and modeling techniques available at the time of the HRSA were clearly insufficient to support credible modeling efforts. However, significant improvements in both data and modeling techniques have occurred over the past 20 years. These advances, which have been recently reviewed by Rose et al. (2001), include measurement techniques for inferring the age, environmental history, and health of individual fish; demonstrations of the operation of specific density-dependent processes in well-studied populations; new methods for modeling fish populations; improved understanding of the relationship between density-dependence and fish life history; comprehensive data bases for the study of spawner-recruit relationships in many fish species; and improved statistical techniques for detecting and quantifying density-dependence from time series of spawner-recruit data. As documented by Rose et al. (2001), detailed studies of individual fish populations and comprehensive analyses of long-term data sets for many fish populations have demonstrated the existence of density-dependence as a general property of fish populations.

Federal and state resource management agencies also recognize the necessity of considering density-dependence when making resource management decisions. The role of density-dependence in maintaining sustainable fisheries is implicitly acknowledged in the federal regulations implementing the Magnuson-Stevens Fishery Conservation Act (NMFS 1998b). Technical committees of the ASMFC have developed spawner-recruit models for two of the species evaluated in the DEIS: striped bass (NMFS 1998a) and weakfish (NMFS 2000). Appendix VI-4-C of the DEIS, which documents a spawner-recruit model for the Hudson River American shad population, was prepared by NYSDEC staff and consultants.

Whether or not there is agreement on the numerical results of the spawner-recruit models used in the DEIS, even the most conservative interpretations of the data (e.g., the "low compensation" fits shown for American shad in Figure 3 of Appendix VI-4-C) provide evidence that density-dependent processes are operating in these populations. These results provide, at a minimum, supporting evidence for the conclusions we have arrived at through examination of population trends: the Hudson River fish populations most likely to be affected by cooling-water withdrawals have in general maintained stable populations over the past quarter century. The few declining trends that have occurred are inconsistent with the expected effects of the stations and are likely related to other causes.

Reductions in entrainment and impingement mortality are unlikely to result in detectable improvements in populations or communities.

We have not performed a benefits analysis related to the mitigation proposals being discussed by the generators, NYSDEC, and Riverkeeper. However, to the extent that these mitigation proposals are intended to reduce cooling-water withdrawals, our evaluation of the data suggests that the ecological benefits of those reductions is likely to be negligible. If measurable changes attributable to cooling-water withdrawals have not occurred over the past 25 years of operation of the stations, then reductions in those withdrawals would be unlikely to result in measurable improvements such as increases in population abundance or species richness.

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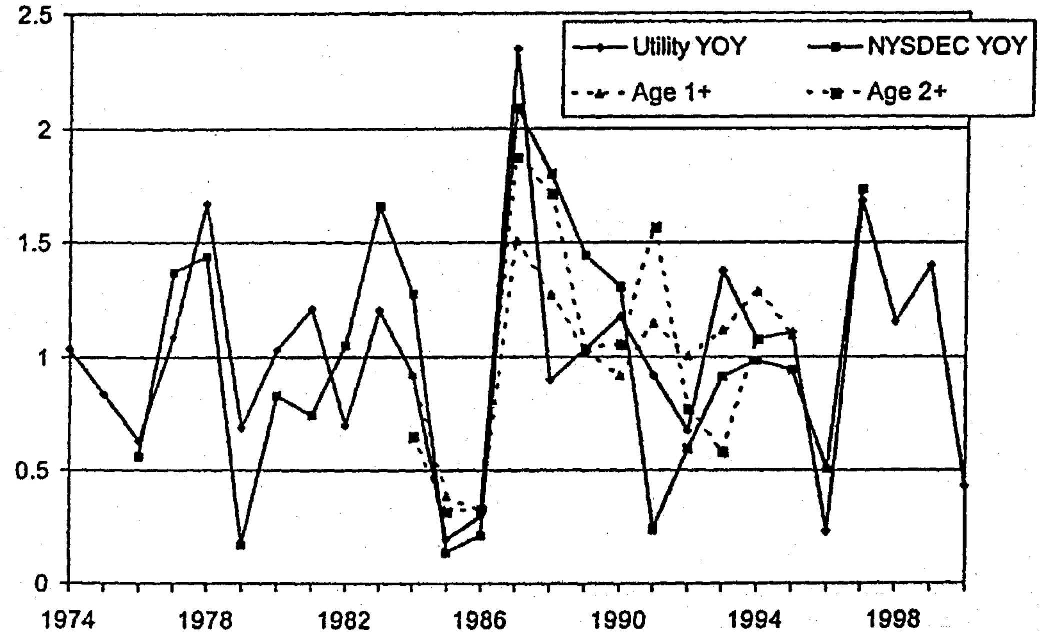

Figure 1. Year class abundance indices for striped bass. Indices plotted include the utility beach seine index (utility YOY), the NYSDEC beach seine index (NYSDEC YOY), and the utility mark-recapture population estimates for one-year-old (age 1+) and two-year-old (Age 2+) fish. The values for the age 1 and age 2 indices reflect the year of spawning of each age group, i.e., the age 1 index value for 1980 reflects one-year-old fish caught in 1981; the age 2 index value for the same year reflects two-year-old fish caught in 1982. Each series of values is normalized to the mean value over the available time series.

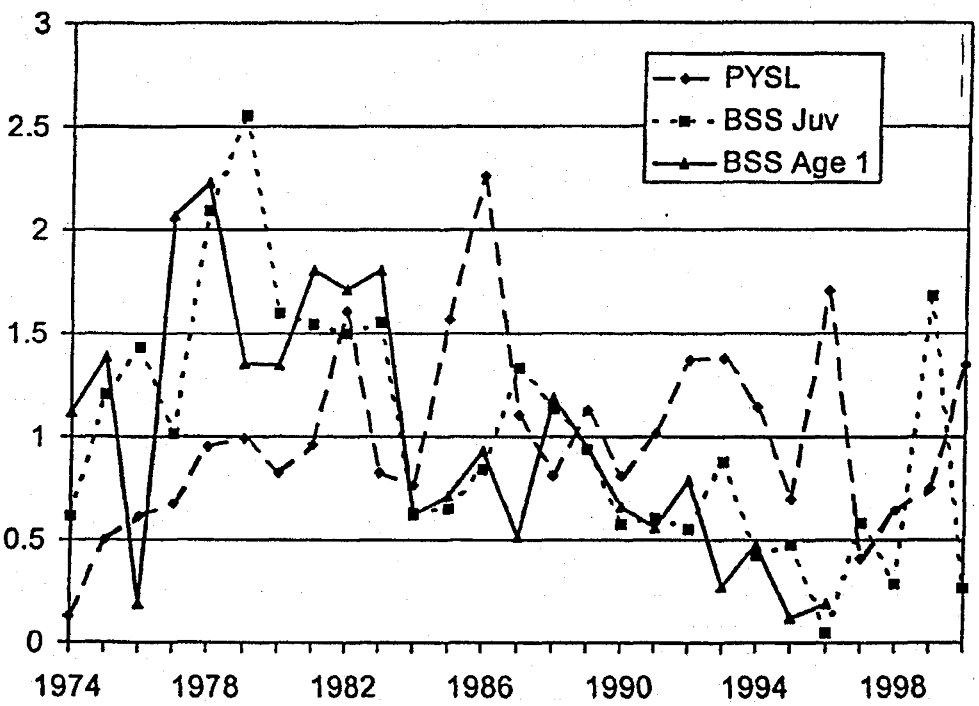

Figure 2. Abundance indices for white perch. Indices plotted include the utility beach seine index for juveniles (BSS Juv), the utility beach seine index for 1-year-old fish (BSS Age 1) and the utilities' ichthyoplankton survey index for post yolk-sac larvae (PYSL). NYSDEC beach seine index (NYSDEC YOY), and the utility mark-recapture population estimates for one-year-old (age 1+) and two-year-old (Age 2+) fish. Each series of values is normalized to the mean value over the available time series.

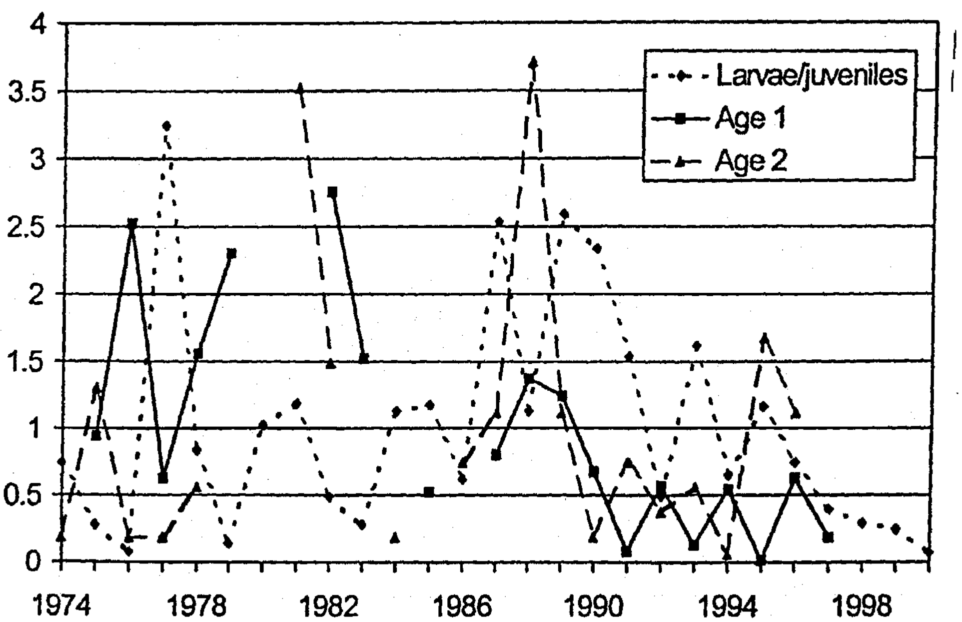

Figure 3. Year class abundance indices for Atlantic tomcod. Indices plotted include the utilities' ichthyoplankton survey index for Atlantic tomcod larvae and juveniles (larvae/juveniles), the mark-recapture population estimate for 1-year-old fish (Age 1), and the mark-recapture population estimate for 2-year-old fish (Age 2). The values for the age 1 and age 2 indices reflect the year of spawning of each age group. Values of each index are normalized to the average value for the available time series.

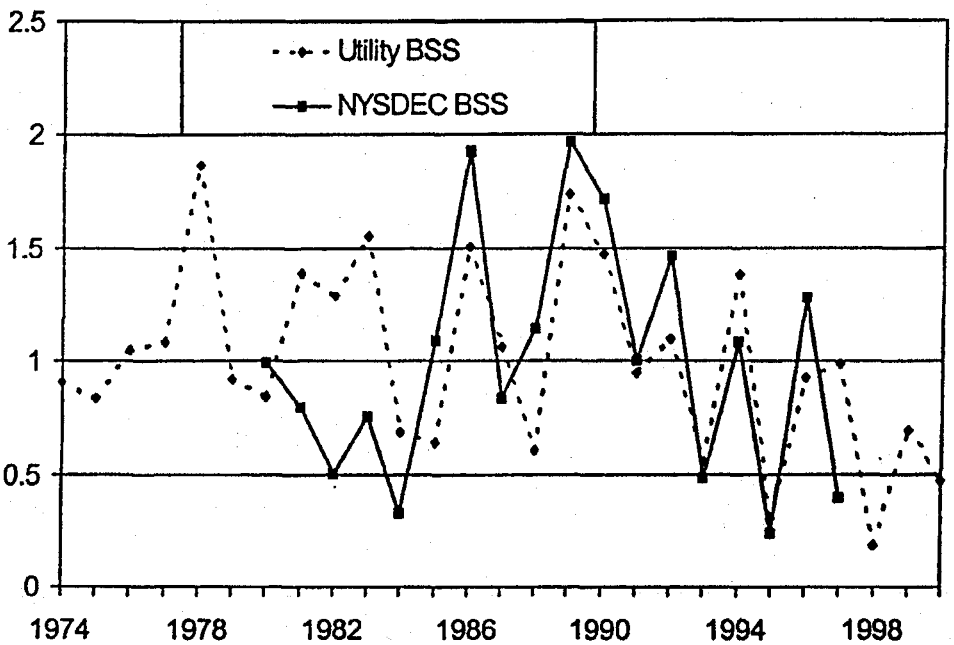

Figure 4. Year class abundance indices for American shad. Indices plotted include the utilities' beach seine index (Utility BSS) and the NYSDEC beach seine index (NSDEC BSS). Values of each index are normalized to the average value for the available time series.

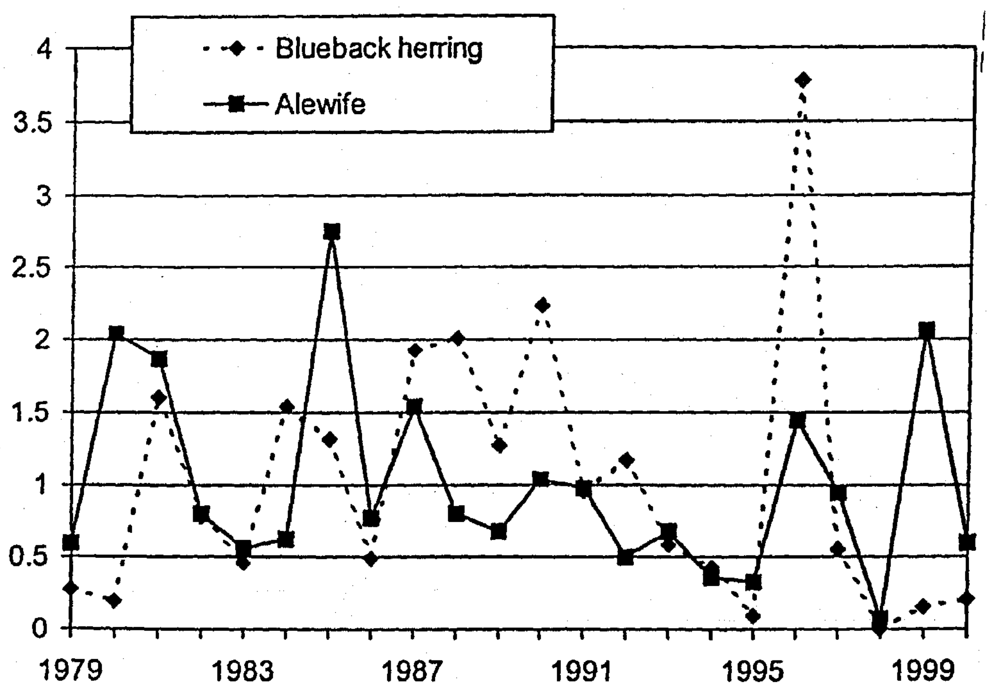

Figure 5. Year class abundance indices for alewife and blueback herring. Values of each index are normalized to the average value for the available time series.

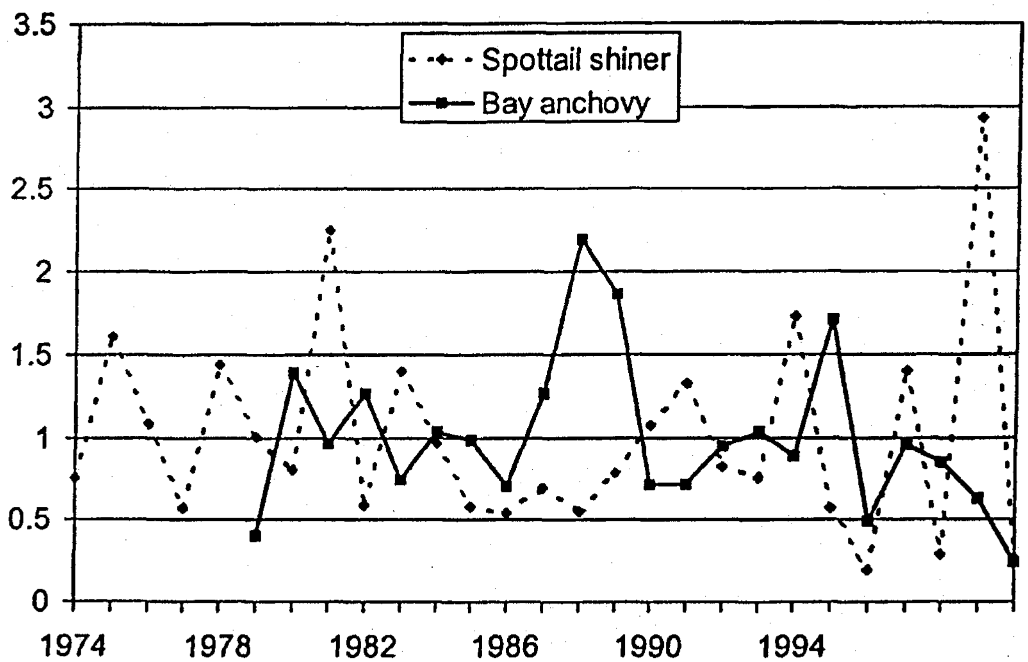

Figure 6. Year class abundance indices for bay anchovy and spottail shiner. Values of each index are normalized to the average value for the available time series.