The status of fish populations and the ecology of the Hudson

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Executive Summary

Using the 2005 year-class report for fish in the Hudson estuary, an assessment of the present status and the trends in fish populations is presented. The physical environment is the foundation upon which the biological community of the estuary rests. Long-term data from the Poughkeepsie Water Treatment Facility show that water temperature in the Hudson is increasing. The mean annual temperature in recent years is about 2 °C (3.6 °F) above that recorded in the 1960s, an increase sufficient to impact some fish. There is, however, not a simple pattern of temperature increase. Recent observations show that the seasonal temperature variation is becoming more extreme. Daily temperatures in 2005 for several summer months were close to the maximum ever recorded. However, in the winter, there were some of the lowest temperatures recorded over a 53-year period. High levels of dissolved oxygen are essential for a healthy ecosystem. Probably linked to the average increase in temperature, there has been a decrease in dissolved oxygen in the estuary.

Statistical analysis shows that the fish community of the Hudson estuary has been continuously changing since systematic recording began in the 1980s. It is concluded that the fish community has been changing rapidly since 1985 and is now showing clear signs of increased instability with greater year-to-year variation in abundance. It is notable that these changes have not been accompanied by changes in total fish species number, which has undergone no appreciable change since 1985.

The population abundance and dynamics of 13 key species subject to intensive study. Three species, striped bass, bluefish and spottail shiner, show a trend of increasing abundance since the 1980s. The other 10 species, including shad, tomcod and white perch, have declined in abundance, some greatly. For example, the rainbow smelt is no longer recorded in the surveys. Further, there were significant negative abundance trends in yearling white perch, juvenile American shad, white catfish and weakfish. Many other important species of fish not included within the key 13 species are also showing long-term declines in abundance. An important example of a once abundant fish now in decline is the American eel.

All the evidence points to the Hudson estuary ecosystem presently being in a state of change, with declining stability. Neither the ecosystem as a whole, nor many of the individual constituent species' populations, is in a healthy state.

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1 Introduction

Riverkeeper asked Pisces Conservation to assess the state of the fish in the Hudson, using the latest available data. This report reviews the fish populations and ecology of the Hudson using the 2005 Year Class Report for the Hudson River Estuary Monitoring Program, reports and assessments prepared by the New York State Department of Environmental Conservation (NYSDEC) and the Atlantic States Marine Fisheries Commission (ASMFC), as well as recently published materials and other literature.

2 Large scale and synoptic features

As we will describe below, the fish community is not stable in the Hudson. The ecosystem appears to be declining in terms of stability. The estuary is in a state of flux, with temperatures increasing, dissolved oxygen decreasing, invasive species, including diseases, expanding their range, and indigenous species both increasing and decreasing.

Because the physical environment is the foundation upon which the biological world is built, we first consider recent changes in temperature and oxygen levels in the estuary. Both these variables are influenced by the power plant discharges. The natural temperature regime in the Hudson is notably extreme for a temperate estuary, with one of the largest known seasonal ranges for a large estuarine habitat. This in turn influences the fish community, and makes the species present particularly vulnerable to changes in temperature, or the local effects of a power plant cooling water discharge.

2.1 Temperature in the Hudson

Water temperature in the Hudson is increasing. This is clearly demonstrated by the statistically significant increase in mean average annual water temperature measured at Poughkeepsie Water Treatment Facility (Figure 1). The mean annual temperature in recent years is about 2 °C (3.6 °F) above that recorded in the 1960s.

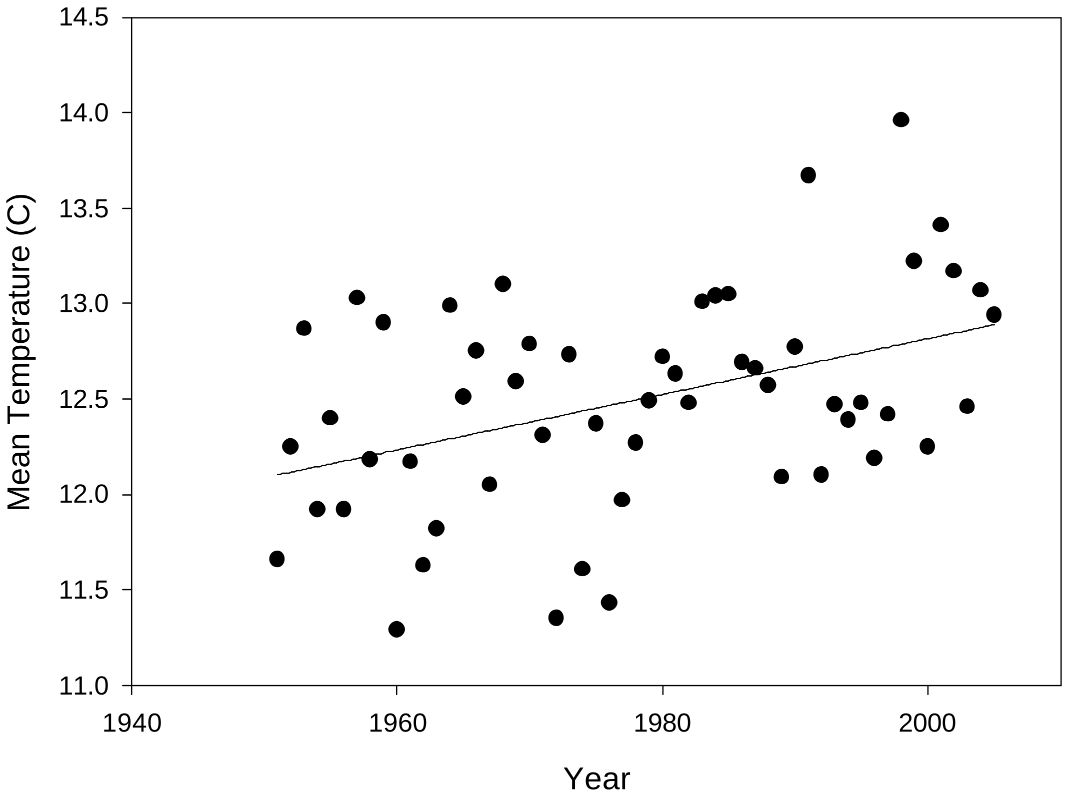

Figure 1: Average annual water temperature (°C) as measured at Poughkeepsie's Water Treatment Facility, 1951 to 2005.
(a = 0.0146, b = -16.32, F = 11.1157, p = 0.0016).
Data from 2005 Year Class report – Appendix B, Table B - 6

Examination of the daily temperatures for 2005 plotted against the mean, minimum and maximum temperatures from 1951 to 2004, show that the temperature for several summer months in 2005 was close to the maximum ever recorded. However, in the winter, it also reached some of the lowest temperatures recorded over a 53-year period. In summary, the temperature regime is becoming more extreme.

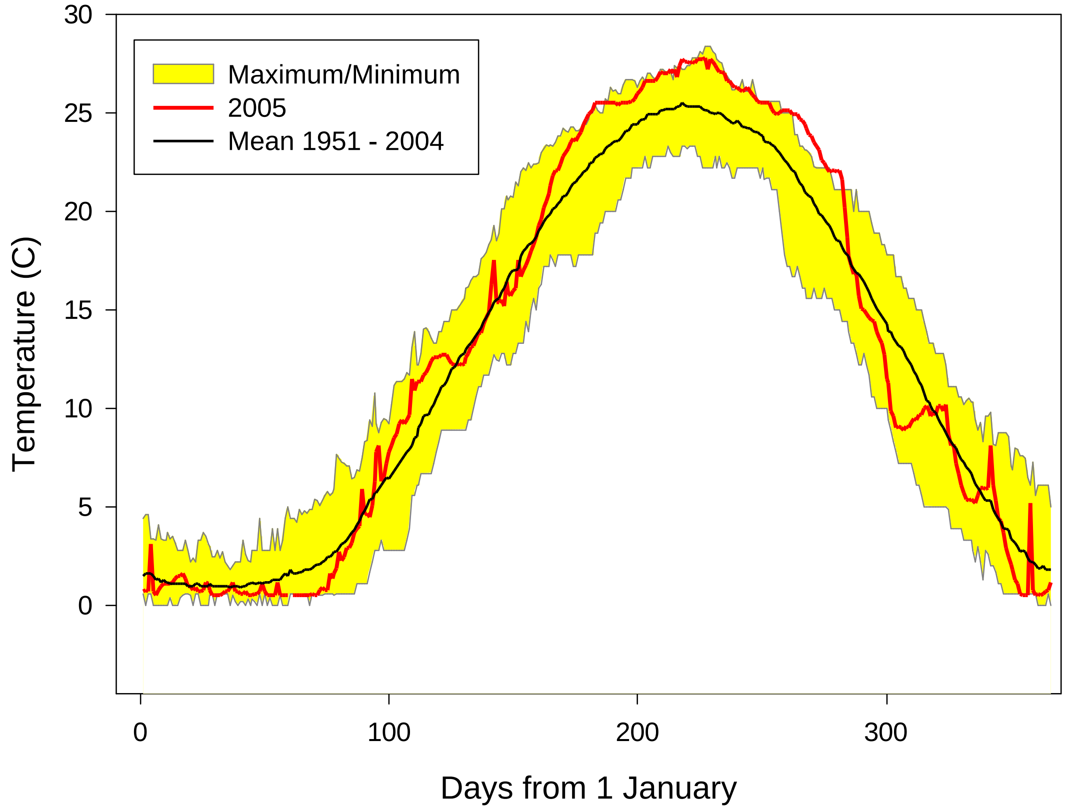

Figure 2: Poughkeepsie's Water Treatment Facility data; mean, minimum, and maximum temperature (°C) for each day of the year, 1951 to 2004.
2005 data plotted in red.
Data from 2005 Year Class report – Appendix B, Table B - 5

2.2 Thermal tolerance of fish species found in the Hudson

The effects of temperature on the biology and ecological requirements of fish have been extensively studied and reviewed. Temperature can affect survival, growth and metabolism, activity, swimming performance and behaviour, reproductive timing and rates of gonad development, egg development, hatching success, and morphology. Temperature also influences the survival of fishes stressed by other factors such as toxins, disease, or parasites. Many of these effects will occur well below the upper lethal temperatures, which are tabulated below for a range of common Hudson fish. In Table 1, the upper temperatures that a range of Hudson River fish can tolerate are given, together with the acclimation temperature. When no size is given, the values are for adults. Generally, young and small fish are more vulnerable to elevated water temperatures than adults. Maximum summer water temperatures in the Hudson are about 81 °F (27.2 °C), which the table shows most fish can just tolerate. For some, such as the tomcod, it is too hot and they must seek cooler waters (for example by heading towards the ocean).

The least temperature-tolerant of the species in Table 1 are tomcod, alewife, rainbow smelt, yellow perch and American shad. As will be discussed later, this list includes species that have seen recent large declines in abundance.

Table 1: The upper tolerance limit for common Hudson estuary fish.
The temperature at which the fish were acclimated prior to testing is also given.
Source: Henderson & Seaby (2007).

Species	Latin Name	Acclimation temperature, ºC	Upper tolerance limit, ºC
Carp	*Cyprinus carpio*	20	31-34
Large mouth bass	*Micropterus salmoides*	20	32.5
		30	36.4
Blue gill	*Lepomis macrochirus*	15	30.7
3-spined stickleback	*Gasterosteus aculeatus*	25-26	30.6
Yellow perch	*Perca flavescens*	15	27.7
Alewife	*Alosa pseudoharengus*	15	23
Rainbow smelt	*Osmerus mordax*		21
Sea lamprey	*Petromyzon marinus*		34
Tomcod	*Microgadus tomcod* 2 cm		19-20.9
	14-15 cm		23.5-26.1
	22-29 cm		25.8-26.1
Common shiner	*Notropis cornutus*	15	30.3
Brown bullhead	*Ictalurus nebulosus*	15	31.8
Striped bass	*Morone saxatilis* yolk sac		Mortalities start at 26
	Post yolk sac		Mortalities start at 30
	Early juveniles		Mortalities start at 34
American shad	*Alosa sapidissima*		28
White perch	*Morone americana*		32-34

2.3 Oxygen in the Hudson

The temperature of water has a direct effect on the dissolved oxygen (DO) concentration, which declines with increasing water temperature. This results in many fish and other aquatic organisms living in below-optimal oxygen levels during hot summer periods. As would be predicted, the significant upward trend in temperature has resulted in a statistically significant downward trend in DO (Figure 3 and Figure 4). The sharp decline in DO in 2004 and 2005 is particularly notable.

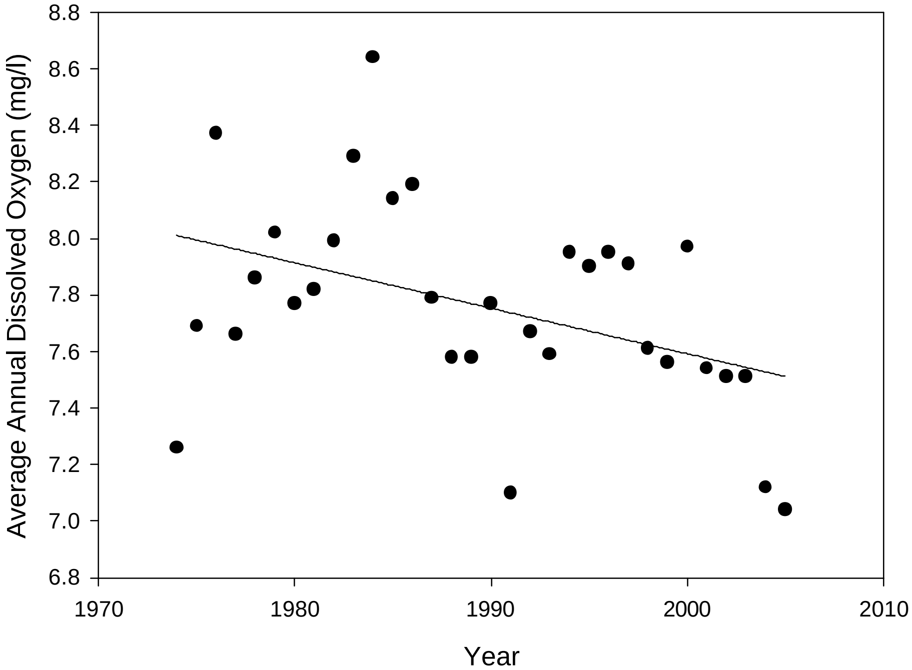

Figure 3: Average Annual Dissolved Oxygen (mg/l) from Long River/Fall Juvenile surveys, 1974 to 2005.
(a =-0.0161, b = 39.7804, F = 6.4047, p = 0.0169).
Data from 2005 Year Class report – Appendix B, Table B - 14

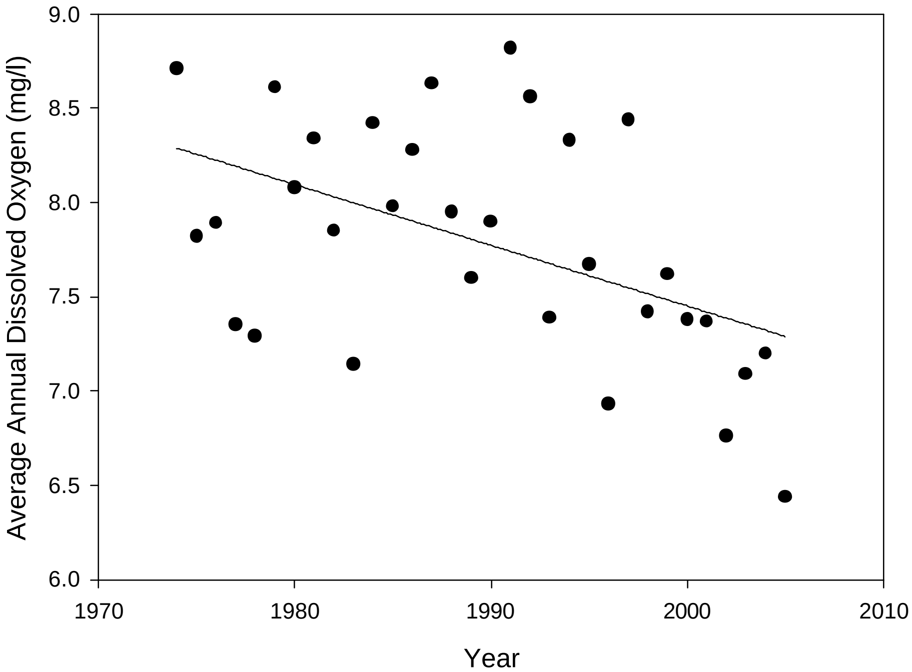

Figure 4: Average Annual Dissolved Oxygen (mg/l) from Beach Seine surveys, 1974 to 2005
(a =-0.0322, b = 71., F =9.5142, p = 0.0044).
Data from 2005 Year Class report – Appendix B, Table B - 16

Given the considerable efforts that have been taken to reduce organic pollution, and the great improvement in water quality in the vicinity of New York City, these declines in DO are disappointing, and potentially important indicators of a decline in water quality for fish.

The distribution of DO within the water column is complex. It can be affected by many factors including tidal flow, riverine metabolism, stratification and atmospheric diffusion. A typical profile of DO versus depth is shown in Figure 5.

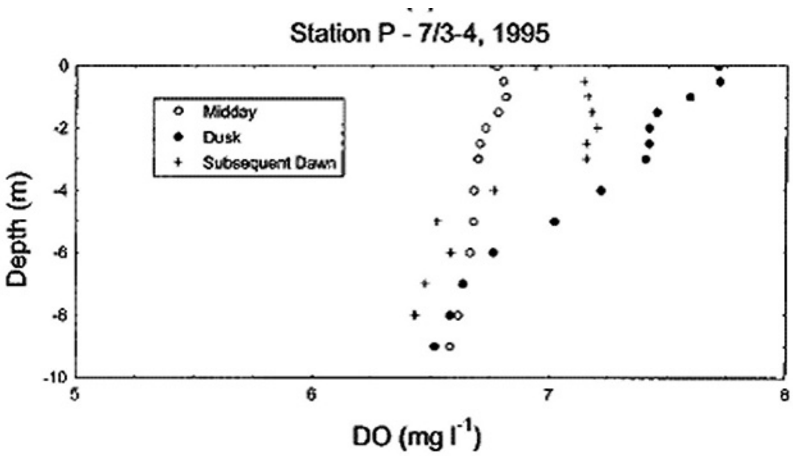

Figure 5: Typical depth profiles of DO measured on 3–4 July 1995 at Haverstraw Bay.
Profiles for three sample times are shown for each station.
Source: Swaney *et al* 1999

This figure shows that the amount of oxygen in the water is often higher at the surface, and is increased during daylight hours as result of oxygen released by photosynthesis. The levels of DO are often reduced overnight as oxygen is metabolised by the organisms in the river.

3 The abundance of fish

3.1 The Annual Year Class Index

Since 1973, data have been collected from the Hudson in an attempt to quantify the size the populations of 16 species of fish that are found in the Hudson. The 16 species of fish were identified by the New York State Department of Environmental Conservation (NYSDEC) as being of interest in relation to the Hudson Settlement Agreement power plants' environmental impact. The data collection changed significantly in 1988, when a new area (Battery) was introduced to the sampling.

The fish of the Hudson live in many different parts of the river, in many different habitats. No single method of surveying fish can adequately represent this variation. The Year Class Index is therefore estimated from three separate studies (Table 2).

Table 2: Names and lengths of the three surveys that make up the Annual Year Class Index

Name	Dates	Known as
Long River Ichthyoplankton Survey	1974-2005	LRS or Long River Survey
Fall Juvenile Survey	1979-2005	FJS or Fall Shoals Survey,
Beach Seine Survey	1974-2005	BSS

3.1.1 Brief descriptions of each survey.

3.1.1.1 Longitudinal River Ichthyoplankton Survey

Sampling encompassed the entire length of the Hudson River estuary, from River Mile (RM) 1 at the Battery in Manhattan to RM 152 at the Federal Dam in Troy.

The LRS is designed to estimate the numbers, and distribution of eggs, larvae and post yolk sac larvae (PYSL) for selected Hudson River fish species – it also catches some juveniles. The primary species were Atlantic tomcod (*Microgadus tomcod*), American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), white perch (*M. americana*) and bay anchovy (*Anchoa mitchilli*). LRS sampling is undertaken during the peak period for the young life stages of the fish, which is spring, summer, and early fall.

The survey is undertaken using a 1m Tucker trawl towed upstream. The Tucker trawl is mounted on an epibenthic sled to sample the deeper waters. 3,647 trawls of 5 minutes' duration were collected in 2005, of which 2,433 were analysed (where multiple trawls were available for the same area and week, only a subset are analysed).

3.1.1.2 Fall Juvenile Survey

Samples are collected every other week from the Battery to the Troy Dam in mid-summer and fall.

The FJS is designed to estimate the number of Young of the Year (YOY) fish in the estuary, and their distribution. The target species are Atlantic tomcod, American shad, striped bass, and white perch.

The survey is undertaken using a 1m Tucker trawl and a 3m beam trawl towed upstream. 2,002 5-minute trawls were collected in 2005.

3.1.1.3 Beach Seine Survey (BSS)

Samples were collected in alternate weeks to those of the FJS, using a beach seine from mid-June through October. The samples are taken from George Washington Bridge (RM 12) to the Troy Dam.

The BSS is designed to estimate the number of Young of the Year (YOY) fish in the estuary, and their distribution. The target species are American shad, Atlantic tomcod, striped bass, and white perch during periods when these species were concentrated primarily in the shallow, near-shore areas.

The survey is undertaken using a 30.5m beach seine. The area sampled was approximately 450m^2 per haul. 1000 hauls were collected in 2005.

The methods and scope of the survey are summarised in Table 3.

Table 3: Summary of 2005 Hudson River surveys
Source: 2005 Year Class report, Table 2-2.

Program Phase	Sampling Schedule Start Week	Sampling Schedule End Week	Number of River Runs	Sampling Frequency	Strata Sampled	Sample Number Collection Projected	Sample Number Collection Actual	Sample Number Lab Analysis	Sampling Gear
Longitudinal River Ichthyoplankton Survey	1 MAR	8 OCT	23	Weekly/ Biweekly	Shoal	588	586	554	1.0-m² net on epibenthic sled, or 1.0-m² Tucker trawl
					Channel	1,670[1]	1,670	957	1.0-m² Tucker trawl
					Bottom	1,389	1,363	922	1.0-m² net on epibenthic sled
Atlantic Croaker Ichthyoplankton Survey	14 NOV	5 DEC	2	Monthly	Shoal	32	32	32	1.0-m² net on epibenthic sled, or 1.0-m² Tucker trawl
					Channel	26	26	26	1.0-m² Tucker trawl
					Bottom	26	26	26	1.0-m² net on epibenthic sled
Fall Juvenile Survey	4 JUL	28 NOV	11	Biweekly	Shoal	427	426		3.0-m beam trawl, or 1.0-m² Tucker trawl
					Channel	648	648		1.0-m² Tucker trawl
					Bottom	1,055	1,054		3.0-m beam trawl
Beach Seine Survey	13 JUN	17 OCT	10	Biweekly	Shore	1,000	1,000		30.5-m beach seine

[1] Includes 125 samples for striped bass otolith analysis.

3.1.2 Where in the river is sampled

The 13 sections of the river (Figure 6), were divided into four habitat types:

- **Shore** - That portion of the Hudson River estuary extending from the shore to a depth of 10 ft (the stratum defined only for BSS).
- **Shoal** - That portion of the Hudson River estuary extending from the shore to a depth of 20 ft at mean low tide.
- **Bottom** - That portion of the Hudson River estuary extending from the bottom to 10 ft above the bottom where river depth is greater than 20 ft at mean low tide.
- **Channel** - That portion of the Hudson River estuary not considered bottom where river depth is greater than 20 ft at mean low tide.

Sampling is spread among the different habitats and river sections, throughout the year. Table 4 shows where the samples were taken from for each survey type.

Table 4: Habitat samples in the 13 regions of the Hudson in 2005
(- indicates no sampling scheduled)
Source: 2005 Year Class report, Table 2-1.

Region	Abbreviation	River Miles	River Kilometers	2005 Surveys Shore	Shoal	Channel	Bottom
Battery	BT	1-11	1-19	--	–	X	X
Yonkers	YK	12-23	19-39	X	X	X	X
Tappan Zee	TZ	24-33	39-55	X	X	X	X
Croton-Haverstraw	CH	34-38	55-63	X	X	X	X
Indian Point	IP	39-46	63-76	X	X	X	X
West Point	WP	47-55	76-90	X	–	X	X
Cornwall	CW	56-61	90-100	X	X	X	X
Poughkeepsie	PK	62-76	100-124	X	--	X	X
Hyde Park	HP	77-85	124-138	X	–	X	X
Kingston	KG	86-93	138-151	X	–	X	X
Saugerties	SG	94-106	151-172	X	–	X	X
Catskill	CS	107-124	172-201	X	--	X	X
Albany	AL	125-152	201-246	X	–	X	X

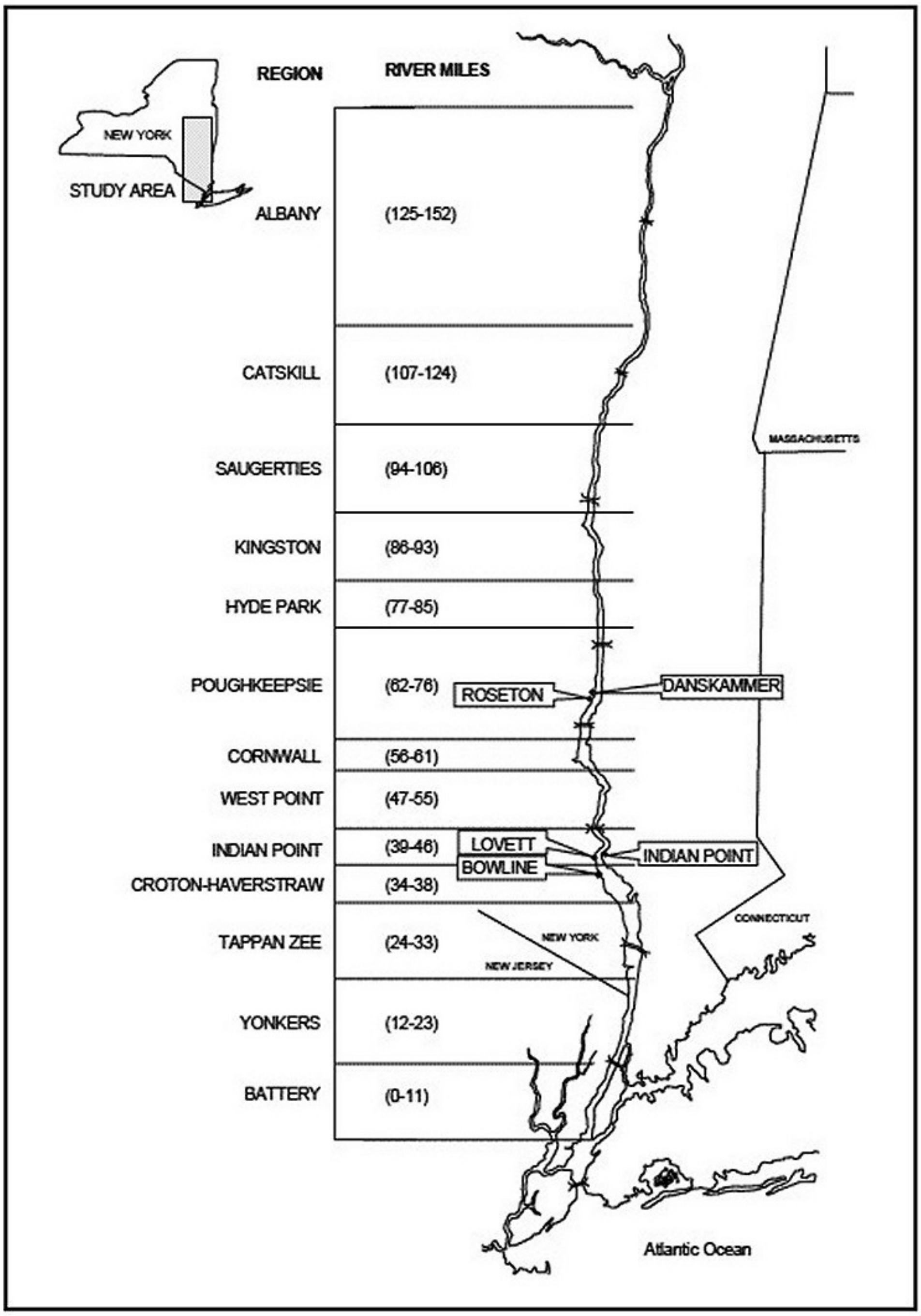

Figure 6: The 13 geographical locations with river mile boundaries used in the 2005 Hudson River surveys.
Source: 2005 Year Class report, Figure 2-1.

3.1.3 What ages of fish are sampled

During the sampling, several different life stages of fish are caught. The definitions for each stage are given in Table 5.

Table 5: Life stages of fish sampled.
Source: 2005 Year Class report, page 2-5.

Egg	Embryonic stage from spawning to hatching
Yolk Sac Larvae (YSL)	From hatching to development of a complete and functional digestive system
Post Yolk Sac Larvae (PYSL)	From development of a complete digestive system to transformation to juvenile form
Young of Year (YOY)	From completed transformation to Age 1.

An index is calculated separately for each of the life stages. For some species only some life stages are well-sampled. For example, bay anchovy breeds at the mouth of the estuary and therefore an index is only calculated for YOY.

3.1.4 How the fish are counted

Each of the three surveys used slightly different methods to catch the fish. Each method has advantages and disadvantages, and a direct one-to-one comparison of the results is not meaningful. Therefore, a series of indices derived from the catch data is used to combine the data into a single value, indicating the population size.

3.1.5 Calculations of the index

Gathering fish sampling data, and processing that information, is not a straightforward procedure. To obtain a reasonable estimation of how many fish of what age are in the Hudson in any year requires three separate surveys, which are undertaken over several months. Combining the data from these surveys is complex, as the efficiency of the fishing gear, effort used in each survey, and the age of the fish is different.

In a survey that is carried out over many years, it is inevitable that some factors will change between years. This can occur in several ways. For example, each year the total number of samples and volume sampled will vary (Figure 7 and Figure 8) due to gear failure, weather and management decisions. In addition, sample sites may be added or removed from the survey, altering the coverage of fish species; for instance the introduction of sampling in the Battery area in the mid-1980s improved the estimate of bay anchovy numbers.

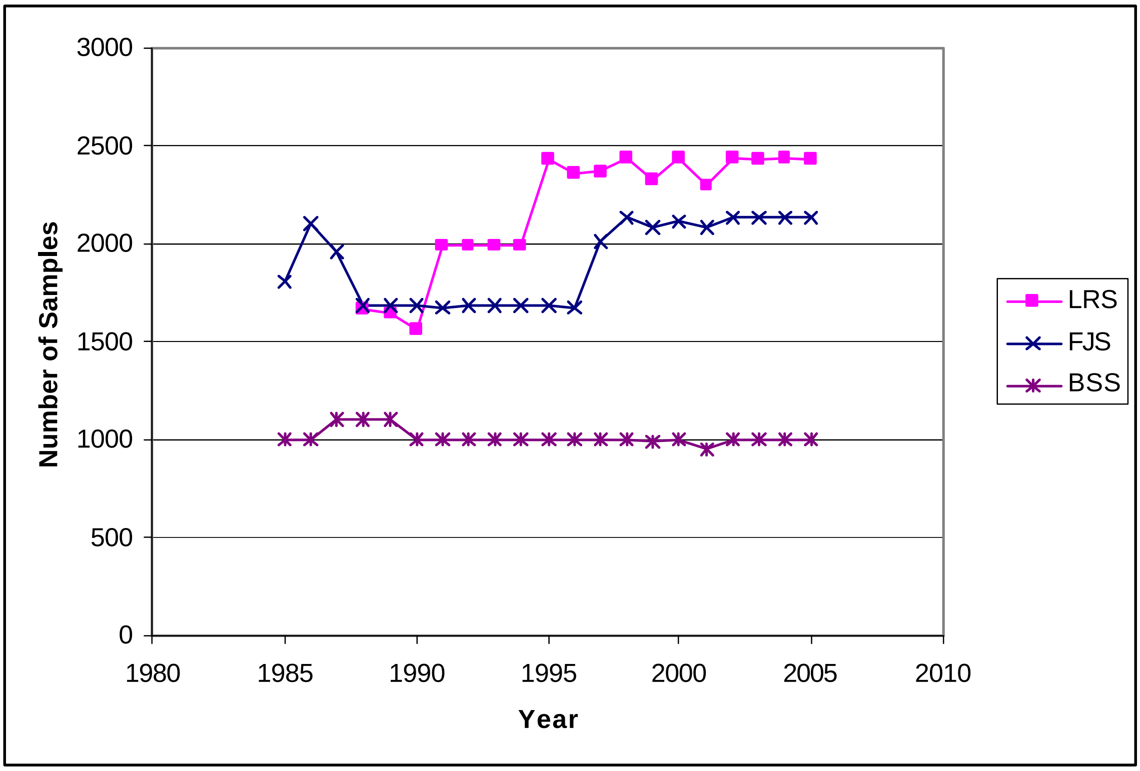

Figure 7: The number of samples per year for the three Hudson River surveys
Source: 2005 Year Class report, Tables C1 to C3

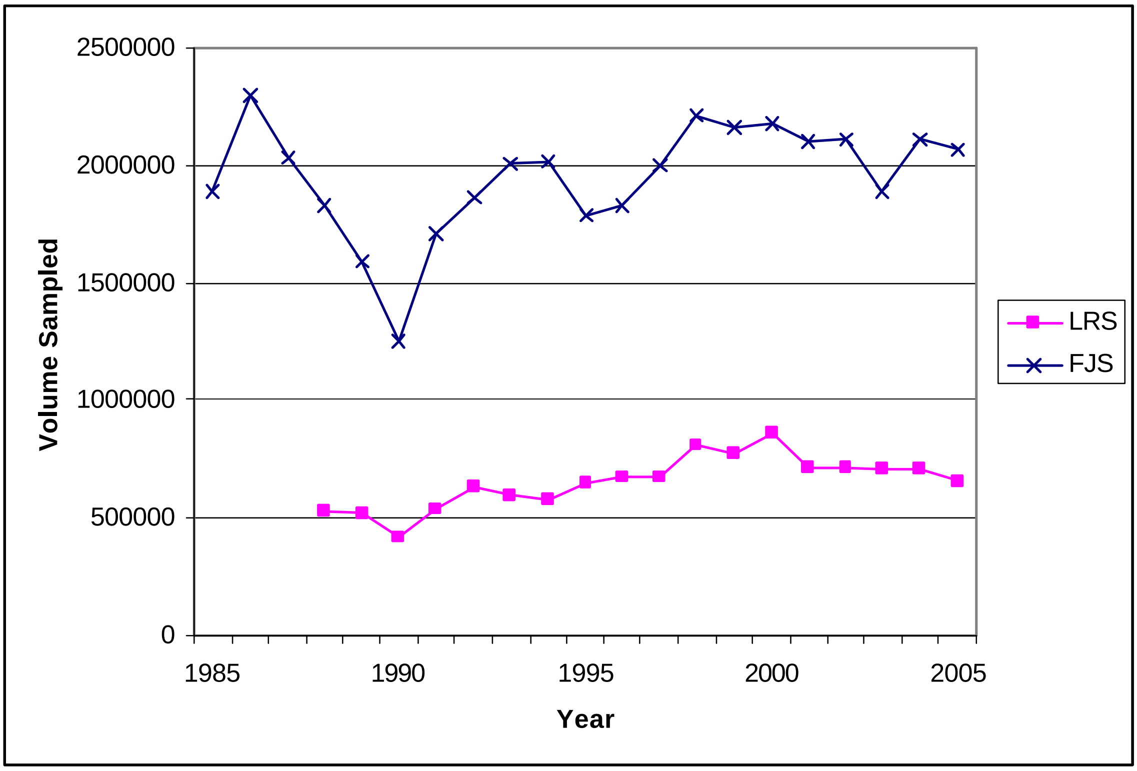

Figure 8: The volume of water sampled in the Long River Survey and the Fall Juvenile Survey.
Source: 2005 Year Class report, Tables C1 and C2.

To cope with the variations in the sampling between years, and also the sampling effort in different areas, an index needs to be calculated that indicates how many fish are present in each year. The actual calculation is complex, but in essence the number of fish actually caught is adjusted in each life stage to a number representing the number caught under some standardized sampling effort.

As a simple example, if 200 fish were caught in a survey of 50 samples in one year, and 100 fish were caught in 10 samples the next year, the index might be standardised at 25 samples, giving an index of 100 for year one and 250 in year two.

Full explanations are given in the 2005 Year Class report, pages 2-11 to 2-17.

3.2 Changes in community structure

The extensive data sets produced by the Long River, Fall Juvenile and Beach Seine Surveys allow a general analysis of the change in fish community structure since the 1980s.

Since 1985, there is no evidence for an appreciable change in total fish species number in the estuary. However, this apparent stability hides great changes in the actual species present and their relative abundances. To compare the structure of the communities through time, the annual abundance data from all three surveys were analysed, using a number of multivariate statistical methods. As all the methods investigated lead to the same conclusion, we use here Principal Components Analysis (PCA), which is a standard technique familiar to most scientists. PCA is a method used to summarise the relationship between objects. Here we use it to summarise the relationship between the fish communities living in the Hudson in different years. PCA allows us to plot a simple graph in which the years most similar, in terms of their fish community, are plotted closest together, and the years most different in terms of their fish are furthest apart. So, for example, in Figure 9 B, the red points represent the fish community in the 1980s. The 5 points forming a distinct cluster towards the right of the graph, indicating that the fish community in these years was similar. In contrast the green points for the years post-1997 are all far to the left indicating that the community after 1997 was very different from that observed in the 1980s.

The graphs in Figure 9 clearly show that there has been a progressive change in the fish community sampled by all three surveys. Samples collected in the 1980s form a relatively tight group, indicating that the community during this period changed little from year to year. In comparison, the community post-1997 is considerably different, and shows increased between-year variability. For example, the plot for the Beach Seine Survey shows that the cluster of points for the 1980s (red points and perimeter), 1990s up to 1997 (blue points and perimeter) and post-1997 to present (green points and perimeter) form clearly different clusters, and the area enclosed by their perimeters is gradually increasing in size. It can be concluded that the fish community has been changing rapidly since 1985 and is showing clear signs of increased instability.

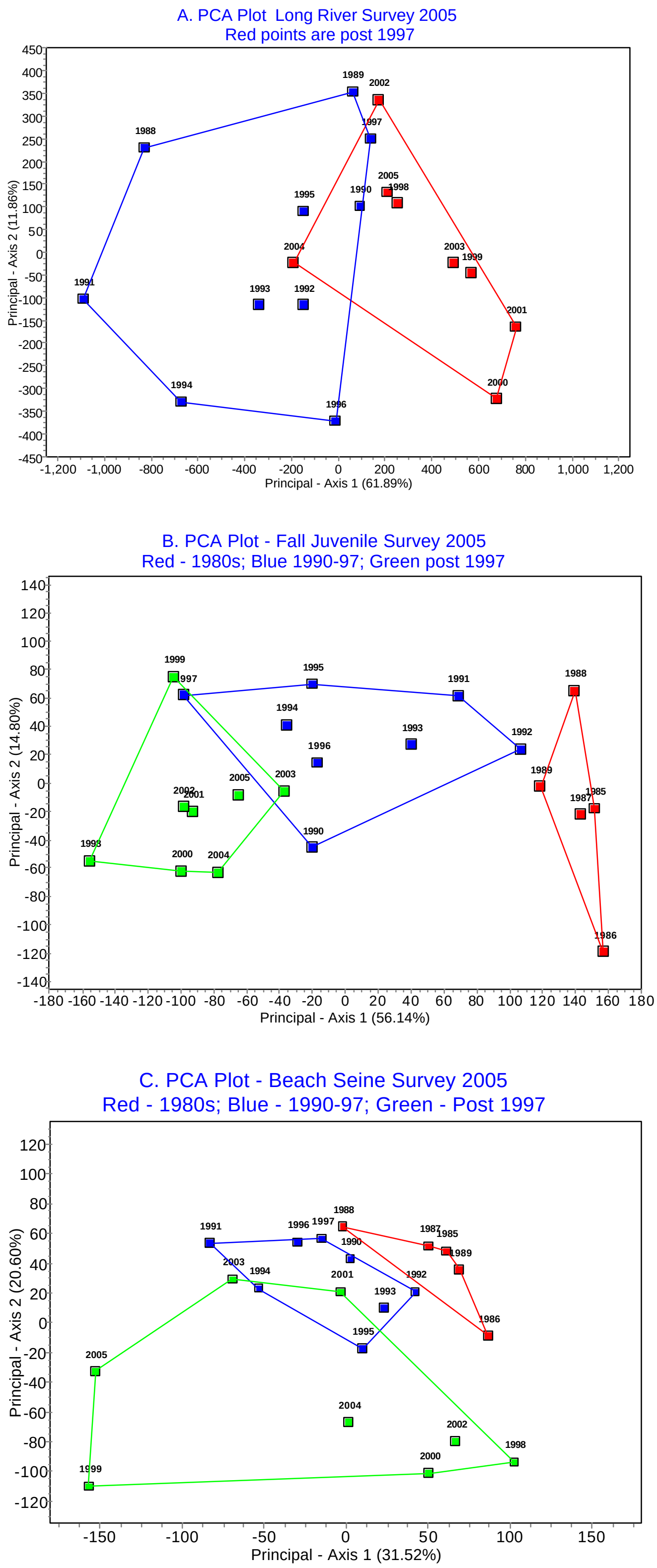

Figure 9: Principal Components Analysis data of fish survey data shows the change in the community from the 1980s to the present.
Data from 2005 Year Class report – Appendix C, Tables C-1 to 3.

3.3 Trends in abundance of the 13 key species

As an index of total fish abundance trends, the average change in the abundance index of the 13 key species reported in the river survey was calculated (Figure 10). To calculate this index, each species index was rescaled to a maximum of 1. This was done by dividing all the indices for a species by the maximum index recorded for that species. This gives equal weighting to all species and allows a general trend in abundance to be summarised. If the data had not been standardized, the trend would have simply reflected the trend in the most abundant species.

Figure 10 shows a statistically-significant downward trend, indicating that the majority of the 13 key species are in long-term decline. Around this declining trend there is considerable variability, so that little can be inferred from an examination of a few isolated observations.

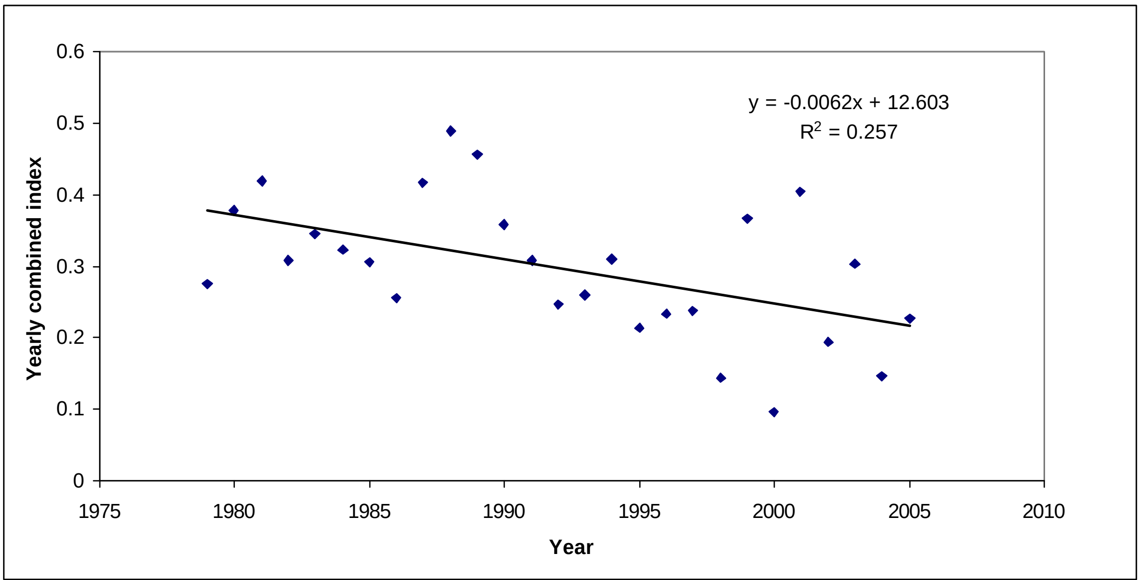

Figure 10: Plot of the average standardised abundance index of the 13 key species recorded in the long river survey - juvenile data
All species standardized so maximum value = 1. Data from 1979 – 2005. (a = -0.0062, b = 12.60, F = 8.647, p = 0.007).
Data from 2005 Year Class report – Appendix D, Table D – 2 to 14

In terms of the trend in abundance, the 13 key species can be divided into those with an increasing trend, and those showing a decline. The three increasing species are striped bass, spottail shiner and bluefish (Figure 11). All the other 10 species show declining trends (Figure 12).

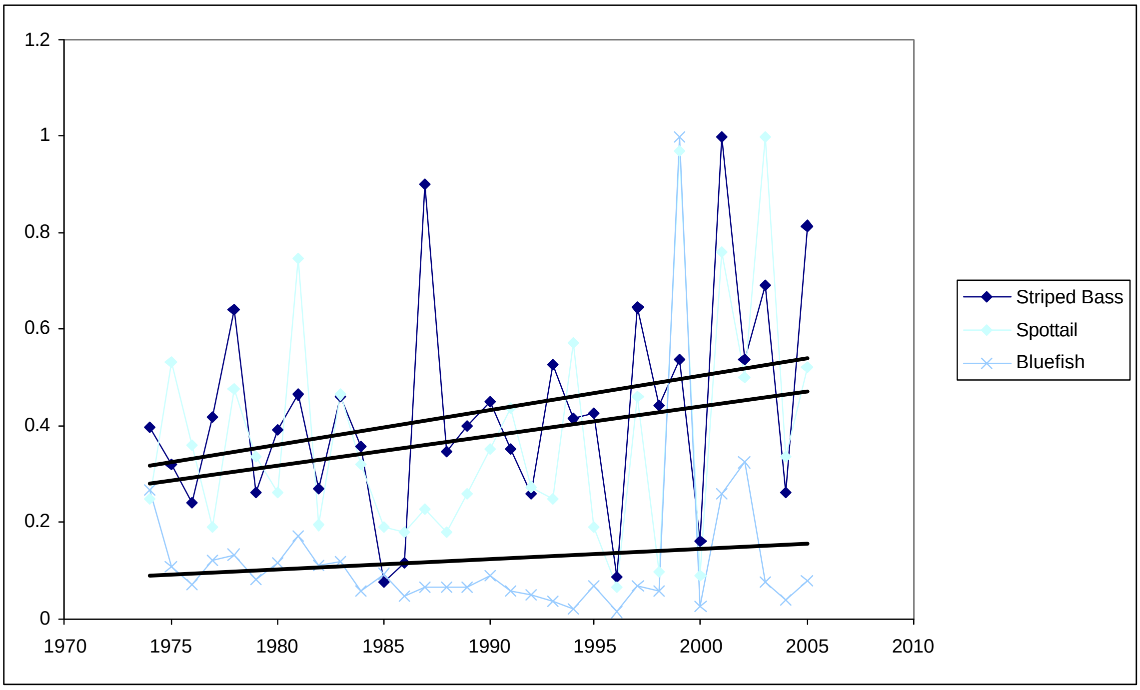

Figure 11: Three positive trends of species – indices standardised to 1.
Data from 2005 Year Class report – Appendix D

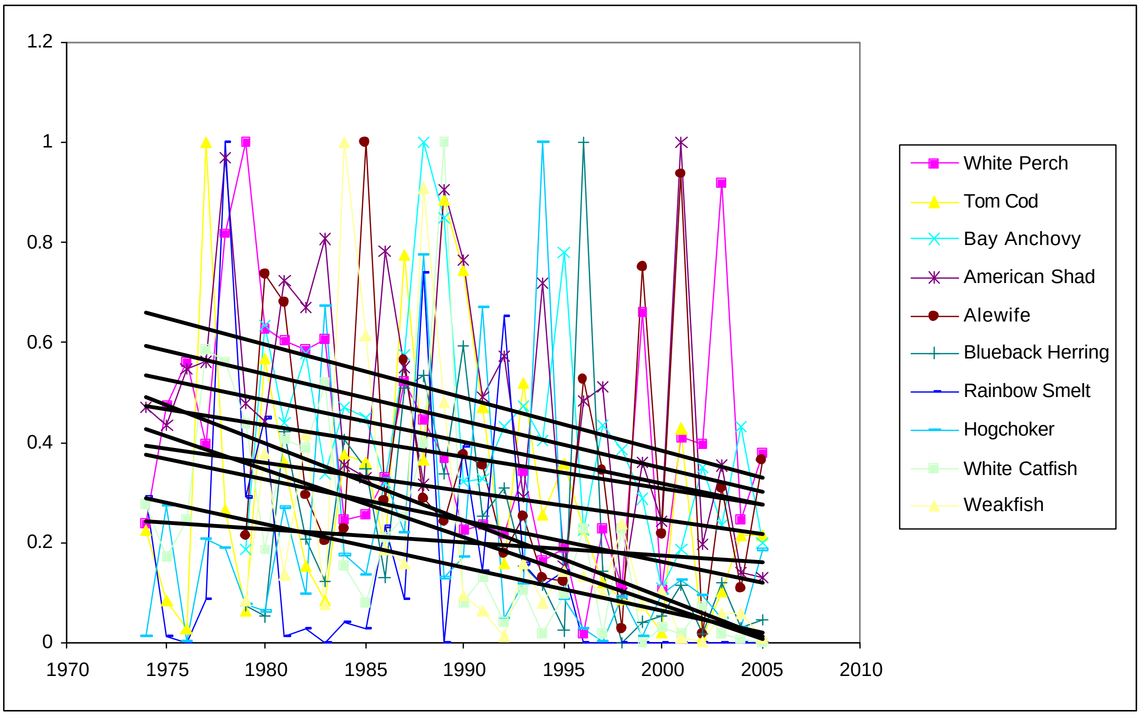

Figure 12: Ten species with negative relationships - indices standardized to 1.
Data from 2005 Year Class report – Appendix D

4 Hudson River fish populations

4.1 Striped bass (*Morone saxatilis*)

Striped bass are anadromous (marine fish that breed in freshwater) members of the temperate bass family. They are found from the St Lawrence river in Canada to Florida. The species has been introduced successfully into several freshwater systems. The Hudson is one of the main breeding rivers for this species. They breed from 4 years old and can live for many years. In the Hudson, spawning occurs from mid May to mid June in the middle reaches of the river. As adults they are top predators.

Striped bass populations are known to be doing well in the north east coast of the USA, and the population has shown a steady increase from the early 1980s (Figure 13). This improvement is shown in the Hudson River Data (Figure 14). The Hudson's population increase is possibly linked to a number of factors, including the reduction of fishing pressure and the improvement in water quality in the vicinity of New York harbour and Long Island Sound increasing the available nursery habitat.

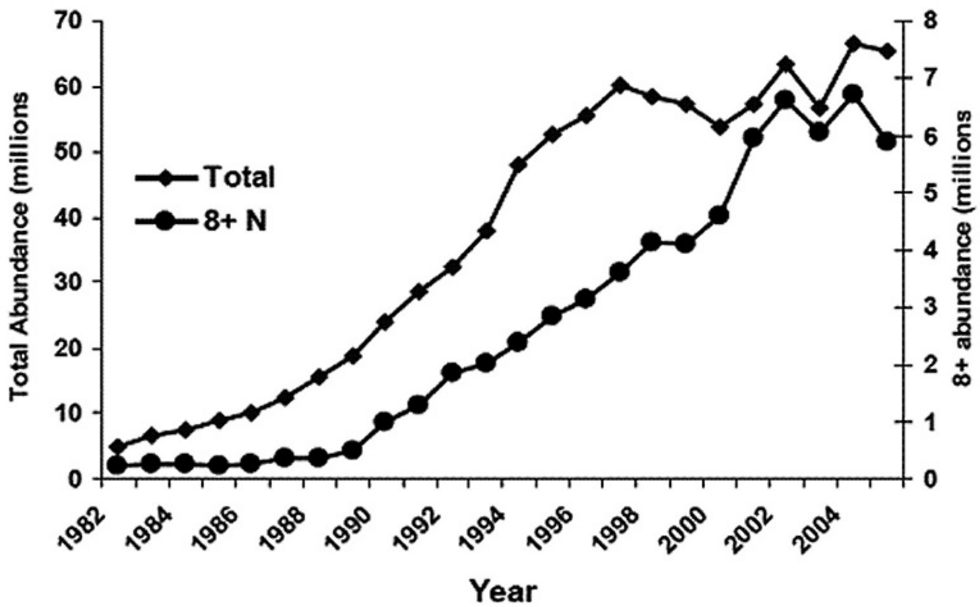

Figure 13: Striped bass population abundance estimates, from 2004 ADAPT model. Source: Committee for the Atlantic Striped Bass Management Board 2005.

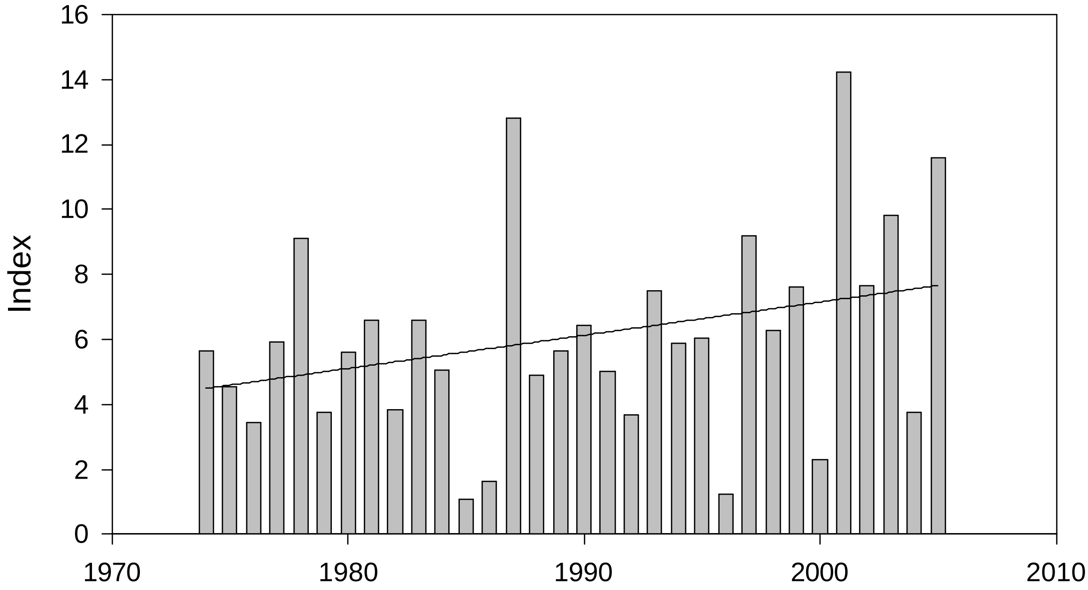

Figure 14: The juvenile index for striped bass in the Hudson, showing an increasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 2

In addition to the Year Class reports, data are collected by the NYSDEC (2006) on the status of the striped bass in New York. This data again shows a large increase in the numbers of the young of year (Figure 15), and correlates well with the juvenile index from the Year Class Report (Figure 16).

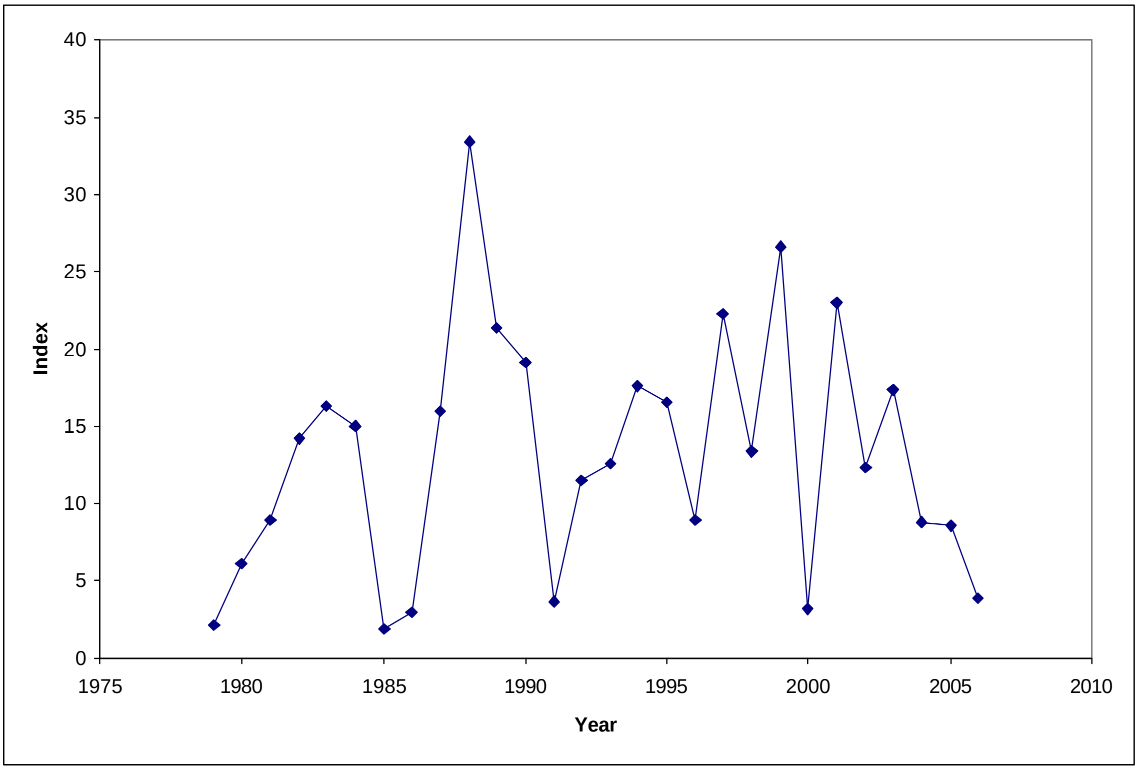

Figure 15: The NY State Hudson River Index of relative abundance for YOY striped bass.
Source: NYSDEC 2006 - table 20.

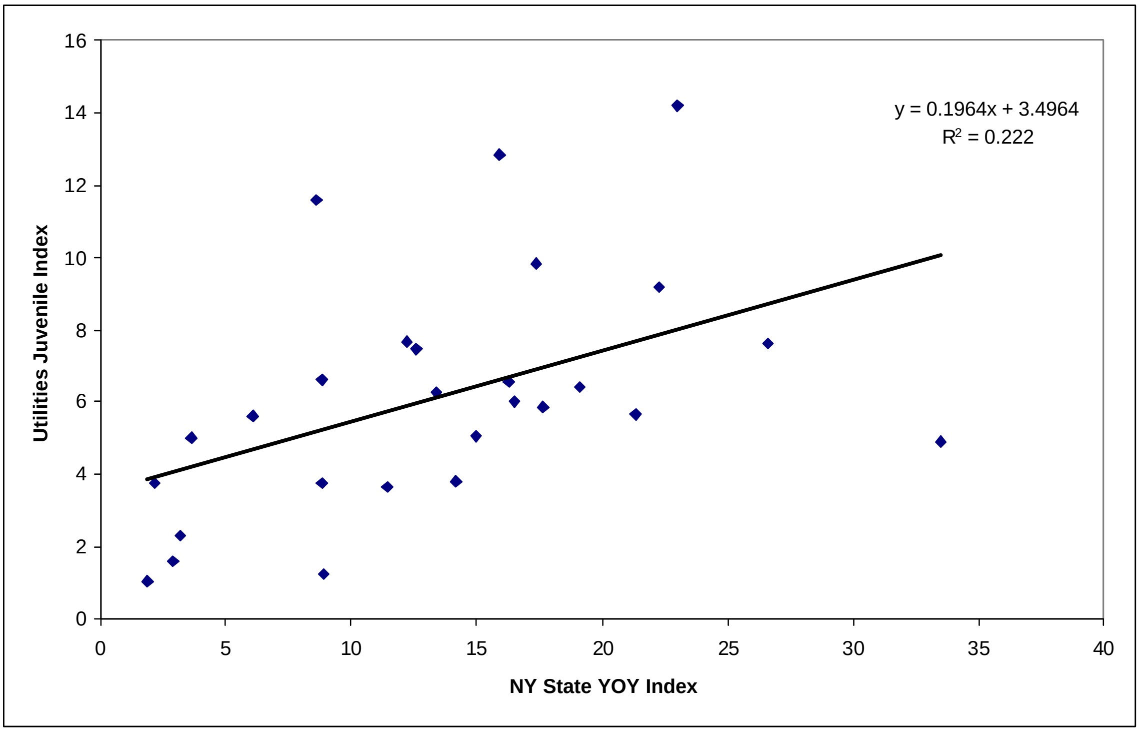

Figure 16: The relationship between the NY State Hudson River Index of relative abundance for YOY striped bass and the Utilities striped bass juvenile index.
Source: NYSDEC 2006 - table 20 and 2005 Year Class report – Appendix D, Table D – 2

4.2 Spottail shiner (*Notropis hudsonius*)

The spottail shiner is a small minnow, which lives in freshwaters in many parts of Canada and the United States. In the Hudson it lives in the middle and upper reaches of the estuary. They are opportunistic predators feeding on a wide range of foods.

The spottail shiner has generally increased in abundance, but has also become far more variable in abundance (Figure 17). This fish particularly favours vegetated shallows, and Strayer *et al.* (2004) showed that species in the Hudson which preferred vegetated habitat have done well since the invasion of zebra mussel, *Dreissena polymorpha.* This mussel is a highly efficient filter feeder, and has made great changes to the ecosystem, increasing light penetration and plant growth. Strayer *et al.* (2004) suggests that this has resulted in both an increased population of spottail shiner, and a change in their distribution.

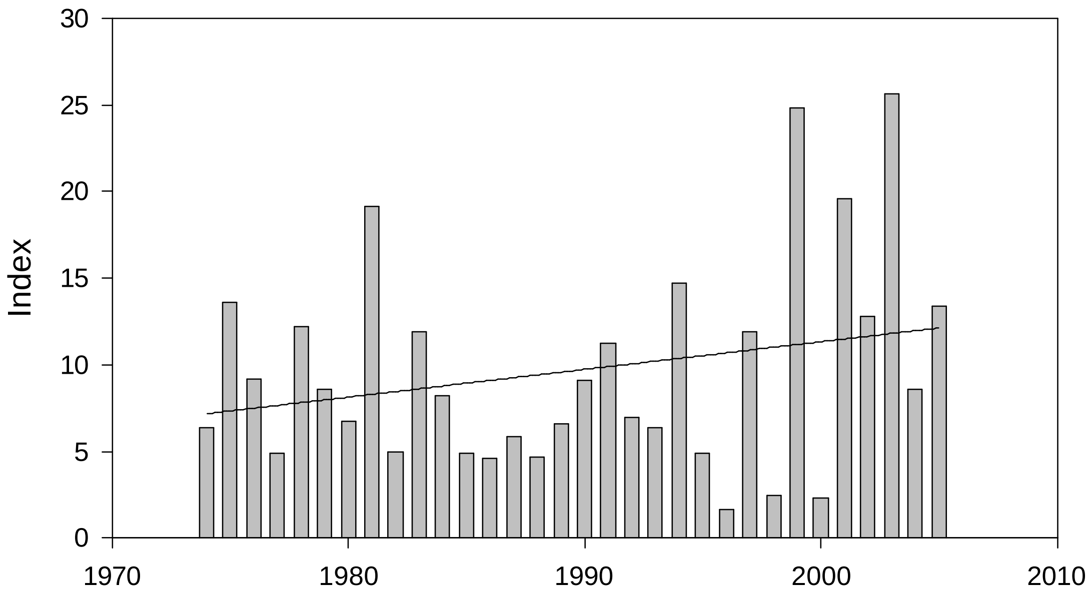

Figure 17: The juvenile index for spottail shiner in the Hudson, showing an increasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 11

4.3 Bluefish (*Pomatomus saltatrix*)

The bluefish is a predaceous oceanic fish, which is found in the western Atlantic. It comes inshore from May to November. Juvenile fish migrate into estuaries and bays, which they use as nursery grounds. In the Hudson they are commoner in the higher salinity regions of the estuary.

The index of juvenile bluefish shows a slight increase over the sampling period (Figure 18). The species population was particularly large in 1999, 2001 and 2002. However, abundance has now declined to levels similar to those observed in the 1980s, suggesting that there is no sustainable long-term increase in abundance.

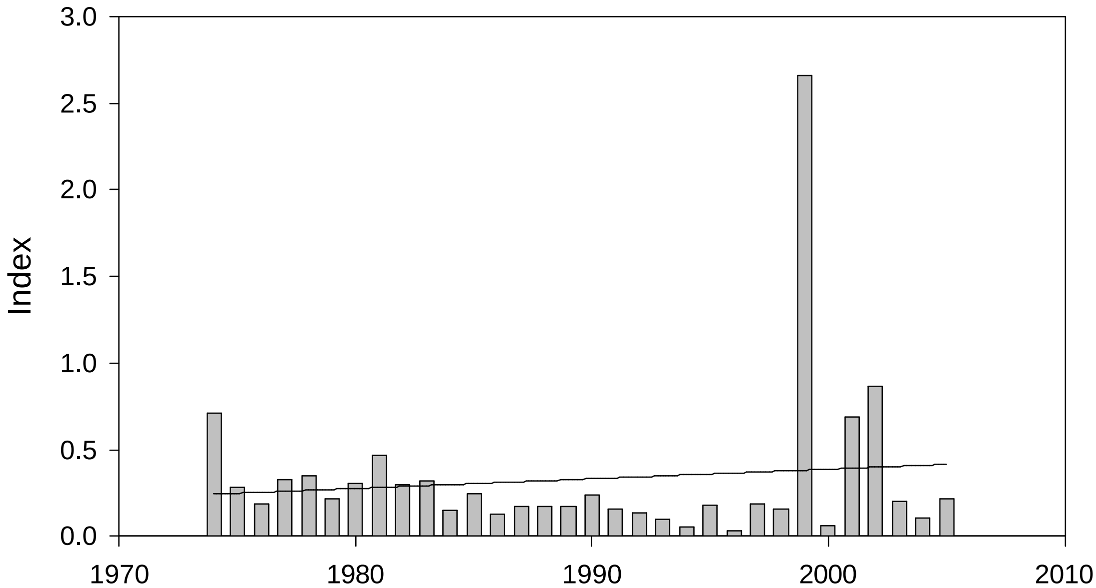

Figure 18: The juvenile index for bluefish in the Hudson, showing an increasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 8.

The biomass of bluefish is estimated in the Atlantic each year by the Atlantic States Marine Fisheries Commission. The numbers of fish dropped from 1982 to 1994, but have subsequently been slowly recovering (Figure 19). The juvenile numbers in the Hudson show a similar decline in the mid 1990s, but seem to have recovered faster.

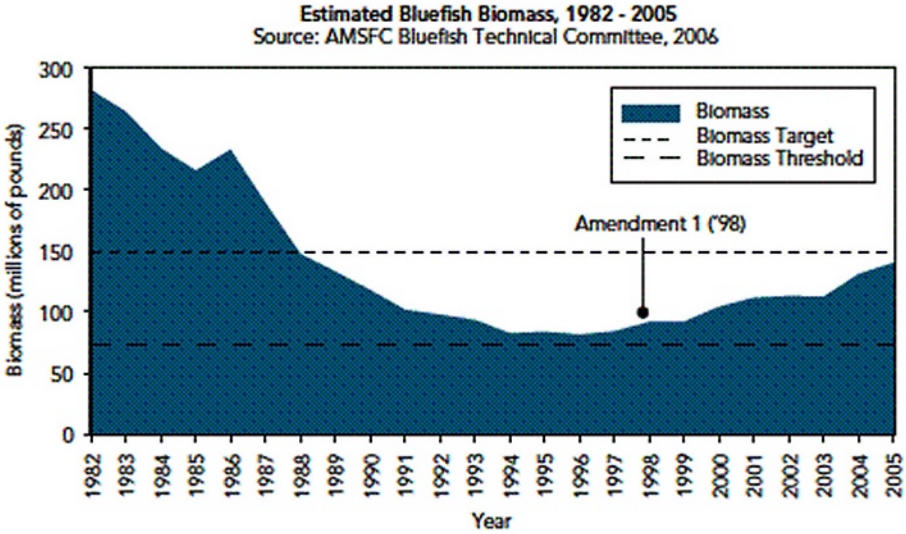

Figure 19: Estimated bluefish biomass.
Source: 65th Annual Report of the Atlantic States Marine Fisheries Commission 2006 (2007)

4.4 White perch (*Morone americana*)

White perch are similar to striped bass, but only grow to a fraction of the size. White perch are estuarine, and are found from Canada to Carolina, and in fresh waters near the coast. They over-winter in the lower estuary, and migrate upstream to freshwater to breed. In the Hudson, breeding usually occurs between mid-May and early July, primarily north of Croton Bay. In the Hudson, some fish mature at 2, but most at 3 to 4 years old.

White perch are showing a decreasing trend in the adjusted index over time (Figure 20). The species reached a particularly low point in the late 1990s, though subsequently it has staged a mild recovery. This species appears to be becoming more variable in abundance since the mid-1990s. In the last 10 years, the white perch abundance index holds the 3 lowest as well as 2 of the highest abundance indices. Increased variation in a population can be an indicator of a species under stress.

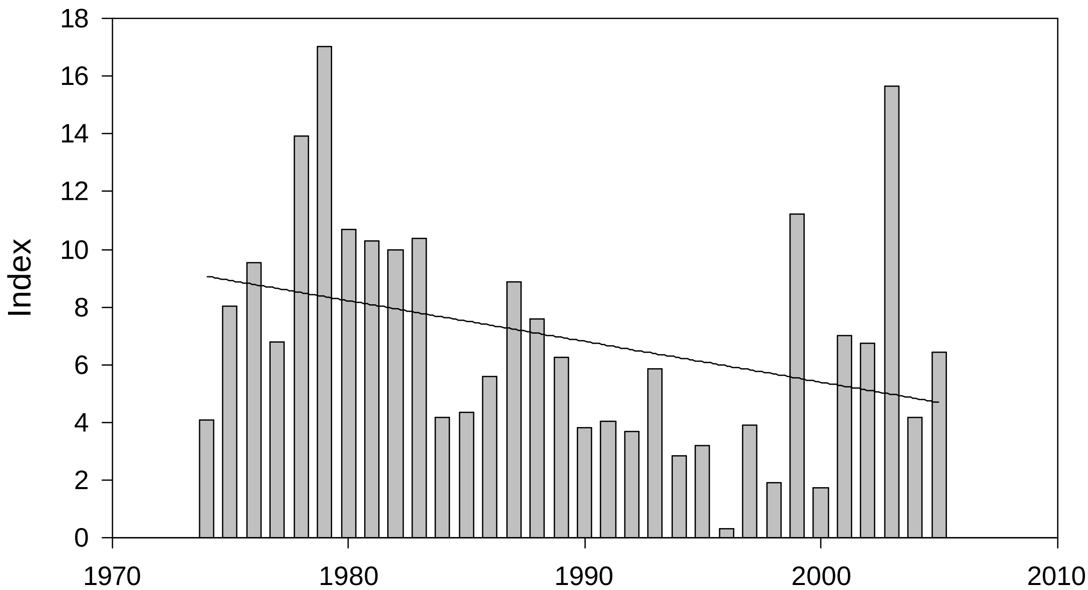

Figure 20: The juvenile index for white perch in the Hudson, showing a decreasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 3

The recent decline in white perch abundance is much more clearly shown in the changing abundance of yearling and older age classes (Figure 21). As was the case for juvenile abundance, the between-year variability is highest in the latter part of the time series. As a population becomes dependent on only one or only a few year classes to reproduce, it is inevitable that the between-year variation will become larger. For example, in an extreme case, where there is only a single age class reproducing, say at 5 years old, there will only be recruits after 5 years.

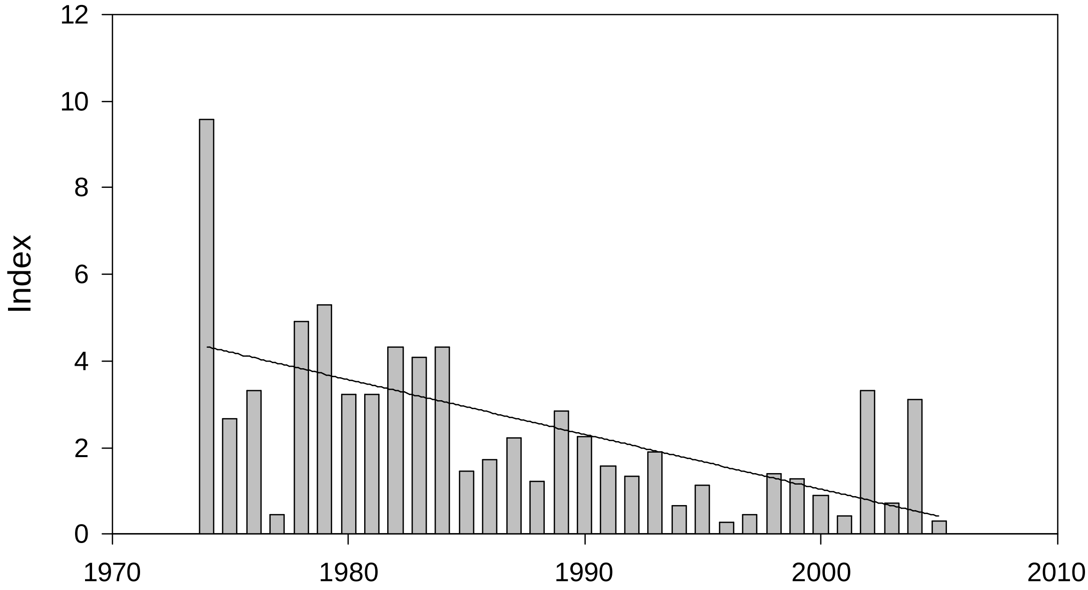

Figure 21: The index for yearling white perch in the Hudson, showing a decreasing trend though time.
The trend is significant (a = -0.1264, b = 253.81, F = 17.72, p = 0.0002).
Data from 2005 Year Class report – Appendix D, Table D – 3.

It is widely accepted that white perch are in decline and the present population size is probably 50% or less of that present in the 1970s and 1980s (See FEIS page 62, NYSDEC 2007).

4.5 Atlantic tomcod (*Microgadus tomcod*)

The Atlantic tomcod is an inshore species that ranges from Labrador to the Chesapeake Bay. It is anadromous, and reaches its southern spawning limit in the Hudson. Tomcod enter estuaries in mid winter to spawn in brackish water. The main spawning area in the Hudson is between West Point and Poughkeepsie. They are unusual in that their growth slows and stops as the water temperature rises.

There are no reliable records of tomcod abundance before the 1970s. The Atlantic tomcod population is showing considerable year-to-year variation, but appears to be in long-term decline (Figure 22). The average standardised index from 1975 until 1995 is 0.158, in comparison the index for the last ten years of sampling (1996-2005) is only 0.0617. In the last 10 years, only 2001 produced a good recruitment, although there are signs of a recent slight improvement in Atlantic tomcod numbers.

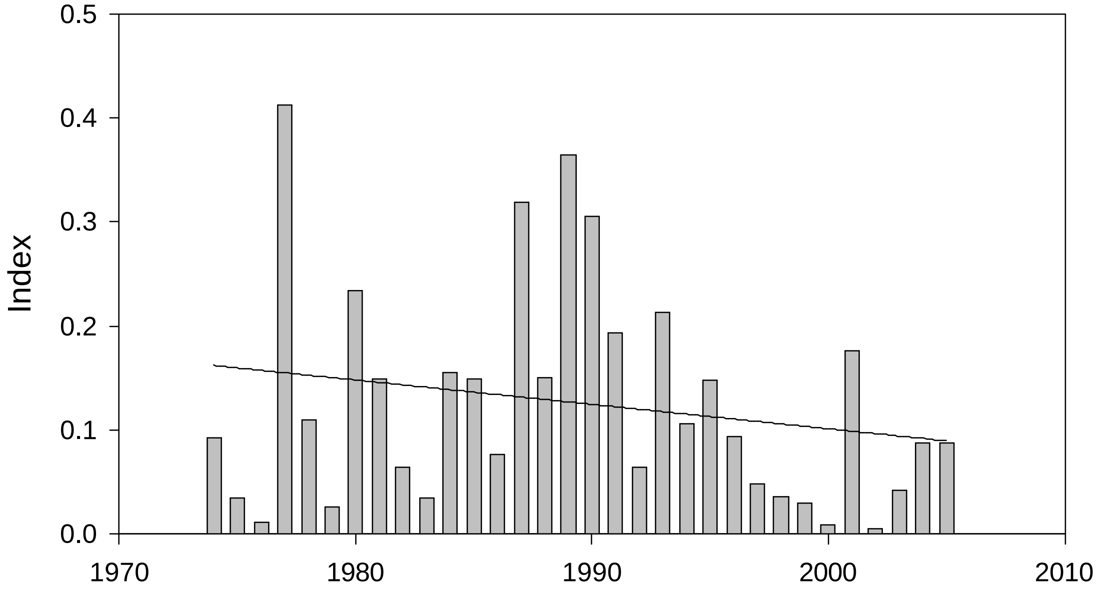

Figure 22: The juvenile index for Atlantic tomcod in the Hudson, showing a decreasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 4

There is also an annual survey of the tomcod to estimate its breeding population (Normandeau Associates, 2007). This survey uses a range of techniques to look at the structure and size of the tomcod population. These data are used to estimate the size of the breeding population each year. Figure 23 shows a similar decline in numbers as seen in the juvenile index, above.

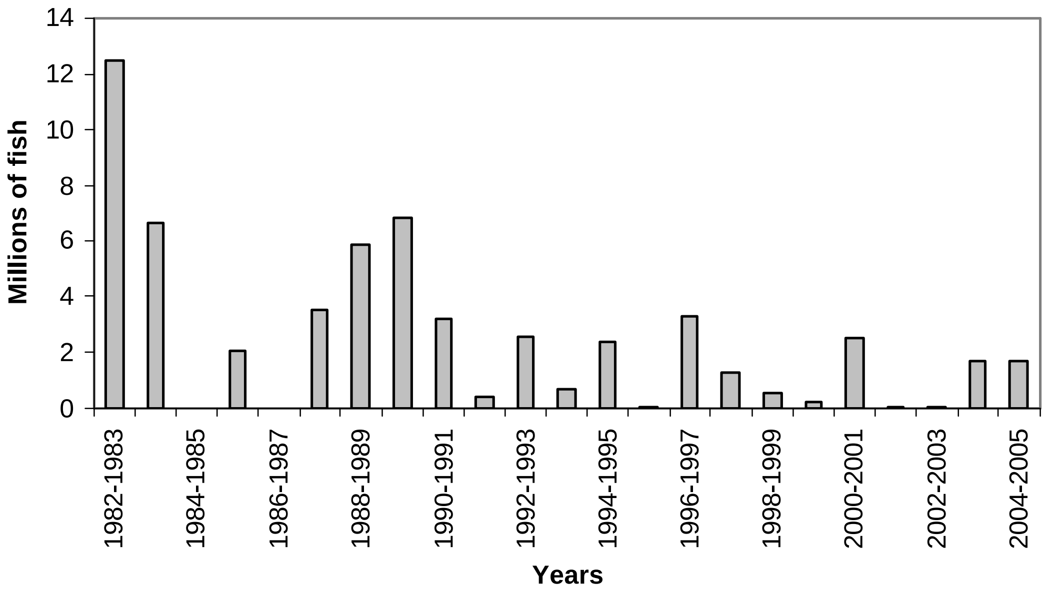

Figure 23: The Petersen estimates of the Hudson River Atlantic tomcod spawning population, winters of 1982-1983 through 2004-2005.
Source: Normandeau Associates, 2007.

The fate of tomcod may be related to river water temperature. The tomcod is a small, short-lived member of the cod family. Because it is at the southern extremity of its geographical range within the Hudson estuary, sensitivity to climatic factors, particularly temperature would be anticipated.

4.6 Bay anchovy (*Anchoa mitchilli*)

The bay anchovy is a small fish of inshore waters, found along the whole of the United States coast. It is tolerant of a range of salinities, and will remain in estuaries the whole year. Bay anchovy are a shoaling fish that feed on plankton. They are short lived, rarely living for more than 2 years. They spawn in the lower part of the Hudson, with each female spawning many times in a single year.

Bay anchovy populations can occasionally reach high abundances, as was observed in 1988, 1989 and 1995 (Figure 24), but this cannot hide a long-term declining trend in abundance. The present population abundance is lower than those observed pre-2000. Schultz *et al* (2006) noted that the abundance of adults in the Hudson has declined 10-fold from the peak levels observed in the late 1980s.

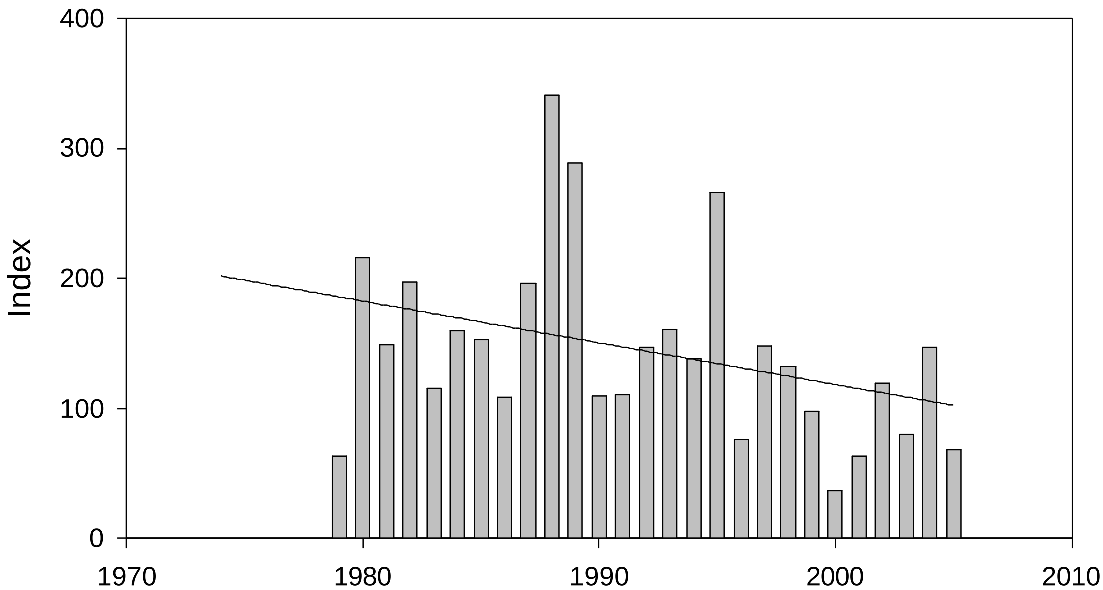

Figure 24: The juvenile index for bay anchovy in the Hudson, showing a decreasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 5

Schultz *et al* (2006) noted a negative correlation of anchovy abundance with that of PYSL striped bass, and a positive correlation with PYSL and juvenile tomcod abundance. They suggest that the positive correlation between tomcod and bay anchovy is probably due to both having negative correlations with striped bass. Thus, the observed decline may be linked to the increase in abundance of the predatory striped bass.

4.7 American shad (*Alosa sapidissima*)

American shad are the largest of the North American species of anadromous herrings. They may live to 13 years and usually become sexually mature after 2-6 years at sea. They have a well-developed homing ability. They are found from Newfoundland to Florida. They return to sea after spawning. Most spawning occurs in May in the upper estuary in the Hudson.

The American shad shows a significant decreasing trend in juvenile abundance (Figure 25). Three of the five lowest indices have been in the last 5 years. The notable exception is 2001, with one of the highest recruitments since regular sampling began.

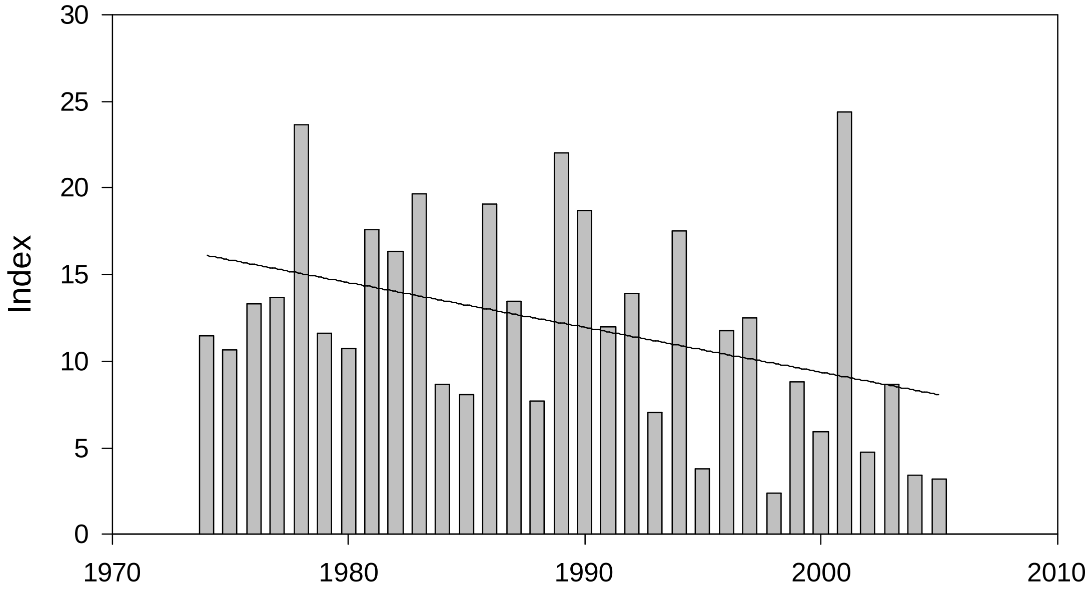

Figure 25: The juvenile index for American shad in the Hudson showing a decreasing trend though time.
The trend is significant (a = -0.2593, b = 527.872, F = 5.8069, p = 0.0223).
Data from 2005 Year Class report – Appendix D, Table D – 6.

American shad has been declining in the Hudson for many years because of overfishing, pollution and other anthropomorphic effects (Figure 26). Even in the 1970s and 1980s, the population was a small fraction of historical abundance (see Figure 26 for the trend in commercial landings). In an attempt to allow the shad population to recover, the ocean intercept fishery was closed in 2005, and further restriction on river fishing introduced (Atlantic States Marine Fisheries Commission 2007).

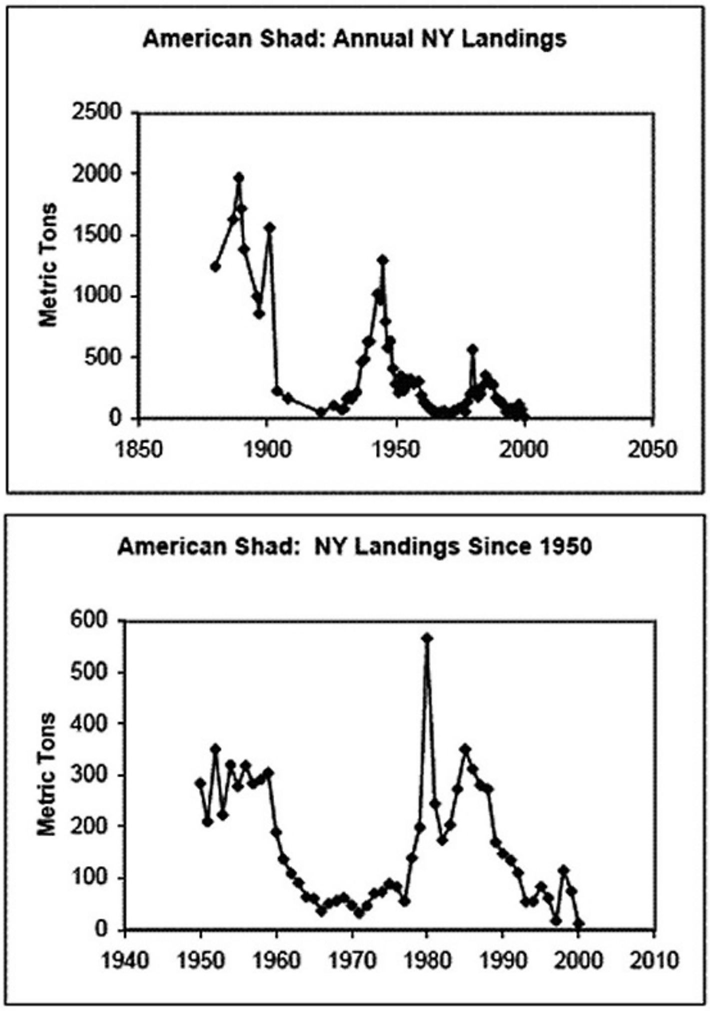

Figure 26: Catches of American shad in New York State. Most of the catches are from the Hudson.
Top panel: trends since 1880. Bottom panel: trends since 1950. Note differences in scale. Sources: National Marine Fisheries Statistics, Walburg and Nichols (1967). Taken from Limburg *et al* 2006.

The Atlantic States Marine Fisheries Commission (2007) also indicates that the American shad is not doing well. The juvenile abundance index showed an increase in the early 1980s, but it has since declined, and reached its lowest-ever value in 2001. It presently remains at this low level (Figure 27).

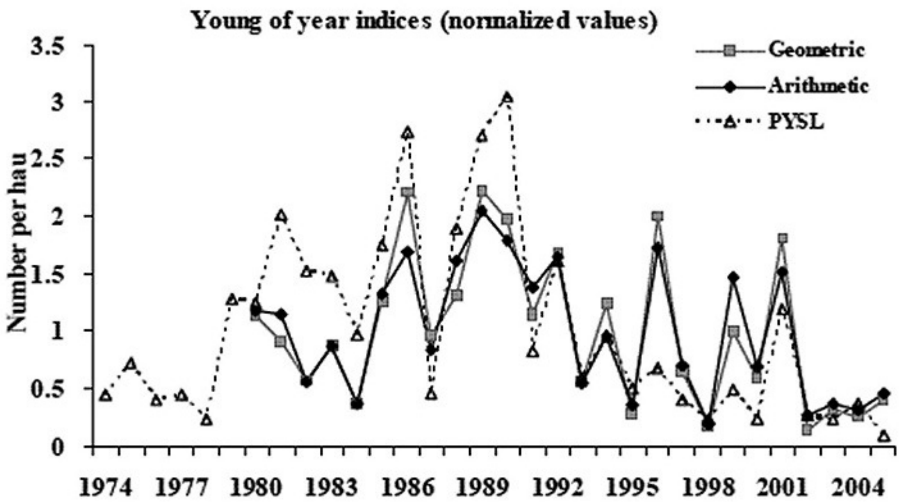

Figure 27: The juvenile abundance indices - American shad (Beach Seine and post-yolk sac larval).
Source: Atlantic States Marine Fisheries Commission, 2007.

4.8 Alewife (*Alosa pseudoharengus*)

Alewife is similar to but smaller than the American shad, and is indistinguishable from blueback herring when young. Alewife spawn most actively when the water is 51 - 71°F. They prefer slow-moving waters, spawning in the upper estuary and spreading to the middle portion of the Hudson as they grow. It is an anadromous species found from Newfoundland to South Carolina, which starts spawning at 3-4 years old and can live for around 9 years. It feeds on plankton, but will take small fish and fish eggs.

The Alewife juvenile index shows a declining trend in the Hudson (Figure 28). However, this trend is far from clear, and possibly the more important feature has been the increase in between-year variability in juvenile abundance. Alewife had very low abundance indices in 1998 and 2002, and high indices in 1999 and 2001. This suggests a population that is becoming destabilised and more dependent on occasionally good recruitment years.

Daniels *et al* 2005, state that

> *There is a negative correlation between the number of alewife larvae exiting Hudson River tributaries and the degree of watershed urbanization (Limburg and Schmidt 1990). Overfishing of stocks has led to the decline of once abundant commercially important species (e.g., Bain et al. 2000; Limburg et al. in press)*

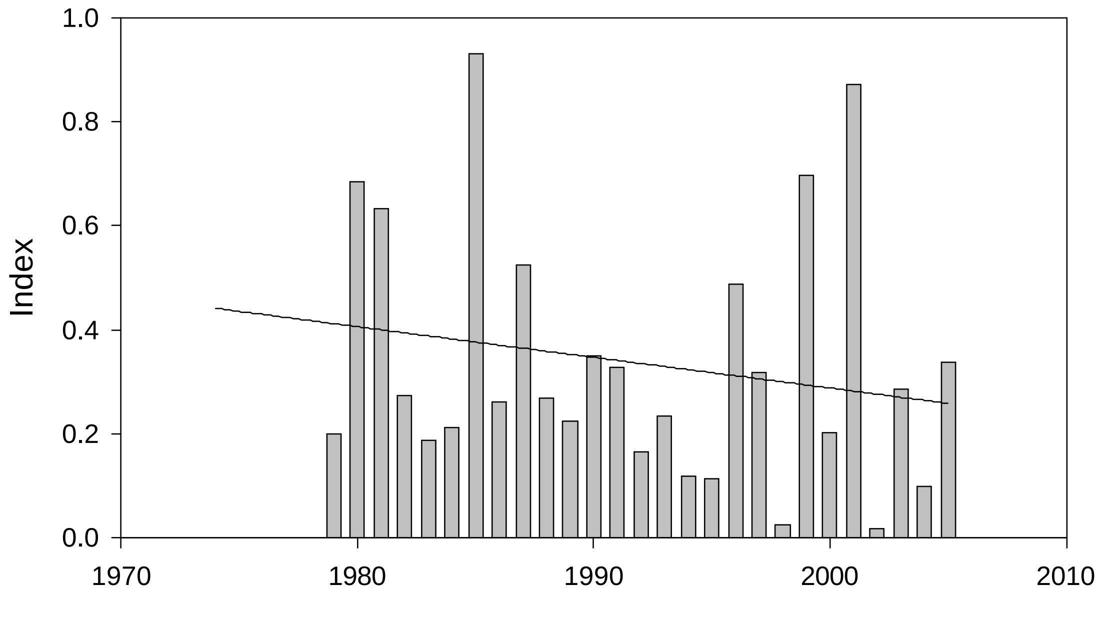

Figure 28: The juvenile index for alewife in the Hudson, showing a decreasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 7

4.9 Blueback herring (*Alosa aestivalis*)

Blueback herring is also similar to but smaller than the American shad, and is indistinguishable from alewife when young. Blueback herring spawn in May, preferring fast flowing waters in the tributaries. They spawn in the upper estuary and spread to the middle portion of the Hudson as they grow. Blueback can be found from Nova Scotia to Florida.

The Blueback herring juvenile index has decreased over the study period (Figure 29), with a particularly marked decline post-1999. Strayer *et al* (2004) suggest that the zebra mussel (*Dreissena polymorpha*) has changed the food web within the Hudson, and that this may have reduced herring food resources. Blueback herring used to feed extensively on planktonic crustaceans, however the changes in primary production caused by the zebra mussels appear to have caused them to switch their diet to littoral and benthic macroinvertebrates (Daniels, 2005). Note that at the threshold to the collapse in population abundance, blueback herring had their largest juvenile abundance.

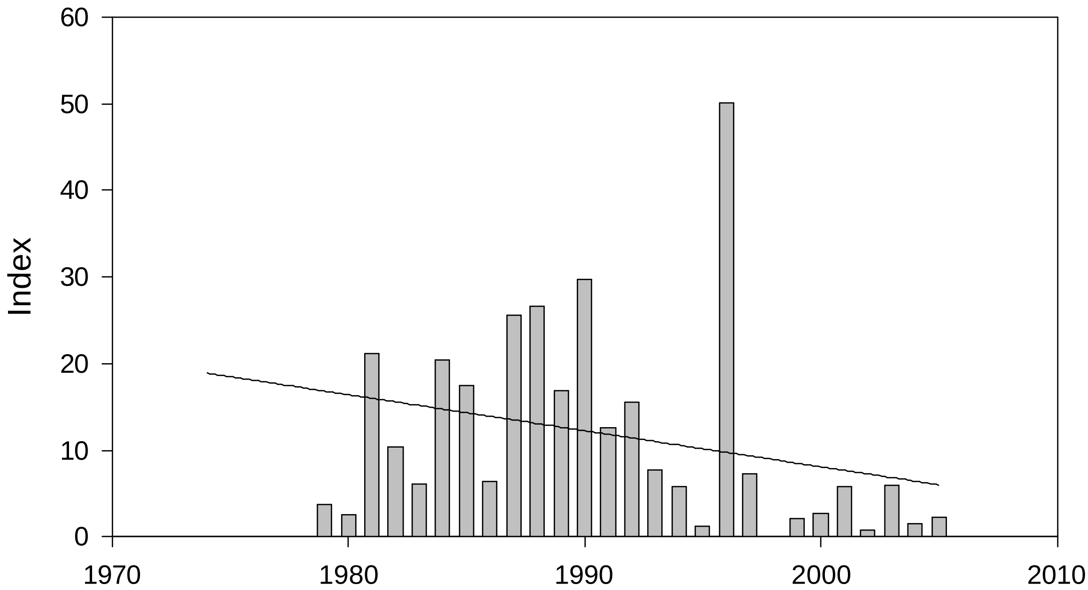

Figure 29: The juvenile index for blueback herring in the Hudson, showing a decreasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 8

4.10 Rainbow smelt (*Osmerus mordax*)

The rainbow smelt is a salmon-like fish which is found from the northern part of the western Atlantic and in many naturally land-locked populations. They can spend most of the year within estuaries. The rainbow smelt spawns in the lower reaches of tributaries at night. They mature at 1 to 5 years old. Historically, juvenile fish were found in mid-June to August in the middle and lower estuary.

Juvenile rainbow smelt have disappeared from the survey since the mid 1990s (Figure 30). This may to be due to a change in their distribution, possibly due to the invasion of zebra mussels, which occurred from 1992 onward (Strayer, 2004). However, as shown in Table 1, rainbow smelt has one of the lowest upper temperature tolerances of Hudson fish. It is therefore possible that the species has declined because of rising water temperatures.

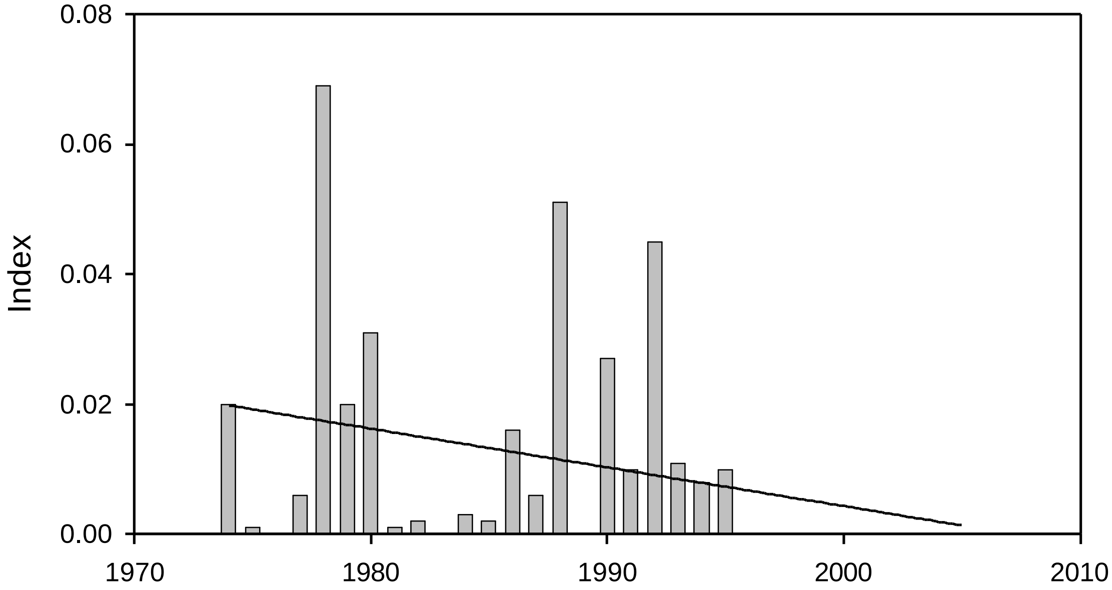

Figure 30: The juvenile index for rainbow smelt in the Hudson, showing a decreasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 9

4.11 Hogchoker (*Trinectes maculatus*)

The hogchoker is a small flatfish, maturing at around 4.5 in. and growing to about 8 in., which tolerates a wide range of salinities and is found from Massachusetts Bay to Panama. They overwinter in low salinity areas of estuaries, and spawn in the lower reaches of the estuary in spring and summer. The young move upstream after hatching.

The hogchoker has shown little trend in abundance since the 1970s (Figure 31) and there were some large recruitments in the 1980s and 90s. However, recent abundance has been low and it is now 11 years since the last large recruitment.

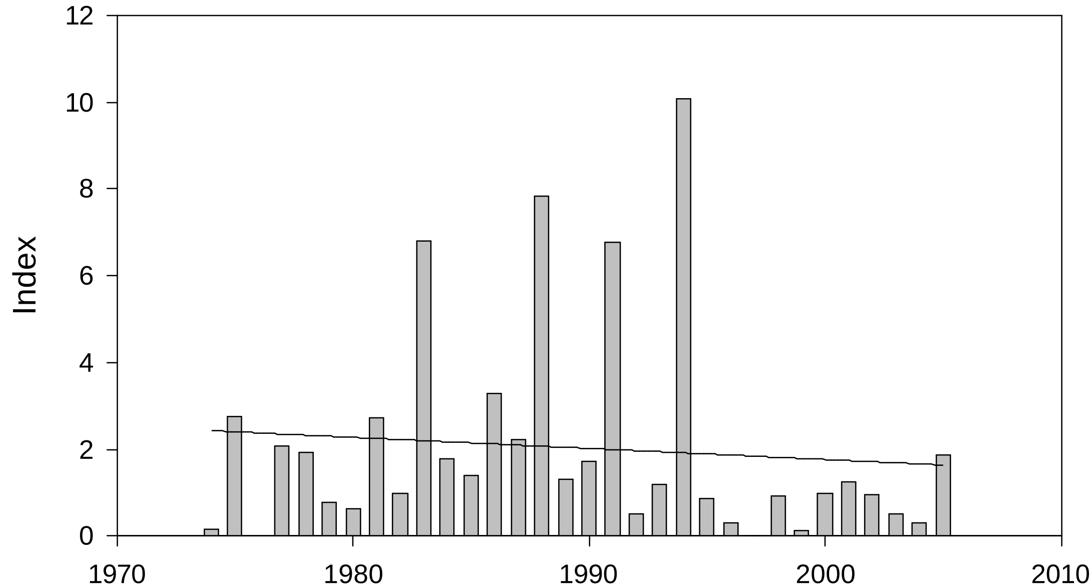

Figure 31: The juvenile index for hogchoker in the Hudson, showing a slight decreasing trend though time.
Data from 2005 Year Class report – Appendix D, Table D – 10

4.12 White catfish (*Ameiurus catus*)

White catfish are naturally found in freshwater, and are found in all the estuaries along the Atlantic coast from the Hudson to Florida. They are slow growing, maturing at 3-4 years old. They move into freshwater to breed, building nests on sand or gravel. They breed in late June and July when the water temperature reaches 70°F. Young fish eat insects, while larger fish are piscivorous.

White catfish have been in steep decline in abundance from 1990 onwards (Figure 32). The reasons for this loss are unknown.

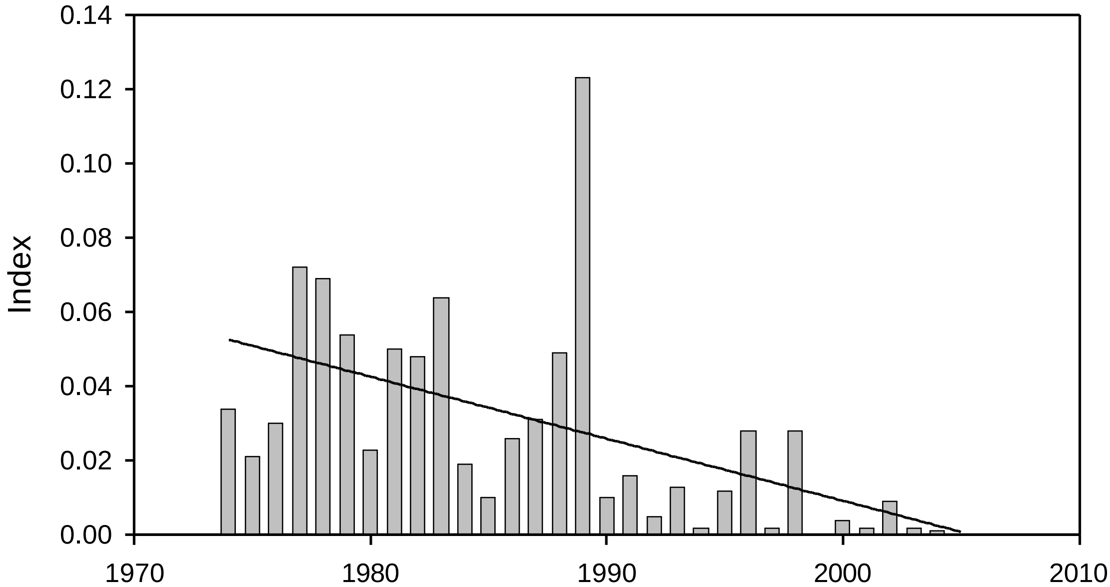

Figure 32: The juvenile index for white catfish in the Hudson, showing a decreasing trend though time.
The trend is significant (a = -0.0017, b = 3.3476, F = 14.0414, p = 0.0008).
Data from 2005 Year Class report – Appendix D, Table D – 12

4.13 Weakfish (*Cynoscion regalis*)

Weakfish are found from New York to North Carolina, offshore in the winter, moving inshore during the spring. Spawning occurs inshore, with larvae rarely being found north of the George Washington Bridge. From June to October the juveniles use the Hudson, with the greatest numbers being found in July

Weakfish have been in steep decline in abundance from 1990 onwards (Figure 33). The reasons for this loss are unknown.

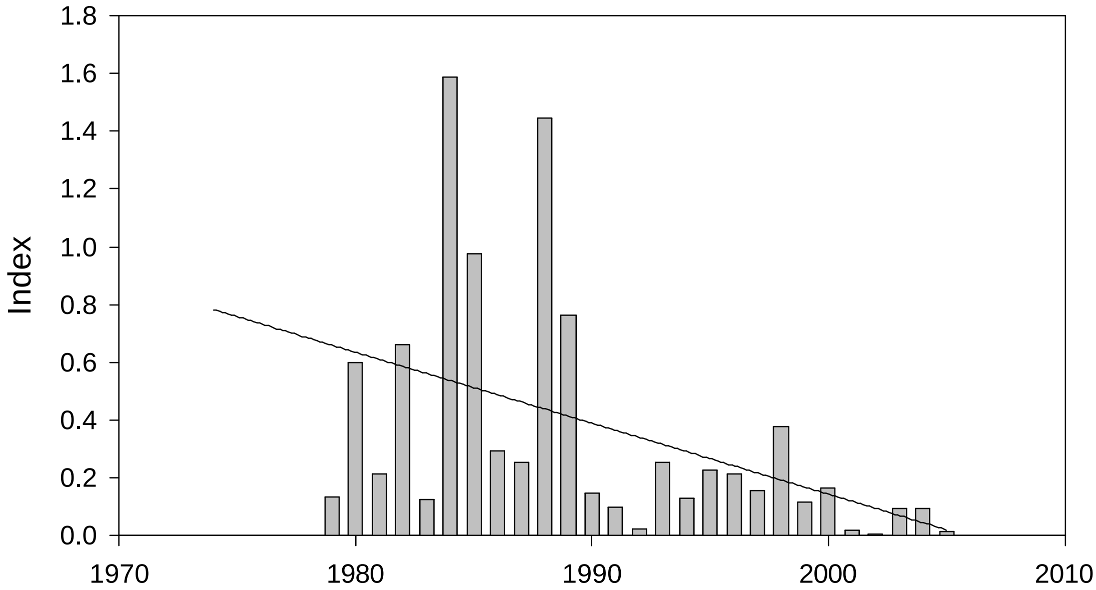

Figure 33: The juvenile index for weakfish in the Hudson, showing a decreasing trend though time.
The trend is significant (a = -0.0246, b = 49.2626, F = 7.0811, p = 0.0134).
Data from 2005 Year Class report – Appendix D, Table D – 13

5 Comment on the 2005 Year Class report.

Section 4 of the 2005 Year Class report (ASA, 2006), section 4.1.2, examines the overall heath of the estuary. At the end of the section the report states:

> *In all, it appears that the Hudson River estuary has a healthy and robust fish population.*

This assertion conflicts with paragraph 5, which mentions that several freshwater fish species have disappeared, and others been found:

> *When the individual species in the freshwater assemblage are examined, there are several species that occurred consistently in the early years and not in the later years, such as cutlips minnow, common shiner, blacknose dace, redfin pickerel, longnose dace, and trout perch. Conversely, there are several species that were not present in the early years but have been recorded recently, such as brook silverside, channel catfish, and freshwater drum.*

The Year Class report also note increases in the number of marine species found, attributing it to water quality and sampling changes, and several changes in the estuarine species. For anadromous fish, the report again noted declines – this time attributing the decline to effects outside of the Hudson River:

> *Declines in the abundance of this anadromous species appear to have occurred to all stocks throughout their geographic range and appear a result of factors outside of the Hudson River, including overfishing in open ocean waters.*

The report describes many changes in the fish population of the estuary, with several species disappearing, new species being found, major declines and increases in the fish species monitored, and yet still summarises the results as:

> *There is no evidence of any substantial long-term changes in composition or abundance of the fish community over the 32-year period, 1974-2005*

It seems difficult to reach such a conclusion, using the analysis presented in the 2005 Year Class report. The report notes several significant changes, yet always finds some other potential cause.

The impact of Indian Point is the largest of several impacts from once-through cooling on the Hudson. When all the power plants are considered, the impact is large. Indeed the NYSDEC Water Quality 2006 report (2007) states

> *Tens- to hundreds-of-millions of eggs, larvae, and juvenile fishes of several species are killed per year for once-through users. The cumulative impact of multiple facilities substantially reduces the young-of-year (YOY) population for the entire river.*

The NYSDEC go on to state that in some years these effects have been very large, and provide examples, shown in Table 6. All the species show between 33 – 79% reductions in Young of Year population.

Table 6: Percentage reduction in selected years in the number of September 1st Young of Year fish attributable to the operation of the power plants in the Hudson
Source: NYSDEC 2007.

Species	Year	% reduction - no through-plant survival	% reduction - power plants estimated through-plant survival
Spottail shiner	1977	79	25
Striped bass	1986	63	27
American shad	1992	60	52
Atlantic tomcod	1985	53	44
Alewife and blueback herring combined	1992	45	39
White perch	1983	44	30
Bay anchovy	1990	33	33

6 Summary

The fish community of the Hudson estuary has been well-studied from the mid 1980s. It has been continuously changing since systematic recording began in the 1980s. There have been many environmental changes during the sampling, with significant improvements in water quality in some parts of the estuary.

There are clear indications, both at the community and individual population levels, that the populations of fish in the estuary are becoming less stable and showing greater year to year variation in abundance.

Of the 13 key species subject to intensive study, three species, striped bass, bluefish and spottail shiner, have shown a trend of increasing abundance since the 1980s. The other 10 species have declined in abundance, some greatly. There were significant negative trends in yearling white perch, and juvenile American shad, white catfish and weakfish. Many other important species of fish are also showing long-term declines in abundance. For example, the American eel has greatly declined.

There has been a recent increase in average water temperature and a decrease in dissolved oxygen levels. This may be influencing some of the changes observed and will increase the impact of thermal discharges. It is important to factor in potentially increasing water temperatures in any discussion of Hudson River fish. Small rises in the background temperature could have a significant effect on the impacts of thermal discharges into the river.

Power companies state that there are not any negative trends in the Hudson River fish populations attributable to the plant operation, this despite the NYSDEC (2007) finding that the power plants can reduce several of the common fish species' recruitment by between 33 and 79% in a year. Even if the power companies are not the sole cause of degradation of the Hudson River fish community, the loss of such high proportions of the fish populations must be important.

All the evidence points to the Hudson ecosystem presently being in a state of change, with declining stability. Neither the ecosystem as a whole nor many of the individual species populations are in a healthy state.

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