D. BIOLOGICAL RESOURCES OF THE ESTUARY

Studies conducted in the 1970s included sampling and evaluation of all trophic levels in the Hudson River estuary. These data provided a framework for describing the interactions of communities and energy pathways in the ecosystem. Key species, populations, and communities were identified. During the 1980s, studies focused more closely on the fish species, particularly those adults and larvae that use the estuary as spawning and nursery habitat.

The following overview of the Hudson River aquatic ecosystem is based on studies conducted in the 1970s and expanded by continued basic research during the 1980s and 1990s. The discussions of selected fish species (Section V-D-2) are based on data collected during the Hudson River Utilities Monitoring Programs conducted between 1974 and 1997. Section V-D-3 reviews the changes that have occurred in the fish communities between 1974 and 1997.

1. Hudson River Estuary Aquatic Ecosystem

An ecosystem consists of all the populations utilizing a given area and the non-living environment affecting the area (Odum 1971). The area of interest defined by this impact assessment is the Hudson River estuary. The populations of primary interest are the 16 fish species and one crab species specifically discussed in the impact assessment. The species populations in rivers are strongly affected by the inflow of water and materials from the watershed. Therefore, the whole drainage basin, not just the river, must be considered as the smallest ecosystem unit when it comes to analyzing the changes in individual populations.

The time scale of this impact assessment is 24 years. This period is long enough for the effects of interactions among species (competition and predation) and perturbations generated by other factors in the ecosystem to spread throughout the foodwebs in this ecosystem. Thus, population changes have to be discussed in context of the foodwebs to which they belong and any perturbations that may have changed the nature and intensity of the interactions within these foodwebs (Pimm 1991).

a. Perturbations to the Hudson River ecosystem

Several events occurred during the period from 1974 through 1997 that could have generated significant perturbations within the Hudson River ecosystem. Some of these events may have affected the amount of habitat available for juvenile fish within the freshwater portion of the estuary and the movement of marine organisms into the brackish water portion of the estuary. These are discussed under the general heading of habitat availability. Other events may have altered and intensified competitive relationships within the foodwebs in the brackish and freshwater portions of the estuary. They are discussed under the general heading of competition. Finally, a series of changes in the commercial and recreational fishing regulations for striped bass may have increased the importance of predation in this ecosystem. These events are discussed under the general heading of predation.

i. Habitat Availability

There were two events that occurred during the period from 1974 through 1997 that probably affected habitat availability. The first occurred when the chemical control program for water chestnut *Trapa natans* was discontinued after the summer of 1976. By the mid-1980s, water chestnut populations had again reached nuisance levels (Kiviat 1993) and the amount of shallow water habitat available to larval and juvenile fish in the freshwater portion of the Hudson River estuary may have been restricted. Dense stands of water chestnut adversely affect water circulation and dissolved oxygen levels fall to very low levels at night (Findlay et al. 1987; Schmidt and Kiviat 1988; Anderson and Schmidt 1989; NAI 1991a, 1991b). Fish densities in the middle of water chestnut beds are low compared to those in beds of submerged vegetation and the number of fish species collected within a water chestnut bed is lower than that collected at the edge of a bed (Pelczarski and Schmidt 1991).

The second event occurred in the portion of the estuary adjacent to Manhattan Island and probably affected the number of marine organisms entering the estuary during the summer months. The construction and upgrading of water treatment plants by New York City decreased the amount of raw sewage discharged into the Hudson River. This increased dissolved oxygen levels during the summer through the 1980s and especially in the early 1990s, when the North River plant was upgraded to full secondary treatment in the spring of 1991 (Brosnan and O'Shea 1996b).

ii. Competition

There were two events that occurred during the period from 1974 through 1997 that could have affected competitive interactions within the estuarine foodwebs. One event occurred throughout the estuary and directly affected the amount of raw sewage discharged into the river. In general, the foodwebs in the Hudson River estuary depend upon particulate organic matter that comes from terrestrial sources. The total consumer production in the lower foodweb for the Hudson River estuary is about 3 times higher than the primary production (Lints et al. 1992). On an annual basis, terrestrial runoff is the major source of particulate organic carbon in the Hudson River estuary (Findlay et al. 1991b; Howarth et al. 1991). However, during the summer months when freshwater flows and terrestrial runoff are low, raw sewage is the primary source of new organic matter, as opposed to resuspended carbon particles that entered the river during the preceding fall or spring (Limburg et al. 1986). Bacteria and fungi form the base of the foodweb (Findlay et al. 1991a). Invertebrates ingest particulate organic matter and digest the organisms growing upon these particles. Small fish feed upon the invertebrates and large fish feed upon small fish (Gladden et al. 1988). In the Hudson River estuary, the foodweb directly links juvenile fish populations to the discharge of raw sewage. In the Potomac River estuary, improvements in wastewater treatment were associated with a decline in the production of juvenile striped bass (Tsai et al. 1991).

In the freshwater portion of the estuary, the major improvements in wastewater treatment occurred prior to 1985. Between 1974 and 1985, the discharge of suspended solids from water treatment plants into the upper Hudson River basin and the Mohawk River basin decreased by 56%. If the discharges from water treatment plants in the New York City area are ignored, the discharge of suspended solids from water treatment plants into the lower Hudson River basin decreased by 52% during the same period (DEC SPDES files).

In the brackish water portion of the estuary, the change in the discharge of untreated wastewater was even greater. In the New York City area, the construction and upgrading of water treatment plants reduced the discharge of untreated wastewater from 450 million gallons per day (mgd) in 1970 to less than 5 mgd in 1988. Additional abatement programs continued the decline in the discharge of raw sewage from 1989 through 1993 (Brosnan and O'Shea 1996). During the early 1990s, the North River (1991) and two of the three plants located on the western bank of the Hudson River opposite Manhattan Island, North Bergen MUA-Woodcliff (1991) and North Hudson Sewerage Authority West New York (1992), went to full secondary treatment. The third plant located on the western bank of the Hudson River opposite Manhattan Island, the North Hudson Sewerage Authority-Hoboken plant, went to full secondary treatment in 1994.

There were also improvements in wastewater treatment located north of the New York City area in the brackish water portion of the estuary. The Yonkers Joint Treatment (1988) and the Rockland County Sewer District #1 (1989) plants, serving a combined population of 637,000 and emptying into the lower Hudson River, were upgraded during the late 1980s (ISC 1994). In the mid-1990s, the Rockland County Sewer District #1 (1995) and Orangetown Sewer District (1996) plants, serving a combined population of 205,000, were upgraded (ISC 1997).

The second event that could have affected competitive interactions within estuarine foodwebs occurred only in the freshwater portion of the estuary. Zebra mussels *Dreissena polymorpha* invaded the Hudson River estuary in May 1991 and spread throughout the freshwater portion of the estuary by the end of 1992 (Strayer et al. 1996). The responses observed in other ecosystems following the introduction of zebra mussels have been a decline in the biomass of phytoplankton and small zooplankton, a rise in water clarity, the spread of macrophyte beds, and increases in populations of benthic invertebrates. The increase in the production of benthic invertebrates can result in an increase in the production of fish (Strayer et al. 1999).

iii. Predation

There was one event that dramatically increased the abundance of the top predator, large striped bass, in the Hudson River ecosystem. During the 1980s, the harvest of striped bass from the Hudson River population was sharply reduced. In November 1983, the recreational and commercial size limits were increased from 18" to 24" total length (TL). In 1986 there was a moratorium on both recreational and commercial fishing. The moratorium was continued on commercial fishing through September 1990. A minimum size limit of 33" TL was imposed on recreational fishing in 1987 and 1988. It was increased to 36" TL in 1989 and 38" TL from May 1990 to September 1990. A relative abundance index for adult and sub adult striped bass was generated from the by-catch of striped bass that occurred during the spring fishery for American Shad *Alosa sapidissima* from 1980 through 1997. During the period from 1980 through 1983, the average value for the by-catch index was 1.25. In 1984, it was 4.78. From 1985 through 1987, it was 8.36; from 1988 through 1991, it was 13.60; and from 1992 through 1994, it was 30.42. Thus, the abundance of the top predator in this ecosystem increased 24-fold between the early 1980s and the early 1990s. A change of this magnitude at the top of the foodweb should affect other fish populations within the Hudson River ecosystem (Pimm 1991).

b. Major Habitats within the Hudson River estuary

There are two major habitats within the Hudson River estuary: the brackish water portion extending from RM 1 throuigh RM 55 (Regions 0-5) and the freshwater portion extending from RM 56 through RM 152 (Regions 6-12). The foodwebs in each of the major habitats are products of differences in physical-chemical conditions (salinity, current velocity, substrate type, and water depth), plant communities within shallow areas, and the dynamic behavior of individual species populations (daily and seasonal differences in reproductive and feeding behavior).

c. Major trophic groups within estuarine foodwebs

In natural ecosystems, organisms can be grouped according to similar feeding (trophic) relationships. Each trophic group (or trophic level in the biological pyramid) consists of several species competing with each other for available resources. The organisms in one trophic level are eaten by those in next higher trophic level. Since energy is lost in each trophic transfer, there are rarely more than 6 trophic levels in a complex foodweb. The number of species within a trophic group is generally determined by finer differences in physical-chemical conditions (salinity, current flow, substrate type, water depth) within the major habitat and temporal variables (season and time of day). The major trophic groups in the Hudson River ecosystem are discussed in the following paragraphs.

i. Phytoplankton

Organic matter usually forms the base of a foodweb. Living plants are the most common source of organic matter in natural ecosystems. Within aquatic ecosystems, phyto-plankton, microscopic plants which are transported about by water currents, often form the base of the foodweb. However in turbid rivers, like the Hudson, light limits phytoplankton growth in all but the upper few feet of the water column and organic matter from terrestrial sources (washed into the river or deliberately discharged into the river) forms the base of the foodweb.

Phytoplankton in the Hudson River estuary fall into one of three broad groups; each with differing spatial and temporal patterns (Storm and Hefner 1976, Marshall 1988). Diatoms, which are numerically dominant throughout much of the year, are must abundant during spring and fall when water temperatures are low and turbulent river flows are high. Green algae are most abundant during summer when water temperatures are higher and freshwater flows are low. Blue-green algae are principally limited to late summer and early fall. Each of these groups are common components of the phytoplankton communities in estuaries along the east coast of the North America.

ii. Rooted aquatic plants

Macrophytes, rooted aquatic plants, provide another source of organic matter within aquatic ecosystems. In turbid rivers, rooted aquatic plants are limited to shallow water (less than 10 feet deep). Generally, ecologists divide rooted aquatic plants into three broad groups. Emergent macrophytes produce leaves that rise above the water surface and occur from the shoreline out to a depth of about 5 feet. Floating leaved macrophytes are attached to bottom and have floating leaves attached to long flexible stems. They occur at depths from 1.5 to 10 feet. Submersed macrophytes do not have aerial or floating leaves and can occur out to a depth of about 32 feet in very clear water. Owing to the high turbidity levels in the Hudson, rooted aquatic plants are found primarily in marginal nearshore areas and extending offshore less than 100 yards. The variety of rooted vegetation tends to be greater in the less saline reaches of the river (Table V-14). These plants are consumed directly by some animals, but probably make their greatest contribution of the aquatic food web when they die and decompose. They also provide habitat for a variety of aquatic invertebrates and fish.

Today, the exotic water chestnut (*Trapa natans*) is the dominant form of rooted vegetation in shallow areas of the estuary upstream of Constitution Island (Schmidt and Kiviat 1988). Water chestnut was introduced into the upper Hudson River drainage in 1884 (Hook 1985) and had developed to pest proportions in the upper Hudson by the 1930s. In 1936, the Hudson River Biological Survey, conducted by the State of New York Conservation Department, recorded only two plants downstream of the Green Island Dam at Troy. By the mid-1940s, water chestnut was reported to be widespread throughout the estuary. An eradication program was initiated by the DEC using the herbicide 2,4-D. This program continued up through 1976 when it was discontinued because of concerns over potential ecological impact of the herbicide treatments. Since that time, water chestnut beds have expanded and now form dense stands throughout the fresh and low salinity brackish areas of the estuary wherever depth, current, and bottom conditions permit.

iii. Zooplankton

Zooplankton are small, typically microscopic, animals which live up in the water column and are transported about by water currents. Zooplankton is typically divided into two components, holoplankton which spend their entire life cycle as part of the plankton community, and meroplankton which spend only a portion of their life cycle as plankton.

TABLE V-14

THE DISTRIBUTION OF SUBMERGENT AQUATIC PLANTS IN THE HUDSON RIVER

PLANT TAXON	KINGSTON[a]	NEWBURGH[b]	HAVERSTRAW BAY[c]	NYACK AREA[d]
Potamogeton perforliatus	X	X	X	X
P. pectinatus	X	X	X	
P. crispus	X	X	X	
P. epihydrus	X	X		
P. filiformis		X		
P. foliosus		X		
P. nodosus		X		
P. richardsonii		X		
P. vaginatus		X		
Vallisneria americana	X	X	X	X
Myriophyllum spicatum	X	X	X	
Trapa natans	X	X		
Najas sp.	X	X		
Zannichellia palustris				X
Heteranthera dubia	X	X		
Ceratophyllum demersum		X		
Chara vulgaris		X		
Elodea sp.		X		

X - plant species observed.

[a]QLM 1973.
[b]LMS 1978.
[c]LMS 1975.
[d]Menzie (unpublished).

Meroplankton include larger macroinvertebrates which move up into the water column on a regular basis as well as the eggs and larvae of macroinvertebrates, shellfish, and fish, which temporarily exist as part of the plankton. In this section, we focus on the holoplankton.

Zooplankton in brackish areas of the Hudson River estuary downstream of RM 40 are dominated by marine forms whereas in freshwater areas upstream of RM 68 freshwater forms dominate. In between, there is a gradual transition from marine to freshwater forms. Sampling of zooplankton from Haverstraw Bay to Albany between April and December 1987 – 1989 identified five taxa that numerically dominated; the cyclopoid copepod *Diacyclops bicuspidatus thomasi*, the cladocern *Bosmina longirostris*, and three rotifers; *Keratella*, *Polyarthra*, and *Trichocera* (Pace et al. 1992). Season abundance of these zooplanktors was negatively related to flow indicating that advection, or downstream transport associated with flow, is an important factor in determining abundance. When abundant in the estuary, these dominant zooplanktors serve as important food for many larval fish utilizing the estuary as a nursery area. Downstream of Haverstraw Bay, copepods numerically dominate the zooplankton community.

Recent declines in the abundance of small zooplanktors (rotifers, tintinnids, and copepod nauplii) in freshwater areas of the Hudson have been reported following invasion of the area by the exotic zebra mussel (Strayer et al. 1999). Whether this apparent decline is attributable to direct harvest by the zebra mussels, loss of phytoplankton food resources, or some other factor has not been determined. Declines in larger zooplanktors (copepods and cladocerns) were also observed. However these declines appear to have started well before the initial invasion of zebra mussels. Consequently, this decline is likely attributable to other factors including increases in the densities of larval predatory fish, such as striped bass, in the area.

iv. Macroinvertebrates and shellfish

This broad group includes organisms that live attached to, in, or near the bottom of the water column. Examples of this group include mussels and oysters which attach to the bottom, various worms and other burrowing organisms which live within the bottom sediments, and amphipods, aquatic insects and shrimp, which live in the water near the bottom. In estuarine ecosystems, this group of organisms often is an important trophic component of the food web connecting non-living organic matter to higher trophic levels like fish. The abundance of these organisms in the Hudson River estuary is greater than reported for many inland freshwater lakes and rivers and is consistent with the high turbidity and high inputs of organic matter into this ecosystem (Howarth et al. 1991).

For most of the past century or so, attached benthic organisms have not played a major role in the Hudson River ecosystem. Historically, oyster beds were prevalent in brackish areas of the Hudson including Haverstraw Bay and the Tappan Zee. However, a combination of overharvesting, habitat alteration, and pollution, led to their demise more than a century ago. In 1991, a small exotic bivalve, the zebra mussel, was first identified in the freshwater areas of the Hudson (Strayer et al. 1996). This mussel, originally from central Europe, was accidentally introduced into the Great Lakes in the 1980s and subsequently spread throughout many waterways of the upper mid-west and northeast, including the Hudson. Population growth of this organism is explosive as evidenced by the fact that the biomass of zebra mussels in freshwater areas of the Hudson exceeded that of all other heterotrophs within 17 months of first being detected (Stayer et al. 1999). As previously discussed, this invasion has had demonstrable effects on the phytoplankton and, possibly, zooplankton communities in freshwater areas of the Hudson.

Benthic macroinvertebrates live within the bottom sediments and primarily feed on detritus (organic materials together with associated bacteria, fungus, and other meiofauna). These organisms serve as important food resources for larger macroinvertebrates and fish.

The distribution of benthic macroinvertebrates on a large scale is determined by salinity with polychaete worms being most abundant in brackish water areas and oligochaete worms being dominant in freshwater areas. Studies in the freshwater portion of the estuary revealed that densities of benthic macroinvertebrates in main channel areas were near the high end of the normal range found in some other large rivers (Simpson et al. 1985). Collections were dominated by the common tubificid worm, *Limnodrilus hoffmeisteri*. This pollution tolerant species favors fine, organically enriched substrates which are common in estuaries. Recent studies in the freshwater portion of the Hudson indicate that the abundance of macroinvertebrates in deeper, areas of the Hudson declined while that in shallow water increased followingthe invasion of the area by zebra mussels (Strayer et al. 1999). It has been suggested that the decline is due to a reduction in the flux of edible suspended particles to deep-water sediments as a result of the filtering capacity of the zebra mussel populations in shallow water and that the increase is due to the deposition of pseudofeces by zebra mussels in shallow water (Strayer et al. 1998).

The third group of macroinvertebrates important to the Hudson River estuary ecosystem are the epibenthos, which live near the surface of the bottom. Many of the epibenthos also migrate up into the water column at night to feed. There they function as part of the zooplankton community. Epibenthic macroinvertebrates can be both detritivores, feeding on the abundance detritus in the estuary, or predators, feeding on other invertebrates as well as fish eggs and larvae. These macroinvertebrates, in turn, are important food resources for the many juvenile and older fish species as well as some other vertebrate wildlife that utilize the Hudson.

In the Hudson, epibenthic macroinvertebrate collections in brackish water areas are typically dominated by mysid shrimp, especially the opossum shrimp (*Neomysis americana*). In freshwater areas, collections of epibenthic macroinvertebrates are dominated by amphipods, especially of the genus *Gammarus*, and, to a lesser extent, the larvae of aquatic insects. These epibenthic species form the bulk of the diet for juvenile fish in the Hudson.

v. Fish

Fish are at the top of the foodweb within the ecosystem of the Hudson River estuary. As this system is a transitional area between the freshwaters of the upper Hudson and Mohawk Rivers and connecting tributaries and the saltwater of the Atlantic Ocean and Long Island Sound, the estuary contains fish representing both fresh and marine ecosystems. In addition, the Hudson lies at the intersection between the warmer ocean waters of the mid- and South Atlantic and the cooler ocean waters of New England and the Maritime Provinces. As a result, the Hudson contains fish adapted to both northern and southern climates. Finally, the opening of the Erie Canal in the early 1800's provides a direct connection between the Hudson and the waters of the Great Lakes allowing species from the Great Lakes and Mississipian Drainages access to the estuary. As a result, the fish community in the Estuary is a composite reflecting elements of the communities residing in each of these outlying areas (Smith and Lake 1990).

To date, over 200 fish species have been collected in the greater Hudson and Mohawk River system. A large percentage of these were collected in the estuarine portion of this system. This group includes a relatively small number of species that are significant contributors to the Hudson's fish community and a much larger group of species that are infrequently encountered.

The 16 fish species discussed in this environmental impact assessment exhibit seasonal differences in their demands upon resources in the Hudson River estuary. Atlantic tomcod spawn during the winter and larval tomcod move down into the lower portion of the estuary during early spring. This species should experience little interspecific competition during the larval and juvenile life stages during the spring because they are the most abundant small fish in the brackish water region during the season. If they exhibit signs of food-limitation, intraspecific competition is the most likely cause.

Adult and sub-adult striped bass move into the lower portion of the estuary during late winter and prey upon the species overwintering within the lower portion of the estuary (juvenile Atlantic sturgeon, hogchoker, white perch, and white catfish) or passing through this portion of the estuary during the spring (alewife, blueback herring, and rainbow smelt). Larval and juvenile striped bass move down into the lower portion of the estuary during late June and early July.

Adult and larval bay anchovy and juvenile bluefish and weakfish move into the lower portion of the estuary during the summer. Larval and juvenile rainbow smelt, striped bass, and white perch and juvenile Atlantic sturgeon also move down into the lower portion of the estuary during the summer. Juvenile tomcod do not grow much during the summer (their growth is apparently suppressed by summer water temperatures in the Hudson River estuary) but competition could occur among the juveniles of the other species present in the lower portion of the estuary. Juvenile tomcod complete their growth and maturation during the fall. At this time, there is the potential for competition between juvenile Atlantic tomcod and the juveniles of other fish species feeding upon invertebrate prey in the lower portion of the estuary.

Gizzard shad, shortnose sturgeon, and spottail shiner are permanent residents in the upper portion of the estuary (regions 6-12). The herrings (Alewife, American shad, and blueback herring) are marine immigrants that enter the estuary in the spring and spawn in this section of the estuary. The adult herrings leave the estuary after spawning. Larval and juvenile herrings remain in the upper portion of the estuary. During the fall, juvenile herring move down river to the ocean.

White perch are found throughout the estuary. Sub-adult and adult white perch are more abundant in the lower portion of the estuary but adult perch move upriver to spawn in the shallow areas in the upper portion of the estuary during the spring. Larval and juvenile white perch disperse throughout the estuary. During the fall, juvenile white perch from the upper portion of the estuary move down river and overwinter in the lower portion of the estuary.

vi. Other vertebrate wildlife

This category includes all vertebrates, other than fish, which depend upon the Hudson River estuary fortrophic resources. While this group has not been well studied as a whole, there do not appear to be any members that depend, exclusively, upon the Hudson River estuary for aquatic resources.

Perhaps, the most common member of this category are the birds. The Hudson provides important feeding habitat for a variety of waterfowl, shorebirds, and other water dependent birds. Ducks and geese are abundant throughout the estuary, especially during winter, while swans can be found in protected areas year-round. Common shorebirds include herons and egrets in backwater areas and pipers and sanderlings along open beaches. Perhaps the most well-known of the other water dependent birds is the bald eagle which frequently utilizes openwater areas of the Hudson for feeding during winter and has recently started to use shoreline areas for nesting.

Other common members of this category include the turtles and amphibians (frogs, newts and salamanders) which can be found in shallow, backwater areas of the estuary. These areas are typically used in a manner similar to the many lakes and ponds in the area. Common mammals that utilize the area include muskrats, raccoons, otters, and minks. These species are principally found associated with backwater areas and tidal sections of tributary streams.

2. Life History and Abundance of Selected Species

The scoping document for this draft environmental impact assessed included 16 fish and one crab species. The life histories for these species are discussed in the following sections. Empirical data from the Hudson River, collected during surveys conducted by the Utilities and the New York State Department of Conservation (DEC), are used to describe temporal changes in abundance measures for these 17 species during the 24-year period from 1974 through 1997 specified in the scoping document. Fisheries information from marine waters was also used for this purpose and to provide information on an important mortality factor for heavily fished species.

The Hudson River monitoring studies were directed toward evaluating the abundance of fish in the estuary. Abundance measures can be classified as relative or absolute. A relative measure provides information about the abundance of the population in any year relative to other years. Relative abundance measures can be used to assess trends through time. An absolute measure provides additional information: an estimate of the actual number in the population. An absolute measure can be used in any analysis requiring a relative measure as well as analyses requiring estimates of actual numbers.

The Utility and DEC surveys were used to obtain information on the abundance of larval, young-of-year (YOY), and subadult fish in the Hudson River estuary. (A full description of the methods and materials employed in these surveys can be found in the individual reports (listed in Appendix V-1. A summary of changes to the program appears in Appendix V-3). The Longitudinal River Ichthyoplankton Survey (LRS) sampled the Hudson River estuary from the George Washington Bridge (RM 12) to the Federal Dam at Troy (RM 152) to provide abundance estimates for fish eggs and larvae during the spring and summer. Sampling was conducted according to a stratified random design in which the 140-mile stretch of the estuary was divided into 13 regions (Figure V-29) and each region was further divided into strata according to river depth (Figure V-30), e.g.:

- *Shoal* - that portion of the estuary extending from shore to a depth of 20 ft at mean low tide

- *Bottom* - that portion of the estuary extending from the bottom to 10 ft above the bottom where the river depth is greater than 20 ft at mean low tide

- *Channel* - that portion of the estuary not considered bottom where the river depth is greater than 20 ft at mean low tide

Two gear types were used to sample the shoal, channel, and bottom strata in the LRS: a 1-m^2 Tucker trawl to sample the channel strata; an epibenthic sled-mounted 1-m^2 net similar in design to the Tucker trawl to sample the bottom strata; and both gear types to sample the shoal strata. In situ measurements of water temperature (°C), dissolved oxygen (mg/liter), and specific conductance (microsieman/cm at 25°C) were taken with calibrated meters at fixed river mile and strata stations in conjunction with field sampling. The physical/ chemical measurements were recorded from surface, mid-, and bottom-water depths at channel stations and from the surface and bottom depths at shoal stations.

The Beach Seine Survey (BSS) was conducted in alternate weeks from mid-June through October along the entire length of the estuary to provide estimates of the abundance of YOY fish in the shore-zone habitat, that portion of the estuary extending from the shore to a depth of 10 ft. The BSS used a 30.5-m bag beach seine to collect YOY fish in the shore zone of each river region. A completed tow swept an area of approximately 450 m^2. Measurements of water temperature, dissolved oxygen, and specific conductance were taken with each beach seine sample.

The Fall Shoals Survey (FSS), conducted on alternate weeks from the Beach Seine Survey, provided estimates of the abundance of YOY fish in offshore habitats. A 1-m^2 Tucker trawl was used to sample the channel strata. A 3-m beam trawl was used in the shoal and bottom strata to collect YOY fish in the offshore habitats. The latter gear was first used in this capacity in the 1985 FSS; prior to 1985 an epibenthic sled was used. Measurements of

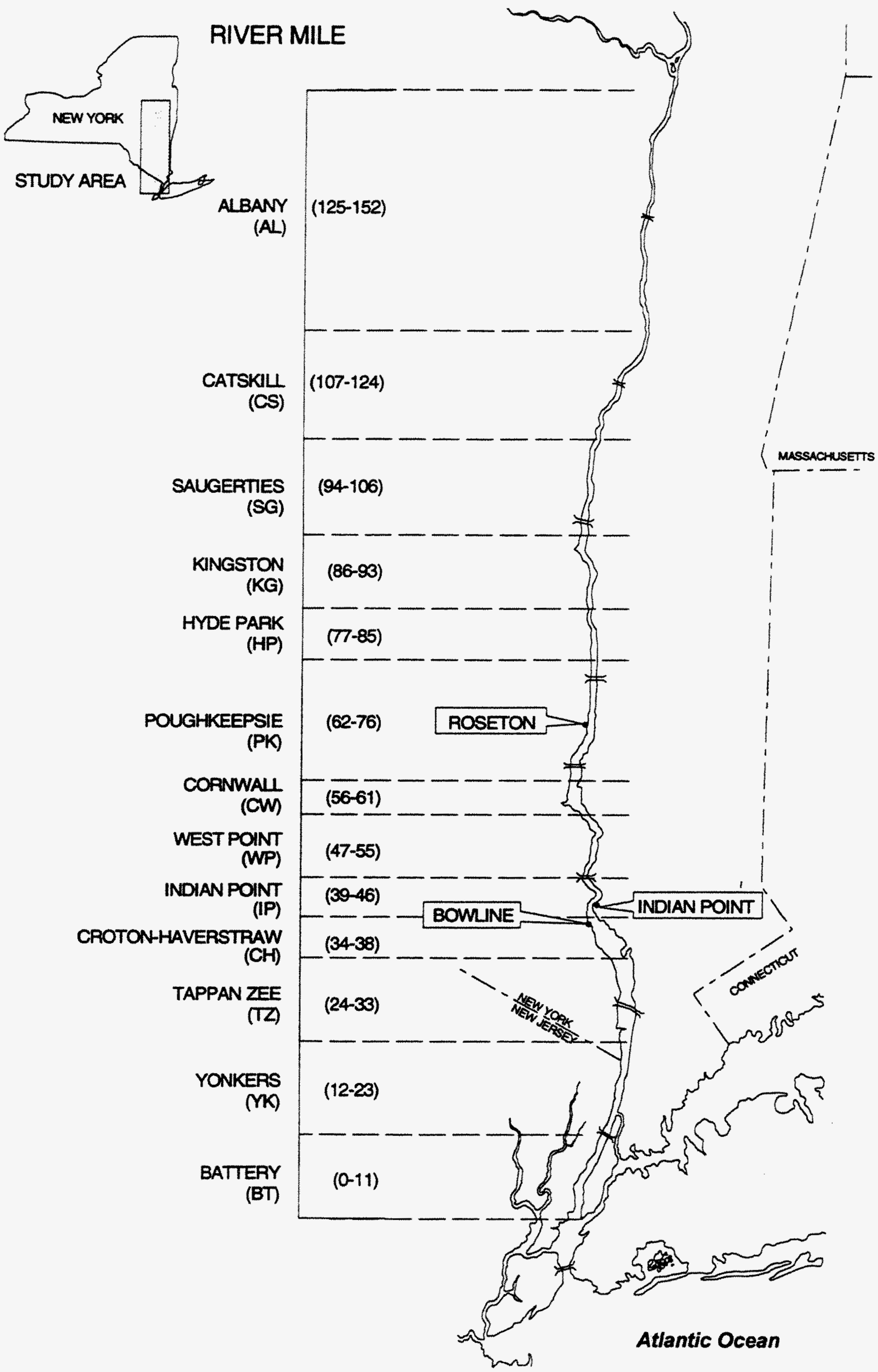
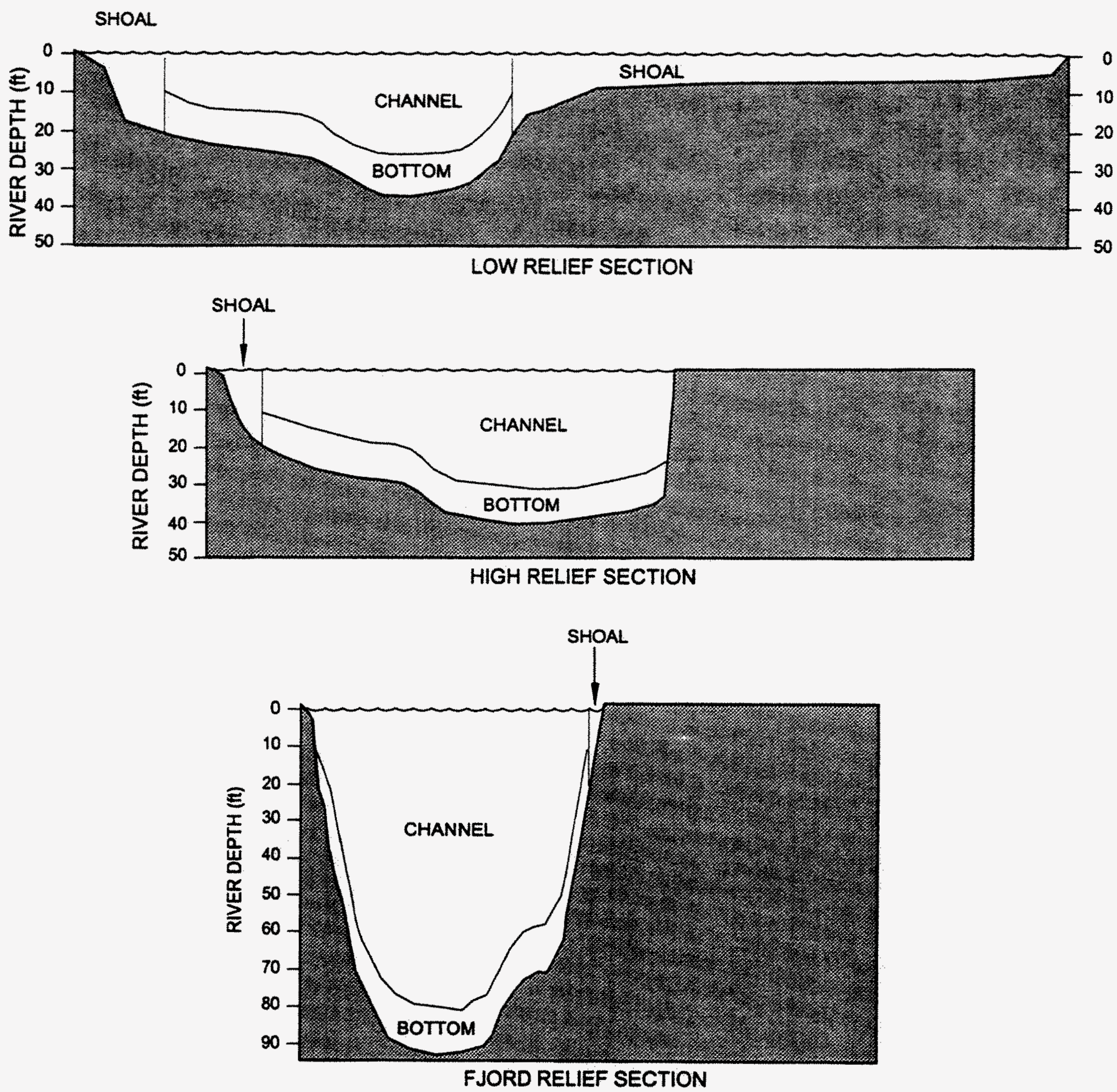


Figure V-29. The lower Hudson River estuary.



	STRATA DEFINITIONS
SHOAL	Water of 20 ft (6 m) or less.
BOTTOM	Water within 10 ft (3 m) of the river bottom in more than 20 ft (6 m) depth.
CHANNEL	Water more than 10 ft (3 m) from the river bottom in more than 20 ft depth.

Figure V-30. Cross sections of the Hudson River showing locations and typical proportional relationships of shoal, bottom, and channel strata.

physical/chemical parameters were recorded from surface, mid-, and bottom water depths at channel stations and from surface and bottom water depths at shoal stations.

Fifteen special winter surveys were conducted from 1974 through 1997 to generate mark-recapture estimates of the number of tomcod in the winter spawning population. These surveys used trap nets and bottom trawls to collect fish for marking and for recaptures. Specific gear types and survey areas are described in the winter survey reports listed in Appendix V-1; methods used to estimate indices of abundance are described in Appendix V-3.

The Striped Bass Mark-Recapture Program (SBMR) began in 1984. The primary objective of this program was to provide estimates of the proportion of hatchery-reared striped bass in the Hudson River striped bass population. A 9-m trawl was used to capture age 1^+ and age 2^+ striped bass in the Battery region of the Hudson River adjacent to Manhattan, and upper New York Harbor in the vicinity of Liberty Island. Sampling began in November continued through March. All striped bass from each tow were measured, and examined for the presence of either external body tags or internal magnetic coded-wire tags. All striped bass over 150 mm in good condition and not already marked were tagged with an anchor tag and released. Fish that died during sampling are returned to the laboratory for determination of length, weight, sex, reproductive state and stomachs contents.

Data from the winter striped bass program were used to estimate the numbers of striped bass >150 mm overwintering in the lower estuary (See Appendix VI.2-B); evaluate biological characteristics such as growth and survival; estimate the proportion of fish that are of hatchery origin; and as input into population models. A detailed description of the program and its results appear in a year-specific report series entitled "Hudson River Striped Bass Hatchery Evaluation/Monitoring Program".

The NYSDEC-Division of Marine Resources (DMR) conducts a Juvenile Striped Bass (JSB) survey (using a 200-ft beach seine) in the lower Hudson River estuary (Tappan Zee - Haverstraw Bay area). The objective of this study is to provide an annual index of relative abundance for young-of-the-year (YOY) striped bass. Twenty-five of 36 sites located between RM 25 and RM 40 are sampled bi-weekly. During the period from 1976 through 1984, the survey began in late August and continued through early November (six bi-weekly runs were conducted). During the period from 1985 through 1997, the survey began in mid-July and continued through early November (nine bi-weekly runs).

The NYSDEC-DMR also conducts a survey for juvenile and subadult striped bass in the bays around western Long Island Sound (WLIS). The survey began in 1985 and has continued through the present. A 200-ft beach seine is used at standard stations in the following bays: Little Neck Bay, Manhasset Bay, Hempstead Harbor, Staten Island, Jamaica Bay, and South Oyster Bay. The bays are sampled twice a month from April through June, and then once a month from July through October or November.

The NYSDEC-Division of Fish and Wildlife (DFW) conducts a Juvenile Alosid Survey (JAS) in the middle and upper regions of the estuary to estimate the relative abundance of YOY American shad and other juvenile fishes. This bi-weekly survey began in 1980 and has continued through the present. A 100 ft beach seine is used in this survey and sampling begins in mid-June and continues through late October or early November in two primary areas: RM 55-77 and RM 121-140. Sampling is conducted during the daytime at approximately 30 standard sites.

NYSDEC-DFW also conducts a haul seine survey in the Hudson River in order to provide information on length, age and sex distribution, and mortality rates for adult American shad and striped bass. The program, which began in 1982 and continues to present, uses large haul seines, either 500 or 1000 ft in length to sample between Kingston (RM 91) and Athens (RM 116).

NYSDEC-DFW staff also monitors the commercial gill net fishery for adult American shad in the Hudson River from April through May. This survey began in 1980 and has continued through the present. The data collected during this survey are used to determine relative abundance, through catch-per-unit-effort, and age structure for the total commercial catch of American shad and for the by-catch of striped bass from this fishery.

a. Striped Bass

i. Life History and Distribution Within the Hudson River

Striped bass (*Morone saxatilis*) are anadromous (i.e., they spend most of their life in the marine environment but return to fresh water to reproduce) members of the temperate bass family (the Percichthyidae). They are native to North America and range along the Atlantic coast from the St. Lawrence River in Canada to the St. Johns River in northern Florida and from western Florida to Louisiana along the coast of the Gulf of Mexico (Figure V-31). They were introduced in the Sacramento-San Joaquin River system in 1879 and are now found from British Columbia to Ensalada, Mexico. Striped bass have also been successfully introduced into the inland waters of at least 24 states. The U.S. east coast rivers and bays that support the principal spawning populations are the Hudson River; Delaware Bay and Delaware River; Chesapeake Bay and tributaries; the Roanoke and Chowan rivers and

Figure V-31. Natural distribution of striped bass in North America.

Albermarle Sound, North Carolina; the Santee River, South Carolina; and the St. Johns River, Florida. Small spawning populations also occur in several river systems in eastern Canada.

On the Atlantic coast adult striped bass, which commonly reach 30 lb and can weigh over 50 lb, feed in nearshore waters from summer through late winter. During the warmer months fish typically travel north and return south as the coastal waters cool in the fall. Northward migration of Hudson River fish extends as far north as the Bay of Fundy, Nova Scotia, and older fish tend to travel farther north. Over the winter adult striped bass tend to aggregate near the mouths of their natal rivers. Once water temperatures rise in the spring, native adults (ages 4 and older) begin moving upriver to spawning areas in the freshwater portions of the estuaries.

Spawning begins in the spring when water temperatures are rising rapidly and reach about 57°F. Peak spawning occurs at about 60 to 65°F in freshwater areas where currents are moderate to swift (Albrecht 1964; Setzler et al. 1980). In the Hudson River spawning occurs primarily between mid-May and mid-June in the middle portion of the Hudson River estuary (Figures V-32 and V-33). Depending on their age and size, females produce up to several million semibuoyant eggs that are suspended by currents. The eggs are relatively large (average 0.125 in. in diameter after water hardening), but vary with the size of the female. Older, larger females tend to have larger eggs.

In 25 to 109 hrs, depending on temperature, yolk-sac larvae (YSL) hatch from the eggs. Typically 0.125 in. long, they initially drift with the current but can swim for short bursts. During the YSL stage the eyes become pigmented, the jaws and digestive tract form, fin buds appear, and they at least partially absorb the yolk-sac and oil globule. Older YSL are mobile and exhibit a positive phototaxis, or movement toward light (Doroshev 1970). The end of the yolk-sac stage is marked by the completion of the digestive tract, although some of the yolk sac and oil globule may still remain. Striped bass YSL are most abundant upriver, where the eggs were most abundant (Figure V-33); this difference in distribution has also been noted in other estuaries. The difference in distribution may mean that YSL migrate upriver using tidal currents, although other explanations have been proposed (Polgar et al. 1976; Fay et al. 1983).

Transformation to the post-yolk-sac larvae (PYSL) stage occurs from four to nine days after hatching, when the larvae are 0.25 in. long. The remainder of the yolk sac and oil globule are absorbed, body pigmentation becomes noticeable, fins begin to form, the gas bladder is inflated, and larvae begin to feed actively on zooplankton. This stage lasts approximately 30 days, ending when the fin rays are fully developed, which occurs when the fish are just over

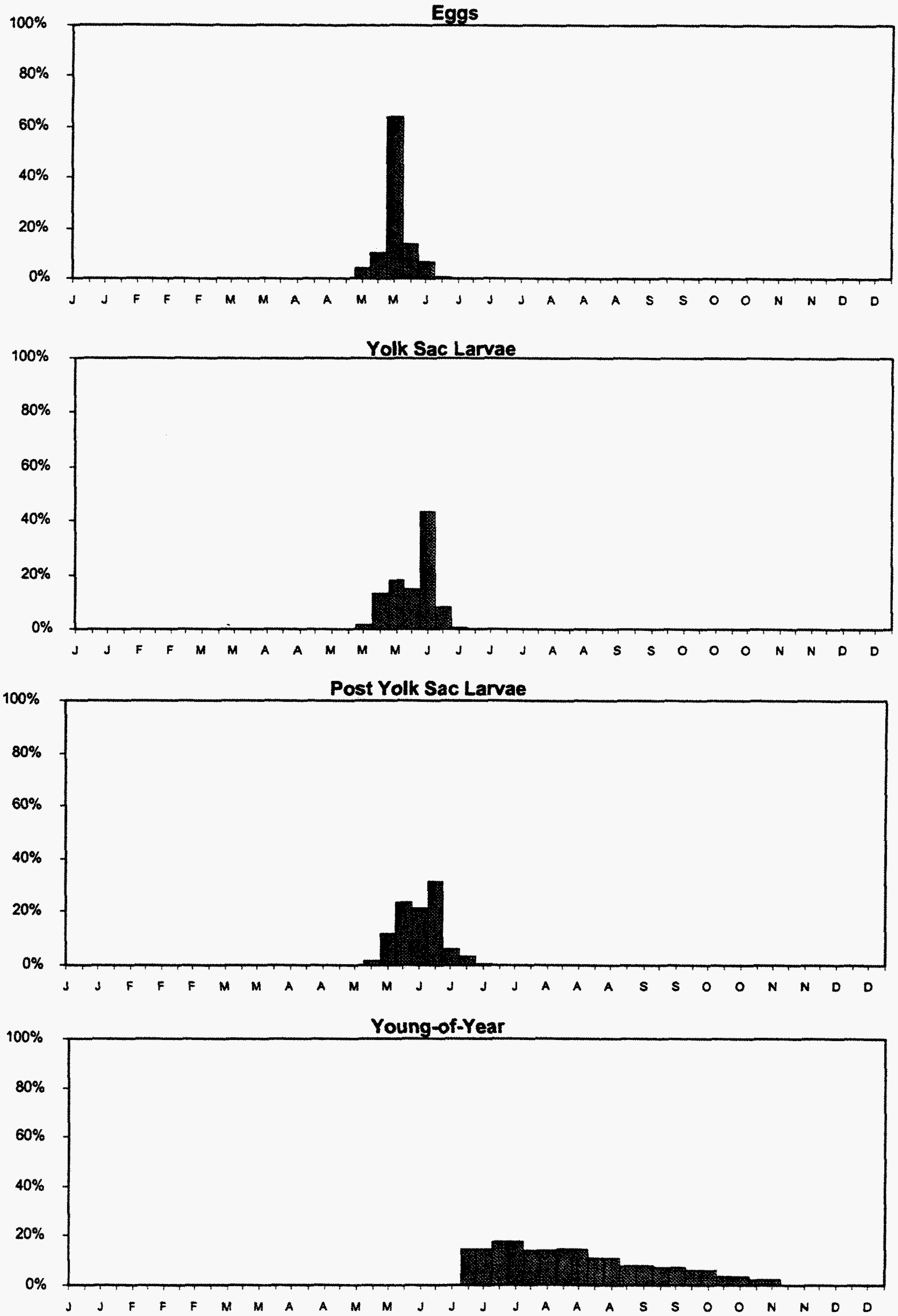


Figure V-32. Temporal distribution indices for striped bass eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during beach seine surveys of the Hudson River estuary, 1991-1997.

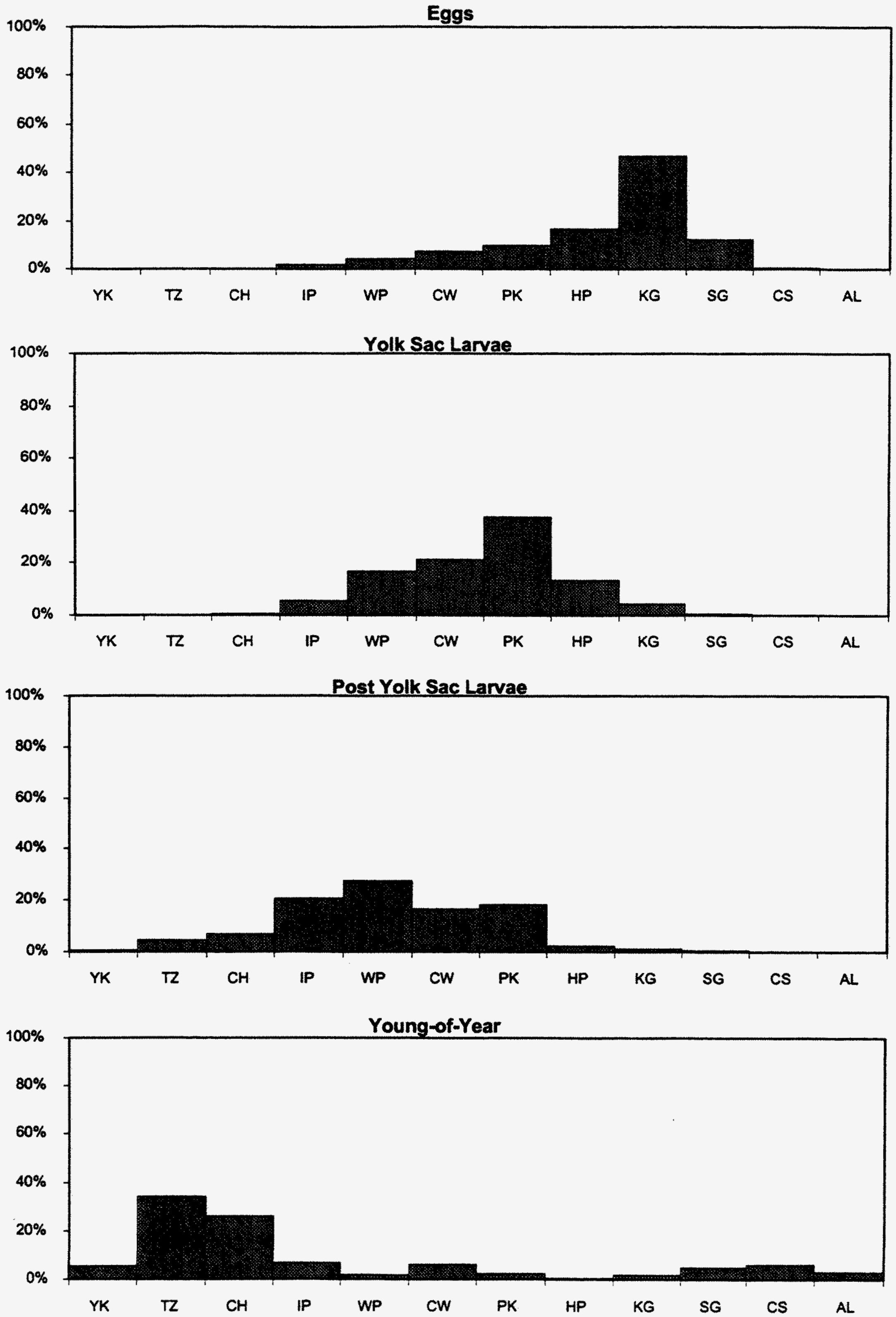


Figure V-33. Spatial distribution indices for striped bass eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during beach seine surveys of the Hudson River estuary, 1991-1997.

0.5 in. long. Striped bass PYSL are most abundant in the middle estuary, but they are found throughout the estuary (Figure V-33).

Toward the end of the PYSL stage young striped bass begin moving out of the middle estuary into the lower estuary, which is broader, shallower, and may be more productive, and they feed on copepods and amphipods. Larger juveniles, over 2.5 in. long, feed on insect larvae, worms, opossum shrimps, crabs, and small fish (Gardinier and Hoff 1982).

The end of the PYSL stage, when striped bass larvae change from living on their stored energy reserves (the yolk sac and the oil globule) to depending on energy obtained through active feeding, may be important in population dynamics. In many marine species the co-occurrence of patches of fish larvae and suitable food is thought to be the critical factor in determining the population size because delays in finding suitable prey can result in starvation (Cushing 1975; Goshorn and Epifanio 1991). Although striped bass larvae may survive food deprivation for some time by consuming energy reserved in the oil globule (Eldridge et al. 1983; Hjorth 1988), growth will be slower (Rogers et al. 1977) and larvae may be at increased risk of being eaten by predators that prey efficiently on smaller larvae (Houde 1978).

By the end of their first summer many of the juvenile striped bass have moved to the southern extreme of the estuary and are found in New York Harbor, western Long Island Sound, and along the south shore of Long Island (DEC 1992a). As striped bass grow, fish become an increasingly important component of their diet. Juvenile striped bass are also prey for some marine and estuarine predator species.

At age 2 or 3 striped bass leave Atlantic coast estuaries and begin the typical seasonal migration, northward during the spring and summer and southward during the fall. Adult striped bass are at the top of a food chain and have few natural enemies other than man. Since they rarely go more than 10 miles offshore, they are typically available to sport and commercial fishermen all along their migration route.

ii. Temporal Changes in Abundance

Sampling Programs

Adult and sub-adult striped bass--An estimate of the relative abundance of sub-adult and adult striped bass is generated from striped bass that are caught in commercial gill nets set for American shad in the Hudson River during the spring. The average catch per unit effort (CPUE) for this by-catch of striped bass is determined for each week of the shad fishery and an annual index, the Commercial Fishery Monitoring (CFM) index, is generated by summing these weekly CPUE estimates. Although the entire striped bass stock moves through the portion of the estuary fished by the commercial gill nets, the CFM index primarily reflects the relative abundance of fish for ages of 4 through 8. Striped bass older than age 7 are not effectively sampled because of the narrow range of mesh sizes, 5.5 to 7.0 in, used by the shad fishermen. The median age in the catch is 5.

Eggs and larvae--Abundance estimates for striped bass eggs and larvae are generated from the ichthyoplankton surveys conducted as part of the utilities' monitoring program. Estimates of relative abundance are generated for the egg stage because its duration is shorter than the interval between the weekly ichthyoplankton surveys. Thus, some eggs hatch between the weekly surveys and are not subject to sampling, which results in underestimates of egg densities during this life stage. Egg densities are also underestimated because some eggs settle out of the water column and cannot be captured by the ichthyoplankton nets. The indices of egg abundance generated from the ichthyoplankton surveys should detect major changes in reproductive, as when strong year classes mature. However, they probably will not detect differences in reproductive effort among years when the reproductive effort is average or below average.

Estimates of relative abundance are also generated for the yolk-sac larval (YSL) stages. Since its duration is shorter than the interval between the weekly ichthyoplankton surveys, some YSL become post yolk-sac larvae (PYSL) between the weekly surveys and are not subject to sampling. This results in underestimates of YSL densities during this life stage. However, the indices of YSL abundance should provide a better description of the differences in reproductive effort during the monitoring program than the egg indices because YSL can swim and do not settle out of the water column. A measure of abundance for YSL is important because striped bass and white perch are more easily discriminated during this life stage. The YSL index can be used to confirm the validity of the PYSL index where mis-identification of PYSL striped bass and white perch is more likely to occur.

The abundance estimates for PYSL striped bass should be more accurate than the YSL estimates because the duration of the PYSL life stage (about 3 weeks) is longer than the interval between the weekly ichthyoplankton surveys. In addition, PYSL striped bass swim actively and are dispersed widely across estuarine habitats, which increases the efficiency of sampling.

Young-of-year (YOY)-Indices of YOY abundance, generated from beach seine surveys, are used to monitor the temporal changes in recruitment to the striped bass stocks along the eastern coast of the United States (Richards and Rago 1999). In the Hudson River, two beach seine surveys are conducted each year. The average number of juvenile striped bass collected per seine haul during the period from late August through early November (6 biweekly samples) is used for the YOY index generated from the JSB survey. The average number of juvenile fish per seine haul from samples collected during the period from mid-August to early October is used for the YOY index generated from the BSS survey.

These two beach seine surveys provide different descriptions of YOY abundance in the Hudson River estuary. The samples from the BSS survey are collected both within and outside of the primary nursery area, before YOY striped bass move down river during late fall. Thus, the YOY index from the BSS provides a description of the distribution of YOY striped bass within the Hudson River estuary. The samples from the JSB survey are collected from the primary nursery area for YOY striped bass in the estuary. The time interval over which the index is calculated includes the period when YOY striped bass from the upper regions of the estuary move down river into the primary nursery area. Thus, the YOY index from the JSB provides a description of the greatest concentration of YOY striped bass within the estuary.

Age 1^+ and age 2^+ striped bass--During the winter, striped bass are sampled with bottom trawls in the upper portion of New York Harbor and in the Hudson River along the western side of Manhattan Island. Age 1^+ fish are tagged and released. Striped bass tagged at age 1^+ and recaptured at age 2^+ are used to estimate the abundance of age 1^+ fish during the winter in which they were tagged. Age 1^+ estimates are available for cohorts from 1984 through 1995. An additional year is needed to estimate cohort abundance at age 2^+ and age 2^+ estimates are available for cohorts from 1984 through 1994.

The age 1^+ and age 2^+ indices provide more reliable measures of recruitment to the adult stock than the YOY indices from the BSS and JSB surveys if larval and YOY striped bass begin moving out of the estuary into other habitats during these surveys. The BSS and JSB indices reflect only the production of striped bass from habitats located within the Hudson River. Age 1^+ striped bass from habitats located within and outside of the river move into the area sampled during the winter mark-recapture program. The age 1^+ estimate from the Utilities' winter mark-recapture program is based upon fish marked at age 1^+ in one winter and recaptured at age 2^+ during the following winter. Since a year elapses between marking and recapture, tagged fish have ample opportunity to mix randomly with untagged fish from all nursery areas used by the Hudson River stock, both within and outside of the river.

Abundance Indices

Eggs--From 1976 through 1986, egg and YOY indices were significantly correlated ($r = 0.710$; $p = 0.014$). After 1986, they were not ($r = -0.297$; $p = 0.376$). From 1976 through 1994, the egg indices were positively related to the abundance of mature striped bass. Egg densities increased when strong cohorts matured. After 1994, egg densities were negatively associated with the number of strong cohorts maturing within the striped bass stock and decreased linearly as the 1988, 1989, and 1990 cohorts began to mature (Table V-15).

YSL--YSL and PYSL abundance were highly correlated during the period from 1974 through 1997 ($r = 0.939$; $p = 0.000$). When the abundance of adult striped bass began to increase, both larval indices accurately reflected the increase in reproductive effort.

PYSL--There were four temporal changes in PYSL abundance (Figure V-34). During the period from 1974 through 1988, there was no trend in PYSL abundance; the PYSL indices ranged from 0.26 to 2.48 larvae per 1000 m^3. From 1988 through 1991, PYSL abundance increased linearly, beginning at 1.48 larvae per 1000 m^3 and ending at 8.01 larvae per 1000 m^3. From 1991 through 1994, PYSL abundance was relatively constant, ranging from 6.38 to 8.45 larvae per 1000 m^3. After 1994, PYSL abundance fluctuated widely, falling to 3.94 larvae per 1000 m^3 in 1995, rising to 15.40 larvae per 1000 m^3 in 1996, and then falling to 4.89 larvae per 1000 m^3 in 1997.

YOY--During the period from 1976 through 1986, there were four strong cohorts, 1977 and 1978, 1983 and 1984 (Figure V-35). During the period from 1987 through 1990, there were four, successive, strong cohorts. During the period from 1991 through 1997, there was only one strong cohort, in 1997.

Age 1^+--Estimates of abundance at age 1^+ are available for the cohorts from 1984 through 1995 (Figure V-36). In order to compare the estimates of cohort strength provided by the age 1^+ and YOY indices, the annual values for each index have been normalized. This was done by dividing the annual values for each index by the maximum value observed for that index and put each index on the same measurement scale. The two indices provide very similar estimates of cohort strength through the 1990 cohort. After the 1990 cohort, the estimates of cohort strength generated from the YOY indices were all lower than those generated from the age 1^+ estimates.

Age 2^+--Estimates of abundance at age 2^+ are available for the cohorts from 1984 through 1994 (Figure V-37). In order to compare the estimates of cohort strength provided by the age 2^+ and age 1^+ indices, the annual values for the age 2^+ index were normalized. The

TABLE 15

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF DIFFERENT LIFE STAGES OF STRIPED BASS (STANDARD ERRORS, WHERE AVAILABLE, ARE GIVEN AFTER "/".)

	ADULT	EGG	YSL	PYSL				Age 1+	Age 2+
YEAR	CFM[a]	LRS[b]	LRS[b]	LRS[b]	BSS[c]	JSB[d]	WLS[e]	SBMR[f]	SBMR[f]
1974		0.006/0.04	0.08/0.02	0.42/0.03	5.65/0.87				
1975		0.08/0.01	0.49/0.03	0.69/0.04	4.56/0.30				
1976		0.10/0.01	0.25/0.01	0.26/0.02	3.45/0.39	16.3			
1977		0.19/0.02	0.57/0.03	0.60/0.04	5.92/0.41	39.7/7.80			
1978		0.08/0.01	0.31/0.02	0.54/0.04	9.11/1.88	41.8/9.70			
1979		0.08/0.01	0.36/0.02	0.47/0.03	3.76/0.76	5.0/0.74			
1980	1.25	0.07/0.01	0.32/0.02	0.83/0.06	5.60/0.83	24.1/4.70			
1981	1.45	0.14/0.02	0.49/0.06	2.48/0.12	6.61/0.91	21.6/3.72			
1982	0.93	0.07/0.01	0.74/0.08	0.82/0.06	3.83/0.54	30.5/4.01			
1983	1.38	0.28/0.19	0.39/0.03	0.59/0.03	6.58/1.25	48.1/9.10			
1984	4.78	0.15/0.02	0.36/0.03	0.87/0.10	5.06/1.01	37.1/7.44		821/152	213/46
1985	9.97	0.05/0.00	0.20/0.02	0.40/0.03	1.07/0.24	3.9/0.48	0.00	342/74	104/26
1986	7.82	0.06/0.01	0.42/0.03	0.72/0.04	1.62/0.39	6.1/0.74	0.00	282/64	108/26
1987	7.28	0.06/0.01	1.45/0.08	1.70/0.07	12.82/2.24	60.7/12.88	0.26	1336/194	611/96
1988	11.39	0.02/0.01	0.71/0.07	1.48/0.14	4.91/0.61	52.3/3.75	2.46	1128/89	560/55
1989	15.99	0.59/0.27	2.94/0.28	4.54/0.34	5.66/0.90	41.9/4.72	1.58	908/153	339/63
1990	13.95	1.22/0.18	3.27/0.29	5.64/0.54	6.41/0.70	38.0/3.65	0.76	817/109	344/53
1991	13.06	0.36/0.06	2.85/0.26	8.00/0.77	5.03/1.07	6.9/0.67	3.70	1017/139	512/87
1992	24.93	0.87/0.15	3.88/0.22	6.38/0.42	3.68/0.58	17.3/1.28	3.70	895/246	252/78
1993	31.05	0.63/0.12	4.81/0.97	8.25/0.73	7.50/1.63	26.5/2.80	14.07	996/497	191/105
1994	35.29	9.83/1.87	3.68/0.53	8.45/0.80	5.88/1.06	28.5/2.63	1.98	1140/276	351/124
1995	17.09	6.27/1.01	1.31/0.20	3.94/0.39	6.04/0.90	27.4/3.72	1.23	971/174	
1996	36.53	4.50/0.65	12.74/1.80	15.40/1.46	1.25/0.33	14.7/1.59	34.76		
1997	10.01	1.03/0.19	1.80/0.30	4.89/0.74	9.18/0.83	50.3/5.39	0.26		

a Catch per 1000 yd^2 hr in fixed nets. Data from NYSDEC data file CFBASSCF.WK1.
b Sum of weighted average number per m^3 for 7 consecutive sampling weeks over period of peak abundance.
c Average number per 100' seine haul for sampling from mid-August to early October (weeks 33-40).
d Geometric mean number per 200' seine haul for 6 week sampling period.
e. Estimated number of age 1+ fish during second winter of life, in 1000s.
f. Applied to the year in which the cohort was spawned.

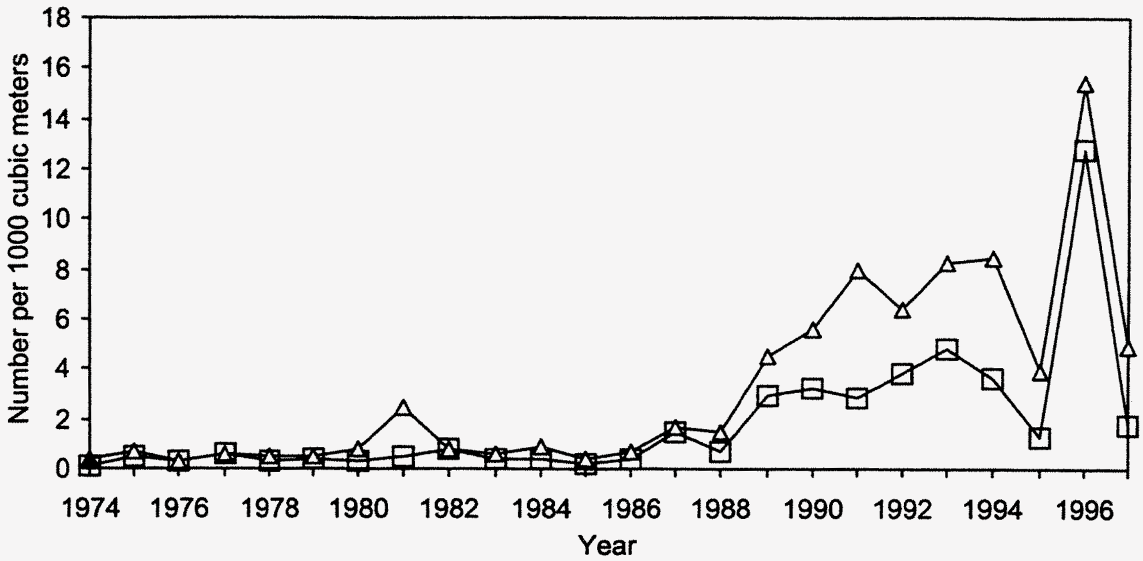


Figure V-34. Striped bass annual abundance indices for yolk-sac larvae (YSL) and post yolk-sac larvae (PYSL), 1974 - 1997.

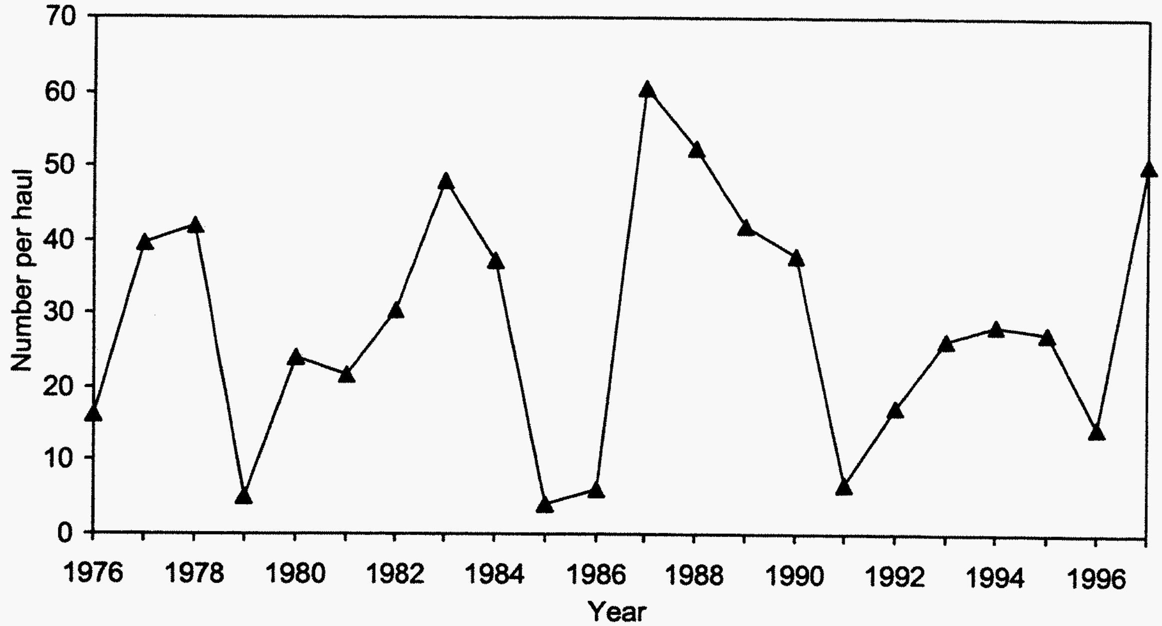


Figure V-35. Striped bass: annual abundance indices for young-of-the-year (YOY) generated from the NYSDEC Juvenile Striped Bass Survey (JSB), 1976-1997.

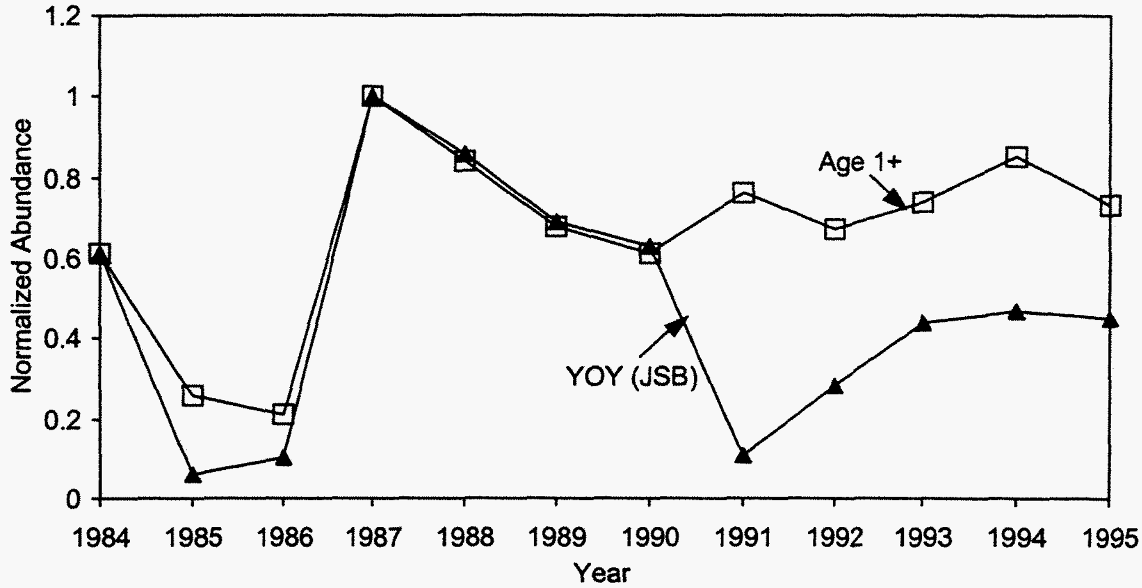


Figure V-36. Striped bass: normalized annual abundance indices for young-of-the-year (YOY) generated from the NYSDEC Juvenile Striped Bass Survey (JSB) and Age 1+, 1984-1995. The indices were normalized by dividing each annual index by the maximum value for that index.

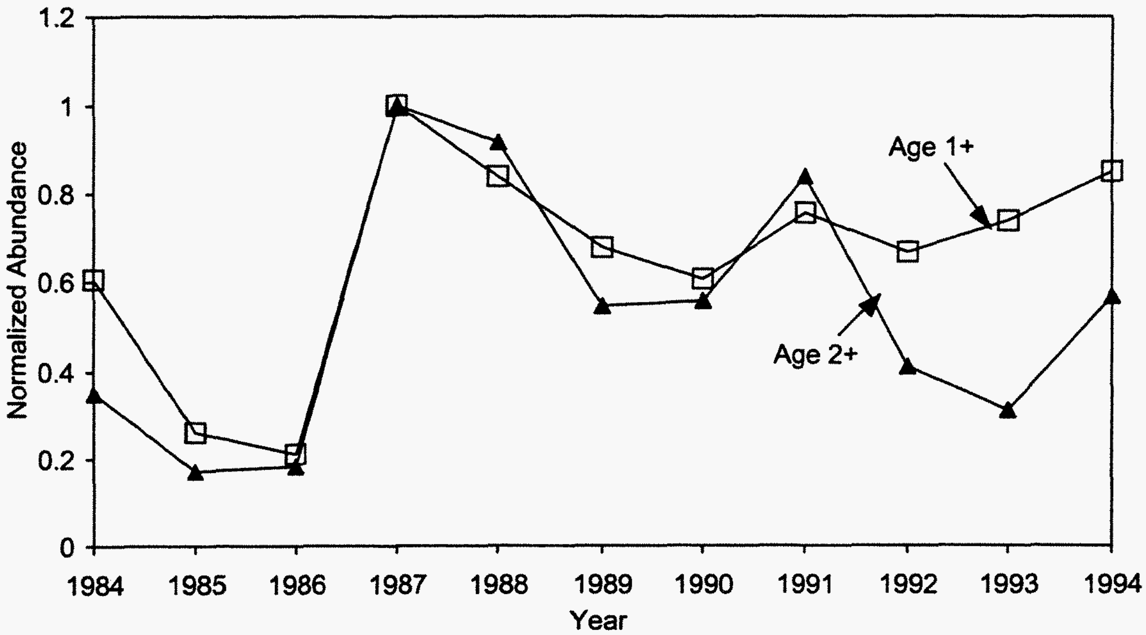


Figure V-37. Striped bass normalized annual abundance indices for ages 1+ and 2+, 1984 - 1995. The indices were normalized by dividing each annual index by the maximum value for that index.

two indices provide very similar estimates of cohort strength through the 1991 cohort. After the 1991 cohort, the estimates of cohort strength generated from the age 2^+ indices were all lower than those generated from the age 1^+ indices.

iii. Potential Influences on Abundance

The potential influences on striped bass abundance are fishing, competition, predation, water withdrawals, and water quality. The factors affecting striped bass abundance are described by life stage, in the following paragraphs.

PYSL - The increase in PYSL abundance observed after 1987 was caused by a series of changes in the fishing regulations for striped bass. The initial change in the fishing regulations was modest. The size limit for striped bass was increased from 18" total length (TL) to 24" TL from November 1983 to May 1986, shifting the age vulnerability from age 4 to age 6 for female striped bass (Hoff et al. 1988). The by-catch of striped bass in the gill net fishery immediately increased in 1984, which confirmed that the Hudson River stock was heavily fished. The subsequent changes in the fishing regulations were far more significant. A moratorium on commercial and recreational harvests was imposed from May 1986 to May 1987 and the ban on commercial harvests was continued until September 1990. In addition, highly restrictive size and bag limits were imposed on the recreational fishery from May 1987 to September 1990. From September 1990 to the present, strict size and bag limits have been imposed on both fisheries.

PYSL abundance should have increased in 1989 and 1990 due to the maturation of the 1983 and 1984 cohorts, the first strong cohorts protected by the changes in fishing regulations. Only about 20% of the females in a cohort of striped bass have matured at age 5. About 60% have matured at age 6 and 90% have matured at age 7 (Hoff et al. 1988). Thus, there shouldn't have been any major increase in PYSL abundance before the 1983 cohort reached age 6 in 1989 and there wasn't (Figure V-34). (Hoff et al. 1988). The maturation of the 1983 and 1984 cohorts also had a detectable effect on egg densities (Figure V-38).

The changes in the fishing regulations for the Hudson River stock also protected the four strong cohorts observed during the period from 1987 through 1990. These cohorts were larger than or as large as the 1983 and 1984 cohorts and their maturation had a tremendous effect on egg densities. When the 1987 cohort reached age 7 in 1994, the egg index increased over 15-fold between 1993 and 1994 (Figure V-39).

However, the increase in egg densities did not affect PYSL abundance. The PYSL index increased only 2% between 1993 and 1994 (Figure V-39). This demonstrates that the

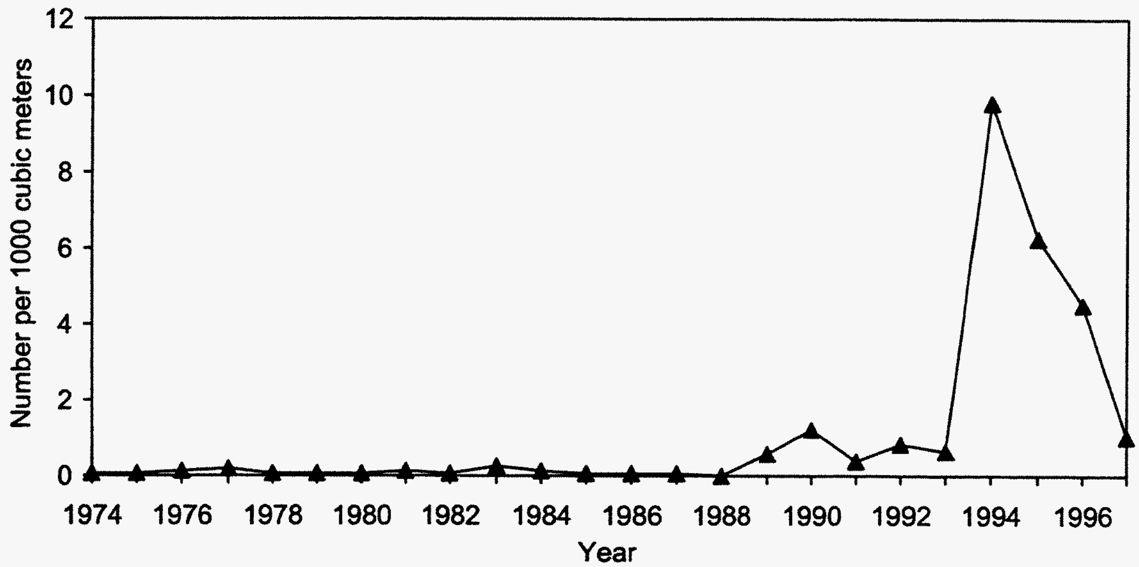


Figure V-38. Striped bass annual abundance indices for eggs, 1974 - 1997.

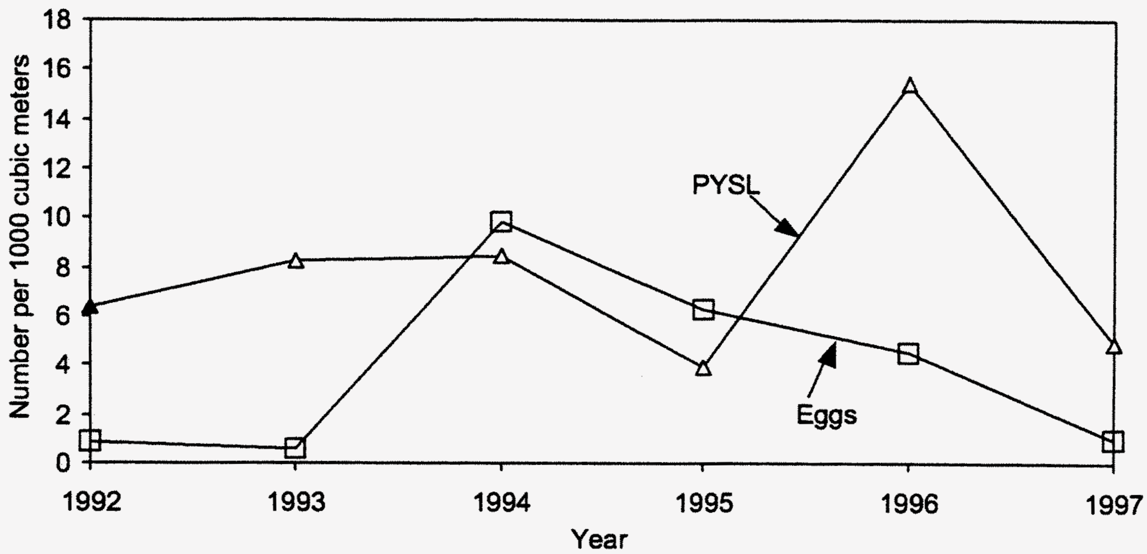


Figure V-39. Striped bass annual abundance indices for eggs and post yolk-sac larvae (PYSL), 1992 - 1997.

hatchability of the eggs and/or larval survival decreased when egg densities increased. Egg abundance decreased by 36% (relative to 1994) in 1995 but the relative difference between the egg and PYSL indices remained the same. This demonstrates that the hatchability of the eggs and/or larval survival was still relatively low. Egg abundance continued to decrease in 1996 and 1997. However, PYSL abundance fluctuated widely, which demonstrates that the hatchability of the eggs and/or larval survival were affected by something other than changes in egg densities.

The factor determining PYSL abundance is probably the maturation of the four strong cohorts and the increasing numbers of striped bass spawning in the Hudson River. The fluctuation in PYSL abundance was reflected in the fluctuation in the by-catch index for striped bass (Figure V-40). The by-catch index decreased in 1995, increased in 1996, and decreased in 1997. The PYSL index exhibited the same temporal pattern, except that the relative increase in PYSL abundance in 1995 was much greater than that in the striped bass by-catch.

Competition for food within the striped bass stock is the simplest explanation for the changes in PYSL abundance observed after 1994. Severe competition could delay the onset of maturation and decrease the number of eggs produced per female among the fish that were mature. A delay in maturation would produce the decrease in the by-catch of striped bass during the spring in 1995 and the decrease in egg production. The increase in the by-catch of striped bass during the spring in 1996 could represent the appearance of fish that failed to mature the previous year. The decrease in egg production in 1996 could be due to a decline in the number of eggs produced per female caused by competition. When competition is very intense, only the larger fish within the stock should produce eggs because they should have a competitive advantage over smaller fish (larger fish can feed upon a greater range of prey). Egg size increases as the size and energy reserves of the female increase. Thus, the proportion of large eggs in the spawn should increase as the intensity of competition increases and the general level of egg abundance decreases. Hatchability and larval survival are positively related to egg size and the disproportionate increase in PYSL abundance in 1996 probably reflects the effects of competition and delayed maturation on egg size. The decrease in CFM, egg, and PYSL indices in 1997 suggests that the level of competition within the Hudson River stock may have forced striped bass to spawn in alternate years.

YOY - The YOY index from the primary nursery area in the river appears to accurately reflect cohort abundance from 1984 through 1990 but not from 1991 through 1997. YOY abundance was significantly correlated with age 1^+ abundance ($r = 0.991$; $p = 0.000$) during the period from 1984 through 1990 (Figure V-36). After 1990, the two abundance measures were not significantly correlated ($r = 0.301$; $p = 0.623$). The divergence of these two

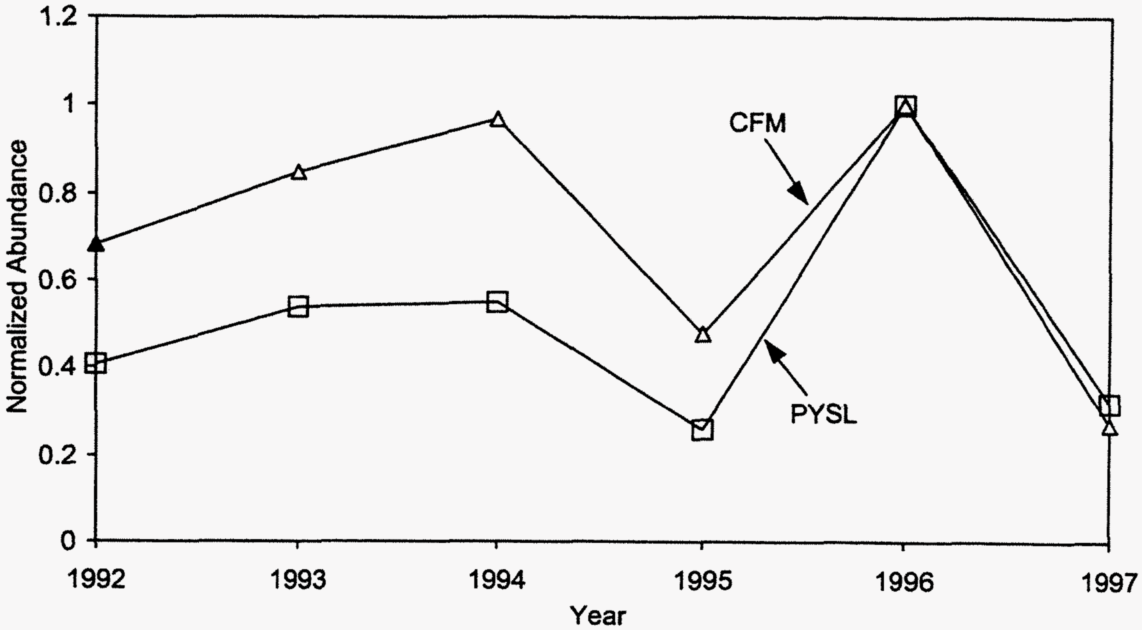


Figure V-40. Striped bass: normalized annual abundance indices for post yolk-sac larvae (PYSL) and the by-catch of striped bass in the commercial gill net fishery for American shad (CFM), 1992 - 1997.

abundance measures appears to be caused by the emigration of PYSL and YOY striped bass out of the river in 1991, which resulted in the production of age 1^+ fish from nursery habitats located outside of the river.

The dispersal of striped bass began when PYSL abundance increased in 1987 but emigration appeared to be limited by water quality until 1991. The average number of YOY striped bass caught per seine haul outside the primary nursery area (regions 6 through 12) increased after 1986 (Figure V-41). The abundance of YOY striped bass caught in DEC beach seine surveys at western Long Island beaches increased in 1988 but low dissolved oxygen levels appear to have impaired the movement of fish through the East River into Western Long Island Sound in 1987 (Table V-16). The sample size is too small (3) for statistical significance ($p = 0.156$) but the correlation between YOY abundance at the Western Long Island beaches and PYSL abundance in the Hudson River is very high for the years when dissolved oxygen levels were not low ($r = -0.970$). This negative correlation suggests that the decrease in survival associated with high PYSL abundance occurred when the PYSL and YOY striped bass were dispersing.

The emigration of PYSL and YOY striped bass appeared to increase after 1990 (Table V-17). The regression of YOY abundance at Long Island Sound beaches on PYSL abundance within the Hudson River estuary was highly significant ($R^2 = 0.839$; $p = 0.003$). However, the relationship between PYSL abundance and YOY abundance was positive, suggesting that the density-dependent mortality observed when emigration was limited occurred within the Hudson River estuary rather than during the movement through the East River and western Long Island Sound. Dissolved oxygen levels in the East River and Western Long Island Sound were also important after 1990. When both variables were included in the regression, the fit increased significantly ($R^2 = 0.973$; $p = 0.001$) and YOY abundance increased when dissolved oxygen levels increased.

The limited emigration of PYSL and YOY striped bass from the Hudson River prior to 1991 may be related to the discharge of untreated sanitary sewage into the Hudson River from the western shore of Manhattan Island. Between 1970 and 1988, the upgrading and construction of wastewater treatment plants reduced the discharge of untreated wastewater into the estuary in the vicinity of Manhattan Island from 450 million gallons per day (mgd) to 5 mgd. Water pollution programs instituted after 1988 virtually eliminated the remaining flow of untreated wastewater by 1993 (Brosnan and O'Shea 1996a). In 1991, the North River wastewater treatment plant completed an upgrade to full secondary treatment. This removed 33,000 kg of organic suspended solids from the effluent discharged into the river. The reduction in suspended solids did not have an immediate effect on dissolved oxygen levels in the river near Manhattan Island, which did not increase until the following summer. However, there is another factor associated

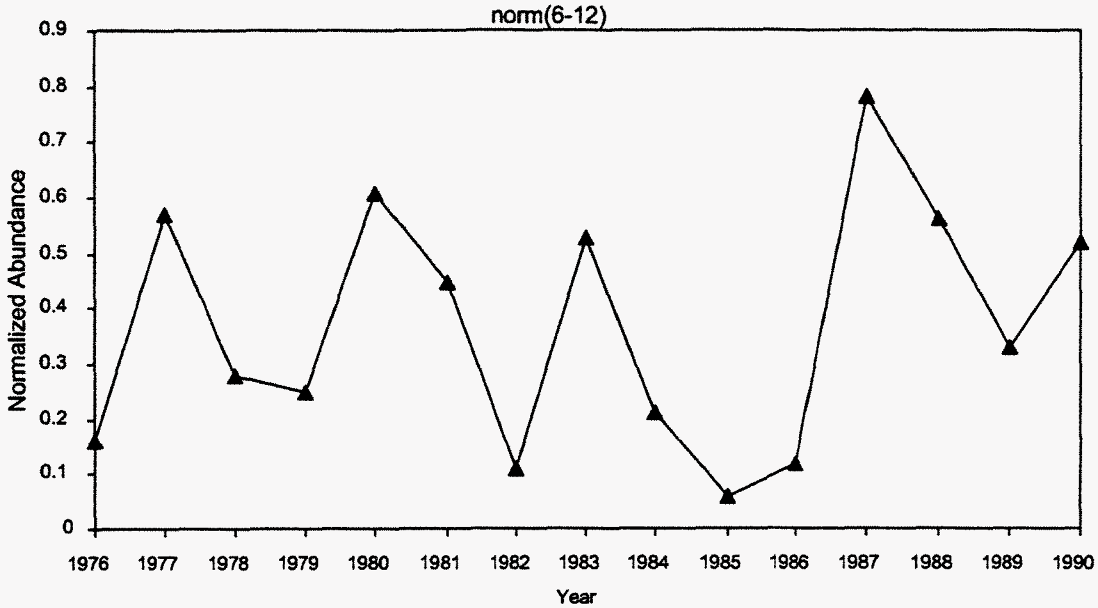


Figure V-41. Striped bass: annual abundance indices for young-of-the-year (YOY) from regions 6 through 12 in the Hudson River, 1974 through 1997.

TABLE V-16

MAXIMUM WEEKLY AVERAGE DISSOLVED OXYGEN IN THE BOTTOM STRATUM DURING JULY AND AUGUST FOR SEVEN SAMPLING STATIONS LOCATED EAST OF HELL GATE IN THE EAST RIVER AND 4 SAMPLING STATIONS LOCATED IN WESTERN LONG ISLAND SOUND (NYCDEP 1997), INDICES OF ABUNDANCE FOR YOY STRIPED BASS GENERATED FROM SOME SAMPLES COLLECTED FROM WESTERN LONG ISLAND BEACHES, AND INDICES FOR PYSL ABUNDANCE ON THE HUDSON RIVER ESTUARY 1985-1990

YEAR	PYSL	MAXIMUM WEEKLY AVERAGE DO (BOTTOM)	YOY WLI
1985	0.41	8.66	0
1986	0.72	4.31	0
1987	1.70	4.12	0.26
1988	1.48	7.17	2.46
1989	4.54	5.02	1.58
1990	5.64	8.09	0.76

TABLE V-17

MAXIMUM WEEKLY AVERAGE DISSOLVED OXYGEN IN THE BOTTOM STRATUM DURING JULY AND AUGUST FOR SEVEN SAMPLING STATIONS LOCATED EAST OF HELL GATE IN THE EAST RIVER AND 4 SAMPLING STATIONS LOCATED IN WESTERN LONG ISLAND SOUND (NYCDEP 1997), INDICES OF ABUNDANCE FOR YOY STRIPED BASS GENERATED FROM SOME SAMPLES COLLECTED FROM WESTERN LONG ISLAND BEACHES, AND INDICES FOR PYSL ABUNDANCE ON THE HUDSON RIVER ESTUARY 1985-1990

YEAR	PYSL	MAXIMUM WEEKLY AVERAGE DO (BOTTOM)	YOY WLI
1991	8.01	4.44	3.7
1992	6.38	6.03	3.7
1993	8.25	5.71	14.07
1994	8.45	4.68	1.98
1995	3.94	6.96	1.23
1996	15.40	5.13	34.76
99	4.89	6.08	0.26/

with wastewater discharges that might immediately affect small fish. The effluent from all New York City wastewater treatment plants has been disinfected with chlorine since 1974 (Brosnan and O'Shea 1996a) and small fish are very sensitive to chlorine. The amount of chlorine required for disinfection is directly related to the load of organic suspended solids in the effluent discharged into the river. Thus, upgrade of the North River wastewater treatment plant in 1991 decreased the amount of chlorine needed to disinfect the discharge. Residual chlorine in the discharge from the North River plant may have been restricting movement of small striped bass past Manhattan Island prior to 1991.

YOY abundance within the Hudson River appeared to have been controlled by predation. YOY abundance tended to decrease after strong cohorts appeared (Figure V-42), which suggests that age 1^+ and 2^+ striped bass may have been preying upon YOY striped bass. The time series for the upper and lower sections of the estuary were significantly correlated ($r = 0.695$; $p = 0.004$), which demonstrates that PYSL abundance was not involved (PYSL abundance was higher in the lower portion of the estuary). Furthermore, the decline in YOY abundance that occurred between 1987 and 1990 began before PYSL abundance began to increase significantly.

Age 1+ - From 1984 through 1990, the abundance of age 1^+ striped bass in the Hudson River stock was determined by YOY abundance. During this period, the relative variation in abundance was high (the coefficient of variation was 47.7).

From 1991 through 1995, the average abundance of age 1^+ striped bass was 25% higher than that during the preceding period and was not determined by the abundance of YOY striped bass in the river. During this period, the relative variation in abundance was low (the coefficient of variation was 9.0). The abundance of age 1^+ striped bass was relatively high and constant during this period, which suggests that the amount of habitat available to YOY striped bass was an important factor affecting the abundance of age 1^+ striped bass after 1990. It appears that additional habitat became available outside of the river when water quality in the New York City area improved. Although the time series for the PYSL and age 1^+ indices were similar (Figure V-43), the correlation between the PYSL and age 1^+ indices was not statistically significant ($r = 0.546$; p 0.341). Thus, PYSL abundance did not appear to determine the production of age 1^+ striped bass after 1990.

Age 2+ - The normalized abundance indices for striped bass at ages 1^+ and 2^+ were very similar until the 1992 cohort (Figure V-37), which means that the factors controlling the variation in abundance at age 1^+ also controlled the variation in abundance at age 2^+. It also means that the abundance of either age group could be used as an index of

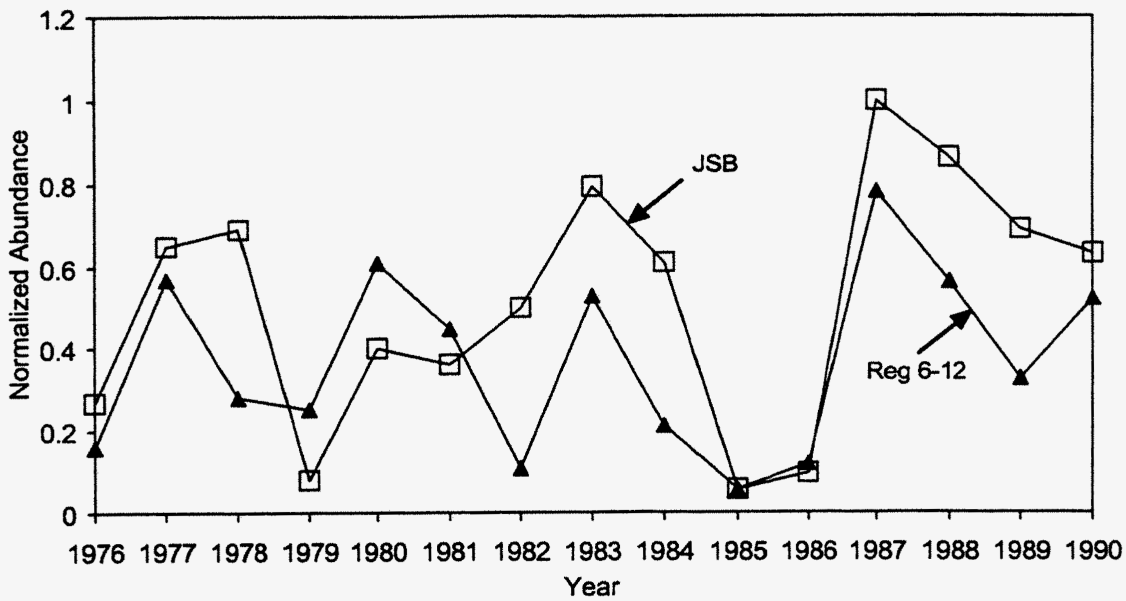


Figure V-42. Striped bass: normalized annual abundance indices for young-of-the-year (YOY) from the primary nursery area (JSB) and from outside of the primary nursing area (Reg. 6-12) during the period when emigration of PYSL and YOY from the river was low, 1976 - 1990. The indices were normalized by dividing each annual index by the maximum value for that index.

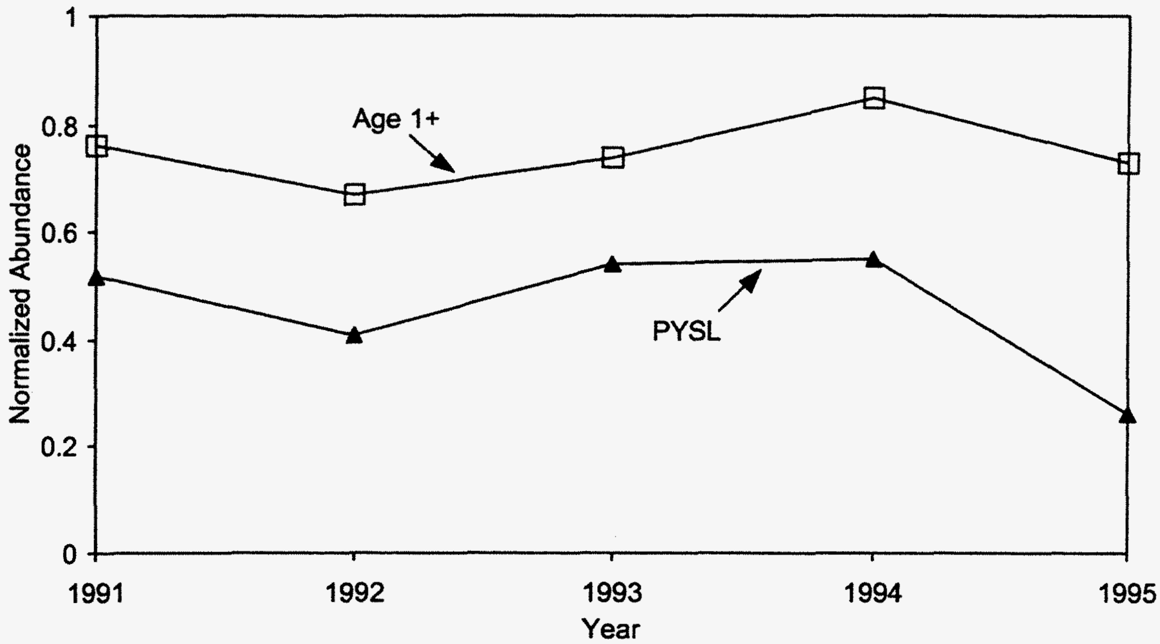


Figure V-43. Striped bass: normalized annual abundance indices for post yolk-sac larvae (PYSL) and age 1^+ during the period when emigration of PYSL and YOY from the river was high, 1991 - 1995. The indices were normalized by dividing each annual index by the maximum value for that index.

recruitment for striped bass cohorts from 1984 through 1991. However, the similarity between the indices of abundance at ages 1^+ and 2^+ abundance disappeared after the 1991 cohort (Figure V-37). For the last three cohorts in this time series, the normalized indices of abundance at age 2^+ were lower than the normalized indices at age 1^+. There was a significant decrease in the survival of striped bass from age 1^+ to age 2^+ between the spring of 1994 and the spring of 1995. Thus, the index of abundance for age 2^+ fish appears to provide a better index of recruitment for the cohorts following the 1991 cohort.

The most likely cause of the decrease in the survival of age 1^+ striped bass after 1993 is the maturation of the four strong cohorts produced during the period from 1987 through 1990. Age 1^+ striped bass will be less competitive than older (and larger) striped bass if competition for food occurs. The potential for competition between age 1^+ and older striped bass is high during the late winter and early spring when they are both in the lower portion of the estuary and the YOY white perch overwintering in the lower portion of the estuary are the most abundant prey available. Large striped bass can also feed upon adult alewives and blueback herring. However, these species do not enter the river until mid-to-late April, which means that YOY white perch may be subject to heavy predation from late February through mid-April. The abundance of yearling white perch is directly dependent upon the abundance of YOY white perch during the spring and the abundance of yearling white perch decreased throughout the Hudson River during the same period when the survival of age 1^+ striped bass decreased (Figure V-44). This observation suggests that food did become limiting for age 1^+ striped bass during late winter and early spring after 1993.

Entrainment (Table V-18) had no detectable effect on striped bass abundance. Entrainment did not prevent the appearance of strong year classes of YOY striped bass, even when the abundance of eggs and larvae was low. It probably did not affect recruitment because the natural processes controlling recruitment occurred after the period when entrainment occurred and the level of entrainment mortality was too low to affect the natural processes determining recruitment.

Fishing

Historically, striped bass have contributed an important commercial fishery in the coastal waters of the northeastern states and in spawning areas such as the Hudson River estuary. Additionally, striped bass have been a popular sport fish because of their large size and fighting ability. Both the sport and commercial fisheries harvested a mixed stock composed of fish from the major spawning rivers (Roanoke River, Chesapeake Bay, Delaware River, Hudson River), with the largest contribution usually from the Chesapeake. In the 1970s the

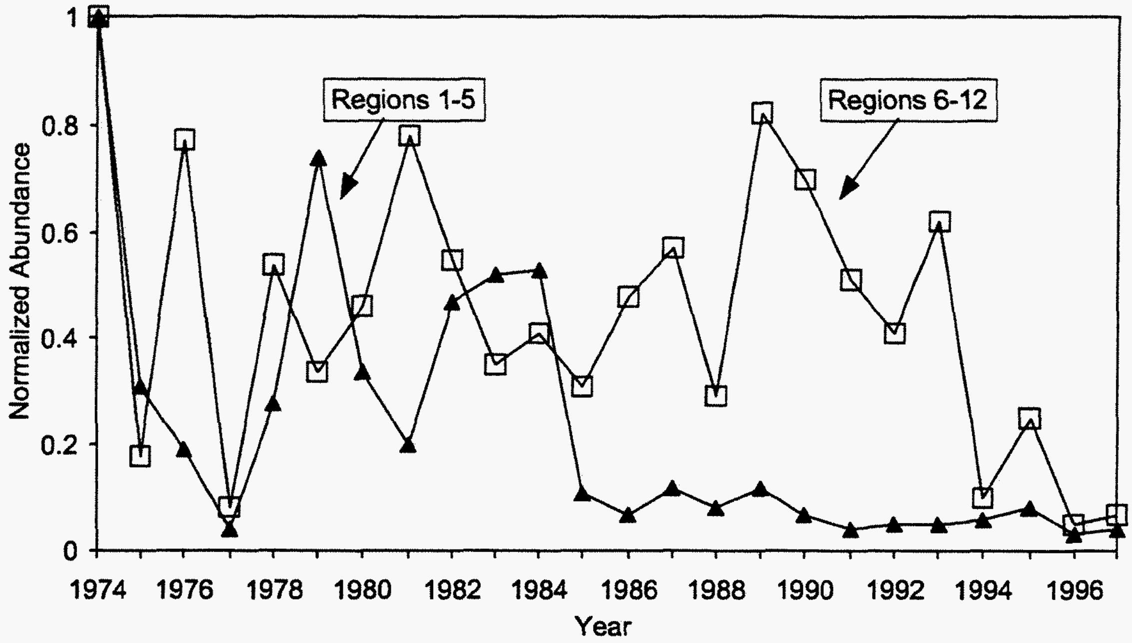


Figure V-44. White perch: normalized annual abundance abundance indices for yearlings from Regions 1-5 and Regions 6-12, 1974-1997. The indices were normalized by dividing each annual index by the maximum value for that index.

TABLE V-18

ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON STRIPED BASS. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	0.72	5.65	0.38	2.16	2.96	0.00	0.03		11.43
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									11.74
1975	E	0.99	7.78	1.71	1.54	3.16	0.05	0.20		14.64
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									14.94
1976	E	1.45	4.73	2.62	2.54	1.61	0.05	0.34		12.67
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									12.97
1977	E	0.98	13.89	2.15	1.80	1.76	0.04	0.15		19.66
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									19.94
1978	E	1.35	8.55	1.41	1.19	2.13	0.00	0.01		14.00
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									14.29
1979	E	1.09	11.92	2.14	1.64	1.41	0.01	0.04		17.37
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									17.65
1980	E	0.95	11.87	3.27	2.72	2.35	0.02	0.09		19.88
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									20.15
1981	E	0.23	4.17	0.43	4.15	2.32	0.02	0.22		11.08
	I	*0.01*	*0.20*	*0.01*	0.13	*0.00*				*0.35*
	T									11.39
1982	E	0.67	6.99	2.90	4.84	2.74	0.01	0.04		17.01
	I	*0.01*	0.20	*0.01*	*0.13*	*0.00*				*0.35*
	T									17.30
1983	E	0.58	7.36	2.34	2.33	5.10	0.02	0.08		16.71
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									17.00
1984	E	2.72	17.25	1.72	1.87	1.72	0.01	0.03	1.28	24.71
	I	0.00	0.80	0.00	0.10	0.00				0.90
	T									25.38
1985	E	0.07	3.97	2.09	2.57	0.76	0.23	0.66	0.63	10.53
	I	0.00	0.30	0.00	0.20	0.00				0.50
	T									10.97
1986	E	0.98	16.26	3.99	5.04	1.59	0.01	0.08	1.26	26.61
	I	0.00	0.50	0.00	0.20	0.00				0.70
	T									27.12
1987	E	0.47	2.30	4.75	7.43	0.72	0.08	0.21	0.68	15.70
	I	0.10	0.50	0.00	0.10	0.00				0.70
	T									16.29
1988	E	0.94	11.63	2.90	3.47	2.13	0.02	0.14	1.39	20.94
	I	0.00	0.00	0.00	0.10	0.00				0.10
	T									21.02
1989	E	0.96	5.96	2.28	2.39	1.82	0.01	0.04	1.14	13.82
	I	0.00	0.00	0.00	0.10	0.00				0.10
	T									13.90
1990	E	0.67	6.12	3.97	4.44	1.85	0.02	0.11	0.91	16.88
	I	0.00	0.10	0.00	0.30	0.00				0.40
	T									17.21
1991	E	0.67	4.95	3.62	4.13	6.14	0.23	1.15	1.12	20.15
	I	0.00	0.00	0.00	0.10	0.00				0.10
	T									20.23
1992	E	0.78	6.16	2.87	2.46	2.42	0.01	0.42	1.52	15.60
	I	0.00	0.00	0.00	0.10	0.00				0.10
	T									15.68
1993	E	0.41	5.60	1.25	1.86	1.36	0.02	0.14	0.93	11.11
	I	0.00	0.00	0.00	0.10	0.00				0.10
	T									11.20
1994	E	0.71	6.81	1.54	0.99	2.18	0.02	0.03	1.32	12.97
	I	0.00	0.00	0.10	0.10	0.00				0.20
	T									13.15
1995	E	0.36	4.22	2.91	2.67	1.24	0.06	0.10	0.84	11.82
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									12.13
1996	E	0.10	12.01	1.44	1.93	1.46	0.02	0.01	1.01	17.15
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									17.43
1997	E	0.46	1.42	3.00	3.62	1.92	0.04	0.07	1.33	11.32
	I	*0.01*	*0.20*	*0.01*	*0.13*	*0.00*				*0.35*
	T									11.62
AVERAGE	E	0.80	7.82	2.40	2.91	2.20	0.04	0.18	1.10	15.99
	I	0.01	0.20	0.01	0.13	0.00				0.35

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A]Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B]Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C]RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21e; Impingement-Appendix VI-2-B, Table 21

Hudson was thought to contribute typically less than 10% of the fish along the coast north of Chesapeake Bay, though ranging up to perhaps 40-50% for some year classes (Van Winkle et al. 1988). Due to the tendency of striped bass to migrate northward upon leaving their natal streams, the contribution of Hudson River fish was principally in New York and the New England states.

Although it is likely that striped bass landings have always been subject to cycles imposed by dominant year classes that occurred periodically in the Chesapeake population, a series of poor recruitment years during the 1970s resulted in sharp declines in landings in the coastal fishery. The decline stimulated a multistate program of research and management coordinated by the Atlantic States Marine Fisheries Commission (ASMFC) to ensure the recovery and continued existence of the populations. The ASMFC management plan forms the basis for management of the Hudson and other Atlantic coast stocks. In New York the presence of high levels of PCBs in striped bass flesh complicates the management of the Hudson River stock as the state attempts to protect people from ingesting harmful doses of PCBs.

Important changes in management of the Hudson River striped bass stock occurred in 1976 and 1986. In 1976 the river commercial fishery was closed due to PCB contamination. Although striped bass caught in the Hudson River could not be sold legally, they were still being caught in the gill nets that fishermen used to catch American shad. In 1986 the coastal fisheries were substantially restricted from Maine to Virginia to help conserve the Chesapeake stock, which migrates along the mid-Atlantic and northeastern states (Rago and Richards 1999). Also, in New York, high PCB levels measured in fish caught along the coast caused DEC to unilaterally end commercial fishing in its jurisdiction.

When a limited commercial fishery was reopened in eastern Long Island in 1990, DEC issued a negative declaration under SEQRA, determining that the commercial and recreational fishery with a combined F value approaching 0.25 would not have significant adverse impacts.

Pollution

PCB contamination has been recognized in Hudson River striped bass for nearly 20 years (see discussion in Section V-C, Organic Contaminants). Concentrations in striped bass flesh have declined from levels seen initially, but have recently fluctuated upward and remain well above the recommended concentrations for human consumption (DEC 1992b). Contamination of young Hudson River striped bass is believed to result in adverse skeletal effects and bone weakening (Mehrle et al. 1982) that may affect survival. On the other hand, contamination of Hudson River striped bass probably also had a beneficial effect on the population through the restrictions on commercial harvest and the health advisories against consumption.

b. White Perch

i. Life History and Distribution Within the Hudson River

White perch (*Morone americana*) resemble the closely related striped bass in general form and structure but are deeper bodied, more laterally compressed, and have no stripes. Adult white perch are much smaller than adult striped bass, averaging less than 10 in. in length and less than 3 lb in weight. Coloration ranges from dark olive to dark gray on the dorsal surface, shading to silvery white on the belly.

The natural range of this species extends along the Atlantic coast of North America from the southern Maritime Provinces of Canada and the St. Lawrence River to South Carolina in brackish and freshwater areas near the coast (Figure V-45). White perch are essentially estuarine, but landlocked populations exist in fresh water throughout their range (Mansueti 1964). Freshwater populations predominate in the northern part of the range and white perch are uncommon in salt water north of Cape Cod (Rounsefell 1975). Probably as a result of dispersal through canals, they are now found in Lakes Ontario and Erie (Hubbs and Lagler 1958). They have also been introduced accidentally into the Missouri River drainage (Hergenrader and Bliss 1971).

Coastal populations overwinter in the deeper waters of middle and lower estuaries (Mansueti 1957; Markle 1976). White perch spawn in shallow water following upstream migrations to areas of fresh or slightly brackish waters during the spring and early summer. Spawning also occurs in tributary streams. After spawning, adult white perch generally return to the lower reaches of estuaries. In the Hudson River estuary spawning occurs from early May to early July (Figure V-46), primarily north of Croton Bay.

Female white perch lay from 20,000 to 321,000 eggs, depending on their age and size. White perch eggs do not contain an oil globule and are small, 0.0625 in. in diameter. They sink to the bottom and, because they are very adhesive, stick to each other and to anything else they contact (Mansueti 1964). In the Hudson River white perch eggs are most abundant in the upper estuary (Figure V-47).

Hatching occurs in 1.5 to 6 days, with development occurring faster at higher temperatures. Newly hatched YSL are 0.0625 to 0.125 in. long. They remain on or near the bottom for three to five days and do not move about actively until the yolk sac is absorbed (Mansueti

Figure V-45. Native distribution of white perch in North America.

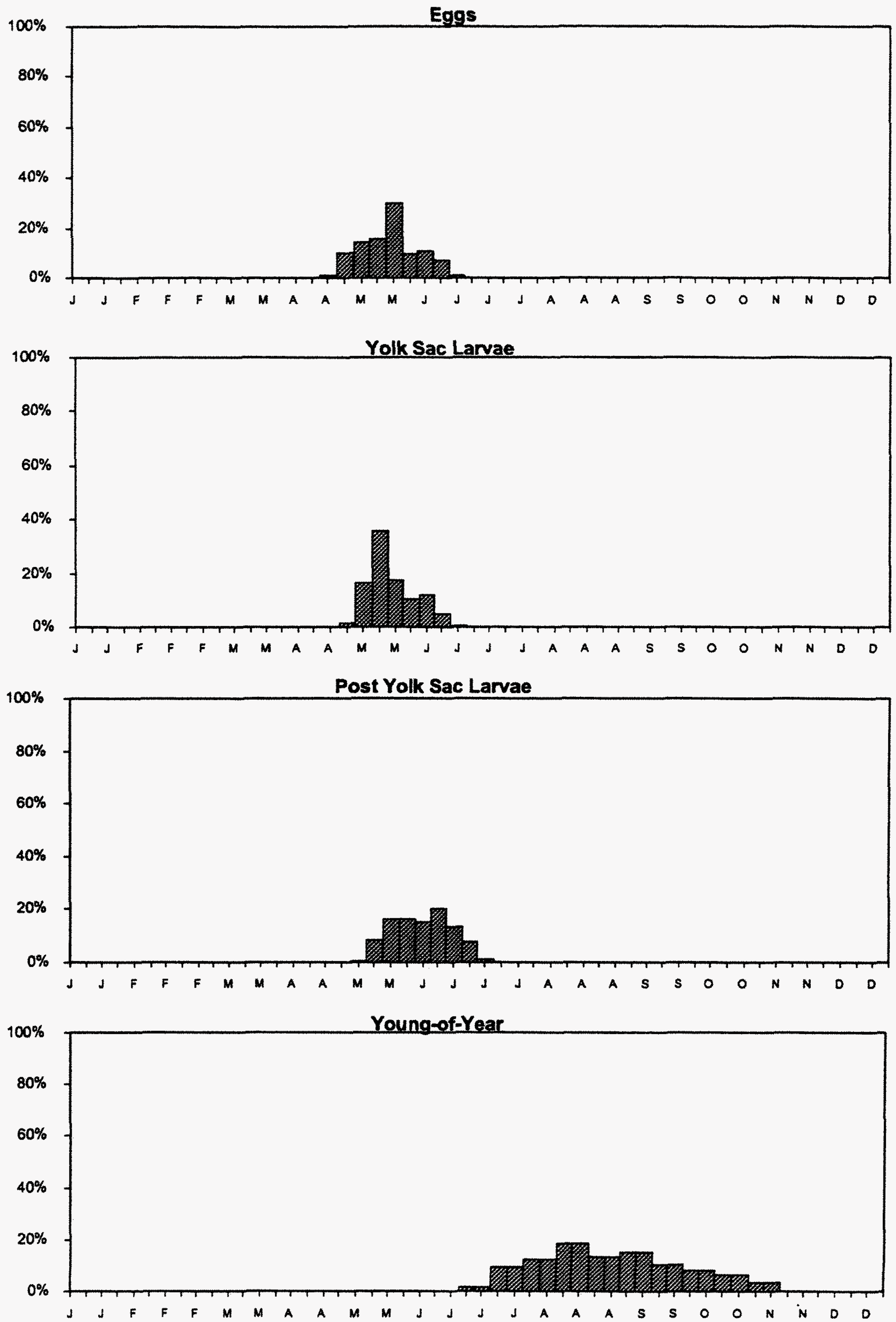


Figure V-46. Temporal distribution indices for white perch eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

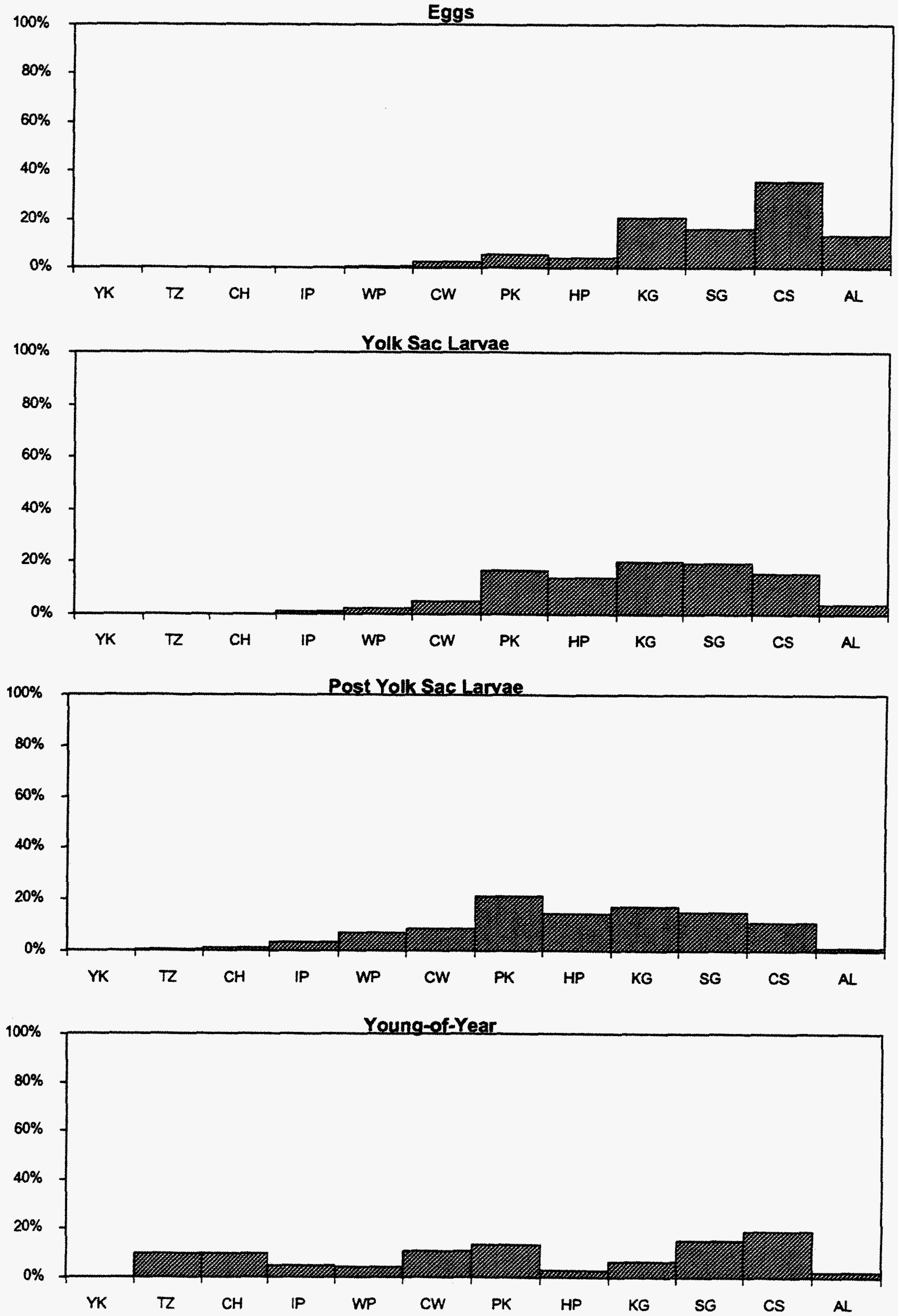


Figure V-47. Spatial distribution indices for white perch eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

1964). White perch YSL larvae are most abundant in the upper estuary but downriver of the area where eggs were most abundant (Figure V-47).

The yolk sac is completely absorbed when the larvae are a little over 0.125 in. long; the end of the PYSL stage occurs when the adult fin complement develops, usually about one month after hatching and when the young white perch are about 1 in. in length. White perch PYSL are abundant in the upper estuary, but co-occur extensively with striped bass PYSL in the middle estuary.

Juvenile white perch are about 3 in. long by the end of their first summer (Klauda et al. 1988a). They are prey for larger predators (including adult white perch and yearling and older striped bass). In the Hudson River estuary some white perch of both sexes become sexually mature at age 2, but all males and females are mature by ages 4 and 5, respectively (Klauda et al. 1988a).

ii. Temporal Changes in Abundance

Sampling Programs

Eggs and yolk-sac larvae are not sampled accurately because the durations of the egg and yolk-sac larval (YSL) stages are shorter than the interval between the weekly ichthyoplankton surveys. Thus, some eggs hatch and some YSL become post yolk-sac larvae (PYSL) between the weekly surveys and are not subject to sampling. This problem is compounded by the fact that white perch spawn in shallow water habitats that are difficult to sample with the ichthyoplankton sampling gear used by the Utilities in their monitoring surveys. PYSL are sampled more effectively than eggs or YSL because the duration of the PYSL life stage (about 3 weeks) is longer than the interval between the weekly surveys and PYSL are dispersed more widely across estuarine habitats. Although the YSL and PYSL indices were significantly correlated during the period from 1974 through 1997 ($r = 0.832$; $p = 0.000$), the average of the PYSL indices (3.6 larvae per 1000 m^3) was 7 times that for the YSL (0.5 larvae per 1000 m^3). YSL abundance may have been severely underestimated and the PYSL indices were used to describe the temporal changes in the abundance of the early life stages.

YOY white perch, like YOY striped bass, move into shallow water habitats and are effectively sampled with beach seines. YOY white perch are distributed more uniformly along the length of the estuary than YOY striped bass. Thus, the catches from the Utilities' beach seine survey (BSS) were used to generate an abundance index for YOY white perch. The average number of YOY white perch collected per seine haul during the period from mid-August to early October was used as the index of YOY abundance for each year. The BSS catches were also used to generate an abundance index for yearling white perch. The average number of yearling white perch collected per seine haul during the period from mid-August to early October was used as the index of yearling abundance for each year.

Abundance Indices

PYSL--During the period from 1980 through 1988, PYSL abundance fluctuated (Figure V-48). The PYSL index never fell below 2.7 larvae per 1000 m^3 (Table V-19) and two distinct oscillations in abundance occurred. The first oscillation peaked at 5.8 larvae per 1000 m^3 in 1982. The second oscillation began three years later when PYSL abundance increased to 5.6 larvae per 1000 m^3 and peaked in the following year at 8.1 larvae per 1000 m^3. Female white perch in the Hudson River estuary are 24% mature at age 2, 88% mature at age 3, and 96% mature at age 4 (Klauda et al. 1988). The time interval between the two peaks in PYSL abundance suggests that the first oscillation generated the second oscillation.

After 1988, the oscillations in PYSL abundance stopped. There was no time trend during the last nine years of the time series ($R^2 = 0.016$; $p = 0.749$). However, PYSL abundance was not low during this period. The average for the period, 3.8 larvae per 1000 m^3, was comparable to that occurring at the end of the initial linear increase in PYSL abundance.

YOY--During the period when PYSL abundance increased linearly (1974 through 1979), YOY abundance also increased linearly ($R^2 = 0.793$; $p = 0.017$) from 4.1 fish per haul to 17.0 fish per haul (Figure V-49) and the two indices were highly correlated ($r = 0.909$; $p = 0.012$).

During the period when the oscillations in PYSL abundance occurred (1980 through 1988), there were no comparable oscillations in YOY abundance and the two indices were not correlated ($r = -0.346$; $p = 0.362$). There was no temporal trend in YOY abundance during this period ($R^2 = 0.289$; $p = 0.136$) and the average abundance was 8.0 YOY white perch per seine haul.

During the period when the oscillations in PYSL abundance disappeared (1989 through 1997), there was no temporal trend in YOY abundance ($R^2 = 0.356$; $p = 0.090$) or correlation between the two indices ($r = -0.259$; $p = 0.501$). However, YOY abundance decreased and the average, 3.8 YOY white perch per seine haul, was significantly different ($p = 0.001$) from that observed during the period from 1980 through 1988.

Yearlings--The abundance of yearling white perch fluctuated between 1974 and 1979, falling from a high of 9.6 fish per haul in 1974 to a low of 0.4 fish per haul in 1977 and then

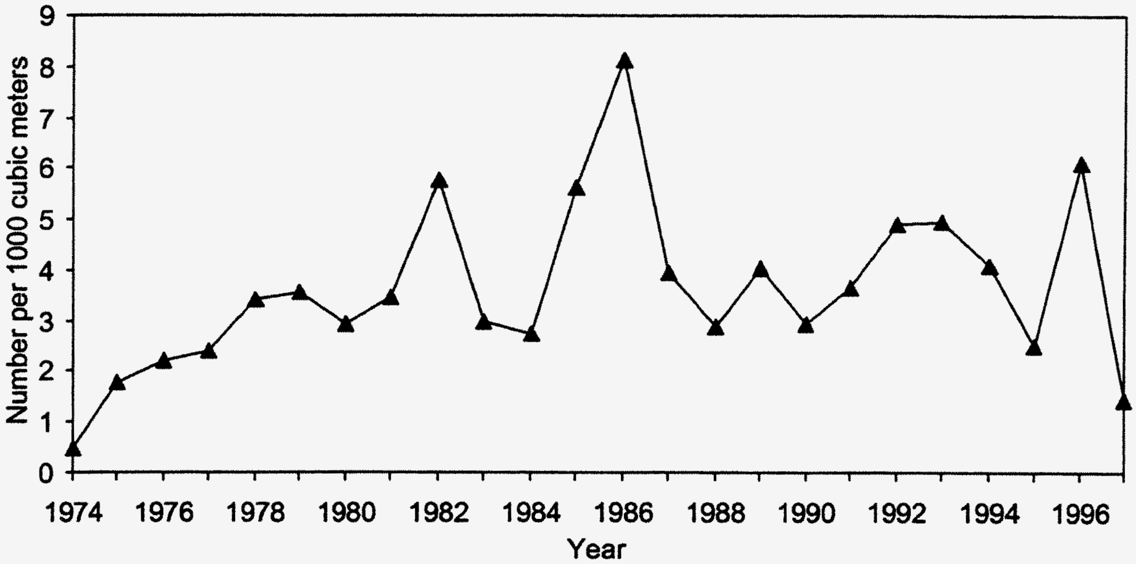


Figure V-48. White perch: annual abundance indices for post yolk-sac larvae (PYSL), 1974-1997.

TABLE V-19

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF DIFFERENT LIFE STAGES OF WHITE PERCH. (STANDARD ERRORS, WHERE AVAILABLE, ARE GIVEN AFTER "/".)

	PYSL	JUVENILE	AGE 1[c]
YEAR	LRS[a]	BSS[b]	BSS[b]
1968			
1969			
1970			
1971			
1972			
1973			9.57/2.24
1974	0.46/0.04	4.09/0.56	2.68/1.41
1975	1.78/0.15	8.04/1.95	3.31/0.43
1976	2.21/0.24	9.54/1.34	0.45/0.07
1977	2.43/0.13	6.78/1.11	4.92/2.37
1978	3.43/0.19	13.93/2.84	5.31/1.63
1979	3.57/0.10	17.03/2.75	3.24/0.94
1980	2.95/0.11	10.68/2.31	3.22/0.62
1981	3.47/0.17	10.30/1.29	4.31/0.80
1982	5.76/0.22	9.99/1.14	4.08/1.60
1983	2.98/0.10	10.36/2.02	4.31/1.11
1984	2.75/0.12	4.17/0.68	1.47/0.53
1985	5.64/0.21	4.35/1.08	1.71/0.43
1986	8.11/0.38	5.60/1.13	2.21/0.26
1987	3.97/0.12	8.88/1.68	1.23/0.25
1988	2.91/0.15	7.61/1.30	2.84/0.51
1989	4.06/0.37	6.28/1.72	2.25/0.59
1990	2.92/0.26	3.84/0.42	1.57/0.43
1991	3.64/0.24	4.03/0.75	1.34/0.18
1992	4.92/0.20	3.68/0.65	1.89/0.55
1993	4.96/0.18	5.84/0.95	0.65/0.19
1994	4.11/0.17	2.84/0.58	1.14/0.34
1995	2.51/0.11	3.21/0.48	0.29/0.10
1996	6.12/0.27	0.31/0.13	0.45/0.07
1997	1.46/0.07	3.91/0.56	

a Sum of weighted average number per m^3 for 7 consecutive sampling weeks over period of peak abundance.

b Average number per 100' seine haul for sampling from mid-August to early October (weeks 33-40).

c Applied to the year in which the cohort was spawned.

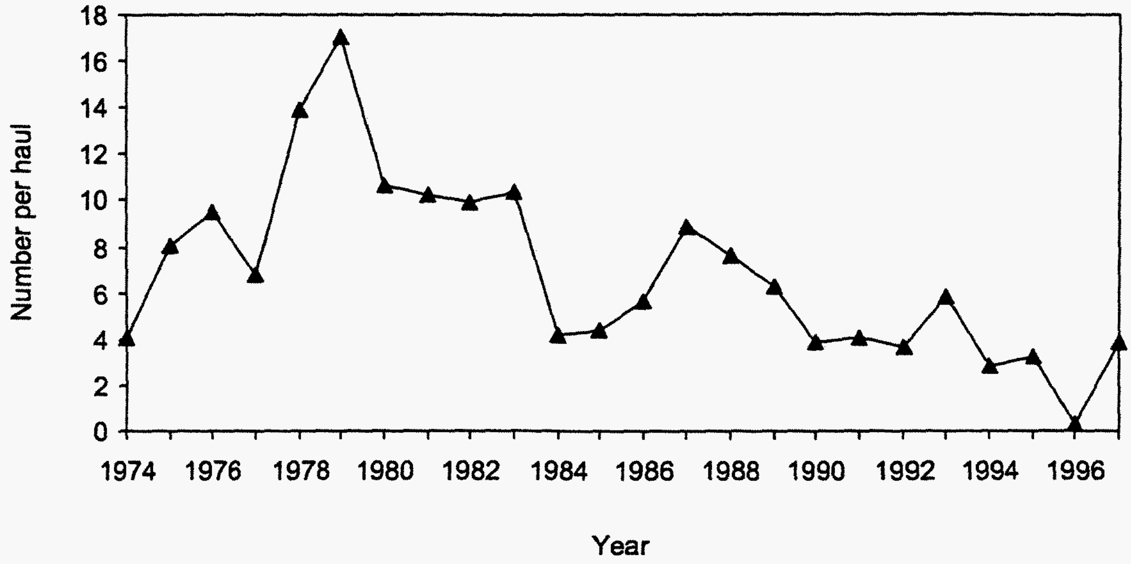


Figure V-49. White perch annual indices of abundance for young-of-the-year (YOY), 1974-1997.

rising to 5.3 fish per haul in 1979 (Figure V-50). During the next 5 years (1980 through 1984), yearling abundance remained relatively constant, averaging 3.8 fish per haul. Yearling abundance decreased in 1985 and remained low for the remainder of the time series, averaging 1.5 fish per haul. Yearling abundance was positively correlated with YOY abundance at the end of the preceding summer over the entire time series.

iii. Potential Influences on Abundance

Fishing mortality is not likely to affect white perch abundance. The commercial fishery that existed for white perch in the Hudson River was closed in 1976 due to levels of PCBs in excess of the FDA limit. White perch are commonly caught by recreational fishermen, but because of their small size in the Hudson River they are not the object of a major recreational fishery. In addition, the public health advisory recommending against the consumption of fish from the Hudson River because of PCB levels in excess of the FDA limit further reduces the recreational interest in this species. Competition, predation, water withdrawals, and water quality are more likely to affect white perch abundance. As a result, fishing was not considered further in the assessment of potential influences on white perch abundance. In the following paragraphs, the effects of the other factors are exasmined within each life stage.

PYSL White Perch

Zebra Mussels - A potential influence on the abundance of PYSL white perch is the zebra mussel *Dreissena polymorpha*. Zebra mussels were first detected within the Hudson River estuary in May 1991 and spread throughout the freshwater portion of the estuary by the end of 1992 (Strayer et al. 1996). Phytoplankton and microzooplankton declined 80 to 90% after 1992 (Strayer et al 1999). However, copepods, which are the preferred prey of small fish, were unaffected by the zebra mussel populations (Pace et al. 1998) and PYSL abundance after the zebra mussel invasion (1993 through 1997) was not consistently lower than that observed during the 6 years preceding the invasion (1987 through 1992). Zebra mussels do not appear to have affected PYSL abundance. The most significant change in the abundance of PYSL white perch, the absence of a very pronounced peak in PYSL abundance in 1990 or 1991 (which should have occurred if the oscillations in PYSL abundance observed during the 1980s had continued into the 1990s), occurred before zebra mussels became abundant in the Hudson River.

Entrainment-- Another potential influence on the abundance of PYSL white perch is the mortality caused by the entrainment of eggs and larvae by power plants withdrawing cooling water from the Hudson River estuary. During the period from 1974 through 1979 when PYSL abundance increased linearly, the cumulative entrainment mortality

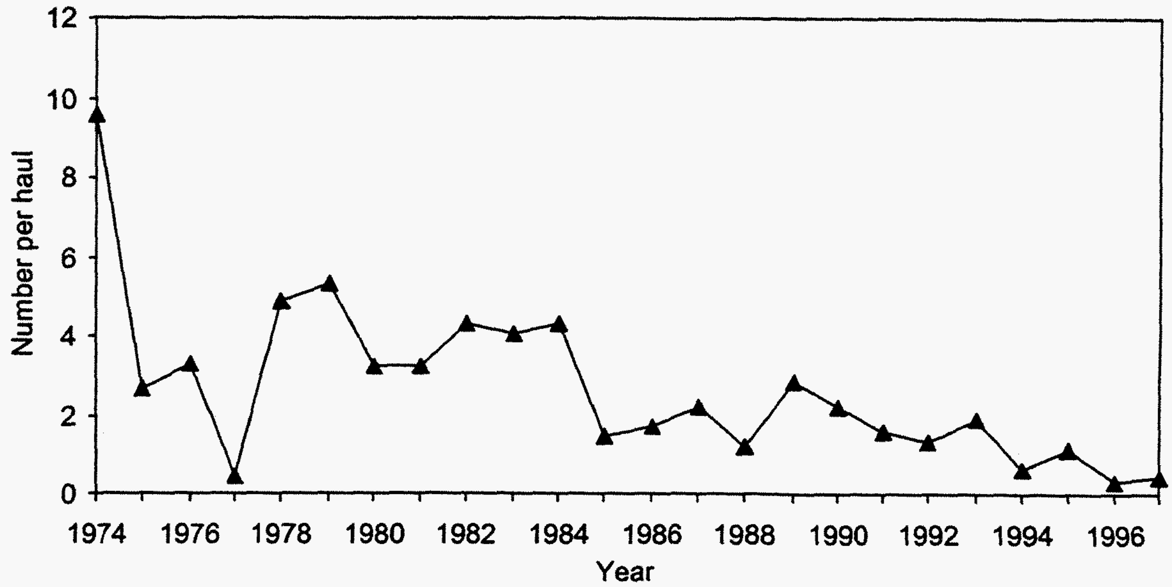


Figure V-50. White perch annual indices of abundance for yearlings, 1974-1997.

from all of the power plants (Figure V-51, Table V-20) ranged from 15.6% to 25.9% and exhibited a negative temporal trend ($R^2 = 0.487$; $p = 0.037$).

The decline in entrainment mortality continued through 1982. Thus, the first oscillation in PYSL abundance during the period from 1980 through 1988 occurred when the cumulative entrainment mortality was low, which is consistent with the hypothesis that entrainment mortality influenced PYSL abundance. However, the second oscillation in PYSL abundance peaked in 1986 when entrainment mortality was relatively high (26.8%) and there was no temporal trend in entrainment mortality over the entire period ($R^2 = 0.035$; $p = 0.627$).

During the period from 1989 through 1997 when there was no temporal trend in PYSL abundance, the cumulative entrainment mortality ranged from 9.0% to 20.9% and exhibited a negative temporal trend ($R^2 = 0.487$; $p = 0.037$). This is the period when the oscillations in PYSL abundance disappeared and there appeared to be a significant decrease in PYSL survival.

Water Quality-- Another factor that might affect PYSL abundance is water quality. Larval white perch are closely associated with shallow, weedy areas (Schmidt et al. 1992). Dissolved oxygen levels in these areas decline at night when the aquatic plants stop producing oxygen. If the nocturnal decline in dissolved oxygen is widespread and precipitous, larval fish may suffocate because their small size and limited swimming ability prevents them from moving out of extensive weed beds. This is more likely to be a problem when untreated sewage is discharged into the estuary and the demand for oxygen from bacteria feeding upon the organic matter in the sewage discharges is high.

Treated effluents from wastewater treatment facilities may also be toxic to larval fish when chlorine is used to disinfect the waste streams. The amount of chlorine needed to disinfect a discharge is directly related to the amount of organic matter present in the waste stream. Thus, improvements in wastewater treatment decrease both biological oxygen demand (BOD) and the amount of chlorine used for disinfection. Although it may not be possible to separate the effects of these two variables on larval fish populations under field conditions, improvements in wastewater treatment should increase the abundance of larval fish.

During the period from 1974 and 1981, a series of improvements in wastewater treatment within the upper Hudson River and Mohawk River basins decreased the BOD in the effluent discharged into the upper portion of the Hudson River estuary (regions 6-12) more than 60% (Darmer 1987). Major improvements in wastewater treatment occurred in each year during the period from 1974 through 1979 and the linear increase in PYSL

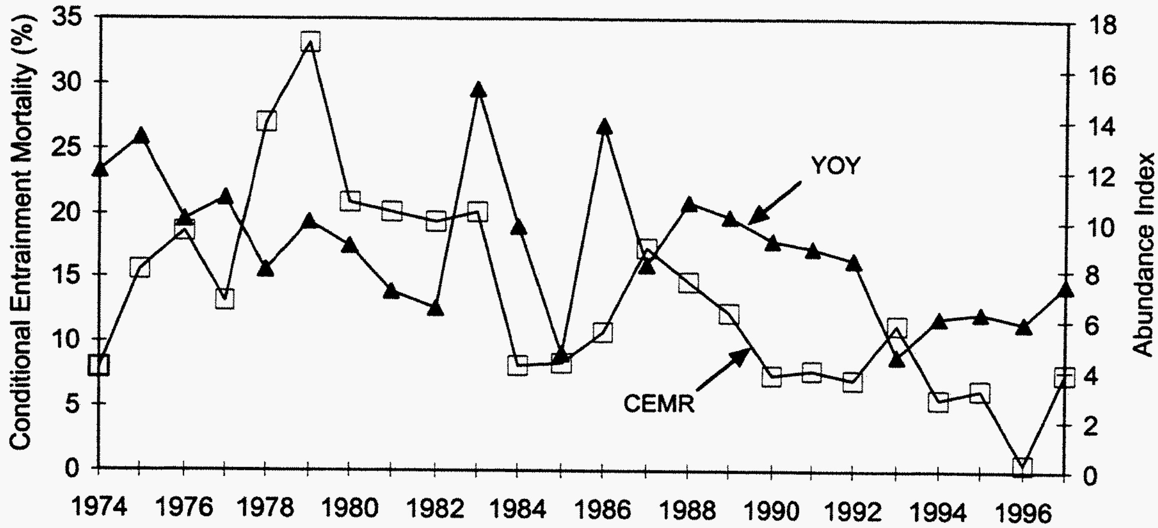


Figure V-51. White perch cummulative conditonal entrainment mortality (CEMR) from all of the power plants on the Hudson River and annual abundance indices for young-of-the-year (YOY), 1974 through 1997.

TABLE V-20

ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON WHITE PERCH. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	9.10	7.45	0.80	4.21	2.73	0.27	0.98		23.21
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									24.87
1975	E	2.96	8.65	6.40	6.89	1.93	0.40	1.81		25.90
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									27.50
1976	E	2.18	3.22	5.98	6.79	0.69	0.47	1.99		19.63
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									21.36
1977	E	2.11	7.27	5.82	5.28	1.00	0.49	1.35		21.30
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									23.00
1978	E	1.17	5.28	4.27	2.63	0.61	0.93	1.74		15.58
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									17.40
1979	E	0.85	8.02	5.91	4.23	0.43	0.25	1.17		19.33
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									21.08
1980	E	0.38	3.36	6.04	5.94	0.73	0.39	2.03		17.57
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									19.35
1981	E	0.32	6.54	1.72	3.74	1.32	0.16	0.92		13.97
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									15.82
1982	E	0.17	4.33	2.49	2.18	1.28	0.50	2.30		12.57
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									14.46
1983	E	1.01	17.23	5.78	3.97	3.16	0.39	1.57		29.61
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									31.13
1984	E	0.65	8.92	3.88	3.31	0.98	0.50	1.76	0.44	18.96
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									20.71
1985	E	0.05	0.55	3.53	3.88	0.24	0.31	0.78	0.12	9.16
	I	0.10	2.60	0.10	0.30	0.00				3.09
	T									11.96
1986	E	0.28	4.07	9.40	14.44	0.61	0.08	0.30	0.28	26.78
	I	0.00	3.20	0.10	0.30	0.00				3.59
	T									29.41
1987	E	0.01	0.66	6.87	7.54	0.38	0.64	0.68	0.22	16.10
	I	0.00	1.20	0.10	0.30	0.00				1.59
	T									17.44
1988	E	0.53	7.94	4.93	4.88	1.80	0.57	1.40	0.65	20.80
	I	0.00	1.10	0.10	0.30	0.00				1.50
	T									21.98
1989	E	0.78	4.03	6.66	4.98	1.30	0.48	2.62	0.54	19.65
	I	0.00	1.40	0.10	0.40	0.00				1.89
	T									21.17
1990	E	0.38	3.48	5.40	5.27	1.07	0.89	2.49	0.35	17.91
	I	0.00	0.70	0.20	0.40	0.00				1.30
	T									18.97
1991	E	0.22	1.40	7.45	6.08	1.70	0.29	0.99	0.34	17.29
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									19.08
1992	E	0.28	2.70	6.17	4.31	1.29	0.21	1.94	0.54	16.31
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									18.11
1993	E	0.12	2.34	1.77	2.96	1.14	0.21	0.38	0.42	9.01
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									10.97
1994	E	0.28	3.14	4.56	2.19	0.89	0.42	0.64	0.39	11.93
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									13.83
1995	E	0.09	1.92	5.04	4.29	0.47	0.37	0.34	0.27	12.22
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									14.12
1996	E	0.07	4.88	2.90	2.61	0.50	0.58	0.30	0.23	11.55
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									13.46
1997	E	0.16	1.29	4.29	6.24	1.66	0.53	0.73	0.49	14.54
	I	*0.02*	*1.70*	*0.12*	*0.33*	*0.00*				*2.16*
	T									16.39
AVERAGE	E	1.01	4.94	4.92	4.95	1.16	0.43	1.30	0.38	17.54
	I	0.02	1.70	0.12	0.33	0.00				2.16

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A]Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B]Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C]RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21q; Impingement-Appendix VI-2-B, Table 22 abundance during this period is consistent with a steady improvement in water quality and increasing larval survival. The major improvements in wastewater treatment were completed in 1981 and water quality should have been good during the 1980s. This improvement in water quality coincided with the maturation of the 1978 cohort in 1982 and high larval survival was probably responsible for the even greater reproductive effort that occurred when the 1982 cohort matured.

Competition-- The disappearance of the oscillations in PYSL abundance after 1986 suggests that another factor began to affect larval survival in the late 1980s. One of the most striking changes occurring in the Hudson River during the late 1980s was a major increase in the number of adult striped bass spawning in the estuary. Moratoria greatly curtailing the commercial and recreational harvest of sub-adult and adult striped bass were instituted from 1986 through 1990. The subsequent increase in the abundance of adult striped bass produced an 8-fold increase in the abundance of PYSL striped bass in 1990 and a 12-fold increase in 1994, relative to the PYSL abundance observed in 1986. Striped bass are larger than white perch of the same age. Thus, striped bass should win whenever the larvae from these two species compete. If the increase in the abundance of PYSL striped bass produced by the changes in the fishing regulations for large striped bass resulted in competition between these two species after 1986, the abundance indices for PYSL striped bass and white perch should be negatively correlated. The abundance indices were positively correlated ($r = 0.673$; $p = 0.023$), which suggests that competition wasn't involved in the disappearance of the oscillations in the abundance of PYSL white perch after 1988.

Predation-- However, competition is not the only interaction that could occur between striped bass and white perch when the abundance of PYSL striped bass is high. Small numbers of striped bass become piscivorous during the late PYSL and early YOY stages when striped bass are reared by intensive culture. At the Hudson River hatchery, if piscivorous individuals were not removed, they eventually consumed all of the smaller striped bass in the rearing tanks. However, when they were removed, some of the remaining individuals became piscivorous and regular grading (separation of larger individuals from smaller ones) was necessary throughout the summer for high production at the Hudson River hatchery. The number of piscivorous individuals generally represents a very small fraction of the population of larval striped bass. Thus, the impact of the piscivorous striped bass PYSL and YOY on the larval population of white perch should decrease as the abundance of larval striped bass increases because the frequency of contact between piscivorous striped bass and smaller white perch will decrease. Thus, predation by piscivorous striped bass will produce a positive correlation between the PYSL indices for striped bass and white perch. The appearance of piscivorous striped bass should also cause the oscillations in the abundance of larval white perch to disappear after 1986 because the relative abundance of white perch in the combined larval population would increase as white perch abundance started to rise. This would increase the frequency of encounter between piscivorous striped bass and larval white perch and the resulting predation should damp the increase in the abundance of larval white perch.

YOY White Perch

Entrainment-- During the period from 1974 through 1979, PYSL abundance increased over 10-fold, from 0.5 larvae per 1000 m^3 to 5.8 larvae per 1000 m^3; YOY abundance increased 4-fold, from 4.1 fish per haul to 17.0 fish per haul. Although the abundance of YOY white perch appeared to be directly related to the abundance of PYSL white perch during this period, there was no correlation between YOY abundance and entrainment ($r = 0.078$; $p = 0.842$).

During the period from 1980 through 1997, the abundance of YOY white perch did not appear to be directly related to the abundance of PYSL white perch. YOY abundance and entrainment were not significantly correlated during this period ($r = 0.352$; $p = 0.152$).

Regrowth of Water Chestnut-- YOY abundance did not appear to be related to the abundance of PYSL white perch after 1979. YOY abundance did not increase when PYSL abundance peaked in 1982 and 1986 and these two life stages were not correlated during the period from 1980 through 1988. Ironically, the same improvements in wastewater treatment that allowed the oscillations in abundance to develop during the PYSL life stage may have prevented them from developing during the YOY life stage. The clarity of the water within the estuary is affected by wastewater discharges during July and August when freshwater flows are low. As a result, water clarity in the upper portion of the estuary should have increased when the improvements in wastewater treatment in this section of the estuary reduced the discharge of suspended solids. Ordinarily, an increase in water clarity should have increased the growth of submerged aquatic plants and increased the survival of small fish by providing more places for them to hide from predatory fish. However, in the upper portion of the Hudson River estuary, water chestnut *Trapa natans* is the dominant plant species. This species has leaves that float on the surface and it eliminates, through shading, the submerged aquatic plants that provide cover for small fish. Water chestnut creates another problem for small fish when extremely dense stands develop during July and August. The dense stands reduce water circulation and dissolved oxygen concentrations fall to very low levels at night (NAI 1991), driving small fish to the periphery where they become vulnerable to predation.

The timing of the changes in YOY abundance are also consistent with the changes in the abundance of water chestnut in the Hudson River estuary occurring between the mid

1970s and the mid 1980s. The herbicide 2,4-D was used by NYSDEC to control water chestnut populations in the Hudson River from 1962 through 1976, when concerns over the effects of 2,4-D on other plants and young fish within the estuary ended the program (Kiviat 1993). The cessation of chemical treatment and the initial recovery of the plant community after the control program was terminated may explain the increase in PYSL and YOY abundance during the 1970s. Water chestnut probably began to dominate the plant community during the 1980s and dense beds of water chestnut were present throughout the freshwater portion of the estuary by the late 1980s (Schmidt et al. 1992). The development of dense beds of water chestnut may be responsible for the disappearance of the positive correlation between PYSL and YOY abundance during the 1980s.

Predation-- The dense beds of water chestnut may have contributed to the decline in the abundance of YOY white perch observed after 1988 but they were probably not the primary causal factor. There was no correlation between YOY abundance and entrainment during this period ($r = 0.332$; $p = 0.382$). The primary causal factor was probably the increase in the abundance of PYSL striped bass and the appearance of piscivorous striped bass. PYSL striped bass are more abundant than PYSL white perch in the lower portion of the estuary (regions 1-5); PYSL white perch are more abundant than PYSL striped bass in the upper portion of the estuary (regions 6-12). Thus, the survival of PYSL and YOY white perch should have been higher in the upper portion of the estuary during the period when the abundance of PYSL striped bass was high. In order to check this prediction, abundance indices for YOY white perch within the lower (regions 1-5) and upper (regions 6-12) portions of the estuary were generated from the Utilities' beach seine survey. The average number of YOY white perch collected per seine haul during the period from mid-August to early October was used as the annual abundance index for each section of the estuary.

The results are consistent with the prediction that the interaction between striped bass and white perch was more intense in the lower portion of the estuary. When the abundance of PYSL striped bass was low and there was a positive trend in the abundance of PYSL white perch (1974 through 1979), YOY white perch were usually more abundant in the upper portion of the estuary (Figure V-52). When the abundance of PYSL striped bass was low and water chestnut began to dominate the community of aquatic plants in the estuary (1980 through 1988), YOY white perch were not consistently more abundant in the upper portion of the estuary. The average level of abundance was also lower than that for the period from 1974 through 1979. When the abundance of PYSL striped bass was high (1989 through 1997), the abundance of YOY white perch in the upper portion of the estuary remained relatively constant. However, in the lower portion of the estuary, YOY abundance declined in 1990 and remained below the lowest level observed prior to 1989 for the remainder of

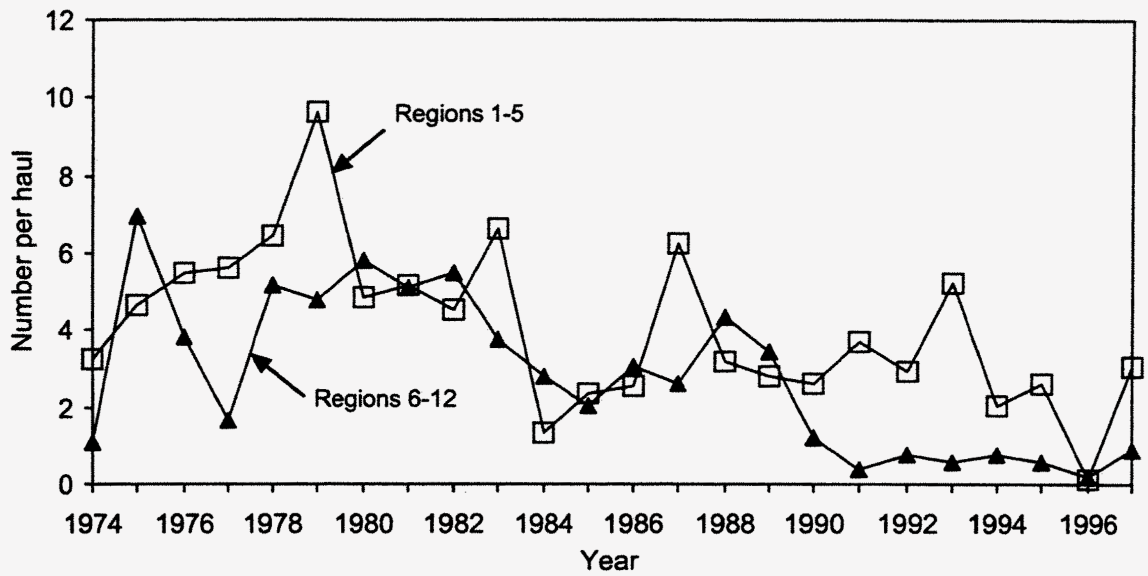


Figure V-52. White perch annual indices of abundance for young-of-the-year (YOY) from regions 1-5 and regions 6-12, 1974 - 1997.

the period. This decrease in the abundance of YOY white perch occurred during the only period when PYSL striped bass were more abundant than PYSL white perch (Figure V-53). Moreover, the abundance of PYSL striped bass was extremely high in 1996 when the abundance of YOY white perch was very low throughout the estuary (Figure V-52).

Yearling White Perch

The factors affecting survival of white perch during the first summer of life appear to determine the abundance of yearling white perch. For the period from 1975 through 1997, yearling abundance was positively correlated with YOY abundance at the end of the preceding summer ($r = 0.700$; $p = 0.000$). However, when the abundance of large striped bass was very high, predation on YOY white perch during the late winter and spring may have determined yearling abundance.

YOY white perch move down river during the fall (LMS 1986) and into the lower portion of the estuary during the winter (Ross et al. 1987). The winter aggregation of YOY white perch breaks up during late April and early May. However, the amount of shallow water habitat in the lower portion of the estuary is twice that in the upper portion of the estuary and the majority of YOY white perch remain in the lower portion of the estuary.

Sub-adult and adult striped bass move into the lower portion of the estuary during late winter and early spring and remain there until late May or early June (Waldman et al. 1990). During the spring, the average ratio for striped bass and their prey in the Hudson River is 0.26 (Dew 1988). YOY white perch are generally less than 4 in. long in the fall and striped bass greater than 15 in. in length should be able to eat the YOY white perch moving down into the lower portion of the estuary. This size group includes the largest age 2, most of the age 3, and all of the age 4 and older striped bass in the Hudson River population (NAI 1997).

The predation on YOY white perch during the winter is probably not heavy. About 10% of the striped bass, greater than 12 in.es in length, collected for stomach analysis during the winter mark-recapture program had YOY white perch or striped bass in their stomachs (Dunning et al 1997). However, striped bass will feed more actively as water temperatures rise and predation on YOY white perch should increase during the spring.

Annual indices of abundance for yearling white perch were generated for the lower (regions 1-5) and upper (regions 6-12) portions of the estuary from the Utilities' beach seine survey. The average number of yearling white perch collected per seine haul during the period from mid-August to early October in each year was used as the abundance index for each portion of the estuary. During the period from 1974 through

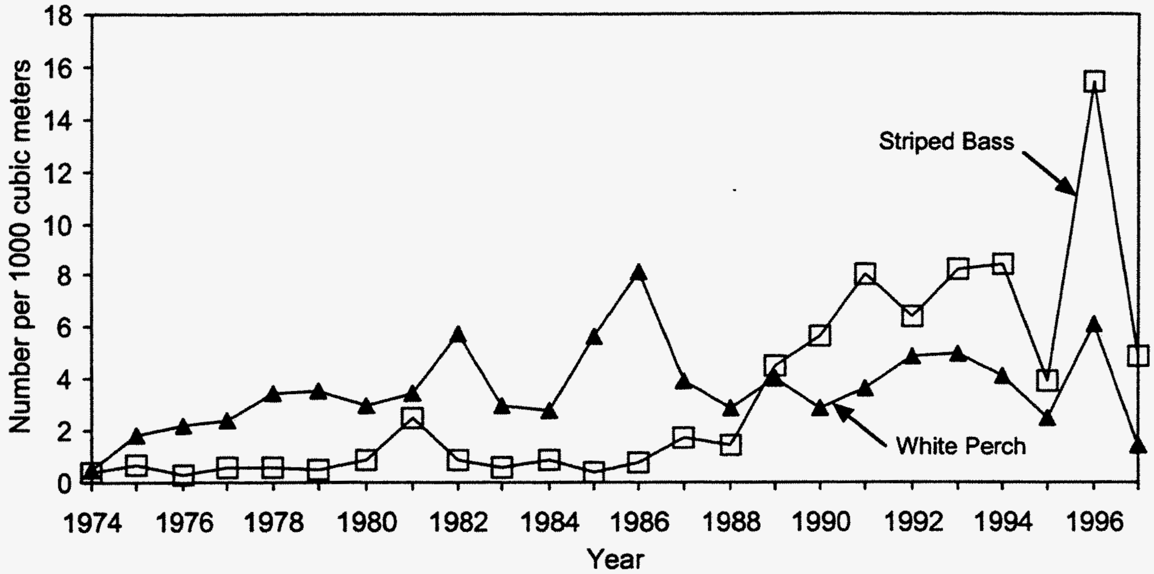


Figure V-53. Annual abundance indices for post yolk-sac larvae (PYSL) white perch and striped bass, 1974-1997.

1986, the average abundance of yearling white perch in the lower portion of the estuary was 2.3 fish per haul and the variance was 2.90. In the upper portion of the estuary, the average abundance was 1.2 fish per haul and the variance was 0.44. During the period from 1987 through 1997, the abundance of yearling white perch in the lower portion of the estuary was 0.4 fish per haul and the variance was 0.04. In the upper portion of the estuary, the average abundance was 1.0 fish per haul and the variance was 0.47. Thus, there was a significant decrease in the average abundance of yearling white perch in the lower portion of the estuary during the period when abundance of post-yearling striped bass was increasing in the Hudson River estuary.

The abundance of yearling white perch in the lower portion of the estuary was low throughout the period from 1985 through 1997 (Figure V-54). The low values observed prior to 1988 may have been a continuation of the fluctuation in yearling abundance that began in 1982 (the decreasing portions of the fluctuations in yearling abundance observed prior to 1982 ranged from 2 to 3 years in length). However, it is unlikely that the low yearling abundance observed in 1988 and 1989 was part of the fluctuation in yearling abundance that began in 1982. Yearling abundance was uniformly low throughout the estuary after 1993. Thus, it appears that the presence of three strong cohorts in the population of striped bass older than age 2 and younger than age 9 reduced the abundance of yearling white perch in the lower portion of the estuary but not in the upper portion of the estuary. The presence of at least 5 strong cohorts in the population of striped bass older than age 2 and younger than age 9 reduced the abundance of yearling white perch throughout the estuary.

c. *Atlantic Tomcod*

i. *Life History and Distribution Within the Hudson River*

Nineteen members of the codfish family (Gadidae) are found along the Atlantic coast of Canada and the United States, but only the Atlantic tomcod, an inshore species that ranges from Labrador to the Chesapeake Bay, is anadromous (Figure V-55); the southern limit of its spawning range is the Hudson River (Grabe 1978). In Canada the Atlantic tomcod occurs in the mid- to lower St. Lawrence River and is landlocked in at least two freshwater lakes (Scott and Crossman 1973).

Atlantic tomcod enter coastal estuaries and rivers to spawn in shallow fresh or brackish water during midwinter. In the Hudson River estuary adult Atlantic tomcod occur at least as far north as the Saugerties region during spawning runs; the largest concentrations, however, are consistently found in the middle estuary between West Point and Poughkeepsie. After spawning in late December or early January, Atlantic tomcod return to coastal waters.

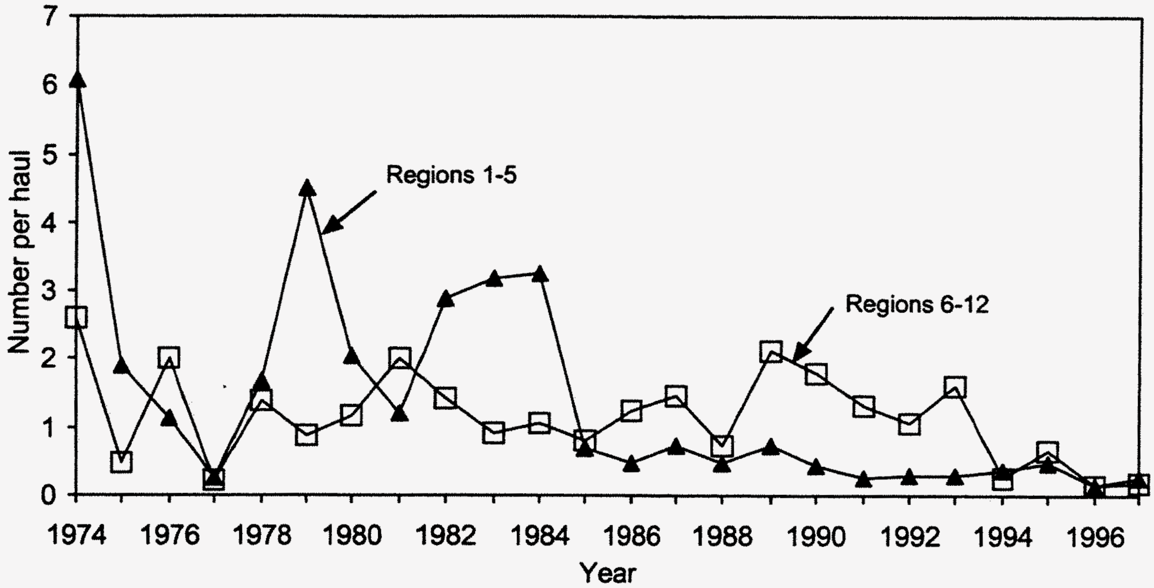


Figure V-54. White perch annual indices of abundance for yearlings from regions 1-5 and regions 6-12, 1974-1997.

Figure V-55. Distribution of Atlantic tomcod in North America.

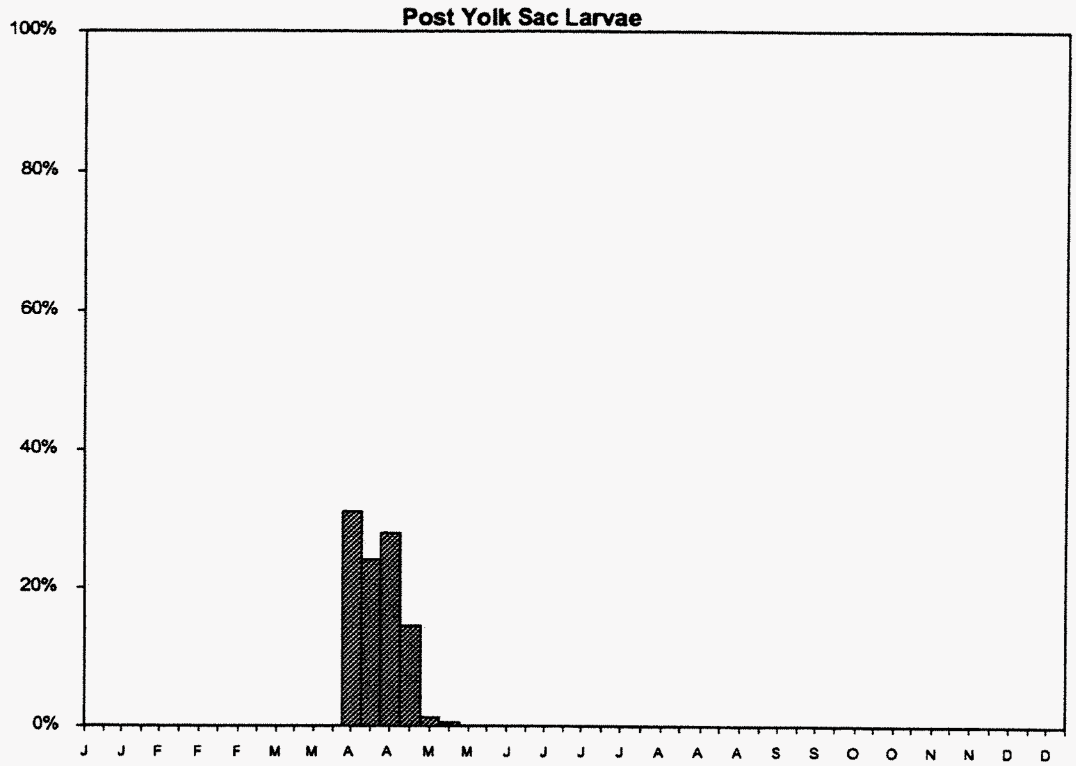
The Hudson River population is the southernmost major breeding population (Dew and Hecht 1976). No spawning has been documented in either the Connecticut River (Marcy 1976) or Long Island Sound (Richards 1959), and limited spawning may occur in the Raritan River and/or Raritan Bay (IA 1977). Unlike more northern populations, age 1 fish constitute most of the Hudson River spawning stock.

Atlantic tomcod eggs are about 0.0625 in. in diameter and nonadhesive. The average number of eggs per female in the Hudson River population has ranged from 12,400 to 22,500 eggs at age 1 and from 32,500 to 53,100 eggs at age 2 (NAI 1992). In the Hudson River water temperatures are generally less than 37°F when spawning occurs, and the eggs take at least a month to hatch.

Tomcod larvae are about 0.1875 in. long at hatching. YSL are pelagic and move downstream as they develop. In the Hudson River the abundance of YSL peaks in March (Figure V-56). YSL are found throughout the lower half of the estuary, whereas PYSL are concentrated in the Yonkers and Tappan Zee regions (Figure V-57). The yolk sac is absorbed by 0.25 in., and onset of feeding by PYSL may depend on water temperatures. PYSL appear during March and peak in abundance during April in the Hudson River estuary. Juvenile Atlantic tomcod appear in April and reach their peak numbers in the Hudson River in mid-May. Although some juvenile tomcod remain in the Hudson River throughout the summer, some proportion of the population may move out of the lower estuary into New York Bay and Raritan Bay when water temperatures rise during late May and June. By mid-May juvenile tomcod range in length from 1 to 2 in.; by July their average length is about 3 in.

Juvenile growth slows or ceases in summer (Grabe 1978; Klauda et al. 1988b). Growth slows at temperatures above 66°F and essentially stops in early July when temperatures exceed 71°F. It begins again when water temperatures fall below 77°F during late August and early September (TI 1978). Following a period of rapid growth during the fall, mature young-of-year (YOY) migrate upriver to spawn. Juvenile tomcod generally double their summer length by December to a mean total length about 6 in. Most of the juvenile Atlantic tomcod in the Hudson River are sexually mature by the end of December and reproduce in early January.

Juvenile tomcod feed on copepods and amphipods. Adult tomcod feed on shrimp, amphipods, marine worms, small mollusks, and occasional juvenile fish. Juvenile tomcod are eaten by many larger predators, including juvenile bluefish during the summer months (Juanes et al. 1993).



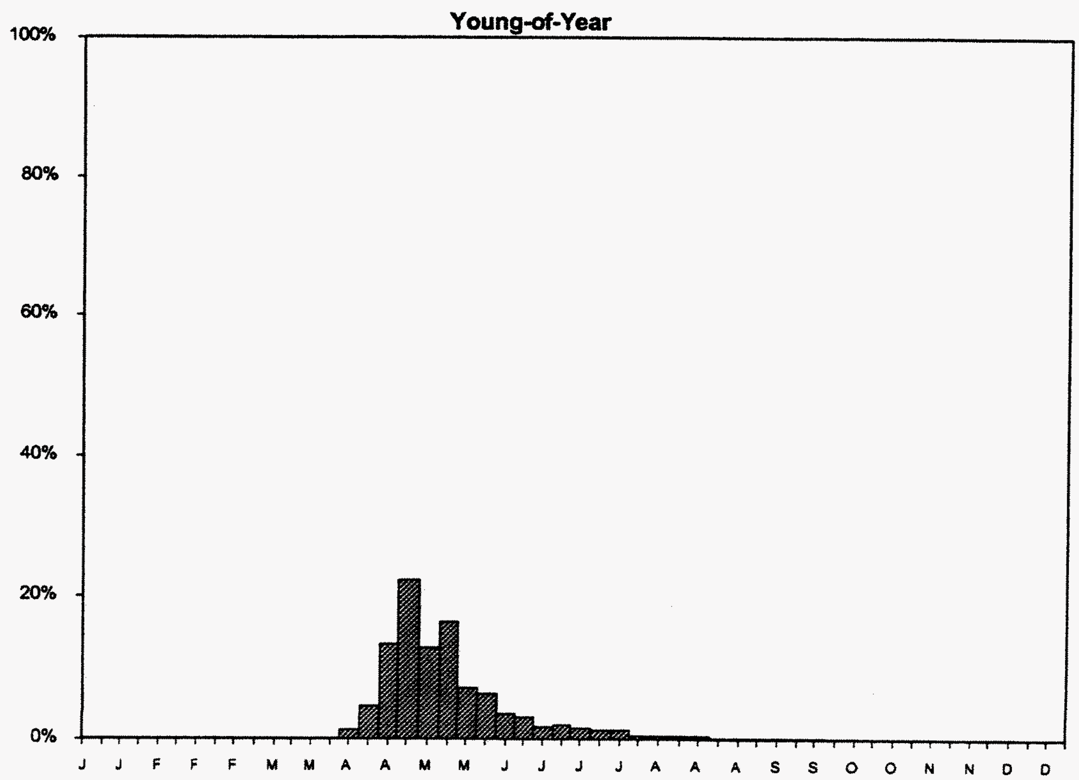


Figure V-56. Temporal distribution indices for Atlantic tomcod collected during Long River surveys of the Hudson River Estuary, 1991-1997.

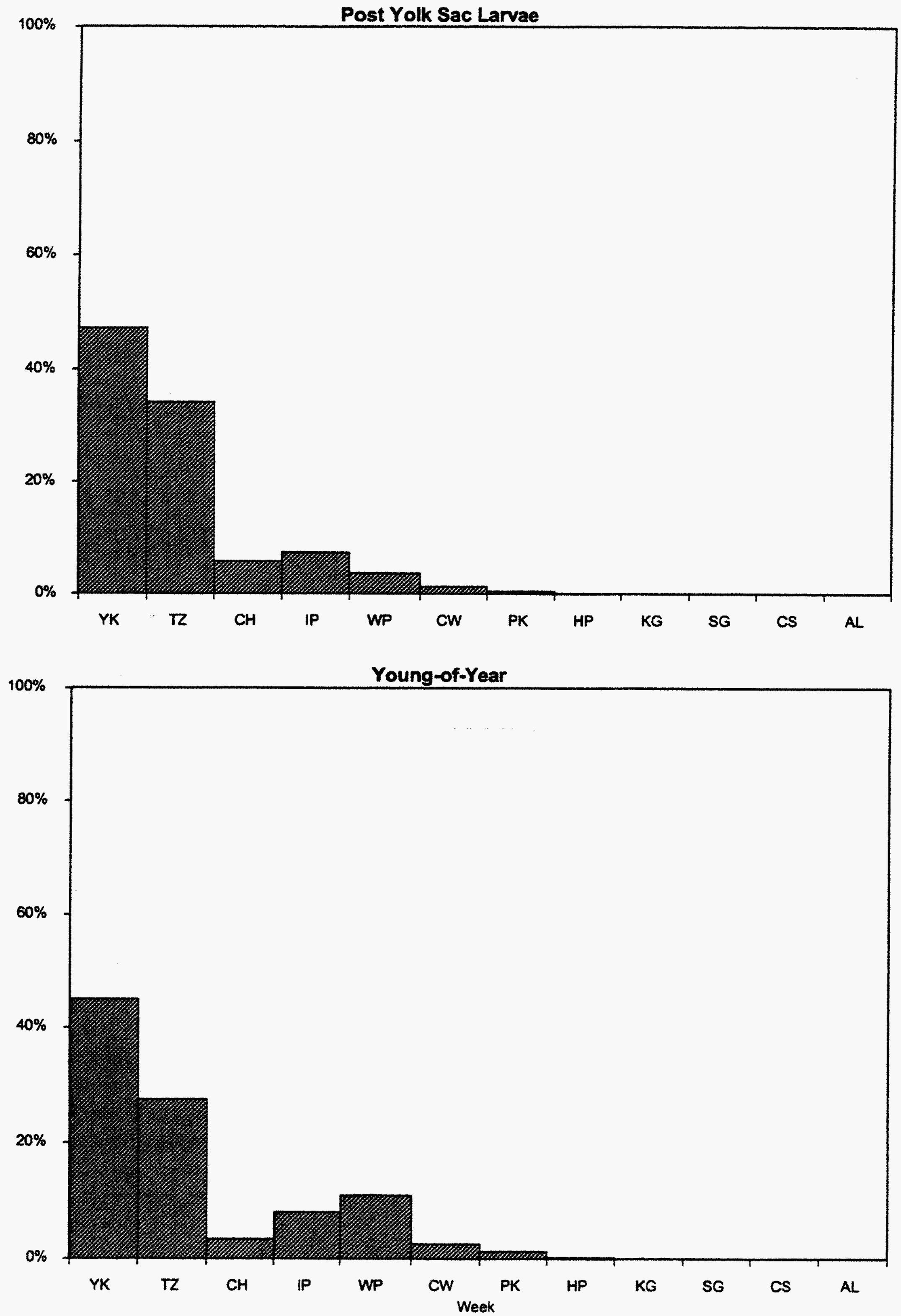


Figure V-57. Spatial distribution indices for Atlantic tomcod collected during long river surveys of the Hudson River estuary, 1991-1997.

ii. Temporal Changes in Abundance

Sampling Programs

Atlantic tomcod spawning within the Hudson River estuary were marked on the spawning grounds in the middle of the estuary and recaptured near the mouth of the estuary after spawning. Information on the age structure, sex ratio by age, and fecundity by age in the spawning population was also collected during the winter surveys. The mark-recapture information was used to generate an absolute estimate of total abundance for the spawning population. The estimate of total abundance was then combined with the age-specific biological information to generate an estimate of the total number of eggs deposited by the spawning population.

The spawning population estimates from the winters of 1987-88 through 1997-98 are the most reliable. These estimates were generated from a marking program involving box traps in the estuary north of Yonkers, a recapture program involving bottom trawls in the lower estuary off Manhattan Island, and a recapture period extending into mid-April. Although mark-recapture estimates from 1974-75 through 1978-79 were calculated by McLaren et al. (1988) using different sampling methods, they have been included in the data series for describing absolute abundance of the spawning stock. These estimates could contain a positive bias due to inclusion of box trap sampling from the lower river regions in the recapture effort (since these samples contained few fish marked in primary spawning regions), however the estimates probably do reflect major patterns of abundance changes among years.

The egg deposition estimates, because of their dependence upon the spawning population estimates, are most reliable for the period from 1988 through 1997. The ichthyoplankton surveys (LRS) generally began too late to sample yolk-sac larvae (YSL) adequately and no abundance estimate was generated for this life stage. The LRS surveys started soon enough to capture post yolk-sac larvae (PYSL) but often missed the period of peak abundance for this life stage. They also did not sample below the George Washington Bridge in March and April (when and where high densities of small larvae may occur) until 1995. However, tomcod larvae move up river during the spring as they grow and the distribution of samples in the LRS program was adequate when abundance peaked during the juvenile stage in late May and early June. A combined PYSL-juvenile index was used to describe cohort abundance at this time.

During the summer and the beginning of the fall, the majority of the young-of-the-year population is located in deeper waters in upper New York Harbor and the lower portion of the estuary. As a result, it is not adequately sampled by the Beach Seine Survey or the Fall

Juvenile Survey (no samples were collected below River Mile 12 during the Fall Juvenile Survey prior to 1996). These programs also do not adequately sample yearling and older tomcod for the same reasons.

Abundance Indices

The combined PYSL-Juvenile indices fluctuated widely between 1974 and 1983 (Figure V-58, Table V-21). From 1983 through 1989, they exhibited an increasing trend. From 1989 through 1997, they exhibited a decreasing trend. The combined PYSL-Juveniles indices were positively correlated with the estimated number of adults in the spawning populations ($r = 0.813$; $p = 0.000$). However, after 1990, the number of Age 1 tomcod produced was negatively correlated with the number of eggs spawned ($r = -0.886$; $p = 0.008$).

iii. Potential Influences on Abundance

Fishing

Fishing is not likely to have had a major effect on the abundance of tomcod. There is no commercial fishery in either the Hudson River or coastal waters. Due to the small size of mature tomcod and their limited availability to fishermen during the mid-winter spawning run, there is only a small active sport fishery in the river. Recreational interest in this species may be further limited by the general health advisory against consumption of Hudson River fish due to PCB contamination. During the 1970s, only 0.5% or less of tags applied to tomcod were returned by fishermen (McLaren et al. 1988).

Water Withdrawal

The total conditional mortality arising from impingement for each tomcod cohort during a three year period (ages 0, 1, and 2) was estimated for eight of the eleven cohorts present during the period from 1987 through 1997. The estimates of the total impingement arising from the combined operation of the Roseton Units 1 and 2, Indian Point Units 2 and 3, and Bowline Point Units 1 and 2 generating stations and the other water withdrawal facilities ranged from 0.2% to 3.0% (Table V-22 and Appendix V-1). The effects of a mortality factor of this magnitude are not detectable in an assessment utilizing empirical data and no further analysis was attempted.

The total conditional mortality arising from entrainment (CEMR) during the first year of life for each tomcod cohort was estimated for each cohort present during the period from 1987 through 1997. The estimates of the total entrainment arising from the combined operation of the Roseton Units 1 and 2, Indian Point Units 2 and 3, and Bowline Point Units 1 and 2

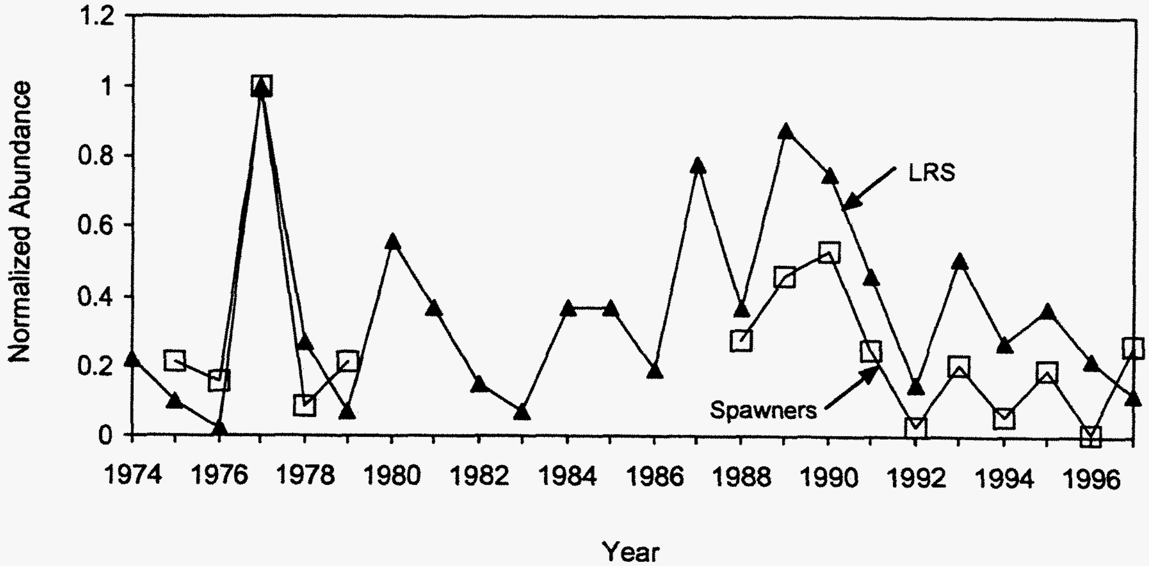


Figure V-58. Atlantic tomcod: normalized annual abundance indices for combined post yolk-sac and juveniles from Long River Survey (LRS) and for spawning adults producing the LRS index in a given year (Spawners), 1974-1997.

TABLE V-21

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF DIFFERENT LIFE STAGES OF ATLANTIC TOMCOD. (STANDARD ERRORS, WHERE AVAILABLE, ARE GIVEN AFTER "/".)

	EGG	PYSL/ JUVENILE	ADULT	
YEAR	ATMR[a]	LRS[b]	Age 1-ATMR[c]	Age 2-ATMR[c]
1974		0.09		0.1[d]
1975		0.04/0.86	3.65[d]	0.7[d]
1976	22	0.01/0.00	9.72[d]	0.1[d]
1977	65	0.41/0.27	2.44[d]	0.1[d]
1978	21	0.11/0.03	5.98[d]	0.3[d]
1979	51	0.03/0.01	8.86[d]	e
1980	57	0.23/0.04	e	e
1981	e	0.15/0.04	e	1.9
1982	e	0.06/0.02	10.6	0.8
1983	98	0.03/0.01	5.88	f
1984	76	0.15/0.07	F	0.1
1985	f	0.15/0.03	2.0	f
1986	26	0.08/0.01	F	0.4
1987	f	0.32/0.05	3.1	0.6
1988	41	0.15/0.03	5.3	2.0
1989	41	0.36/0.08	4.8	0.6
1990	87	0.31/0.13	2.6	0.1
1991	52	0.19/0.03	0.3	0.4
1992	7	0.06/0.02	2.2	0.2
1993	30	0.21/0.05	0.5	0.3
1994	7	0.11/0.02	2.1	0.03
1995	32	0.15/0.02	0.06	0.9
1996	2	0.09/0.01	2.4	0.6
1997	47	0.05/0.01	0.7	

a Estimated number of eggs spawned in billions determined from average age-specific fecundity and estimated populations. Estimate applied to the year that began during the winter the eggs were spawned.
b Weighted average number per m^3 for 4 consecutive sampling weeks in May (weeks 19-22).
c Estimated population size in millions applied to the year that began in the winter the cohort was spawned.
d Population estimates and age composition from McLaren et al. 1988. Sampling conducted entirely above RM 12.
e Insufficient number of fish recaptured to calculate an estimate.
f No sampling program conducted.

1 = Data should be useful for assessing abundance trends
2 = Data may be useful for assessing abundance trends
3 = Data are likely to be of limited use for assessing abundance trends

NS = Not effectively sampled
NU = Not used
Numbers 5 and 6 indicate the chapter of the DEIS, or appendix indicated by "A", in which the survey was used for information on abundance trends.

TABLE V-22

ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON ATLANTIC TOMCOD. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	5.61	3.65	0.26	0.62	2.98	0.00	0.00		12.54
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									13.20
1975	E	9.16	6.75	1.20	0.25	2.71	0.00	0.00		18.78
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									19.39
1976	E	10.60	8.76	0.94	0.36	2.89	0.00	0.00		21.82
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									22.41
1977	E	5.43	10.15	3.41	1.02	1.14	0.00	0.00		19.69
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									20.30
1978	E	9.18	10.60	2.32	0.81	2.96	0.00	0.00		23.66
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									24.24
1979	E	6.85	18.80	2.33	0.71	1.53	0.00	0.00		27.77
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									28.32
1980	E	6.10	25.47	1.81	0.58	5.13	0.00	0.00		35.19
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									35.68
1981	E	7.88	11.68	1.65	0.60	4.01	0.00	0.00		23.65
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									24.23
1982	E	6.57	17.47	1.72	0.70	3.95	0.00	0.00		27.72
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									28.27
1983	E	6.65	7.69	1.59	0.59	2.31	0.00	0.00		17.65
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									18.27
1984	E	5.77	16.58	1.61	0.70	1.45	0.00	0.00	0.95	25.03
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									25.60
1985	E	6.70	34.50	2.03	0.78	3.95	0.00	0.00	1.86	44.00
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									44.43
1986	E	8.22	11.36	1.82	0.70	3.58	0.00	0.02	1.69	24.83
	I	0.00	0.80	0.00	0.10	0.00				0.90
	T									25.51
1987	E	4.53	14.61	2.17	0.86	1.79	0.00	0.00	0.98	23.11
	I	0.00	3.00	0.00	0.10	0.00				3.10
	T									25.49
1988	E	7.15	23.94	1.84	0.78	3.25	0.00	0.00	1.57	34.50
	I	0.00	0.50	0.00	0.00	0.00				0.50
	T									34.83
1989	E	7.47	4.49	1.72	0.68	2.74	0.00	0.00	0.99	16.93
	I	0.00	0.30	0.00	0.00	0.00				0.30
	T									17.18
1990	E	6.72	5.52	2.00	0.80	2.62	0.00	0.00	0.82	17.25
	I	0.00	0.40	0.00	0.10	0.00				0.50
	T									17.66
1991	E	6.65	6.99	1.81	0.63	5.71	0.00	0.01	0.98	20.91
	I	0.00	0.20	0.30	0.10	0.00				0.60
	T									21.39
1992	E	7.25	14.11	1.66	0.51	2.65	0.00	0.00	0.98	24.87
	I	0.00	0.20	0.00	0.10	0.00				0.30
	T									25.09
1993	E	5.38	3.67	1.05	0.29	1.42	0.00	0.00	0.78	12.04
	I	0.00	0.20	0.10	0.00	0.00				0.30
	T									12.30
1994	E	4.48	7.57	1.57	0.47	2.47	0.00	0.00	0.80	16.32
	I	0.00	0.20	0.00	0.40	0.00				0.60
	T									16.82
1995	E	6.75	5.77	1.19	0.50	3.36	0.00	0.01	1.58	17.84
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									18.46
1996	E	1.61	8.47	0.84	0.31	1.09	0.00	0.00	0.52	12.41
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									13.07
1997	E	0.55	10.35	1.63	0.74	1.47	0.00	0.00	0.71	14.83
	I	*0.00*	*0.62*	*0.03*	*0.10*	*0.00*				*0.75*
	T									15.48
AVERAGE	E	6.39	12.04	1.67	0.62	2.80	0.00	0.00	1.09	22.22
	I	0.00	0.62	0.03	0.10	0.00				0.77

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A]Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B]Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C]RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21b; Impingement-Appendix VI-2-B, Table 17 generating stations and the other water withdrawal facilities ranged from 12.0 to 34.5% (Table V-22 and Appendix V-1). The time series from 1987 through 1997 for the CEMR and age 1 recruits produced by each cohort are illustrated in Figure V-59. There was no signficant correlation between the changes in CEMR and the changes in recruitment that occurred during this period ($r = 0.542$; $p = 0.085$).

Pollution

During the 1970s, cancerous tumors were observed in 80% of the adult tomcod examined in the Hudson River estuary and were thought to be associated with increased levels of PCBs (Smith et al. 1979; Klauda et al. 1981). However, many other toxic compounds become soluble under anaerobic conditions and low dissolved oxygen (DO) levels in the New York City area may have also contributed to this phenomenon. PCB levels have declined since the 1970s (Sloan and Armstrong 1988; more recent reference). DO levels increased consistently through the 1980s into the 1990s as existing wastewater treatment plants were upgraded, new ones were built, and pollution abatement programs were instituted (Brosnan and O'Shea 1996a, 1996b; NYCDEP 1997). In the 1995-1996 spawning season, the incidence of cancerous tumors in Hudson River tomcod was less than 2% (Table V-23).

Ecological Factors

Temperature

The growth of juvenile tomcod declines when water temperatures rise above 55°F (Dew and Hecht 1994b) and stops when they exceed 71°F (McLaren et al. 1988). The cessation of growth during the summer months appears to result because tomcod do not satisfy their energy requirements due to either a loss of appetite or cessation of feeding (Grabe 1978; Salinas and McLaren 1983). Summer temperatures within portions of the river approach or exceed the reported upper incipient lethal temperature for tomcod (80°F) and the tomcod data from 1974 through 1979 suggested that summer water temperatures negatively affected the recruitment of age 1 adults into the spawning population (McLaren et al. 1988). However, none of the summers during this period was particularly hot. The average daily water temperatures during the months of July and August never exceeded 78°F (Table V-24). In 1988, the average daily water temperature during the month of August exceeded the reported upper incipient lethal temperature for tomcod but the recruitment of age 1 adults was not particularly low. In 1995, the average daily water temperature in August was 79°F and recruitment was only 1% of that in 1988. In 1994, the average daily water temperature in July was only 0.2°F cooler than that in August 1995 and recruitment was 40% of that in 1988. The recruitment during these three years was not controlled by the high water temperatures occurring during the July and August and there was no correlation between the

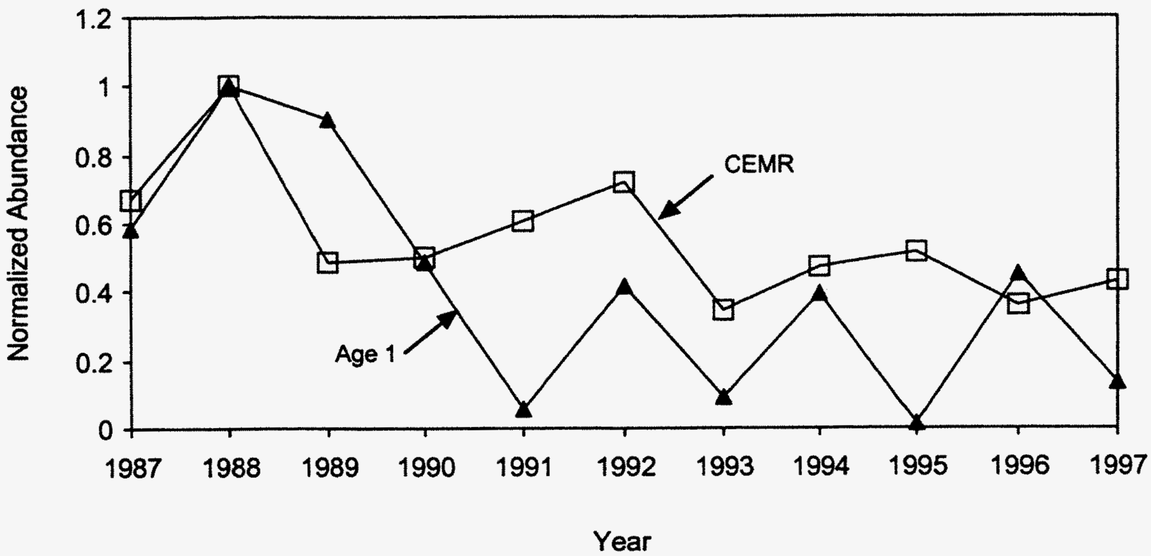


Figure V-59. Atlantic tomcod: normalized annual abundance indices for age 1 tomcod and cumulative conditional entrainment mortality (CEMR), 1988 - 1997. The indices were normalized by dividing each annual index by the maximum value for that index.

TABLE V-23

INCIDENCE OF ABNORMAL LIVERS IN ATLANTIC TOMCOD ADULTS DURING THE 1995-1996 SPAWNING SEASON

LIVER CATEGORY	AGE 1		AGE 2	
	NUMBER	PERCENTAGE	NUMBER	PERCENTAGE
Normal (1)	66	90	35	69
Spots (2)	4	5	9	18
Gross Pathology (3)	3	4	7	14
Total	73		51	

Liver category follows Dey et al. 1994.

TABLE 24

THE AVERAGE DAILY WATER TEMPERATURE DURING THE MONTHS OF JULY AND AUGUST AT THE INTAKE TO POUGHKEEPSIE WATERWORKS (POUGHKEEPSIE, N.Y.): 1975 THROUGH 1997.

YEAR	JULY	AUGUST
1975	24.9	24.9
1976	24.5	23.2
1977	24.3	25.1
1978	24.1	25.3
1979	23.8	25.3
1988	24.5	27.0
1989	24.5	25.4
1990	24.5	25.5
1991	25.3	25.8
1992	23.6	23.7
1993	25.4	25.3
1994	26.0	25.0
1995	24.2	26.1
1996	2.3	24.2
1997	24.8	25.1

peak monthly average water temperature and tomcod recruitment over the entire period from 1988 through 1997 ($r = 0.189$; $p = 0.602$).

Predation

Predation is another factor reported to affect tomcod recruitment. Juvenile tomcod are the preferred prey of large juvenile bluefish (Juanes et al. 1993) and striped bass may also prey upon juvenile tomcod (Gardinier and Hoff 1982; Dew and Hecht 1994b). The time series from 1988 through 1997 for the abundance indices for juvenile bluefish generated from the Utility BSS surveys and the estimates of the number of age 1 recruits produced by each cohort are illustrated in Figure V-60. The values for each variable in this figure have been normalized, by dividing by the maximum value observed within each time series, so that they can be plotted on the same scale. From 1988 through 1994, there is no correlation between the abundance of juvenile bluefish and tomcod recruitment. However, from 1994 through 1997, there is a negative correlation between these two variables. However, these two variables were probably not causally related during this four-year interval because the alternating pattern in tomcod recruitment began in 1991, three years before the abundance of juvenile bluefish began rising and falling.

The time series from 1988 through 1997 for the abundance indices for sub adult and adult striped bass (SBCFM) generated from the by-catch in the gill nets used in the commercial shad fishery is contrasted with that for tomcod recruitment in Figure V-61. From 1988 through 1994, there is no correlation between the abundance of sub adult and adult striped bass and tomcod recruitment. However, from 1994 through 1997, there is a positive correlation between these two variables. These two variables were probably not causally related during this four-year interval. First, any predatory relationship between these two species would generate a negative correlation. Second, the alternating pattern in tomcod recruitment began in 1991, three years before the abundance of sub adult and adult striped bass began rising and falling.

The time series from 1988 through 1997 for the abundance indices for yearling striped bass generated from the winter mark-recapture programs is contrasted with that for tomcod recruitment in Figure V-62. The values for each variable in this figure have been normalized, by dividing by the maximum value observed within each time series, so that they can be plotted on the same scale. There is no correlation between the changes in the abundance of yearling striped bass and tomcod recruitment during this period.

McLaren et al. (1988) observed a negative relationship between adult abundance, egg deposition and subsequent first-year survival. The survival estimates in their study were not statistically independent of the abundance estimates and this negative relationship

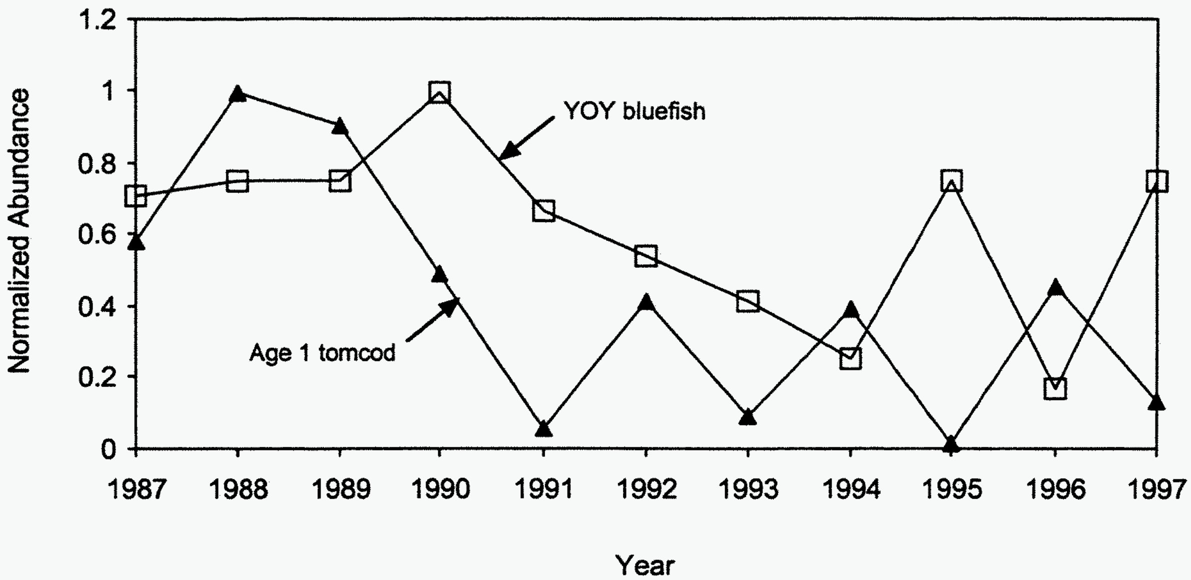


Figure V-60. Atlantic tomcod: normalized annual abundance indices for age 1 tomcod and young-of-the-year (YOY) bluefish, 1987 - 1997. The indices were normalized by dividing each annual index by the maximum value for that index.

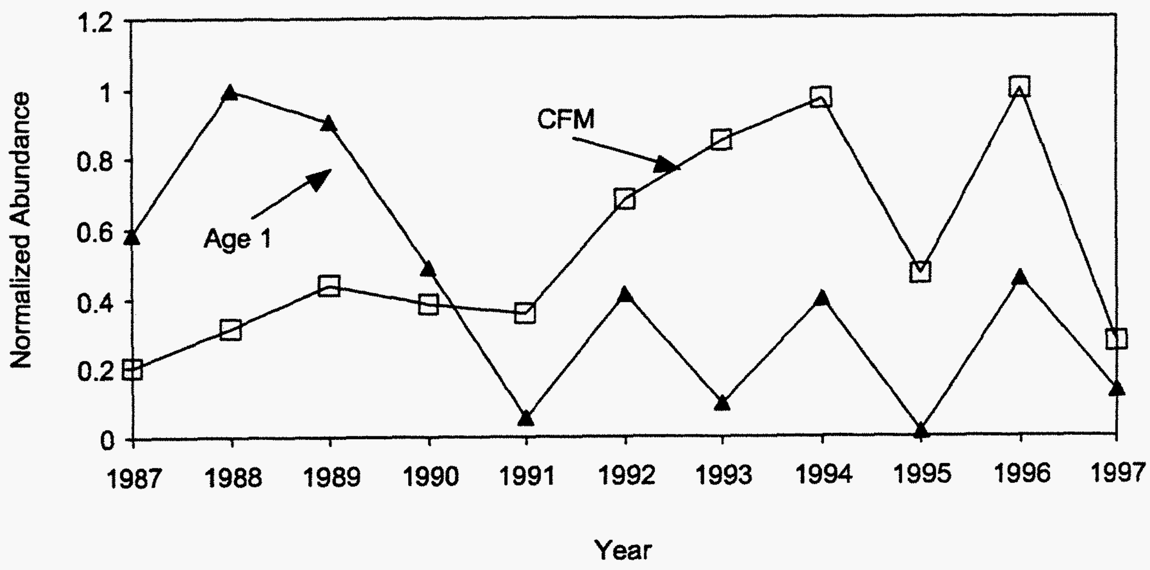


Figure V-61. Atlantic tomcod: normalized annual abundance indices for age 1 tomcod and the striped bass by-catch in the commercial gill net fishery for American shad (CFM), 1987 - 1997. The indices were normalized by dividing each annual index by the maximum value for that index.

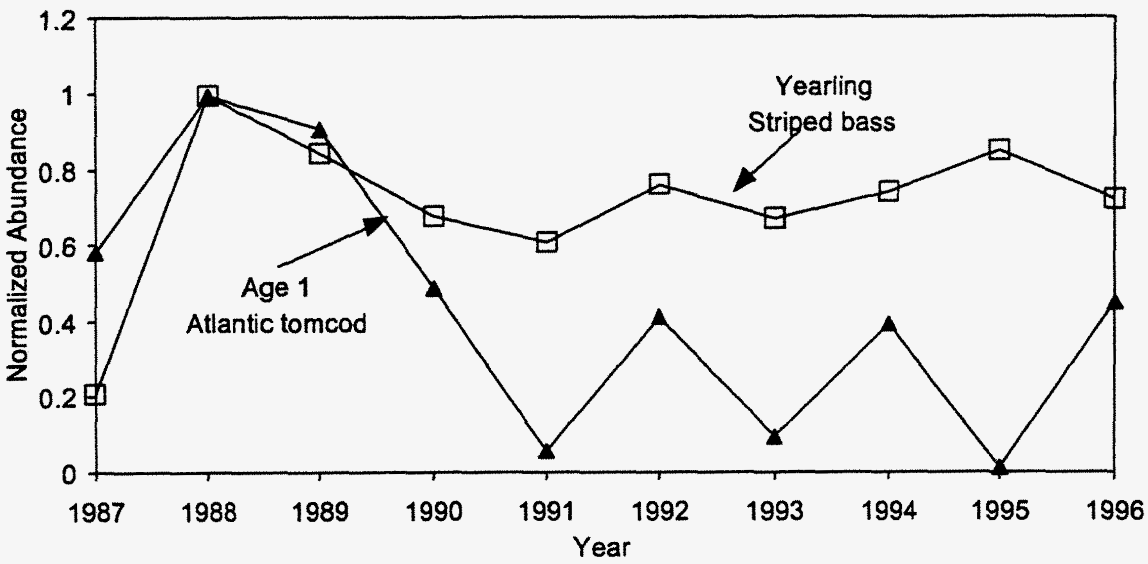


Figure V-62. Atlantic tomcod: normalized annual abundance indices for age 1 and yearling striped bass. 1987 - 1996. The indices were normalized by dividing each annual index by the maximum value for that index.

must be viewed with caution. However, the spatial distributions of juvenile and adult tomcod in the Hudson River estuary exhibit considerable overlap throughout the year (Woodhead 1992) and cannibalism does occur. Adult tomcod (age 1 and 2) consume tomcod eggs in the winter, and larvae and juveniles during the spring (Grabe 1980). The time series from 1988 through 1997 for the abundance indices for age 1 and age 2 tomcod generated from the winter mark-recapture programs are illustrated in Figure V-63. Tomcod recruitment and the abundance of older tomcod in the same year are positively correlated over the ten year period ($r = 0.704$; $p = 0.023$), which suggests that cannibalism by older tomcod did not control tomcod recruitment.

Competition

However, large and small tomcod both feed upon invertebrates like Gammarus, Neomysis, Crangon, and Chaoborus (Nittel, 1976; Grabe 1978, 1980) and they both may be limited by invertebrate production. Invertebrate production in the Hudson River ecosystem is depends upon particulate organic matter (Gladden et al. 1988). Formerly, sewage discharges from the New York City area were a significantsource of particulate organic matter within the lower portion of the Hudson River estuary (Limburg et al. 1986). However, the construction and upgrading of water treatment plants in the New York City area reduced the discharge of untreated wastewater into the lower portion of the Hudson River estuary from 450 mgd in 1970 to less than 5 mgd in 1988. The largest wastewater treatment plants emptying into the Hudson River outside of the metropolitan area were upgraded during the late 1980s, the Yonkers Joint Treatment plant in 1988 and the Rockland County Sewer District #1 plant in 1989 (ISC 1994). In the early 1990s, the North River plant (in 1991) and two of the three plants located on the western bank of the Hudson River opposite Manhattan Island, North Bergen MUA--Woodcliff (in 1991) and North Hudson Sewerage Authority--West New York (in 1992), went to full secondary treatment. The third plant located on the western bank of the Hudson River opposite Manhattan Island, the North Hudson Sewerage Authority-Hoboken plant, went to full secondary treatment in 1994. In the mid-1990s, the Rockland County Sewer District #1 (in 1995) and Orangetown Sewer District (in 1996) plants, serving a combined population of 205,000, were upgraded (ISC 1997).

Fecal coliform bacteria are uniquely associated with raw sewage and were used to monitor the effects of the improvements in wastewater treatment (Brosnan and O'Shea 1996a). The time series for the averages of the weekly average fecal coliform counts (#/100 ml) in water samples collected during June, July, and August from the lower Hudson River (RM 0-15) are contrasted with tomcod recruitment in Figure V-64. Between 1988 and 1991, tomcod recruitment declined steadily in concert with the averages of the weekly average fecal coliform counts and the distinct alternating pattern

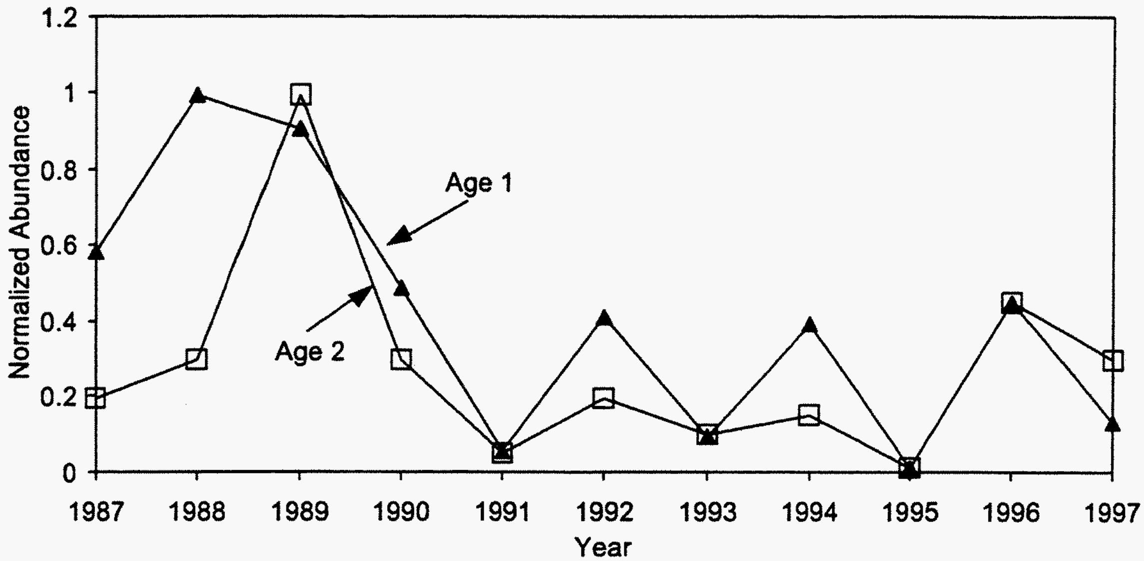


Figure V-63. Atlantic tomcod: normalized annual abundance indices for ages 1 and 2, 1987 - 1997. The indices were normalized by dividing each annual index by the maximum value for that index.

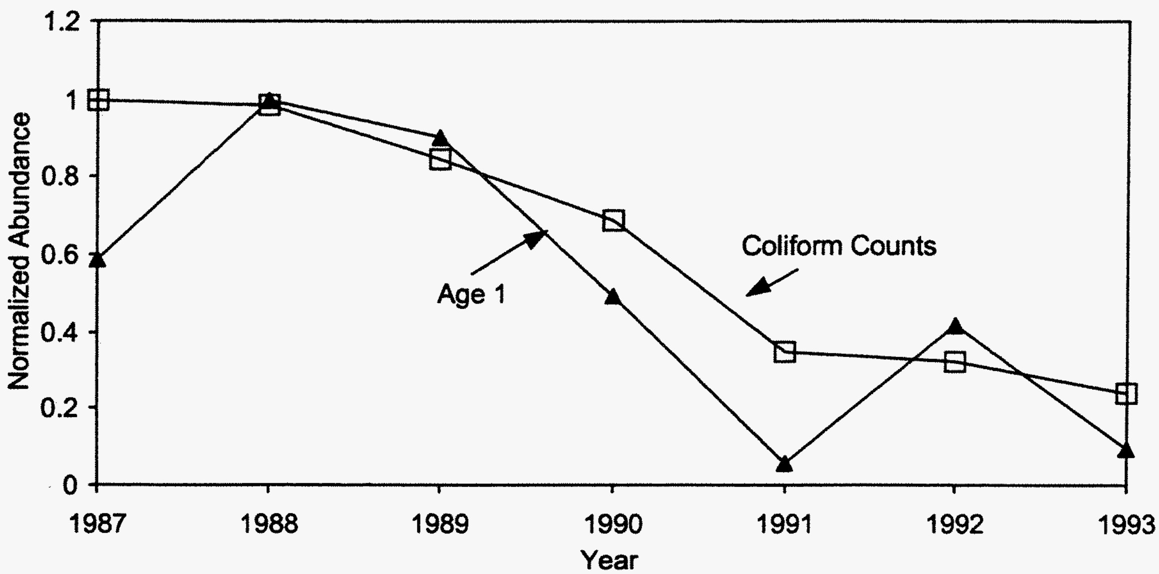


Figure V-64. Atlantic tomcod: normalized annual abundance indices for age 1 tomcod and average weekly average fecal coliform counts for June, July, and August from the NYCDEP sampling stations N1-N5, 1987 - 1993. The indices were normalized by dividing each annual index by the maximum value for that index.

in tomcod recruitment began in 1991, the same year that the North River plant went to full secondary treatment.

The time series for the normalized indices for age 0 (eggs) and age 1 tomcod are contrasted in Figure V-65. Tomcod recruitment decreased in 1990 when egg abundance increased. In 1991, egg abundance decreased but recruitment continued to drop, suggesting that another factor had changed between 1990 and 1991. From 1991 through 1997, recruitment and egg abundance strongly negatively correlated ($r = -0.886$; $p = 0.008$). Thus, the mechanism that best explains the variation in tomcod recruitment occurring during the period from 1988 through 1997 is competition for food during the spring. Most of the mortality generated by this competition process probably occurs during the summer when this boreal species, at the southern limit of its breeding range, becomes thermally stressed.

d. American Shad

i. Life History and Distribution Within the Hudson River

American shad, *(Alosa sapidissima)* are the largest of the North American species of anadromous herrings. They range from Newfoundland to northern Florida along the Atlantic coast and over the continental shelf (Figure V-66). They may live to 11 years (Smith, 1985), attain a length of 30 in. (Bigelow and Schroeder, 1953), and weigh up to approximately 12 lb (Weiss-Glanz et al., 1986).

Shad have been reported to spawn on dark afternoons or evening hours over shallow, broad flats washed by moderate currents in the main body of coastal rivers (Leggett 1976). Peak spawning activity for American shad in the Hudson River occurs during May in the upper estuary (Figures V-67 and V-68). Shad spawn over the entire length of the river, 160 miles from the mouth to the troy dam, with the greatest activity above rkm 200 (Limburg and Ross 1995). At present shad are not known to utilize Hudson River tributaries or the Mohawk River for spawning purposes (Schmidt et al. 1988), although historically the Mohawk and upper Hudson may have been part of the shad spawning and nursery range.

American shad produce 116,000 to 468,000 eggs per female (Lehman, 1953). The eggs are 0.0625 to 0.125 in. in diameter, semi-buoyant, and nonadhesive. They hatch in three to 12 days, depending upon water temperature. In the Hudson River, hatch dates have been estimated to occur between early May and early June (Limburg, 1996). Newly hatched YSL are approximately 0.25 in. long and grow very rapidly. They absorb the yolk sac within one week and are approximately 0.5 in. long at the beginning of the PYSL stage. Although some downriver dispersal is apparent, both YSL and PYSL are found primarily in

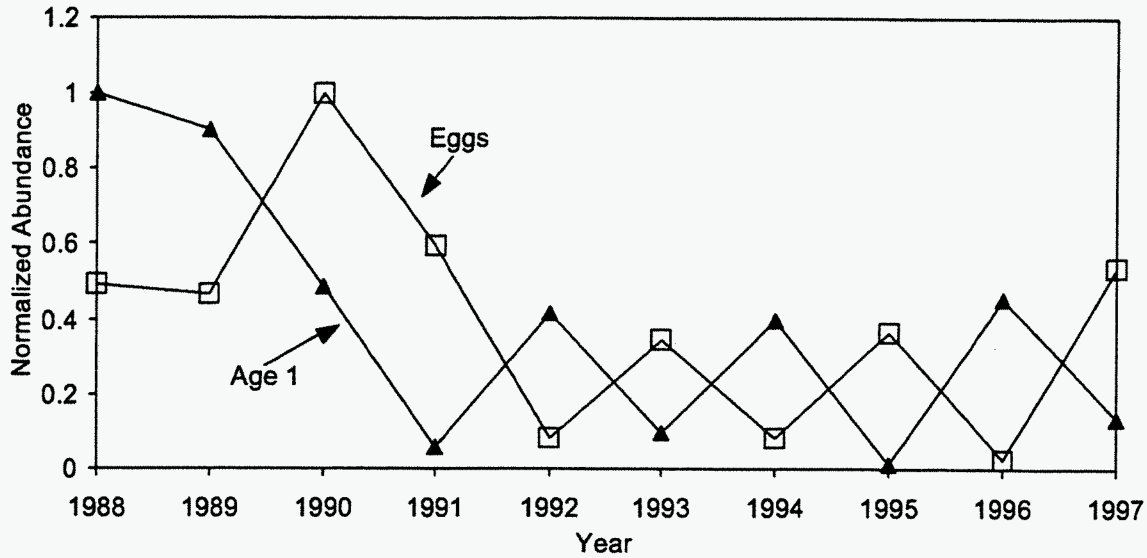


Figure V-65. Atlantic tomcod: normalized annual abundance indices for eggs and age 1, 1988 - 1997. The indices were normalized by dividing each annual index by the maximum value for that index.

Figure V-66. Distribution of American shad in North America.

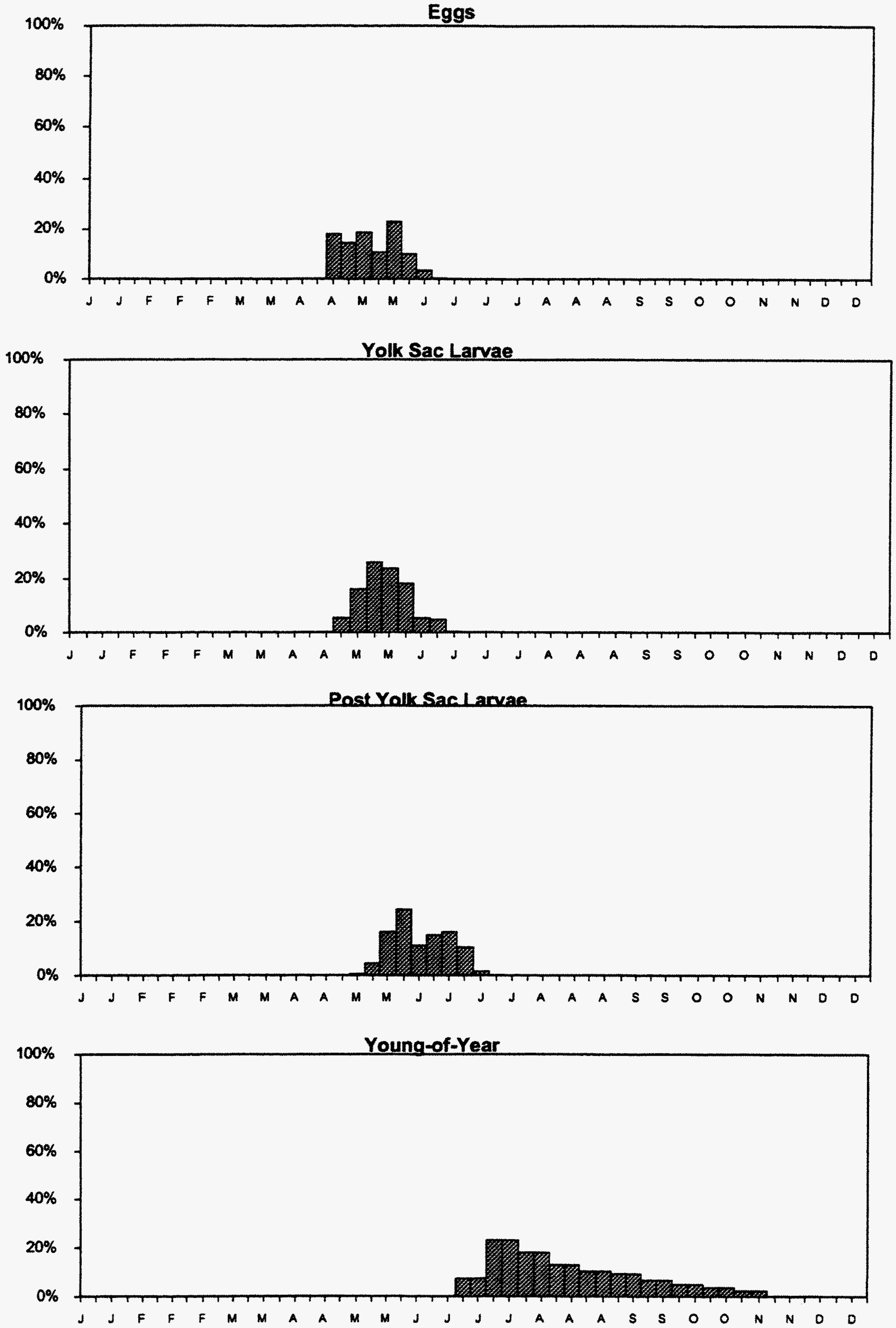


Figure V-67. Temporal distribution indices for American shad eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

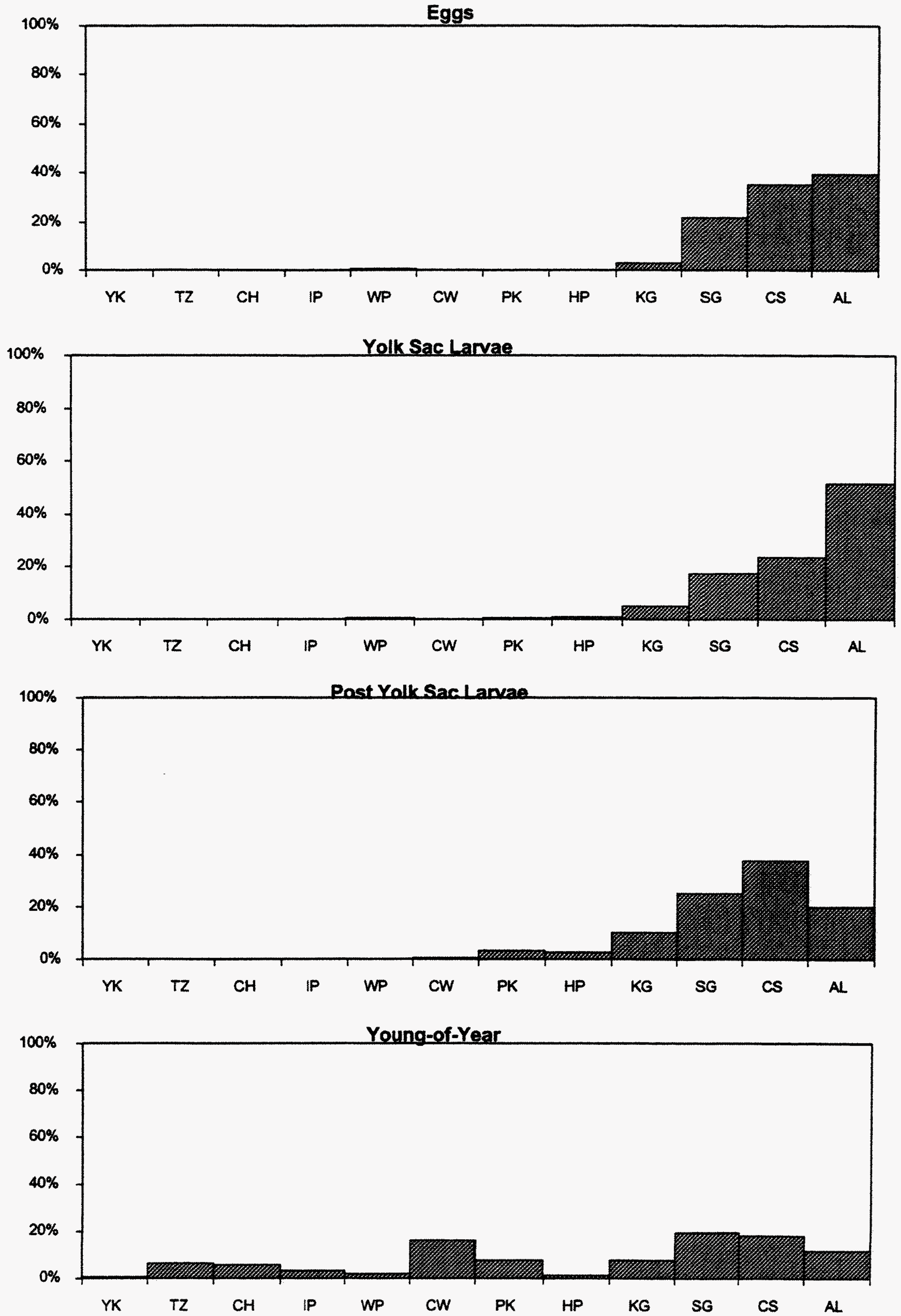


Figure V-68. Spatial distribution indices for American shad eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

the upper estuary between Poughkeepsie and Albany (Figure V-68). Larval shad alternately swim toward the surface and passively sink (Chittenden 1969), but behavior has not been completely described. Within a month the young shad develop the full complement of fins about 1 in. long and are classified as juveniles that resemble miniature adults. Juvenile shad are found throughout the estuary and are most abundant in the upper estuary (Figure V-68).

American shad usually become sexually mature after three to six years at sea, although some males may mature within two years. Most fish mature by their fourth or fifth year, and nearly all fish are mature by their sixth year (Talbot 1954).

American shad larvae were found to eat Bosmina spp., cyclopoid copepodites, and chironomid larvae (Crecco and Blake, 1983). Juvenile shad are considered opportunistic feeders, consuming the most available food source (Walburg, 1957; Watson, 1968; Levesque and Reed, 1972; Marcy, 1976). Juvenile shad feed generally on floating or free-swimming organisms at the surface or in the water column (Leim, 1924; Chittenden, 1969; Levesque and Reed, 1972). Miller et al. (1972), examining stomach contents of juvenile shad collected from the upper Delaware River during late summer and early fall, found that adults and aquatic larvae of the insect orders Diptera and Tricoptera were the dominant food organisms, Grabe (1996) found that juvenile shad in the Hudson River fed primarily on insects, specifically, hymenopterans and chironomid larvae. The diet of American shad was composed mainly of chironomids (43.1%) and ostracods (28.4%), with peak consumption occurring at 2000 hours (Johnson and Dropkin, 1995). Walburg and Nichols (1967) described the American shad adult at sea as primarily planktivorous, swimming with mouth open and gill covers extended, straining the water for food.

At the time they emigrate from the Hudson at the end of the summer, juvenile shad range from 3 to 4 in. long. This emigration is triggered by declining water temperatures and may be related to size (Schmidt et al. 1988): larger juveniles may tend to emigrate earlier. The shad emigration is a gradual movement of the population seaward over several months. Shad emigrate from the estuary earlier than either of the other two anadromous herrings commonly found in the Hudson River, alewives and blueback herring, and Schmidt et al. (1988) speculated that the earlier migration might be a behavioral adaptation that reduces competition with juveniles of the other two herring species.

In the spring American shad migrate north, and by summer they are feeding in the Gulf of Maine, the Bay of Fundy, Georges Bank, and the Gulf of the St. Lawrence (Neves and Depres 1979; Dadswell et al. 1987). In fall they move south again along the perimeter of the Gulf of Maine and Georges Bank at depths greater than 60 m (Neves and Depres 1979); by winter they may congregate along the edge of the continental shelf. Based on tagging experiments conducted in 1950 and 1951, Talbot (1954) reported that American shad of

Hudson River origin were recaptured from Maine to North Carolina. Most recaptured fish were from the fishery along the New Jersey coast in spring. Prespawning adults move along the coast in the spring to their natal rivers (Dadswell et al. 1987), which they enter as river temperatures reach 50° to 60°F.

Shad, like many anadromous herrings, have well-developed homing abilities and are capable of returning to their natal rivers and tributaries from far off the coast. After spawning, the adults soon return to the ocean. They can repeat their annual spawning sequence up to five times (Talbot, 1954). In more southerly rivers along the Atlantic coast increasing percentages of the adult population die after spawning; south of Cape Fear, North Carolina, all spawners die on their first run.

Wilk et al.(1996) studied the abundance of American shad in the Hudson-Raritan Estuary from January 1992 through December 1993. Shad was listed as one of the fifteen most abundant species in the estuary. Schmidt et al. (1988) reported peak abundance for Hudson River American shad juveniles in the estuary occurring in July.

ii. Temporal Changes in Abundance

Sampling Programs

The DEC commercial fishery monitoring program has provided data on catch per unit effort (CPUE) for males and females since 1980 (HREMP, 1992). Because the fishery is dominated by ages 5 to 7 (Kahnle et al., 1988a; Kahnle and Stang, 1988), the CPUE values may reflect reproductive success 5 to 7 years earlier. The female CPUE could also be an index of adult spawning stock that could be used to determine whether stock and recruitment are closely related.

Alternative annual indices of reproductive success developed from early life-stage data of the LRS program extend back to 1974. However, because the egg and YSL life stages have a duration less than the interval between sampling events, and the duration varies with temperature, these life stages may not be sampled consistently from year to year. The PYSL should be sampled more consistently since that life stage is much longer.

Beach seines capture large numbers of juvenile American shad and therefore may be an appropriate gear to use for developing an index. Both the utility BSS data and the DEC shad survey data (JAS) were examined as potential indicators of year class strength.

Abundance Indices

Over the sampling period there was no significant trend (average annual rate of change) in the DEC gill net catches of either sex in the commercial fishery monitoring program. Highest catches occurred in the middle of the time series (Table V-25). Overall, the PYSL index exhibited no significant trend (+1% per year).

The utility BSS and DEC-JAS indices were significantly correlated (r=0.58) over the period 1980-1997. Neither index indicated a significant trend in juvenile abundance over the period of sampling. Since the DEC JAS beach seine program both decreased its geographic extent and changed from randomized to sampling standard beaches in 1983 (Versar, 1988), the utilities' BSS YOY index (Figure V-69) is the index preferred for examining trends. It also provides a longer time series.

Emigration of juvenile American shad occurs during the time when their abundance is being measured: therefore, emigration rates, should they vary from year to year, represent a potential source of variability in the juvenile indices.

iii. Potential Influences on Abundance

Ecological Factors

Models of the ecological constraints on growth and movement of juvenile American shad in the Hudson River estuary showed that most size classes of fish utilize the middle estuary during September and October. Fish move into the lower estuary even in the face of higher predation risks because of a combination of lower food resources and thermal risks in the upper and middle estuary (Limburg and Ross, 1995)

American shad eggs were reported to be preyed upon by the American eel (*Anguilla rostrata*) and catfishes, (*Ictalurus* spp) (Walburg and Nichols, 1967). Larvae were found to be preyed upon by bluefish *(Pomatomus saltatrix)* in the Hudson River estuary. (Juanes and Marks, 1993). Johnson and Ringler (1995) found that the major predators of American shad larvae released into the Juniata River, PA, included: cyprinids, small-mouth bass, other centrarchids, and walleye. Hildebrand (1963) stated that young shad may fall prey to larger predatory fish, water birds, turtles, and water snakes. PSE&G (1998) reported juvenile striped bass and bluefish as predators of juvenile American shad. Eels (Mansueti and Kolb, 1953); seals (Scott and Crossman, 1973); sharks, bluefin tuna, and kingfish (Leach, 1925); and porpoises (Walburg and Nichols, 1967) have been reported as predators of adult American shad.

TABLE V-25

ESTIMATES OF RELATIVE ABUNDANCE OF AMERICAN SHAD
AT DIFFERENT AGES

YEAR CLASS OR COHORT	LRS PYSL[a] INDEX (S.E.)	FSS YOY[a] INDEX (S.E.)	DEC YOY[b] BEACH SEINE	GILL NET CPUE, MALE	GILL NET CPUE, FEMALE
1974	0.17 (0.06)	11.50 (0.82)			
1975	0.28 (0.18)	10.63 (1.43)			
1976	0.16 (0.05)	13.32 (0.87)			
1977	0.17 (0.03)	13.70 (1.39)			
1978	0.09 (0.03)	23.67 (2.66)			
1989	0.49 (0.07)	11.64 (1.74)			
1980	0.48 (0.22)	10.75 (2.46)	23.87	4.28	19.11
1981	0.78 (0.31)	17.62 (2.17)	19.12	6.17	14.47
1982	0.59 (0.12)	16.31 (1.92)	12.17	3.04	8.02
1983	0.57 (0.09)	19.68 (3.89)	18.24	5.55	9.16
1984	0.38 (0.17)	8.69 (1.84)	7.79	3.42	9.49
1985	0.67 (0.17)	8.08 (1.30)	26.25	10.66	26.65
1986	1.05 (0.15)	19.06 (3.74)	46.32	24.54	52.09
1987	0.18 (0.08)	13.47 (2.28)	20.20	13.00	47.34
1988	0.73 (0.34)	7.72 (1.01)	27.59	19.40	42.22
1989	1.04 (0.79)	22.05 (2.41)	47.30	9.30	33.79
1990	1.17 (0.73)	18.67 (1.74)	41.24	3.53	16.61
1991	0.32 (0.12)	11.96 (3.16)	24.05	2.32	18.31
1992	0.62 (0.21)	13.92 (1.05)	35.17	0.91	13.02
1993	0.23 (0.12)	7.07 (0.87)	11.64	0.91	13.02
1994	0.37 (0.13)	17.56 (3.28)	26.09	0.86	24.35
1995	0.19 (0.06)	3.77 (0.43)	5.74	1.40	11.49
1996	0.26 (0.06)	11.77 (1.92)	30.89	2.19	20.25
1997	0.15 (0.03)	12.54 (2.04)	9.51	0.91	7.11

CPUE - Catch per unit effort.
S.E. - Standard error.

[a]Number per thousand cubic meters.
[b]Catch per haul.

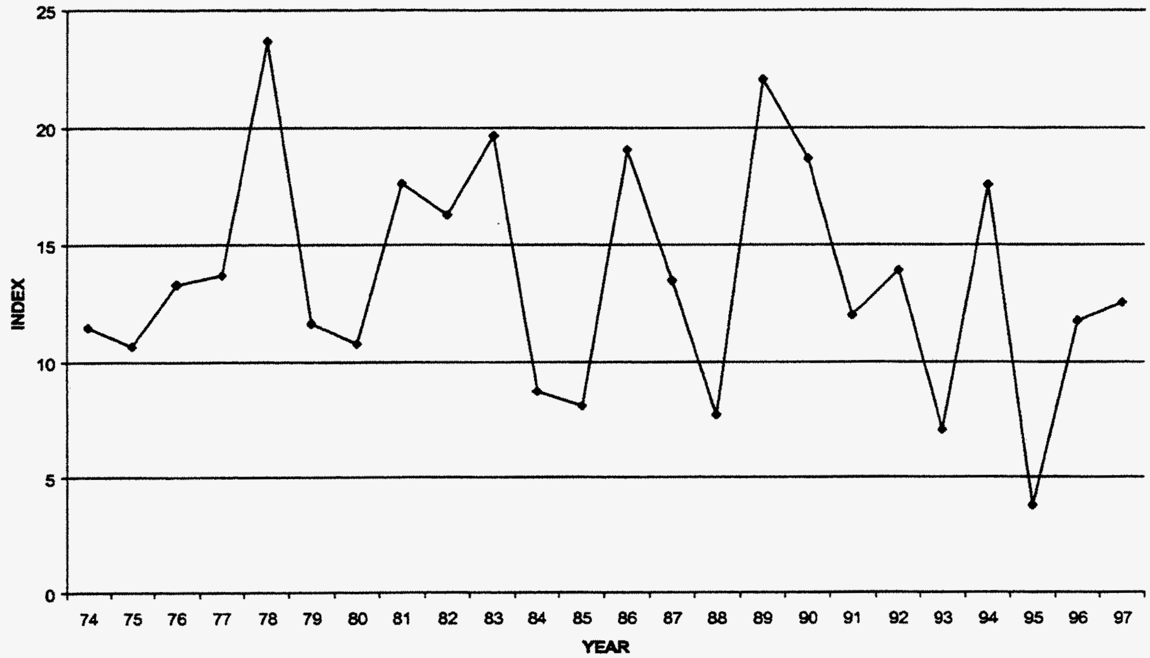


Figure V-69. American shad BSS juvenile index.

American shad, as estuarine spawners, are affected by environmental conditions in the estuary before and during the spawning season. Shad migrations have been adversely affected by low dissolved oxygen (DO) conditions in the Delaware River (Maurice et al. 1987), and in the Connecticut River juvenile production is limited by rainfall and, after spawning, river flow (Crecco and Savoy 1984).

In the Hudson River the low DO conditions that used to occur south of Albany were eliminated after installation of improved sewage treatment facilities in the late 1960s. The improvement in DO has allowed adult shad to spawn below the Troy Dam, although they cannot travel to the upriver areas to spawn as they do in the Delaware River. Improved DO levels in the upper estuary are also better for the growth and survival of eggs, larvae, and juveniles. Although DO has improved continuously in the lower Hudson River estuary over the period of study (CNYDEC 1987), there is no evidence that DO affected the spawning run.

The movement and survival of shad do not appear to have been greatly influenced by other water quality or pollution problems. Due to their short residence in the estuary, cessation of feeding during spawning runs, and diet, adult shad are believed not to accumulate high concentrations of toxic substances like PCBs. However, concern over consumption of shad from a contaminated water body has arisen recently. Because of this concern, and the fact that the last reported data on PCB levels in shad are from 1989, sampling occurred in 1992 and 1993. The American shad fishery on the Hudson River has not been closed, although shad is covered by the general advisory to limit consumption of Hudson River fish.

Density-dependent regulatory processes may also be important in determining shad abundance. Gibson et al. (1988) reviewed the stock and recruitment data for many east coast stocks and used a density-dependent model to describe the relationship between stock and recruits. For the Hudson River stock from 1950 to 1980 the density-dependent relationship was not very precise, but parameter estimates for the Shepard stock-recruitment model indicated a type of relationship in which the highest levels of recruitment would occur at intermediate stock sizes (Gibson et al. 1988).

Hattala and Kahnle (1997) report that the history of the shad in the Hudson River may be linked to its current state of decline. They suggest that the two past declines, one at the turn of the centruy, and one after WWII, have lowered shad numbers to a point where they are still recovering. At the present time, shad stocks in the Hudson River are at an all-time low.

Fishing

Extensive commercial fisheries for American shad developed along the east coast of the United States during the 19th century, reaching a peak in 1896 of 50 million lb (Talbot 1954). Landings declined to less than a sixth of the peak catch by 1950 and continued to decline through the 1970s when average annual landings were 3.7 million lb (ASMFC, 1988). Although excessive fishing is one of the factors believed to have caused the decline in American shad landings, other factors, such as pollution of the lower Delaware River and blockage of spawning migrations on the Susquehanna River, are also believed to have played a major role (Anderson 1984).

The Hudson River commercial fishery is conducted with staked and anchored gill nets in the lower estuary and with drift gill nets in the middle and upper estuary. In the Hudson, as elsewhere, the shad fishery appears to be limited by the market, with prices declining when landings increase (Brandt 1988).

In recent years the coastal ocean fishery has increased its take of American shad (Harris and Rulifson 1989). Most of the ocean landings are taken in New Jersey, Maryland, Virginia, South Carolina, and Florida.

Water Withdrawals

Entrainment and impingement effects were estimated as described in Appendices VI-1 and VI-2. On the average, from 1974 to 1997, entrainment mortality is estimated to have caused an annual reduction in the number of juvenile American shad by 23.8%; impingement may have further reduced the number of shad by less than 1% (Table V-26). However, the majority of the entrainment mortality is estimated to occur in the Albany region at the Albany Steam Station and Empire State Plaza. Due to the proximity of the Troy Day and its effect on tidal flow, it is likely that the entrainment mortality estimates for these sites are biased high.

Pollution

Although PCB contamination has been recognized in Hudson River striped bass for nearly 20 years, levels in American shad have generally been low due to the differences in habitat, migration, and feeding habits. No health advisories have been issued for American shad other than the general advisory to limit consumption of fish caught in the Hudson River.

TABLE V-26

ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON AMERICAN SHAD. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	0.10	0.22	0.15	0.82	0.68	0.11	1.02	.	3.06
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									3.06
1975	E	0.11	0.35	2.67	2.31	1.00	1.84	30.91	.	36.45
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									36.45
1976	E	0.22	0.33	2.01	1.28	0.59	1.90	31.36	.	35.61
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									35.61
1977	E	0.02	0.38	1.42	0.96	1.22	0.38	2.96	.	7.14
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									7.14
1978	E	0.09	0.24	1.92	1.29	0.43	0.78	14.90	.	18.88
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									18.88
1979	E	0.04	0.20	1.06	0.96	0.07	1.72	26.61	.	29.53
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									29.53
1980	E	0.00	0.03	0.31	0.28	0.14	2.00	35.99	.	37.74
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									37.74
1981	E	0.02	0.20	0.35	0.79	0.24	0.95	13.29	.	15.47
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									15.47
1982	E	0.16	0.44	0.33	0.91	1.03	0.72	8.17	.	11.43
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									11.43
1983	E	0.02	0.09	0.74	1.19	0.60	1.28	15.69	.	18.94
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									18.94
1984	E	0.05	7.50	1.08	0.71	1.11	0.98	10.84	0.32	20.97
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									20.97
1985	E	0.00	0.00	0.17	0.27	0.07	1.63	17.77	0.03	19.55
	I	0.00	0.00	0.00	0.00	0.00				0.10
	T									19.63
1986	E	0.00	3.56	0.32	0.73	0.09	0.46	5.92	0.02	10.73
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									10.73
1987	E	0.01	0.00	0.42	0.30	0.12	3.82	26.61	0.05	30.04
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									30.04
1988	E	0.01	0.15	0.20	0.22	0.86	2.19	36.45	0.18	38.84
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									38.84
1989	E	0.20	0.28	1.16	0.91	1.20	1.95	35.44	0.24	39.18
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									39.18
1990	E	0.08	0.43	2.24	1.88	1.68	2.97	42.36	0.31	47.69
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									47.69
1991	E	0.01	0.07	0.41	0.44	0.74	1.51	30.64	0.12	32.90
	I	0.00	0.00	0.00	0.00	0.00				0.10
	T									32.97
1992	E	0.01	0.05	0.22	0.15	0.48	1.34	50.85	0.15	52.02
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									52.02
1993	E	0.01	0.13	0.23	0.22	1.19	1.29	6.46	0.32	9.58
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									9.58
1994	E	0.03	0.12	0.37	0.25	0.47	2.61	18.32	0.13	21.53
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									21.53
1995	E	0.01	0.10	0.39	0.35	0.61	1.33	9.75	0.12	12.34
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									12.34
1996	E	0.03	0.42	0.24	0.32	0.65	1.29	3.47	0.17	6.45
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									6.45
1997	E	0.01	0.05	0.32	0.50	0.76	1.99	13.65	0.14	16.86
	I	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*
	T									16.86
AVERAGE	E	0.05	0.64	0.78	0.75	0.67	1.54	20.39	0.16	23.87
	I	0.00	0.00	0.00	0.00	0.00				0.01

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A]Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B]Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C]RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21a; Impingement-Appendix VI-2-B, Table 16

Other

The other environmental changes taking place in the upper portion of the Hudson River (the increase in water chestnut in the upper and middle portions of the estuary since 1976, potential increases in fresh water withdrawn for New York City water supply, invasion of the freshwater portion of the estuary by zebra mussels, and improvements in water quality) do not appear to have affected the abundance of juvenile shad.

e. Blueback Herring

i. *Life History and Distribution Within the Hudson River*

Blueback herring *(Alosa aestivalis),* an anadromous member of the herring family *(Clupeida)* range from southern New Brunswick and Nova Scotia southward to northern Florida (Figure V-70). Although they are caught as far as 70 to 80 miles offshore, little is known about the oceanic migration patterns. The presence of blueback herring in the Bay of Fundy has led to speculation that this species has an oceanic migratory pattern similar to that of American shad (See section d. i.), although that has not been confirmed (Harris and Rulifson 1989). The degree to which blueback herring of Hudson River origin return to the Hudson River is not known nor is the degree to which spawning stocks from different river systems mix. Jessop (1994) reported blueback herring homing to the Saint John River system with moderate to high fidelity (63-97%). Results of tagging studies also conducted in the Saint John River, New Brunswick, indicated that blueback herring return with accuracy once a year to natal areas within their home river.

Of the three anadromous herring species that spawn in the Hudson River estuary, blueback herring are the last to begin their spring spawning run, preferring warmer water than American shad or alewives. Their peak spawning activity occurs near the end of May. Spawning occurs within the river, but preferred spawning habitat is in fast-flowing tributaries, where eggs are released over hard substrates (Loesch and Lund 1977). Blueback herring are known to run in Hudson River freshwater tributaries located well below the salt front (Limburg and Schmidt, 1990) and to the headwaters (Owens et al., 1998). In the Hudson, blueback herring travel through the locks, and spawning occurs within the Mohawk River and upper Hudson River.

Blueback herring produce 45,000 to 350,000 eggs per female. The eggs are 0.0625 in. in diameter and adhesive upon release, but they may later become dislodged and be pelagic (Loesch and Lund, 1977). In the Hudson River peak abundance of herring eggs (combined alewife and blueback herring) appears to occur in the upper estuary in the Catskill region

Figure V-70. Distribution of blueback herring in North America.

during mid-May (Figure V-71). Development proceeds rapidly and hatching occurs in two to three days. Newly hatched blueback herring are 0.125 in. long and the yolk sac is absorbed in about four days. At the beginning of the post-yolk-sac stage the larvae are about 0.1875 in. long. In the Hudson River PYSL appear to be most abundant within the Albany and Catskill regions of the estuary during late May (Figures V-71 and V-72).

Blueback herring larvae feed upon amphipods, copepods, isopods, cumaceans, mysids, decapod larvae and icthyoplankton while at sea (Hildebrand, 1963; Scott and Crossman, 1973; Holland and Yelverton, 1973). Juvenile blueback herring were found to select for copepods in the size range of 0.6-1.8 mm, whereas the generally smaller cladocerans (e.g., *Bosmina* 0.25-0.31 mm) were rejected (Domermuth and Reed, 1980). Stone and Daborn (1987) reported that calanoid copepods, which made up the highest portion of the diet of adult blueback herring in Minas Basin, Nova Scotia. They were also found to be eating *Crangon volutator*, *Neomysis americana* meroplankton and *Crangon septemspinosa*. Grabe (1996) found the blueback herring in the lower Hudson River estuary to feed primarily on chironomid larvae and copepods, with the lowest feeding occuring at night.

Within a month of hatching, the young blueback herring assume adult characteristics and are about 0.5 in. long. In the Hudson River the peak abundance of early juveniles occurs in the upper estuary in the Albany region during the last half of June (Figures V-71 and V-72). Juvenile blueback remain in the upper estuary throughout the summer (Figures V-71 and V-72). Juvenile blueback herring grow more slowly than juvenile alewives and begin their downriver migration later than the other herring species. Schmidt et al., 1988 reported that juvenile blueback herring in the Hudson River migrate rapidly downriver in October after spending the summer in the vicinity of their natal areas. It has been reported that blueback herring exhibit a tendency to spend their first year or two in the lower reaches of estuaries (Hildebrand 1963).

ii. Temporal Changes in Abundance

Sampling Programs

The life history of blueback herring makes it difficult to accurately measure their relative abundance. Adults are in the estuary only a short time during and after the spawning season. The Tucker trawls and epibenthic sleds used in the LRS program are probably not efficient adult sampling devices. The Hudson River haul seine and gill net sampling programs designed to collect American shad and striped bass, are also not effective for blueback herring because the meshes are too coarse for the smaller blueback herring.

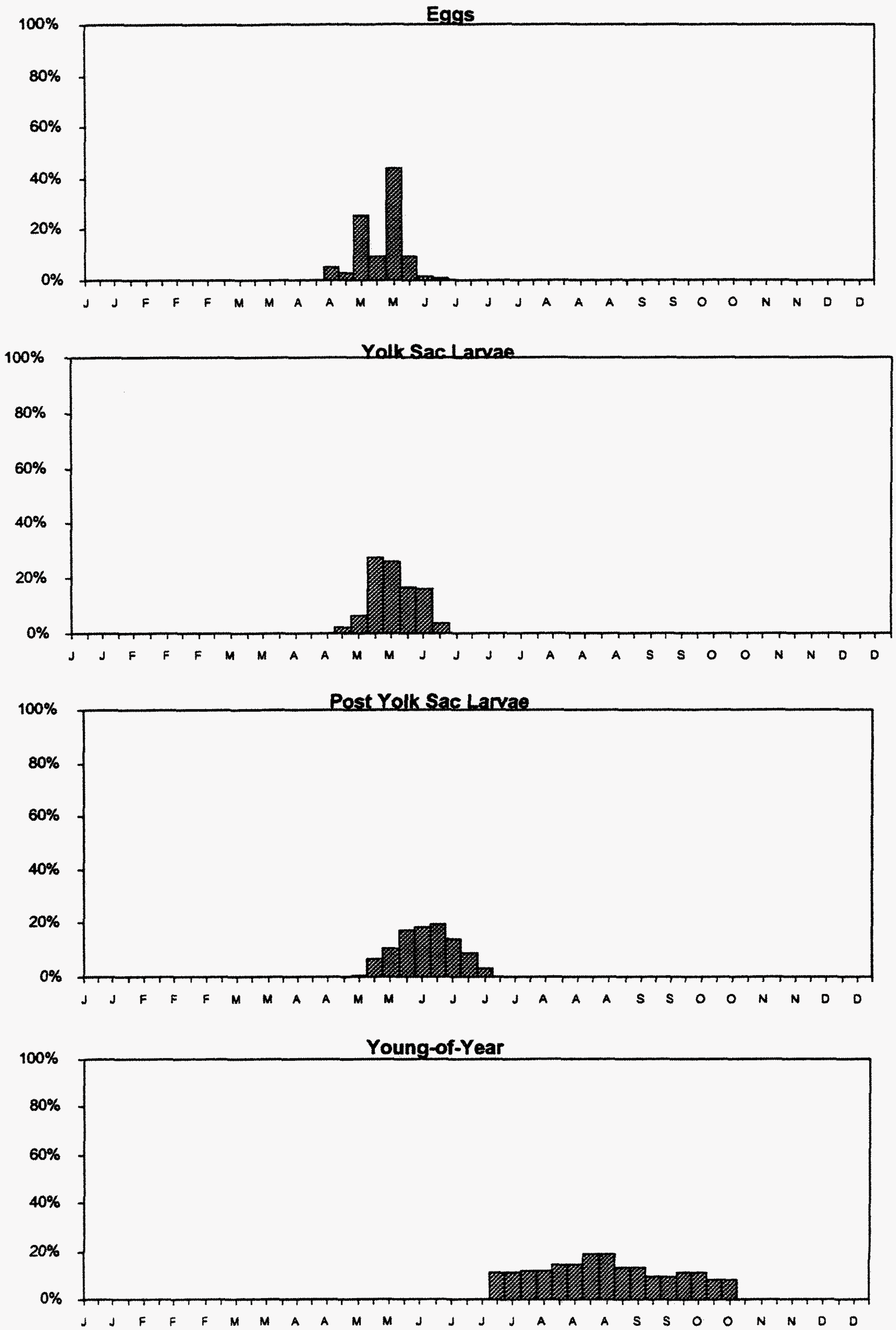


Figure V-71. Temporal distribution of blueback herring by life stage.

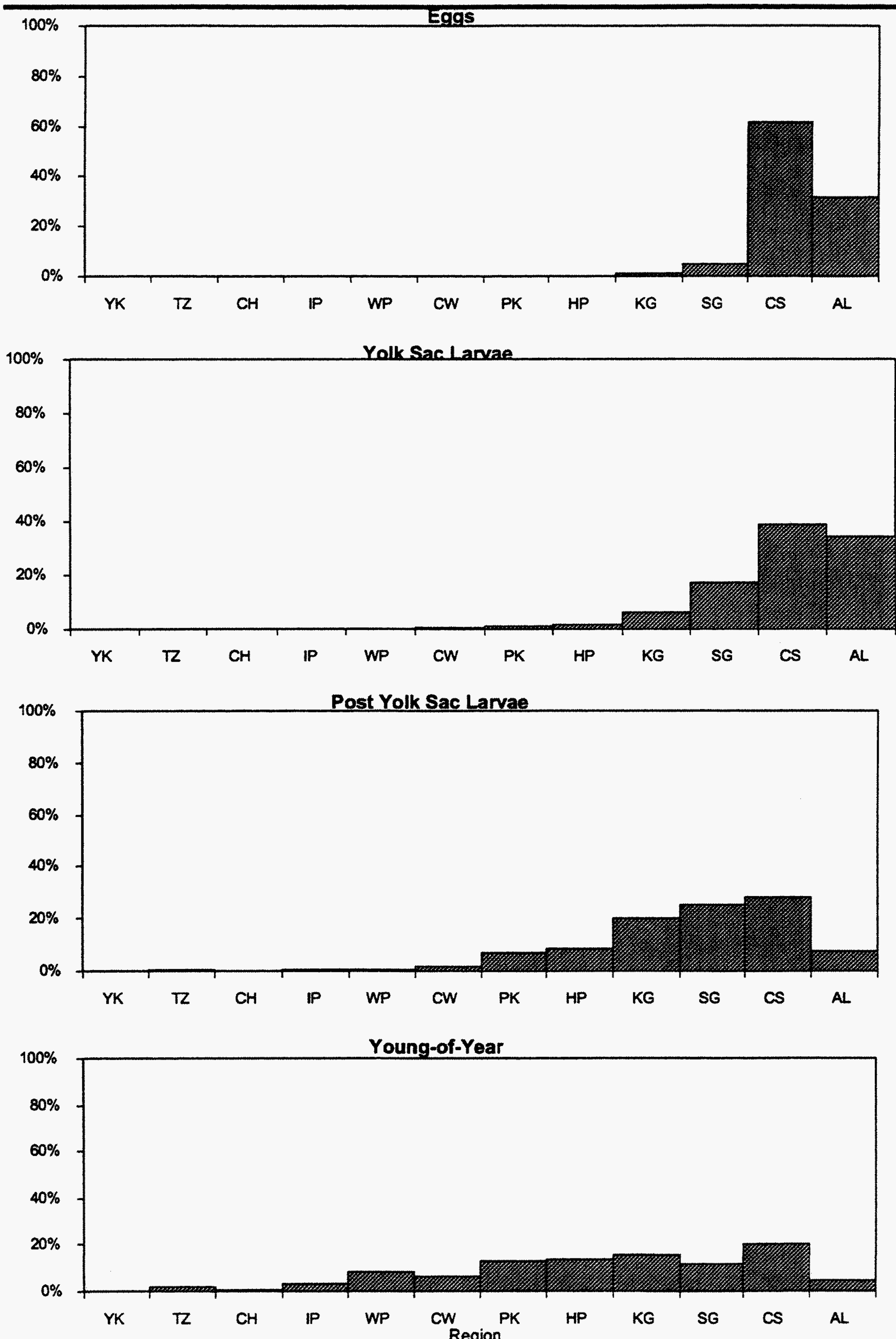


Figure V-72. Spatial distribution indices for Alosa spp. eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year blueback herring collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

Since an unmeasured proportion of spawning occurs outside the river proper, in tributaries and in the Mohawk River, sampling of the early life stages within the Hudson may underestimate the true abundance of adults or spawning effort. Hudson River sampling of eggs and larvae of alewives and blueback herring are not differentiated. Any references in this document to eggs and larvae pertain to the combined numbers from both species. Juveniles of these two species are differentiated by the size of the eyes and the mouth morphology and color of the periotoneum. Older blueback are distinguishable from alewives by their proportionately smaller eyes and thinner bodies. The abundance of PYSL within the river may be an index of spawning in the river, but this is an unknown, and perhaps variable, fraction of the total spawning effort of the Hudson estuary population

Due primarily to the blueback herring's pelagic nature, the best available index for examining young-of-the-year (YOY) abundance is the mean density from the channel stratum of the FSS. This sampling, conducted since 1979, is done with a 1-m^2 Tucker trawl during the night. The FSS survey, was chosen because the diel movements of the blueback herring place it toward the surface at night (Schmidt, 1988). An index based on channel samples was generated because the mean densities in the channel were as high or higher than those in the bottom and shoal strata, and the sampling gear used in the channel has been consistent over the duration of the program.

Like juvenile shad, juvenile blueback herring were caught in significant numbers in beach seine samples. However, the blueback herring BSS index was not correlated with the FSS channel index and the use of the longer BSS time series in the analysis of temporal changes in abundance for this species could not be justified.

The abundance index is calculated from weeks 33-40 (mid-August to early October.

Abundance Indices

Over the time period from 1979 through 1997, there was a slight increasing trend (+1% per year) in the FSS juvenile index (Table V-27).

iii. Potential Influences on Abundance

Ecological Factors

The abundance of juvenile blueback herring during the fall may have been affected by competition with juvenile bay anchovy during the period from 1988 through 1997. If the adjustment for a decrease in invertebrate production (Appendix V-3) is applied to both juvenile bay anchovy and juvenile blueback herring for 1988, 1989, and 1990, there is a

TABLE V-27

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF YOUNG-OF-YEAR (YOY) BLUEBACK HERRING

YEAR	FSS CHANNEL YOY INDEX (S.E.)
1979	3.70 (0.75)
1980	2.61 (0.75)
1981	21.20 (5.86)
1982	10.33 (2.06)
1983	6.08 (1.07)
1984	20.38 (3.67)
1985	17.42 (4.58)
1986	6.48 (1.38)
1987	25.61 (12.36)
1988	26.69 (4.30)
1989	16.83 (5.41)
1990	29.69 (10.64)
1991	12.65 (4.47)
1992	15.52 (3.87)
1993	7.72 (1.59)
1994	5.77 (1.90)
1995	1.27 (0.42)
1996	50.16 (15.89)
1997	7.30 (1.43)

negative relationship between these two species over the entire period from 1988 through 1997 ($r = -0.694$; $p = 0.026$). The highest blueback herring abundance occurred in 1996 when bay anchovy abundance was lowest (Table V-27).

Environmental factors in the ocean have been correlated to commercial landings of river herrings. Sutcliffe et al. (1977) and Dow (1983) correlated alewife commercial catches with sea surface temperatures four years previously. These references indicate that the population dynamics of river herring are affected strongly by the oceanic environment. Although the citations do not refer specifically to Hudson River fish, the Hudson River fish are also subject to the same oceanic factors. Cabilio et al. (1987) found a relationship with an 18-year tidal amplitude cycle, which may influence retention of larvae within estuaries, nutrient recirculation, or thermal mixing.

Fishing

The river herring fishery is one of the oldest fisheries in the United States, historically providing large harvests along the Atlantic coast. The commercial fishery does not distinguish alewife from blueback herring, but instead refers to their combined numbers as river herring. River herrings were fished in rivers and estuaries during the spawning runs and along the coast. More than 90% of the U.S. commercial catch was landed within 3 miles of the coast (Fay et al. 1983). From 1966 to 1970 annual landings were over 50 million pounds per year.

Although river herrings were exploited exclusively by the inshore fishery by domestic fishermen until the late 1960s, exploitation by foreign offshore fleets began in the 1970s, and the stocks began to decline (Anderson 1984). Although directed fishing by the foreign fleets ended in 1980, river herrings are also taken as by-catch in the offshore mackerel fishery. By-catch appeared to increase between 1981 and 1989 when by-catch limits were set at 99790 kg (220,000 lb).

Landings of river herring in New York and New Jersey are relatively small compared to other states (Harris and Rulifson 1989). From 1978 through 1987 New York accounted for about 0.3% and New Jersey about 0.1% of total Atlantic coast landings. By contrast, Maine and North Carolina accounted for 22 and 53%, respectively. An average of 40% of New York's reported annual harvest came from other than the ocean, presumably the Hudson River, while 100% of New Jersey's reported annual harvest of river herrings came from oceanic waters.

Although there is no commercial fishery for river herrings in the Hudson River, several hundred commercial scap net licenses are issued annually. These licenses are believed to be used to catch herring for personal use (K. Hattala, DEC, pers. commun.). Recreational fishing, with a smaller scap net, also captures an unknown number of herring.

Water Withdrawals

Entrainment and impingement effects were estimated as described in Appendices VI-1 and VI-2. For the Hudson River population the effects of water withdrawals vary from year to year. Entrainment mortality, which is calculated for the combined abundance of blueback herring and alewife, has ranged from 8 to 41% from 1974 through 1997 (Table V-28), while impingement of blueback herring is estimated to be between 0.2 to 0.7% for each annual cohort (Table V-28). The relative contribution of the stations applying for permit renewal is 67% for impingement and 11% for entrainment.

Other Factors

Low DO levels in the Hudson River south of Albany improved with improved sewage treatment in the late 1960s. This improvement of water quality may have been beneficial to blueback herring, which pass through this area moving upriver on spawning runs and downriver on seaward migrations both as postspawning adults and as YOY.

f. Alewife

i. Life History and Distribution Within the Hudson River

Alewife *(Alosa pseudoharengus)* is a member of the herring family (Clupeidae). Adults are typically about 10-12 in. long and have a maximum life span of about nine years. Alewives are physically similar to blueback herring and can be distinguished from blueback herring on the basis of the color of the lining of the body cavity, eye size, and body shape. Alewife are usually anadromous and inhabit coastal waters from Newfoundland to South Carolina (Figure V-73). They spend most of their lives in salt water and return to fresh water to spawn in lakes and quiet stretches of rivers (Scott and Crossman 1973). Alewife have also been introduced into the upper Great Lakes and inland lakes in Rhode Island, Maine, New Hampshire, Virginia, Ontario, and New York, where they provide forage for large predatory species.

Alewife spawning activity is most intense when water temperatures are 51° to 71°F, which results in slightly earlier spawning than that of blueback herring. In the Hudson River system, tributaries are important spawning sites. Many of these tributaries are located below the salt front. Limited suitable spawning habitats may limit alewife reproduction in the

TABLE V-28

ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON BLUEBACK HERRING. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	0.17	0.83	0.64	2.91	0.47	1.76	22.03		27.19
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									27.45
1975	E	0.19	1.42	13.00	13.17	0.45	1.53	18.57		40.67
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									40.88
1976	E	0.79	1.85	5.70	4.38	0.58	1.61	19.78		31.10
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									31.35
1977	E	0.49	2.47	6.26	8.81	0.43	1.57	17.58		32.99
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									33.23
1978	E	0.21	1.26	2.99	2.01	0.34	1.75	20.95		27.50
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									27.76
1979	E	0.09	2.24	4.10	3.22	0.10	1.85	18.34		27.42
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									27.68
1980	E	0.06	0.48	2.87	2.62	0.48	1.23	18.58		24.71
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									24.98
1981	E	0.02	0.57	2.30	2.46	0.23	0.30	6.59		11.98
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									12.29
1982	E	0.17	0.81	1.90	1.87	1.51	0.42	3.46		9.74
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									10.07
1983	E	0.31	3.05	4.60	4.97	1.09	0.91	8.26		21.22
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									21.50
1984	E	0.15	5.34	1.65	1.56	1.26	1.10	15.57	0.33	24.80
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									25.07
1985	E	0.00	0.02	1.03	1.95	0.01	1.16	11.02	0.00	14.68
	I	0.00	0.30	0.00	0.10	0.00				0.40
	T									15.02
1986	E	0.01	0.92	1.62	3.70	0.10	0.26	3.83	0.03	10.09
	I	0.00	0.40	0.10	0.20	0.00				0.70
	T									10.72
1987	E	0.01	0.04	2.89	2.04	0.06	3.82	25.98	0.02	32.36
	I	0.00	0.20	0.00	0.10	0.00				0.30
	T									32.57
1988	E	0.04	0.51	3.59	4.26	0.19	1.35	16.01	0.05	24.12
	I	0.00	0.10	0.00	0.10	0.00				0.20
	T									24.28
1989	E	0.41	1.41	4.53	3.09	1.17	1.74	23.49	0.24	32.67
	I	0.00	0.10	0.00	0.10	0.00				0.20
	T									32.80
1990	E	0.85	2.94	2.31	1.94	1.24	1.95	20.96	0.30	29.65
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									29.91
1991	E	0.08	0.41	1.55	1.07	0.27	1.31	17.80	0.05	21.63
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									21.91
1992	E	0.06	0.41	2.04	1.20	0.43	1.68	35.74	0.09	39.45
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									39.67
1993	E	0.04	0.23	0.91	0.69	0.41	0.95	8.21	0.12	11.24
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									11.56
1994	E	0.07	0.49	1.96	1.18	0.34	1.75	11.95	0.11	17.03
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									17.33
1995	E	0.02	0.12	4.23	3.80	0.13	1.37	5.44	0.04	14.34
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									14.65
1996	E	0.01	0.49	1.31	1.55	0.21	1.73	2.56	0.07	7.69
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									8.02
1997	E	0.22	0.60	4.83	6.09	1.28	2.08	9.13	0.29	22.36
	I	*0.00*	*0.22*	*0.02*	*0.12*	*0.00*				*0.36*
	T									22.64
AVERAGE	E	0.19	1.20	3.28	3.36	0.53	1.47	15.08	0.12	23.19
	I	0.00	0.22	0.02	0.12	0.00				0.36

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A]Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B]Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C]RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21d; Impingement-Appendix VI-2-B, Table 19

Figure V-73. Distribution of alewife in North America.

Hudson River (Limburg and Schmidt, 1990). Fecundity estimates for alewife have been reported to range from a low of 48,000 (Kissil, 1969) to a high of 456,700 (Jessop, 1993).

Alewife eggs are semidemersal and slightly adhesive, but easily suspended and carried by currents. The egg diameter is about 0.0625 in. Hatching takes two to 15 days depending upon temperature. The larval yolk-sac reduces in size and is absent by the third day (Jones et al, 1978). At this time, larvae are approximately 0.25 in. long (Cianci, 1969). Alewife larvae undergo metamorphosis to the juvenile stage at about 0.8 in. TL (Wang and Kernehan, 1979; PSE&G, 1984). Anadromous male alewives reach sexual maturity in about three years, while females reach sexual maturity in about four years.

The alewife is chiefly a plankton feeder; copepods, amphipods, shrimps, and appendicularians are the chief diet. Larvae (0.25 in.) feed on small cladocerans and copepods, changing to larger species as they grow (Pardue, 1983). YOY alewives were found to feed on dipteran midges in July, switching to cladocerans in August and September (Pardue, 1983) In the lower Hudson River estuary, (Grabe, 1996) reported juvenile alewife feeding on chironomid larvae and the amphipod, *Corophium lacustre*. However, they also take small fish, such as herring, eels, lance, cunners, and their own species, as well as fish eggs. After returning to the lower estuary following spawning, alewife feed heavily on shrimp (Bigelow and Schroeder 1953).

Larval alewives are transported downstream by water currents. Like young blueback herring, alewife assume adult characteristics at about one month of age and about 0.5 in. long. At this stage they tend to move inshore during the day and offshore into deeper waters at night. Young alewives remain in estuaries until water temperatures begin declining in the fall, when they move into coastal waters. Emigration occurs over several months, like that of American shad, and is apparent from the gradual disappearance of alewife juveniles in the catches of the monitoring program (Figure V-74). Timing of migration may also be related to size, and larger juveniles migrate earlier (Schmidt et al. 1988). Little is known about offshore distribution patterns at sea. The presence of alewives and blueback herring in the Bay of Fundy has led to speculation that these species have an oceanic migratory pattern similar to American shad, although that has not been confirmed (Harris and Rulifson 1989).

The degree to which alewife of Hudson River origin return to the Hudson River is not known nor is the degree to which spawning stocks from different river systems mix. Alewives have demonstrated the capability of homing to their natal rivers after they mature at ages 3 or 4, even though substantial numbers may not return and considerable mixing of river stocks may occur (reviewed in Fay et al. 1983).

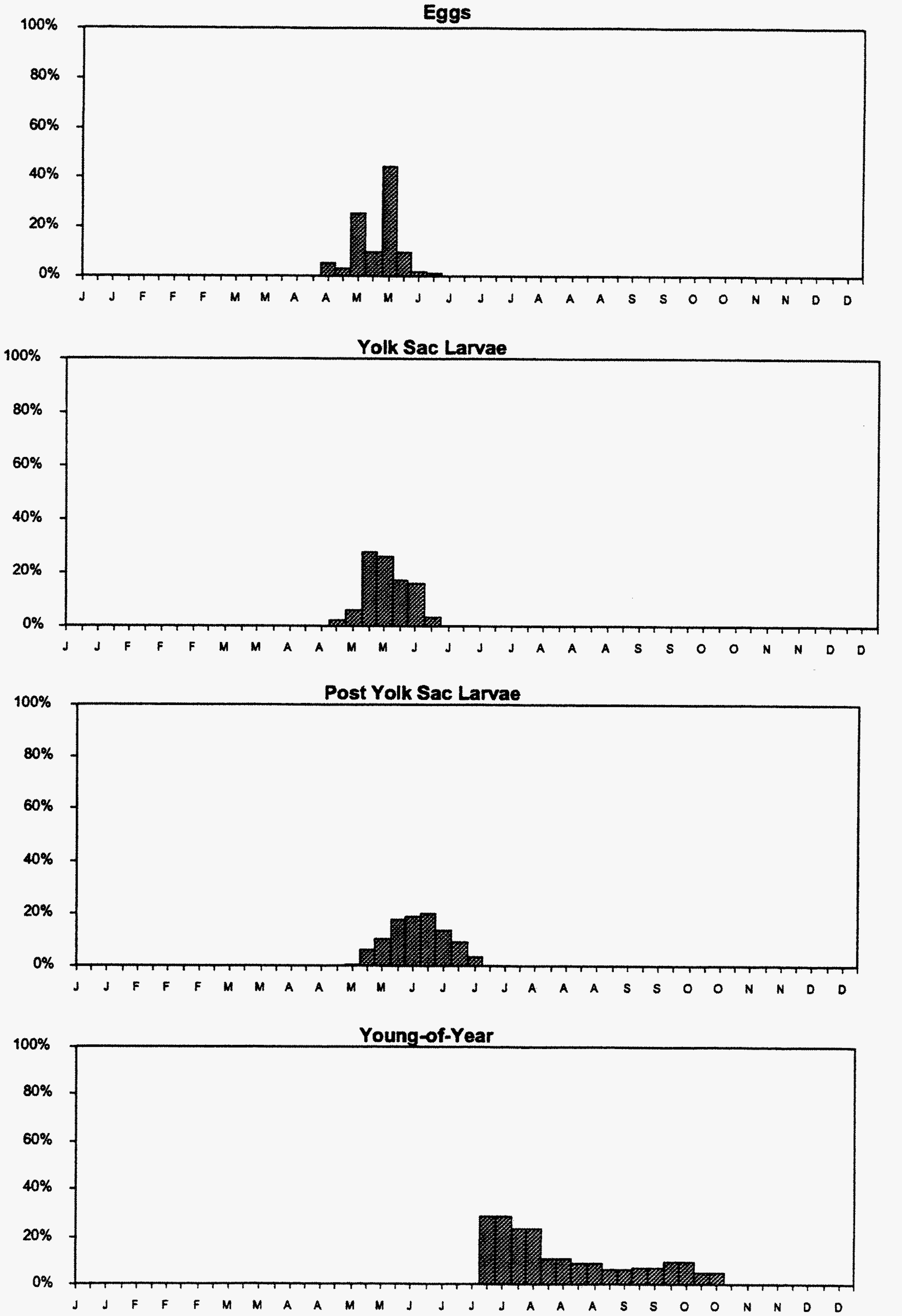


Figure V-74. Temporal distribution indices for Alosa spp. eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year alewife collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

In the Hudson River peak abundance of river herring eggs (alewife and blueback herring combined) appears to occur in the upper reaches of the estuary in the Catskill region during mid-May (Figures V-74 and 75). River herring post yolk-sac larvae are most abundant in early June. Peak abundance of young-of-the-year alewife occurs during the mid-summer months in the vicinity of Hyde Park (Figures V-74 and V-75). This suggests that only a small portion of the river herring eggs caught in the Catskill region are alewife eggs, the rest would then be attributed to blueback herring spawners which migrate further upriver than alewife during their spawning run.

ii. Temporal Changes in Abundance

Sampling Programs

Alewife movement patterns make it difficult to accurately measure their relative abundance. Adults are in the estuary only a short time during and after the spawning season. The Tucker trawls and epibenthic sleds used in the LRS program are probably not efficient sampling adult sampling devices. The haul seine and gill net sampling for American shad and striped bass are also not effective because the meshes are too coarse to effectively collect alewife or blueback herring.

The abundance of post-yolk sac larvae (PYSL) within the river may be a useful spawning index in the river, but this is an unknown, and perhaps variable, fraction of the total spawning effort of the Hudson estuary population. There is also an unknown, but probably large, fraction of the abundance composed of blueback herrings.

Due to the pelagic nature of herrings, the best available index for examining YOY abundance is the mean density from the channel stratum of the Fall Shoals Survey (FSS). This sampling, conducted since 1979, is done with a 1-m^2 Tucker trawl during the night. The FSS sampling was selected primarily because the channel stratum is a large fraction of the river, the stratum is sampled in a random fashion, juvenile alewife use the stratum, and the sampling gear does collect juvenile fish. While catches may typically be larger for beach seines, the seinable fraction of the shore zone is very small.

Although blueback herring move away from the bottom and distribute themselves in the water column at night, making them vulnerable to the Tucker trawl used in the channel stratum, alewives move inshore at night. The onshore nocturnal movement was observed in 1973 when night seine samples produced higher catches than daytime samples (TI 1976). The Beach Seine survey is conducted during the day and, consequently, neither of the two juvenile surveys matched the behavior and habitat preference of the species.

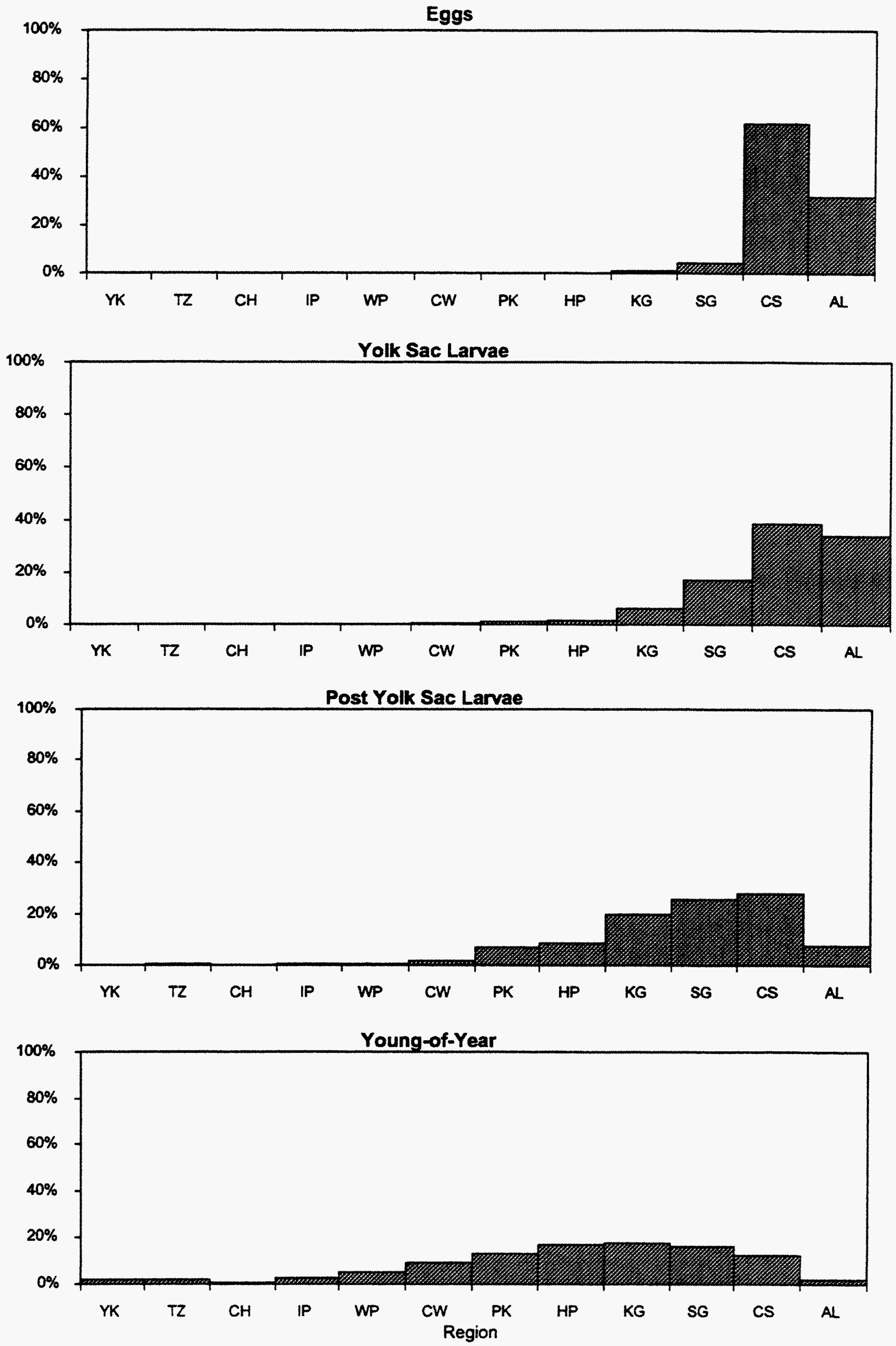


Figure V-75. Temporal distribution indices for *Alosa* spp. eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

Alewife catches were approximately two orders of magnitude lower than the corresponding catches for blueback herring in all gear. Catches in both the shorezone and channel stratum were low and did not provide a justification for selecting one survey over the other. We selected the FSS channel samples for our index of abundance because the channel stratum represents a larger fraction of the total river habitat than the shorezone does and it was sampled randomly during the Fall Shoals survey.

Abundance Indices

Unlike the increase in blueback herring, there was a slight declining trend of –3% per year in alewife abundance index values over the period 1979 through 1997 (Figure V-76 and Table V-29).

iii. Potential Influences on Abundance

Ecological Factors

The abundance of juvenile alewives during the fall may also be affected by the abundance of juvenile bay anchovy. The highest abundance observed during the period from 1988 through 1997 occurred in 1996 when the lowest abundance of bay anchovy occurred (Table V-29).

Sutcliffe et al. (1977) reported that commercial catches of alewives in New England from 1928 to 1971 were correlated ($R = 0.85$) with April-May sea surface temperatures lagged four years. Dow (1983) later reported that total Maine landings of alewife for the period 1949 to 1968 were correlated with Boothbay Harbor sea surface temperatures lagged four years. Cabilio et al. (1987) examined long-term fisheries catch records from the New England-Bay of Fundy and Grand Banks area in relation to a long-term tidal cycle (18.61-year period). Tidal cycles were assumed to have the potential to influence retention of larvae within the estuary; nutrient recirculation to surface waters, which would affect primary productivity; and thermal mixing, which would in turn influence sea surface temperatures. They found a significant linear relationship between alewife catch and strength of tidal mixing.

Predation on alewife eggs has been attributed to spottail shiner (*Notropis hudsonius*), emerald shiner (*N. atherinoides*) (Edsall, 1964), "pond suckers" (Hay, 1959), and white perch (*Morone americana*) (Kissil, 1969). Alewife larvae are prey to the yellow perch, *(Perca flavescens)* (Wells, 1980). Stephan and Bigford (1997) reported bluefish, striped bass and weakfish as predators of juvenile alewife. Predators of adults in fresh water include gulls, terns, green heron, otter, and mink. American eel, white perch, chain pickerel,

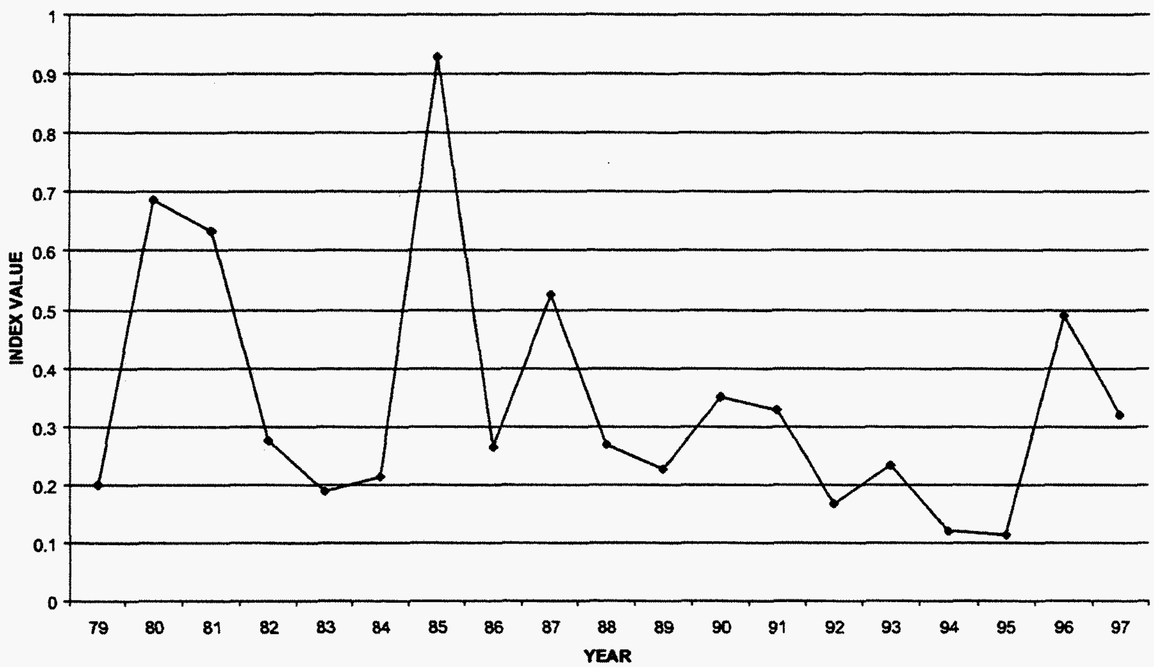


Figure V-76. Alewife FSS channel juvenile index.

TABLE V-29

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF YOUNG-OF YEAR (YOY) ALEWIVES

YEAR	FSS CHANNEL YOY INDEX (S.E)
1979	0.20 (0.08)
1980	0.69 (0.35)
1981	0.63 (0.21)
1982	0.27 (0.08)
1983	0.19 (0.07)
1984	0.21 (0.13)
1985	0.93 0.41)
1986	0.26 0.08)
1987	0.52 (0.27)
1988	0.27 (0.13)
1989	0.23 (0.07)
1990	0.35 (0.14)
1991	0.33 (0.12)
1992	0.17 (0.08)
1993	0.23 (0.08)
1994	0.12 (0.06)
1995	0.11 (0.03)
1996	0.49 (0.15)
1997	0.32 (0.10)

S.E. - Standard error.
CSC - Combined standing crop estimates from the BSS and FSS program.

[a]Some samples were not completely enumerated.

largemouth bass, yellow perch, and pumpkinseed prey on juveniles in fresh water. Striped bass, bluefish, and weakfish prey on adults at sea and in estuaries (Fay et al. 1982).

Fishing

The river herring (alewives and blueback herring) fishery is one of the oldest fisheries in the United States, historically providing large harvests along the Atlantic coast. River herrings were fished in rivers, estuaries and along the coast during the spawning runs. More than 90% of the U.S. commercial catch was landed within 3 miles of the coast (Fay et al. 1983). From 1966 to 1970 annual landings were over 50 million lb. per year.

Although river herring exploitation was exclusive to inshore domestic fishermen until the late 1960s, exploitation by foreign offshore fleets began in the 1970s and the stocks began to decline (Anderson 1984). Although directed fishing by the foreign fleets ended in 1980, river herrings are also taken as by-catch in the offshore mackerel fishery. By-catch increased between 1981 and 1989 at which time by-catch limits were set at 220,000 lb (Harris and Rulifson, 1989).

Landings of river herring in New York and New Jersey are relatively small compared to other states (Harris and Rulifson 1989). From 1978 through 1987 New York accounted for about 0.3% and New Jersey about 0.1% of total Atlantic coast landings. By contrast, Maine and North Carolina accounted for 22 and 53%, respectively. An average of 40% of New York's reported annual harvest came from other than the ocean, presumably the Hudson River, while 100% of New Jersey's reported annual harvest of river herrings came from oceanic waters.

Although there is no commercial fishery for river herrings in the Hudson River, several hundred commercial scap net licenses are issued annually. These licenses are believed to be used to catch herring for personal use (K. Hattala, DEC, pers. commun.). Recreational fishing, with a smaller scap net, also captures an unknown number of herring.

Water Withdrawals

Entrainment and impingement effects were estimated as described in Appendices VI-1 and VI-2. For the Hudson River population the effects of water withdrawals vary from year to year. From 1974 through 1997 entrainment mortality, which is calculated for the combined abundance of blueback herring and alewife, ranged from about 8 to 41% (Table V-30), and impingement mortality is estimated to range from 1.1 to 1.9% for each annual cohort of alewife (Table V-30). The relative contribution of the stations applying for permit renewal is 24% for impingement and only about 11% for entrainment.

TABLE V-30

ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON ALEWIFE. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	0.17	0.83	0.64	2.91	0.47	1.76	22.03		27.19
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									28.23
1975	E	0.19	1.42	13.00	13.17	0.45	1.53	18.57		40.67
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									41.52
1976	E	0.79	1.85	5.70	4.38	0.58	1.61	19.78		31.10
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									32.09
1977	E	0.49	2.47	6.26	8.81	0.43	1.57	17.58		32.99
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									33.95
1978	E	0.21	1.26	2.99	2.01	0.34	1.75	20.95		27.50
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									28.54
1979	E	0.09	2.24	4.10	3.22	0.10	1.85	18.34		27.42
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									28.46
1980	E	0.06	0.48	2.87	2.62	0.48	1.23	18.58		24.71
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									25.79
1981	E	0.02	0.57	2.30	2.46	0.23	0.30	6.59		11.98
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									13.24
1982	E	0.17	0.81	1.90	1.87	1.51	0.42	3.46		9.74
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									11.04
1983	E	0.31	3.05	4.60	4.97	1.09	0.91	8.26		21.22
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									22.35
1984	E	0.15	5.34	1.65	1.56	1.26	1.10	15.57	0.33	24.80
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									25.88
1985	E	0.00	0.02	1.03	1.95	0.01	1.16	11.02	0.00	14.68
	I	0.00	0.20	0.20	1.20	0.00				1.59
	T									16.04
1986	E	0.01	0.92	1.62	3.70	0.10	0.26	3.83	0.03	10.09
	I	0.00	0.20	0.20	1.50	0.00				1.89
	T									11.79
1987	E	0.01	0.04	2.89	2.04	0.06	3.82	25.98	0.02	32.36
	I	0.00	0.10	0.20	1.10	0.00				1.40
	T									33.31
1988	E	0.04	0.51	3.59	4.26	0.19	1.35	16.01	0.05	24.12
	I	0.00	0.10	0.20	0.80	0.00				1.10
	T									24.96
1989	E	0.41	1.41	4.53	3.09	1.17	1.74	23.49	0.24	32.67
	I	0.00	0.10	0.20	0.90	0.00				1.20
	T									33.47
1990	E	0.85	2.94	2.31	1.94	1.24	1.95	20.96	0.30	29.65
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									30.66
1991	E	0.08	0.41	1.55	1.07	0.27	1.31	17.80	0.05	21.63
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									22.75
1992	E	0.06	0.41	2.04	1.20	0.43	1.68	35.74	0.09	39.45
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									40.32
1993	E	0.04	0.23	0.91	0.69	0.41	0.96	8.21	0.12	11.24
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									12.52
1994	E	0.07	0.49	1.96	1.18	0.34	1.75	11.95	0.11	17.03
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									18.22
1995	E	0.02	0.12	4.23	3.80	0.13	1.37	5.44	0.04	14.34
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									15.57
1996	E	0.01	0.49	1.31	1.55	0.21	1.73	2.56	0.07	7.69
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									9.01
1997	E	0.22	0.60	4.83	6.09	1.28	2.08	9.13	0.29	22.36
	I	*0.00*	*0.14*	*0.20*	*1.10*	*0.00*				*1.44*
	T									23.48
AVERAGE	E	0.19	1.20	3.28	3.36	0.53	1.47	15.08	0.12	23.19
	I	0.00	0.14	0.20	1.10	0.00				1.44

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A]Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B]Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C]RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21d; Impingement-Appendix VI-2-B, Table 15

Other Factors

Low DO levels in the Hudson River south of Albany improved with improved sewage treatment in the late 1960s. This improvement of water quality may have been beneficial to alewife, which pass through this area moving upriver on spawning runs and downriver on seaward migrations both as postspawning adults and as YOY.

Studying the Hudson River, Limburg and Schmidt (1990) found a strong negative relationship between densities of alewife eggs and larvae and the index of urbanization. The data indicate a strong threshold effect of urbanization on anadromous spawning success, as measured by densities of eggs and larvae collected at the confluence of stream and estuary.

g. Bay Anchovy

i. Life History and Distribution Within the Hudson River

The bay anchovy (*Anchoa mitchilli*) is a small, slender fish, from 1.5- to 4.0-in. long with greenish blue coloring above the lateral line and pale silver below it (Wang and Kernehan, 1979; Jones et al., 1978; Hildebrand, 1963). The bay anchovy ranges widely from temperate to subtropical waters along the Atlantic and Gulf coasts, between Maine (although infrequently north of Cape Cod, MA) and the Yucatan Peninsula, Mexico (Hildebrand and Schroeder, 1928; Burgess, 1980; DeLancey, 1989) (Figure V-77). It is particularly abundant in estuaries, nearshore coastal waters, and bays (Springer and Woodburn, 1960). Bay anchovy occur in clear and turbid waters and over all types of substrates (Breuer, 1963). They have a wide salinity tolerance from fresh water to more than twice the salinity of normal sea water, though they prefer salinities typical of seaward ends of estuaries (Wang and Kernehan, 1979).

Where water temperatures drop below 41°F during the winter, trawl data from the National Marine Fisheries Service indicate that bay anchovy move out of coastal estuaries and southward during the fall. Overwintering areas range from Cape Hatteras to Delaware Bay resulting in the virtual absence of bay anchovy from the inshore continental shelf of New York and New Jersey during the winter months (Vouglitois et al., 1987).

Onshore-offshore movements of bay anchovies within estuaries have also been documented. MacGregor (1994) reported significantly higher abundance of eggs and recently hatched larvae offshore in Chesapeake Bay, indicating that the adults moved offshore to spawn. Similar movements were reported for the Hudson estuary where

Figure V-77. Distribution of bay anchovy in North America.

adults remained near shore until early June when they moved offshore to spawn (Schmidt, 1992). In the New York Bight, spawning occurs from May through September, with peak egg abundance occurring in late June or early July, where water temperatures are greater than 70°F and salinities are greater than 10 ppt (Figure V-78). Egg viability apparently declines at salinities less than 8 ppt, and egg abundance is typically highest where salinity is greater than 20 ppt. Bay anchovy spawn throughout the Hudson-Raritan Bay complex, including Raritan and Newark Bays, Arthur Kill, Kill van Kull, and the Upper and Lower New York bays as well as Long Island Sound (EA EST, 1995).

Bay anchovy grow rapidly and rarely survive more than 2 years. Maturity occurs in roughly 10 months at a length of 1.5- to 1.8-in. in the mid-Chesapeake Bay (Zastrow et al., 1991; Dorsey et al., 1996). Other studies report maturity in 6 months, at a length of 1.8-in. (Winemiller and Rose, 1992; Boreman, 1981; Luo and Musick 1991; Morton, 1989; Zastrow et al., 1991). In Peconic Bay, NY (Ferraro, 1980), and in the ocean and bays near Little Egg Inlet, NJ (Milstein et al., 1977), spawning begins in the evening and continues throughout the night. Individual females may spawn more than 50 times per year, with daily batch fecundities ranging from 429 to 2,026 (Zastrow et al., 1991; Houde and Zastrow, 1991; Luo, 1991; Luo and Musick, 1991).

Bay anchovy eggs are about 1/16-in. long, transparent, and initially buoyant, though become demersal in about 12-16 hours. Within the Hudson River, the eggs are most abundant in the Yonkers and Tappan Zee regions (RM 12-24) (EA EST, 1995). Hatching occurs in about 24 hours at ambient temperatures of 80.6 to 82.4 C. Newly hatched yolk-sac larvae are 1/16- to 1/8-in. long and drift along the bottom with the tidal currents. According to Houde (1974), yolk absorption is rapid during the first 20 hr and decreases thereafter, all yolk being absorbed within 50 hr of hatching (75.2-89.6°C). Tucker (1989) reported that eye pigmentation occurs in 60 hr, first-feeding success occurs in 72 hr, and complete yolk absorption occurs in 80 hr (after fertilization), at 75.2°C. The post yolk-sac larval stage lasts about a month, and peak abundance in the Hudson River occurs during July. Their distribution is shifted slightly upriver compared to the eggs and yolk-sac larvae (EA EST, 1995).

Bath et al. (unpubl. ms., ca. 1983) reported that bay anchovy eggs were more abundant near the bottom in the low salinity (0-6 ppt) region of the Hudson River during both day and night. Larvae were found to be more abundant in mid- and bottom waters in the Mystic River, CT, estuary (Pearcy and Richards, 1962), in Long Island Sound (Richards, 1959), and in the Hudson River at Indian Point Units 2 and 3 (Lauer et al., 1974). Bath et al. (unpubl. ms., ca. 1983) reported finding prolarvae more abundant at the bottom, but no depth preference by postlarvae in the low salinity (0-6 ppt) region of the Hudson River.

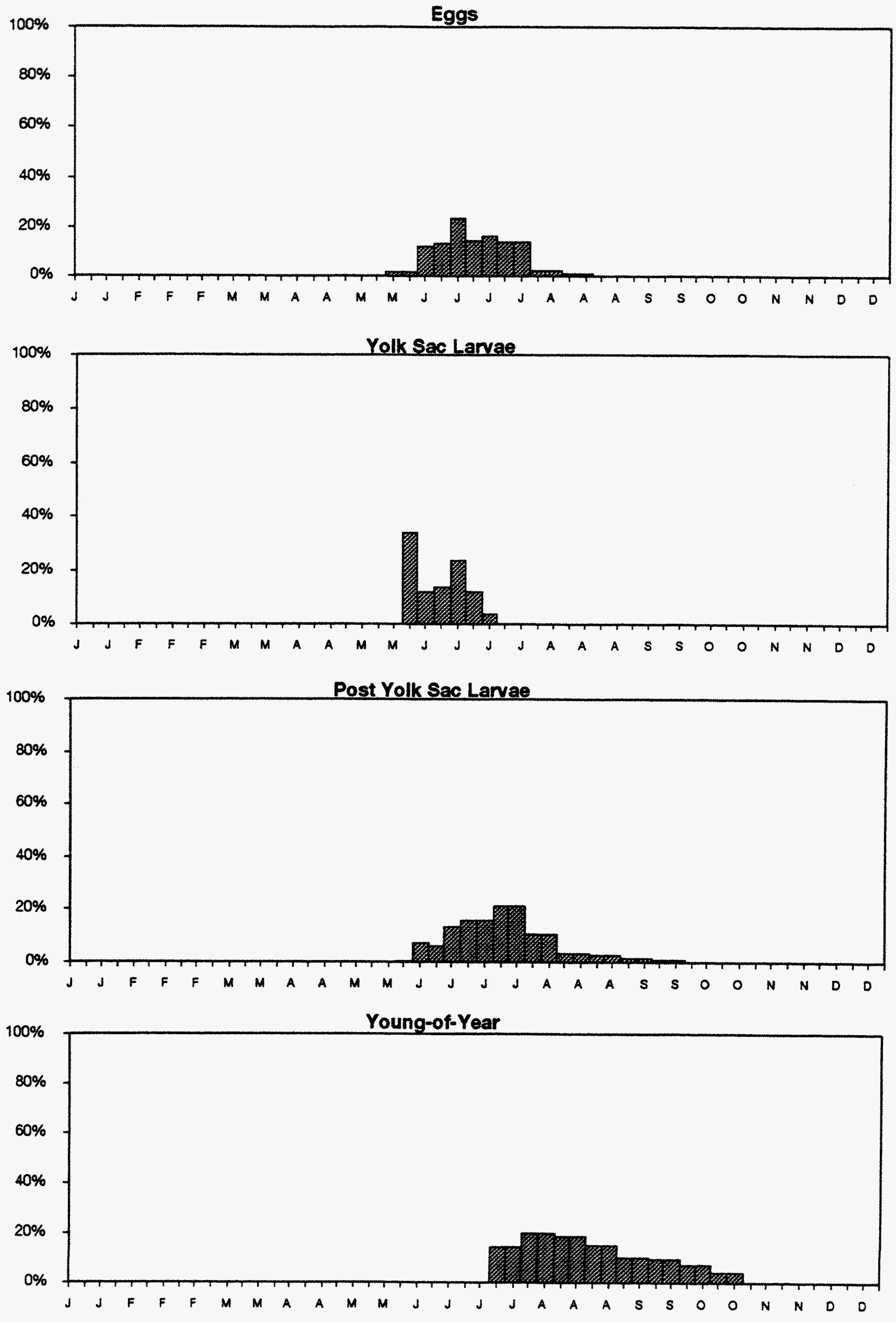


Figure V-78. Temporal distribution indices for bay anchovy eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

Neither Lauer et al. (1974) nor Bath et al. (unpubl. ms., ca. 1983) reported diel differences in vertical distribution occurring in the Hudson River. Schmidt (1992) attributed the apparent movement of postlarvae northward in the Hudson estuary to the movement of spawning adults, as net transport in the upper estuary is downstream.

Spatial and temporal variability in larval growth rate has been examined in the Hudson River and Chesapeake Bay. Jordan et al. (1997) investigated larval growth rate in the Hudson River estuary during July in each of two years (1995 and 1996). The growth rates obtained from age on length regressions of the 1995 data ranged from 0.39 mm/day to 0.88 mm/day, with a median of 0.48 mm/day; the growth rates in 1996 ranged from 0.41 mm/day to 0.77 mm/day, with a median of 0.55 mm/day. Significant differences in growth rate were found among sites within the Hudson River separated by as little as 15 km, and among dates as little as a week. Jordan et al. postulated that the spatial differences may be due to variation in habitat quality and that larval flux between these habitats is restricted over a 15-km spatial scale. The temporal differences were attributed to water temperature.

At the beginning of the juvenile stage, bay anchovy are about ½-in. long. Recruitment in the Hudson River reportedly begins in July, and juveniles may be found as far upriver as Albany through October (Schmidt, 1992). However, most of the juvenile population occurs downstream of RM 77 (EA EST, 1995).

Bay anchovy school in large numbers and feed primarily on zooplankton, including crab megolopeae, crab zoeae, copepods, cladocerans, amphipods, and mysids (Johnson et al., 1990). In the Hudson River estuary, YOY bluefish have been observed to prey predominantly upon juvenile and older bay anchovy (Juanes et al., 1993; Buckel and Conover, 1997; Scharf et al., 1997). Bay anchovy have also been reported as major prey for YOY bluefish in Sandy Hook, NJ (Friedland et al., 1988). Juvenile and older bay anchovy are consumed by YOY bluefish (Scharf et al., 1997) and mature striped bass (Gardinier and Hoff, 1982) in the Hudson River estuary. Bay anchovy was the most abundant fish by volume in the stomachs of 200- to 300-mm TL summer flounder (*Paralichthys dentatus*) taken near Little Egg Inlet, NJ (Bieder, 1976).

ii. Temporal Changes in Abundance

Sampling Programs

The index of abundance for young-of-the-year (YOY) bay anchovy was developed from channel samples collected with a 1-m Tucker trawl during the Utilities' fall juvenile survey. Shoal and bottom samples were not included because of a change in sampling gear in 1985, when the 3-m beam trawl replaced the epibenthic sled. The 3-m trawl is more effective than the epibenthic sled for YOY striped bass and white perch. However, it is not as effective for YOY bay anchovy because the mesh of the netting used in the 3-m beam trawl is wider than that used in the 1-m Tucker trawl. The sampling in the channel in the upper portion of the estuary during the fall juvenile survey did not begin until 1979 and the time series for the YOY index runs from 1979 through 1997.

Temporal patterns

The YOY index ranged from 63.3 to 340.7 and there was no time trend (Figure V-79, Table V-31). Particularly high values occurred in 1988 (340.7), 1989 (288.9), and 1995 (266.0).

iii. Potential Influences on Abundance

Predation

Predation by PYSL and YOY striped bass should be one of the major influences on the abundance of YOY bay anchovy in the Hudson River. Both PYSL and YOY striped bass are capable of feeding upon PYSL bay anchovy and they overlap temporally and spatially with PYSL and YOY bay anchovy. PYSL bay anchovy appear in lower portion of the estuary during June and are most abundant during the first half of July. PYSL striped bass move downriver into the lower portion of the estuary during June. YOY striped bass are most abundant during late June and early July. The PYSL index for striped bass ranged from 1.48 to 15.40 during the period from 1988 through 1997 and the regression of the YOY bay anchovy indices on the PYSL striped bass indices during this period was statistically significant ($p = 0.010$). The predation hypothesis explained about 60% of the variation in the abundance of YOY bay anchovy ($R^2 = 0.580$). A transform (the natural logarithms of the YOY bay anchovy indices) did not reduce the scatter around this regression line.

Competition

Competition for food resources between YOY tomcod and adult bay anchovy may have also affected the abundance of YOY bay anchovy. Both YOY tomcod and adult bay anchovy feed upon zooplankton, especially the larger copepods. YOY tomcod feed upon zooplankton during April and May, before adult bay anchovy move into the river. The recovery of the zooplankton populations from tomcod predation is affected by the generation time of the zooplankton species and the amount of suspended particulate organic matter within the estuary because zooplankton production in this ecosystem

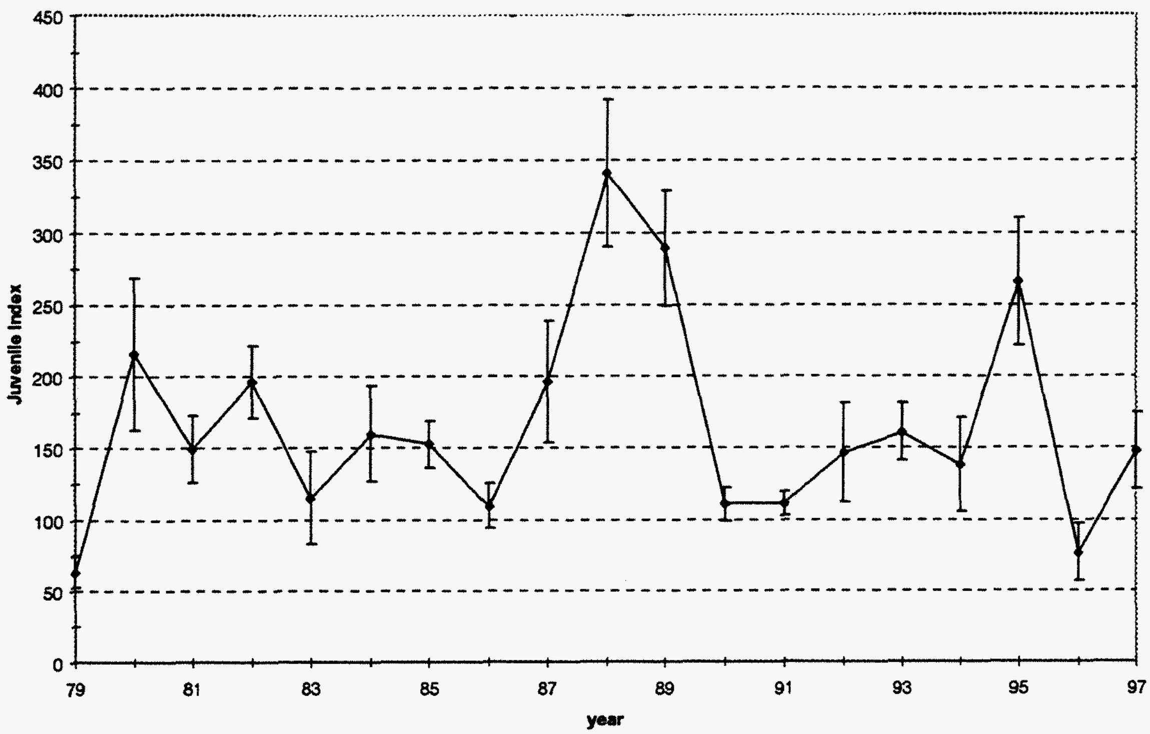


Figure V-79. Hudson River bay anchovy juvenile FSS index.

TABLE V-31

ESTIMATES OF RELATIVE ABUNDANCE OF DIFFERENT LIFE STAGES OF BAY ANCHOVY (STANDARD ERRORS, WHERE AVAILABLE, ARE GIVEN AFTER "/")

	PYSL	JUVENILE
YEAR	LRS[a]	FSS[b]
1974	5.99/0.40	
1975	7.67/0.69	
1976	3.84/0.64	
1977	5.13/0.37	
1978	2.28/0.14	
1979	1.50/0.09	63.35/10.36
1980	1.20/0.19	215.91/53.15
1981	2.19/0.17	149.45/23.70
1982	0.10/0.01	196.61/25.20
1983	1.90/0.59	114.99/32.41
1984	2.61/0.39	159.99/33.09
1985	1.96/0.13	152.68/16.31
1986	0.68/0.05	109.35/15.80
1987	1.53/0.09	196.01/42.21
1988	15.71/1.72	340.70/50.62
1989	8.95/1.21	288.92/40.24
1990	4.70/0.43	110.38/11.75
1991	26.47/2.27	110.74/8.44
1992	4.72/0.43	146.69/35.02
1993	10.26/0.62	161.0/20.1
1994	24.34/1.56	138.4/32.8
1995	9.59/0.46	266.0/44.1
1996	3.95/0.31	76.2/20.2
1997	8.13/0.92	147.8/26.6

a Weighted average number per m^3 for 7 consecutive sampling weeks over period of peak abundance.
b Weighted average number per 1000 m^3 for sampling from mid-August to early October (weeks 33-40).

depends upon bacterial production (Lints et al. 1992). Sewage discharges are the primary source of particulate organic matter during the summer months in the lower portion of the Hudson River estuary (Limburg et al. 1986). The discharge of untreated sewage into the estuary from the New York City decreased by 99% between 1970 and 1988 (Brosnan and O'Shea 1996a). The last major change in the discharge of particulate organic carbon into the Hudson River in the New York City area occurred in April 1991, when the North River wastewater treatment plant went to full secondary treatment, removing 72,765 pounds of suspended solids from the discharge (Brosnan and O'Shea 1996b). The analysis of the variation in the abundance of age 1 tomcod strongly suggested that recruitment to the Atlantic tomcod population in the Hudson River estuary was limited by intraspecific competition after 1990.

If food resources were limiting for larval and YOY tomcod, they were probably limiting for adult bay anchovy. Therefore, the number of tomcod eggs spawned during the winter and the relative growth of larval and YOY tomcod during the spring were used to adjust the YOY indices for bay anchovy to reflect the effects of resource limitation. The adjusted YOY indices were regressed on the PYSL striped bass indices for the period from 1988 through 1997 and the amount of unexplained variation decreased by two-thirds (R^2 = 0.894). A transform (the natural logarithms of the standardized YOY indices) further reduced the scatter around the regression line (R^2 = 0.959). Thus, the variation in the abundance of PYSL striped bass accounted for about 60% of the variation in the abundance of YOY bay anchovy. The variation in the abundance and growth of larval and YOY tomcod during the spring accounted for about 35% of the variation in the abundance of YOY bay anchovy.

Water Withdrawals

From 1974 through 1997, estimated entrainment conditional mortality rates ranged from 10% to 33%, and averaged 21% (Table V-32). Impingement mortality rates ranged from 0% to 0.4%, averaging less thatn 0.1%. Interpretation of these cnditional mortality rates is somewhat different than it is for species like striped bass or Amerian shad, which spawn entirely within their natal river and therefore represent a closed population. Bay anchovy are part of a coastal population that spawns not only in the Hudson River but in many other parts of the Hudson-Raristan estuary complex. Estimates must be used with caution even when they apply to a "local population" that occurs within the sampled portion of the Hudson River. While an estimate of reduction for a short period may accurately reflect the effect of water withdrawal, the abundance of anchovy within the river may change continually, due to movements of anchovy into and out of the estuary.

TABLE V-32
ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON BAY ANCHOVY. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	5.00	7.31	0.05	0.04	7.95	0.00	0.01		19.03
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									19.08
1975	E	4.20	6.61	0.18	0.07	6.10	0.05	0.63		16.77
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									16.82
1976	E	3.67	3.45	0.20	0.07	3.41	0.00	0.06		10.46
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									10.52
1977	E	4.96	13.78	0.22	0.07	8.00	0.02	0.21		25.00
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									25.05
1978	E	6.00	12.54	0.48	0.14	7.86	0.00	0.00		24.72
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									24.77
1979	E	6.30	10.80	0.52	0.16	4.11	0.00	0.04		20.43
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									20.48
1980	E	6.35	18.44	0.21	0.09	9.07	0.00	0.02		30.77
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									30.81
1981	E	4.01	18.56	0.23	0.11	8.94	0.00	0.01		29.06
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									29.11
1982	E	1.82	4.19	0.31	0.14	5.29	0.00	0.02		11.33
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									11.38
1983	E	2.95	9.04	0.51	0.21	6.34	0.00	0.00		17.91
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									17.97
1984	E	3.01	6.26	0.43	0.20	4.63	0.00	0.01	0.82	14.55
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									14.61
1985	E	3.07	10.06	0.47	0.20	8.17	0.05	0.57	1.11	21.85
	I	0.00	0.20	0.00	0.00	0.00				0.20
	T									22.01
1986	E	1.84	5.07	0.13	0.06	4.52	0.00	0.01	0.71	11.84
	I	0.00	0.40	0.00	0.00	0.00				0.40
	T									12.19
1987	E	5.50	9.99	0.38	0.11	5.67	0.01	0.14	1.21	21.24
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									21.24
1988	E	5.21	17.73	0.76	0.29	6.83	0.02	0.25	1.13	29.11
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									29.11
1989	E	3.59	7.96	0.11	0.03	4.62	0.00	0.01	0.57	15.97
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									15.97
1990	E	5.24	20.85	1.07	0.40	8.48	0.00	0.03	1.10	33.13
	I	0.00	0.00	0.10	0.00	0.00				0.10
	T									33.19
1991	E	3.72	9.09	1.44	0.59	6.99	0.00	0.01	0.95	21.00
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									21.00
1992	E	3.55	7.12	0.20	0.08	6.82	0.01	0.20	0.74	17.55
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									17.55
1993	E	3.17	7.08	0.50	0.29	7.03	0.01	0.15	0.82	17.82
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									17.82
1994	E	2.69	5.94	0.09	0.04	6.85	0.01	0.07	0.85	15.64
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									15.64
1995	E	3.55	14.99	1.82	0.96	6.74	0.01	0.05	0.96	26.40
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									26.40
1996	E	1.27	15.55	0.07	0.05	7.19	0.00	0.00	0.94	23.44
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									23.49
1997	E	3.61	6.62	1.78	0.98	7.95	0.01	0.05	0.98	20.26
	I	*0.00*	*0.05*	*0.01*	*0.00*	*0.00*				*0.06*
	T									20.31
AVERAGE	E	3.93	10.38	0.51	0.22	6.65	0.01	0.11	0.92	20.64
	I	0.00	0.05	0.01	0.00	0.00				0.06

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A]Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B]Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C]RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21c; Impingement-Appendix VI-2-B, Table 18

h. Atlantic and Shortnose Sturgeon

i. General Life History Characteristics

The Hudson River estuary supports populations of two species of sturgeon, the Atlantic sturgeon, *Acipenser oxyrhynchus*, and the shortnose sturgeon, *Acipenser brevirostrum*. The Atlantic sturgeon has two recognized subspecies, *A. o. oxyrhynchus* and *A. o. desotoi.* The former ranges from Hamilton River, Labrador, and George River, Ungava Bay, to northeastern Florida (Figure V-80), while the latter is confined to the northeastern Gulf of Mexico (Gruchy and Parker 1980a). The shortnose sturgeon, *Acipenser brevirostrum,* is less widespread (Figure V-81), inhabiting large coastal rivers along the Atlantic Ocean from the St. John River, New Brunswick, to the St. Johns River, Florida (Gruchy and Parker 1980b). Nineteen distinct stocks of shortnose sturgeon are recognized, ranging in size from less than about 100 adults in the Merrimack River, Massachusetts to greater than about 38,000 (now 60,000) adults in the Hudson River, New York (NMFS 1998a).

Sturgeon are members of the family acipenseridae, which has an extensive evolutionary history dating back about 200 million years. All sturgeon, including the Atlantic and the shortnose sturgeons, retain ancestral body characteristics that make them recognizable as relict fishes (Bemis et. al. 1997). Adults possess barbels extending across most of the width of the snout, heavy bony plates (called scutes) covering the body, and an extended upper lobe of the tail fin. As adults, shortnose sturgeon can be distinguished from the Atlantic sturgeon by a shorter and blunter snout, wider mouth, and smaller size of the anal fin. Individuals over 4 ft long are invariably Atlantic sturgeon, which is one of the largest fish in North America with a maximum recorded length of about 14 ft (Bain 1997). In contrast, shortnose sturgeon is the smallest species of sturgeon in North America, with a maximum length in the Hudson River of about 3.5 ft (Dovel et. al. 1992). Young sturgeon of the two species, under 2 ft, and especially larvae, are difficult to distinguish.

Sturgeon are long-lived, slow-maturing fishes. In the Hudson River the maximum reported age for shortnose sturgeon is 37 years (Dadswell et. al. 1984) and for Atlantic sturgeon 29 (Smith 1985). However, both are reported to reach considerably older ages in other river systems. The oldest known shortnose sturgeon is a 67-year-old female from St. John River, Canada, while the oldest known Atlantic sturgeon is a 60-year-old individual from the St. Lawrence River (Gilbert 1989). For both species, age at maturity varies by geographic location and spawning appears to be a non-annual event. In the Hudson River Estuary, male shortnose sturgeon reach sexual maturity at age 3-5 and females at age 6-7 (Dadswell et al. 1984). The first spawning, however, may follow

Figure V-80. Native distribution of Atlantic sturgeon in North America.

Figure V-81. Native distribution of shortnose sturgeon in North America.

maturation in males by 1-2 years, while in females spawning may be delayed up to 5 years (Dadswell 1979). Based on the percentage of fish examined from August to March that were developing sexually, Dadswell (1979) suggested that female shortnose sturgeon spawn once every third year and males every other year. Other evidence (annuli of the pectoral ray) suggests a 5- to 11-year interval between spawnings (Dadswell 1979). However, annual spawning has been suggested by tagging studies on the Hudson River that tracked shortnose sturgeon to the spawning grounds in successive years (Dovel et al. 1992). Atlantic sturgeon mature somewhat later than do shortnose sturgeon, males generally not until at least 12 years and females 18-19 years (Dovel and Berggren 1983). The inter-annual spawning period may range from 3-5 years, and during non-spawning years adults use marine waters either all year or seasonally (Bain 1997).

Atlantic sturgeon are anadromous. They spawn in freshwater, but spend most of their life in marine waters, often undertaking long distance migrations along the Atlantic Coast (Bain 1997). For example, Atlantic sturgeon tagged in the Hudson River have been recaptured as far north as Marblehead, Massachusetts, and as far south as Ocracoke, North Carolina (Dovel and Berggren 1983). Since Delaware Bay and Chesapeake Bay commercial fisherman returned many of the tags, it is clear that Atlantic sturgeon from the Hudson River may spend at least part of their lives in other estuary systems. Coastal movements of Atlantic sturgeon may be largely confined to the biogeographic province in which their natal rivers belong. If so, most Atlantic sturgeon in rivers of the central Atlantic coast are probably from the Hudson River population since there are no Atlantic sturgeon populations within the Virginia Province that are larger than relict size (Waldman 1996).

Although shortnose sturgeon also enter freshwater to spawn, they may be better described as amphidromous since they appear to spend most of their life in their natal river, and only occasionally enter nearby coastal water (Bemis and Kynard 1997). Dadswell et at. (1984) reported that whether each river population of shortnose sturgeon is distinct from the others must await future studies. He noted, however, that southern populations might mix in the sea while northern populations appear confined to their separate drainage systems. Shortnose sturgeon move considerable distances within the Hudson River; but appear rarely to migrate to the ocean or to neighboring systems.

Both Atlantic and shortnose sturgeon produce large numbers of eggs. Fecundity estimates derived from a number of river systems indicate that Atlantic sturgeon produce between 0.8 to 3.75 million eggs per female and that the number of eggs is closely related to the weight of the fish. Shortnose sturgeon females produce somewhat fewer eggs than Atlantic sturgeon.

During spawning, Atlantic sturgeon broadcast their eggs into flowing water. The eggs are large, demersal, and adhesive, and attach within about 20 minutes to rocks, gravel, plants, roots, and other objects (Smith 1985). Ripe (unfertilized) eggs of the Atlantic sturgeon are 2.5-2.6 mm in diameter and globular in shape; fertilized eggs are 2.0-2.9 mm in diameter and become oval as development proceeds (Jones et al. [1978; Van Den Avyle [1984]). Hatching time ranges from about 4 days at about 20°C (Dean 1895) to 7 days at 17.8° C (Vladykov and Greeley 1963).

Atlantic sturgeon typically hatch at 7-9 mm SL and complete their yolk sac absorption by 13-14 mm SL (Snyder 1988). Under culture conditions, they can reach about 19.9 mm TL in 20 days and 177 mm in 204 days (Smith et al. 1980, 1981). The newly-hatched young (or prolarvae) are reportedly active swimmers. By the time their yolk sac is absorbed (about 9-10 days post hatch), the larvae clearly exhibit a predominantly benthic behavior, swimming on the bottom or near bottom with increased scouring activity (Smith et al 1980, 1981; Ross and Bennett 1996). In the Hudson River, the larvae reside on the bottom in deep channel habitats (Bain 1997). Transition from the larval to juvenile stage appears to occur by about 31.5 mm TL (Bath et al. 1981).

Shortnose sturgeon are broadcast spawners with external fertilization of eggs (NMFS 1987). Similar to Atlantic sturgeon, the eggs are demersal and adhere to objects on the river bottom within minutes of fertilization. Ripe eggs and fertilized eggs have diameters of 3.0-3.2 mm and 3.5 mm, respectively (Dadswell et al. 1984; Buckley and Kynard 1981). Between 8 and 12 C, eggs hatch 13 days after fertilization. At 17 C, hatching occurs in 8 days (Buckley and Kynard 1981). Upon hatch, larvae are 7.3-11.3 mm long (Taubert 1980a; Buckley and Kynard 1981).

Recent research on shortnose sturgeon larval behavior indicates that hatchlings are photonegative and vigorously seek cover under any available structure immediately after hatching (Richmond and Kynard 1995). During the first 1-2 days following hatch, larvae denied or dislodged from cover will exhibit "swim-up and drift" behavior, which in the wild allows them to move short distances to seek available cover. Yolk-sac larvae continue to seek bottom cover for about a week, but after 1-2 days post-hatch their movements are predominantly horizontal along the bottom (Richmond and Kynard 1995). Ten-day-old larvae reportedly attempt to remain on the bottom or place themselves under any available cover (Pottle and Dadswell 1979; Washburn and Gillis Associates 1980). At this age (9-12 days post hatch), larvae are 15 mm long (TL), the yolk sac is completely absorbed, and the fry are feeding on zooplankton (Buckley and Kynard 1981; Washburn and Gillis Associates 1981). By about 14-17 mm TL, shortnose sturgeon, resembling miniature adults, become photopositive and leave cover to swim in the water column, although remaining bottom oriented. In the wild, larvae of this size probably migrate downstream (Richmond and Kynard 1995).

Early growth is rapid for both species. For shortnose sturgeon, larvae are approximately 0.7 in. in total length at the end of May and 4.9 to 5.1 in. by the end of July. By the end of their second summer, they average approximately 11.5 in. (Dovel et al. 1992). Atlantic sturgeon grow at a similar rate during their early years. Dovel and Berggren (1983) reported that by the end of their second summer average size is 12.8 in. After about the third year of life for both species, growth slows considerably. Greeley (1937) reported a maximum size of about 34 in. at 15 years for shortnose sturgeon while Dadswell et al. (1984) reported a maximum of approximately 35 in. at age 40. Atlantic sturgeon continue to grow at a much faster rate than do shortnose sturgeon. Dovel and Berggren (1983) reported that by age 29, Atlantic sturgeon averaged 7.8 ft.

Juvenile and adult sturgeon feed by rooting along the bottom and vacuuming' with their protrusible mouths. This leads to a large amount of nonfood matter, mostly mud, in the stomach. Young shortnose sturgeon feed on amphipods and dipteran larvae. Insect larvae and small crustaceans predominate in the diet of juveniles while adults feed primarily on small mollusks (Dadswell et al. 1984). Actual food items include mollusks, polychaete worms, gastropods, shrimp, isopods, amphipods, and small benthic fishes.

ii. Distributions Within the Hudson River

Extensive scientific studies of the Hudson River sturgeon first began in the 1970's following the 1967 listing of shortnose sturgeon as an endangered species in the United States (32 FR 401, Appendix I). More recently, efforts to understand the Hudson River life cycle of both species have been renewed, partly in response to emerging concern about the status of Atlantic sturgeon stocks and the desire to continue adequate protection of the shortnose sturgeon. These efforts have refined somewhat the knowledge about distributions of the two species in the Hudson River. Direct observation of the early life histories of these species has been limited due to the difficulty in distinguishing between the eggs, larvae, and YOY of the two species coupled with the infrequency of their capture. However, the temporal and spatial distribution of the early life stages of Atlantic and shortnose sturgeon in the Hudson River can be inferred from recent observations of spawning adults and long term average distributions of sturgeon larvae. A summary of the available life histories of both species in the Hudson River is presented in Figures V-82 and V-83.

Mature male Atlantic sturgeon enter the Hudson estuary by early April, before water temperatures rise above 43^{0}F, while mature females do not arrive until several weeks

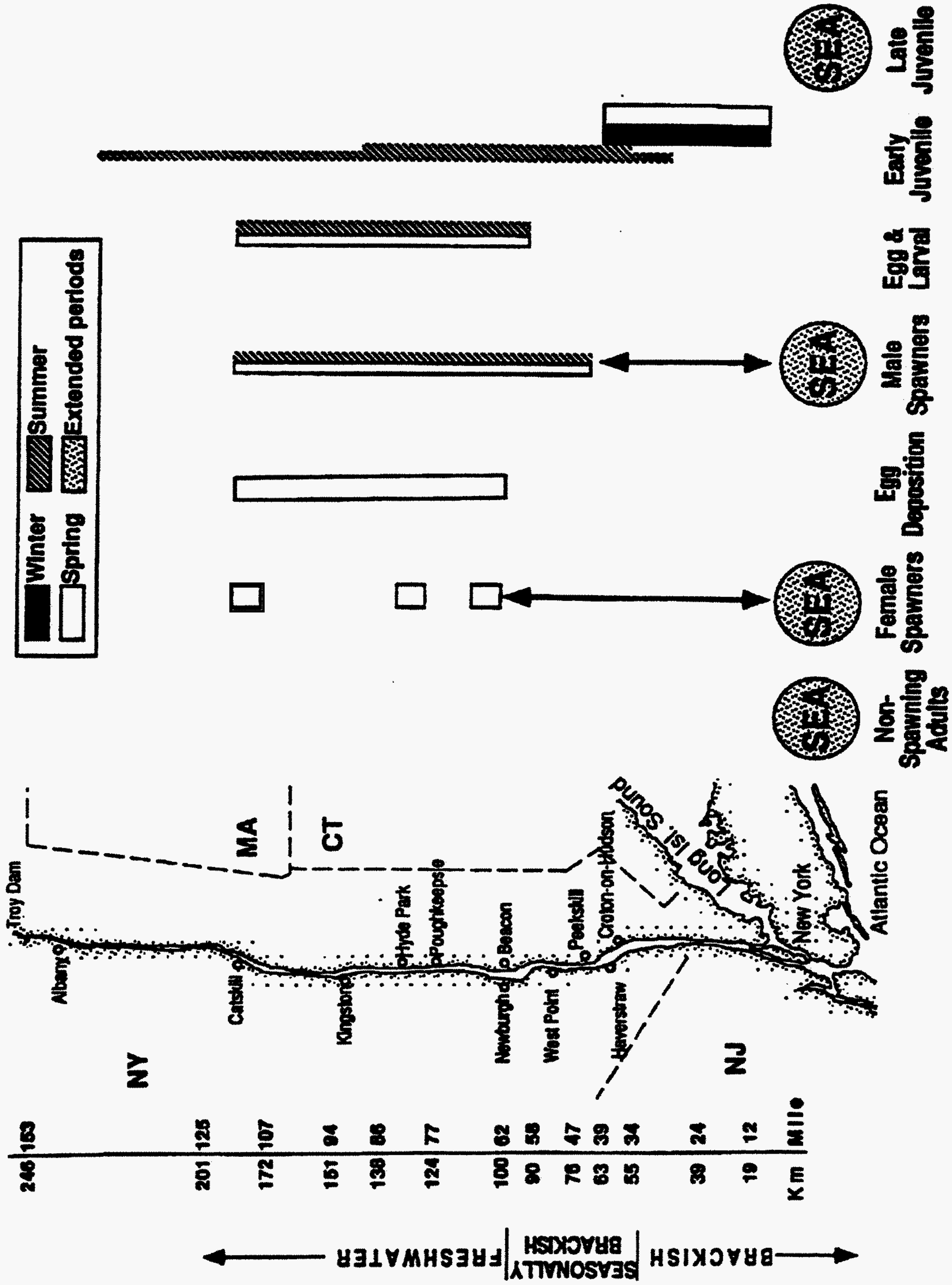


Figure V-82. Longitudinal distribution of Atlantic sturgeon life stages in the Hudson River Estuary. (adapted from Bain 1997, Nack and Bain 1996)

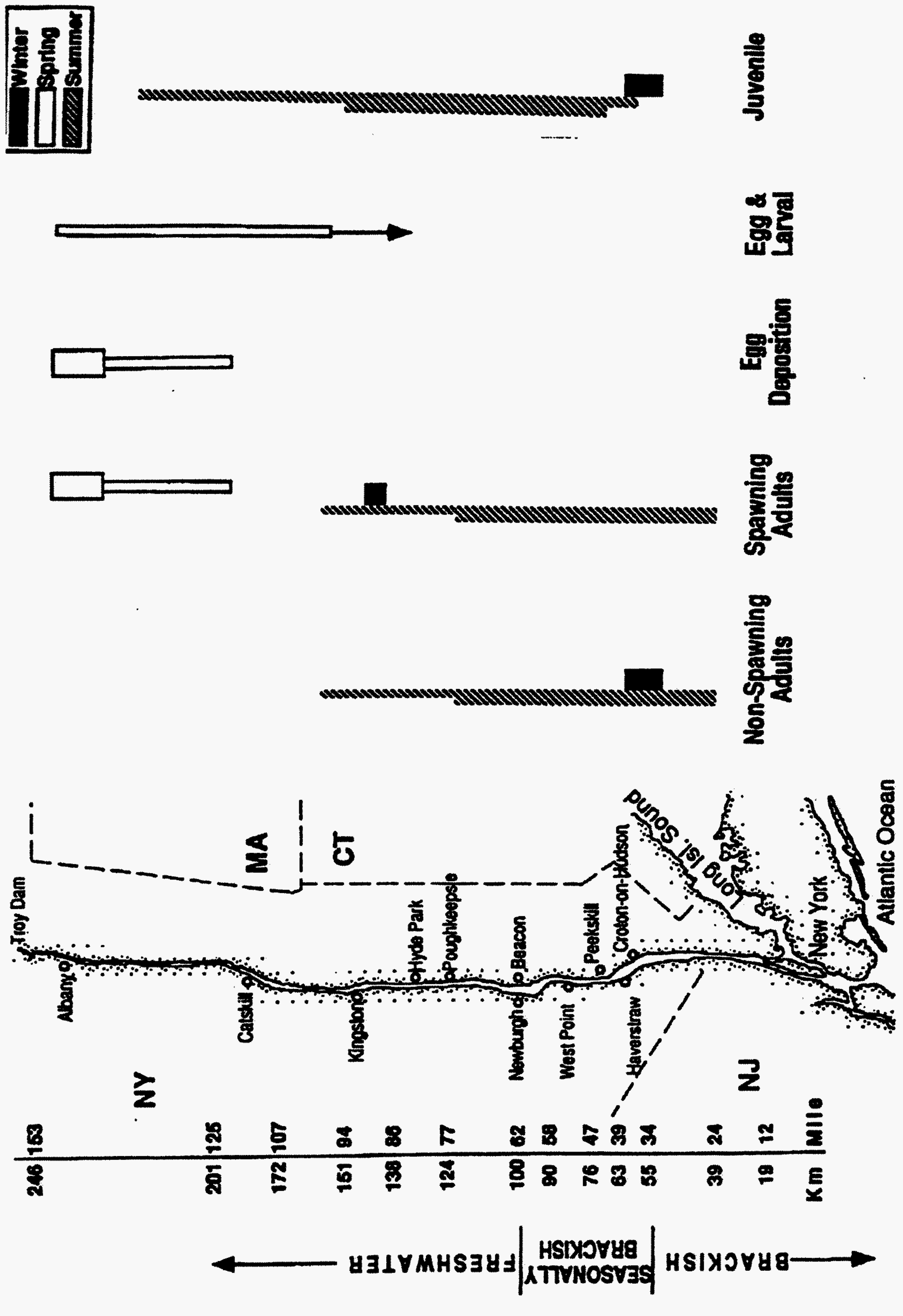


Figure V-83. Longitudinal distribution of shortnose sturgeon life stages in the Hudson River Estuary. (adapted from Bain 1997) later (Dovel and Berggren 1983, Van Eenennaam et al. 1996). Adult females move directly to the spawning grounds, which are deep, channel or off-channel habitats (Dovel and Berggren 1983). Adult males appear to move upstream on incoming tides and then remain stationary for several hours. During upstream movement, the males meander back and forth across the channel staying in water greater than 25 ft (7.6 m) deep. After spawning, female sturgeon return quickly to marine waters, while at least some males remain in the Hudson as late as November (Smith 1985; Dovel and Berggren 1983). More recently it has been observed that some females also remain in the river and leave gradually during late summer and early fall (Nack and Bain 1996).

Atlantic sturgeon spawning begins about mid-May (Figure V-82), when temperatures are approximately 55°F. Dovel & Berggren (1983) report that spawning first occurs near the edge of the salt front when gravid females appear in upper Haverstraw Bay (RM 38), and as the season progresses moves progressively upriver with the advancing salt-front, but no farther than about Catskill (RM 113). They indicate that most spawning occurs between Croton Point (RM 35) and Hyde Park (RM 81) from May to August, usually in water over 25 ft deep. Van Eenennaam et al. (1996) collected spawning Atlantic sturgeon only from two historically important fishing sites near Hyde Park (RM 81) and Catskill (RM 113) in which gravid females are known to congregate (Figure V-82). They argue that spawning is unlikely to occur near brackish water because sturgeon eggs, embryos, and larvae are intolerant of saline conditions and some significant habitat is needed down-stream of a spawning site to accommodate dispersal of embryos and larvae. Based on the recent collection and tracking of spawning females in the Hudson River, Atlantic sturgeon appear to spawn primarily between about RM 70 and RM 114 (Nack and Bain 1996). Telemetry studies (1994 and 1995) indicate that Atlantic sturgeon may spawn at several primary sites within this range.

Within the Hudson River estuary, shortnose sturgeon display complex migratory behavior with non-spawning and spawning adults using different habitats and displaying different migratory behavior (Bain 1997). From late spring through early fall, most adult shortnose sturgeon are distributed in deep, channel habitats of the freshwater and brackish reaches of the Hudson River estuary. As water temperatures decline in the fall, adult shortnose sturgeon typically concentrate in a few overwintering areas, particularly near Kingston (RM 87) for pre-spawning adults and near Haverstraw (RM 33-38) for non-spawning adults (Figure V-83) (Dovel et al. 1992; Bain 1997).

During their spawning migrations, shortnose sturgeon move upriver as far as accessible habitat permits (Dovel et al. 1992). As early as the first week of April, adult shortnose sturgeon reach the spawning grounds between Coxsackie and Troy (RM 118-148) (Figure V-83). Spawning occurs from late April to early May (Dovel et al. 1992). After spawning, adults move downriver to feed and disperse over the tidal portion of the Hudson River estuary, but are primarily south of Kingston (Bain 1997). Non-spawning adults are also distributed in this portion of the estuary after migrating upstream from their overwintering areas in the spring.

Little information is available on the actual distribution of the early life stages of Hudson River sturgeon during their first growth season because of the infrequency of their capture. Descriptions of the distribution of eggs and larvae have largely been inferred from the distribution of spawning adults. For example, data from 24 years of utilities' monitoring (1974-1997) document the collection of only 213 sturgeon larvae and 11 first year juveniles. Generally, larval sturgeon captured in the estuary were associated with deep waters and strong currents (Hoff et al. 1988; Pekovitch 1979).

Species identification at the larval stage is difficult and uncertain, and identification has been attempted in only a small percentage of the larvae collected in the utilities' monitoring in most years. The seasonal and spatial distribution of yolk-sac and post yolk-sac sturgeon larvae collected over the 24 year period is shown in Figure V-84. Two distinct distributions of yolk-sac larvae are evident. One occurs upstream above about RM 120 during a brief period in early to mid-May, the other extends from approximately RM 48 to RM 110 in the estuary and occurs over a more protracted period between mid-May and early-July. These upriver and down river groupings of yolk-sac larvae are consistent with the known seasonal timing and location of spawning for shortnose sturgeon and Atlantic sturgeon, respectively. The sturgeon post-yolk-sac larvae collected also reflect this bimodal distribution, but shifted slightly down river and one to two weeks later in the season, as would be expected for older larvae (Figure V-84). The distributions are consistent with earlier suggestions that the nursery region for Atlantic sturgeon is located downriver between RM 43 and RM 118 from May through mid-July (Hoff et al. 1988).

Considered in light of the known distributions of spawning adults described above, the long-term average distributions of sturgeon larvae suggests that the young of the two species may occupy largely non-overlapping (allopatric) ranges during their first summer of growth. However, very few young-of-year sturgeon have been collected in the utilities monitoring or other research programs. How long this separation may persist is therefore unclear, but by late fall and early winter, most juveniles of both species occupy brackish water overwintering areas located downriver. Atlantic sturgeon are primarily distributed between about RM 11-45 (Dovel & Berggren 1983), and most shortnose sturgeon occupy the area between about RM 34-39 (Dovel et al. 1992).

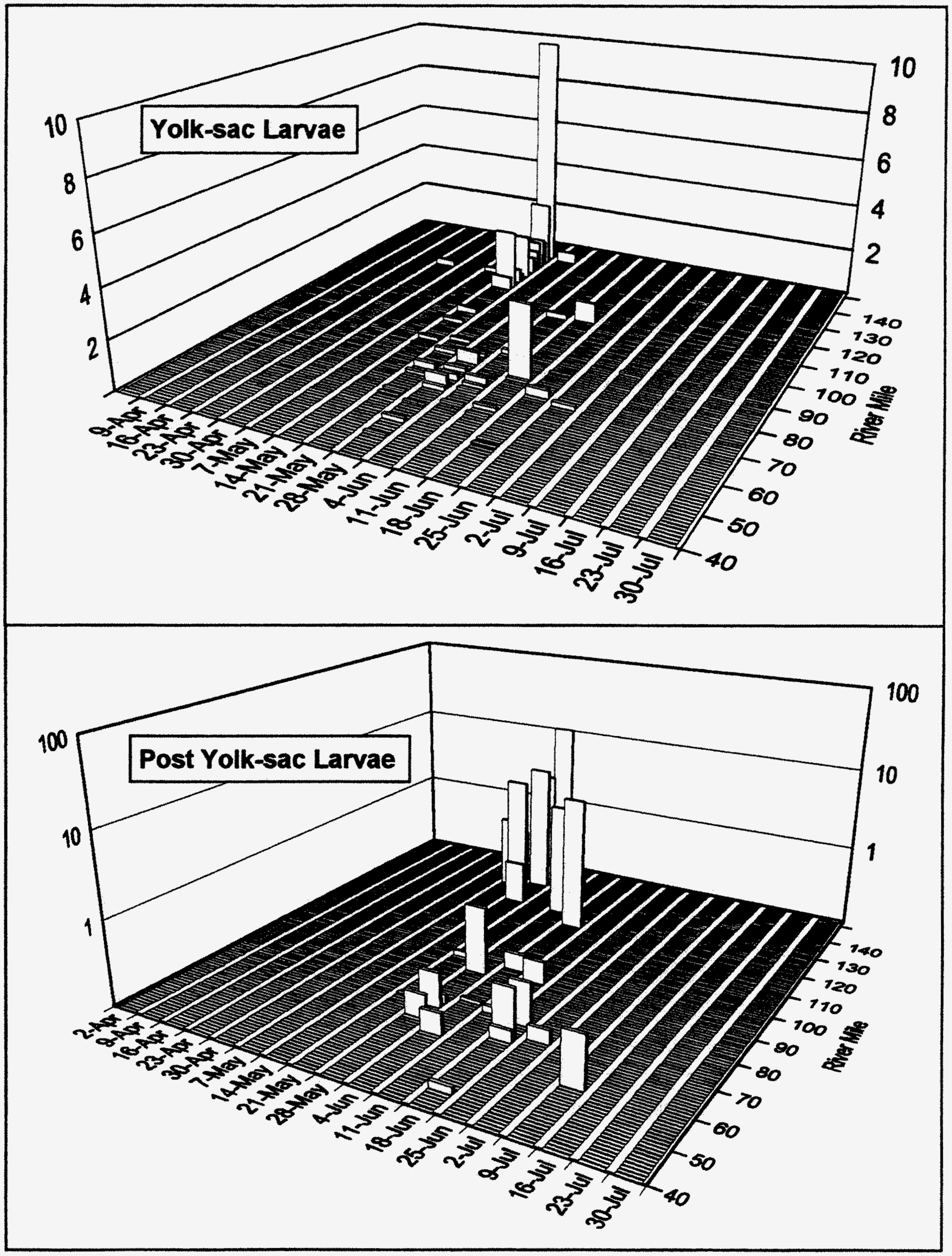


Figure V-84. Relative density of all sturgeon larvae collected in the utilities' monitoring program by river mile and week. 1974-1997.

During the warm seasons, yearling or older juveniles of both species are well distributed throughout the estuary (Figure V-82, 83). Juvenile shortnose sturgeon are reported to use a large portion of the tidal reach of the Hudson River (Dovel et al. 1992), with a distribution centered on the mid-river region (Geoghegan 1992). During the summer, Haley et al. (1996) reports that more juvenile shortnose sturgeon are found in the relatively shallow, freshwater zone of the estuary around Poughkeepsie (RM 66-86) than in the deeper, more saline zone near West Point (RM 42-56). From July through September, the largest number of Atlantic sturgeon juveniles were reported to be located from about RM 39 to about RM 87 (Dovel & Berggren 1983). The long-term average longitudinal distributions of yearling and older sturgeon juveniles collected by beam trawls in the utilities' monitoring program from 1985 to 1997 are shown in Figure V-85.

iii. Temporal Changes in Abundance

Information on changes in abundance of the Atlantic and shortnose sturgeon comes from estimates of population size reported in the literature and relative catch of immature sturgeon collected incidentally in monitoring other fish species. Although catches of sturgeon species in the Utilities' monitoring program are low and incidental to the collection of other fish species (Table V-33), they provide a useful measure of relative abundance of Atlantic and shortnose sturgeon for examining population trends.

The Hudson River estuary stock of Atlantic sturgeon appears to have declined in recent years. The population of immature Atlantic sturgeon in the Hudson River estuary was estimated at 14,500 to 36,000 fish for the 1976 year class at age one (Dovel and Berggren 1983). Kahnle et. al. (1998) estimated that there were 4,600 age zero Atlantic sturgeon in the estuary in 1994, a substantial decline from abundance of the 1976 year class.

The 3-m beam trawl, which has been deployed since 1985, had by far the highest catch rates of sturgeon in the utilities' monitoring programs. The catches from this gear suggest that there has been a decline in the relative abundance of Atlantic sturgeon since 1986 (Figure V-86). The bycatch of young (<1 meter) Atlantic sturgeon in the commercial gill net fishery in the Hudson River estuary has been monitored by DEC annually since 1980. Compilation of catch per unit effort data indicates a substantial decline in the relative abundance of Atlantic sturgeon between the early 1980s and the 1990s (Kahnle et al. 1998). The reported declines in the Hudson River Atlantic sturgeon stocks have been attributed primarily to over harvest beginning in the early to mid 1980s (Kahnle et. al. 1998).

The population of shortnose sturgeon in the Hudson River Estuary appears to have increased over the past few decades and the Estuary presently contains the largest

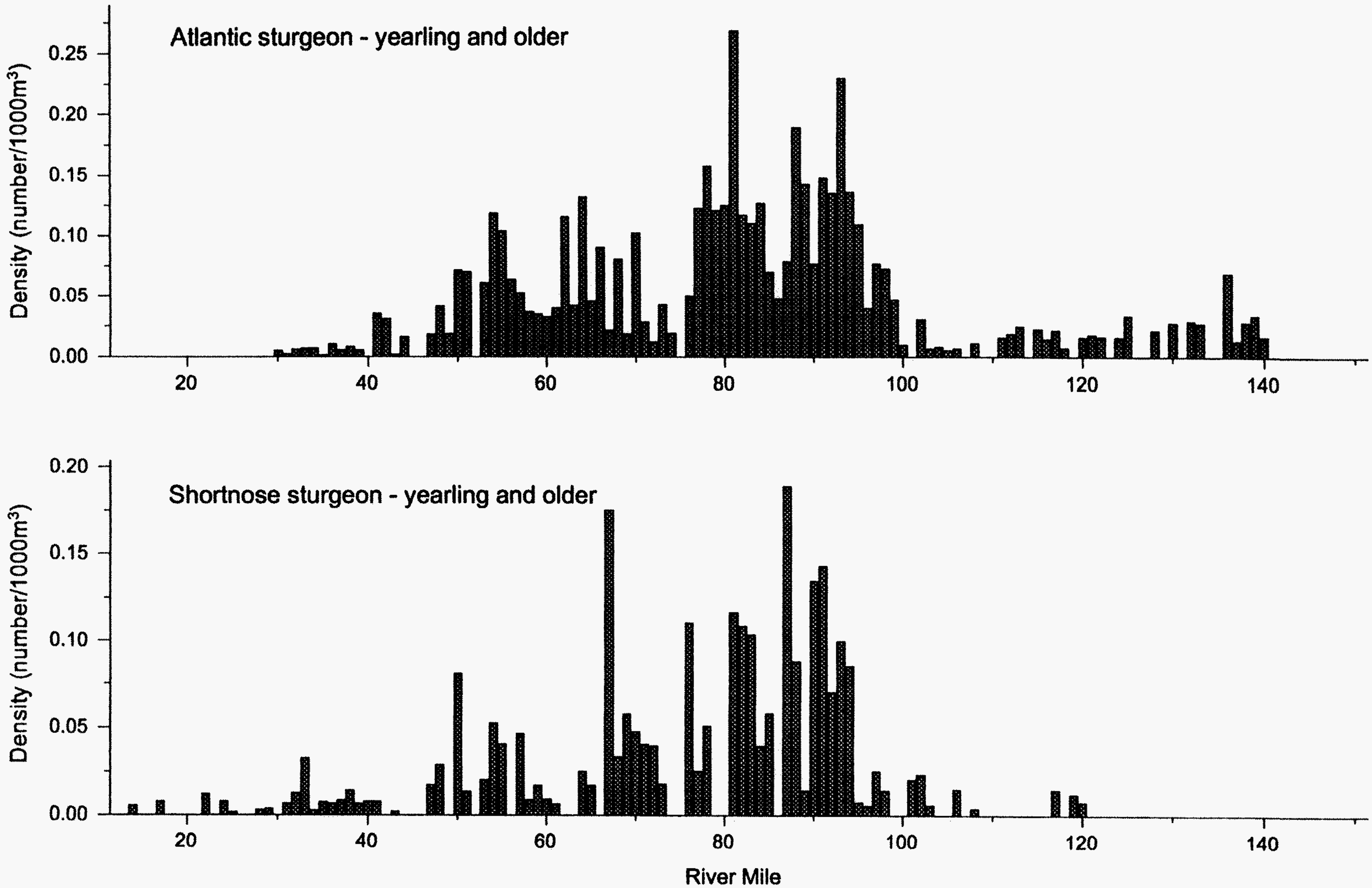


Figure V-85. Mean density of Atlantic and Shortnose sturgeon YORL collected in the utilities monitoring program using beam trawls, 1985-1997.

TABLE V-33

TOTAL CATCH OF ATLANTIC AND SHORTNOSE STURGEON IN THE HUDSON RIVER MONITORING PROGRAMS

Year	Long River Survey [a]			Fall Shoals Survey [a]			Beach Seine Survey [a]			Mark-Recapture Program [b]		
	Shortnose sturgeon	Atlantic sturgeon	*Acipenser* spp.	Shortnose sturgeon	Atlantic sturgeon	*Acipenser* spp.	Shortnose sturgeon	Atlantic sturgeon	*Acipenser* spp.	Shortnose sturgeon	Atlantic sturgeon	*Acipenser* spp.
1974	9	64	19	--	68	--	--	3	--	NS	NS	NS
1975	--	46	12	--	7	1	--	--	--	NS	NS	NS
1976	2	28	2	1	12	--	--	--	--	NS	NS	NS
1977	1	14	1	5	11	--	--	--	--	NS	NS	NS
1978	1	13	3	2	11	--	--	--	--	NS	NS	NS
1979	--	21	1	4	12	--	--	2	--	NS	NS	NS
1980	1	6	7	2	6	--	--	--	--	NS	NS	NS
1981	4	4	6	4	14	--	--	--	--	NS	NS	NS
1982	--	5	13	1	4	--	--	--	--	NS	NS	NS
1983	11	9	10	3	28	--	--	--	2	NS	NS	NS
1984	4	19	8	5	15	6	--	--	--	NS	NS	NS
1985	--	8	2	16	96	--	--	1	--	NA	NA	NA
1986	2	5	8	8	184	--	--	--	--	NA	NA	NA
1987	--	12	2	11	149	--	--	--	--	NA	NA	NA
1988	3	13	4	20	117	--	--	--	--	NA	NA	NA
1989	--	8	6	15	67	--	--	3	--	NA	NA	NA
1990	2	6	18	2	6	--	--	--	--	NA	NA	NA
1991	7	26	9	19	10	--	--	--	--	NA	NA	NA
1992	6	4	--	76	11	--	--	--	--	NA	NA	NA
1993	15	--	--	82	7	--	--	--	--	NA	NA	NA
1994	13	7	--	50	16	--	--	--	--	NA	NA	NA
1995	12	3	--	36	15	--	1	--	--	NA	NA	NA
1996	41	2	--	48	8	--	--	--	--	NA	NA	NA
1997	3	3	--	26	40	--	--	--	--	NA	NA	NA
1998	6	3	--	30	30	--	--	--	--	NA	NA	NA
Total	143	329	131	466	944	7	1	9	2	NA	NA	NA

-- = None collected; NS = No Sampling; NA = Not readily available
Source: [a] Hudson River Surveys database; [b] D.Dunning, New York Power Authority

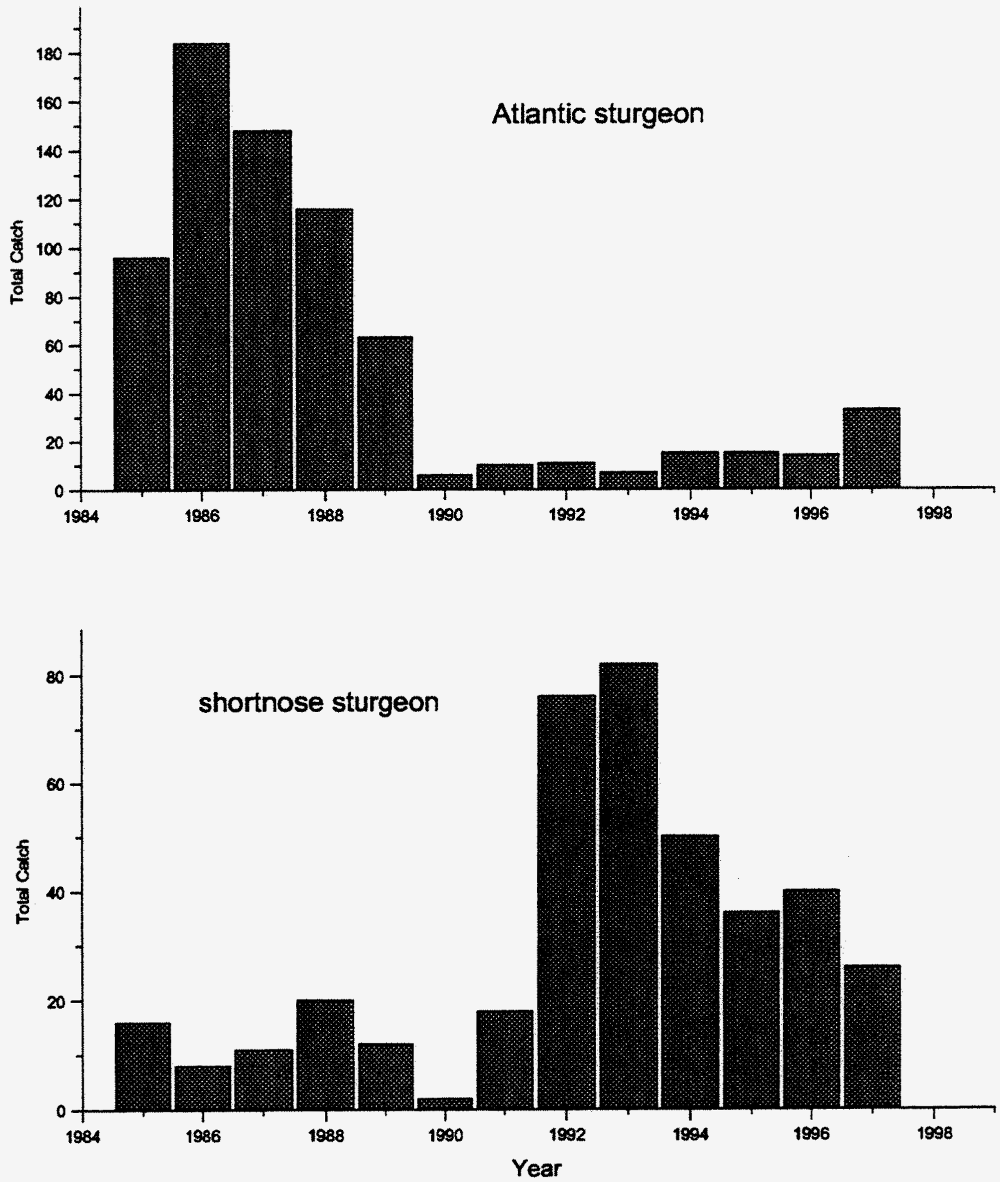


Figure V-86. Annual catch of Atlantic and Shortnose sturgeon yearling in beam trawls in the utilities' monitoring program.

discrete population of shortnose sturgeon reported anywhere. In the late 1970s, Dovel (1979) estimated the shortnose sturgeon population in the Hudson River Estuary at 13,844 fish. In the 1990s, researchers from Cornell University conducted a similar mark-recapture study (Bain et al. 1995, 1998). Using techniques identical to that of Dovel, these researches provided a preliminary population estimate of 38,024 adults (Bain et al. 1995). Subsequently, this estimate was refined to 56,708 individuals based on additional data suggesting a four-fold increase in population size since the 1970s (Bain et al. 1998). Further, refined analytical techniques indicate that the most appropriate population estimate based on the Cornell study is 61,057 fish, 1-year-old and older (Bain et al. 1998). These estimates reflect those fish in the overwintering and spawning concentration areas and, thus are likely just a subset of the total adult population. Additionally, because shortnose sturgeon do not appear to spawn every year, the majority of the population may be non-spawners and, thus, not included in this population estimate.

The recent increase in size of the Hudson River shortnose sturgeon population determined by the mark-recapture studies is also supported by catches from the utilities' 3-meter beam trawl sampling show a higher abundance of shortnose sturgeon in the period from 1992 to 1997 than in the sampling years from 1985 to 1991 (Figure V-86). The timing of this increase suggests that it may be associated with the zebra mussel invasion. Therefore, the available data appear to indicate that the population of shortnose sturgeon in the Hudson River Estuary is in excellent condition and that this species is reproducing and adding young fish to the Hudson population (Bain et al. 1998). Currently, the population appears to number more than six times that determined by NMFS as having a low risk of extinction (Thompson 1991). Bain et al. (1998) in their review relative to ESA protection efforts concluded that the population was "safe" and that available data "...reinforces the general conclusion that the species status can be judged excellent in the Hudson River." This conclusion is consistent with the "Shortnose Sturgeon Status Review" drafted by NMFS, which recommended that the status of the Connecticut, Delaware, and Hudson Rivers' populations of shortnose sturgeon be changed from endangered to threatened (NMFS 1998).

iv. Potential Influences on Abundance

Fishing

Sturgeons have traditionally been an important commercial species in most northeast estuaries, including the Hudson River estuary. During the late 1800's, the Hudson River supported a moderate fish and roe industry for both Atlantic and shortnose sturgeon. Historically, both Atlantic and shortnose sturgeon were reported as "common sturgeon" (Murawski and Pacheco 1977), and therefore the relative importance of the two species could not be ascertained with certainty. Due to its larger size, Atlantic sturgeon likely constituted the greatest percentage of the landings. The maximum reported landing was approximately 426,000 lb in 1897 (McHugh 1977). Catches reported by New Jersey were considerably greater (about 1600 metric tons for 1887-1889) than those reported by New York, but this also included catches from the Delaware River estuary. Between 1880 and 1910 the sturgeon fishery from New York to South Carolina went into near or total collapse (Murawski and Pacheco 1977), possibly as a result of overfishing and deliberate destruction to prevent damage to nets used for other species (McHugh 1977). Hudson River landings reported for New York fell sharply after 1927 and remained low, typically less than 5000 lb, through 1974.

The coastal fishery began an erratic recovery in the early 1920s, with reported annual landings eventually fluctuating around 200,000 lb through the 1960s and 70s. However, landings subsequently declined and during the mid and late 1980s they tended toward the 100,000 lb level. In this latter period, New York's reported landings (marine and Hudson River combined) varied from about 20,000 to nearly 60,000 lb. No obvious downward trend occurred in New York, but reporting was probably inconsistent. In 1990 the ASMFC, prompted by the reduced coastal landings, established a management plan with more restrictive harvest guidelines to be followed by the member states. Consistent with those guidelines, DEC promulgated new sturgeon regulations that became effective in the spring of 1993. One of the long term objectives of DEC's 1990 draft Hudson River Estuary Management Plan is to contribute to the restoration of Atlantic sturgeon stocks to a level that will sustain annual coastwide landings of 700,000 lb. In 1993 through 1995, DEC regulated the Atlantic sturgeon fishery with size limits, seasons, area closures, and quotas derived from the preliminary population modeling. As more data became available, DEC concluded that the Hudson River Atlantic sturgeon stock was being over fished and, in response implemented a harvest moratorium in 1996. New Jersey followed with a zero quota catch limit in the same year.

Water Withdrawals

Due to many of the life-history characteristics described above, the Hudson River populations of Atlantic and shortnose sturgeons have very low vulnerability to impacts from operation of the water intakes at the six generating stations. The eggs and larvae of shortnose sturgeon are located primarily above RM 110, well upriver of the intakes of Bowline Point Units 1 and 2 (RM 37), Indian Point Units 2 and 3 (RM 43), and Roseton Units 1 and 2 (RM 66) (Figures V-83, V-84). Atlantic sturgeon eggs and larvae are distributed primarily upriver (RM 48 to RM 110) of the Bowline Point Units 1 and 2 and Indian Point Units 2 and 3 intakes, but occur in the vicinity of Roseton Units 1 and 2. Though the distribution of eggs and larvae of Atlantic sturgeon includes the location of the Roseton Units 1 and 2 intake, they are not very susceptible to entrainment. The eggs are demersal and adhere to objects within minutes of release. Larvae are active swimmers, have a strong benthic orientation, apparently prefer deeper water, and grow rapidly.

As a result of these factors very few sturgeon larvae of either species have been collected in entrainment monitoring at each of the power plants from 1972 to 1987 (Table V-34). These results include very extensive entrainment monitoring conducted nearly 24 hours per day, on 4 to 7 days per week, for 10 to 12 weeks per year during the peak entrainment season from 1981 through 1987. In addition sturgeon are quite tolerant of handling stress, and other species with such hardiness have been generally found to have high entrainment survival. Therefore, a high percentage of the few sturgeon entrained are likely be returned to the river unharmed.

While sturgeon juveniles of both species are found throughout the Estuary, none of the power plants, with the sole exception of Bowline Point Units 1 and 2, is located within any known concentration areas. Further, juvenile sturgeon prefer the deeper waters of channel areas where they are found on the bottom. However, Bowline Point Units 1 and 2 withdraws water from a man-made embayment called Bowline Pond and the intakes are set back over 2,200 ft from the shoreline, well away from channel congregation areas. Based on their distribution and habitat preference, juvenile sturgeon have relatively low vulnerability to impingement at any of these power plants.

Low impingement vulnerability of sturgeon is evident in the results of extensive impingement monitoring studies conducted at each of the power plants since the early 1970s (Table V-35 and 36). Since the start of impingement monitoring in 1972, few shortnose sturgeon and Atlantic sturgeon have been collected annually in impingement samples from all six power plants. Based on available survival information, it appears that most of these survived impingement and were returned safely to the estuary. Most Atlantic sturgeon were impinged during the winter. No seasonal pattern was present in the impingement data for shortnose sturgeon. The size of impinged Atlantic sturgeon at Indian Point Units 2 and 3 ranged from about 5 to 31 in., but most were approximately 9 to 16 in. long. Shortnose sturgeon ranged from 12 to 28 in.

TABLE V-34

ACTUAL NUMBER OF SHORTNOSE STURGEON (SNS), ATLANTIC STURGEON (ATS), AND ACIPENSERIDAE COLLECTED DURING ENTRAINMENT SAMPLING AT EACH POWER PLANT, 1972-1998

	Bowline	Lovett	Indian Point Unit 2	Indian Point Unit 3	Roseton	Danskammer Point	Annual Total
1972	NS	NS	NR	Not Operational	Not Operational	NS	—
1973	NS	NS	NR	Not Operational	NS	NS	—
1974	NS	NS	NR	Not Operational	0	0	0
1975	0	0	NR	Not Operational	0	0	0
1976	0	0	NR	NR	0	ATS Present	ATS Present
1977	0	0	NC	NC	0	0	0
1978	0	NS	NC	NC	0	0	0
1979	0	NS	NC	NC	0	0	0
1980	0	NS	0	0	0	0	0
1981	0	NS	0	0	0	0	0
1982	0	NS	NS	NS	0	0	0
1983	NC	NS	0	0	0	2 *Acipenser*	2 *Acipenser*
1984	NC	NS	0	0	0	3 (1)[a] SNS, 1 (1) *Acipenser*	3 (1) SNS, 1 (1) *Acipenser*
1985	NC	NS	0	0	0	0	0
1986	0	NS	0	0	0	0	0
1987	0	NS	0	0	0	0	0
1988	NS	NS	NS	NS	NS	NS	—
1989	NS	NS	NS	NS	NS	NS	—
1990	NS	NS	NS	NS	NS	NS	—
1991	NS	NS	NS	NS	NS	NS	—
1992	NS	NS	NS	NS	NS	NS	—
1993	NS	NS	NS	NS	NS	NS	—
1994	NS	NS	NS	NS	NS	NS	—
1995	NS	NS	NS	NS	NS	NS	—
1996	NS	NS	NS	NS	NS	NS	—
1997	NS	0	NS	NS	NS	NS	0
1998	NS	0	NS	NS	NS	NS	0
Total	0	0	0	0	0	3 (1) SNS, 3(1) *Acipenser*	3 (1) SNS, 3(1) *Acipenser*

[a] Numbers in parenthesis indicate number collected during a special study of simultaneous sampling at Danskammer Point and Roseton.
NOTE: NS = No Sampling; NC = No Catch; NR = Not Reported.
SOURCES: Annual entrainment monitoring reports.

TABLE V-35

ACTUAL NUMBER OF ATLANTIC STURGEON COLLECTED DURING IMPINGEMENT SAMPLING AT EACH POWER PLANT, 1972-1998

	Bowline	Lovett	Indian Point Unit 2	Indian Point Unit 3	Roseton	Danskammer	Yearly Total
1972	No Sampling	No Sampling	5	Not Operational	Not Operational	89	94
1973	11	7	47	Not Operational	3	6	74
1974	6	11	100	12	4	5	138
1975	18	3	118	Not Operational	9	1	149
1976	5	1	8	8	2	1	25
1977	3	0	44	153	11	6	217
1978	4	1	16	21	5	1	48
1979	1	0	32	38	0	1	72
1980	0	0	9	10	1	0	20
1981	0	0	3	5	3	1	12
1982	0	0	1	1	1	1	4
1983	0	0	3	0	3	2	8
1984	1	0	3	5	1	3	13
1985	0	0	7(1)	5(12)	0	1	13 (13)
1986[b]	0	0	2	1(3)	1	1	5 (3)
1987	0	0	(2)	1	1	1	3(2)
1988	0	0	(1)	0	0	1	1(1)
1989	0	0	0	0	0	0	0
1990	0	0	0	0(2)	0	1	1 (2)
1991	0	0	No Sampling	No Sampling	1	0	1
1992	0	0	No Sampling	No Sampling	0	1	1
1993	0	0	No Sampling	No Sampling	0	0	0
1994	0	0	No Sampling	No Sampling	2	1	3
1995	0	0	No Sampling	No Sampling	0	3	3
1996	0	0	No Sampling	No Sampling	0	0	0
1997	0	0	No Sampling	No Sampling	0	1	1
1998	0	0	No Sampling	No Sampling	0	1	1
Total by Plant	49	23	398 (4)	260 (17)	48	129	907 (21)

Note: Numbers in parenthesis indicate number of Atlantic sturgeon taken on non-sample days. Sources: Hoff, Klauda, and Belding 1977; annual impingement monitoring report
[a]Sampling limited to other years; no identified sturgeon collected. [b]Not included in counts is one Atlantic sturgeon collected during 1986 for which Unit was not recorded

TABLE V-36

ACTUAL NUMBER OF SHORTNOSE STURGEON COLLECTED DURING IMPINGEMENT SAMPLING AT EACH POWER PLANT, 1972-1998

	Bowline	Lovett	Indian Point Unit 2	Indian Point Unit 3	Roseton	Danskammer	Yearly Total
1972	No Sampling	No Sampling	1	Not Operational	Not Operational	4	5
1973	1	0	2	Not Operational	0	2	5
1974	1	0	3	Not Operational	1	0	5
1975	0	0	1	Not Operational	0	0	1
1976	1	0	2	0	0	0	3
1977	0	0	6	1	0	1	8
1978	0	0	2	3	0	0	5
1979	0	0	2	2	0	0	4
1980	0	0	0	1	0	0	1
1981	0	0	0	0	0	0	0
1982	0	0	0	0	0	3	3
1983	0	0	0	0	0	1	1
1984	0	0	1	1	2	3	7
1985	0	0	0	0	1	2	3
1986	0	0	0	0	0	0	0
1987	0	0	1(1)	1	0	0	2(1)
1988	0	0	0(3)	1	1	0	2(3)
1989	0	0	0	0(1)	0	0	0(1)
1990	0	0	0(1)	0	0	2	2(1)
1991	0	0	No Sampling	No Sampling	0	0	0
1992	0	0	No Sampling	No Sampling	0	1	1
1993	0	0	No Sampling	No Sampling	0	0	0
1994	0	0	No Sampling	No Sampling	1	0	1
1995	0	0	No Sampling	No Sampling	1	1	2
1996	0	0	No Sampling	No Sampling	0	0	0
1997	0	0	No Sampling	No Sampling	0	0	0
1998	0	0	No Sampling	No Sampling	0	2	2
Total by Plant	3	0	21(5)	10(1)	7	22	63(6)

Note: Numbers in parenthesis indicate number of shortnose sturgeon taken on non-sample days
Sources: Hoff & Klauda 1979; annual impingement monitoring reports
[a]Sampling limited compared to other years; no identified sturgeon collected

i. Bluefish

i. Life History and Distribution Within the Hudson River

Bluefish (*Pomatomus saltatrix*) is a migratory, pelagic fish species generally found in temperate and semi-tropical inshore and offshore waters. The body is elongate, muscular, and moderately compressed, with a large head and projecting jaws, each containing a single row of large teeth. The body color is blue green above and silvery below with dark patches at the base of the pectoral fins. The tail is deeply forked and the body, head and bases of the dorsal and anal fins are covered with moderately ctenoid scales. Adult bluefish can attain lengths greater than 3 ft. and may reach 11 or 12 years in age. The maximum size has been reported to be 45 in. and 30 lb.

In North America, bluefish range from Nova Scotia to Florida and also occur in the Gulf of Mexico from Florida to Texas. Seasonal distribution and spawning area information indicate northwest Atlantic and Gulf of Mexico stocks are separated, although some intermingling may occur (MAFMC 1998).

Population research suggests that the bluefish stock along the Atlantic coast is separated into two major spawning aggregations: a spring spawning stock that spawns in the South Atlantic Bight primarily during April and May, and a summer spawning stock that spawns in the mid-Atlantic Bight from June through August (Kendall and Walford 1979; Chiarella and Conover 1990). Although consistent morphological differences suggest some isolation of the stocks (Pottern et al. 1989), no significant genetic differentiation was detected among young-of-year and yearling bluefish spawned from different geographic locations (Graves et al. 1992). Recent evidence indicates that bluefish spawn continuously over a protracted season, beginning as early as March and lasting to at least September (Hare and Cowen 1993; Smith et al. 1994). Additional studies may be required to definitively determine which of the competing hypothesis (two distinct spawning aggregations versus one sequential spawning aggregation) is more correct (MAFMC 1998). Bluefish occurring along the Atlantic coast are currently defined as a single management unit under the Bluefish Fishery Management Plan (MAFMC 1998).

Adult bluefish along the Atlantic coast migrate north during the spring and summer from offshore and nearshore wintering areas near Georgia and south Florida. Spawning begins in early May on or near the continental shelf, where the Gulf Stream and shelf water meet between northern Florida and Cape Hatteras. During summer, spawning activity is centered in the Mid-Atlantic Bight, in continental shelf waters off New Jersey. Although the majority of spawning takes place in mid-shelf waters, bluefish eggs have been reported within 6 mi.

of shore (Smith et al. 1994) and recently hatched larvae have been collected in both the lower Chesapeake Bay and in Narragansett Bay (MAFMC 1998).

North of Cape Hatteras adults move shoreward and smaller spent bluefish may spend summers in the Chesapeake and Delaware bays and Albemarle Sound. Large adult bluefish continue north, migrating in schools of similar size fish to the Gulf of Maine and as far north as Nova Scotia. Larger fish move north longer than the smaller bluefish and migrate farther. In autumn, bluefish migrate back to wintering areas off south Florida and the south Atlantic (Pottern et al. 1989). Based on daily otolith growth increments of juvenile bluefish collected in Maine waters, Creaser and Perkins (1994) suggested that the known spawning areas (South Atlantic and Mid-Atlantic Bight) have extended to the northeast or that unknown bluefish spawning areas may exist closer to Maine.

In the New York Bight, bluefish is a common inshore inhabitant that arrives in May and usually departs by November. Most of the bluefish population in the New York Bight probably originates from spring-spawned eggs (Chiarella and Conover 1990). Juvenile bluefish produced in the spring travel north with the Gulf Stream (Hare and Cowen 1993) and migrate across the continental shelf to the mid-Atlantic bays and estuaries, which act as productive nursery areas, in early to mid-June (McBride and Conover 1991).

Spring-spawned juveniles spend most of their first summer in estuaries (Kendall and Walford 1979). In fall they migrate southward along the coast to winter off south Florida. The following spring, yearlings migrate north along the coast and return to the mid-Atlantic bays and estuaries and, to a lesser extent, the sounds of North Carolina (Pottern et al. 1989). Some summer-spawned larvae have also been reported in the more saline parts of estuaries in the mid-Atlantic Bight. Summer-spawned juveniles may spend only about a month in estuaries, but most are found along the shore (Kendall and Walford 1979).

Bluefish reach sexual maturity during their second year of life. Annual fecundities range from 0.6 to 1.4 million eggs per female, depending upon size (Pottern et al. 1989). Bluefish eggs are buoyant and pelagic and hatch in about two days. The newly hatched larvae are also pelagic and remain in offshore waters for one to two months before migrating shoreward toward shallow-water nursery areas. In the New York Bight YOY bluefish occur in the shallow-water nursery areas as two groups. The first, from eggs spawned in the spring in the south Atlantic, are about 1 to 2 in. long when they enter the nursery areas in June or early July to feed and grow rapidly. The second, from eggs spawned later during the summer in the mid-Atlantic Bight, arrive in September.

In the Hudson River YOY bluefish typically first occupy areas north of the George Washington Bridge in early June and remain at least until early October (Figure V-87).

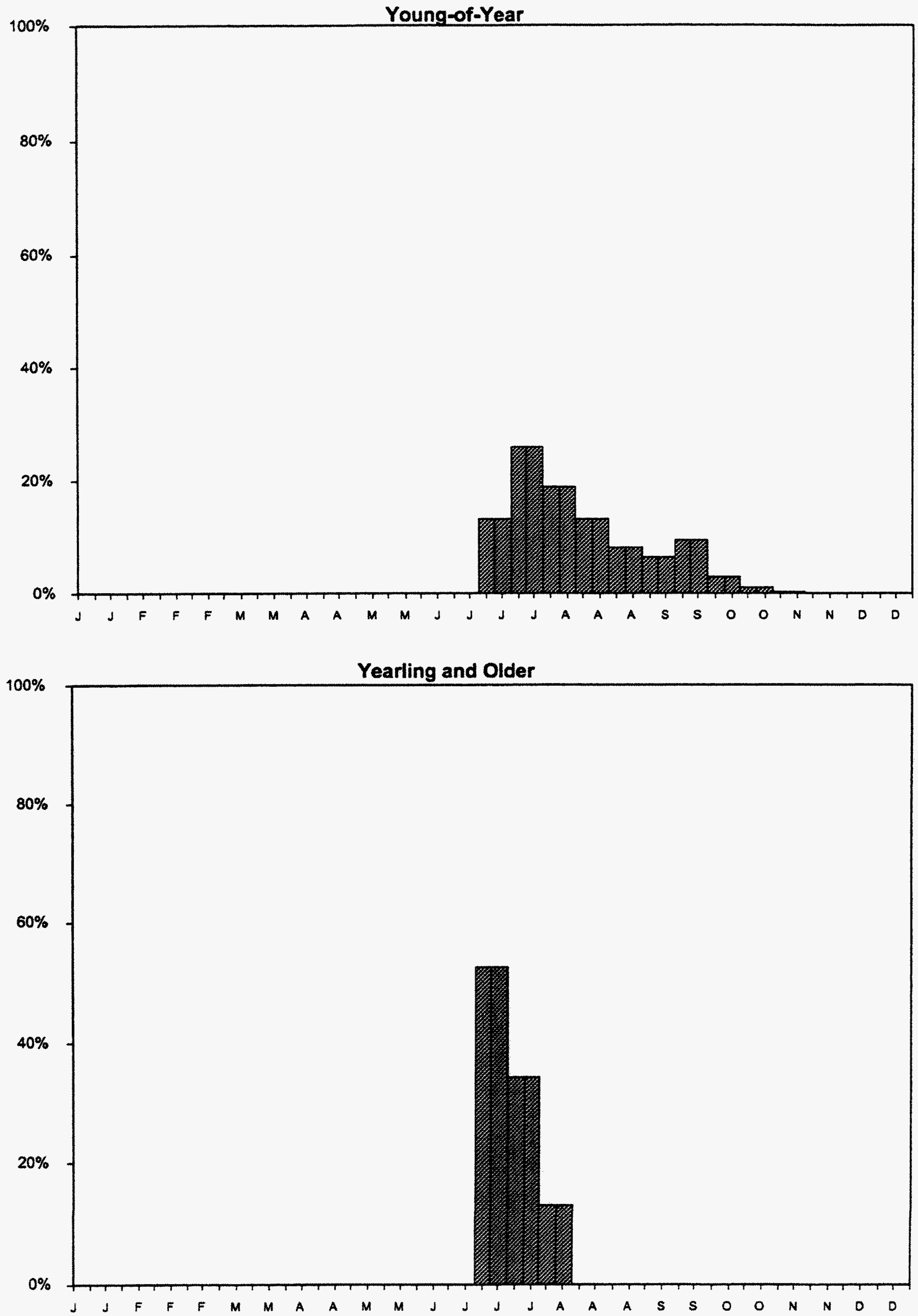


Figure V-87. Temporal distribution indices for bluefish collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

They are most common in shallow, more saline areas of the estuary, including the Tappan Zee and Haverstraw Bay, but typically range as far upriver as Newburgh Bay (Figure V-88). Salinity intrusions into the estuary appear to be a major determinant of longitudinal distribution within the estuary. YOY bluefish are also abundant in areas of the estuary south of the George Washington Bridge and adjacent waterways, which are part of the larger, coastal distribution.

In the Hudson YOY bluefish aggressively feed on a variety of macroinvertebrates and fish, including bay anchovy and Atlantic silverside, as well as striped bass, blueback herring, Atlantic tomcod and American shad (Juanes et al. 1993; Buckel and Conover 1997). YOY bluefish grow rapidly to a size of 7.5 to 15 cm (3 to 6 in.) by the time they begin to leave the estuary in late summer. Older bluefish, including adults, occasionally enter the lower estuary during summer and feed on a wide variety of available forage fish such as bay anchovy, young menhaden and river herrings. All ages of bluefish often travel in schools and are voracious feeders that commonly destroy more than they can eat.

ii. Temporal Changes in Abundance

Sampling Programs

Bluefish are marine species that spawn at sea. Juvenile bluefish enter the estuary in summer and are sampled most effectively by beach seines. The average catches from the utilities' beach seine survey (BSS) and the NYSDEC Juvenile Striped Bass (JSB) surveys are used as measures of the relative abundance of juvenile bluefish. The Northeast Fisheries Science Center Fall inshore trawl index was used for comparison with the seine data.

Abundance Indices

Both BSS and JSB indices of abundance (Table V-37) have generally declined since a peak in 1981 and 1982, reaching a low of in 1996. NEFSC data show a similar declining trend. The average decline rates were –6% per year for BSS and NEFSC, and –8% per year for the JSB data.

iii. Potential Influences on Abundance

Reasons for the fluctuations in YOY bluefish abundance and distribution within the lower Hudson River estuary are unknown prior to 1989, but likely reflect a combination of changes in coastwide juvenile production as well as other factors such as water temperature and salinity patterns. Two years of high abundance in the Hudson (1977 and 1984) were also reported to be years of high juvenile production coastwide. Since 1984, only two

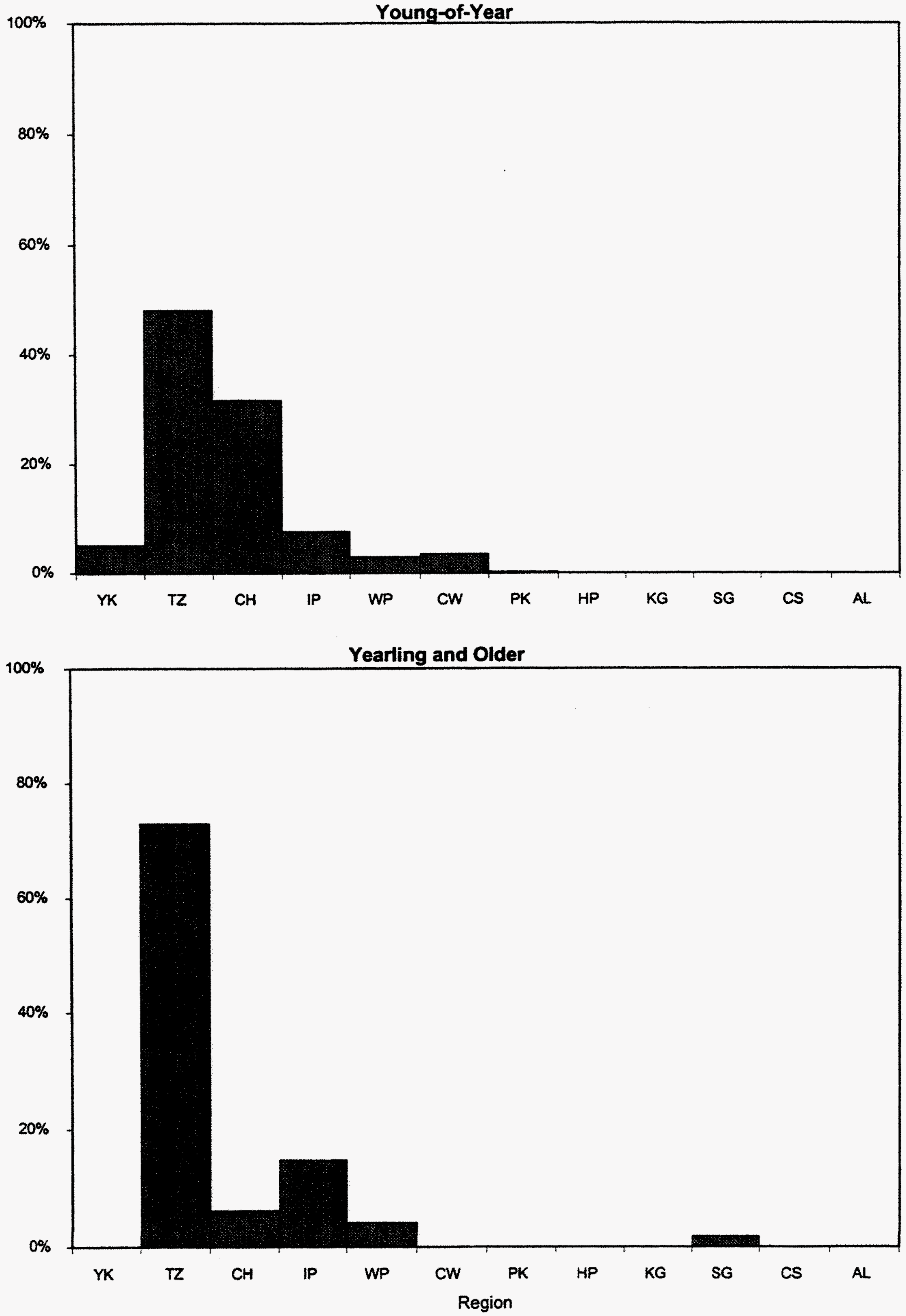


Figure V-88. Spatial distribution indices for bluefish collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

TABLE V-37

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF YOUNG-OF-YEAR (YOY) BLUEFISH

YEAR	BSS YOY INDEX (S.E.)	NEFSC FALL INSHORE INDICES	DEC JSB YOY INDEX
1974	0.71 (0.02)	1.48	
1975	0.28 (0.07)	15.59	
1976	0.19 (0.03)	5.57	
1977	0.33 (0.10)	6.55	
1978	0.35 (0.08)	5.88	
1979	0.22 (0.05)	7.44	
1980	0.30 (0.05)	7.03	2.05
1981	0.46 (0.12)	3.18	2.85
1982	0.30 (0.06)	4.82	2.99
1983	0.32 (0.10)	3.96	2.45
1984	0.15 (0.03)	7.68	1.20
1985	0.24 (0.07)	3.45	2.36
1986	0.13 (0.05)	3.91	2.15
1987	0.17 (0.05)	2.70	0.95
1988	0.18 (0.03)	1.98	3.59
1989	0.18 (0.04)	9.13	1.33
1990	0.24 (0.05)	2.51	1.46
1991	0.16 (0.04)	2.06	0.56
1992	0.13 (0.05)	1.36	0.71
1993	0.10 (0.03)	0.74	0.67
1994	0.06 (0.02)	1.67	0.81
1995	0.18 (0.04)	2.05	1.56
1996	0.04 (0.01)	2.26	0.43
1997	0.19 (0.03)	1.37	1.35

S.E. - Standard error.

[a]Some samples were not completely enumerated.

strong year classes were produced coastwide, in 1989 and 1994 (MAFMC 1998). Juvenile abundance in both the Hudson and in the NMFS inshore trawl surveys have been reported to be low since 1984. These facts suggest that the abundance patterns for YOY bluefish in the Hudson may reflect annual differences in juvenile production along the entire east coast.

Historically, bluefish stocks along the east coast have exhibited considerable fluctuations in abundance, with periods of especially high abundance interspersed with periods when populations appeared to be low. Analysis of long-term juvenile abundance trends in inshore waters along the East Coast by the NMFS revealed no evidence of a systematic decline in juvenile production from 1974 through 1986. Reasons for these abundance patterns are unknown but may be related to fluctuations in environmental conditions in offshore spawning areas, changes in the abundance of prey species and/or competition with other species (MAFMC 1998).

However, during the period when the PYSL index for striped bass was greater or equal to 3.94 (1989 through 1997), the abundance of bluefish in the Hudson River estuary was negatively correlated with the abundance of PYSL striped bass ($r = -0.796$; $p = 0.010$). Thus, there may be competition between these two species during the summer when striped bass abundance is high.

Fishing

Bluefish are among the most sought sport fish by U.S. fishermen along the North Atlantic coast (Mid-Atlantic Fishery Management Council [MAFMC] and Atlantic States Marine Fisheries Commission [ASMFC] 1989). Pottern et al. (1989) found that bluefish "ranked first among sport fish in the mid-Atlantic region and in the United States overall in terms of both number and weight nearly every year since it first achieved that distinction in 1970." An increase in the number of marine anglers, an apparent increase in bluefish abundance, and a decline in the abundance of other sought after fish species (e.g., striped bass, weakfish) during this period may explain this development (MAFMC 1989).

State and federal regulations on the commercial catch of bluefish have existed at least since the 1970s (Wilk 1977; MAFMC and ASMFC 1989) and international agreements limit capture of bluefish on their southern wintering grounds (Wilk 1977). The commercial and recreational bluefish fishery are currently managed under the Bluefish Fishery Management Plan (FMP); prepared by the Mid-Atlantic Fishery Management Council (MAFMC) and approved by NMFS in March 1990 in response to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) of 1976, as amended by the Sustainable Fisheries Act (SFA), and the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA). Under the ACFCMA, individual states are required to implement management measures specified by the FMP. Management measures may include commercial size limits and quotas, recreational size and possession limits, and permit and reporting requirements.

Currently, all Atlantic coast states except Georgia impose a recreational possession limit of 10 fish per angler; and all states require a commercial license to sell bluefish (MAFMC 1998). Many states also choose to adopt management measures that are more restrictive than the federal management plan. New York restricts commercial fishing or sale of bluefish to fish measuring greater than 9 in. and imposes seasonal limits on gear type and bycatch. New Jersey also imposes seasonal restrictions on gear type and catch limits. Both New York and New Jersey have issued restrictions on consumption of bluefish due to levels of PCBs in the flesh that exceed FDA guidelines for interstate commerce (Pottern et al. 1989).

Recreational catches of bluefish in the North Atlantic have historically and continue to exceed commercial catches. Between 1981 and 1996, annual coastwide recreational and commercial bluefish landings averaged 49.8 and 12.7 million lbs., respectively (MAFMC 1998). Among recreational catches along the Atlantic coast, New York and New Jersey have had the greatest harvests in recent years, each accounting for approximately 21% of the average annual catch between 1987 and 1996 (MAFMC 1998).

Coastwide recreational and commercial bluefish landings have declined sharply since the 1980s. In 1994, the MAFMC reported that the bluefish stock was over-exploited and at a low level of abundance, noting that recreational catch levels were about 25% of the catch level of the 1980s. Recent bluefish stock assessments still consider the stock overexploited, although fishing mortality rates have declined since highs of 0.93 and 0.94 in 1987 and 1991, respectively. The decline in fishing mortality rates since 1991 coincides with the implementation of the FMP and a decline in bluefish popularity among recreational anglers. MRFSS data for 1991 and 1996 indicate a switch in angler preference from bluefish to striped bass, concurrent with the recovery of striped bass stocks. In 1991, 34% of anglers interviewed identified bluefish as the primary species sought; while 11% of anglers identified striped bass as the primary species. In 1996, the primary species sought had switched to 12% and 44% for bluefish and striped bass, respectively.

Water Withdrawal

Bluefish spawn in marine waters, and entrainable life stages (eggs and larvae) have not been found in either the ichthyoplankton or the entrainment samples from Roseton Units 1 and 2, Indian Point Units 2 and 3, and Bowline Point Units 1 and 2 (see Section VI-A). In some years juvenile bluefish are impinged, but the numbers are relatively small.

j. **Hogchoker**

i. Life History and Distribution Within the Hudson River

The hogchoker (*Trinectes maculatus*) is a small, oval shaped, right-eyed member of the sole family (Soleidae) with no pectoral fin. These characteristics along with tiny eyes, small mouth, and brownish color with crosslines or a variegated pattern of transverse lines and irregular marbling help to distinguish it from other right-eyed flatfish (Smith 1985). Hogchokers reach a length of 2 to 3 in. in their first year, mature at about 4.5 in., and attain a maximum size of about 8 in. (Bigelow and Schroeder 1953). Females become sexually mature at a total length of about 2.8 in. (Miller, Burke, and Fitzhug 1991).

Hogchokers inhabit estuaries and nearshore coastal waters and range along the Atlantic coast from Massachusetts Bay to Panama (Figure V-89). Within this range, they are abundant from the Chesapeake Bay southward, and moderately common as far north as southern New England (Bigelow and Schroeder 1953). This small flatfish is very abundant in the Hudson River estuary and its adjacent bays and coastal waters. They can tolerate a wide range of salinities and are found from marine waters up into fresh water, although older individuals tend to be found in more saline waters. Hogchoker adults are most abundant in mesohaline and oligohaline waters from late spring through early fall, and migrate to deeper channels as water temperatures decline in late fall (Wang and Kernehan 1979).

Adult hogchokers pass the winter in low salinity regions (Koski 1973) buried in bottom sediments and spawn in the lower regions of estuaries and offshore from estuary mouths during the spring and summer. In some areas (eastern Chesapeake Bay) spawning appears to be restricted to sandy substrates. Dovel et al. (1969) reported that the hogchoker population in the Patuxent River was a resident population confined for the most part to that estuary in the Chesapeake Bay complex and concluded that the hogchoker population in the Chesapeake Bay system was probably composed of subpopulations that were generally confined to the bay and various tributaries. The relationship of Hudson River hogchokers to Atlantic coastal populations is unknown.

Individual hogchokers produce from 11,000 to 54,000 eggs, depending upon the size of the female (Bigelow and Schroeder 1953). The eggs are slightly buoyant, spherical, or slightly oblong, size varies with salinity (0.66 to 0.92 mm in diameter), with the smallest eggs generally found in higher salinity water (Hildebrand and Cable 1938; Dovel et al. 1969). In the Hudson River estuary hogchoker spawning occurs from May to October although eggs are more commonly collected during the period from the last week in May through July (Figure V-90), in the more saline areas of the lower estuary, RM 12 to RM 24

Figure V-89. Distribution of hogchoker in North America.

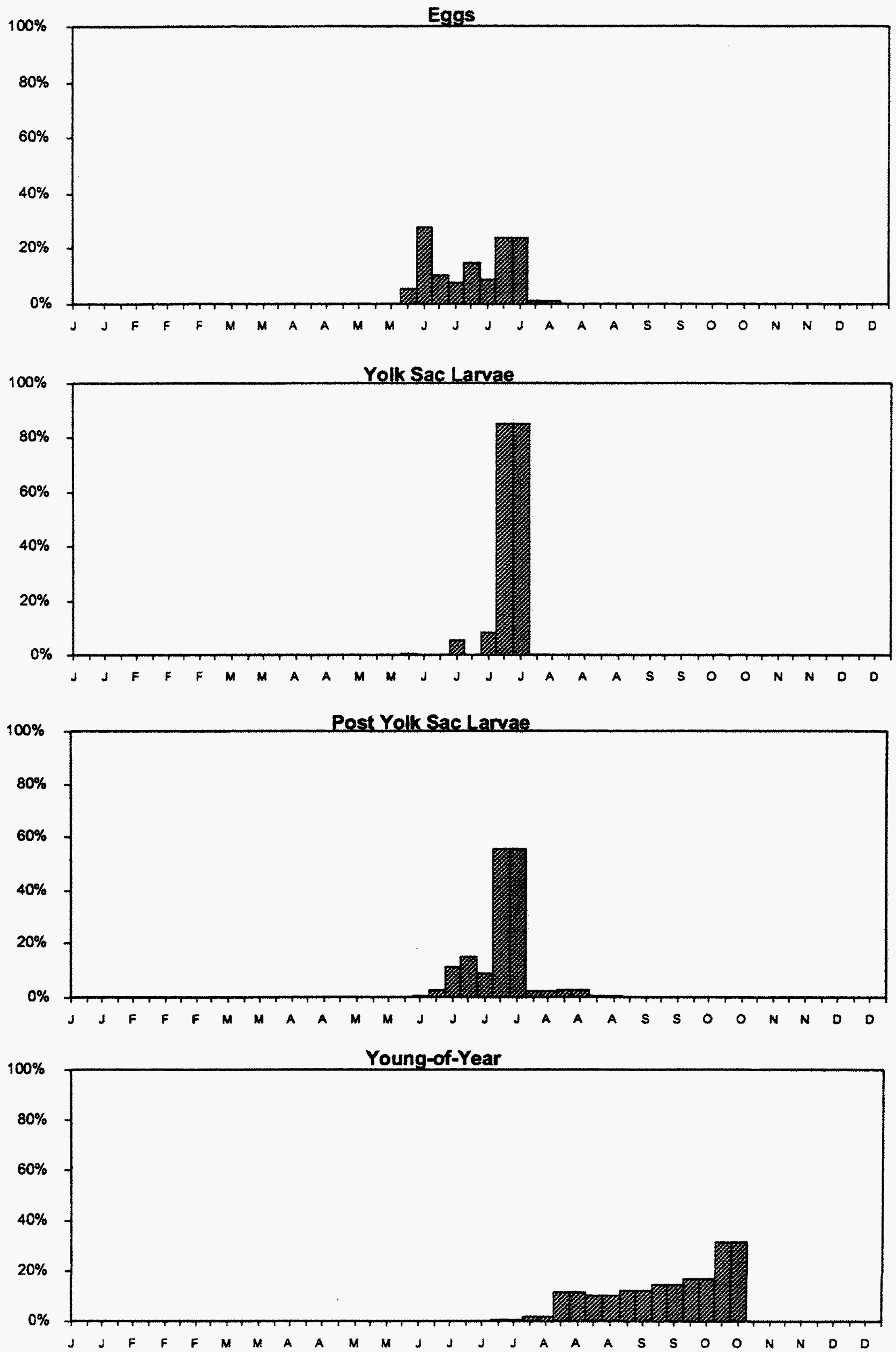


Figure V-90. Temporal distribution indices for hogchoker eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

(Figure V-91). Hogchoker lay demersal eggs that hatch after 24-36 hours at 23.3 to 24.5C (Hildebrand and Cable 1938).

The newly hatched larvae are about 0.1 in. in total length. Eye migration (at the onset of the juvenile period) occurs at 0.2-0.4 in. in total length (Miller, Burke, and, Fitzhug 1991). Growth of young-of-year is relatively slow. Examination of length-frequency for males in the Patuxent River (Dovel et al. 1969) suggests that young-of-year are approximately 0.4 to 2 in. by November, do not grow over the winter, and are approximately.8 to 2.5 in. by the following spring when they are age 1. Growth estimates based on scales from fish collected in the Patuxent River indicate an average back-calculated length of 1.6 in. at age 1 and 2.6 in. at age 2 (Mansueti and Pauly 1956). In the Hudson, hogchokers generally reached sexual maturity at age 2, although some males were mature at age 1 (Koski 1973). The oldest males in the Hudson were age 4 while the oldest females were age 6.

After hatching, the yolk-sac larvae move upstream from the spawning areas and may use the net upstream flows in the deeper saline waters of the estuary. In the Hudson River YSL are most abundant during the same time period as the eggs, although the center of the YSL distribution, between RM 24 and RM 33, is upriver from that of the eggs. The upstream movement continues through the post-yolk-sac stage. In the Hudson River PYSL are most abundant during the period from the last week in May through July and their upstream distribution extends to RM 55.

Surprisingly, little is known of the habitats of this abundant species. Larger larvae and recently transformed juveniles are reported to migrate rapidly upriver to low-salinity nursery areas where the smallest juveniles are typically collected (Able and Fahay 1998).

Juvenile hogchoker are abundant in monitoring program catches from August through early October. They are found upriver to RM 76, and the majority inhabit the middle estuary. The occurrence of juvenile hogchokers in collections well before the peak in egg abundance suggests that juveniles may move into the Hudson River estuary from the lower bay complex. By the end of the sampling season the highest density of juvenile hogchokers is in the middle estuary, where they remain during their first winter.

During the spring and summer, young hogchokers gradually move down into the lower estuary. In the Hudson River the yearling and older hogchokers overlap spatially with a portion of the juvenile population (Koski 1973). The majority of the juveniles are found above RM 39, however, and the majority of the yearling and older fish are found below RM 34. Koski (1973) found adult hogchokers also appear to move in sexually segregated groups.

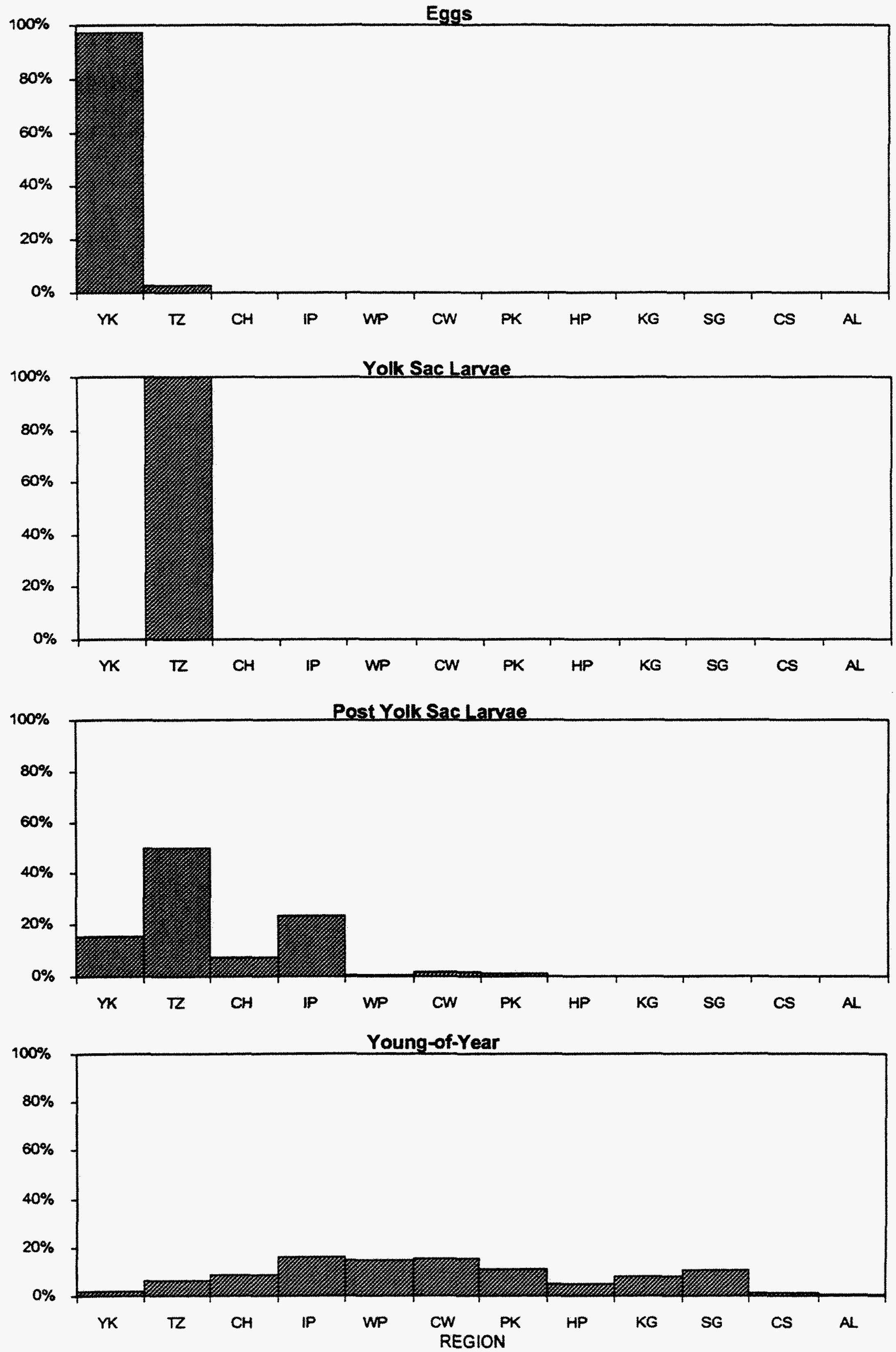


Figure V-91. Spatial distribution indices for hogchoker eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

Hogchokers feed near the bottom on a variety of benthic invertebrates, including annelid worms and smaller crustaceans. In the Hudson River, Koski (1973) analyzed the stomach contents of 604 hogchokers collected between river mile 35 and 47. He found polychaetes, one isopod (*Cyathura sp.*), amphipods (primarily *Gammarus fasciatus*), and chironomid larvae were the major food items. Amphipods and Polychaetes were the dominant food items found.

The occurrence and numbers of food items were related to the occurrence and abundance of benthic organisms. Koski (1973) found a shift in the diets of 46 hogchoker collected in freshwater sections of the Hudson River (river mile 67 and 96). Amphipods and chironomid larvae were most abundant.

Hogchokers collected in April and December had empty stomachs, no collections were made through the winter months (Koski 1973). Data suggest little feeding occurs during winter.

ii. Temporal Changes in Abundance

Sampling Program

The hogchoker is an offshore, bottom-dwelling flatfish preferring deep-water that is sampled most consistently by the FSS bottom trawls. Juvenile hogchokers move into the part of the estuary sampled by the Fall Shoals Survey (FSS) by September, and most of the population should be fully recruited to the FSS trawls in October. An index of relative abundance, the weighted mean density, was developed from the Fall Shoals Survey catches from the bottom stratum in weeks 40 to 43 (October).

Abundance Indices

Overall, from 1974-1997, the index of abundance of juvenile hogchokers in the Hudson River estuary has been relatively stable. The average temporal trend is a non-significant increased of 1% per year (Figure V-92). In 1985, the gear used to sample the bottom stratum in the FSS was changed; the epibenthic sled was replaced with a 3-m beam trawl. The change in the sampling gear did not appear to affect the catches of YOY hogchoker. The change in the sampling gear did have a dramatic effect on the catches of yearling and older hogchoker. The average catch quadrupled when the epibenthic sled was replaced.

There was no time trend in YOY abundance and, during the period from 1985 through 1994, the spikes in YOY abundance preceded the spikes in the abundance of yearling and older hogchokers by one year, which is as expected. However, the spike in YOY

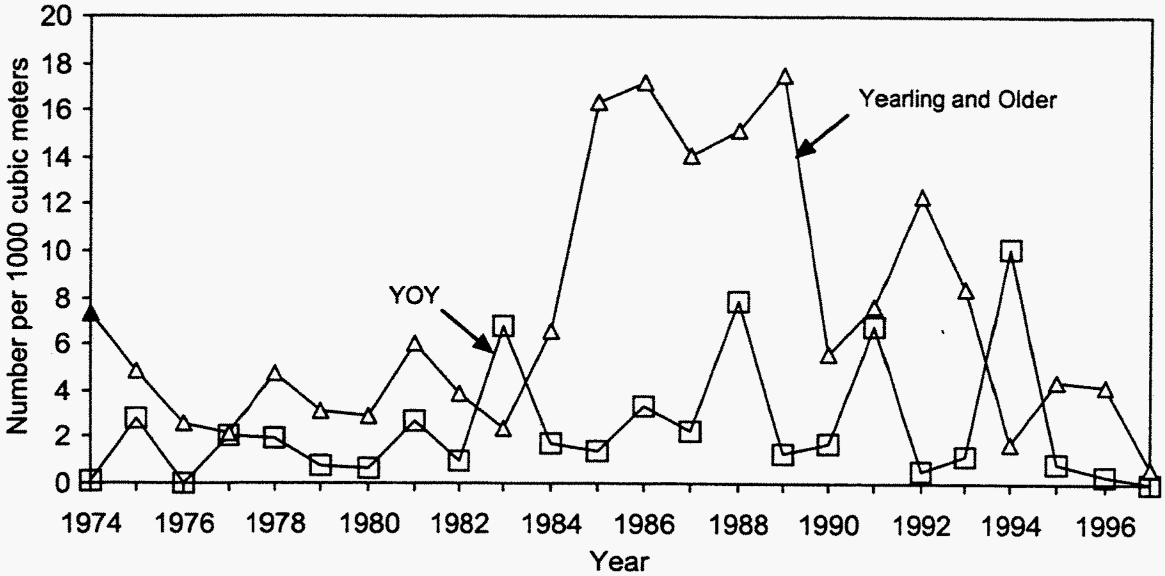


Figure V-92. Indices of abundance for young-of-the-year (YOY) and yearling and older (YROL) hogchoker generated from the bottom trawl used during the Fall Shoals Survey, 1974-1997.

TABLE V-38

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF HOGCHOKER

	FSS BOTTOM	
YEAR	**YOY**	**YRL+**
1974	0.15	7.27
1975	2.75	4.81
1976	0.02	2.55
1977	2.09	2.18
1978	1.93	4.7
1979	0.79	3.11
1980	0.62	2.92
1981	2.73	5.99
1982	0.98	3.9
1983	6.79	2.34
1984	1.77	6.6
1985	1.4	16.36
1986	3.3	17.17
1987	2.23	14.06
1988	7.83	15.2
1989	1.32	17.53
1990	1.73	5.62
1991	6.77	7.65
1992	0.5	12.39
1993	1.19	8.36
1994	10.08	1.75
1995	0.88	4.44
1996	0.3	4.17
1997	0.03	0.62

abundance that occurred in 1994 was not followed by an increase in the abundance of yearling and older hogchokers.

There was no time trend in the abundance of yearling and older hogchokers during the period from 1974 through 1985. There was a negative trend during the period from 1985 through 1997 ($R^2 = 0.772$; $p = 0.000$).

iii. Potential Influences on Abundance

Ecological Factors

Predation

Predation by large striped bass may be a factor affecting the abundance of yearling and older hogchokers. The negative trend in abundance began in 1990 when the strong striped bass cohorts from 1983 and 1984 reached ages 6 and 7 and intensified in 1994 when the even stronger cohorts from 1987 and 1988 reached ages 6 and 7.

Temperature, salinity, and availability of food affect growth and survival of hogchokers (Peters and Boyd 1972). Salinity has also been cited as an important cueing factor for hogchokers migrating in estuaries (Dovel et al. 1969). The reduced nutrient loading resulting from increased capacity of NYCDEP treatment plants may have some negative effects on the food base of benthic invertebrates eaten by hogchokers.

Fishing

There is no known commercial or recreational fishery on hogchokers.

Water Withdrawal

Hogchoker larvae are demersal and found mainly in the deeper channel areas within the estuary. They are not usually captured during the Longitudinal River Survey and few larvae are entrained at the generating stations along the Hudson River. Juvenile hogchokers are not captured in high numbers during the Beach Seine and Fall Shoals surveys, and impingement for all life stages is low. Yearling and older hogchokers are most abundant below RM 34, and so most are not exposed to the generating stations. Those that are impinged have demonstrated little sign of injury with little post-impingement mortality.

k. Weakfish

i. Life History and Distribution Within the Hudson River

Weakfish (*Cynoscion regalis*) is a member of the drum family (Sciaenidae) commonly inhabiting near-shore waters along the western Atlantic ocean. The body is slim with a relatively deep caudal peduncle; the caudal margin is rounded in young but slightly concave in adults. The head is large and conical with a large projecting lower jaw containing sharp teeth in narrow bands. The upper jaw contains 2 tapered canines; (one of which is sometimes vestigial); canines are absent from the lower jaw. The body color is greenish above, with purple and bronze metallic reflections, and silvery below. Ventral, anal and the margins of the caudal and pectoral fins are yellow.

Adult weakfish range in size from approximately 6 to 31 in. TL. Weakfish can live up to 11 years and reach a maximum size of 32 in. and about 20 lb. Fish longer than approximately 3 ft TL are rare (Bigelow and Schroeder 1953). The maximum age reported is a 17-year-old weakfish collected in Delaware Bay in 1985 (Lowerre-Barbieri et al. 1995). The maximum age previously reported was age-12 from Chesapeake Bay (Shepherd 1988). However earlier age determinations were almost exclusively based on scale annuli analyses which can underestimate the age of older (>6 yrs) fish (Lowerre-Barbieri et al. 1994). The same fish classified as a 17-year-old using otolith analysis by Lowerre-Barbieri et al. (1995) was aged as a 7-year-old using scale analysis (Villoso 1989).

Weakfish range along the Atlantic coast of North America from southern Florida to Massachusetts Bay and occasionally stray to Nova Scotia (Wilk 1979; Bigelow and Schroeder 1953). It is most common from North Carolina to New York (Mercer 1983; Shepherd and Grimes 1983), with its range centered in the Delaware estuary (Seagraves 1995).

Weakfish overwinter in deeper waters (10-55 fathoms [20-100 m]) of the continental shelf, generally between Chesapeake Bay and Cape Fear, North Carolina (Pearson 1932; Bigelow and Schroeder 1953; Wilk 1979). When inshore waters begin to warm each spring, older weakfish begin to move toward shore and then head north along the coast. These older individuals are followed by successively younger groups of adult weakfish. During April through November, weakfish are found throughout inshore waters and estuaries in their geographic range, with larger individuals the most abundant in northern areas. Adult weakfish are found in a variety of estuarine habitats but appear to favor shallow waters with sand bottoms (Able and Fahay 1998) with moderate to high salinity (about 10 ppt and above). As water temperatures decline in the fall, weakfish begin to migrate southward and return to offshore overwintering areas.

Most weakfish are sexually mature by the end of their second summer and practically all are mature by the end of their third summer (Merriner 1976; Wilk 1979; Shepherd 1982). The principal reproductive range is from Chesapeake Bay to Montauk, Long Island, NY (Colton et al. 1979); however, spawning has been reported from the Gulf of Maine (Bigelow and Schroeder 1953) to Georgia (Mahood 1974). Spawning occurs in near-shore coastal and marine waters in spring and summer, depending upon geographic location.

In the New York Bight spawning typically occurs from May to mid-July, with two spawning peaks. These peaks likely reflect either the influx of younger age groups spawning for the first time, or multiple spawning by individuals as evidenced by Daiber (1956a) and Epifanio et al. (1988) in Delaware Bay and Merriner (1976) in North Carolina. Weakfish eggs are buoyant and hatch in about two days. The newly hatched larvae, which are less than 3.17 mm (0.125 in.) long, are weak swimmers and move shoreward into bays and estuaries. Larval growth and development appears to depend partially on prey density. In the Hudson River estuary weakfish larvae are rarely encountered north of the George Washington Bridge, preferring more saline waters. Weakfish juveniles (YOY) typically first enter the areas north of the George Washington Bridge during July and most have emigrated from the estuary by mid-August (Figure V-93).

In the nursery areas young weakfish feed on invertebrates and grow rapidly. They reach a length of 7.6 to 15.2 cm (3 to 6 in.) by the end of the first summer. Young weakfish can be found throughout the saline and brackish areas of estuaries but tend to be most common in areas where salinities are over 10 ppt. In the Hudson River, YOY weakfish are most common in the most southern (higher salinity) areas sampled but can be found as far upriver as Newburgh Bay (Figure V-94). YOY weakfish abundance generally increases downstream, suggesting that YOY are more abundant in areas of the estuary south of the George Washington Bridge, a pattern consistent with that observed in other estuarine systems. As water temperatures decline in fall, juvenile weakfish begin to leave northern estuaries and move toward southern overwintering areas.

Weakfish prey on a wide range of crustaceans, annelids, and pelagic mollusks (Bigelow and Schroeder 1953). Principal prey items include anchovies, herrings, spot, weakfish, mysids, crabs, molluscs, and small crustaceans (Peterson and Peterson 1979). As weakfish reach adulthood, fish become an increasingly important component of their diet. Larger young and adults are predominantly piscivorous, their diets often dominated by herring and menhaden (Welch and Breder, 1923). Growth in adult weakfish appears to be related to environmental factors, prey availability, and migratory energy requirements.

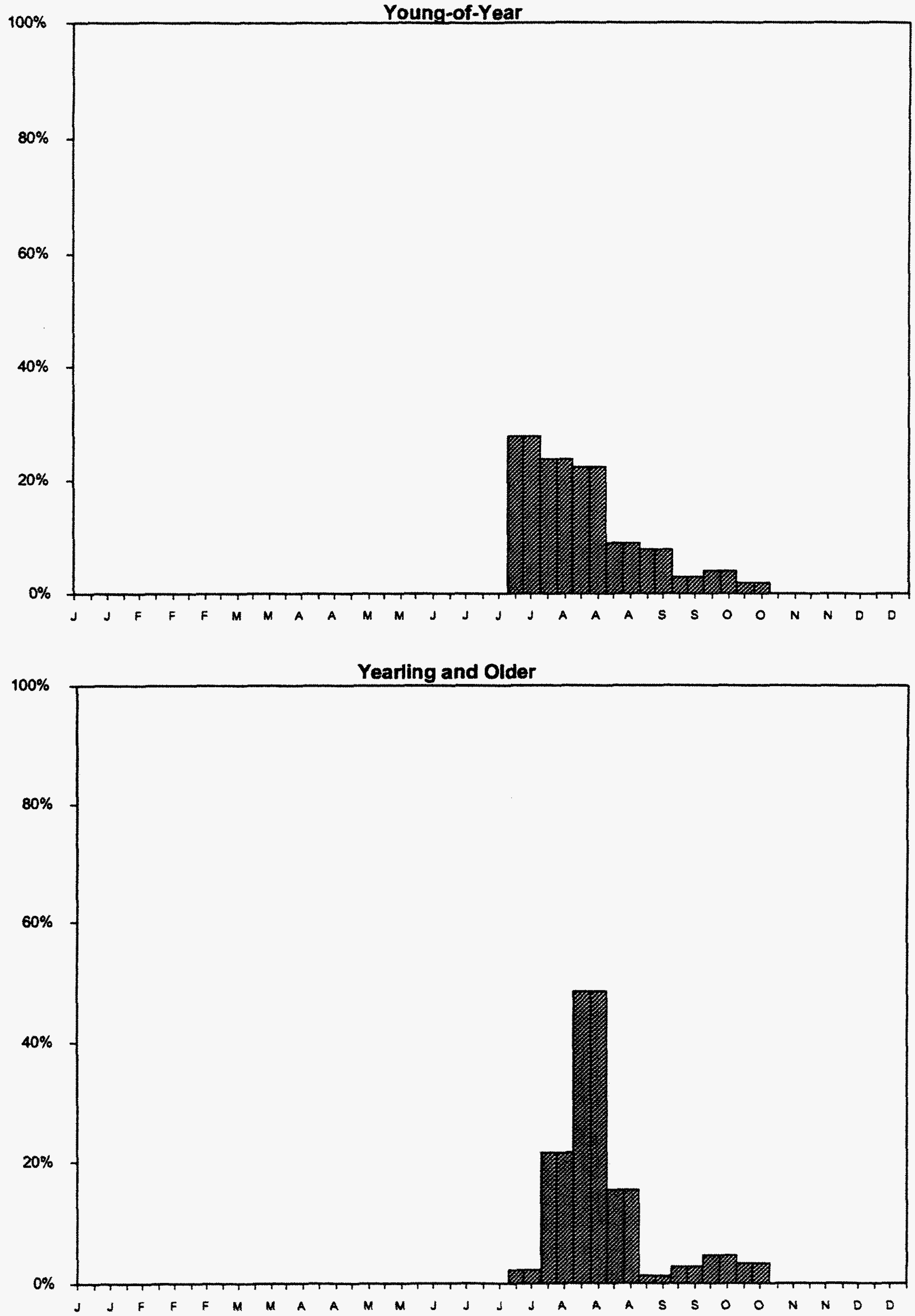


Figure V-93. Temporal distribution indices for weakfish collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

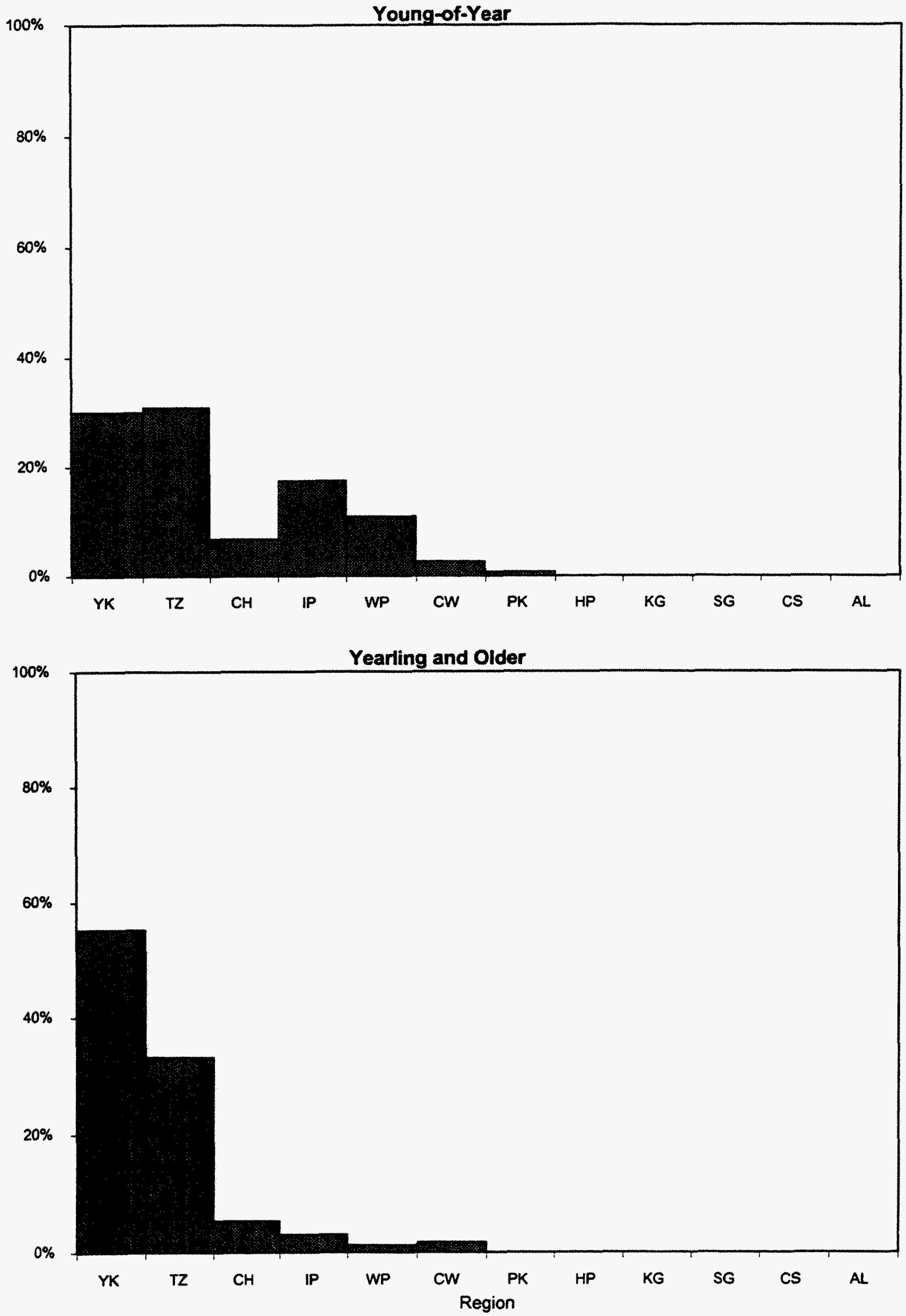


Figure V-94. Spatial distribution indices for weakfish collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

ii. Temporal Changes in Abundance

Sampling Programs

The relative abundance of juvenile weakfish measured as the average density in the Fall Shoals Survey (FSS) channel samples was used to assess long-term trends in the abundance of YOY weakfish that use the Hudson River estuary as a nursery ground. Weakfish spawn at the mouths of estuaries, and so many of the eggs and larvae are outside the geographic range of the LRS. Weakfish are most consistently sampled in the FSS channel samples, which began in 1979 and were always sampled with the same type of gear.

Abundance Indices

Based on the FSS data on juveniles, abundances in the Hudson River estuary declined by about 6% per year from 1979-1997 (Table V-39). Weakfish abundance fluctuated from 1979 through 1990; from 1990 through 1997, abundance was low and the fluctuations were damped.

iii. Potential Influences on Abundance

Ecological Factors

Competition with PYSL and YOY striped bass may be responsible for the low abundance of YOY weakfish during the period from 1990 through 1997. A comparison of the normalized indices for PYSL striped bass and YOY weakfish (Figure V-95) suggests that the disappearance of the fluctuations in the abundance of YOY weakfish coincided with the increase in the abundance of PYSL striped bass.

Fishing

The weakfish is a valuable commercial and recreational species along the Atlantic Coast. Fishing throughout the species range of Florida to Massachusetts Bay may affect the number of weakfish entering the Hudson River. Most of the directed commercial landings have historically been harvested in the southern half of the species range (VA and NC) where, additionally, juveniles are exploited in a scrapfish fishery. In the northern half of the species range, where older and larger fish occur, weakfish have supported an extensive recreational fishery since at least the 1800s.

Commercial landings have had two peaks. From the 1800s landings increased to a peak in the 1940s (37,600,000 lb in 1945), when most of the landings were made in the Chesapeake

TABLE V-39

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE FOR YOUNG-OF-YEAR (YOY) WEAKFISH

YEAR	FSS CHANNEL INDEX (S.E.)
1979	0.13 (0.07)
1980	0.60 (0.28)
1981	0.22 (0.12)
1982	0.66 (0.30)
1983	0.12 (0.09)
1984	1.59 (0.63)
1985	0.98 (0.48)
1986	0.29 (0.11)
1987	0.25 (0.18)
1988	1.44 (0.60)
1989	0.76 (0.24)
1990	0.15 (0.09)
1991	0.10 (0.06)
1992	0.03 (0.02)
1993	0.25 (0.15)
1994	0.13 (0.06)
1995	0.23 (0.13)
1996	0.21 (0.16)
1997	0.16 (0.05)

S.E. - Standard error.

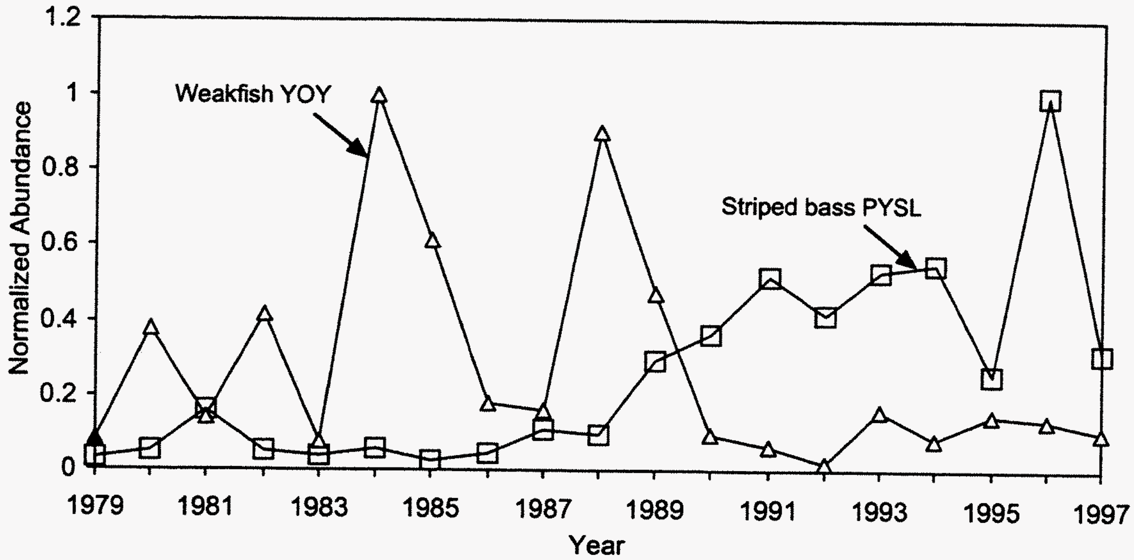


Figure V-95. Normalized indices of abundance for young-of-the-year weakfish (WF YOY) and striped bass post yolk-sac larvae (SB PYSL), 1979-1997.

Bay area. A second peak occurred in 1980. Most landings in 1980 were made in North Carolina, probably due to an increase in the mobility of the North Carolina fishing fleet rather than a change in distribution of the stock (Mercer 1989). Recent recreational fishery statistics indicate that a peak of recreational landings occurred in 1980 and that the peak was followed by a sharp decline (Mercer 1989).

From 1980 through 1990 both commercial and recreational landings decreased. Fishing pressure and habitat alteration have been suggested as possible causes of the decline (Mercer 1989). Recent analyses by the Atlantic States Marine Fisheries Commission (Seagraves 1991) indicate that 52% of the fish that are recruited to the fishery (ages 2 and older) die annually due to fishing. Estimated instantaneous fishing mortality rates (F) were 0.9 or greater. The ASMFC's Scientific and Statistical Committee concluded that the current rates of fishing were too high to maintain the stock over the long term, and recommended immediate reduction in fishing rates.

The migratory nature and commercial importance of weakfish led, in 1985, to the development of an Atlantic coast Fishery Management Plan (FMP) for weakfish by the Atlantic States Marine Fisheries Commission (ASMFC). The plan recommended that northern states (Rhode Island to Virginia) harvest only weakfish older than age 1, and that trawl efficiency devices (TEDs) be used in the South Atlantic shrimp fisheries to reduce by-catch mortality (ASMFC 1992). The continued decline of weakfish stocks and failure of states to implement the FMP during the ensuing period led to the development of Amendment 1 in March 1992, which was also largely ignored by state agencies. Passage of the Atlantic Coastal Fisheries Cooperative Management Act in 1993 conferred on the Secretary of Commerce the authority to close fishing in state waters for those states not in compliance with the FMP. Commercial and recreational exploitation of the Atlantic coast weakfish stock is now governed by minimum size restrictions, harvest strategies, and gear restrictions recommended in the FMP.

Between 1987 and 1989 New York landings accounted for only about 1% of the annual commercial weakfish landings along the Atlantic coast (Seagraves 1991). In 1996 New York landings accounted for approximately 5% of the Atlantic coast commercial catch. Since 1990, New Jersey landings have accounted for 10-14%.

In 1998, NMFS (1998b) reported that the weakfish stock is increasing in abundance and fully exploited both commercially and recreationally. Neither New York State nor New Jersey have bans on the sale or restrictions on consumption of weakfish.

Water Withdrawals

Because weakfish spawn in higher salinity areas, weakfish eggs and larvae are not commonly entrained at Hudson River power plants, but their subsequent movement into the estuary results in some entrainment of early juveniles in late winter and early spring and impingement of larger juveniles toward the end of the summer (see Sections VI-A and VI-B).

l. ***Rainbow Smelt***

i. Life History and Distribution Within the Hudson River

The rainbow smelt (*Osmerus mordax*) are greenish, slender, salmon-like fish with deeply forked tails. They occur along the Atlantic coast from Manitoba (Remnant et al. 1997) and Labrador to the Delaware River, along the Arctic Coast, and along the coasts of Alaska and British Columbia (Figure V-96). They are landlocked naturally in many lakes and ponds in Canada, Maine and New Hampshire and have been introduced to other landlocked freshwaters (Smith 1985). In the Great Lakes region, smelt have established large populations in many of the landlocked freshwaters where they have had strong negative effects on native fishes through predation and interspecific competition (Evans and Loftus 1987; Franzin et al. 1994; Hrabit et al. 1998). Within New York State rainbow smelt are found in the Hudson River, Long Island streams, several Adirondac lakes, and the Great Lakes (Smith 1985).

Anadromous rainbow smelt may spend the whole year in or near estuaries. In the fall, they move into the bays and estuaries. Rainbow smelt spawn in tributaries in spring when the water temperature reaches 48°F. Even landlocked populations continue to migrate from their lake habitats to tributary streams to spawn. Spawners move into the lower reaches of streams in the evening, spawn at night, and move out in the day. Adult smelt leave the tributaries immediately after spawning. They spawn where water velocities are high, and larval survival decreases where water velocities are low (Buckley 1989). In the summer adults move to deeper, cooler water just outside bays and estuaries.

Adult smelt usually average 7 to 8 in. in total length, but occasionally reach lengths of 13 to 14 in. Female smelt grow faster than males and may reach maturity as early as age 1 along the southern edge of their range. However, maturity occurs more commonly at ages 2 through 5. The number of eggs produced by an adult smelt may range from 7,000 to 70,000 (Bigelow and Schroeder 1953; Smith 1985; Buckley 1989).

Figure V-96. Distribution of rainbow smelt in North America.

Unfertilized eggs are 0.8 to 0.9 mm (0.0315 to 0.0354 in.), demersal and adhesive, irregular in shape, and contain a granular yellow yolk with numerous oil globules. Fertilized, water-hardened eggs are approximately 1.0 to 1.6 mm (0.0394 to 0.0625 in.) in diameter and spherical (Bigelow and Schroeder 1953; Cooper 1978). In the Hudson River, rainbow smelt eggs are most abundant in the ichthyoplankton catches from the upper estuary from RM 107 to RM 124 (Figure V-29). They hatch in about a week to almost a month, depending on temperature, and eggs are present in the Hudson River ichthyoplankton catches for about two weeks, which suggests a short spawning period (Figure V-97). It could be inferred (although there is no direct evidence) that free-floating eggs in the Hudson River, since they do not appear to be in an environment that maximizes their survival probability, have been dislodged from preferred spawning areas in the tributaries. However, no studies have been conducted that confirm the transport of smelt eggs into the river.

Newly hatched larvae are about 0.20 to 0.24-in. long (Cooper 1978). These larvae are carried downstream and out of the tributaries by current flows. YSL are abundant from the first week through the third week in May and are uniformly distributed downriver from RM 106 to RM 56. The yolk sac is absorbed when the fish are about 0.25 in. in length (Cooper 1978). PYSL are commonly found from RM 106 to RM 23, and are abundant from the third week in May through the second week in June. As rainbow smelt larvae grow, they move closer to the bottom during the day and move back toward the surface at night, probably to feed on zooplankton, which exhibit similar vertical migrations in the water column. At about 0.75 in., they begin to school. Rainbow smelt larvae are similar to several clupeid larvae and could be mistakenly identified. Reliable characteristics for separating larval smelt from alewife and gizzard shad are presented in Cooper (1978).

Transition to the juvenile stage occurs when all fin rays are complete, at about 1.42 in. in length. Juvenile smelt are exceedingly slender and nearly transparent, until they reach about 1.57 in. and become "dusky" in appearance (Cooper 1978). They are abundant in the LRS catches from the third week in June through the first week in July. Juveniles grow quickly and are at least 2-in. long by August. The older juveniles are most abundant in the lower estuary, RM 24 to RM 33, but are common from RM 33 to RM 61 (Figure V-98). The young smelt leave the estuary by late summer.

Age-0 and older smelt exhibit diel vertical migrations related to light and temperature, moving to deeper waters during the day and to shallower waters at night (Heist and Swenson 1983; Burczinsky et al. 1987; Buckley 1989; Appenzeller and Leggett 1995). Temperature is the major sensory cue for depth distribution at night, and light prevails during the day. During times of the year when surface temperatures are cold, the upper boundary of nighttime smelt distribution approaches the surface. When epilimnetic temperatures are >64°F, the upper boundary of nighttime smelt distribution is near the base

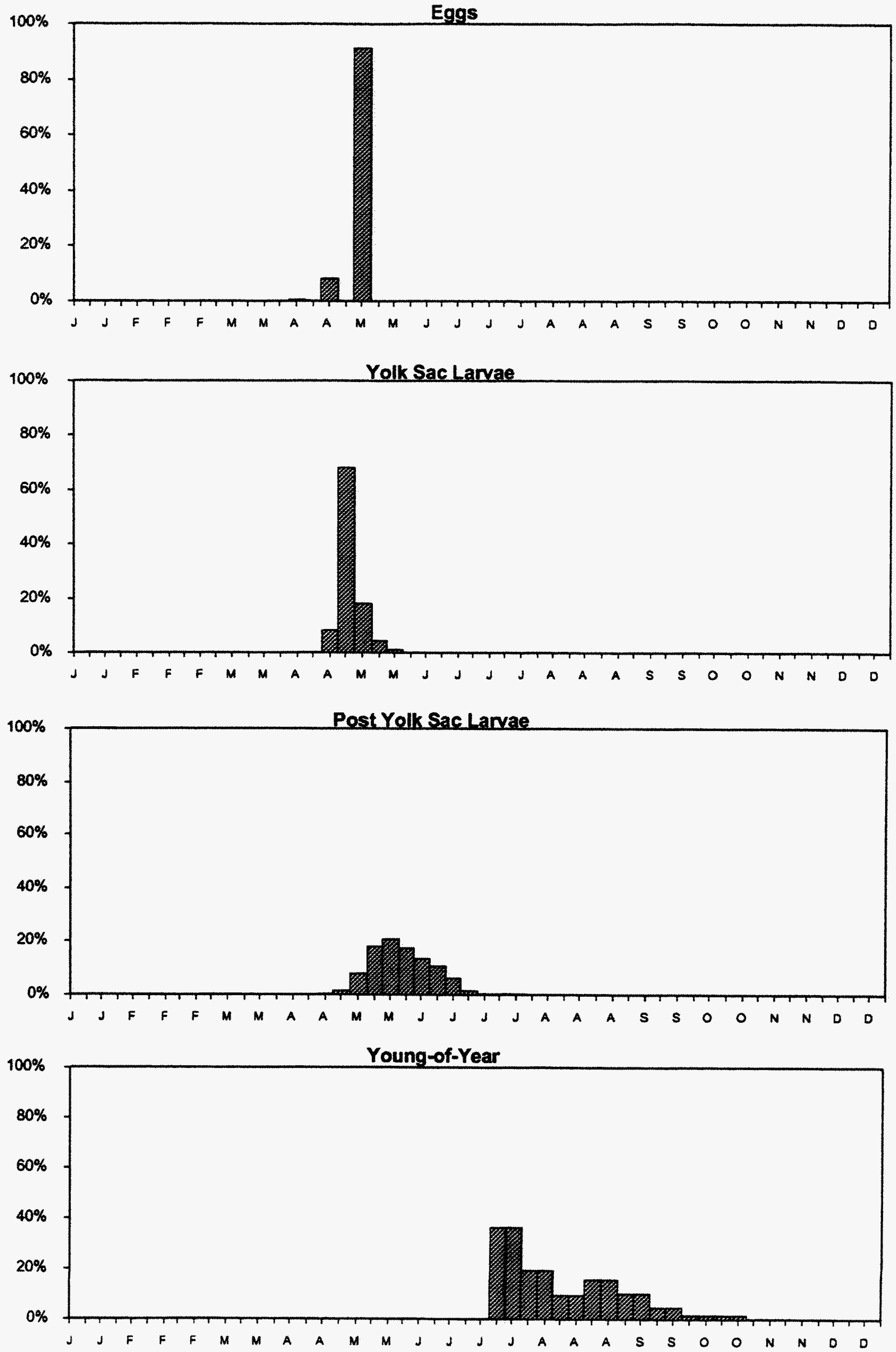


Figure V-97. Temporal distribution indices for rainbow smelt eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

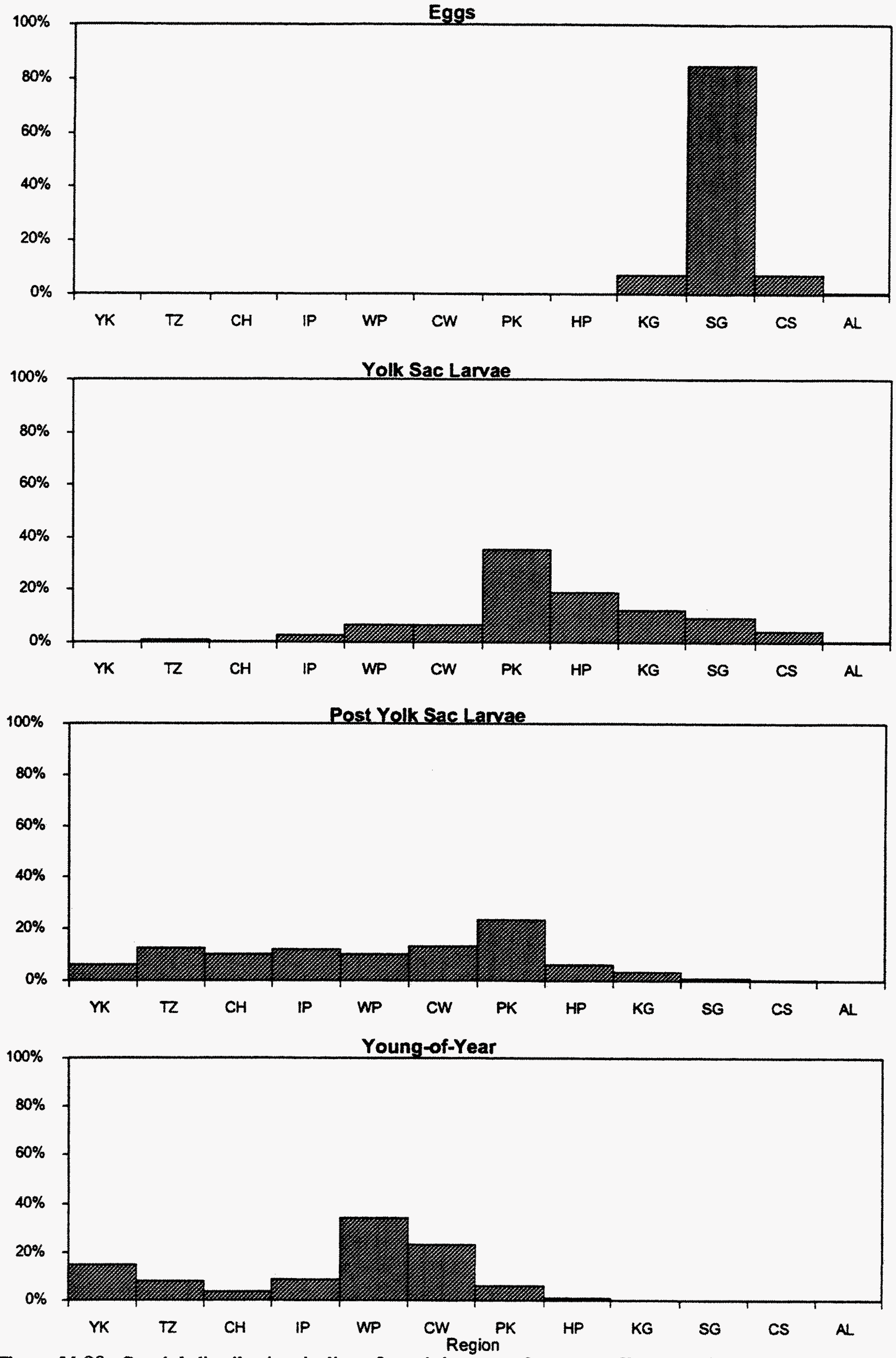


Figure V-98. Spatial distribution indices for rainbow smelt eggs, yolk sac and post yolk sac larvae collected during Long River surveys and young-of-year collected during Fall Shoals surveys of the Hudson River estuary, 1991-1997.

of the thermocline in midwater (Appenzeller and Leggett 1995), though some age-0 smelt may occur above the thermocline (Burczynski 1987). Daytime vertical distribution is significantly related ($r^2 = 0.83$) to ambient light levels: smelt are negatively phototactic, and strongly avoid light levels >0.1 $\mu W/cm^2$ (Appenzeller and Leggett 1995).

Aggregation patterns also show diel variation. Smelt form dense schools during daylight hours near the bottom, and disperse at night as they migrate towards the surface (Burczynski 1987; Appenzeller and Leggett 1995).

Smelt are omnivorous, their diet varying from small zooplankton to fish up to a maximum prey size of about 6% of their own body weight. Preferred prey include crustaceans (e.g., amphipods, cladocerans, copepods, and mysids) and insects (e.g., dipterans and ephemeropterans) (Evans and Loftus 1987, Mills et al. 1994). Other prey include young herring, mummichogs, cunners, anchovies, sand lance, stickleback, silversides, anchovies, shellfish, squid, and crabs (Smith 1985). Adult rainbow smelt are preyed upon by striped bass, bluefish, harbor seals, and other large visually oriented predators (Buckley 1989, Evans and Loftus 1987).

Yearling and older smelt gather in brackish estuaries and may move into and out of small harbors with the tides. Smelt overwinter in estuaries between harbor mouths and brackish water (Bigelow and Schroeder 1953).

Rainbow smelt stocks are generally confined to their natal estuaries and nearby coastal areas. Bigelow and Schroeder (1953) concluded that rainbow smelt move down the river to the lower part of the estuary or to near-shore coastal waters as they grow, and they reported that smelt have never been observed or captured much more than one mile from shore or in depths greater than 20 ft. Landlocked populations, however, have been reported to occur at much greater depths. In Lake Memphremagog, Quebec/Vermont, smelt typically concentrate in the upper 33-49 ft during nighttime hours and migrate to deeper waters during daylight where peak distributions occur at depths of 98-131 ft (Appenzeller and Legget 1995). In Lake Oahe, South Dakota, smelt most commonly occur at depths greater than 33 ft (Burczynski 1987) and in Lake Superior, smelt were most abundant in waters less than 164-ft deep (Heist and Swenson 1983).

Rainbow smelt exploited in the Parker River system in Massachusetts (Murawski et al. 1980) appeared to remain within the river system, although they may not have returned to their natal streams. Rupp (1968) reported that rainbow smelt stocks did "wander" among rivers during spawning in a Maine estuary, although this behavior was seen only occasionally in the Miramachi River in New Brunswick, Canada (McKenzie 1964). Frechet et al. (1983) concluded that the degree of homing to natal rivers was inversely related to the distance between rivers within a specific geographic area, such as an estuary. Therefore, it is unlikely that rainbow smelt of Hudson River origin contribute significantly to other coastal stocks.

ii. Temporal Changes in Abundance

The average juvenile density in the Fall Shoals Survey in channel strata was used to generate annual indices of abundance for the period from 1979 through 1997 (Table V-40). There was no time trend (Figure V-99).

The monthly estimated number of rainbow smelt impinged at Lovett, Roseton Units 1 and 2, and Danskammer is shown in Figure V-100 for the years during which this species was collected and enumerated. Figure V-101 shows the average monthly impingement rate at each station over all collection years. The highest impingment rates occur during the spring when rainbow smelt enter the river to spawn. Impingement rates of rainbow smelt at the Lovett, Roseton Units 1 and 2, and Danskammer Generating Stations decreased after 1994.

iii. Potential Influences on Abundance

Ecological Factors

Geographical and vertical migrations of rainbow smelt are strongly temperature dependent (Heist and Swenson 1983; Burczynski et al. 1987). Sudden decreases in water temperatures can cause rainbow smelt to cease spawning, whereas prolonged periods of low temperatures in spring can result in prolonged spawning (Argyle 1982). Exposure of rainbow smelt eggs to brackish water could adversely affect early survival. Rainbow smelt typically spawn just above tidewater, and saltwater intrusions in brackish ponds have been reported to kill the eggs. Parasitic infestations of smelt populations have resulted in debilitation, mortality, and decreases in fecundity. Historical declines in smelt populations have been linked to industrial pollution, loss of estuarine habitats such as eelgrass beds, and blockage of migration routes by dams (Bigelow and Schroeder 1953; Scott and Crossman 1973; Buckley 1989).

Rose (1993) examined data from the LRS sampling from 1974-1990 to determine if rainbow smelt were declining in abundance in the Hudson River. He concluded that the larval data did not support such a hypothesis, rather postlarvae abundance over time showed highly variable patterns both temporally and spatially. Although the smelt were not evenly distributed in the river, there was no apparent overall decline in abundance. Rose postulated that the perceived decline in abundance by the naturalists, biologists, and fisherman that were interviewed during the study may be attributable to a shift in the smelt's spawning

TABLE V-40

ESTIMATES OF RELATIVE ABUNDANCE FOR YOUNG-OF-YEAR (YOY) RAINBOW SMELT

YEAR	FSS CHANNEL INDEX (S.E.)	LRS YOY INDEX (S.E.)
1974		0.02 (0.00)
1975		0.00 (0.00)
1976		0.00 (0.00)
1977		0.01 (0.00)
1978		0.07 (0.01)
1979	0.23 (0.09)	0.02 (0.00)
1980	0.10 (0.09)	0.03 (0.00)
1981	0.00 (0.00)	0.00 (0.00)
1982	0.13 (0.03)	0.00 (0.00)
1983	0.00 (0.00)	0.00 (0.00)
1984	0.42 (0.14)	0.00 (0.00)
1985	0.07 (0.04)	0.00 (0.00)
1986	0.96 (0.07)	0.02 (0.00)
1987	0.12 (0.06)	0.01 (0.00)
1988	0.04 (0.02)	0.05 (0.01)
1989	0.00 (0.00)	0.00 (0.00)
1990	1.14 (0.27)	0.03 (0.00)
1991	0.00 (0.00)	0.01 (0.00)
1992	6.72 (1.84)	0.04 (0.00)
1993	1.19 (0.56)	0.01 (0.00)
1994	0.10 (0.10)	0.01 (0.00)
1995	0.00 (0.00)	0.01 (0.00)
1996	0.00 (0.00)	0.00 (0.00)
1997	0.00 (0.00)	0.00 (0.00)

S.E. - Standard error.

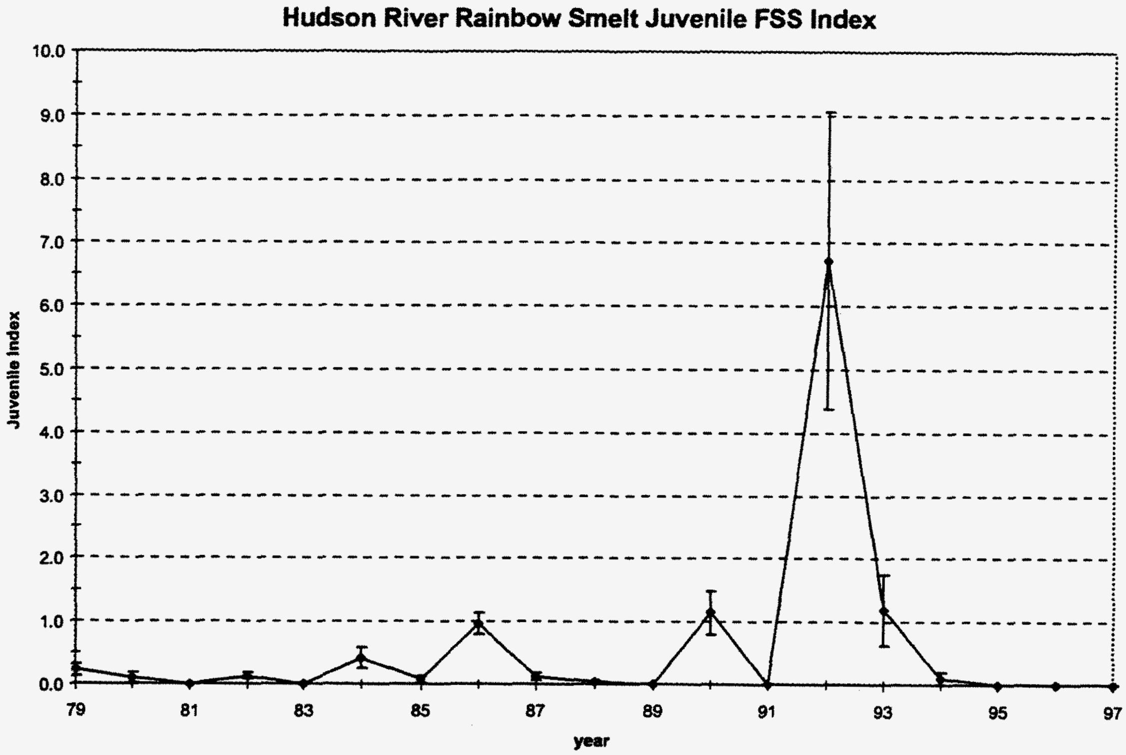


Figure V-99. Rainbow smelt juvenile Fall Shoals Survey index (+/- 1 S.E.).

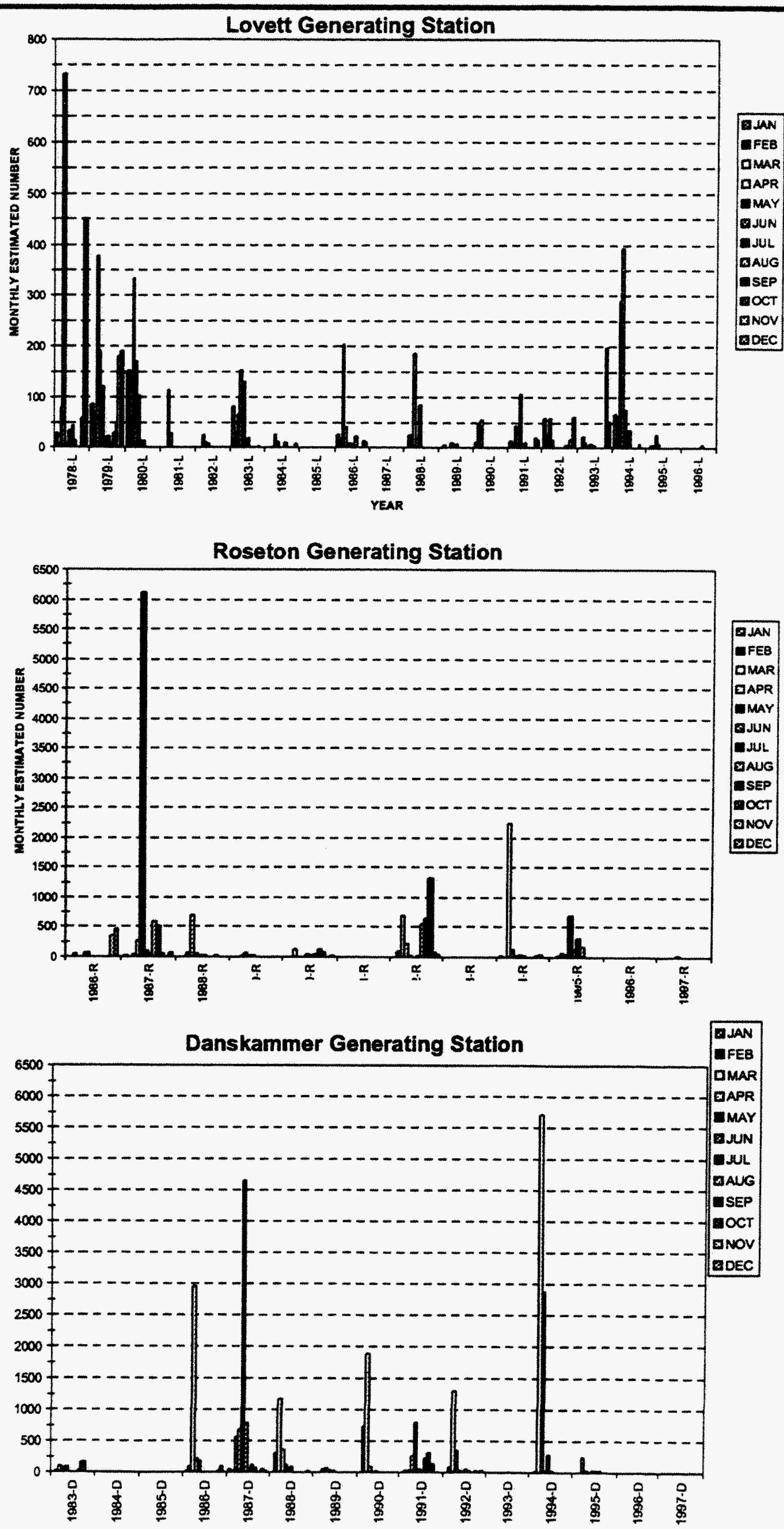


Figure V-100. Monthly estimated impingement rates for rainbow smelt in the Hudson River

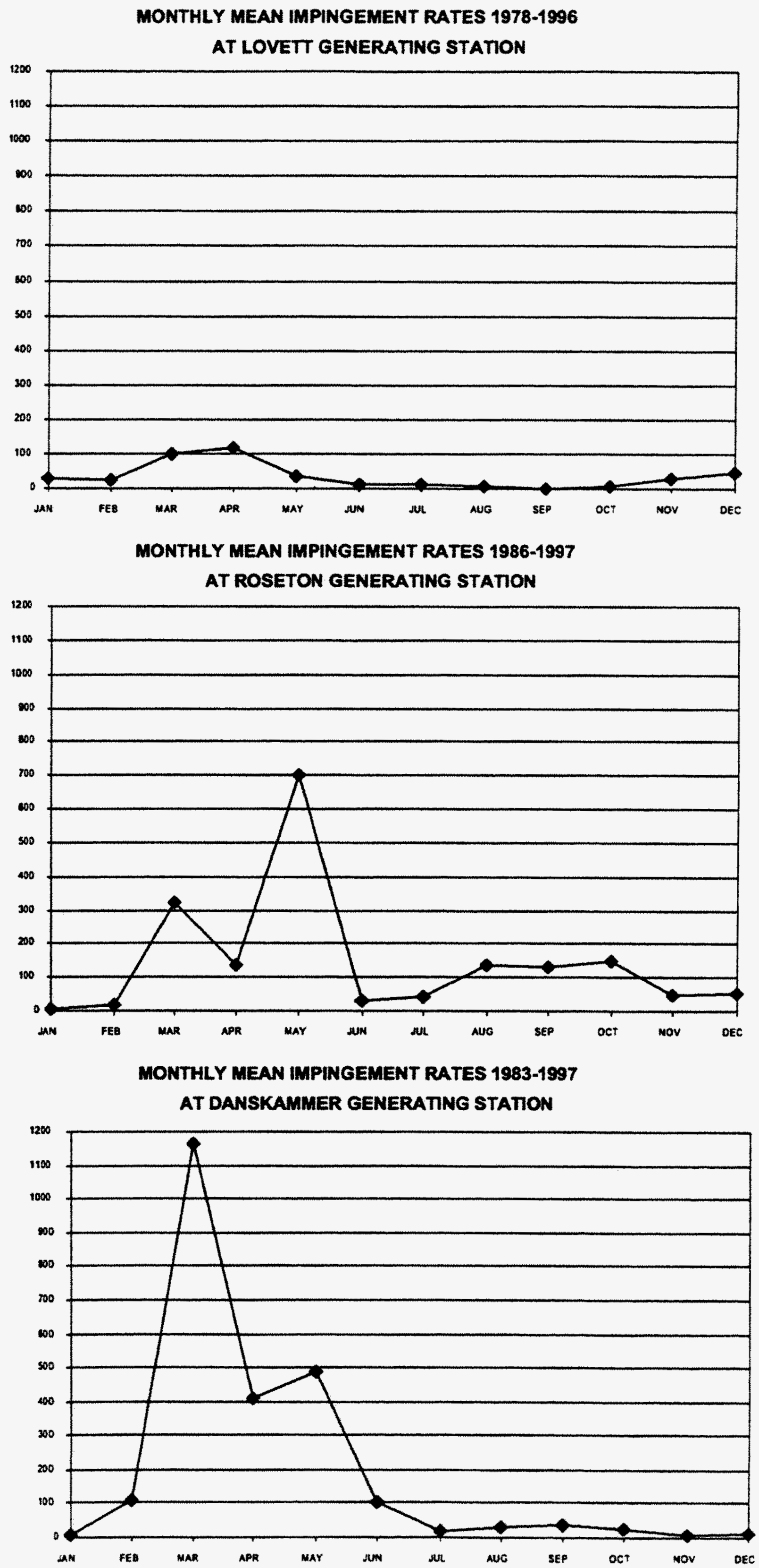


Figure V-101. Average monthly impingement rates over all sampling years for rainbow smelt in the Hudson River behavior from the tributaries to the main river channel in response to the effects of pollution and urbanization. The data from 1991 through 1997 are consistent with this interpretation.

However, YOY abundance decreased after 1993 and the impingement of adult smelt decreased after 1994. The abundance of large striped bass peaked during the spring of 1994. Heavy predation on adult rainbow smelt by large striped during the spring of 1994 (and the following years) may have reduced the adult stock to point where it affected reproductive effort in 1994 and adult abundance after 1994.

Fishing

Historically, there have been commercial fisheries for rainbow smelt in New England, the Great Lakes, and the Finger Lakes of New York (Buckley 1989). There are no recent data on the commercial catch of rainbow smelt specifically from the Hudson River. Recreational catches ranging from less than 30,000 to more than 2 million smelts were reported from the New England region in the National Marine Fisheries Service Marine Recreational Fisheries Statistics Survey (NMFS MRFSS) for the years 1979 through 1982. Thereafter, smelt were pooled in an "other" category. No recreational catches were reported from New York or New Jersey marine or estuarine waters from 1979 through 1997.

Water Withdrawals

Rainbow smelt eggs are entrained at the Hudson River power plants during March and April. However, since rainbow smelt eggs are adhesive when spawned, these free-floating eggs may not represent the eggs that generate the larval population. LRS data (Figure V-98) show that eggs are found in the Hudson River primarily in the Saugerties and Catskill regions, far upstream of the subject power plants. PYSL appear in the entrainment samples during May and early June, and juveniles appear in mid-June as these life stages move downriver (NAI 1987).

m. Gizzard Shad

i. Life History and Distribution Within the Hudson River

The gizzard shad (*Dorosoma cepedianum*) is a freshwater member of the herring family (Clupeidae) that sometimes ranges into brackish water and seawater along the coast. It is an open-water species, usually living at or near the surface, and is found in large rivers, reservoirs, lakes, swamps, bays, borrow pits, bayous, estuaries, temporary floodwater pools along large river courses, sloughs, and similar quiet open waters. The geographic range of the gizzard shad includes the Great Lakes and St. Lawrence River to south-eastern South Dakota and central Minessota, south across MS and Great Lakes drainages to about 40°N latitude on Atlantic coast (Megrey, 1979) (Figure V-102). The northern extent of the range along the Atlantic coast is Sandy Hook, the Hudson River, and Long Island (Smith 1985). Gizzard shad can grow to a length of 19 in., but the usual adult size is 10 - 14 in. and 1 - 3 lb in weight (Miller 1960).

Gizzard shad spawn when the water temperature reaches 50° to 70°F (April to June, depending upon the location). Adults mill near the surface and spawning sometimes takes place in water less than a foot deep. Following release and fertilization, the eggs sink slowly and adhere to the bottom. Eggs are less than 0.0625 in. in diameter and the number of eggs produced by adult females ranges from 59,000 (Smith 1985; Scott and Crossman, 1973) to 686,000 eggs (Jons and Miranda, 1997). Michaletz (1998) reported that fecundity was highly variable among similar sized fish, but did appear to increase with body size. Average diameter of mature eggs was reported as 0.03 in. Hatching occurs in one and a half to seven days, depending upon water temperature (Smith 1985; Scott and Crossman 1973).

Gizzard shad larvae are generally pelagic and widely distributed in many types of habitat, though Turner et al., (1994) found them to be more abundant in slough and low flow tributary habitats, as well as floodplain areas. Gizzard shad larvae begin eating by the fifth day after hatching and feed on microzooplankton until they are about 1 in. long. Shepherd and Mills (1996) reported age 0 gizzard shad consume daphnids, small cladocerans, adult copepod, copepod nauplii, rotifers, algae and detritus. After the fifth day the digestive system begins to change and the young shad become herbivorous and eat phytoplankton, algae, and microscopic bottom plants (Scott and Crossman 1973). Adult gizzard shad often feed on detritus grazed from bottom sediments when live food is unavailable. Gizzard shad are capable of processing sediment to concentrate detritus before ingesting it (Mundahl 1991).

Growth during the first five or six weeks is typically rapid, but then slows. By the end of the first summer, gizzard shad are generally between 4 and 10 in. long. Young gizzard shad tend to school and prefer clear, slow-moving water. They sometimes move into small streams and can tolerate high turbidity (Smith 1985; Scott and Crossman 1973).

Gizzard shad typically mature at age 2 or 3, and the life span is about seven years in northern populations and less in southern ones. In estuarine populations gizzard shad move into waters of higher salinities as they age; spring spawning runs have been reported in some instances (Miller 1960). Young gizzard shad are eaten by most predatory fish, but adults are generally too large to be eaten easily.

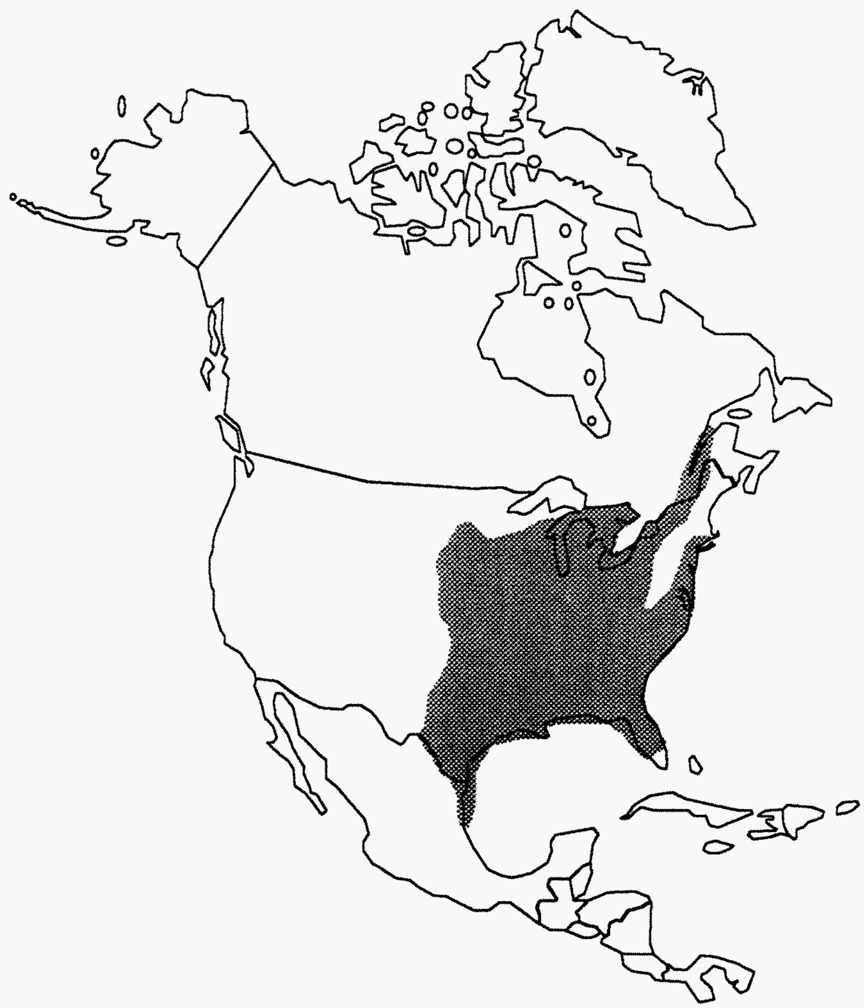


Figure V-102. Native distribution of gizzard shad in North America.

It is currently known that a spawning population exists in the Mohawk River, but of the low catches of gizzard shad in the utility sampling programs do not indicate that there is a spawning population in the Hudson River. The early life stages of this species have been caught only occasionally in the utilities' sponsored Hudson River surveys. However, the presence of these fish in the vicinity of the Roseton Units 1 and 2 Generating Station suggests the possibility that there is a spawning population of gizzard shad in the Hudson River. Length-frequency data for gizzard shad at Roseton Units 1 and 2 Generating Station in 1995 show approximately 75 gizzard shad sized in the range of 2-4 in. impinged during the months of July and August. With the exception of one other gizzard shad in the size range of 15.4-15.7 in., no other gizzard shad were impinged during this time period. The fish impinged represent young developing gizzard shad that were spawned in the spring. Adult fish observed in winter impingement collections may be emigrants from the established populations in the Mohawk River (Smith, 1985) or may be from a small resident population in the lower Hudson.

ii. Temporal Changes in Abundance

Abundance Indices

No index of abundance could be developed for gizzard shad from the field sampling programs because of the low capture rates in these programs. One potentially useful index of abundance for gizzard shad exists in the form of weekly impingement estimates from Danskammer, Roseton Units 1 and 2 and Lovett Generating Stations. These data are an estimate of the number of gizzard shad impinged at the plant and can be used to generate annual numbers of fish impinged as well as seasonal distribution patterns.

Impingement estimates are available for gizzard shad from 1980 though 1997, depending on the station. Annual impingement of gizzard shad at Danskammer and Roseton Units 1 and 2 Generating Stations shows a potential increasing trend over the time period from 1988 through 1997. Before 1988, no trend in impingement estimates was observed. For 1993, no data was available for Danskammer and Roseton Units 1 and 2 stations. When this is taken into consideration, the impingement numbers appear to be fluctuating yearly, but with an overall upward trend (Figure V-103). Annual impingement at Lovett is also fluctuating yearly, and showing no signs of either an increasing or decreasing trend through 1996.

Monthly estimates of gizzard shad impingement at all three stations indicate peak adult impingement during the winter months, though Danskammer and Roseton Units 1 and 2 show a smaller summer peak composed of young-of-the-year (Figure V-104). This may be reflect young gizzard shad that have been impinged.

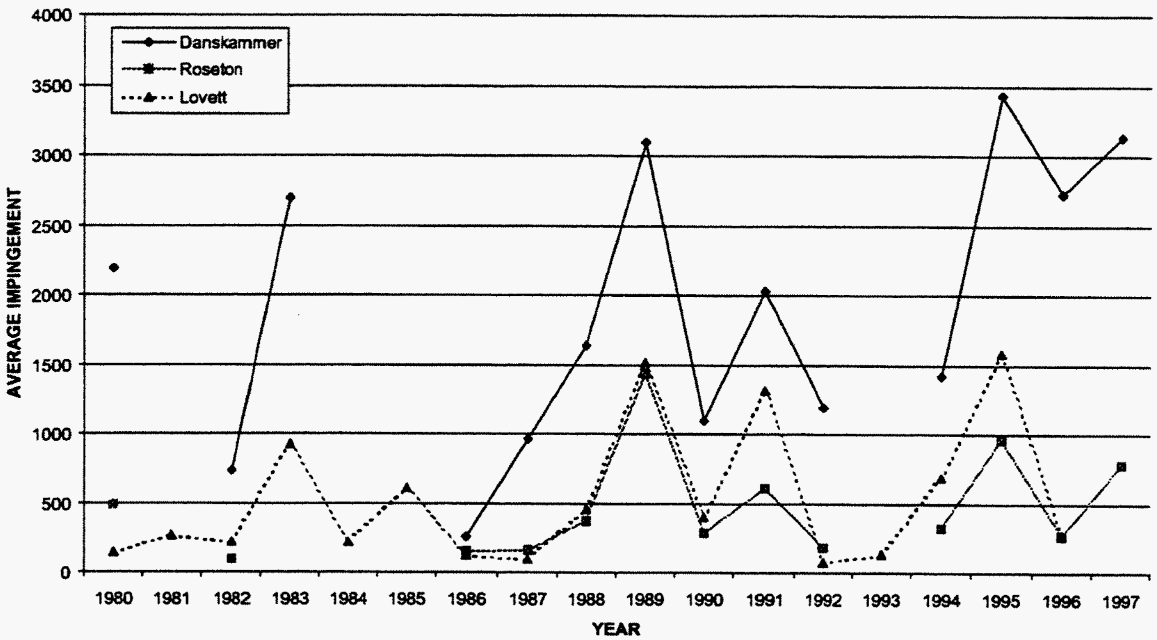


Figure V-103. Average annual impingement of gizzard shad at Danskammer, Roseton, and Lovett generating stations.

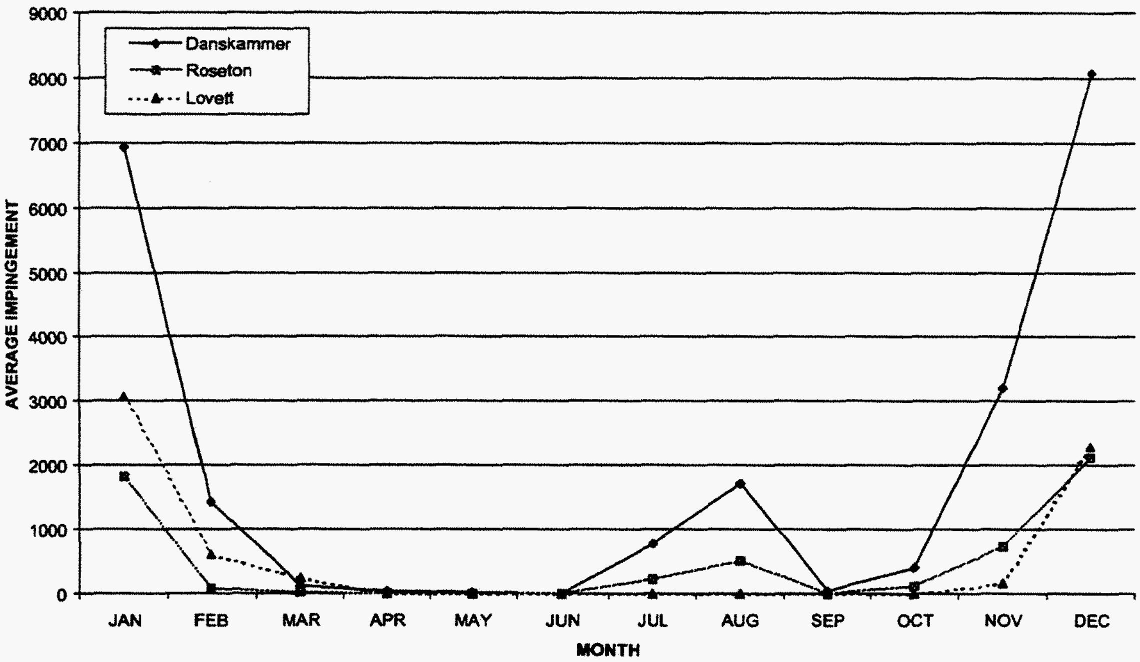


Figure V-104. Average monthly impingement of gizzard shad at Danskammer, Roseton, and Lovett generating stations.

iii. Potential Influences on Abundance

Ecological Factors

Gizzard shad feed on planktonic algae, which they filter out of the water with their fine gill rakers. Phytoplankton production represents a small component of the basic carbon flows within the Hudson River below the Troy Dam (Lints et al. 1992), which may explain why gizzard shad are not abundant in the lower Hudson River.

Larval gizzard shad are typically not important prey species due to their small size. Once they begin to grow, their importance as a prey species increases. Because of the fast rate of growth of the gizzard shad, age 0 gizzard shad are popular prey items. Striped bass largemouth bass, white crappie, black crappie and white bass and spotted bass were reported as predators of age 0 gizzard shad (Michaletz, 1997; Dettmers et al., 1998).

Fishing

There is no commercial or sport fishery for gizzard shad in the Hudson River.

Water Withdrawals

Established populations of gizzard shad are located above the Troy Dam. Young gizzard shad should generally be located in the upper estuary, away from all but the Albany generating station. The fact that gizzard shad larvae were only collected from the lower Hudson occasionally during the Utility sampling programs suggests that the resident gizzard shad in the lower Hudson to the extent that there is a resident population, spawn in shallow areas with little current. Otherwise, the larvae would be carried out into the areas sampled during the ichtyoplankton surveys. The rarity of small gizzard shad in the Utility ichthyoplankton catches suggests that the probability of entrainment for these life stages is also low. The rarity of juvenile gizzard shad in the beach seine catches suggests that either larval survival is low or the juveniles remain in the shallow, more heavily vegetated regions of the river. Sub-adult and adult gizzard shad are impinged during the winter at the Hudson River power plants and this may arise from an attraction to the warm water discharges when river temperatures are low.

n. Spottail Shiner

i. Life History and Distribution Within the Hudson River

The spottail shiner (*Notropis hudsonius*) is a small, silvery, freshwater minnow (family Cyprinidae) that reaches a maximum total length of over 5 in. in the Hudson River. It is usually recognizable by a large oval spot at the base of the tail, but in large individuals, the spot is sometimes small and masked by silvery pigment. It occurs in a variety of freshwater habitats from large lakes and rivers to small streams and is widely distributed in Canada and the United States (Smith 1985) (Figure V-105). Since the spottail shiner is primarily a freshwater species and does not enter marine coastal waters, the Hudson River population is probably isolated from those in other coastal rivers along the Atlantic Coast of the United States.

Adult spottail shiners may form large spawning aggregations over sand or gravel substrates in shallow water or at the mouths of tributaries (Scott and Crossman 1973). In the Hudson River, adult spottail shiners appear in the ichthyoplankton samples from the upper, freshwater regions of the estuary during May (Figures V-106 and V-107). Spottail shiners produce from 100 to 2,600 eggs, depending upon the age and size of the female (Smith 1985). Very few eggs and larvae have been collected during the Long River Surveys, which probably reflects the fact that this species spawns in shallow-water habitats that are not sampled efficiently during the ichthyoplankton surveys. Juvenile spottail shiners first appear during early July and are most abundant in the shore zone above RM 86, which is also the portion of the estuary with the greatest number of tributaries (Figures V-106 and V-107).

In general, spottail shiners are opportunistic predators that feed on aquatic insect larvae, zooplankton, benthic invertebrates, and the eggs and larvae of fish, including their own species. The smaller fish eat the smaller organisms and zooplankton (Scott and Crossman 1973). Johnson and Dropkin (1993) examined the diel feeding habits of spottail shiners in the Juniata River, PA, and found that chironomids dominated their diet (100%) at 0400 hrs, potamanthids were the major food item (100%) at 0800 hrs, algae was the primary food source (75-100%) from 1200 to 2000 hrs, and chironomids and algae were equally consumed at 2400 hrs. Peak feeding occurred between 2000 and 2400 hrs, thus making algae and chironomids the most important food of spottail shiners.

ii. Temporal Changes in Abundance

Abundance indices for juvenile spottail shiners (weighted mean densities per seine haul) were generated from the Hudson River Beach Seine Survey catches (Table V-41).

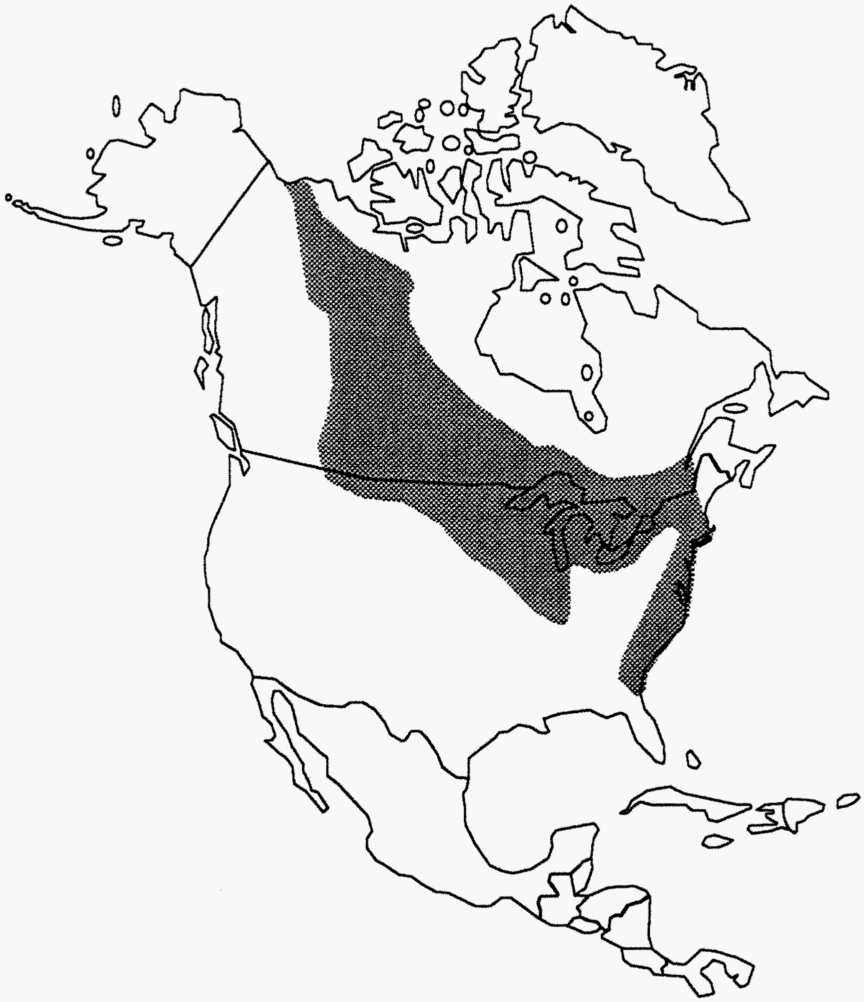


Figure V-105. Distribution of spottail shiner in North America.

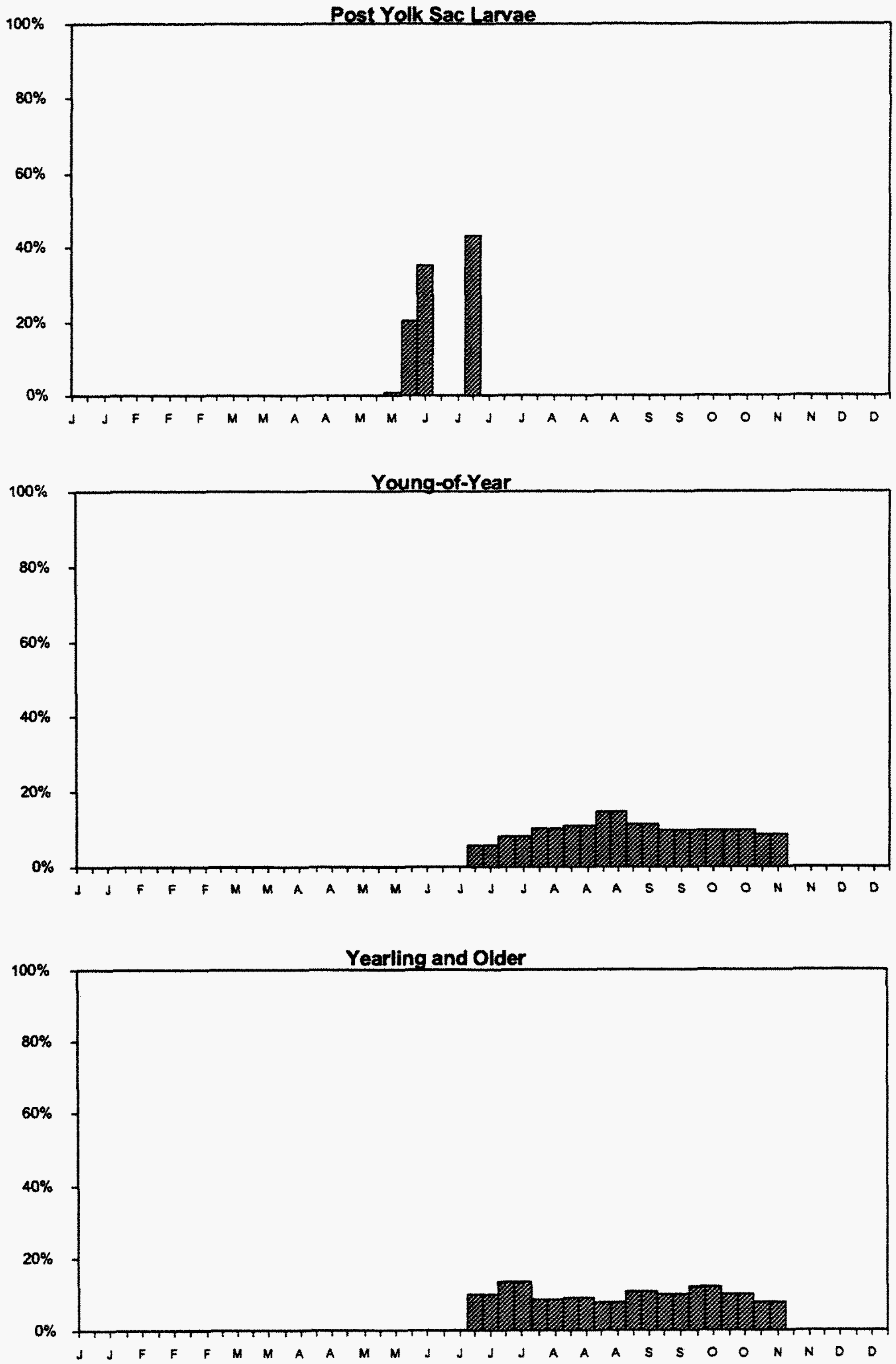


Figure V-106. Temporal distribution indices for spottail shiner post yolk sac larvae collected during Long River surveys and young-of-year and yearling and older collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

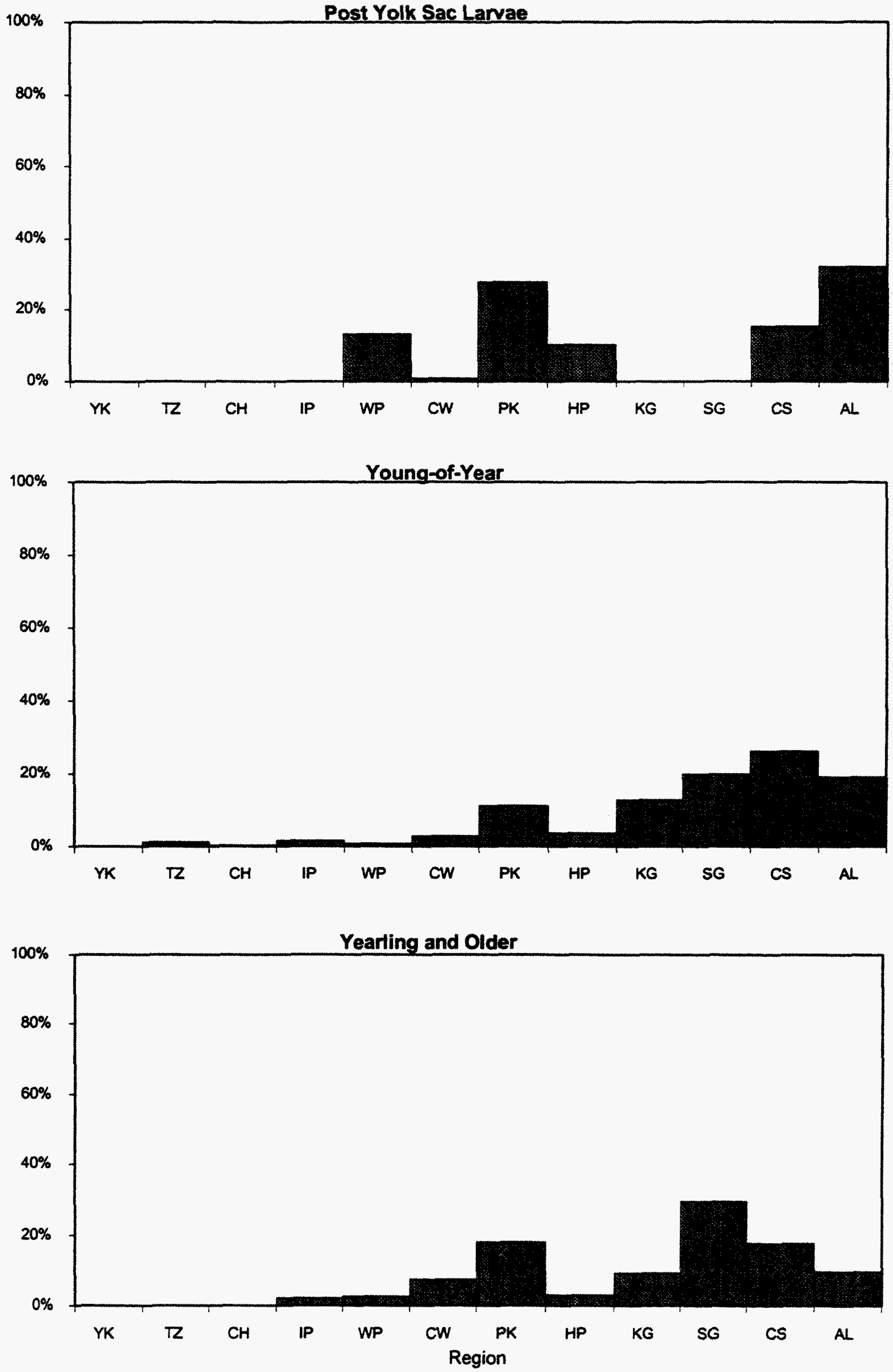


Figure V-107. Spatial distribution indices for spottail shiner post yolk sac larvae collected during Long River surveys and young-of-year and yearling and older collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

TABLE V-41

ESTIMATES OF RELATIVE AND ABSOLUTE ABUNDANCE OF SPOTTAIL SHINER

YEAR	BSS YOY INDEX (S.E.)	[illegible]
1974	6.41 (1.42)	
1975	13.65 (3.19)	
1976	9.21 (1.45)	
1977	4.86 (1.11)	
1978	12.23 (1.72)	
1979	8.56 (1.35)	
1980	6.79 (1.28)	
1981	19.13 (3.98)	
1982	4.99 (0.82)	
1983	11.89 (3.01)	
1984	8.20 (1.94)	
1985	4.92 (0.78)	
1986	4.63 (1.16)	
1987	5.87 (1.40)	
1988	4.66 (0.72)	
1989	6.63 (1.47)	
1990	9.10 (1.51)	
1991	11.22 (1.88)	
1992	6.99 (1.07)	
1993	6.38 (0.80)	
1994	14.68 (2.02)	
1995	4.88 (0.70)	
1996	1.68 (0.63)	
1997	11.88 (1.74)	

S.E. - Standard error.

Abundance were quite variable among years and the overall trend (-2% per year) was not statistically significant (Figure V-108).

iii. Potential Influences on Abundance

Ecological Factors

The abundance of spottail shiner was low during the 1980s (Figure V-108) when the abundance of PYSL white perch was high. There may have been competition between these two species during this period. The increase in the abundance of PYSL striped bass does not appear to have affected spottail shiners

Hankin and Schmidt (1992) found that fish species composition was very different between water-celery (*Vallisneria americana*) and water-chestnut (*Trapa natans*) beds in the tidal Hudson River. The increase in abundance of carp (*Cyprinus carpio*) and the decrease in spottail shiners may signal significant changes that the expansion of water-chestnut has caused in the Hudson River fish community. However, Schmidt et al. (1992) reported that water-chestnut beds in the Hudson River are important spawning habitat for spottails. A light trap study indicated that water chestnut beds (Tivoli Bays area, RM 100) contained more larvae than those of water-celery or watermilfoil (*Myriophyllum spicatum*).

Fishing

There is no commercial or sport fishery for this species, although they are collected for use as bait. In 1992, the estimated total volume and value of baitfish shiners sold by retail dealers in the north-central region of the U.S. was approximately 98,000 gallons and $13.9 million, respectively, making it the second largest baitfish. Spottail shiners are sold as bait along with emerald shiners (*N. atherinoides*) and sand shiners (*N. stramineus*) in a collective group called "Lake shiners" (Meronek et al. 1997).

Water Withdrawals

The spottail shiner population is entrained and impinged at the various water intakes on the Hudson River. (Entrainment and impingement effects were estimated as described in Appendices VI-1 and VI-2.) Riverwide, from 1974 through 1997, entrainment at these facilities may have reduced the number of early juveniles produced each year from about 10% in 1995 to about 25% in 1977; impingement of juvenile and older fish may have further reduced the number of survivors from each year class from less than 1% in 1990-1995 and 1993 to about 0.8% in 1987 (Table V-42).

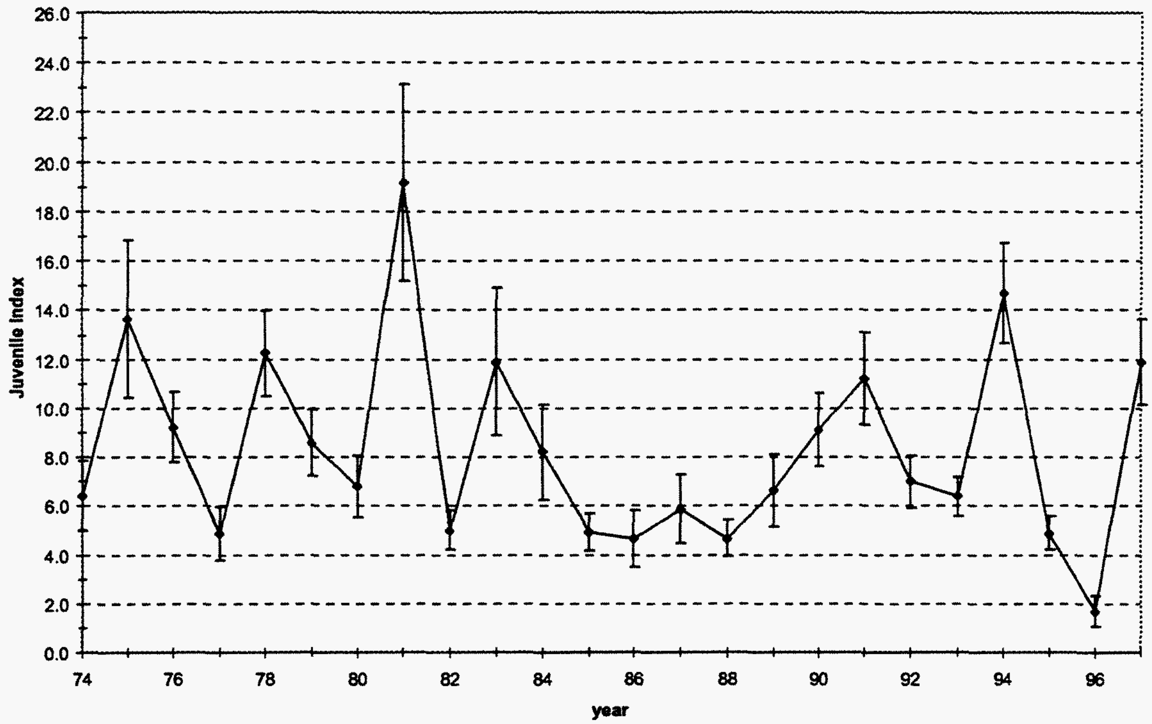


Figure V-108. Spottail shiner juvenile beach seine survey index (+/- 1 S.E.)

TABLE V-42

ENTRAINMENT (E), IMPINGEMENT (I), AND CUMULATIVE TOTAL (T) EFFECTS OF WITHDRAWAL FACILITIES ON SPOTTAIL SHINER. TABLED VALUES REPRESENT CONDITIONAL MORTALITY RATES EXPRESSED IN %.

YEAR		BOWLINE POINT	INDIAN POINT	ROSETON	DANSKAMMER[A]	LOVETT	EMPIRE STATE PLAZA[B]	ALBANY STEAM STATION[B]	WESTCHESTER RESCO[C]	CUMULATIVE EFFECTS
1974	E	0.49	0.87	0.22	0.66	0.24	3.32	5.75		11.12
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									11.30
1975	E	0.56	1.04	0.65	1.32	0.27	5.98	10.14		18.71
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									18.87
1976	E	1.17	1.38	1.14	1.03	0.38	3.04	5.48		12.94
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									13.11
1977	E	0.43	1.41	0.59	1.00	0.18	8.80	14.91		25.16
	I	0.00	0.10	0.02	0.08	0.00				*0.20*
	T									25.31
1978	E	0.79	2.32	0.73	1.14	0.47	5.87	10.01		19.82
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									19.98
1979	E	0.64	1.62	1.45	1.66	0.40	3.74	6.51		15.09
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									15.26
1980	E	0.23	1.66	1.06	2.26	0.30	4.59	7.96		16.93
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									17.10
1981	E	0.36	3.43	0.88	1.06	0.46	2.00	5.39		12.91
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									13.08
1982	E	0.60	2.06	0.91	1.07	0.36	3.96	6.68		14.78
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									14.95
1983	E	0.43	3.17	1.70	1.24	1.37	4.72	8.11		19.17
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									19.34
1984	E	0.55	1.58	0.79	1.00	0.19	5.25	9.35	0.28	17.82
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									17.98
1985	E	0.35	1.77	0.92	1.15	0.41	5.41	6.48	0.36	15.84
	I	0.00	0.20	0.00	0.40	0.00				0.60
	T									16.35
1986	E	0.42	1.55	1.44	1.91	0.34	3.69	4.69	0.40	13.64
	I	0.00	0.10	0.00	0.10	0.00				0.20
	T									13.81
1987	E	0.43	1.53	1.39	1.06	0.16	6.22	8.42	0.28	18.21
	I	0.00	0.70	0.00	0.10	0.00				0.80
	T									18.86
1988	E	0.39	4.10	1.30	2.66	0.52	5.43	7.57	0.29	20.43
	I	0.00	0.00	0.10	0.20	0.00				0.30
	T									20.66
1989	E	0.70	8.32	0.93	1.73	0.76	4.12	7.12	0.35	21.94
	I	0.00	0.10	0.00	0.00	0.00				0.10
	T									22.02
1990	E	0.46	2.18	1.07	2.06	0.26	4.79	7.61	0.30	17.48
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									17.48
1991	E	0.62	3.92	1.14	3.06	2.66	3.46	8.57	0.45	21.73
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									21.73
1992	E	0.31	0.99	1.09	0.48	0.24	2.15	6.35	0.30	11.45
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									11.45
1993	E	0.32	0.89	0.83	0.64	0.56	2.82	4.94	0.28	10.83
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									10.83
1994	E	0.36	1.10	1.20	0.75	0.38	3.96	5.18	0.27	12.57
	I	0.00	0.00	0.00	0.00	0.00				0.00
	T									12.57
1995	E	0.27	2.54	0.86	0.56	0.28	2.90	2.78	0.19	9.97
	I	0.00	0.00	0.10	0.10	0.00				0.20
	T									10.15
1996	E	0.20	1.89	0.59	0.56	0.48	4.34	2.85	0.34	10.78
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									10.96
1997	E	0.29	0.64	1.02	0.62	0.33	4.69	3.17	0.34	10.66
	I	*0.00*	*0.10*	*0.02*	*0.08*	*0.00*				*0.20*
	T									10.84
AVERAGE	E	0.47	2.17	1.00	1.28	0.50	4.39	6.92	0.32	15.83
	I	0.00	0.10	0.02	0.08	0.00				0.20

NOTE: Chelsea Pumping Station and 59th Street Generating Station did not have substantial withdrawals during this period; data necessary for estimating entrainment and impingement effects of World Trade Center, and for estimating impingement effects of Empire State Plaza and RESCO, were not available. When data were unavailable for other facilities, the average values for the years when data were evaluated, indicated by italics, were substituted.

[A] Withdrawal factor estimates for Danskammer are unusually large and may be causing entrainment conditional mortality rates to be biased high.

[B] Entrainment mortality estimates for Empire State Plaza (MP 144) and Albany Steam Station (MP 142) are biased high. A high rate of freshwater flow, averaging 20,000 cfs in May and 10,000 cfs in June, makes passively drifting organisms below MP 140 unavailable to entrainment; only a small fraction of such organisms above MP 140, essentially the ratio of plant flow (<900 cfs) to riverflow, will be vulnerable to entrainment.

[C] RESCO began operations in 1984.

Sources: Entrainment-Appendix VI-1-B, Table X-21f; Impingement-Appendix VI-2-B, Table 20

o. White Catfish

i. Life History and Distribution Within the Hudson River

The white catfish (*Ictalurus catus*) is a moderate-sized member of the catfish family Ictaluridae with a forked tail, depressed head, and dorsal spine with serrae (Smith 1985). In southern waters young white catfish are about 3 in. long at the end of the first growing season. White catfish generally do not mature until they are three to four years old and 7 to 8 in. long. They continue to grow slowly, attaining lengths of 17 in. at age 8 and 22 in. at age 11. This species seldom exceeds 3 lbs in weight. Schaffter and Kohlhorst (1997) found average annual mortality ranged from 0.32 to 0.36 to 0.44 for white catfish less than 7.4 in., between 7.5 to 8.5 in. and greater than 8.5 in., respectively, for the Sacramento-San Joaquin Delta in California.

White catfish occur in freshwater lakes and ponds and have been introduced widely on the west coast and into the Northeast (Smith 1985). The natural distribution was originally from the Chesapeake Bay region in coastal streams southward to Texas (Figure V-109). However, other authors consider it's native range from the lower Hudson river drainage to the Pascagoula River, Mississippi (Lee et al. 1980, Page and Burr 1991). It is found in estuaries all along the Atlantic coast from the Hudson River to Florida and west along the Gulf of Mexico to Mobile Bay. White catfish prefer fresh and slightly brackish waters and moderate water currents and are found in river channels and streams with sluggish currents (Boyer, 1995, Cooper, 1983), and have a preference for estuarine waters (Smith, 1985). White catfish do not tolerate high salinity, so estuarine populations generally remain in their natal systems. They have been found in salinities as high as 8 ppt (Markle, 1976).

White catfish move upstream to spawn with Cooper (1983) indicating that they do not migrate far prior to spawning. In spring white catfish have been reported in tidal creeks and shallow marsh habitats (Smith 1985). Like the other members of the catfish family, the white catfish is a nest builder. Both parents participate in the construction of a nest up to 3 ft in diameter on sand and gravel bars (Smith 1985). Spawning occurs when water temperatures reach about 70°F, i.e., in late June and early July in the Hudson River. An 11- to 12-in. female carries 3200 to 3500 eggs, that are approximately 0.25 in. in diameter. The male (or less often both parents) protects and fans water over the eggs in the nest. The young are also guarded, usually by the male, for a short period after hatching (Cooper 1983).

White catfish eggs, larvae, and early juveniles were infrequently collected during the utilities' ichthyoplankton surveys; however, the PYSL that were collected indicated that spawning is more prevalent in the upper regions of the estuary (Figure V-110). Yearling and older catfish were collected throughout the estuary during the summer months (Figures

Figure V-109. Native distribution of white catfish in North America.

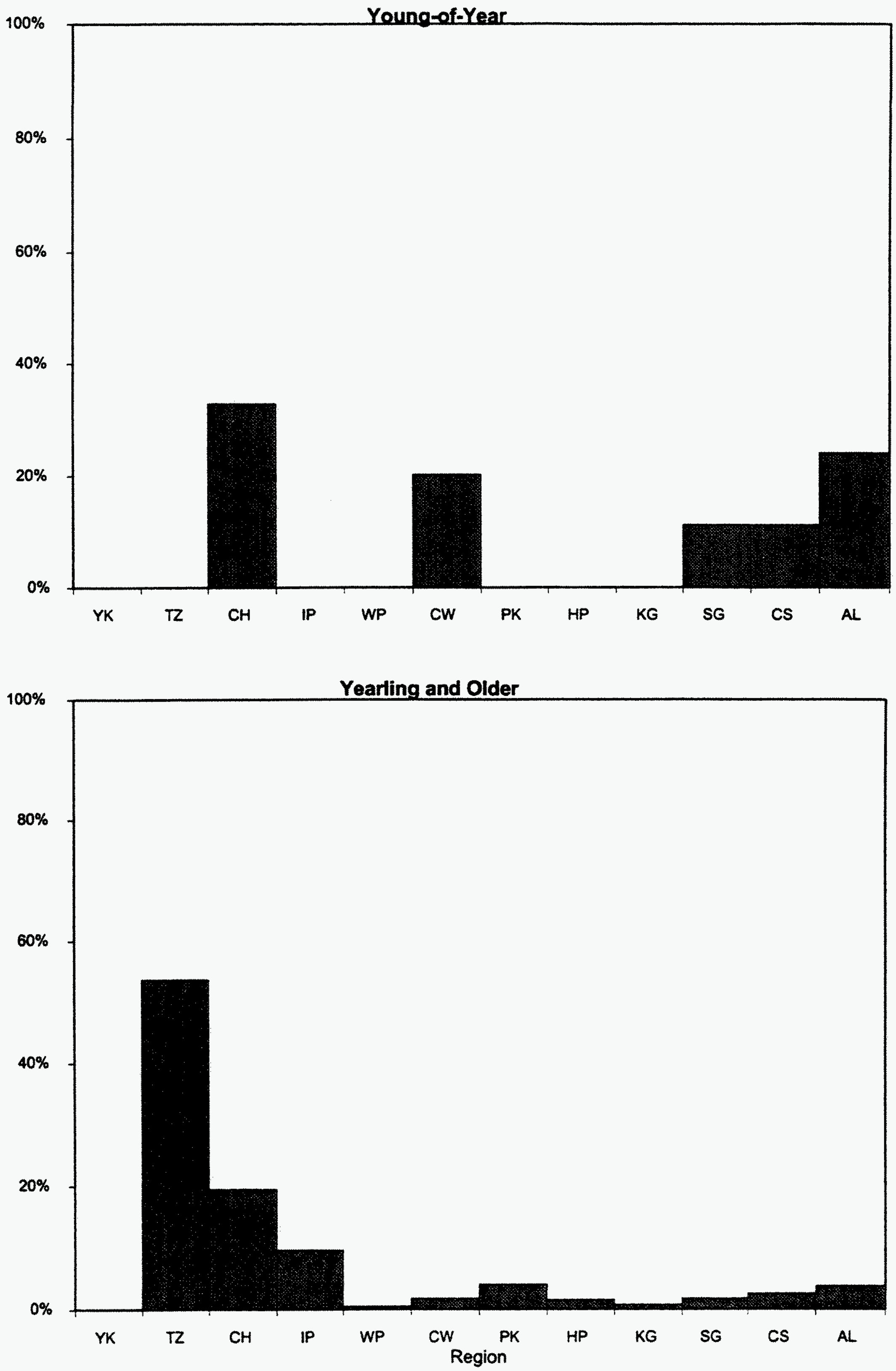


Figure V-110. Spatial distribution indices for white catfish collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

V-110, V-111). After moving into the deeper river strata during September and October, yearling and older white catfish migrate downstream to overwinter in the lower estuary when temperatures in the upper estuary drop below 59°F (NAI 1985).

Small white catfish feed on midge larvae and macro-invertebrates. Larger white catfish have a diverse diet that includes midge larvae, crustaceans, algae, fish eggs, and a variety of fish (Smith 1985). Turner (1966) found amphipods were consumed by almost 94% of the young white catfish examined and made up about 80% of the volume of foods eaten. They were followed by mysid shrimp that were consumed by over 21% of the young white catfish examined and made up almost 13% by volume of foods eaten. These species were common food items in all seasons in the Sacramento-San Joaquin Delta in California. Older white catfish consumed a high volume of fish over 47.6%, however, amphipods continued to make up a high percentage (17.3) by volume followed by crayfish (10.5%), clams (6.1%), and mysid shrimp (4.8%).

ii. Temporal Changes in Abundance

Sampling Programs

White catfish eggs and larvae are seldom collected by any of the standard Hudson River ichthyoplankton sampling programs because spawning and early development occurs in nests in shallow water. Juvenile, yearling, and older white catfish appeared in low abundance in bottom stratum samples of the Fall Shoals Survey, but the change in gear in 1985 prevented use of this data set for addressing long-term trends. The best available index to assess relative abundance for white catfish is the average catch per haul of yearling and older fish (Table V-43) from the utility (BSS) and NYSDEC (JSB) beach seine surveys.

Abundance Indices

From 1974-1989, the average index of white catfish abundance was 0.044. The highest index value occurred in 1989 and was followed by much lower index values (Figure V-112). The average from 1990 through 1997 was 0.010.

From 1980 through 1989, the average index of white catfish abundance from the JSB survey was 0.15 and the coefficient of variation was 143.8. The average from 1990 through 1997 was 0.02 and the coefficient of variation was 57.0.

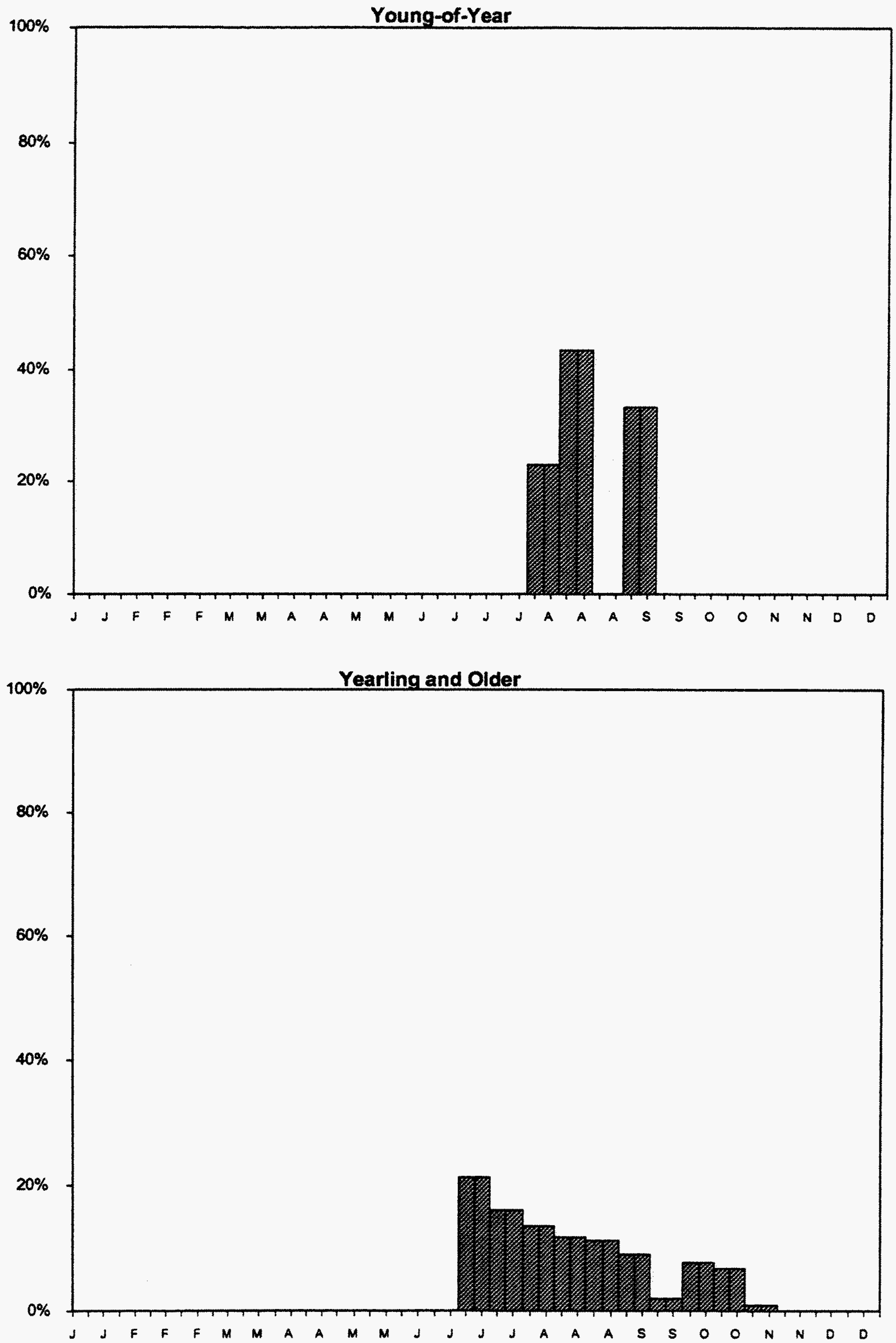


Figure V-111. Temporal distribution indices for white catfish collected during Beach Seine surveys of the Hudson River estuary, 1991-1997.

TABLE V-43

ESTIMATES OF RELATIVE ABUNDANCE OF WHITE CATFISH

YEAR	BSS YEARLING AND OLDER INDEX (S.E.)	JSB CATCH/EFFORT (TOTAL CATCH)
1974	0.03 (0.02)	
1975	0.02 (0.01)	
1976	0.03 (0.01)	
1977	0.07 (0.02)	
1978	0.07 (0.03)	
1979	0.05 (0.03)	
1980	0.02 (0.01)	0.05 (8)
1981	0.05 (0.03)	0.06 (8)
1982	0.05 (0.03)	0.16 (23[a])
1983	0.06 (0.04)	0.77 (114)
1984	0.02 (0.01)	0.09 (13)
1985	0.01 (0.00)	0.02 (3)
1986	0.03 (0.01)	0.05 (8)
1987	0.03 (0.02)	0.15 (22)
1988	0.05 (0.02)	0.06 (9)
1989	0.12 (0.06)	0.13 (20)
1990	0.01 (0.00)	0.04 (6)
1991	0.02 (0.01)	0.04 (6)
1992	0.00 (0.00)	0.02 (3)
1993	0.01 (0.01)	0.03 (4)
1994	0.00 (0.00)	0.01 (1)
1995	0.01 (0.01)	0.02 (3)
1996	0.03 (0.02)	0.01 (2)
1997	0.00 (0.00)	0.01 (2)

S.E. - Standard error.
[a]Some samples were not completely enumerated.

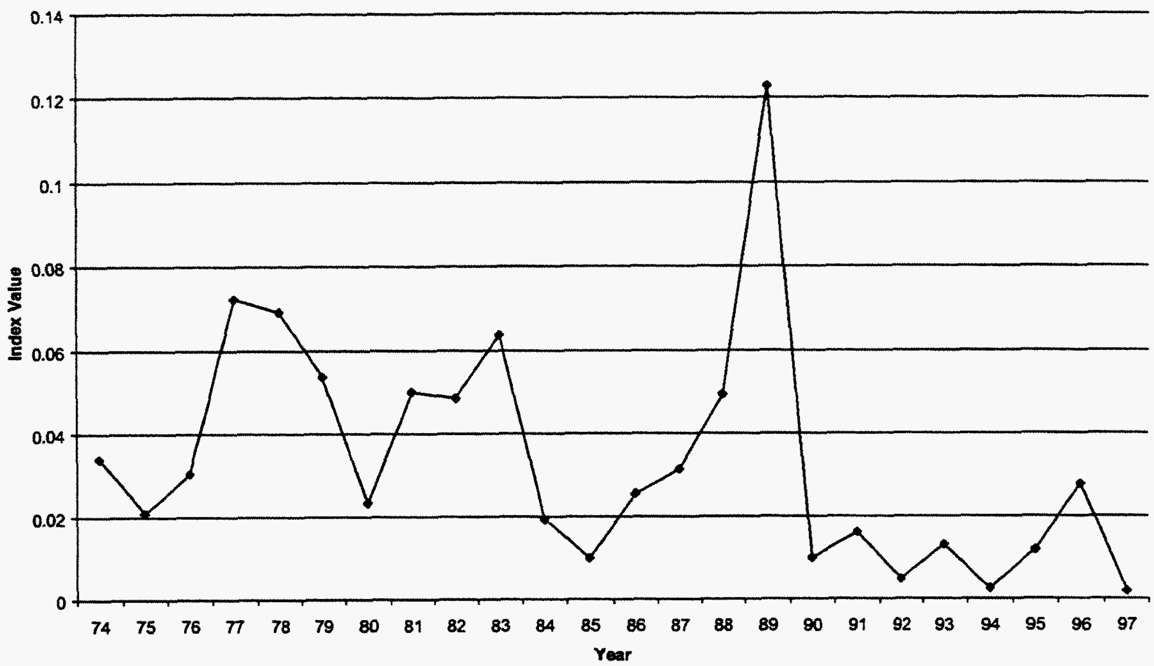


Figure V-112. White catfish FSS bottom juvenile index.

iii. Potential Influences on Abundance

Ecological Factors

Competition

The timing of the decrease in the abundance of white catfish closely coincided with the increase in the abundance of PYSL striped bass. Because of the reproductive behavior of white catfish, direct interactions between the larval or YOY white catfish and striped bass are not likely. Therefore, if the decrease in the abundance of white catfish is causally related to the increase in the abundance of PYSL striped bass, the mechanism may involve resource depletion (caused by the PYSL and YOY striped bass) and food limited growth and survival among larval and YOY white catfish.

Fishing

There is some recreational fishing for white catfish in the Hudson River. It occurs despite advisories against the consumption of white catfish, issued by DEC (Green and Jackson 1991) because of elevated concentrations of PCBs in the flesh of these fish. The New Jersey Department of Environmental Protection also issued an advisory for limited consumption of white catfish from the northern region of the state, including the lower Hudson River and the Hudson River-Raritan Bay complex (Belton et al. 1983).

Water Withdrawals

White catfish spawn in prepared nests and the early life stages remain near the nest and are guarded by their parents. Because of this spawning strategy, the early life stages are not susceptible to entrainment and have seldom been seen in samples of the cooling water (see Section VI-A). Juveniles and older white catfish are occasionally impinged, but typically in low numbers. At Indian Point Units 2 and 3 white catfish were 0.42% of total fish impinged, but at Roseton Units 1 and 2 and Bowline Point Units 1 and 2 they accounted for <0.01% (see Appendix VI).

p. Blue Crab

i. Life History and Distribution Within the Hudson River

The blue crab (*Callinectes sapidus*) is a decapod crustacean in the family Portunidae (swimming crabs). The blue crab is found in marine and brackish waters from Nova Scotia southward to the northern part of Argentina. In the United States it is abundant from Massachusetts to southern Texas, where it supports major commercial and recreational fisheries. Detailed studies of blue crab life history have not been conducted in the Hudson River (Wilson and Able 1992). However, based on studies from other systems, particularly the Delaware and Chesapeake bays, much of its life history can be inferred.

Blue crabs mate from May through October, while they are in the soft-shell state following their last, or pubertal molt. Spawning occurs in the relatively low-salinity waters of the upper estuary and lower portion of the river (Epifanio et al. 1984). Males may mate several times during their last three intermolts (Van Engel, 1958). Sperm is stored up to one year by the female and may be used to fertilize up to three broods (Stewart 1996, Van Engel, 1958, Epifanio et al. 1984). Ordinarily, females mate only once (Van Engel, 1958; Williams, 1974).

After mating in fresher water of estuaries, females migrate to the higher-salinity areas (20-32 ppt) of lower estuaries, sounds, and nearshore areas where they overwinter by burrowing into the mud. Higher-salinity waters have been found to be favorable for larval development (Millikin and Williams, 1984; McClintock et al., 1993). This migrational pattern has been observed in many geographical regions, including Delaware Bay (Cronin, 1954) and Chesapeake Bay (Van Engel, 1958; Hines et al., 1995).

The following summer, females extrude their fertilized eggs into a cohesive mass or "sponge" attached to the abdominal appendages. A sponge may contain as many as 700,000 to 2 million eggs (Willams 1965). Recent studies in the Chesapeake Bay have found females carrying 3 to nearly 8 million eggs (Prager et al. 1990).

Eggs remain attached to the female from the time of extrusion to the time of hatching. After a seven- to 14-day incubation period, the eggs hatch into a swimming larva called a zoea. In the lower Delaware estuary zoeal abundance peaks in early August and again in early September (Epifanio et al. 1984). These larvae molt seven to eight times in 35 days, during optimum conditions, before reaching the next stage, the megalops (Epifanio et al. 1984). The megalop stage lasts from one to two weeks (Sulkins and Van Heukelem 1986). Blue crab zoea are unable to complete development to the megalops stage at salinities below 25 ppt. Peaks in megalops abundance occur about five weeks after the peak zoeal abundance. In the Delaware Bay, strong currents carry the zoeae southward away from the Bay (Garvine 1991) and the larvae develop in open waters of the Continental Shelf.

Movement by zoeae while developing in the ocean has been attributed to both longshore currents and to wind-induced currents (Epifanio and Dittel, 1982). Epifanio et al. (1989) concluded that zoeae are rapidly flushed from Delaware Bay, travel long distances southward in prevailing currents, and then are carried back north by wind-driven surface currents. These scenarios obviously permit intermixing of larvae from different spawning areas and suggest that re-invasion of estuaries by postlarvae is not restricted to those individuals spawned in that estuary. Postlarvae or megalopae were found to be abundant near the surface in the open ocean (McConaugha et al., 1983; Epifanio, 1988; Epifanio et al., 1989) where wind-generated surface currents influence their distribution along the coast.

Migration up the estuary by megalopae is accomplished by selective tidal-stream transport. Typically, megalopae migrate to vegetation beds (if available). The megalops stage typically lasts from six to 20 days, after which the larvae molt into the "first crab" stage and begin to move upriver. The juvenile first crab, while only approximately 0.125 in. wide (from tip to tip of the carapace lateral spines), begins to develop the proportions and appearance of an adult blue crab (Hill et al. 1989).

In the Hudson River juvenile blue crabs are most abundant in August through October, depending on the location. Peak abundance occurred in August at the farthest downriver sites studied by Wilson and Able (1992) - Liberty State Park, Piermont Marsh, and Croton Bay. At upriver sites - Iona Marsh and Moodna Creek - peak abundance did not occur until September. Where present, aquatic vegetation appears to be a favored habitat and may serve to reduce predation on juveniles. Wilson and Able (1992) found that in the Hudson River greatest concentrations of juvenile blue crabs less than 2 in. occurred in sites heavily vegetated with Vallisneria sp. And Potamogeton sp.

Growth and maturation occurs through a series of molts and intermolt phases. Molting and growth ceases during the winter but resumes as the water warms in the spring. Blue crabs generally reach maturity during the spring or summer of the year following the hatching year (Hill et al. 1989). Males continue to molt and grow after they reach sexual maturity while females cease to grow after they mate. The average carapace width at maturity is approximately 7 in. (Churchill 1919). Individual females at maturity may range from 2 to 8 in. while males may reach 8 in. (Williams 1984). Most investigators have reported that blue crabs live from 2.5 to 3.5 years (Van Engel, 1958; Williams, 1965; Havens and McConaugha, 1990). More recent information suggests that they can live for at least 5.5 years (Smith, 1997) and perhaps as long as seven or eight years (Leffler, 1996).

Blue crab zoeae consume phytoplankton, dinoflagellates, and copepod nauplii (Tagatz 1968); megalops feed on fish larvae, small shellfish (including blue crab), and aquatic plants (Van Engel 1958; Darnell 1959; Tagatz 1968). Since much of the early development occurs in offshore coastal waters, the first crab stage imports energy into the estuary. Postlarval blue crabs are considered general scavengers, bottom carnivores, detritivores, and omnivores. The results of numerous studies indicate that adult blue crabs are mainly predators, not scavengers. The blue crab is an exceptionally capable predator in tidal marshes (Kneib 1982). They were found to be potentially important aquatic predators on fishes in confined habitats. Their diet is dominated by mollusks and other blue crabs, however a substantial portion of their diet includes small fish.

In turn, blue crabs are prey to a variety of animals. Larval blue crabs are consumed by fish, shellfish, jellyfish, comb jellies, and a variety of other planktivores; juvenile and adult blue crabs are preyed on by a wide variety of fish, birds, and mammals. In the Hudson juveniles were found in the stomach of striped bass, white perch, banded killifish, weakfish, and hogchoker (Wilson and Able 1992).

ii. Temporal Changes in Abundance

Blue crab sampling has not been part of the river monitoring programs, so historical records for the Hudson River are not available. Impingement sampling for crabs at the Roseton Units 1 and 2, Indian Point Units 2 and 3, and Bowline Point Units 1 and 2 power plants has been fairly regular since 1980; however, no sampling has occurred at Indian Point Units 2 and 3 since 1990 when the Ristroph screens began operation. Due to blue crabs' preference for higher salinity, and the variable intrusion of the salt front into the middle estuary, data from Bowline Point Units 1 and 2 (especially) and Indian Point Units 2 and 3 probably provide a more consistent estimate of abundance than do data from Roseton Units 1 and 2. The estimated impingement rates suggest that prior to about 1988 the numbers of blue crabs in the Hudson River were relatively low (Table V-44). From 1988 through 1997 impingement rates varied substantially, but typically were an order of magnitude or higher than in prior years. Indian Point Units 2 and 3 and Bowline Point Units 1 and 2 data exhibited almost identical abundance patterns (Table V-44).

iii. Potential Influences on Abundance

Ecological Factors

EA (1991) concluded that environmental factors may be important in the recent population increase. Climatological factors immediately preceding spawning and in the first eight months of blue crab life are major factors in establishing the ultimate population size (Van Engel and Harris 1980; Van Engel 1987). Kennish et al. (1982) suggested that the severity of the winter may also influence the survival of the population. The relatively mild winters of recent years may have resulted in higher survival of overwintering individuals.

TABLE V-44

ESTIMATED BLUE CRAB IMPINGMENT RATES AT ROSETON, INDIAN POINT, AND BOWLINE POINT GENERATING STATIONS

YEAR	ROSETON (No./MCM)	BOWLINE POINT (No./MCM)	INDIAN POINT (No./MCM)
1974		28.62	
1975			
1976			
1977			
1978			
1979			
1980	4.65		
1981	1.90	8.42	
1982	1.63	10.72	
1983	0.19	0.70	0.64
1984	0.08	0.38	0.20
1985	7.92	5.95	6.23
1986	0.10	1.27	2.75
1987	1.43	1.75	1.08
1988	11.41	28.85	24.37
1989	29.28	62.02	112.20
1990	7.76	29.76	26.71
1991	355.94	41.68	
1992	198.22	87.42	
1993		5.20	
1994	37.59	147.01	
1995	122.87	80.35	
1996	4.25	30.24	
1997	127.14		

MCM - million cubic meters.
1992-1997 rates calculated by dividing the number collected by the intake flow sampled in MCM.

Alternatively, the improvement in water quality in the lower portion of the estuary may be related to the increase in blue crab abundance in the late 1980s. Females migrate to the higher-salinity areas (20-32 ppt) in the lower estuary, burrow into the mud and overwinter. It is not unreasonable to assume that overwintering conditions in the lower portion of the Hudson River estuary were not very good when the discharge of raw sewage from the New York City area was high.

Fishing

Blue crabs are harvested throughout the year but most are taken during the summer and early fall (Music 1979). Hard crabs (having hardened exoskeletons) are taken primarily with crab pots or trotlines in shallow waters. Dredges and scrapes are used in deeper, offshore waters to harvest the buried overwintering crabs. Recently molted "soft-shell" crabs represent a much smaller proportion of the overall industry. Although these crabs command a much higher price, the amount of effort tending them discourages most fisherman.

The blue crab also supports a popular recreational fishery over most of its range. Fishing gear includes handlines, pots, and collapsible traps. Recreational landings are rarely quantified.

Commercial landings since 1974 for New York, New Jersey, and Delaware have increased substantially (Figure V-113). The highest landings on record, 6850 and 7253 metric tons, occurred during 1993 and 1995. The New York contribution, however, is still small. Prior to 1926, New York typically contributed more than 50% of the tri-state landings. New York landings then began to decrease until by 1939 landings were negligible. Landings remained low until 1978. After 1978, New York landings increased slightly, but to only 2-6% of the tri-state landings. New York landings increased from 297 metric tons in 1989 to a peak of 1043 metric tons in 1996. From 1995 to 1997, New York contributed 15.2% of the total catch for the tri-state area.

Although landings data are unavailable for the Hudson River specifically, presumably they make up only a small fraction of the total for the state. This is especially true since 1976, when restrictions were placed on commercial and recreational fishing in the Hudson River after the discovery of PCB contamination. Although the average concentration of PCB in their muscle tissue is relatively low, < 1 ppm, the New York State Department of Health has issued an advisory against the consumption of blue crabs. Of main concern are the high concentrations of PCB (> 5 ppm) and cadmium in the hepatopancreas (liver or tomalley) (Sloan and Armstrong 1988). Many people consider this organ a special delicacy.

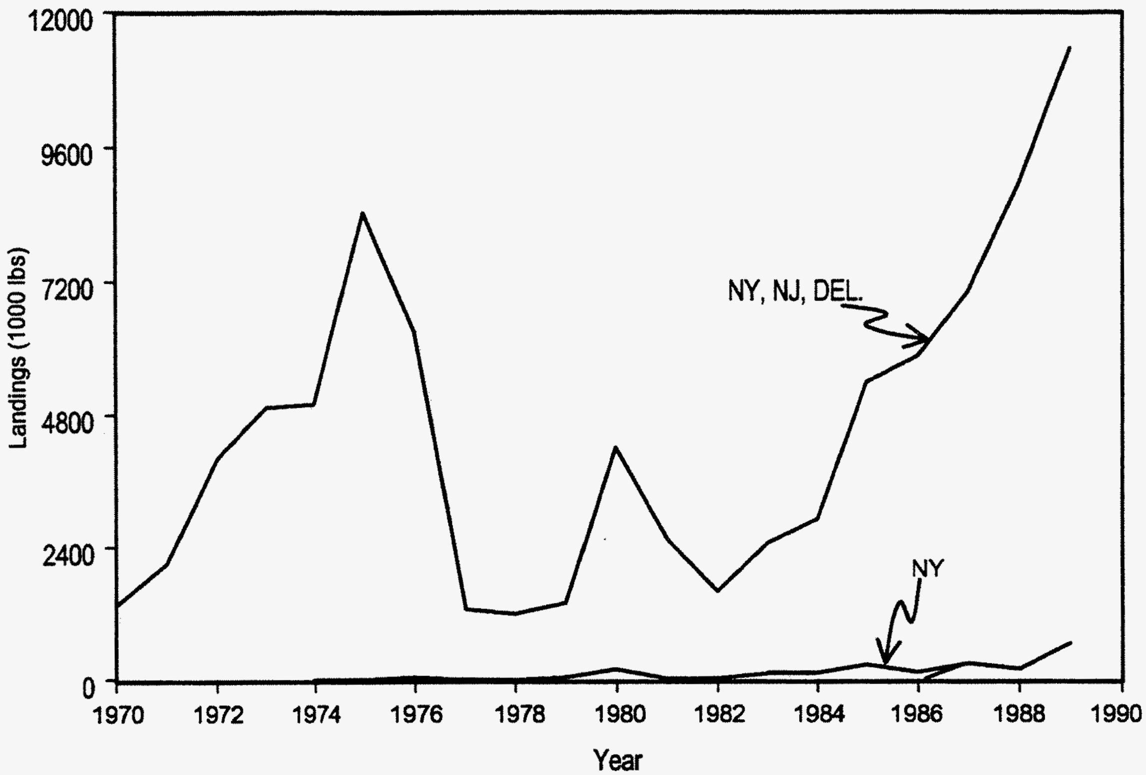


Figure V-113. Middle Atlantic Fisheries historical catch statistics, blue crabs 1970-1989.

Water Withdrawals

Blue crabs spawn in high salinity waters, approximately 23 to 28 ppt (Sandoz and Rodgers 1944), and larval stages occur in marine coastal waters (Epifanio et al. 1984). Because these high salinities do not occur in the vicinity of the Hudson River generating stations, egg and larval stages of blue crab are almost certainly not entrained.

Juvenile and older blue crab are reported in impingement samples at Roseton Units 1 and 2, Indian Point Units 2 and 3, and Bowline Point Units 1 and 2 since record keeping began in 1980 and they were observed before then. As many as 423,000, 196,000, and 63,000 have been reported from Roseton Units 1 and 2, Indian Point Units 2 and 3, and Bowline Point Units 1 and 2, respectively, in individual years since 1988, but the numbers killed are much lower because post-impingement survivals of crabs are relatively high. At Indian Point Units 2 and 3 annual blue crab survival has been on the order of 80% (EA 1991).

Since there are no estimates of the numbers of crabs in the Hudson River, it is not possible to estimate the fractional reduction of the population.

3 Fish Community

This section focuses on the fish communities in the Hudson River Estuary and serves as a complement to the individual species assessments previously discussed. There are two primary objectives for this section. The first is to describe the nature of the existing fish communities. The second is to determine whether or not there have been long-term changes in the fish communities which could be attributed to power plant operations or other changes in estuarine conditions.

These two objectives are addressed by assessing potential patterns in the following four specific community attributes:

1. Species richness – The total number of unique species comprising the community at any point in space or time.

2. Species diversity – A quantitative measure of the distribution of abundance across the individual species comprising the community.

3. Dominance succession – Changes in the abundance of individual species that comprise the vast majority of individuals collected and exert a major controlling influence on the community character.

4. Target species succession – Changes in the relative abundance of species that are the focus of this impact assessment.

Spatial and temporal patterns in these four attributes form the basis of the assessment of the status, condition, health, and trends in the fish communities of the Estuary presented in this section. Owing to the strong influence of salt concentration on the composition of the fish communities, the Estuary is geographically divided into two areas, a brackish water zone which includes Regions 1 – 5 (RM 12 - 55), and a tidal freshwater zone including Regions 6 – 12 (RM 56-152) for all temporal analyses.

For this assessment, three fish communities in the Estuary are individually addressed. First, analysis of the larval fish community addresses the role of the Hudson as spawning habitat for a variety of fish species; many of which have substantial recreational, commercial, and/or ecosystem importance. Second, analysis of the young-of-year community focuses on the role of the Estuary as nursery habitat for a broad range of marine, estuarine, freshwater, and diadromous species. Third, analysis of the yearling and older fish community focuses on those species which are regular and often year-round resident of the Estuary. The results of this assessment for each community and zone are presented below.

i. Patterns by Community

Larval Fish

The Hudson River Estuary is an important spawning and nursery area for a variety of fish species, including both year-round inhabitants as well as species that move into the Estuary solely for the purposes of spawning. Many of the fish species that spawn in the Hudson have significant commercial and recreational importance, both locally and regionally. These species typically utilize the Estuary in spring and summer for spawning and/or larval development. The waters of the Estuary offer an abundance of food needed for rapid growth and development of the larval stages. It is for these reasons that this part of the assessment focused the overall abundance and species composition on the early life stages of fish found in the Hudson.

Data for this assessment were collected by the Long River Survey that samples egg and larval fish throughout the Estuary in areas greater than 10 ft deep. Intensive sampling was conducted weekly throughout the Estuary during the spring and early summer of each year from 1974 through 1997 (Appendix V-3). Samples were collected using both Tucker trawls and epibenthic sleds in order to cover the entire water column. All samples were collected in a standardized manner and egg and larval fish collected were identified to lowest practical taxon and life stage, and counted. Currently available identification procedures are not sufficient to permit identification of all individuals to species; many could only be identified to higher levels (e.g., genus, family). However, each taxon was treated as a unique group for this assessment. This assessment focused on the more mobile post yolk-sac larval stage, as it's distribution throughout the water column rendered it most effectively sampled by the ongoing programs.

Based on the results of sampling, which extended from late February to as late as early October in some years, it can be seen that both the number of taxa and overall abundance of post yolk-sac larvae were typically highest from late May through July (Figure V-114). Overall, marine taxa were most frequently collected throughout the year. Freshwater taxa were next most frequently collected, followed by the diadromous and estuarine taxa groups. Diadromous larvae dominated collections during spring. Two periods of peak larval abundance were evident; in late March and early April principally as a result of the winter spawning species, Atlantic tomcod, and in late May and June, which includes a variety of spring spawning species. During summer, marine larvae, especially bay anchovy, dominated collections. Estuarine taxa were most abundant as post yolk-sac larvae from mid-May through mid-July while freshwater taxa never contributed significantly to the overall abundance of post yolk-sac larvae.

For the detailed examination of spatial patterns and long-term trends in the post yolk-sac larval component of the fish community, analysis was restricted to May and June (weeks 19 – 26) based on two factors. First, this period coincides with the highest overall abundance of post yolk-sac larvae throughout the Estuary and, second, this period was most consistently sampled across the entire 24-year period of available data (1974 – 1997).

Overall, a total of 67 taxonomic groups which could be identified at least to the genus level were collected as post yolk-sac larvae in the Long River Survey during May and June between 1974 and 1997. Most of these species were marine (29 taxa) or freshwater (20 taxa) with the remainder being spit between the estuarine (11 taxa) and diadromous (9 taxa) groups (Table V-45). The relatively large number of taxonomic groups collected in these surveys as post yolk-sac larvae demonstrates that the Estuary is a species rich environment and is consistent with the Hudson being healthy ecosystem. However despite being relatively species rich, the larval fish community does not exhibit a high degree of species diversity. This is evidenced by the fact that only 7 taxa accounted for

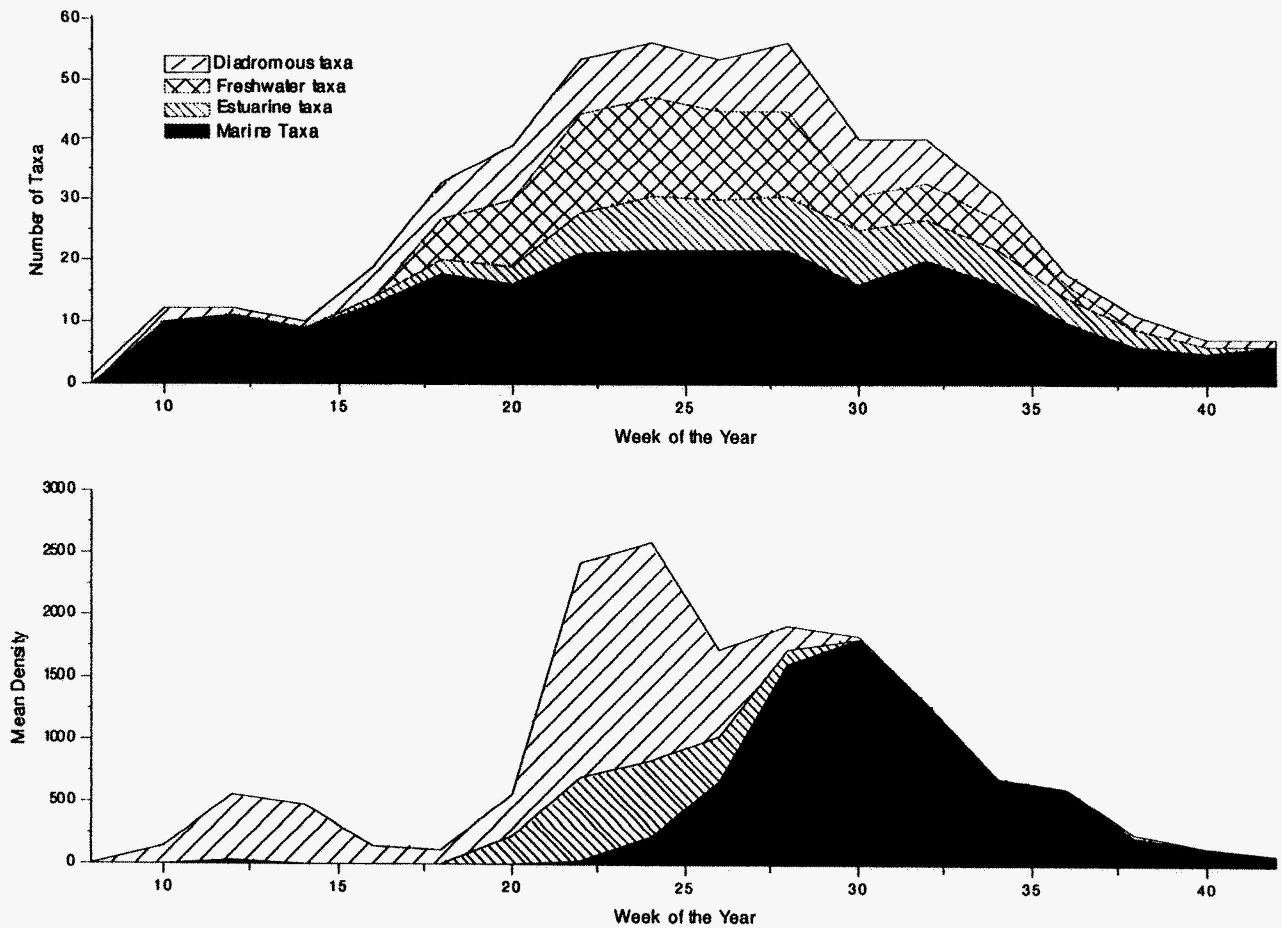


Figure V-114 Seasonal pattern in species richness and overall abundance of post yolk-sac larval fish in the Hudson River Estuary, 1974-1997.

TABLE V-45 (Page 1 of 2)

OVERALL SPECIES COMPOSITION OF POST YOLK-SAC LARVAE COLLECTED BY ICHTHYOPLANKTON SAMPLING IN THE HUDSON RIVER ESTUARY DURING MAY AND JUNE, 1974-1997.

COMMON NAME	MEAN DENSITY	CUMULATIVE %
River herring	1,021.8682	47.95
White perch	488.4760	70.88
Striped bass	339.9140	86.83
Bay anchovy	208.3282	96.61
American shad	42.1811	98.59
Rainbow smelt	21.9104	99.61
Tessellated darter	2.1429	99.72
Atlantic tomcod	1.2163	99.77
Weakfish	1.1515	99.83
Atlantic menhaden	0.7072	99.86
Yellow perch	0.6303	99.89
Unidentified sunfish	0.3793	99.91
Banded killifish	0.2666	99.92
Carp	0.2601	99.93
Winter flounder	0.2567	99.94
Atlantic herring	0.2465	99.96
Windowpane	0.1625	99.96
Inland silverside	0.1343	99.97
Northern pipefish	0.1261	99.97
Atlantic silverside	0.0900	99.98
Rough silverside	0.0726	99.98
Hogchoker	0.0591	99.99
Conger eel	0.0557	99.99
Goldfish	0.0354	99.99
Freshwater drum	0.0311	99.99
Gizzard shad	0.0286	99.99
White sucker	0.0263	99.99
Northern puffer	0.0254	99.99
Northern kingfish	0.0165	100.00
Grubby	0.0155	100.00
Smallmouth bass	0.0118	100.00
Tautog	0.0100	100.00
Logperch	0.0072	100.00
American eel	0.0071	100.00
Atlantic mackerel	0.0058	100.00
Shortnose sturgeon	0.0056	100.00
Spottail shiner	0.0051	100.00
Atlantic sturgeon	0.0041	100.00
Cunner	0.0033	100.00
Walleye	0.0021	100.00
Summer flounder	0.0018	100.00
Striped searobin	0.0017	100.00
Spot	0.0016	100.00
American sand lance	0.0014	100.00

TABLE V-45 (Page 2 of 2)

OVERALL SPECIES COMPOSITION OF POST YOLK-SAC LARVAE COLLECTED BY ICHTHYOPLANKTON SAMPLING IN THE HUDSON RIVER ESTUARY DURING MAY AND JUNE, 1974-1997.

COMMON NAME	MEAN DENSITY	CUMULATIVE %
Fourbeard rockling	0.0013	100.00
Black crappie	0.0012	100.00
Smallmouth flounder	0.0006	100.00
Bluefish	0.0006	100.00
Butterfish	0.0006	100.00
Red hake	0.0005	100.00
Speckled worm eel	0.0005	100.00
Fourspine stickleback	0.0005	100.00
Threespine stickleback	0.0004	100.00
Mummichog	0.0004	100.00
Naked goby	0.0004	100.00
Silvery minnow	0.0003	100.00
Eastern mudminnow	0.0003	100.00
Largemouth bass	0.0002	100.00
Brown bullhead	0.0002	100.00
Emerald shiner	0.0002	100.00
Northern searobin	0.0002	100.00
Trout perch	0.0001	100.00
Yellowtail flounder	0.0001	100.00
Atlantic needlefish	0.0001	100.00
Longhorn sculpin	0.0001	100.00
Golden shiner	0.0001	100.00
White catfish	0.0001	100.00
Total	2,130.8921	

more than 99% of the mean catch throughout the Estuary. Thus, it is clear that the larval fish community in the Hudson in late spring is dominated by a small number of very abundant species that are well adapted to the dynamic estuarine environment.

Analysis of the overall spatial patterns in the larval fish community in the Hudson during May and June reveals a general decline in the number of taxa collected from the highest salinity areas downstream (Region 1) to the upper-most freshwater areas (Region 12). This decline is principally a result of a decline in the number of marine taxa (Figure V-115). Few marine taxa were found upstream of Region 5, the general upper range of brackish water at this time of the year, and few freshwater taxa were found in Region 1. The number of estuarine and diadromous taxa collected was relatively constant throughout the Estuary. The overall spatial pattern in mean density was largely driven by the abundance of diadromous taxa that had highest abundance in Regions 9 through 11. Marine taxa were most abundant in Regions 1 – 4 while freshwater taxa were most abundant in Regions 5 – 12. The mean abundance of estuarine taxa was relatively uniform throughout. Species diversity, as measured by the Shannon-Wiener Diversity Index, was highest in the middle reaches of the Estuary at the brackish-freshwater interface. This pattern undoubtedly is a result of the overlap between fresh and marine components of the ecosystem. In extreme upstream areas, diversity was reduced owing to the overwhelming numerical dominance by a relatively small number of diadromous taxa. Likewise, in extreme downstream areas, diversity was reduced owing to the numerical dominance by a few marine taxa, especially bay anchovy.

Collections of marine taxa were largely restricted to brackish water areas and consisted almost exclusively of a single species, bay anchovy (Figure V-116). This schooling species is the most abundant species in inshore marine waters along the Atlantic coast of North America. Other marine taxa commonly collected as post yolk-sac larvae include weakfish, Atlantic menhaden, winter flounder, and Atlantic herring. Collections of post yolk-sac larval estuarine taxa were also dominated by a single species, white perch, (Figure V-116). Other commonly collected estuarine taxa as post yolk-sac larvae include banded killifish, inland silversides, northern pipefish, and Atlantic silversides. The small number of freshwater taxa collected as post yolk-sac larvae were principally members of the minnow family (Figure V-116). Other commonly collected freshwater taxa included yellow perch, members of the sunfish family, and carp. Collections of diadromous species were dominated by two taxonomic groups, river herring (consisting of alewife and blueback herring) and striped bass (Figure V-116). Striped bass were most abundant in the middle reach of the Estuary (Regions 3 – 7) whereas, river herring were more abundant further upriver. Other commonly collected post yolk-sac larval diadromous taxa included American shad and rainbow smelt.

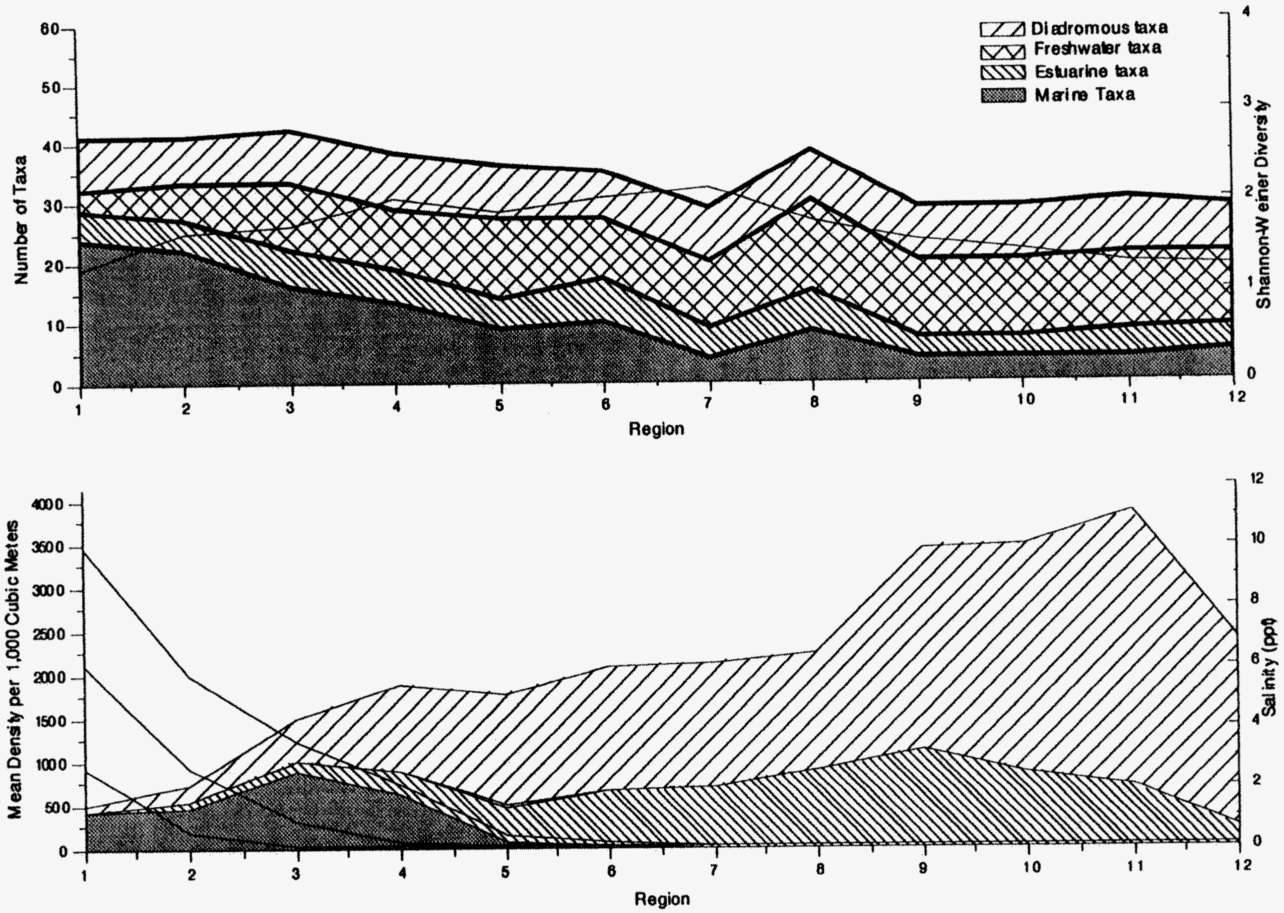


Figure V-115 Spatial pattern in species richness, diversity and overall abundance of post yolk-sac larval fish in the Hudson River Estuary during May and June, 1974 – 1997.

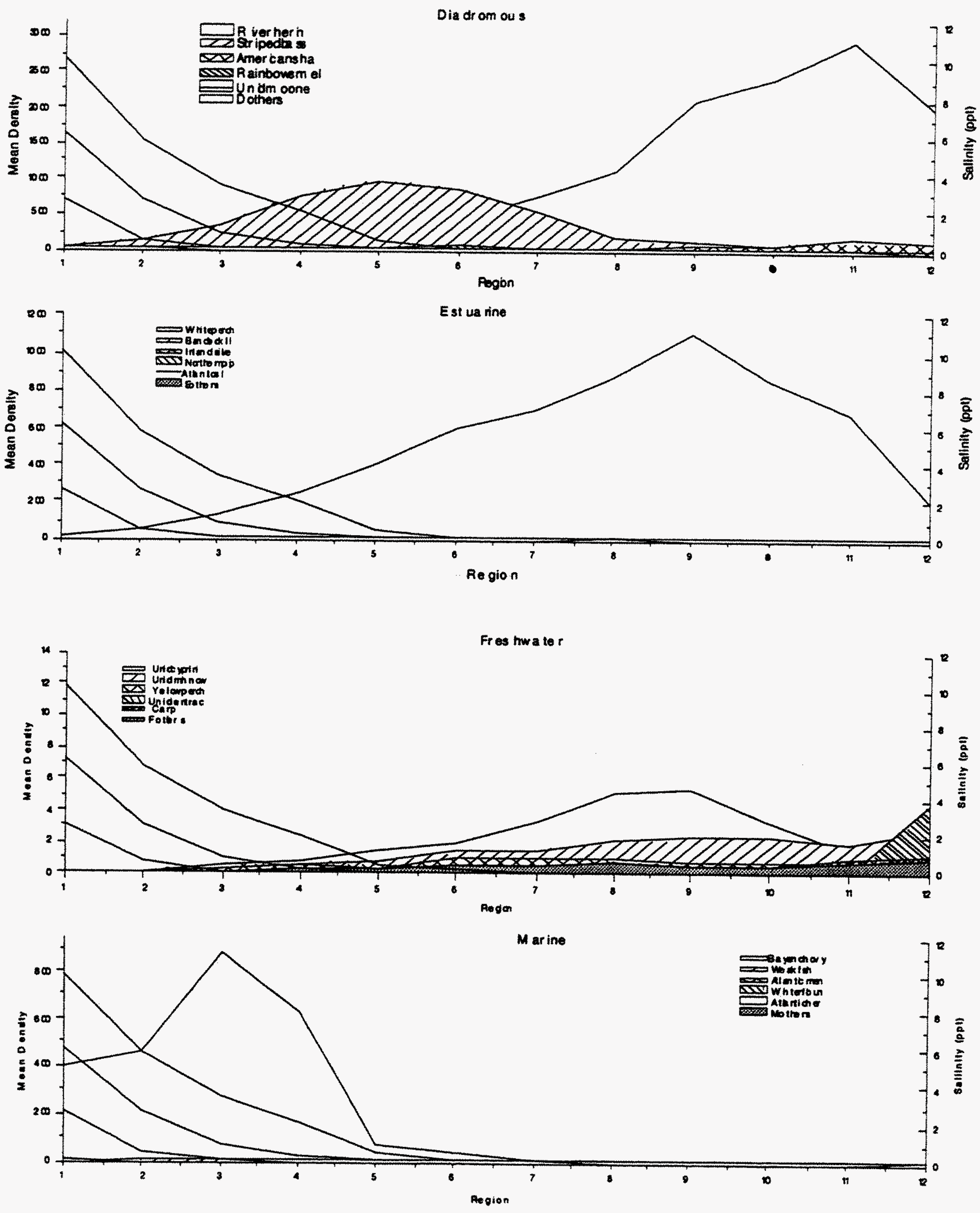


Figure V-116 Spatial pattern in the abundance of post yolk-sac larval fish of the dominant species in the Hudson River Estuary during May and June, 1974 – 1997.

Each of the 16 target fish species which are the focus of the overall impact assessment has been collected at one time or another as post-yolk sac larvae in the Hudson (Table V-45). Together these 16 species accounted for more than 99 percent of the overall mean post yolk sac larval catch. However, only 7 of these species could be considered common. Three of these common target taxa, river herring (blueback herring/alewife), white perch, and American shad, were substantially more abundant in the freshwater zone (Regions 6-12) during May and June while the other three common target taxa, striped bass, bay anchovy, and rainbow smelt were more abundant in the brackish zone (Regions 1-5) at this same time (Figure V-117).

Analysis of the long-term trends in the post yolk-sac larval fish community in the Estuary during May and June revealed an overall increase in the total number of taxa collected in the brackish (Regions 1-5) zone (Figure V-118). This increase appears primarily a result of an increase in the number of marine taxa over the 24-year period. Over this same period, there was an increase in overall abundance, particularly among the marine and diadromous taxonomic groups. Both the higher number of marine taxa and greater overall abundance of this group coincides with a general increase in mean salinity observed in this area of the Estuary since 1984. The unusually high mean density in 1991 was solely a result on high densities of marine taxa. The overall species diversity in this zone exhibited a general decrease over this 24-year period. This pattern suggests that observed increases in overall abundance was largely driven by increases in a small number of taxa.

In the freshwater zone (Regions 6-12), there also appeared to have been an overall increase in the number of taxa in the post yolk-sac larval fish community primarily as a result of increases within the marine habitat group over the 24-year period (Figure V-119). Overall abundance in this area of the Estuary is driven by the abundance of diadromous taxa which exhibited considerable year-to-year variability with a slight increase prior to the mid-1980s. Species diversity exhibited a fairly consistent increase over the 24-year period suggesting that an increasing number of taxa are contributing significantly to overall community abundance.

Analysis of the abundance trends in the dominant taxa among post yolk-sac larval fish revealed considerable year-to-year variability in both zones of the Estuary (Figure V-120). In the brackish zone (Regions 1-5), recent increases in overall abundance appear a result of increases in striped bass and bay anchovy and the unusually high abundance in 1991 appears to have been a result of large numbers of bay anchovy. Increases in bay anchovy abundance are most likely are result of higher mean salinities observed in this area of the Estuary in recent years. Other commonly collected taxa, including white perch, river herring, and rainbow smelt, did not exhibit substantial changes in abundance.

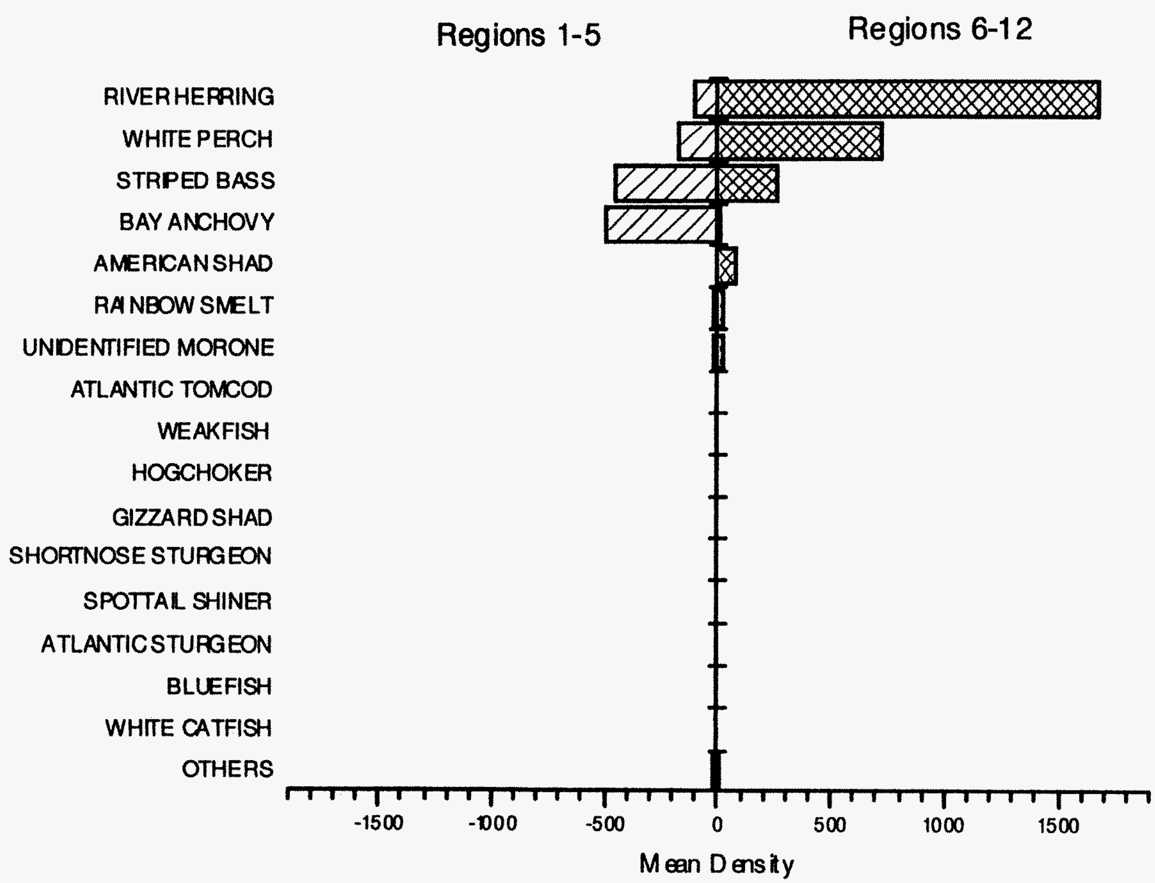


Figure V-117 Comparison of the mean abundance of post yolk-sac larval fish of selected species between brackish and freshwater areas of the Hudson River Estuary during May and June, 1974 – 1997.

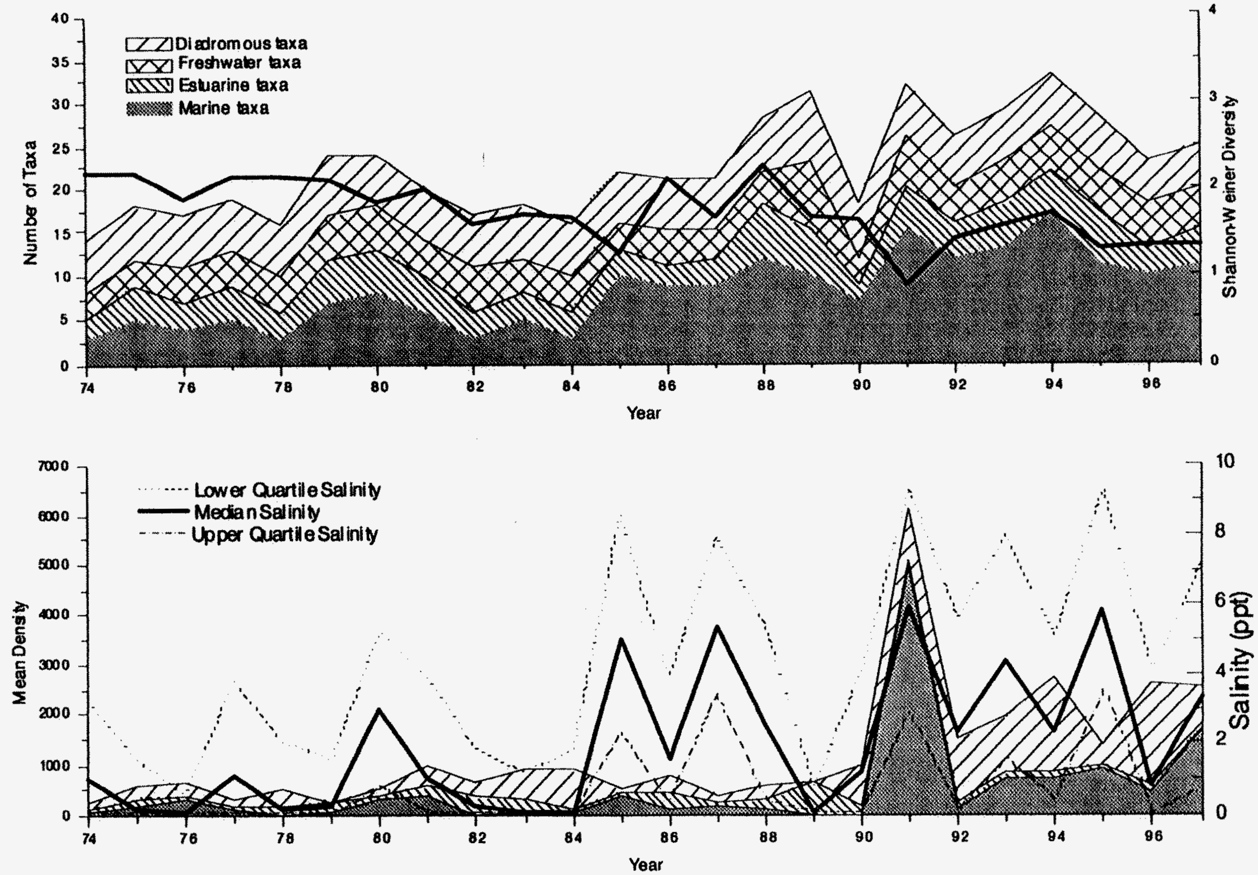


Figure V-118 Long-term trends in species richness and overall abundance of post yolk-sac larval fish in brackish areas of the Hudson River Estuary during May and June, 1974 – 1997.

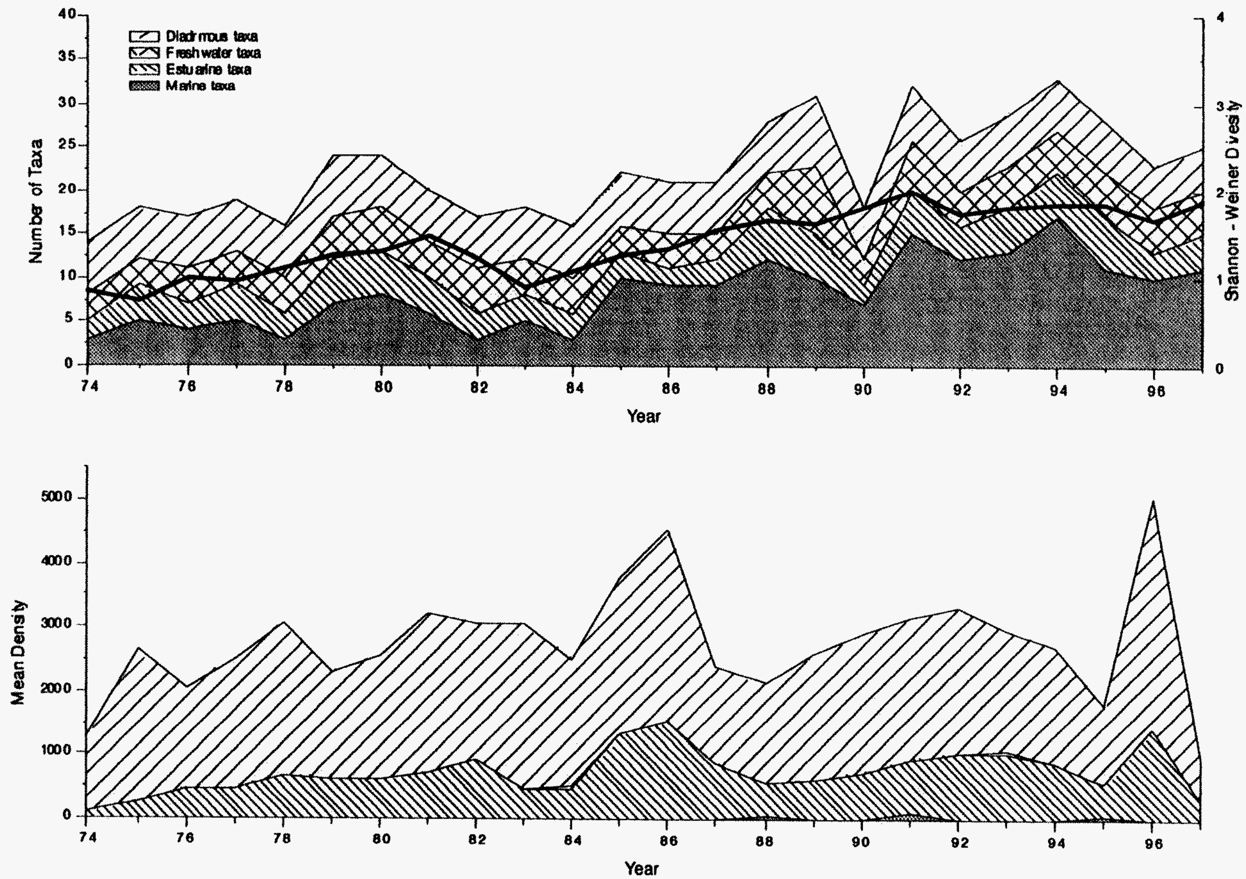


Figure V-119 Long-term trends in species richness and overall abundance of post yolk-sac larval fish in freshwater areas of the Hudson River Estuary during May and June, 1974 – 1997.

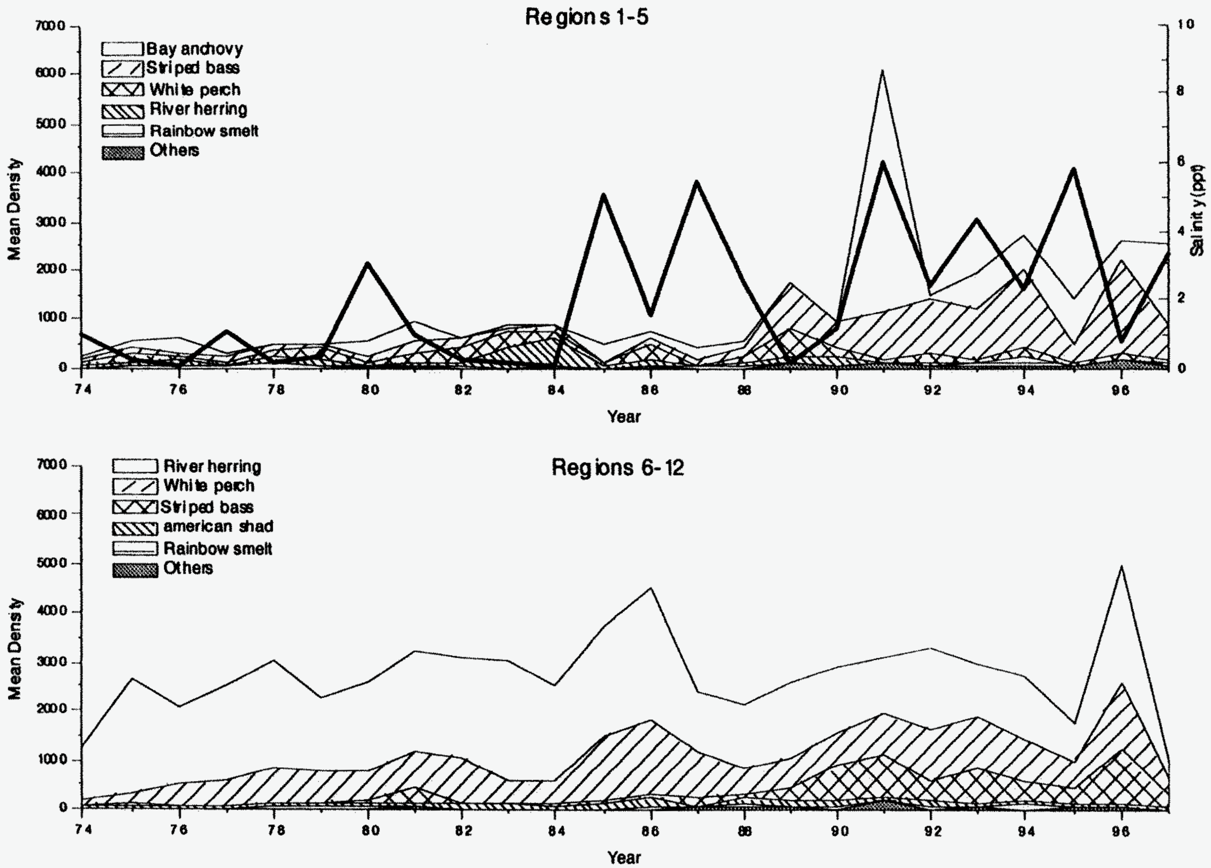


Figure V-120 Long-term trends in the abundance of post yolk-sac larval fish of the dominant species in the Hudson River Estuary during May and June, 1974 – 1997.

In the freshwater zone (Regions 6-12), much of the year-to-year variability in abundance appears to be driven by the abundance of a single taxon, river herring. On the other hand, recent increases in overall abundance appear largely driven by the abundance of striped bass. None of the other commonly collected taxa, including white perch, American shad, and rainbow smelt, exhibited such wide fluctuations in abundance.

As a final step, potential long-term changes in the larval fish community in May and June were evaluated by comparing the abundance of target species during the first 7 years of available data (1974 – 1980) to that observed in the most recent 7 years of data (1991 – 1997). This comparison revealed that the overall abundance in the brackish water zone (Regions 1-5) was substantially higher in recent years for three of the target taxa, bay anchovy, and striped bass, rainbow smelt and lower for one of the target taxa, river herring (Figure V-121). No trend was apparent for white perch and the other 7 target taxa were not collected in sufficient numbers for evaluation. In the freshwater zone (Regions 6-12), overall abundance was higher in recent years for five taxa, white perch, striped bass, American shad, rainbow smelt, and bay anchovy, and lower for one taxa, river herring. There was insufficient catch to evaluate the remaining target species.

Young of year

The Hudson River Estuary also provides important nursery habitat for a variety of fish species from each of the four habitat groups. Many of these fish species have significant commercial and recreational importance, both locally, as well as regionally. The young of many of these species utilize the shallow water areas of the Estuary during the warmer months of their first year of life prior to moving to deeper waters of the Estuary or offshore marine waters to overwinter. These shallow water areas offer cover protection from larger predators and an abundance of food needed for rapid growth and development. Owing to the importance of the shallow, littoral areas of the Estuary to this life stage, this assessment focused on the fishes inhabiting these areas.

Data for this assessment were collected by the Beach Seine Survey which was designed to sample young fish throughout the Estuary in areas along the shore less than 10 ft deep. Intensive beach seine sampling was conducted throughout the Estuary weekly during most of each year from 1974 through 1980 and biweekly from early July through late September thereafter (Appendix V-3). All samples were collected in a standardized manner and all young-of-year fish collected were identified to species and counted.

Based on the results of the temporally-extended sampling of 1974 – 1980, it can be seen that young of year were rare prior to the end of June and most had left these shallow water areas of the Estuary by late fall (Figure V-122). In the freshwater zone (Regions 6-

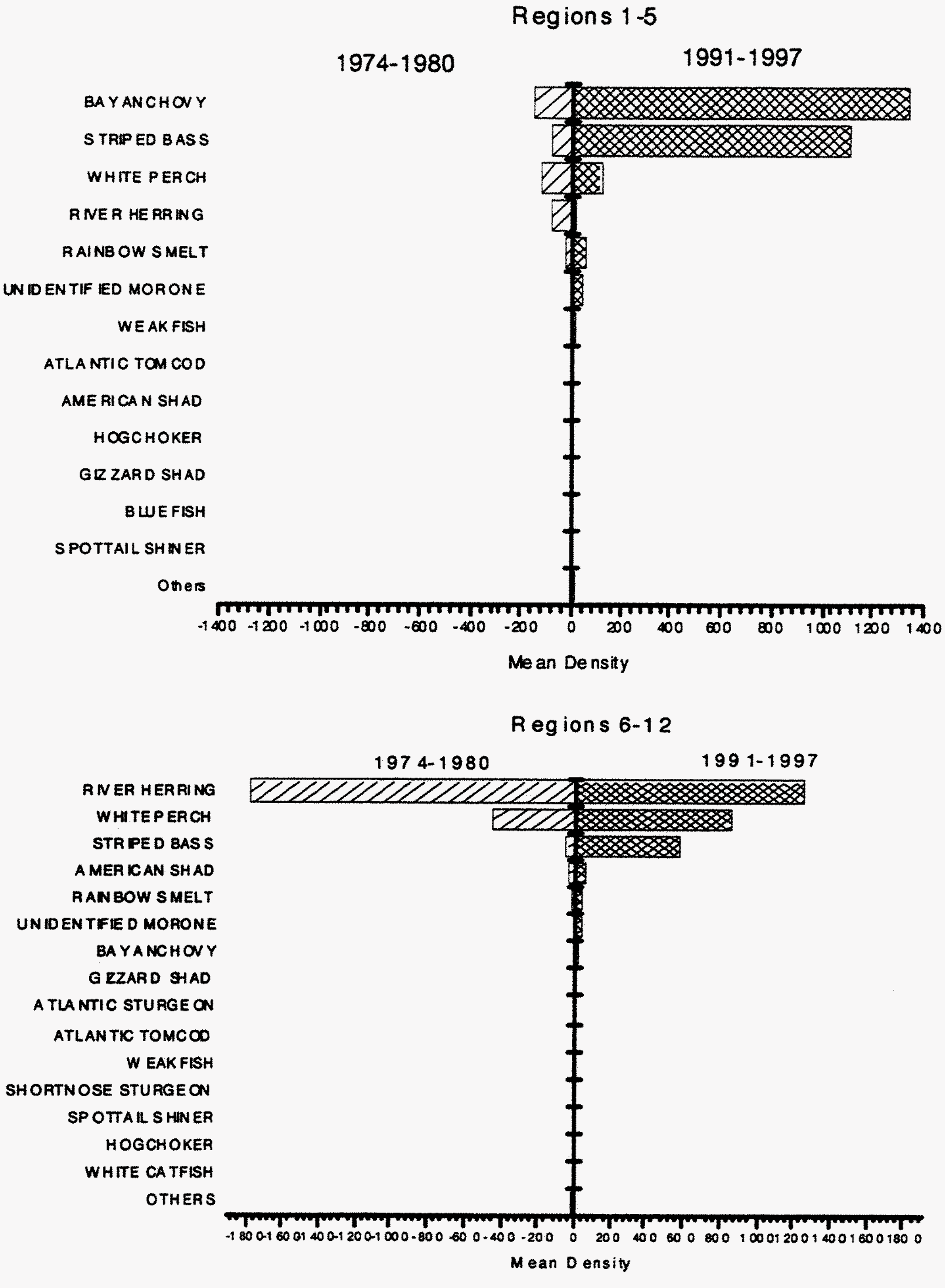


Figure V-121 Comparison of the mean abundance of post yolk-sac larval fish of selected species in May and June between two periods, 1974 – 1980 and 1991 – 1997, in the Hudson River Estuary.

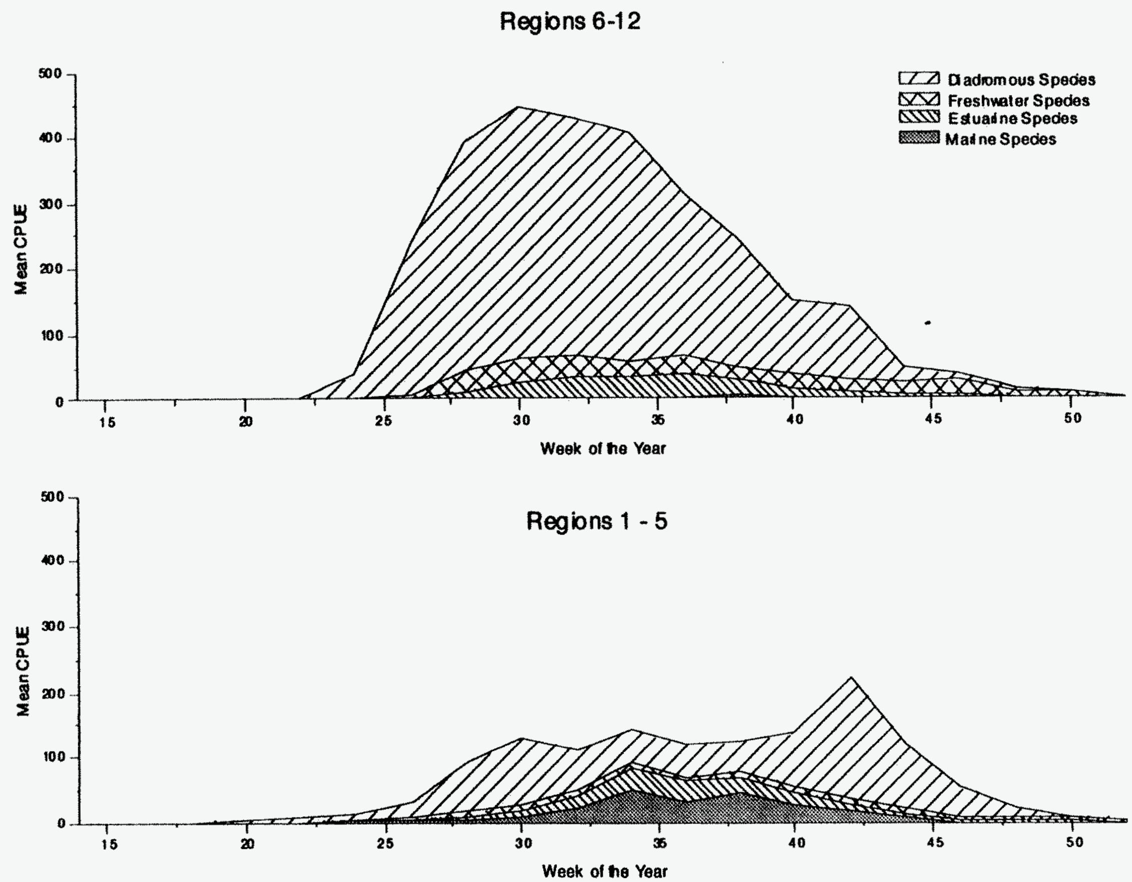


Figure V-122 Seasonal pattern in species richness, diversity and overall abundance of young of year fish in littoral areas of the Hudson River Estuary, 1974 – 1997.

12), collections were dominated by diadromous species and there was a single period of peak abundance from July through September (Weeks 26 – 38). In the brackish zone (Regions 1-5), collections were more evenly distributed across all four species groups and the period of peak abundance for most groups was slightly later than upstream, extending from mid-July through early October (Weeks 28 – 40). In this zone, there was a period of peak abundance for the diadromous species in October (Weeks 40 – 44), most likely a result of migration of river herring through the area on their way from freshwater nursery grounds to the ocean as water temperatures decline in late fall.

For the detailed examination of spatial patterns and long-term trends in the young-of-year fish community, analysis was restricted to July and August (Weeks 27 – 34) based on three factors. First, this period coincides with the highest young-of-year abundance throughout the Estuary. Second, this period ends prior to the start of the emigration of anadromous species in fall which would confound spatial analysis. Third, this period was most consistently sampled across the entire 24-year period of available data (1974 – 1997).

Overall, 80 species of fish were collected as young-of-year in the Beach Seine Survey during July and August 1974 and 1997. Most of these species were freshwater (33 species) or marine (27 species) with the remainder being spit between the estuarine (11 species) and diadromous (9 species) groups (Table V-46). The relatively large number of young-of-year species collected in these surveys demonstrates that the littoral areas of the Estuary are species-rich environments and this is consistent with the Hudson being a healthy ecosystem. However despite being relatively species rich, the young-of-year fish community does not exhibit a high degree of species diversity. This is evidenced by the fact that more than 98 percent of the mean catch throughout the Estuary is composed of only 10 species, and the top three accounted for more than 75 percent of the catch. On the other hand, 71 species (89 percent of the total number collected) accounted for less than 1 percent of the total catch combined. Thus, it is clear that the young-of-year fish community in littoral areas of the Hudson in late summer is dominated by a small number of very abundant species which are well adapted to the dynamic estuarine environment.

Analysis of the overall spatial patterns in the young-of-year fish community in the Hudson during July and August reveals that the number of species collected was highest in Regions 2 and 3, principally as a result of an influx of marine species (Figure V-123). Few marine species were found upstream of Region 5, the general upper range of brackish water at this time of the year. Few freshwater species were found in Region 1 and there was a slight increase in the number of freshwater species collected in the extreme upstream regions. The number of estuarine and diadromous species collected was relatively constant throughout the Estuary. The overall spatial pattern in mean catch

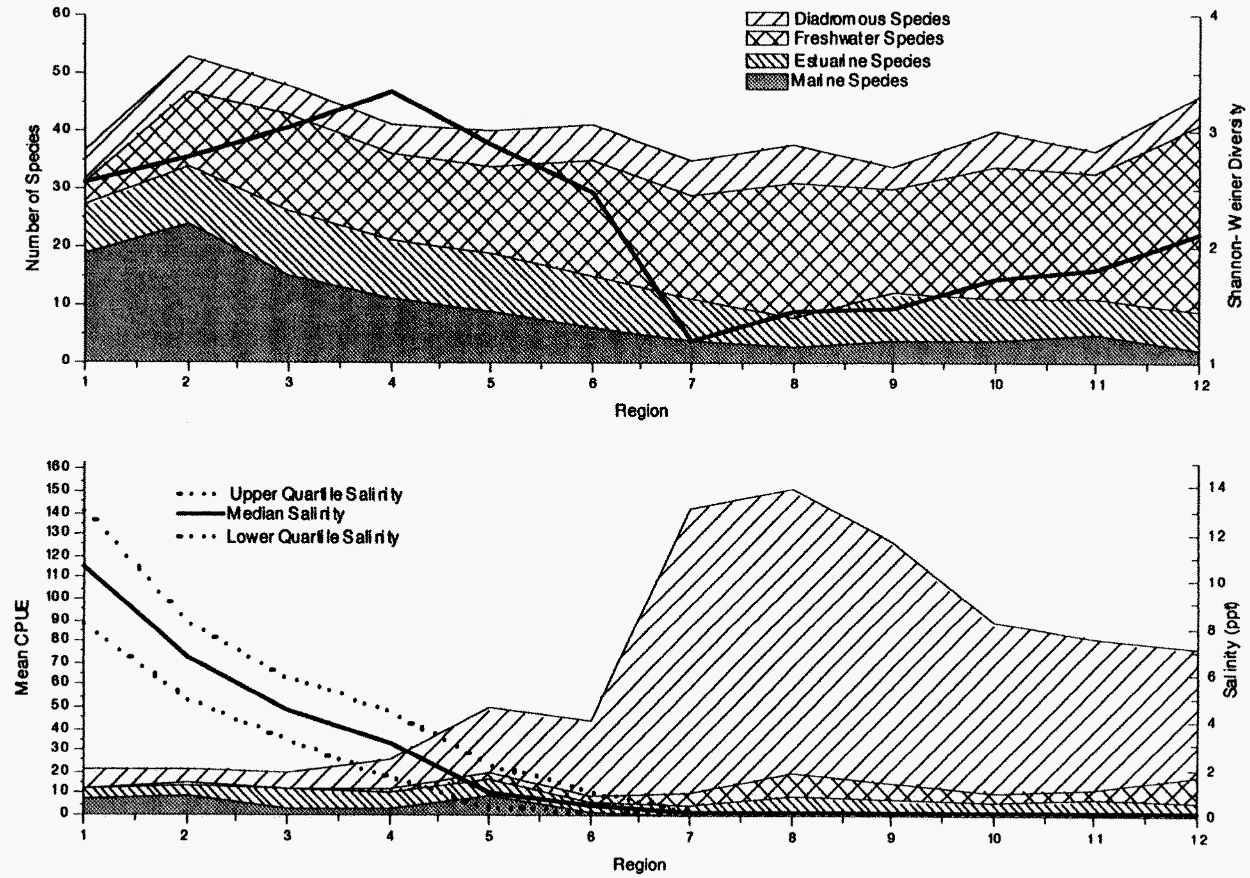


Figure V-123 Spatial patterns in species richness, diversity and overall abundance of young-of-year fish in littoral areas the Hudson River Estuary during July and August, 1974 – 1980.

TABLE V-46 (Page 1 of 2)

OVERALL SPECIES COMPOSITION OF YOUNG-OF-YEAR FISH COLLECTED BY BEACH SEINE SAMPLING IN THE HUDSON RIVER ESTUARY DURING JULY AND AUGUST, 1974-1997.

Common Name	Mean CPUE	Cumulative %
Blueback herring	44.411	62.776
American shad	7.826	73.838
White perch	2.839	77.851
Spottail shiner	3.117	82.257
Bay anchovy	2.486	85.771
Striped bass	2.609	89.458
Banded killifish	1.967	92.239
Alewife	1.910	94.938
Atlantic silverside	1.541	97.116
Tessellated darter	0.906	98.396
Golden shiner	0.061	98.482
Pumpkinseed	0.071	98.583
Silvery minnow	0.158	98.807
Bluefish	0.200	99.089
Atlantic menhaden	0.129	99.272
Mummichog	0.093	99.404
Redbreast sunfish	0.007	99.413
American eel	0.001	99.414
Hogchoker	0.017	99.438
Goldfish	0.074	99.543
Bluegill	0.016	99.565
Northern pipefish	0.012	99.582
Brown bullhead	0.038	99.636
Largemouth bass	0.038	99.689
Emerald shiner	0.002	99.691
Carp	0.008	99.702
Fourspine stickleback	0.013	99.720
Yellow perch	0.008	99.732
Atlantic needlefish	0.009	99.745
Atlantic tomcod	0.024	99.779
Gizzard shad	0.015	99.801
Inland silverside	0.015	99.823
Winter flounder	0.020	99.851
White catfish	0.001	99.852
Rough silverside	0.012	99.869
Smallmouth bass	0.007	99.879
Spot	0.006	99.888
White sucker	0.002	99.891
Spotfin shiner	0.002	99.894
Weakfish	0.009	99.906
Black crappie	0.002	99.909
Striped searobin	0.005	99.916

TABLE V-46 (Page 2 of 2)

OVERALL SPECIES COMPOSITION OF YOUNG-OF-YEAR FISH COLLECTED BY BEACH SEINE SAMPLING IN THE HUDSON RIVER ESTUARY DURING JULY AND AUGUST, 1974-1997.

Common Name	Mean CPUE	Cumulative %
Summer flounder	0.003	99.920
Northern kingfish	0.005	99.926
Crevalle jack	0.004	99.932
Rock bass	0.002	99.934
Satinfin shiner	0.001	99.936
Fall fish	0.001	99.936
Tautog	0.001	99.938
Silver perch	0.001	99.940
Redfin pickerel	0.001	99.942
Common shiner	0.001	99.944
White crappie	0.001	99.946
Inshore lizardfish	0.001	99.948
Northern puffer	0.001	99.950
Northern searobin	0.001	99.952
Sea lamprey	0.001	99.954
Bluntnose minnow	0.001	99.956
Rainbow smelt	0.001	99.958
Fathead minnow	0.001	99.960
Threespine stickleback	0.001	99.962
Northern hog sucker	0.001	99.964
Northern stargazer	0.001	99.966
Naked goby	0.001	99.968
Blacknose dace	0.001	99.970
Lookdown	0.001	99.972
Creek chub	0.001	99.974
White mullet	0.001	99.976
Windowpane	0.001	99.978
Trout perch	0.001	99.980
Hickory shad	0.001	99.982
Spotfin mojarra	0.001	99.984
Longnose dace	0.001	99.986
Gray snapper	0.001	99.988
Cunner	0.001	99.990
Orangespotted filefish	0.001	99.992
Permit	0.001	99.994
Shield darter	0.001	99.996
Brook stickleback	0.001	99.998
Smallmouth flounder	0.001	100.000
Total	70.710	

per unit effort was largely driven by the abundance of diadromous species which had highest abundance in Regions 7 through 9. Marine species were most abundant in Regions 1 – 5 while freshwater species were most abundant in Regions 6 – 12. The mean abundance of estuarine species was relatively uniform throughout. Species diversity, as measured by the Shannon-Wiener Diversity Index, was highest downstream reflecting a more even distribution of catch across the species. In upstream areas (Regions 6-12), diversity was low owing to the overwhelming dominance by a relatively small number of diadromous species.

Collections of marine species were largely restricted to brackish water areas and consisted almost exclusively of a single species, bay anchovy (Figure V-124). This schooling species is the most abundant species in inshore marine waters along the Atlantic coast of North America. Other marine species commonly collected as young of year in littoral areas include bluefish, Atlantic menhaden, winter flounder, and rough silversides. Collections of young-of-year estuarine species were dominated by three species, white perch, banded killifish, and Atlantic silversides (Figure V-124). White perch were common throughout the Estuary whereas Atlantic silversides and banded killifish were largely restricted to the brackish and freshwater zones, respectively. Other commonly collected estuarine species include mummichog and hogchoker. Collections of freshwater species as young of year were largely restricted to the freshwater zone and were dominated by two species, spottail shiner and tessellated darter (Figure V-124). Collections of spottail shiner were highest in Regions 8 and 12 while collections of tessellated darter were highest in Regions 9 and 12. Other commonly collected freshwater species included silvery minnow, goldfish, and pumpkinseed. Collections of young-of-year diadromous species were dominated by the single species, blueback herring, in the freshwater and low salinity brackish areas of the Estuary (Figure V-124). American shad was also relatively abundant in these areas. Collections in higher salinity brackish areas were dominated by striped bass. Other commonly collected diadromous species included alewife and Atlantic tomcod.

All but 1 of the 16 target fish species which are the focus of the overall impact assessment have been collected in the Beach Seine Survey (Table V-46). Together these 16 species accounted for more than 92 percent of the overall mean young-of-year catch. However, only 7 of these species could be considered common. Five of these common target species, blueback herring, American shad, spottail shiner, white perch and alewife, were substantially more abundant in freshwater littoral areas (Regions 6-12) during late summer while the remaining two common target species, striped bass and bay anchovy, were more abundant in brackish areas (Regions 1-5) at this same time (Figure V-125).

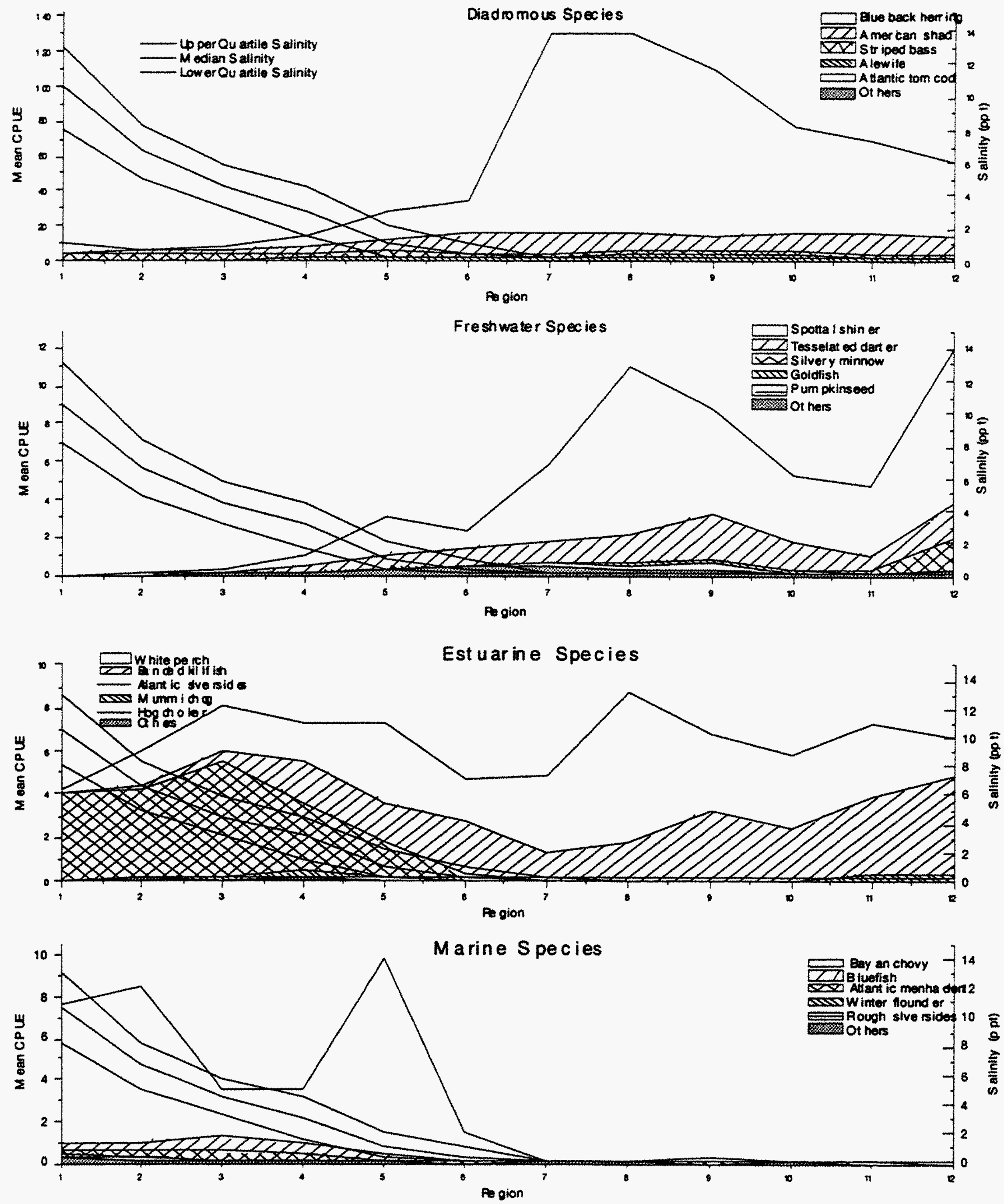


Figure V-124 Spatial pattern in the abundance of young-of-year fish of the dominant species in the Hudson River Estuary during July and August, 1974 – 1997.

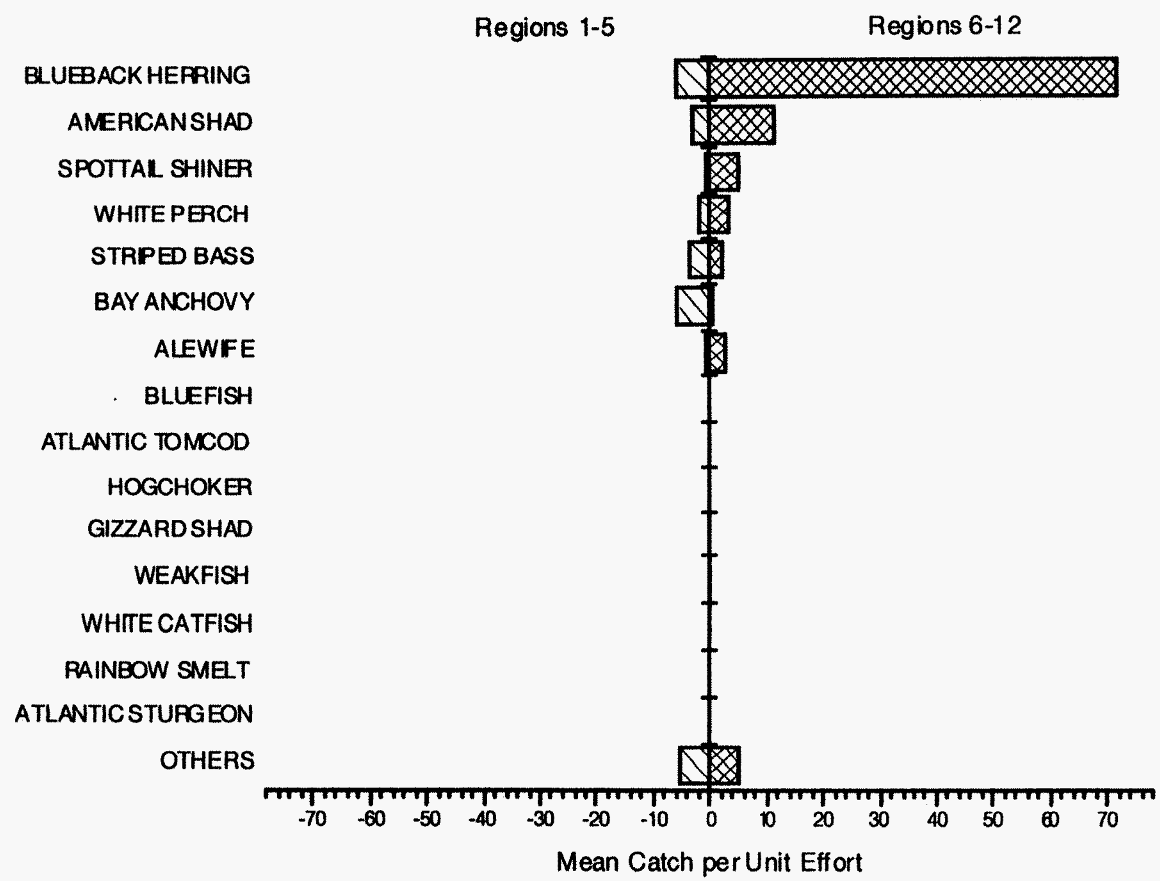


Figure V-125 Comparison of the mean abundance of young-of-year fish of selected species between brackish and freshwater littoral areas of the Hudson River Estuary during July and August, 1974 – 1997.

Analysis of the long-term trends in the young-of-year fish community in the littoral area of the Estuary during July and August revealed a slight overall decline in the total number of species collected in the brackish (Regions 1-5) zone over the 24-year study period (Figure V-126). This decline appears a result of a decrease in the number of freshwater species, principally in the past decade. As opposed to the decline in number of species, however, overall mean abundance in this brackish zone appears to have substantially increased over this same period. Although there is considerable year-to-year variability, this increase appears attributable to increases in the abundance of marine and, to a lessor extent, estuarine species. Some of this variability appears related to year-to-year differences in means salinity in the brackish zone of the Estuary. The overall species diversity in this area of the Estuary also exhibited a slight decline, a pattern similar to that observed for the total number of species collected. This decline can most likely be explained by the fact that observed increases in abundance were limited to a relatively small number of species.

In the freshwater zone (Regions 6-12), there was an overall decline in the number of species in the young-of-year fish community, which occurred principally among the freshwater habitat group (Figure V-127). However, this decline appears to have occurred earlier than observed further downstream, primarily in the 1970s and early 1980s. Overall abundance in this area of the Estuary is driven by the abundance of diadromous species that exhibited considerable year-to-year variability with an apparent overall decline in abundance in the early 1980s. Despite a decline in the number of species and overall abundance, there was no apparent trend in species diversity in this zone suggesting that the overall decline in abundance must have affected many of the species similarly.

Analysis of the abundance trends in the dominant species among the young-of-year fish revealed considerable year-to-year variability in both zones of the Estuary (Figure V-128). In the brackish zone (Regions 1-5), much of the year-to-year variability was driven by two factors. First, year-to-year variation in the abundance of both blueback herring and bay anchovy and second, an apparent increase in the abundance of Atlantic silversides since 1990. Other commonly collected species in this zone included striped bass and American shad, neither of which appeared to dominate collections. In the freshwater zone (Regions 6-12), overall abundance appears to be driven by the abundance of a single species, blueback herring. None of the other commonly collected species, including American shad, spottail shiner, white perch or alewife, exhibited wide fluctuations in abundance.

As a final step, potential long-term changes in the young-of-year fish community in July and August were evaluated by comparing the abundance of target species during the first

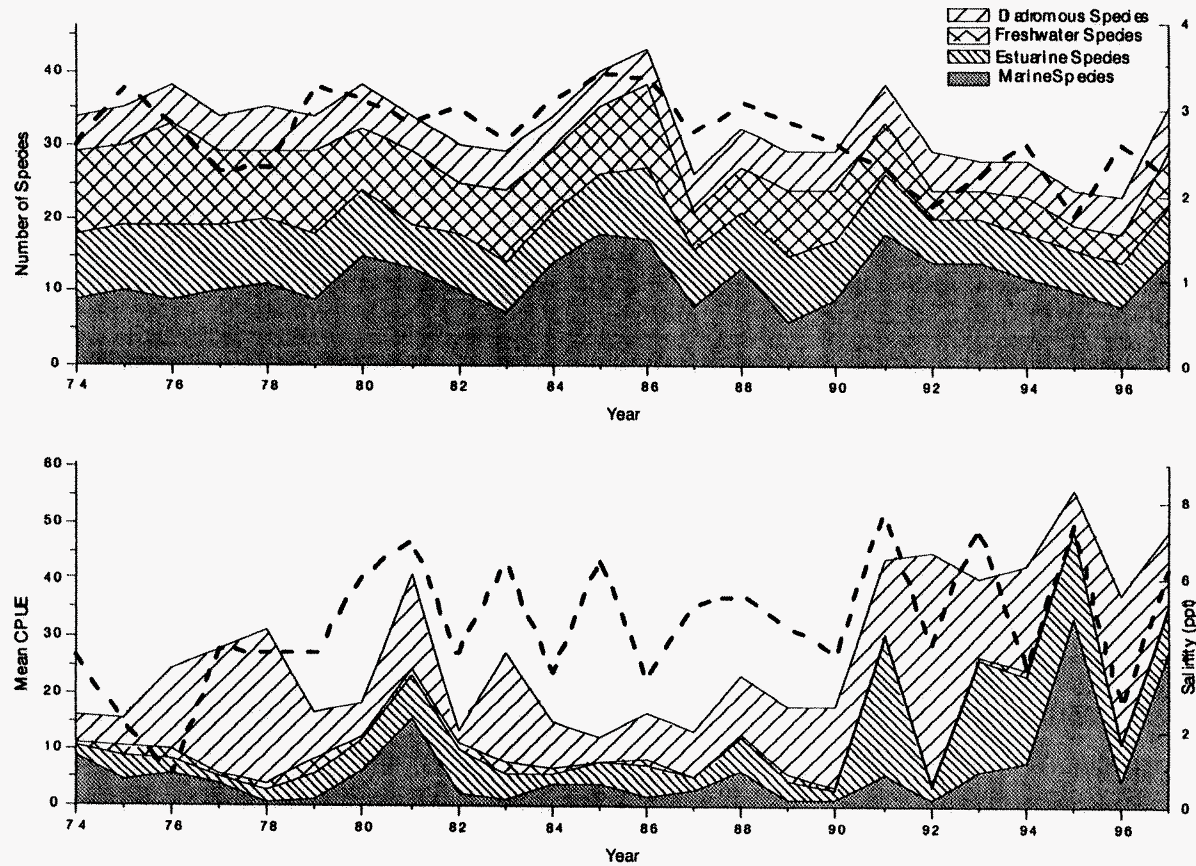


Figure V-126 Long-term trends in species richness and overall abundance of young-of-year fish in brackish littoral areas of the Hudson River Estuary during July and August, 1974 – 1997.

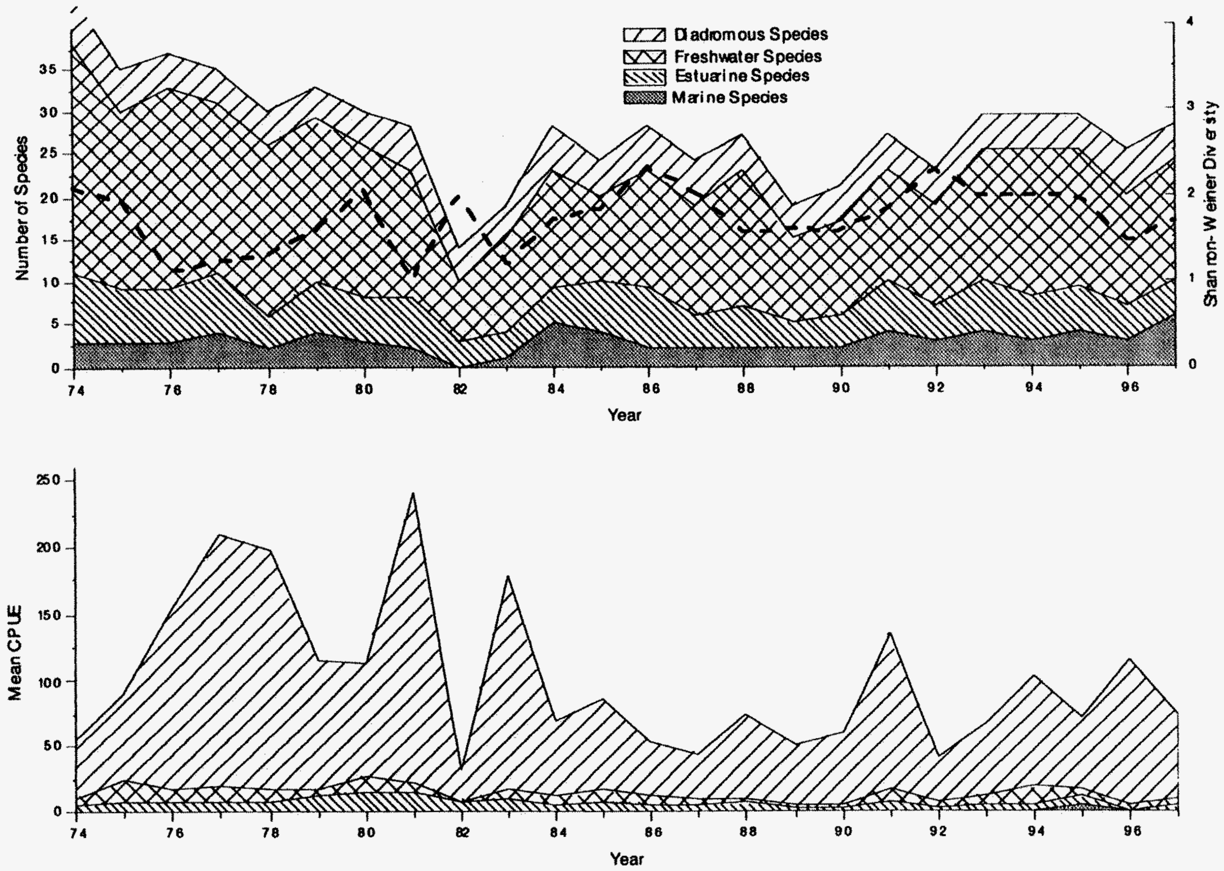


Figure V-127 Long-term trends in species richness and overall abundance of young-of-year fish in freshwater littoral areas of the Hudson River Estuary during July and August, 1974 – 1997.

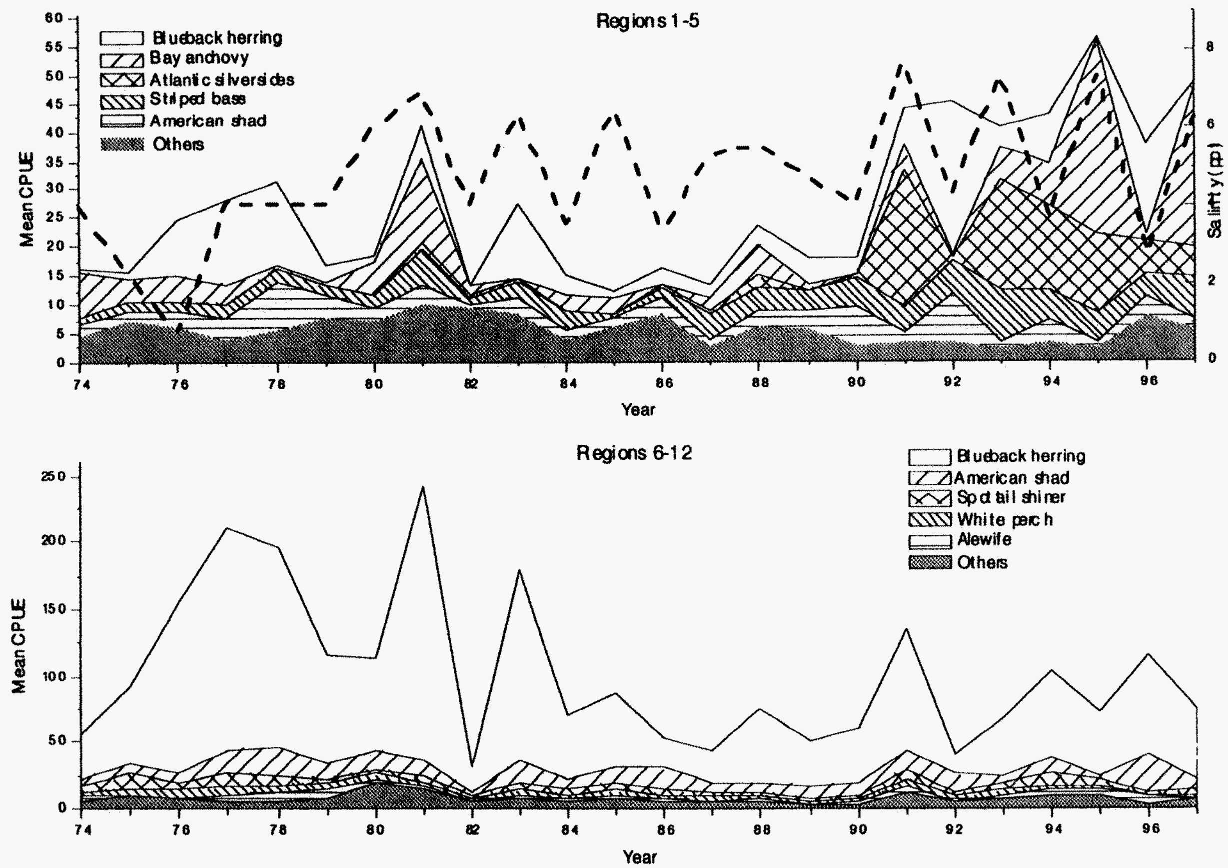


Figure V-128 Long-term trends in the abundance of young-of-year fish of the dominant species in littoral areas of the Hudson River Estuary during May and June, 1974 – 1997.

7 years of available data (1974 – 1980) to that observed in the most recent 7 years of data (1991 – 1997). This comparison revealed that the overall abundance in the brackish water zone (Regions 1-5) was higher in recent years for three of the target species (blueback herring, bay anchovy, and striped bass), and lower for four of the target species (American shad, white perch, spottail shiner, and bluefish) (Figure V-129). No trend was apparent for alewife and data were insufficient to determine trends for the other 7 target species collected. The substantial increase in non-target species can be attributed to increases in the single species, Atlantic silversides. In the freshwater zone (Regions 6-12), overall abundance was higher for one species, striped bass, and lower for two species, blueback herring and white perch. No trend was evident for either spottail shiner or alewife and data were insufficient to determine trends for the remaining 9 target species. The small decline observed in non-target species can not be attributed to any individual species or group of species.

Yearling and Older

In addition to larval and young-of-year fish, the Hudson River Estuary serves as habitat for a variety of yearling and older individuals as well. This component includes both year-round residents as well as regular seasonal visitors and strays. Throughout the warmer months of the year, many in this group also occupy the littoral areas of the Estuary. It is for this reason that data from the Beach Seine Survey were used to assess the status and trends in this component of the fish community as well.

Based on the results of the temporally extended sampling of 1974 – 1980, it can be seen that yearling and older fish were present in shallow water areas of the Estuary throughout most of the year although relatively rare in late fall (Figure V-130). In the freshwater zone (Regions 6-12), collections were dominated by freshwater and estuarine species with peak abundance during May. In the brackish zone (Regions 1-5), peak abundance was from mid-May through June when collections were dominated by marine species. Thereafter, collections were more evenly spread across all habitat groups.

For the detailed examination of spatial patterns and long-term trends in the yearling and older components of the fish community, analysis was restricted to July and August (weeks 27 – 34) because this period was consistently sampled across the entire 24-year period of available data (1974 – 1997). This is the same interval used for assessment of the young-of-year component.

A total of 95 species of yearling and older fish were collected during the July-August time period from 1974 through 1997. Most of these species were freshwater (46 species) or marine (28 species) with the remainder being split between estuarine (12 species) and

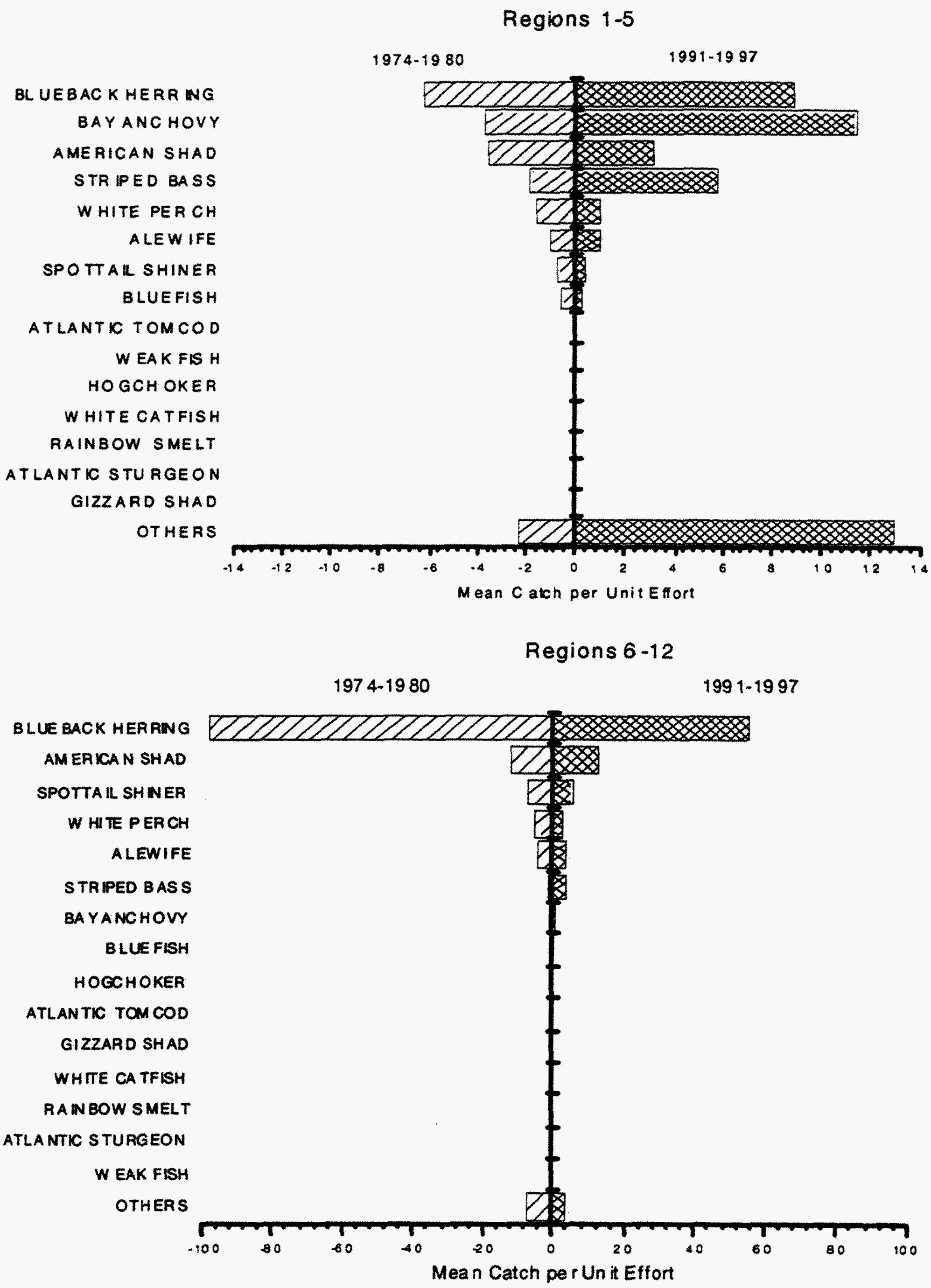


Figure V-129 Comparison of the mean abundance of young-of-year fish of selected species in July and August between two periods, 1974 – 1980 and 1991 – 1997, in littoral areas of the Hudson River Estuary.

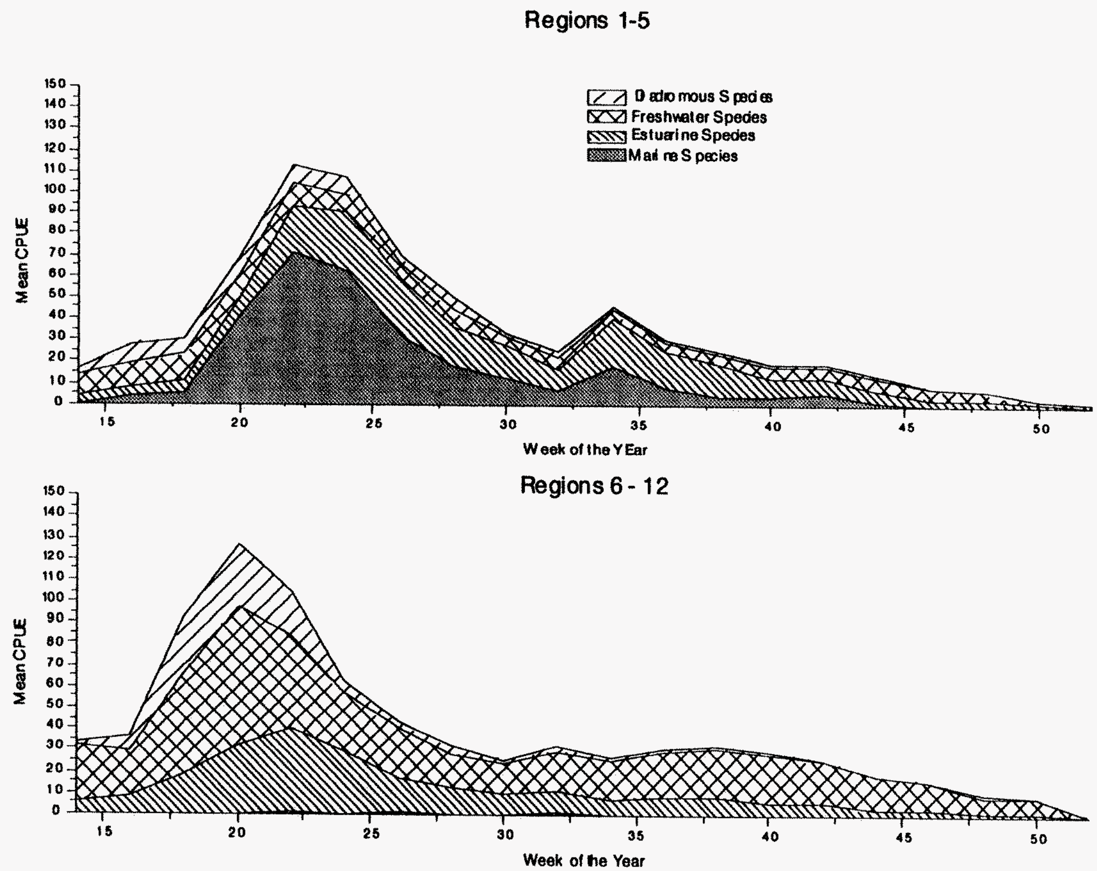


Figure V-130 Seasonal pattern in species richness, diversity and overall abundance of yearling and older fish in littoral areas of the Hudson River Estuary, 1974 – 1980.

diadromous (9 species) groups (Table V-47). The relatively large number of species collected as yearling and older during this time provides further proof that the littoral areas of the Estuary are species rich environments and this is consistent with the Hudson being a healthy ecosystem. However, as did the other fish communities, yearling and older fish exhibited relatively low species diversity. This is evidenced by the fact that the top 10 species accounted for more than 87% of the catch and that 65 of the species (68% of the total number collected) combined accounted for less than 1% of the total catch. These results demonstrate that the yearling and older fish community is dominated a relatively small number of species which are well adapted to the dynamic estuarine environment.
Analysis of the overall spatial patterns in the yearling and older fish community in the Hudson during July and August reveals that the number of species collected was highest in Region 2, principally as a result of an influx of marine species (Figure V-131). Few marine species were found as yearling and older individuals upstream of Region 3. Few freshwater species were found in Region 1 and there was a slight increase in the number of freshwater species collected upstream of Region 5. The number of estuarine and diadromous species collected was relatively constant throughout the Estuary. The mean catch per unit effort of all species combined was highest in the lower and upper regions of the Estuary. Marine species were most abundant in Regions 1 and 2 while freshwater species were most abundant in areas upstream of Region 6. Diadromous individuals were not abundant and exhibited no spatial pattern. Species diversity, as measured by the Shannon-Wiener Diversity Index, was highest upstream of Region 3 reflecting a more even distribution of catch across the species in this area. In downstream areas (Regions 1-3), diversity was reduced suggesting that the catch was dominated by a relatively few species.

Collections of yearling and older marine species were largely restricted to brackish water areas and consisted almost exclusively of a single species, bay anchovy (Figure V-132). This is similar to that observed for young of year. Other marine species commonly collected as yearling and older in littoral areas include Atlantic menhaden, Atlantic needlefish, spot, and summer flounder. As for young of year, collections of yearling and older estuarine species were dominated by three species, white perch, banded killifish, and Atlantic silversides (Figure V-132). White perch were common throughout the Estuary whereas Atlantic silversides and banded killifish were largely restricted to the brackish and freshwater zones, respectively. Other commonly collected estuarine species include hogchoker and mummichog. Collections of freshwater species as yearling and older were largely restricted to the freshwater zone and were dominated by spottail shiner, golden shiner and pumpkinseed (Figure V-132). The abundance of all three of these species was highest in Regions 7 and 8. Other commonly collected freshwater species included tessellated darter and redbreast sunfish. As opposed to young of year,

TABLE V-47 (Page 1 of 3)

OVERALL SPECIES COMPOSITION OF YEARLING AND OLDER FISH COLLECTED BY BEACH SEINE SAMPLING IN THE HUDSON RIVER ESTUARY DURING JULY AND AUGUST, 1974-1997

Common Name	Mean CPUE	Cumulative %
White perch	2.518	33.790
Spottail shiner	1.038	47.715
Bay anchovy	0.837	58.950
Banded killifish	0.661	67.822
Golden shiner	0.366	72.736
Atlantic silverside	0.340	77.296
Pumpkinseed	0.333	81.766
Striped bass	0.153	83.825
Tessellated darter	0.138	85.683
American eel	0.131	87.441
Redbreast sunfish	0.127	89.145
Silvery minnow	0.118	90.724
Hogchoker	0.113	92.237
Atlantic menhaden	0.056	92.993
Mummichog	0.052	93.692
Emerald shiner	0.049	94.344
Bluegill	0.041	94.899
Northern pipefish	0.040	95.442
Carp	0.035	95.907
Goldfish	0.027	96.263
Fourspine stickleback	0.024	96.584
Blueback herring	0.020	96.849
Yellow perch	0.019	97.109
Alewife	0.018	97.357
White catfish	0.018	97.593
Atlantic needlefish	0.016	97.808
Brown bullhead	0.014	97.996
Largemouth bass	0.013	98.171
White sucker	0.010	98.301
Spotfin shiner	0.009	98.415
Gizzard shad	0.008	98.525
Inland silverside	0.008	98.632
Smallmouth bass	0.007	98.733
Spot	0.007	98.823
Black crappie	0.006	98.903
American shad	0.005	98.973
Summer flounder	0.004	99.026
Rough silverside	0.003	99.068
Bluefish	0.002	99.099
Rock bass	0.002	99.120

TABLE V-47 (Page 2 of 3)

OVERALL SPECIES COMPOSITION OF YEARLING AND OLDER FISH COLLECTED BY BEACH SEINE SAMPLING IN THE HUDSON RIVER ESTUARY DURING JULY AND AUGUST, 1974-1997

Common Name	Mean CPUE	Cumulative %
Satinfin shiner	0.001	99.138
Tautog	0.001	99.156
Silver perch	0.001	99.174
Northern searobin	0.001	99.192
Rainbow smelt	0.001	99.210
Fathead minnow	0.001	99.227
Threespine stickleback	0.001	99.245
Longear sunfish	0.001	99.263
Northern hog sucker	0.001	99.281
Northern stargazer	0.001	99.299
Chain pickerel	0.001	99.317
Atlantic croaker	0.001	99.335
Naked goby	0.001	99.352
Blacknose dace	0.001	99.370
Lookdown	0.001	99.388
Creek chub	0.001	99.406
White mullet	0.001	99.424
Comely shiner	0.001	99.442
Windowpane	0.001	99.459
Channel catfish	0.001	99.477
Trout perch	0.001	99.495
Hickory shad	0.001	99.513
Grass pickerel	0.001	99.531
Spotfin mojarra	0.001	99.549
Longnose dace	0.001	99.567
Brown trout	0.001	99.584
Bridle shiner	0.001	99.602
Gray snapper	0.001	99.620
Brook silverside	0.001	99.638
Cunner	0.001	99.656
Green sunfish	0.001	99.674
Fourspot flounder	0.001	99.691
Walleye	0.001	99.709
Cutlips minnow	0.001	99.727
Logperch	0.001	99.745
Black bullhead	0.001	99.763
Longhorn sculpin	0.001	99.781
Atlantic sturgeon	0.001	99.798
Yellow bullhead	0.001	99.816
Fall fish	0.001	99.834

TABLE V-47 (Page 3 of 3)

OVERALL SPECIES COMPOSITION OF YEARLING AND OLDER FISH COLLECTED BY BEACH SEINE SAMPLING IN THE HUDSON RIVER ESTUARY DURING JULY AND AUGUST, 1974-1997

Common Name	Mean CPUE	Cumulative %
Striped searobin	0.001	99.850
Striped anchovy	0.001	99.866
Atlantic tomcod	0.001	99.881
Winter flounder	0.001	99.895
Redfin pickerel	0.001	99.908
Weakfish	0.001	99.920
Inshore lizardfish	0.001	99.931
White crappie	0.001	99.942
Northern pike	0.001	99.951
Common shiner	0.001	99.960
Northern kingfish	0.001	99.969
Crevalle jack	0.001	99.978
Striped mullet	0.001	99.986
Bluntnose minnow	0.001	99.993
Butterfish	0.001	100.000
Total	7.453	

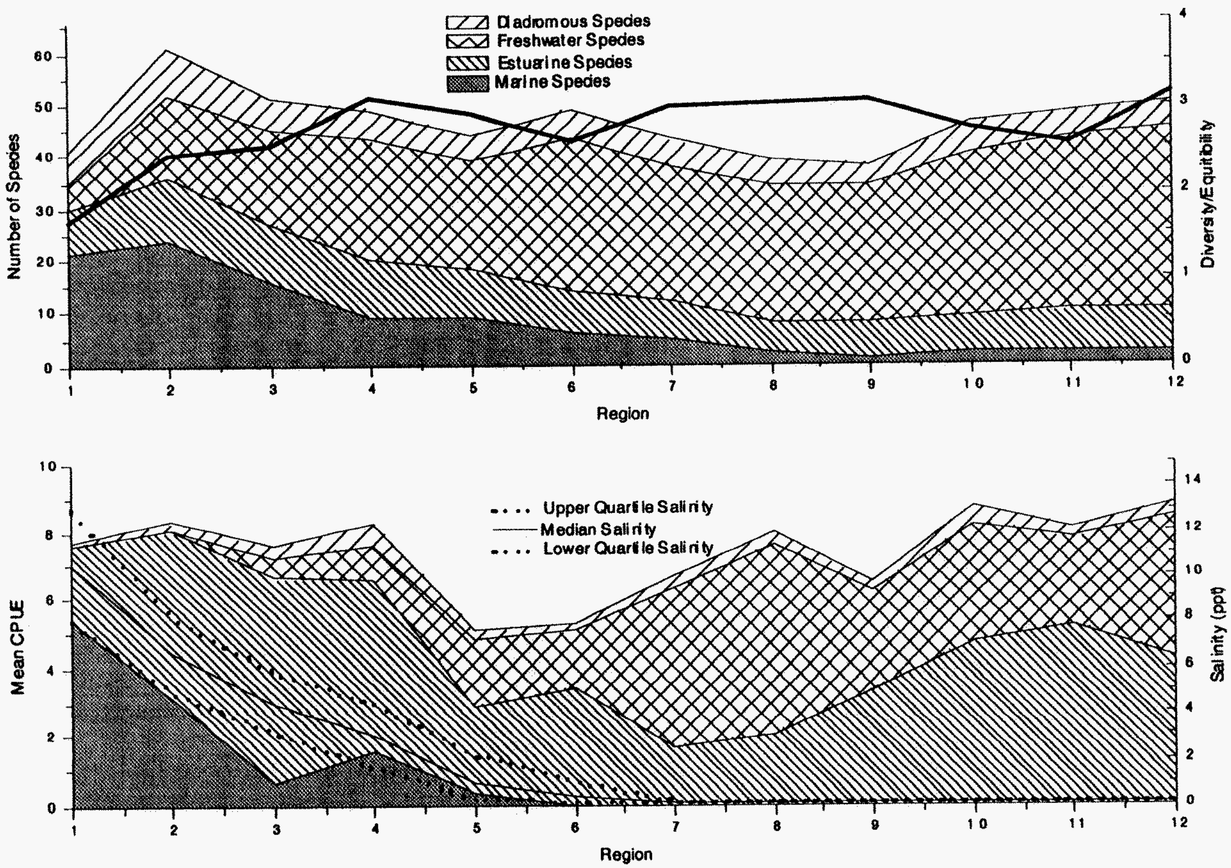


Figure V-131 Spatial pattern in species richness, diversity and overall abundance of yearling and older fish in littoral areas the Hudson River Estuary during July and August, 1974 – 1997.

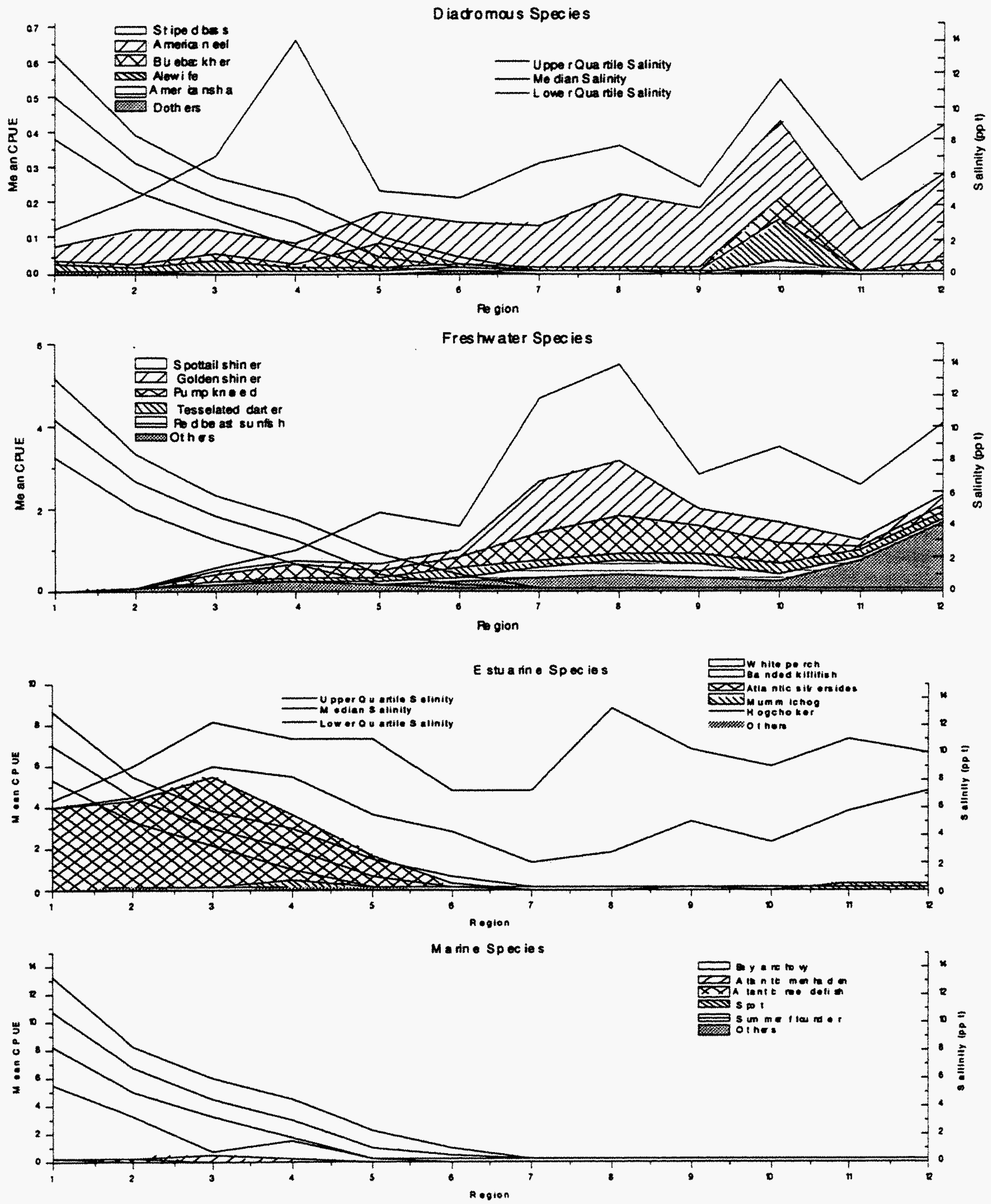


Figure V-132 Spatial pattern in the abundance of yearling and older fish of the dominant species in the Hudson River Estuary during July and August, 1974 – 1997.

few yearling and older diadromous species were collected. Most abundant were striped bass, principally in Region 4, and American eel (Figure V-132).

All but 1 of the 16 target fish species which are the focus of the overall impact assessment have been collected as yearling and older in the Beach Seine Survey (Table V-47). Together these 16 species accounted for more than 63% of the overall mean yearling and older catch. However, only 5 of these species could be considered common. Three of these common target species, bay anchovy, striped bass and hogchoker, were more abundant in the brackish zone (Regions 1-5) during July and August while the one of the common target species, spottail shiner was more abundant in freshwater zone (Regions 6-12) at this same time (Figure V-133). The most abundant species as yearling and older, white perch, did not exhibit substantial differences in mean abundance between the two zones.

Analysis of the long-term trends in the yearling and older fish community in littoral areas of the Estuary during July and August revealed a slight overall decline in the total number of species collected in the brackish (Regions 1-5) zone (Figure V-134). This decline appears to be a result of a decrease in the number of freshwater species, principally in the past decade. While there is considerable variability in the overall abundance of fish across the 24-year period, mean catch per unit effort of yearling and older fish appears slightly lower since the early 1990s, principally as a result of declines in the number of marine fish collected. The abundance of estuarine fish appears to have slightly increased in the 1980s while no trend was apparent for either freshwater or diadromous species in this zone. Overall species diversity in this zone also exhibited a slight decline, a pattern similar to that observed for the total number of species collected.

In the freshwater zone (Regions 6-12), there also appears to have been a slight decrease in the number of species in the yearling and older fish community, especially among the freshwater habitat group (Figure V-135). This decease, similar to that observed for young of year, appears to have occurred principally in the 1970s and early 1980s. Overall mean abundance in this zone exhibited considerable year-to-year variability with no long-term trend apparent. Collections were consistently dominated by freshwater and estuarine species. Overall species diversity in this zone also exhibited a slight decline, a pattern similar to that observed for the total number of species collected and that observed in downstream areas.

Analysis of the abundance trends in the dominant species among the yearling and older fish revealed considerable year-to-year variability in both zones of the Estuary (Figure V-136). In the brackish zone (Regions 1-5), the year-to-year variability was principally driven by year-to-year variation in the abundance of bay anchovy. In addition, there was

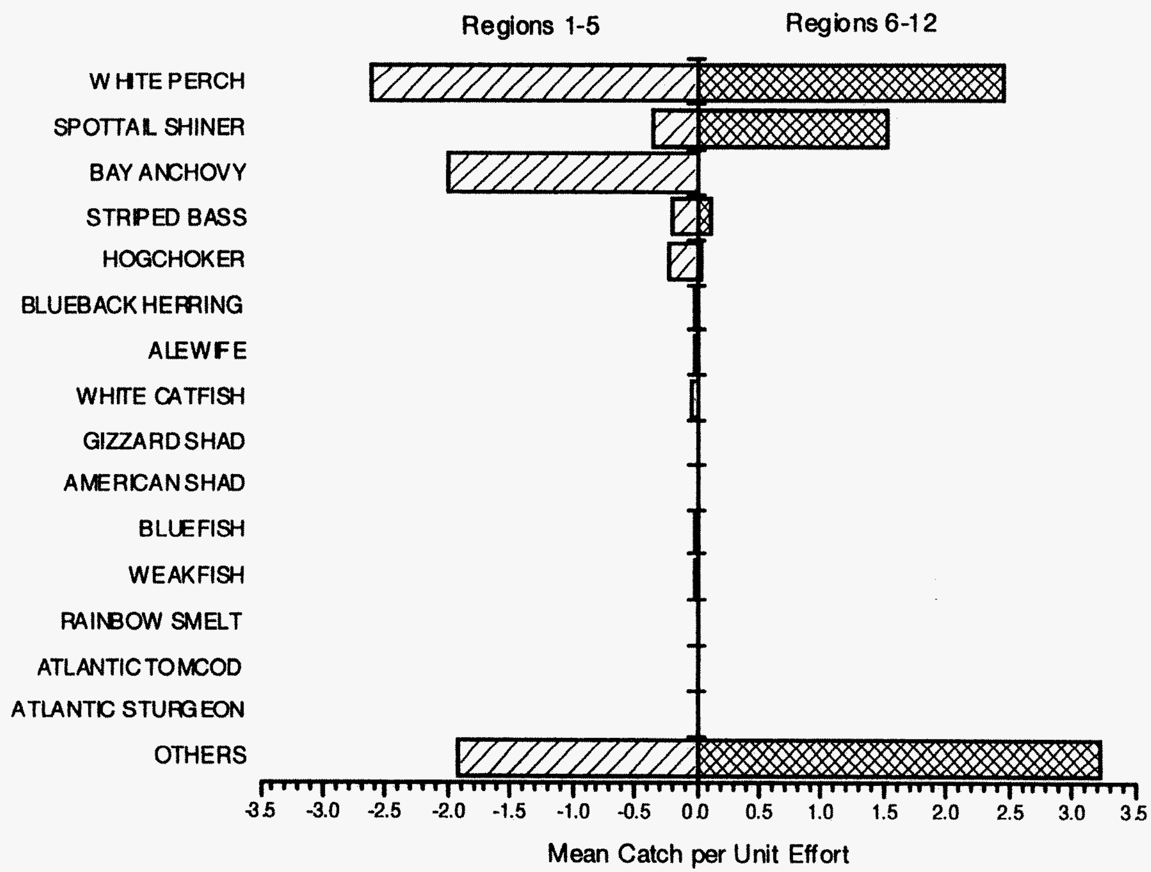


Figure V-133 Comparison of the mean abundance of yearling and older fish of selected species between brackish and freshwater littoral areas of the Hudson River Estuary during July and August, 1974 – 1997.

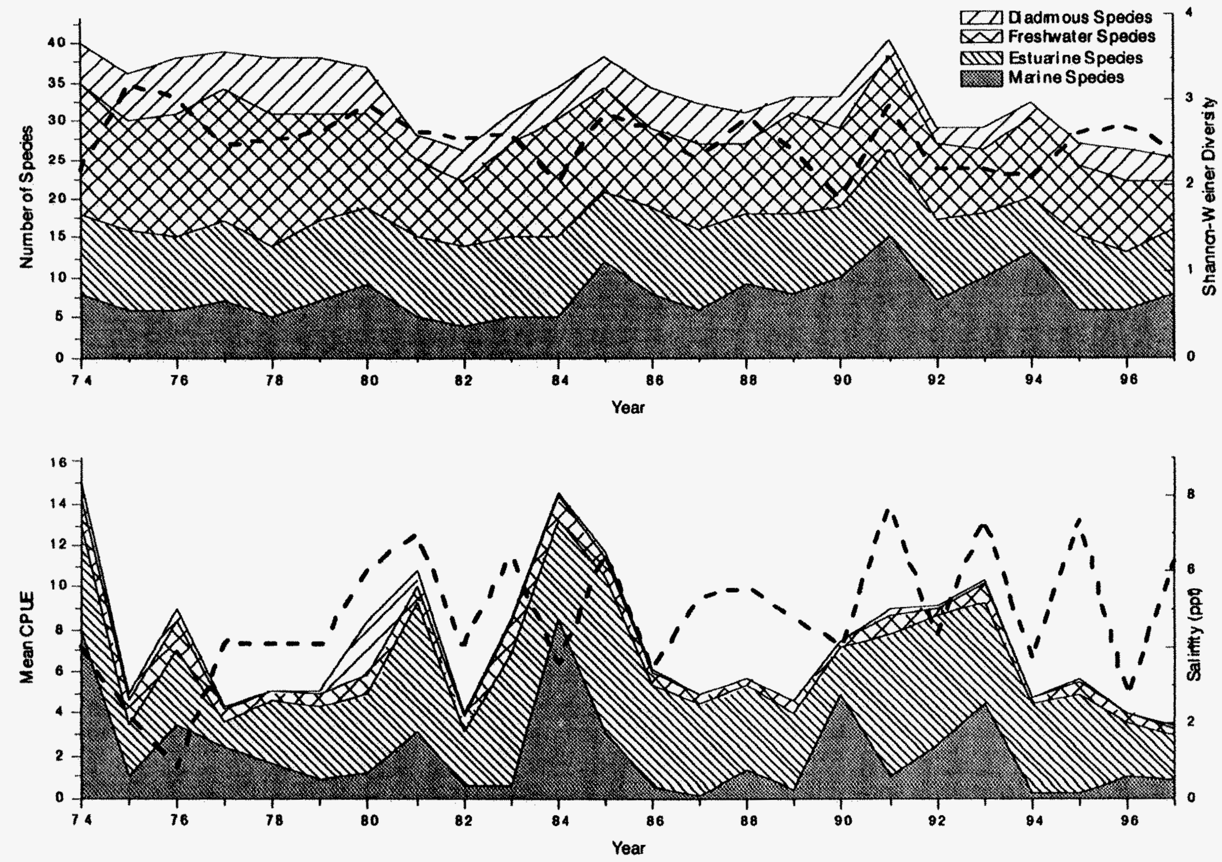


Figure V-134 Long-term trends in species richness and overall abundance of yearling and older fish in brackish littoral areas of the Hudson River Estuary during July and August, 1974 – 1997.

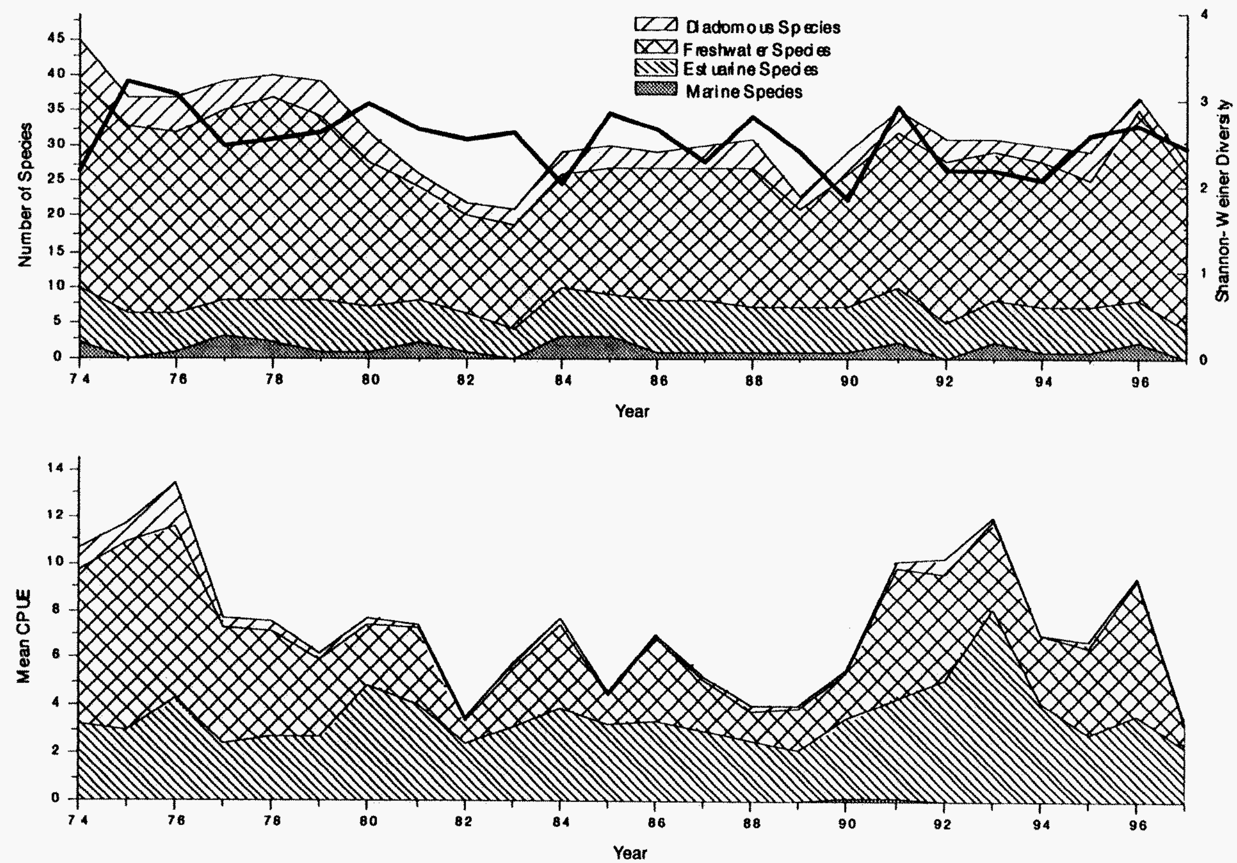


Figure V-135 Long-term trends in species richness and overall abundance of yearling and older fish in freshwater littoral areas of the Hudson River Estuary during July and August, 1974 – 1997.

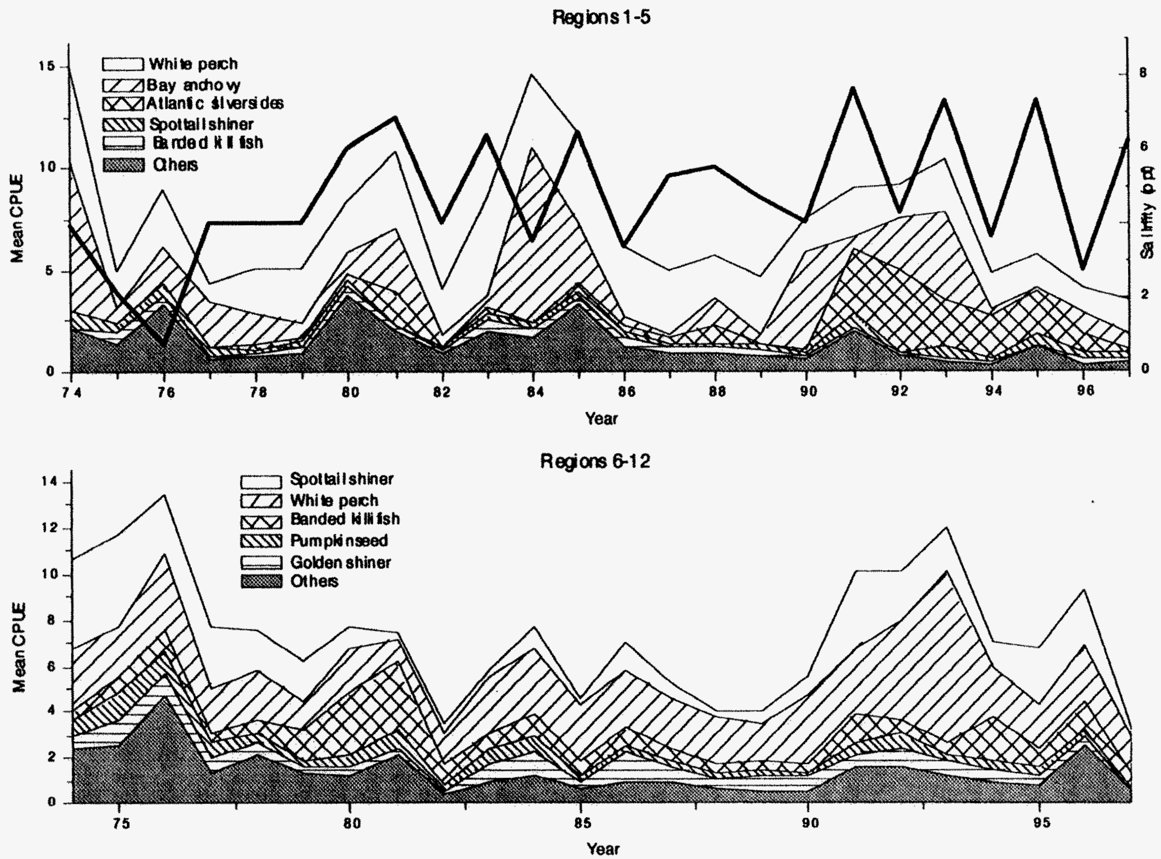


Figure V-136 Long-term trends in the abundance of yearling and older fish of the dominant species in littoral areas of the Hudson River Estuary during May and June, 1974 – 1997.

a substantial increase in the abundance of Atlantic silversides since 1990. Other commonly collected species in this zone included white perch, spottail shiner, and banded killifish, none of which exhibited significant year-to-year variability. In the freshwater zone (Regions 6-12), overall abundance patterns appear to be driven by the abundance of two species, white perch and spottail shiner. Other commonly collected species, such as banded killifish, pumpkinseed and golden shiner, did not exhibit wide fluctuations in abundance.

As a final step, potential long-term changes in the yearling and older fish community in July and August were evaluated by comparing the abundance of target species during the first 7 years of available data (1974 – 1980) to that observed in the most recent 7 years of data (1991 – 1997). This comparison revealed that yearling and older abundance in the brackish water zone (Regions 1-5) was higher in recent years for one target species, hogchoker, and lower for six target species, white perch, bay anchovy, striped bass, blueback herring, alewife, and white catfish (Figure V-137). Data were insufficient to determine trends for the other 8 target species collected. The substantial increase in non-target species can be attributed to increases in the single species, Atlantic silversides. In the freshwater zone (Regions 6-12), overall abundance in recent years was higher for one species, white perch, and lower for two target species, spottail shiner and striped bass. Data were insufficient to determine trends for the remaining target species.

ii. Overall Discussion

This assessment of the fish communities in the Hudson River Estuary focused on threecommunities, larval fish, young-of-year fish, and yearling and older fish. Each of these communities was selected to provide a measure of three key roles the Estuary serves for the fish community: as spawning habitat, as nursery habitat, and as year-round habitat for resident species. The assessment focused on four community characteristics: species richness, species diversity, dominant species succession, and target species succession. Together, these four characteristics provide a basis for assessing the overall health and condition of the fish communities in the Hudson.

This assessment is based on the results of intensive fisheries investigations of the Estuary conducted annually over the 24-year interval from 1974 through 1997. This time interval covers the period of increased cooling water withdrawals from the Hudson for electric generation, improvements in water quality resulting from improvements in wastewater treatment, substantial increases in areal coverage by water chestnuts as a result of the cessation of herbicide treatments, invasion of tidal freshwater areas by zebra mussels, and an increase in the abundance of large striped bass as a result of a substantial decrease in

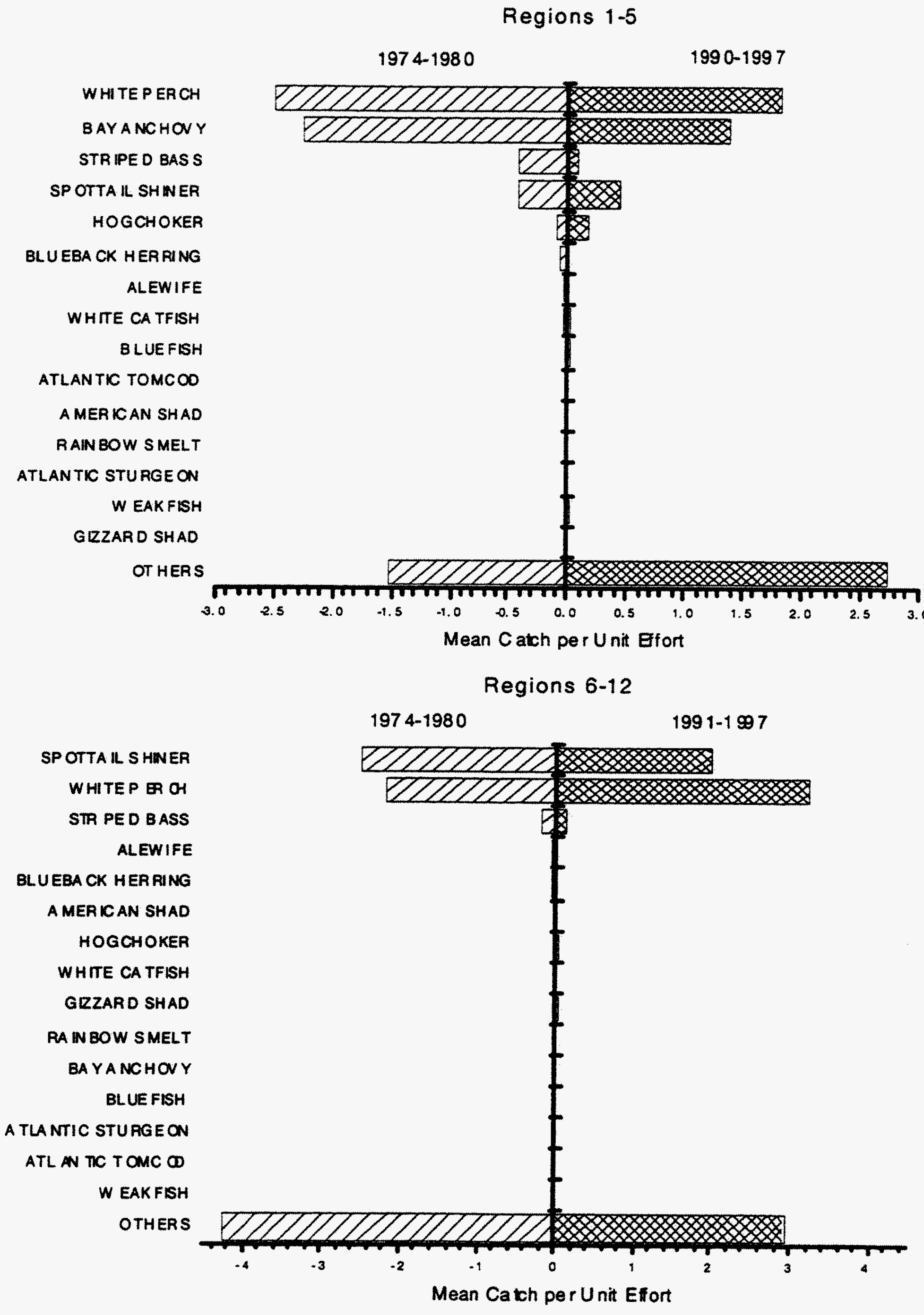


Figure V-137 Comparison of the mean abundance of yearling and older fish of selected species in July and August between two periods, 1974 – 1980 and 1991 – 1997, in littoral areas of the Hudson River Estuary.

commercial and recreational harvests. Each of these factors has the potential to alter the indigenous fish communities.

Key findings of this assessment of the fish communities are as follows:

1. The Estuary's is species rich. Each of the fisheries investigations used in this assessment reveals that a large number of species can be found in the Estuary at all life stages. Such high levels of species richness are often used as an indicator of a healthy ecosystem in which habitat and other water quality conditions allow a wide variety of species to occupy the habitat. The large number of species collected reflects the fact that the Hudson is at the intersection between the freshwaters of the upper Hudson watershed and the saltwaters of the Atlantic Ocean and at the intersection of warm- and cold-water areas of the Atlantic coastal environment (Smith and Lake 1990). In addition, the Erie Canal provides a pathway for fish species from the Great Lakes and Mississippi Drainages to enter the Estuary.

2. The Estuary's fish communities lack diversity at the species level. Despite the large number of species that can occasionally be found in the Estuary, a relatively small number are common. Usually, 10 – 15 percent of the species collected account for more than 99 percent of the catch. In an environmentally stable system, low species diversity is often associated with environmental stress. However in highly dynamic systems like the Hudson River Estuary, the biological communities are typically dominated by a few species well adapted to such naturally variable systems. Most of the energy in estuaries is directed towards production of a few species, many of which have considerable commercial and recreational importance to man.

3. The fish community in brackish areas is dominated by marine species whereas in tidal freshwater areas the fish community is dominated by diadromous species as larvae and young of year and by freshwater and estuarine species as yearling and older. Marine species appear largely limited to areas with salinities greater than 1 ppt, which in the Hudson typically includes areas downstream from Region 6. Most of the fish production in low salinity brackish and freshwater areas of the Estuary during spring and summer is directed towards diadromous species including river herring (alewife and blueback herring), striped bass, and American shad. These diadromous fish leave the Estuary in fall of their first year of life leaving the community of older individuals consisting primarily of resident species.

4. Species richness and overall abundance of the larval fish community increased since 1974. These increases are evident in all areas of the Estuary. The increase in species richness is largely attributable to the greater number of marine species collected, which may be related to improved water quality in New York Harbor allowing passage of more species from the ocean to the Estuary. Increases in overall abundance are due to increases in the abundance of larval striped bass throughout the Estuary as well as increases in the abundance of larval bay anchovy in brackish water areas. The increase in larval striped bass is a result of a decrease in the harvest of large striped bass and the subsequent increase in the number of adults spawning in the Hudson each year.

5. Species richness for the young-of-year fish community decreased whereas overall abundance has increased in brackish areas of the Estuary since 1974. Decreases in species richness appear a result of declines in the number of freshwater species collected in this area of the Estuary. Increases in overall abundance appear largely a result of recent increases in the abundance of two marine species, bay anchovy and Atlantic silversides. Both of these changes may be due to an increase in salinity across the years.

6. Species richness and overall abundance of the young-of-year fish community decreased in freshwater areas of the Estuary since 1974. Decreases in species richness appear largely a result of declines in the number of freshwater species collected, especially during the 1970s. This period coincides with the rapid expansion of water chestnut beds in freshwater areas of the Hudson following cessation of herbicide treatments. Dense beds of water chestnut do not provide favorable habitat for young-of-the-year fish because water circulation within these dense beds is poor and dissolved oxygen levels are very low at night. Overall abundance also declined during this same period, largely a result of declines in a single species, blueback herring. Declines in the abundance of this anadromous species appear to have occurred to all stocks throughout their geographic range and appear to be a result of factors outside of the Hudson, including overfishing in open ocean waters.

7. Species richness and overall abundance of the yearling and older fish community decreased in brackish areas of the Estuary since 1974. The decline in species richness appear to be largely a result of declines in the number of freshwater species collected, a pattern similar to that observed for young of year. Apparent decreases in the overall abundance of yearling and older fish in this area of the Estuary appear largely limited to the last 4 years

and to be primarily a result of a decline in bay anchovy abundance. As with young of year, the abundance of one species, Atlantic silverside, has substantially increased in this area of the Estuary since 1990.

8. <u>Species richness in the yearling and older fish community decreased in freshwater areas of the Estuary whereas overall abundance exhibits no long-term trend since 1974.</u> As for young of year, declines in the species richness appear to be largely attributable to changes in the number of freshwater species collected. As previously discussed, this may be related to habitat alternations resulting from expansion of water chestnut beds in the 1970s. Overall abundance exhibited considerable year-to-year variability in the abundance of a variety of freshwater and estuarine species, most notably white perch. No apparent long-term trend in abundance was evident.

4 Summary

a. Changes in the Environment

Four major changes occurred in the Hudson River ecosystem during the period from 1974 through 1997. Two affected the brackish water portion of the estuary (Regions 1-5) and two affected the freshwater portion of the estuary (Regions 6-12).

1. The decrease in the discharge of untreated wastewater into the estuary improved water quality, especially near Manhattan Island, and decreased ecosystem productivity in the lower portion of the estuary.

   The foodwebs in the Hudson River ecosystem are based upon non-living, particulate organic carbon from terrestrial sources. The discharge of untreated wastewater was a more important source of non-living, particulate organic carbon in the lower portion of the estuary than it was in the upper portion of the estuary. Relative to the upper portion of the estuary, human population densities were higher, aquatic plant production was lower, and agricultural and forest inputs were lower in the lower portion of the estuary.

2. The decrease in the recreational and commercial harvest of large striped bass increased the abundance of the top predator in the Hudson River ecosystem.

   Large striped bass are at the top of the foodweb in the Hudson River ecosystem and the increase in their abundance increased the predation pressure on young-of-the-year (YOY) and yearling fish in the brackish water portion of the estuary. It also increased the abundance of larval striped bass, which increased competition and predation among larval fish in the brackish water portion of the estuary.

3. The recovery of water chestnut populations to nuisance levels decreased the amount of shallow water habitat available to YOY fish in the freshwater portion of the estuary.

   Dense beds of water chestnut impair water circulation and cause dissolved oxygen levels to fall to very low levels at night. They also increase the production of organic matter within the freshwater portion of the estuary, which offsets the effect of decreases in the discharge of untreated wastewater on particulate organic carbon in this portion of the estuary.

4. The invasion by zebra mussels altered the lower portion of the foodweb in the freshwater portion of the estuary.

   The dense populations of zebra mussels filtered particulate matter out of the water column, improving water clarity and shifting invertebrate production from fine particle feeders in deep water (benthic invertebrates) to large particle feeders in the zebra mussel beds (epibenthic invertebrates).

b. Effects on Selected Hudson River Fish Species

The changes occurring in the Hudson River ecosystem during the period from 1974 through 1997 affected predatory and competitive relationships among the more common fish species that were selected for specific emphasis in this impact assessment.

1. Predation by large striped bass appeared to control the abundance of the following species and life stages:

   a) Age 1^+ and age 2^+ striped bass
   b) YOY bluefish
   c) Yearling and older hogchoker
   d) YOY white perch
   e) Adult rainbow smelt
   f) YOY white catfish
   g) Sub-adult American shad (the predation occurs in marine waters)

2. Predation by late post yolk-sac larval (PYSL) and early YOY striped bass appeared to control the abundance of the following species and life stages:

   a) PYSL and YOY striped bass
   b) PYSL white perch
   c) YOY bay anchovy
   d) YOY weakfish
   e) YOY spottail shiners (This species was negatively affected by the increase in the abundance of PYSL white perch during the 1980s and the negative effect of PYSL striped bass on the abundance of PYSL white perch during the late 1980s and 1990s had a positive effect on the abundance of YOY spottail shiners.)

3. Competition within and between the following species and life stages appeared to control their abundance after the decrease in the discharge of untreated wastewater into the brackish water portion of the estuary:

   a) PYSL and YOY Atlantic tomcod
   b) YOY bay anchovy
   c) YOY blueback herring

4. The improvement in water quality following the decrease in the discharge of untreated wastewater into the brackish water portion of the estuary appeared to have a positive effect on the abundance of two species that overwintered near the mouth of the estuary:

   a) Adult hogchoker (the increase in the abundance of adult hogchoker is reflected by a positive temporal trend in the abundance of YOY hogchoker.)

   b) Blue crab

5. The recovery of the water chestnut populations in the freshwater portions of the estuary appeared to have a negative effect on the abundance of YOY white perch before the abundance of large striped bass increased.

6 The invasion of the freshwater portion of the estuary by zebra mussels appeared to have a positive effect on the abundance of shortnose sturgeon, which is consistent with an increase in the production of epibenthic invertebrates.

7. The abundance of alewife and gizzard shad appeared to be unaffected by the changes in the Hudson River ecosystem.

8. Atlantic sturgeon was overfished and the effects of the changes in the Hudson River ecosystem could not be determined for this species.

c. Effects on Hudson River Fish Communities

The diversity of species within the fish communities in the Hudson River ecosystem was generally affected more by the ecosystem changes that affected water quality (the fish community in the brackish portion of the estuary) and habitat availability (the fish community in the freshwater portion of the estuary). The number of marine species entering the estuary increased when water quality increased in the New York City area. However, the diversity of YOY, yearling, and older fish in the lower portion of the estuary was more strongly affected (decreased) by the increase in the abundance of large striped bass. The number of freshwater species in the upper portion of the estuary decreased when the water chestnut populations recovered and achieved nuisance levels in the late 1970s and early 1980s.