

THE DIADROMOUS FISH FAUNA OF THE HUDSON RIVER:
LIFE HISTORIES, CONSERVATION CONCERNS, AND RESEARCH AVENUES

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Left running head: J. R. Waldman

Right running head: Diadromous Fishes

ABSTRACT

The Hudson River hosts populations of about 10 diadromous fishes—species that migrate between marine and fresh waters. Only one of these, American eel, is catadromous (spawns at sea); the remained are anadromous (spawning in fresh waters of the Hudson). Three anadromous species have been subjected to large, long-term, commercial fisheries: American shad, Atlantic sturgeon, and striped bass. Striped bass also support an intensive recreational

fishery both in and out of the river. Because of protection afforded the coastal migratory striped bass stocks, the abundance of the Hudson River stock is high at this time. Only American shad have low enough body burdens of polychlorinated biphenyls (PCBs) to allow commercial harvests today; the Hudson River stock has shown a long-term decline in which a recent component may be due to ecological or environmental factors. Because of commercial overfishing that occurred on the Hudson River stock of Atlantic sturgeon in the mid-1980s and early 1990s and because of the depleted status of most other populations, this species is being conserved under a fishing moratorium that may extend 40 years from its enactment in 1998. The river's other acipenserid, shortnose sturgeon, was one of the original taxa listed under the 1973 U.S. Endangered Species Act; there is evidence that its abundance has multiplied four-fold since then. Among the other herrings, marine-migrating blueback herring have colonized the Mohawk River—thus extending their distribution and increasing their abundance in the system. And hickory shad appear more numerous in the lower estuary but it remains unknown whether this poorly understood species reproduces in the Hudson River. Two cold-water fishes at the southern margin of their ranges have shown declines that may be related to thermal stress stemming from global warming. Recent studies have increased knowledge of the Hudson River's diadromous ichthyofauna, but many questions remain, particularly concerning the effects of non-native species and shifting community compositions. Opportunities exist to mitigate population declines through habitat enhancement. The future of the power industry, a major user of river water and source of fish mortality, will be an important factor influencing the trajectory of fish abundance, including the anadromous forms.

INTRODUCTION

Diadromous fishes are species that, as a routine phase of their life cycle, and for the vast majority of the population, migrate between marine and fresh waters (McDowall 1988). Of the diadromous fishes, anadromous species spawn in fresh water and catadromous forms spawn in salt water. The Hudson River presently hosts a diadromous ichthyofauna of about 10 species. They range from large, commercially valuable fishes such as Atlantic sturgeon (*Acipenser oxyrinchus*) and striped bass (*Morone saxatilis*) to small, largely ignored ones such as hickory shad (*Alosa mediocris*) and rainbow smelt (*Osmerus mordax*). The majority of the diadromous forms that occur in the Hudson are anadromous; the only catadromous species is the American eel (*Anguilla rostrata*). The Hudson also hosts a number of euryhaline species that typically remain within the estuary (e.g., white perch *Morone americana*, gizzard shad *Dorosoma cepedianum*). Two of these, shortnose sturgeon (*Acipenser brevirostrum*) and Atlantic tomcod (*Microgadus tomcod*), make seasonal movements between fresh and marine waters to the degree that they are often considered to be anadromous. Diagnostic keys, morphological descriptions, and information on the basic biology of the diadromous fishes of the Hudson River are available in Smith (1985). Additional sources of basic information on these species include Bigelow and Schroeder (1953), Scott and Crossman (1973), Murdy et al. (1997), and Able and Fahay (1998).

It is generally accepted that populations of anadromous fishes in the Hudson River were established recently—within about 10,000 years—as the river was colonized or recolonized following deglaciation (Schmidt 1986). Other rivers within the Hudson River estuary complex, such as the Raritan, Passaic, Hackensack, and smaller tributaries supported or still support a portion of the suite of diadromous species that run up the Hudson; the extent of reproductive interchange among these subpopulations remains unknown. Several commercially-fished species have undergone large fluctuations in abundance in historical times that are at least partly, and in some cases, largely, due to anthropogenic effects. Commercial and recreational overharvest, either within the estuary or outside it, or both, is primary and largely traceable through catch statistics. Entrainment and impingement mortality by electric-generating stations also has decreased the abundance of some diadromous species in the Hudson River. Some information on fluctuations of abundance of a variety of fish species is available from surveys conducted by the Hudson River electric generating companies (e.g., Barnthouse et al. 1988). Much of the results of the utilities-sponsored monitoring have not entered the peer-reviewed literature but are available in reports; sources include the library of the Hudson River Environmental Society housed at Marist College, Poughkeepsie, and the Hudson River

Foundation, New York, New York.

The most recent synopses of information about certain of the Hudson River's diadromous fishes can be found in Barnthouse et al. (1988), and Smith (1988; 1992). In this paper I briefly summarize the life histories of the diadromous fishes of the Hudson River, focusing on recent findings, and on conservation concerns, and status and trends of these fishes. I also explore commonalities and differences among them and point to problems in their biology that would benefit from further research. The species are presented in phylogenetic order (Nelson 1976) by family.

LIFE HISTORY AND RECENT-RESEARCH SYNOPSES

Petromyzontidae

Petromyzon marinus sea lamprey.—Sea lamprey is a large parasitic lamprey with a complex life cycle (Beamish 1980). Although sea lamprey spawn and are numerous in the two large systems that bracket the Hudson River, i.e., the Connecticut and Delaware rivers, adult lamprey are scarce in the Hudson. Greeley (1937) listed them as rare in the mainstem river. No directed studies of sea lamprey in the Hudson drainage have occurred but there have been reports that suggest some reproduction takes place in a few of the more than 60 tributaries between New York City and the federal dam at Troy. The system-wide survey by Greeley (1937) found a larval specimen from Rondout Creek and an adult from Catskill Creek; none were found in the Roeliff Jansen Kill, Croton River, or other tributaries sampled. They also were observed near the confluence of Catskill and Kaaterskill creeks (R. Schmidt, Simon's Rock of Bard College, personal observation). Sea lamprey have been taken at Fort Edward (Smith 1985), indicating they can pass the dam at Troy (although it is possible that they were of freshwater origin and arrived via the canal system). Subadult sea lampreys are sometimes seen in the Hudson River attached to American shad (Greeley 1937; HRA 1998) and gizzard shad (HRA 1998).

Why sea lamprey should be highly abundant in the Delaware and Connecticut rivers but not in the intervening Hudson is not obvious but may be due to habitat limitations. Although either ammocoetes or spawning size sea lamprey have been documented to occur in at least 134 coastal rivers in North America, they do not reproduce in every river available, particularly in the southern part of their range (Beamish 1980). Sea lamprey construct nests for spawning composed of rubble and gravel, in sections of rivers with moderate flows, often as far upriver as movement allows. After hatching, their larvae leave the nest and drift downstream to suitable silt beds

(e.g., eddies, backwaters, behind obstructions) where the ammocoetes mature.

The main channel of the Hudson River clearly does not provide suitable spawning habitat for sea lamprey, nor are ammocoetes known to occupy tidal waters. Although some sea lamprey reproduction may occur in a few tributaries to the Hudson River, I believe it is limited by the generally small sizes of these systems, their short lengths below the fall line, and perhaps, their infrequent combinations of good spawning and nursery habitats.

Acipenseridae

Acipenser oxyrinchus Atlantic sturgeon—Atlantic sturgeon is a large, marine-migrating acipenserid of considerable commercial value. Extant populations of the east coast subspecies, A. o. oxyrinchus occur from the St. Lawrence River to rivers in southern Georgia, and possibly to the St. John River, Florida (Waldman and Wirgin 1998). This sturgeon was known to exceed 300 kg in weight and 60 yr in age.

Dovel and Berggren (1983) performed the first comprehensive studies of Atlantic sturgeon in the Hudson River. Sonic transmitters were used to follow specimens and describe the seasonal movement patterns, which included delineation of spawning as occurring near the salt front (~km 55) in late May and moving upstream as far as Hyde Park later in the season. Growth of younger specimens was found to occur primarily between May and October and to slow after age three. Conventional tagging of immature Atlantic sturgeon showed that some leave the Hudson River as early as their fifteenth month but no later than age six. Immature specimens were recaptured in coastal waters as far north as Marblehead, Massachusetts, and south to Ocrocoke, North Carolina. Most recaptures occurred in the Delaware River and Chesapeake Bay estuaries, and their phenology implied a northerly migration in spring and southerly movements in autumn. Dovel and Berggren (1983) estimated that the 1976 year class of Atlantic sturgeon in the Hudson River totaled about 25,000 in 1978.

A flourish of studies in the 1990s extended the fundamental life history work of Dovel on the Atlantic sturgeon population of the Hudson River. Analysis of fin ray sections suggested that Hudson River-stock females spawn on average every four years (Secor et al. 1997). VanEennaam et al. (1996) could collect spawning specimens only at two historically important upriver fishing sites (Hyde Park and Catskill) and they argued that spawning near the salt front was unlikely given the physiological requirements of the species' early life stages. Sonic tagging by Bain et al. (1998) showed that spawning occurs over a period of weeks at several sites between km 113 and 184. They also found that large numbers of subadults and adults (some of which were believed to be post-

spawners) aggregate during mid-summer through fall just upstream of the Bear Mountain Bridge.

Haley (1998) developed a gastric lavage technique to study sturgeon food habits without sacrificing them. In her application of this approach to 23 Atlantic sturgeon specimens captured between June and September 1996, she found major prey items to include polychaetes, isopods, and amphipods.

In October 1994, 4,929 hatchery-reared, 6-mo old Atlantic sturgeon were stocked into the Hudson River at km 89 and 90. Because these fish were fin-clipped and tagged, they were distinguishable from wild specimens from the same year class. Peterson et al. (2000) used this difference to perform a Peterson estimate of abundance of wild age-1 Atlantic sturgeon, which generated a value of 4,313 individuals, with a 95% confidence interval of 1,917 - 10,474. Although based on only one wild year class, this estimate was about 80% lower than estimates obtained by Dovel and Berggren (1983) from the mid-1970s.

Atlantic sturgeon had been fished in the Hudson River since prehistoric times (Brumbach 1986) and in the late 19th and early 20th centuries, special nets were used to harvest them and they were skinned, sliced, and then sold under the name “Albany beef” (Greeley 1937). However, the Hudson River’s population appeared not to experience the magnitude of overfishing that occurred in the Delaware River during the caviar craze of the late nineteenth century (e.g., Secor and Waldman 1999). This may have been due, in part, to the difficulties in fishing gill nets near the bottom of a deep, strongly tidal river, which offered only four, more easily fished, but brief, slack-water periods per 24 h. Greeley (1937) noted that some commercial fishermen believed that young Atlantic sturgeon with their more pronounced snouts (referred to as “pelicans”) were a different species. American shad fishermen commonly destroyed these fish so as to not trouble them again.

But there was no evidence of a significant population abundance change until the mid-1980s. At that time, observed numbers of juvenile Atlantic sturgeon in commercial fishing bycatch and utilities-sponsored monitoring programs declined substantially (Bain et al. 1998), precipitating increased research interests in this population. Moreover, as alternative target species continued to decline in abundance, commercial fishermen both inside and outside of the Hudson River began to focus on Atlantic sturgeon. Landings in New Jersey’s coastal waters increased from 5,900 kg in 1988 to approximately 100,000 kg in 1990. And New York’s coastal harvest rose from about 7,700 kg in 1993 to almost 16,000 kg in 1994 (Waldman et al. 1996). Mixed-stock analysis using mitochondrial DNA markers showed that approximately 99% of the sturgeon in the New York Bight fisheries were of Hudson River origin (Waldman et al. 1996a).

However, in response to this increase and the overall scarcity of Atlantic sturgeon in other river systems (Waldman and Wirgin 1998), a moratorium on commercial harvest in U.S. waters was enacted in 1998 that may extend for as much as 40 yr to establish 20 protected year classes of females in each spawning stock. This extreme measure was justified because the Atlantic sturgeon's late age at maturity, low relative fecundity, and infrequent spawning results in extreme sensitivity to low rates of exploitation (Secor et al. 1997).

Acipenser brevirostrum shortnose sturgeon—Shortnose sturgeon is a small, amphidromous acipenserid which occurs in about 20 estuary systems from the St. John River, New Brunswick, to the St. Johns River, Florida. Many of its populations have been sharply reduced and number only in the hundreds to thousands (ASMFC 1998). It was one of the original taxa listed under the 1973 U.S. Endangered Species Act.

Shortnose sturgeon are long-lived, reaching almost 70 years. In the Hudson River they have been caught up to at least 105 cm (total length) and 10.7 kg (Dovel et al. 1992). Hudson River males don't mature until age 3, and females not until age 6, or later (Bain 1997). Early growth is rapid: yearlings may exceed 30 cm by their second summer (Dovel et al. 1992). However, the rate of growth declines substantially as subadults and adults (Bain 1997). Indeed, it may stop completely based on the results of Bain et al. (1998) who recaptured 19 individuals between 1993 and 1995 that were tagged by Dovel et al. (1992) in 1979 and 1980. Of these recaptures, 17 were adults when tagged and on average had grown only 86 mm and some showed no increase in length at all.

Information on the feeding habits of shortnose sturgeon in the Hudson River is scarce, partly because it is difficult subject to study for an endangered species. Carlson and Simpson (1987) were able to examine stomachs of 42 young-of-the-year and 10 yearling specimens that were impinged and killed on the cooling water intake screens at a power plant at km 228. Predominant prey varied seasonally but included midge larvae, amphipods, and isopods. Although Carlson and Simpson (1987) found little reliance on molluscs for young age classes, Bain (1997) summarized observations from the 1930s that adults consumed considerable numbers of molluscs, in addition to insects and crustaceans. Bain et al. (1998) determined that shortnose sturgeon also eat the non-native but extremely abundant zebra mussel Dreissena polymorpha. Haley (1998) found principal food items to include both soft-bodied invertebrates (e.g., amphipods, chironomids, and isopods) and shelled organisms such as snails and zebra mussels.

Syntheses of data (Geoghegan et al. 1992) from three utilities-sponsored fish monitoring programs between 1983-1988 (excluding winter) showed that shortnose sturgeon from 10 to 120 cm TL were most common between

km 140 and 149 (near Kingston) and at km 55 (near Croton Point). Investigations by Dovel et al. (1992) and Bain (1997) have demonstrated a complicated seasonal pattern of movements for reproductively-mature adults that is dependent on whether individuals are spawning in a given year. The frequency of spawning for the St. John River population was estimated at between every third to fifth year for females, and every second year for males (Dadswell 1979). However, these values may not apply to the Hudson River population inasmuch as Dovel et al. (1992) reported the occurrence of some tagged shortnose sturgeon on the spawning grounds in successive years.

Pre-spawning adults overwinter in one large concentration at a bend in the river near Esopus Meadows (Bain 1997). These reproductively-active adults then re-aggregate and spawn far up the tidal Hudson River from about Coxsackie (km 190) to immediately downstream of the federal dam. Later, individuals that spawned disperse widely, mixing with reproductively-quiescent adults, primarily in deep, channel habitats of the fresh- and brackish-water reaches. As winter approaches adults again segregate according to whether they will spawn the following year, with non-spawners wintering farther downriver than spawners, between km 54 and 61 (Bain 1997).

Recent work demonstrated stock differences between shortnose sturgeon from the Hudson River and other populations. These included a number of morphometric features in comparison with specimens from the Kennebec and Androscoggin Rivers (Walsh et al., in press) and in mitochondrial DNA control region sequences in comparison with populations ranging across the entire range of the species (Grunwald et al., submitted).

There does not appear to have been a concerted commercial fishery for shortnose sturgeon in the Hudson River (where they were also known as “roundnosers”; Dovel et al. 1992), although some individuals were harvested (Boyle 1969; Dovel et al. 1992), particularly in the central Hudson, near Rhinecliff, where Greeley (1937) stated it was of “some commercial importance.” Bain (personal communication, Cornell University) estimated the abundance of adult shortnose sturgeon in the Hudson River during the late 1990s as approximately 61,000, a more than four-fold increase since the early 1980s (based on the work of Dovel et al. 1992). Bain believes the Hudson River population may exceed in abundance the total of the approximately 20 other populations of the species. As such, they suggest that the shortnose sturgeon population of the Hudson River is recovered and is a candidate for de-listing under the 1973 U.S. Endangered Species Act. If de-listing should occur, it would be the first instance for a segment of an endangered fish species.

Anguillidae

Anguilla rostrata American eel—This catadromous species spawns in the Sargasso Sea; afterwards its developing larvae (leptocephali) are advected toward North America (ASMFC 2000). Leptocephali metamorphose into glass eels (unpigmented and transparent juveniles) in coastal habitats and are subsequently transported into estuaries. They become pigmented as they move inland into rivers and estuaries. After one to two years they pigment fully to become “yellow” eels, residing for upwards of 30 yr before metamorphosing into “silver” eels and returning to the Sargasso Sea to spawn and die. Because of their dispersive and random recruitment to individual river systems, American eels form one genetically panmictic population. However, eels in the northern portion of their range mature at greater ages and sizes than in more southerly regions, resulting in northern females being more fecund and having a relatively long life span.

Eels have been little studied within the Hudson River estuary. They were known to move upstream past the federal dam as far as Saratoga Lake (Brumbach 1986) and into several Adirondack lakes (Greeley 1933). The survey by Greeley (1937) found eels in numerous streams and lakes in the drainage of the lower Hudson River.

Peak immigration of elvers into the Hudson estuary occurs from mid-March through April (Mattes 1989). Stomach analysis by Mattes (1989) of 468 eels trawled between Manhattan and Troy revealed a generalized feeding pattern with 48 species of prey found. Important food items included crustaceans, molluscs, and fish.

Parasites of American eels in the Hudson River have received attention. Hunter (1937) described a roundworm which occupies the fish’s body cavity and which renders them unfit for table use or market. Barse and Secor (1999) documented the occurrence in American eels in the Hudson River of a swimbladder infesting nematode native to eastern Asia.

The commercial fishery for yellow eels in the Hudson River has been closed since 1976 because of contamination with polychlorinated biphenyls (PCBs); Hudson River specimens were found to have PCB levels of 50 to 75 ppm (Blake 1982). Overall landings of American eel in the U.S. together with estimates of eels passed at dams and taken in surveys indicate a substantial decline in the species’ abundance since 1979 (ASMFC 2000). Although a significant glass eel fishery never developed in New York, in 1995 the state has imposed a minimum length limit for harvest in marine waters of 15 cm (ASMFC 2000).

Clupeidae

Alosa sapidissima American shad.—The American shad is the largest North American alosid, reaching weights of 10 pounds or more. Populations occur in medium- to large-sized rivers between the St. Lawrence and St. Johns Rivers. Because its PCB body burdens meet federal standards, American shad is the only fin fish still legally harvestable in the Hudson River by commercial fisherman. It is sought for both its flesh and roe.

Within-population variation of American shad has received little attention. Interesting differences in external characteristics were observed by commercial fishermen early in the 1900s (Greeley 1937). Greeley reported that two types were observed: a form called the “blueback” and the much less common “yellowback.” These types differed subtly in ground color, pigmentation pattern, and snout dimensions (Greeley 1937). Yellowbacks already were very scarce at the time of Greeley’s survey.

American shad spawn in spring at water temperatures between 12^o and 21^oC; most spawning occurs between dusk and midnight. In the Hudson River, American shad are main channel spawners (although I am aware of anecdotal reports of adult American shad occurring in the Croton and Rondout Rivers). Eggs of American shad have been collected over a broad reach of the Hudson River, from the Albany area downstream to about km 83, but with highest densities in northern sections (Schmidt et al. 1988). American shad larvae show progressive dispersal downstream from areas of highest egg densities. Limburg (1996) performed a fine-scale study of the patterns of growth and seaward migration of the 1990 year class of American shad in the Hudson River. She found migration to be both size- and age-related, with upriver fish consistently smaller and younger than downriver specimens until late in the season. Otolith analysis showed that recruitment of juveniles from the 1990 year class was not spread proportionately across birth dates. Although most American shad spawning activity occurred in early to mid-May, the year class was established mainly by individuals hatched in June; a discrepancy attributed to probable weather-related effects on food availability to larvae.

Juvenile American shad in the Hudson River feed primarily on epiphytic rather than benthic invertebrates, particularly chironomid larvae and formicid hymenopterans (Grabe 1996). They often feed at the surface during afternoon and evening, consuming terrestrial insects.

American shad range coastally from Labrador to Florida. They are long-distance, but mainly, inshore, migrators; during an average life span of 5 yr at sea, an individual may travel more than 20,000 km (Dadswell et al. 1987). Dadswell et al. (1987) analyzed 1,837 returns from 11,579 American shad tagged in the Hudson River and New York Bight. Although more than 85% of recaptures occurred in the Hudson River, recaptures from outside the

river ranged from just south of Cape Hatteras to the upper reaches of the Bay of Fundy and to Halifax on Nova Scotia's east coast.

Leggett and Carscadden (1978) demonstrated that American shad show latitudinal variation in reproductive characteristics, including whether all individuals in a population died after first spawning (semelparity) or if repeat spawning occurred (iteroparity). Repeat spawning of American shad in the Hudson River appears to occur at a rate of more than 40% (ASMFC 1998).

American shad population size in the Hudson River is believed to have declined from about 2.3 million in 1980 to 404,000 in 1996 (ASMFC 1998). Inriver commercial landings declined from about 2.6 million pounds in 1980 to less than 250,000 pounds in 1996. Although inriver fishing mortality rates declined over that period, coastal fishing mortality rates ("intercept fishery") increased, and total fishing mortality rates have remained stable and independent of stock decline from 1980 to 1996. Moreover, juvenile recruitment has been high and relatively stable, yet adult stock size continued to decline to historic low levels. It may be that abiotic or biotic factors (possibly striped bass predation) rather than overfishing have caused the recent decline in the Hudson River shad stock (ASMFC 1998).

A number of baseline genetic studies have shown significant differences among American shad stocks, including the Hudson River's (e.g., Bentzen et al. 1989, Nolan et al. 1991, Waldman et al. 1996). Brown et al. (1999) extended this work to estimate the relative contributions of American shad stocks to coastal intercept fisheries in Maryland and Virginia and found that the composition of harvests were variable from year to year and location to location. Brown (1996) also applied this approach to intercept fishery landings from locations in New Jersey ranging from Sandy Hook to Cape May. In these New York Bight waters proximal to the Hudson River, the Hudson River stock was estimated to compose 21% of the 1994 catch and 22% of the 1995 catch. A recent pilot study of trace element signatures in otoliths also showed promise in discriminating the Hudson River stock of American shad (Thorrold et al. 1998). All coastal intercept fishing for American shad will be phased out by 2003.

Alosa mediocris hickory shad.—The hickory shad is a medium-sized alosid (maximum size approximately 60 cm) that ranges from the Bay of Fundy to the St. Johns River, Florida. Its general life history remains largely undescribed. Adults often occur in inshore waters in the New York Bight and Long Island Sound, sometimes in high abundance, particularly near river mouths. Unlike the other North American shads, hickory shad is highly

piscivorous, but it also consumes invertebrates.

Little is known of hickory shad within the Hudson River. Beebe and Savidge (1988) noted that it has been recorded from the Yonkers, Tappan Zee, and Indian Point regions of the Hudson River. Smith (1985) reported that anglers occasionally take them in the Hudson. Bean (1903) stated that it was commonly caught at Gravesend Bay (at the mouth of the Hudson estuary) between September and November. Bean (1903) reported that the ascent of hickory shad precedes that of American shad in rivers where they co-occur. But although hickory shad have been caught in the Hudson River, there does not seem to be any conclusive evidence that they reproduce there.

I believe hickory shad abundance in the coastal waters of the New York Bight and Long Island Sound have increased substantially in the 1990s based on anecdotal reports in the angling literature and my personal observations, a trend that also has been noted in Connecticut and the Chesapeake Bay (ASMFC 1999). If so, it is not clear whether this increase represents increased reproduction in the Hudson River or immigration from other sources.

Alosa pseudoharengus alewife.—Alewife are small alosines that occur in drainages and coastal waters from Newfoundland to South Carolina. They differ morphologically from the other “river herring,” the blueback herring, in several characteristics, most notably by their greater body depth and their pale instead of black or sooty peritoneum. A simple, scale-based discrimination approach has also been suggested (MacLellan et al. 1981).

Alewives co-occur with blueback herring in many drainages, between New Brunswick and South Carolina. A maximum total length of 38 cm has been attributed to both species (Loesch 1987), but such specimens are rare. Unlike blueback herring, the alewife landlocks readily, often in dwarf form. These populations are referred to as “sawbellies” and are widely used as bait for salmonids. Landlocked alewives exist in numerous reservoirs in the Hudson River drainage, including in the New York City Reservoir Supply System (e.g., Kensico Reservoir; Greeley 1937).

Alewives begin spawning at between 5 and 10⁰C and prefer slow-flowing sections of streams or ponds and lakes. Fecundity is variable but is related to size and age, reaching as high as 467,000 eggs. First spawning of both river herrings occurs from ages 3 to 6, but is dominated by age-4 fish (Loesch 1987). Fecundity appears to peak at age-6 and declines afterward. Alewives return to sea after spawning but little is known of their marine migrations. Juveniles move down their natal rivers and, most, if not all exit these systems before their first winter. However,

resident subpopulations may occur in large estuaries such as in the upper Chesapeake Bay (Foerster and Goodbred 1978).

There has been little targeted research on either river herring in the Hudson River drainage, but a variety of surveys have yielded some system-specific information. Schmidt et al. (1988) analyzed data from early life history surveys performed between 1976 and 1979. Juvenile alewives appeared in seine collections from late June to early July, about a month later than juvenile American shad. In the upper and middle zones of the estuary, catches declined in early July while they increased in offshore bottom trawl catches, signifying a movement from the shallows and mouths of tributary streams to deeper waters. Summer catches showed an overall movement downriver, with numbers declining after August, presumably because of emigration. But juveniles were found downriver through the end of sampling in mid-December; some may remain in the estuary all winter. Indeed, elemental composition analysis of small but spawning adult alewives from Cocksackie Creek indicated that some alewives may remain within the Hudson River estuary for their entire life cycle (R. Schmidt, personal communication). Hudson River juveniles feed primarily on chironomids and amphipods, with no diel differences in feeding activity (Grabe 1996).

Lake and Schmidt (1997) surveyed fish usage during spring of a small Hudson River tributary, Quassaic Creek, located near Newburgh, NY. In 1996, the first alewife specimens were seen on April 3. Only males were caught until April 14. Peak spawning appeared to occur on April 19 at a water temperature of 9.4°C, with a secondary peak in mid-May, but spawning continued until early June. Adult males averaged 267 mm TL; females averaged 6 mm longer. The total adult spawning run in Quassaic Creek for 1996 was estimated at about 5,600 individuals. Lake and Schmidt (1998) investigated the alewife spawning run in Quassaic Creek more intensively in 1997. They found fecundity to range from 15,000 to 135,000 eggs and female total lengths from 232 to 318 mm. Alewife spawning activity was similarly bimodal to 1996 and the total number of eggs deposited in this single system was estimated at 162 million. In more extensive surveys in 1998 and 1999, Schmidt and Lake (2000) documented river herring (mainly alewife) runs in 28 of the 38 Hudson River tributaries they sampled.

Although river herring are rarely sought for food from the Hudson River, they are heavily harvested for bait for striped bass during the stripers spring spawning run; Vargo (1995) considers them to be the best bait for large striped bass. Anglers catch their own or buy them from local commercial collectors who use large dip nets in tributaries.

Alosa aestivalis blueback herring.—Blueback herring is one of the two “river herrings,” but although it is sympatric with the alewife over part of its range, it has a more southern distribution. Blueback herring range from Nova Scotia to Florida. Where they co-occur in spawning rivers with alewives, blueback herring achieve some niche separation by running later in the season (peak spawning lagged by 2-3 wk) and by choosing relatively swiftly running sites to spawn in (Loesch 1987). Lengths of spawning adult blueback herring are similar to alewives.

Because they spawn later, recruitment of juvenile blueback herring in the Hudson River system occurs later than that for American shad and alewife (Schmidt et al. 1988). Schmidt et al. (1988) found that juvenile blueback herring numbers dwarfed the other alosids in summer; they believed this reflects actual abundances in the system despite a higher vulnerability of blueback herring to sampling gear. Blueback herring are the most planktivorous of juvenile alosids in the Hudson River and are most active during daylight (Schmidt et al. 1988; Grabe 1996). Primary prey includes copepods, chironomids, and cladocerans.

Blueback herring have not been well-studied in the Hudson River system and most of what is known has been obtained tangentially or anecdotally. Daniels (1995) noted that the survey by Greeley (1937) found blueback herring at only 4 of 112 sites sampled; whereas in Daniels' own 1990 survey and in monitoring conducted in the 1970s and 1980s, blueback herring dominated summer catches at inshore sites. Surveys have shown that blueback herring are either absent or uncommon in most of the tributaries examined that enter the Hudson River below the dam at Troy. In their surveys of 1998 and 1999, Schmidt and Lake (2000) found adult blueback herring in only 7 of the 28 tributaries in which river herring were encountered. The percentages of blueback herring of all river herring ranged from 0.5% ($N = 200$) in Canterbury Brook (km 93) to 50.0% ($N = 6$) in the Normans Kill (km 225). Blueback herring were seen in the four northernmost tributaries, which ranged to the Poesten Kill (km 241).

A large number of blueback herring on their spawning run swim through the mainstem tidal Hudson River to the federal dam, where they often aggregate as they attempt to pass the dam through the turbines or the navigation lock. Adult blueback herring are commonplace in the Mohawk River system during spring. MacNeill (1998) believes they spawn near Rome, New York, at the highest elevation of the Mohawk corridor.

Osmeridae

Osmerus mordax rainbow smelt.—Rainbow smelt is a slender, elongate fish that ranges from the Hudson River

northward to the Arctic and which occurs in landlocked form both naturally and through stocking in freshwater lakes. Maximum size is about 30 cm. Little is known of the marine movements of anadromous populations. Spawning occurs after individuals have passed two winters at sea. Rainbow smelt reproduce in early spring; egg fecundity ranges between 10^3 - 10^4 and eggs hatch in 10 to 30 d. In marine waters smelt eat crustaceans, nereid worms, and fish. In fresh water they consume shrimp, amphipods, oligochaetes, and insect larvae.

In his summer, 1936, survey of the lower Hudson River watershed, Greeley (1937) encountered young rainbow smelt at seven river stations between Rhinecliff and Port Ewen. Rainbow smelt once ran into many Hudson River tributaries in early spring when the mainstem reached about 4^0 C (Boyle 1969). These runs were actively fished in some locations, such as the Rondout River and Saugerties Creek (Greeley 1937). They've also been observed in the Croton River (Boyle 1969, Rose 1993), Wappingers Creek, Columbiaville Creek, Roeliff-Jansen Kill, Black Creek, Crum Elbow Creek, Fishkill Creek, and Esopus Creek (Rose 1993). The last significant tributary runs appear to have occurred in 1979 (Rose 1993) and recreational net fisheries have since essentially disappeared.

All indications are that rainbow smelt have declined considerably during this century. Daniels and Lawrence (1991) reviewed data from the Hudson River utilities near-shore fish collections. Between 1974 and 1980, annual catches ranged from 108 to 1880 (mean = 735) individuals. But in 1981, the survey caught only 46, and just a single specimen was sampled between 1982 and 1989. In a survey of a suite of Hudson River tributaries conducted in 1988, Schmidt and Limburg (1989) caught several rainbow smelt larvae in Catskill Creek but not in 15 others (located between km 42 and 220). Schmidt and Lake (2000) caught a single smelt larvae in the Moordener Kill in 1998.

Rose (1993) analyzed the Hudson River utilities Long River Survey data base to better describe the spawning locations and population abundance trends in the Hudson River between 1974 and 1990 (these data include channel and deepwater stations). Although collected anecdotal accounts showed that Hudson River tributary tributary runs had dwindled to almost undetectable levels by the early 1980s, the Long River Survey data did not indicate a decline in the Hudson River over that period, i.e., high average densities of post yolk sac larvae were seen in 1986, 1988, and 1990. However, Rose (1993) found that the center of abundance of post yolk sac larvae had shifted since the 1970s from the lower river to the Catskill to Albany regions.

Microgadus tomcod Atlantic tomcod—The southern spawning-stock distribution of this small, euryhaline species terminates at the Hudson River, and extends northward to Labrador. In the Hudson River, spawning by tomcod occurs during early- to mid-winter, primarily between the Tappan Zee and Poughkeepsie reaches, and centered near West Point (Klauda et al. 1988). Egg incubation lasts 61 to 70 d (Dew and Hecht 1994). Larvae become distributed throughout the Hudson River, but at highest densities downriver. Between April and November juveniles are most abundant in the Tappan Zee and West Point regions and south to Manhattan (Dew and Hecht 1994). However, summer distributions appear to advance upriver with the salt front, with high monitoring catches being made in the Indian Point region (Klauda et al. 1988).

Juvenile Atlantic tomcod in the Hudson River were found to feed mainly on invertebrates, particularly calanoid copepods (McLaren et al. 1988). Adults displayed greater piscivory, but invertebrates still predominated, especially Gammarus, Neomysis, Crangon, and chironomid larvae. McLaren et al. (1988) identified three phases of first-year growth for Hudson River tomcod: a summer phase of little or no growth (because of high temperature stress) separated rapid growth phases of spring and fall. Dew and Hecht (1994) estimated a decrease in weight gain from 2.9% d to 1.3% d as temperatures rose above 13°C in late May.

The Hudson River population has an unusual maturation schedule and age-structure. Both sexes begin to mature reproductively at 9 mo and are capable of spawning at 11 mo. However, unlike in northern estuaries where they may live for several more years, only three age classes are known from the Hudson River, with individuals older than age-1 being rare. McLaren et al. (1988) found that among spawners collected during the winters of 1975-1976 through 1979-1980, age-1 fish composed 92 - 99% of the annual totals, with age-2 individuals making up almost the entire remainders. Age-3 fish were extremely rare (<0.1% of total).

Because the tomcod population is made up almost completely of one age class, its annual abundance is extremely responsive to environmental conditions that influence recruitment and subsequent survival; thus, its abundances fluctuate widely. For example, winter spawning population estimates were 12.5 million in 1982-1983, and 6.7 million, 2.1 million, 3.5 million, and 5.9 million in succeeding years (Mattson et al. 1992).

In early winter, newly-mature age-0 tomcod move upriver along with older individuals to spawn. Although it appears that most Hudson River tomcod remain within the estuary for life, a few individuals tagged in the Hudson River in the late 1970s were recaptured by anglers in lower New York Bay, the East River, and western Long Island Sound (Klauda et al. 1988), suggesting broader limits for this population.

Because it is bottom dwelling, dependent on benthic prey, has a lipid-rich liver, and tends to remain within its natal estuary, tomcod from highly polluted systems tend to accumulate unusually high concentrations of contaminants. In the Hudson River, these include PCDD's, PCDF's, and PCB's (Courtenay et al. 1999). Tomcod from the Hudson River exhibit biochemical responses and molecular damage not observed in tomcod from cleaner estuaries, including elevated levels of hepatic CYP1A1 mRNA expression, overall hepatic DNA damage (Wirgin et al. 1994), K-ras oncogene activation (Wirgin et al. 1989), and an extraordinarily high prevalence of liver tumors (Dey et al. 1993).

Moronidae

Morone saxatilis striped bass—This species appears to be the most popular sport fish in the Hudson River. It also was heavily harvested commercially until the fishery was closed because of PCB contamination in 1976. The striped bass population of the Hudson River is the northernmost of the three main migratory stocks (together with Chesapeake Bay and Delaware River) that support the fishery along the northeast U.S. coastline.

Striped bass spawn (semi-buoyant eggs) in the Hudson River from early May through early June. Based on studies conducted between 1974 and 1979, maximum egg densities occurred at water temperatures of 12° - 22°C and a spatial peak was seen between km 54 and 98 each year, although eggs, yolk-sac larvae, and post yolk-sac larvae were encountered in all regions between Albany and Yonkers (Boreman and Klauda 1988). However, the downriver limit of egg deposition is usually associated with the position of the salt front. Sample densities of juveniles peaked between km 38 and km 74. But juveniles may occur anywhere within the estuary and even well into western Long Island Sound (LoBue and McKown 1998). A high proportion of juveniles and yearlings winter in the lower river, particularly off Manhattan.

Several studies have attempted to better describe early life history processes of striped bass in the Hudson River. Pace et al. (1993) examined relationships among abundances of early life stages and temperature and flow conditions across 17 yr (1974-1990) of monitoring data. They concluded that temperature and river flow were not related to interannual variation in recruitment, and that there were no statistically significant relationships between the abundances of yolk-sac larvae, post yolk-sac larvae, and juveniles. They also stated that the absence of relationships among early life stages suggest that differences in mortality were less important than variability in the number of eggs spawned in determining larval abundance. However, they believed that the ability to evaluate these

relationships may have been hampered by sampling limitations and errors in species identifications.

Limburg et al. (1997) tracked the abundance and food consumption of larval striped bass during 1994. The cladoceran Bosmina longirostris and large copepodites and adult copepods composed 97.4% of their diets. They found that larval cohorts extant before the zooplankton bloom had the least available food but also the lowest respiration costs. Postbloom cohorts had both high consumption rates and respiration rates due to increased temperatures. Cohorts coincident with the bloom had moderately high consumption rates and lower metabolic costs relative to late cohorts. The investigators concluded that larval cohorts coincident with the bloom possess an energetic advantage relative to early cohorts but not relative to late cohorts.

Hurst and Conover (1998) explored the possible effects of winter mortality stemming from bioenergetic stresses on striped bass recruitment in the Hudson River. In their analysis of annual survey data, they found that age-1 abundance was negatively correlated with the severity of winter; however, numbers of age-0 fish were not correlated with abundance at age-1—leading to the conclusion that winter mortality greatly modified year class strength. A progressive increase in the mean length of young-of-the-year fish, coupled with a decrease in the coefficient of variation in length, occurred during some winters. This, combined with laboratory experiments that showed that growth in length requires temperatures in excess of 10°C suggest that these changes result from a bias toward greater mortality of smaller specimens. Dunning et al. (1997) provided evidence that subadult striped bass in the lower Hudson River feed during winter at temperatures well below 10°C (although consumption was not compared with growth).

As part of the Hudson River Cooling Tower Settlement Agreement, the electric utilities were to operate a hatchery that would seek to plant 600,000 young-of-the-year striped bass in the Hudson River annually (Dunning et al. 1992). Hatchery-reared individuals were marked with coded magnetic-wire tags before stocking. In the course of sampling with trawls for these individuals in the Hudson River estuary to estimate their contributions to the Hudson River stock, many wild specimens were caught and these were tagged with external tags to learn more about their movements and to monitor year class abundance. The goal of 600,000 hatchery-reared specimens per year never was met because of disease problems and the resultant contributions to the stock of the 1.3 million fish stocked from 1983 through 1987 were small (e.g., 0.1% to 1984 cohort, 3% to 1985 cohort). Moreover, the hatchery-reared striped bass showed more limited movements inside the Hudson River than did wild fish (Wells et al. 1991). For these reasons, the hatchery ceased operations in 1995.

Striped bass stockings in the Hudson River appear to have made little contribution to coastal waters. Waldman and Vecchio (1996) examined hatchery-reared specimens from Hudson River and Chesapeake Bay sources among more than 1,500 striped bass caught in haul seines in eastern Long Island in 1991 and 1992. Hatchery-reared specimens composed 3.5% of the total catch in 1991 and 2.5% in 1992. Although only about twice as many marked individuals were stocked in Chesapeake Bay as in the Hudson River, the recapture ratio of Chesapeake Bay to Hudson River specimens was 62:1 in 1991 and 37:2 in 1992—a difference attributed to differences in relative survival or vagility. Hatchery-reared specimens from both stocks also showed a pronounced increase in the incidence of broken striping patterns, a phenomenon that remains unexplained (Waldman and Vecchio 1996).

The increase in the abundance of the Hudson River striped bass stock that occurred since the late 1970s in conjunction with protection afforded migratory east coast striped bass stocks to restore the collapsed Chesapeake Bay stock and the lowered fishing pressure on the Hudson River stock because of PCB contamination appears to have affected its coastal migratory range. Tagging studies performed between 1948 and 1952 concluded that the Hudson River stock limited its movements outside the river to western Long Island (Raney et al. 1954). McLaren et al. (1981), based on tagging done in 1976 and 1977 reported somewhat broader coastal movements, but only as far northward as Newburyport, Massachusetts, and an absence of a relationship between fish length and distance from the river. But tagging of striped bass conducted in the Hudson River between 1984 and 1988 showed an expansion of range, with recoveries made northward as far as Maine and the Annapolis River, Nova Scotia (Waldman et al. 1990a). They also found a strong relationship between fish length and distance from the river, and interpreted the absence of such a relationship in the results of McLaren et al. (1981) as an artifact of size-dependent tag retention (Waldman et al. 1990b).

Although the Hudson River striped bass stock is known to make coastal migrations, it was long suspected that not all individuals participated and that there were “contingents” (Clark 1968) that were residential in the freshwater reach of the river (Raney et al. 1954) or that did not move beyond the lower estuary (Clark 1968). Secor (1999) used strontium/calcium ratio analysis and other elements of otoliths to reconstruct the salinity history of individual striped bass in relation to age. His work supported the notion of contingents, finding support for the existence of resident Hudson River, New York harbor, western Long Island Sound, and coastal Atlantic components to the total Hudson River stock. Individuals of the Hudson River-resident contingent (primarily males) showed

elevated PCB body burdens consistent with greater lifetime exposure to PCB sources (Zlokovitz and Secor 1999).

The relative contributions of each of the migratory striped bass stocks to coastal waters varies with their spawning success and subsequent conservation. Berggren and Lieberman (1978) analyzed striped bass specimens caught in coastal waters in 1975 using a suite of morphological stock identification approaches and estimated that the Hudson River population composed only 7% of the stock mixture, with 90% originating from the Chesapeake Bay. However, VanWinkle et al. (1988) reanalyzed these data on a year class basis and found that the contribution of the Hudson River stock approached 50% for some cohorts. Wirgin et al. (1993) applied a mitochondrial DNA-based approach to this question with a collection of specimens ($N = 112$) from eastern Long Island made in 1989 and estimated a Hudson River stock component of 73%. A similar study (Wirgin et al. 1997) performed on a larger sample ($N = 362$) collected in 1991 and including nuclear DNA markers also showed a Hudson River stock contribution of about 52%. These later estimates of large contributions of the Hudson River population to coastal waters reflect both its increased abundance and the decline of the Chesapeake Bay stock across this period.

CONSERVATION CONCERNS AND RESEARCH AVENUES

Habitat

Changes to the habitat of the Hudson River estuary have undoubtedly diminished its runs of diadromous fishes. For example, the degree of urbanization was shown to correlate negatively with runs of river herring in Hudson River tributaries (Limburg and Schmidt 1990). Other habitat alterations are unequivocal in their effects. The southernmost dam on the Hudson River was constructed in 1832 near Troy, New York (Brumbach 1986). Prior to the construction of this and other upstream dams, American shad and river herring ascended to at least the Battenkill River (Greeley and Bishop 1933), Fish Creek (Brumbach 1986), and possibly, Glens Falls (Boyle 1969); American eels penetrated considerably farther upriver (Greeley and Bishop 1933). Today some fish move upriver through the navigation locks or through the dam's hydroelectric turbines (at their peril—during their spawning migration wounded adult blueback herring often drift immediately downcurrent of these turbines) of the hydroelectric facility, but these obstacles create a bottleneck for fish movements in the upper river.

South of the federal dam but north of Manhattan, about half of the approximately 60 tributaries have manmade barriers on them that impede or prohibit fish passage (Schmidt 1996). Artificial obstacles are also found on many, if not most, tributaries entering greater New York Harbor (Durkas 1992; Waldman 1999). Larger rivers

capable of supporting diadromous fishes have also been compromised by contamination. For example, the Passaic (Waldman 1999) and Hackensack Rivers (Zeisel 1995) once sustained runs of a variety of diadromous fishes, including American shad, river herring, sturgeon, smelt, and tomcod.

It is reasonable to assume that the overall contraction of available habitat for diadromous fishes has resulted in an decrease in their abundance, albeit, one that is difficult to quantify. I am aware of only two instances in which available habitat has enlarged in recent decades. One is the Mohawk River, which following improvements in water quality, now supports a large run of blueback herring which ascend from the Hudson River after working their way past the federal dam. The other is the increase in water quality in the area of the Albany Pool, which suffered severe contamination and deoxygenation from industry and sewage disposal. It is likely that passage of the Clean Water Act in 1972 helped offset fish losses due to habitat restriction.

The most beneficial proactive improvement to diadromous fish habitat would be the removal of dams on tributaries, and where this is not feasible, the construction of fish passage facilities. A particularly attractive location for a fish ladder is the Eddyville Dam near Kingston, which would open up seven miles the Rondout River, potentially large enough to support American shad reproduction. However, many additional sites have been identified (Schmidt 1996; Schmidt and Lake 2000).

Also, the Hudson River estuary lost the last of its vast oyster reefs approximately a century ago (Waldman 1999). Oyster reefs are not only sources of human food but perhaps more importantly, vital nursery and feeding grounds for a host of estuarine fishes, including diadromous forms (Coen 1999). It is almost certain that construction of artificial oyster reefs in the Hudson River estuary, as is actively occurring in the Chesapeake Bay at this time, would be beneficial to the river's ichthyofauna and overall ecology.

Ecological Interactions

One focus of future research on the Hudson River's diadromous fish fauna is to achieve a better understanding of their ecological interactions with each other, with non-diadromous fishes, and with other organisms. Much of the work that has occurred on the diadromous fishes has been autecological and abundance- and mortality-based. Comparatively little attention has been given to the competitive and predatory connections among Hudson River fishes. For example, is the recent decline in white perch abundance partly attributable to the increase in the striped bass population? Have striped bass reduced the stock size of American shad and alewife? Did the protection

afforded the river's shortnose sturgeon population provide them with a competitive advantage over Atlantic sturgeon? Young bluefish appear to prey heavily on juvenile striped bass (Juanes et al. 1994). How important are bluefish in modulating recruitment of the Hudson's anadromous fishes? How important are sometimes abundant juvenile menhaden Brevoortia tyrannus in the lower estuary to subadult striped bass, a summer and autumn prey form that appears to be highly important in coastal settings? What would application of Haley's (1998) gastric lavage approach to shortnose sturgeon and Atlantic sturgeon caught contemporaneously from the same river reach tell us about their trophic niches?

Strikingly little attention has been paid to the fishes of the Hudson River on the community level (see Gladden et al. 1988 for one example). Daniels (1995) stated that "Although the Hudson River is among the most-studied aquatic systems in North America, data necessary to confirm population trends in its fish assemblage are scant." Although some changes in the relative abundances of particular species can be explained, many cannot. Moreover, how a dynamic community composition affects its individual components is not often clear.

Some species behaviors and interactions pose interesting evolutionary questions. Is carrying capacity a factor in the abundances of anadromous fishes? Why is it that shortnose sturgeon—the far more residential of the two sturgeons—appears to nearly stop growing at adulthood and at a small size for an acipenserid whereas the marine waters-inhabiting Atlantic sturgeon continues to grow and to a potentially massive size? Is the shortnose sturgeon adapted to the finite resources of a highly discrete river system and the Atlantic sturgeon to the nearly infinite resources of a vast coastal range? Likewise, does the relative abundance of the marine-migrating contingent of striped bass increase with stock size as a means to exploit resources outside the river? Are the rapid growth dynamics of young bluefish evolved to stay ahead of and capitalize on recruitment of a suite of fish prey species, including the anadromous component, as hypothesized by Juanes et al. (1994).

And how have the diadromous fishes responded to the many colonizations by non-native species? Do the now highly-abundant gizzard shad compete with alosines? How heavily do largemouth and smallmouth bass compete with or prey on anadromous piscivores? Shortnose sturgeon consume zebra mussels but how has the bivalve's substantial cropping of phytoplankton production (Smith et al. 1998) affected larval stages of anadromous fishes? What is the net effect on anadromous fish nursery habitats of the replacement in entire freshwater coves of native plants such as Vallisneria by the Asian water chestnut Typha natans?

Fishing and Fish Mortality from Power Plants

Any complex fish community is affected by sharp changes in abundance or age structure generated by unnatural sources of mortality. Because of PCB contamination, the entire diadromous fish complex of the Hudson River are not subject to legal commercial harvest in the river, albeit at the price of any sublethal effects stemming from their PCB body burdens. Moreover, the planned phase out of the intercept fishery for American shad and the moratorium on harvest of Atlantic sturgeon in all U.S. waters afford further protection. It is likely that angling harvests are depressed by health advisories concerning consumption of Hudson River fishes.

The effects of electric generation plants on the Hudson River anadromous fish stocks continue to be monitored but not necessarily well understood. Much of the knowledge gained between 1963 and 1980 through studies conducted in the course of the controversies over the effects of existing and proposed power plants on the Hudson River was summarized in Barnthouse et al. (1988). However, comparatively little information learned over the next score of years has reached the peer-reviewed literature and much of it remains in narrowly distributed and thinly distilled reports. Although the Settlement Agreement included provisions to reduce power plant-mortality of anadromous fishes, fundamental issues persist, such as whether compensatory processes mitigate mortalities to significant degrees. The role of power plants in the population dynamics of Hudson River fishes is likely to remain unclear in the near-term future as a reshuffling of ownership because of deregulation of the power industry and the possible construction of a new generation of power plants that use far less river water.

Climate Change

Ashizawa and Cole (1994) analyzed long-term water temperature data from the Hudson River at Poughkeepsie and found a statistically significant trend of a 0.12°C increase per decade from about 1920 to 1990, a change they believed was consistent with suggested rates of global increases. The biological effects of global warming are becoming more apparent as the physical changes become more pronounced and as the time spans monitored become lengthier. Oglesby (1995) showed evidence of significantly earlier blooming of vegetation and spring arrivals of migratory birds in the Hudson Valley. However, they did not detect a change in the average arrival time of anadromous fish in the Hudson River, due, in part, to high interannual variances.

Nonetheless, the status of rainbow smelt at the limits of its southern distribution may be a bellwether. Decades ago smelt entered the Delaware River and its tributary, Brandywine Creek in Maryland; the last known capture in the Delaware River system occurred in 1986 (Raasch and Altemus 1991). It may be that smelt and

another cold-water species at the margin of its distribution—Atlantic tomcod—will be increasingly stressed with time and become extinct in the Hudson River estuary.

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