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Changes in Fish Assemblages in the Tidal Hudson River, New York

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Abstract.—The main channel of the Hudson River is a tidal estuary from its mouth in New York Harbor to Troy, New York, 247 km upstream. It drains about 35,000 km^2 and is an important navigational, commercial, and recreational system. Since the arrival of European settlers over 400 years ago, it has undergone numerous environmental changes. These changes have included channel maintenance by dredging, wholesale dumping of industrial and domestic wastes, scattered in-basin urbanization and shoreline development, deforestation of the watershed and an increase in agriculture, and water removal for commercial, industrial, and agricultural needs. In addition, the biota of the river has supported commercial and recreational harvesting, exotic species have become established, and habitats have become fragmented, replaced, changed in extent, or isolated. The tidal portion of the Hudson River is among the most-studied water bodies on Earth. We use data from surveys conducted in 1936, the 1970s, the 1980s, and the 1990s to examine changes in fish assemblages and from other sources dating back to 1842. The surveys are synoptic but use a variety of gears and techniques and were conducted by different researchers with different study goals. The scale of our assessment is necessarily coarse. Over 200 species of fish are reported from the drainage, including freshwater and diadromous species, estuarine forms, certain life history stages of primarily marine species, and marine strays. The tidal Hudson River fish assemblages have responded to the environmental changes of the last century in several ways. Several important native species appear to be in decline (e.g., rainbow smelt *Osmerus mordax* and Atlantic tomcod *Microgadus tomcod*), others, once in decline, have rebounded (e.g., striped bass *Morone saxatilis*), and populations of some species seem stable (e.g., spottail shiner *Notropis hudsonius*). No native species is extirpated from the system, and only one, shortnose sturgeon

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Acipenser brevirostrum, is listed as endangered. The recent establishment of the exotic zebra mussel *Dreissena polymorpha* may be shifting the fish assemblage away from open-water fishes (e.g., *Alosa*) and toward species associated with vegetation (e.g., centrarchids). In general, the Hudson River has seen an increase in the number and importance of alien species and a change in dominant species.

Introduction

Fish assemblages in large rivers are among the most altered of any in northern temperate regions (Tallman, this volume). The extent of change is difficult to assess in any given river because most such rivers were extensively modified before synoptic studies of the fish were undertaken. Norris and Hawkins (2000) argue that the best way to assess change when descriptions of the original assemblage or system are absent is to examine trends in the status and condition of individual species. Others (e.g., Karr et al. 1986; Daniels et al. 2002) suggest that the entire species assemblage best reflects system-wide change. All recognize the need to use several types of data, including historical distribution of fishes, in order to establish reference conditions with which to compare change (e.g., Hughes 1995). However, in most rivers the historical record is too short to provide information adequate for distinguishing reference conditions. Northeastern rivers have long records, but alterations were extensive before these records began, again limiting their value in establishing reference conditions. For the Hudson River, a series of reports detailing fish distribution extends to the early years of the 19th century and offers an unusually, if not uniquely, long data series on fish assemblages in the river. Although a 200-year record of fish distribution is useful in assessing change in the fish assemblage, it is important to recognize that this river was already affected by environmental change as a direct result of European settlement before fish distribution within the river was assessed.

Modifications within the tidal Hudson River are extensive and include impacts that range from local to regional to global. Limburg et al. (1986) and Barnthouse et al. (1988) note examples of modifications related to pollution, urbanization and shoreline development, water removal, and power plant operations. Agriculture has been an important activity within the basin for more than two centuries, and 14% of the land in the basin currently supports agricultural activities (Wall and Phillips 1998). The banks of the tidal Hudson River also are urbanized. Runoff from both agricultural and urban areas brings pesticides and other pollutants into the river, although the type and amount of contaminants entering the system vary seasonally and regionally (Wall and Phillips 1998; Phillips et al. 2002). Urbanization has increased the amount of sewage entering the river as well. As late as 1970, the "Albany Pool," an area from the Troy Dam to about 45 km downstream, was devoid of dissolved oxygen and had extremely high coliform densities (Boyle 1979). The condition described by Boyle (1979) was long in the making. Faigenbaum (1935, 1937) noted the extent and type of pollutants entering the river in the 1930s; his numbers are only slightly different from those reported by Boyle (1979). In addition to raw sewage entering the river, Faigenbaum (1935, 1937) reported wholesale dumping of wastes from paper production, tanneries, textile production, and canneries. Sewage problems were severe until the implementation of the Clean Water Act revisions of 1972, but still exist in the New York Harbor vicinity (Stanne et al. 1996). Toxic substances were also discharged for decades in the Hudson (Limburg et al. 1986), and the large load of polychlorinated biphenyls (PCBs) discharged from several General Electric factories above the Troy Dam continues to pollute downriver food webs (Baker et al. 2001). The presence of PCBs in fish tissue has led to restrictions on, and closures of, commercial and sport fisheries.

The channel has been modified over the last two centuries by episodic dredging for navigation (beginning in 1834), alteration of shoreline wetlands related, in part, to construction of railroads (Squires 1992), and the construction of dams in the upper drainage and on tributaries in the lower drainage. Schmidt and Cooper (1996) noted that dams exist on 30 of the 62 larger tributaries to the tidal Hudson River. These dams not only store significant amounts of floodwater, but also alter flow regimes by reducing peak discharges downstream and mete out flow over time to maintain minimum depths for navigation (e.g., Lumia 1998). Dams in the Hudson River drainage, as elsewhere, restrict fish movement between the main channel and tributaries and among tributaries, effectively fragmenting the watershed (Schmidt and Cooper 1996). The most extreme land-use alterations came in the form of deforestation, primarily for agriculture, timbering, and tanning in the mid-1800s to late 1800s (McMartin 1992) and were noted as serious problems for fisheries by the end of the 19th century (Stevenson 1899). Although agricultural activity is considerably less widespread in the watershed today, problem areas still exist (Phillips et al. 2002). These and other types of environmental change have affected the composition of the Hudson River fish assemblage and the abundance of species in them.

Commercial fishing also has affected fish abundance and assemblage structure. Striped bass *Morone saxatilis*, Atlantic tomcod *Microgadus tomcod*, American shad *Alosa sapidissima*, and sturgeon *Acipenser* spp. currently or formerly supported commercial harvesting. The history of the Atlantic sturgeon *A. oxyrhyinchus* fishery is typical of commercial operations in the Hudson River. In the 19th century, sturgeon, called Albany beef (Lossing 1876), was shipped across the country. This harvesting depleted stocks drastically; the population had a long and slow recovery, and there was a short period of harvesting in the 1980s and 1990s, followed by a second decline and fishing closure in 1996 (Bain et al. 2000).

The role of alien species in the development and composition of the current assemblage is also important. Mills et al. (1997) discuss changes related to the introduction of exotic aquatic species and list 65 animals and 55 plants. The effect of exotic species on native fishes varies. For example, the invasion of the Hudson River by zebra mussel *Dreissena polymorpha* may have had a pervasive effect on the native fish assemblage. Zebra mussels first appeared in the Hudson in 1991 and, since September 1992, have constituted more than half of heterotrophic biomass in the freshwater tidal section of the river (Strayer et al. 1996). Consequently, in the freshwater tidal Hudson, river kilometer (rkm) 100–247 (rkm 0 is at the southern tip of Manhattan Island), biomass of phytoplankton and small zooplankton declined 80–90%, whereas biomass of planktonic bacteria, water clarity, and concentrations of dissolved nutrients rose substantially (Caraco et al. 1997; Findlay et al. 1998; Pace et al. 1998). Most directly relevant to fish, overall biomass of forage invertebrates (zooplankton plus macrobenthos, excluding large bivalves) fell by 50% (Pace et al. 1998; Strayer and Smith 2001). This change in the forage base was distributed unevenly through the habitats of the Hudson: biomass of zooplankton and deepwater macrobenthos fell sharply, whereas biomass of macrobenthos in the vegetated shallows actually rose. Strayer et al. (2004) hypothesized that the zebra mussel invasion should have caused growth and population size of open-water fishes to fall, and the abundance of these species to increase downriver into brackish-water reaches where zebra mussels are scarce or absent. Littoral fishes were hypothesized to show opposite trends in growth, abundance, and distribution.

Here, we examine change in the tidal Hudson River fish assemblage by comparing species composition and richness of the assemblage over time and by examining trends in the abundance and distribution of selected species. We attempt to relate these changes to human-related changes occurring within the river channel, its tributaries, and surrounding landscapes.

Methods

Study Area

The Hudson River arises from Lake Tear of the Clouds in the Adirondack Mountains of upstate New York, on the flanks of Mount Marcy, the highest point in the state. From there it flows southward some 507 km and drains into the Atlantic Ocean at Manhattan. The drainage area is 34,680 km^2 (Limburg et al. 1986). A dam at Troy, New York (rkm 247), effectively bisects the river into nontidal upriver and tidal downriver sections. Additionally, the Mohawk River, a major tributary, enters the Hudson River just above Troy (Figure 1). The Hudson River and its Mohawk River tributary are closely linked to an extant, and historically more extensive, canal network that tied the Hudson River system to all other drainages in the state (Daniels 2001).

Below Federal Dam at Troy, the Hudson is a drowned river valley that becomes an estuary, with only a 1.5-m drop in elevation from Troy to the estuary mouth (Helsinger and Friedman 1982). The upper tidal reach is fresh, averages 8 m in depth, and has a bottom substrate composed of mud and sand. Below Poughkeepsie, the tidal river widens into Newburgh Bay (rkm 93–103), the first of three embayments in the southern, downriver reach. Just below Newburgh Bay, the river becomes a fjord, deepening and passing over a series of sills. This is the reach of the dramatic Hudson River Highlands, where the Continental Army stretched a great chain across the river from Garrison to West Point beginning in 1778 to prevent upriver movement of British ships. South of the fjord, the Hudson opens into Haverstraw Bay (rkm 50–64) and the Tappan Zee (rkm 39–50). These are both important nursery areas for many fish species. The river deepens and narrows again as it passes the Palisades, a basalt formation of columnar cliffs rising above the river's western shore, and remains moderately deep to where it empties into New York Harbor. Nevertheless, sediment transport necessitates dredging both the harbor and many upriver areas to maintain a 9-m to 11-m shipping channel (McFadden et al. 1978).

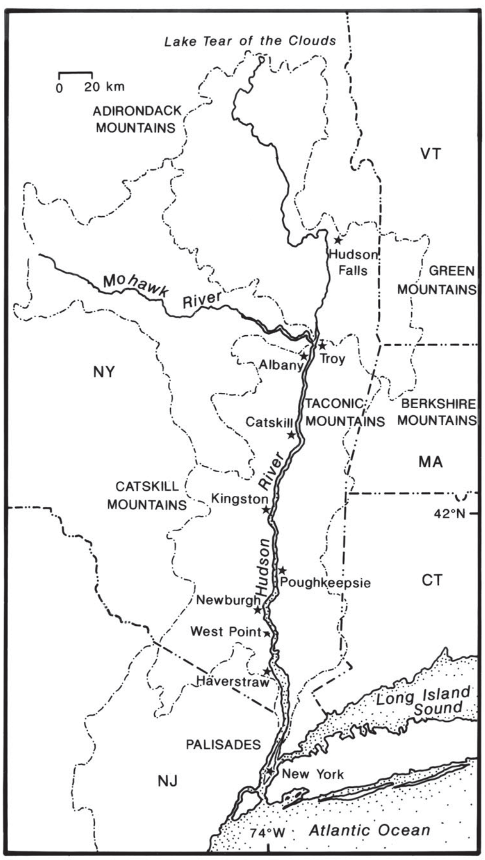

Figure 1.— The Hudson River drains most of eastern New York and parts of Vermont, Massachusetts, and Connecticut. It flows southerly into New York Bay from headwaters in the Adirondack Mountains.

Freshwater discharge averages 390 m^3/s at Green Island, which is near the Troy dam (U.S. Geological Survey records, 1948–1994), but varies seasonally, with highest flows in spring freshets driven by snowmelt within the watershed and lowest flows in July and August (Figure 2). Freshwater flows in the lower Hudson River are 538–567 m^3/s (Central Hudson Gas and Electric 1977). The flushing time, estimated as the ratio of water volume to mean freshwater discharge, is 126 d (Simpson et al. 1974), which makes the Hudson one of the fastest flushed of the East Coast estuaries.

Salinities in the tidal Hudson vary with season and freshwater discharge. The river above rkm 97 remains fresh except in drought; thus, the city of Poughkeepsie at rkm 121 draws its drinking water from the Hudson, and New York City maintains an

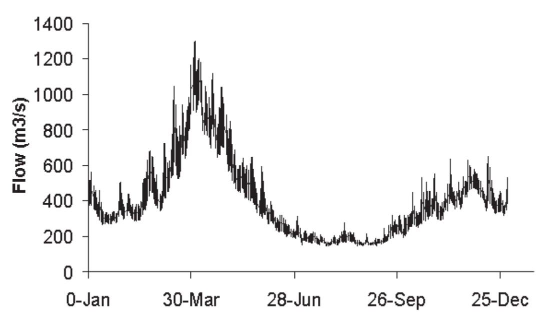

Figure 2.—Freshwater discharge based on daily averages at Green Island, New York, 1948–1994.

emergency pump station at Chelsea (rkm 108). Haverstraw Bay and the Tappan Zee vary from oligohaline (0–5 practical salinity units [psu]) in higher flows to mesohaline (5–18 psu) in summertime. The salt front (defined as 0.5 psu) generally remains below Newburgh, although in times of drought it has been recorded as far north as Kingston (rkm 145; Butch et al. 2001). The Hudson is polyhaline (18–30 psu) in its lower reaches.

Vertical salinity and temperature measurements show that the tidal Hudson is mostly a well-mixed system, due in large part to its semidiurnal tides. This is particularly true in the tidal freshwater zone (Cole et al. 1992; Howarth et al. 1996). When discharges are high, a layer of freshwater can ride over the denser brackish water in the lower Hudson (Busby and Darmer 1970). In summertime low flows, water residence time increases, and the residence time of water (which differs from flushing time by including the influence of tidal influxes of seawater) in the photic zone (where primary production occurs) can be on the order of 7–10 d (Howarth et al. 2000). At that time, some thermal stratification can occur in the relatively shallow bays of Haverstraw and the Tappan Zee.

Tidal flow is 10–100 times greater than flows resulting from upper basin and tributary input (Cooper et al. 1988; Firda et al. 1994) and can exceed 14,000 m^3/s. In general, tidal flow reverses the current direction twice a day, but vertical and horizontal distribution of flow is not uniform due to the morphometry of the channel and effects of the salt front. Shoreline points and bends in the channel produce eddies that affect the flow regime. Tidal amplitude is greatest at Albany (rkm 240), with a mean of 1.6 m, and least at West Point (rkm 83), with a mean of 0.8 m (Giese and Barr 1967).

Data Collection

We used data obtained from many diverse sources. DeKay (1842) and Bean (1903) reviewed the fish fauna of New York. DeKay did not describe his data collection methods, but they appear to have been a mixture of reports, sightings, and collections from local fish markets. For our analysis, we regard the species as present in the Hudson River if DeKay (1842) specifically identified the species as occurring in the Hudson River or if he noted its presence in all waters in the state. Bean (1903) relied on the results of synoptic surveys (e.g., Bean 1899, 1900; Scott 1902), but he also gleaned information from markets, anglers, and commercial fishers. He included a table of fish distribution by drainage and, for our analysis, we accept his tabulation. DeKay (1842) and Bean (1903) only noted the presence of the species in the drainage; species distribution and abundances within the drainage were not detailed.

The first detailed, synoptic survey of fishes undertaken in the tidal Hudson River was completed in 1936 (Greeley 1937). All fish were identified, the abundance of each species was assessed (usually by an actual count, sometimes by a relative abundance estimate), and many specimens were vouchered for later study. Greeley (1937) collected fish via seines, gill nets, and angling. Beginning in 1970, interest in the fishes of the Hudson River increased and both long- and short-term surveys have been conducted by several private and government agencies during the last three decades. We include information from surveys using seines, bottom trawls, and midwater trawls. Because the sampling equipment and effort varied among the studies, we use only presence-absence information when making comparisons among studies. If comparing information within a study, we use all the data.

Some of the data presented here were taken from the Hudson River Estuary Monitoring Program (HRMP), an annual monitoring program sponsored by the utility companies on the Hudson River. Rainbow smelt *Osmerus mordax* and gizzard shad *Dorosoma cepedianum* larval and adult Atlantic tomcod distribution information came from the HRMP's Long River Ichthyoplankton Survey and the catfish young-of-year data from its trawl survey. These two surveys are river-wide and cover early and late seasons, respectively. They have been performed continuously since 1974 with few changes in methodology. The details of the sampling methods and survey design are in Klauda et al. (1988b).

Pop nets (see Serafy et al. 1988) were deployed in dense water chestnut *Trapa natans* beds in Tivoli South Bay (rkm 156) during several studies (Pelczarski and Schmidt 1990; Hankin and Schmidt 1991; Gilchrest and Schmidt 1997) following the protocol outlined in Pelczarski and

Schmidt (1990). Twenty-two samples were taken between 1989 and 2002.

To examine changes in abundance of nongame fishes and to test for zebra mussel effects on fish populations, we used data collected by the electric utilities and the New York State Department of Environmental Conservation (NYS DEC). To test for zebra mussel effects on fish populations, Strayer et al. (2004) divided the fish assemblage into two groups: open-water species such as American shad, blueback herring *Alosa aestivalis*, alewife *A. pseudoharengus*, gizzard shad, white perch *Morone americana*, and striped bass, and littoral species, such as spottail shiner *Notropis hudsonius*, common carp *Cyprinus carpio*, banded killifish *Fundulus diaphanus*, fourspine stickleback *Apeltes quadracus*, redbreast sunfish *Lepomis auritus*, pumpkinseed *L. gibbosus*, bluegill *L. macrochirus*, smallmouth bass *Micropterus dolomieu*, largemouth bass *M. salmoides*, and tessellated darter *Etheostoma olmstedi*. Their analyses were restricted to young-of-year fish. Strayer et al. (2004) should be consulted for further methodological details.

Results

The rich Hudson River fish fauna comprises a mixture of freshwater, diadromous, estuarine, and marine species. To date, 210 species have been reported from the Hudson River drainage (Appendix A). Of these, 129 species are found in the main channel of the tidal portion of the river; the remaining 81 are confined to tributaries of the lower Hudson River or are reported only from the upper Hudson River or Mohawk River systems (Table 1). Of the species present in the tidal portion of the river, 49 are primarily marine visitors and 80 species are either resident freshwater or diadromous forms.

The number of species reported from the Hudson River drainage has increased since first tabulated in 1842 (Table 1). The trend is consistent: species richness has increased over time in the lower drainage, the main channel, and in the freshwater component. There has been a 1.5 to 2-fold increase in the number of species in the drainage since the 1930s (Table 1). The increase is due partially to an increase in the effort spent in collecting and reporting species. It is also due, in part, to the number of exotic species now known to occur in the lower drainage. Although the number of native, freshwater species has increased about 21% in the past 70 years, the number of alien, freshwater species has increased 130%. The presence of two alien species (common carp and rock bass *Ambloplites rupestris*) in the lower Hudson River was noted by DeKay (1842), indicating that they gained access to the system before any assessment of the fauna was undertaken. The number of alien fishes in the system has increased during each sample period, doubling since the 1930s and increasing by seven species in the last decade. Moreover, the extent of the range of alien species and the size of their populations are increasing in the tidal Hudson River.

The effect of alien species on the native assemblage varies across species. The effect of long-established species, such as those noted as alien by DeKay (1842) is impossible to evaluate. Sufficient data exist to assess the status of several of the new arrivals. Gizzard shad has been collected consistently in the Hudson River since 1974, and a single specimen was reported from a pound net on Long Island in 1975 (Hickey and Lester 1976). Reports of gizzard shad in the Connecticut River (O'Leary and Smith 1987), Merrimack River (Hartel et al. 2002), and Kennebec River suggest that this species is expanding its range northward through a combination of marine migrations and accidental stockings. Marine migration may have been the mechanism of introduction of the Hudson River population. A second hypothesis explaining the presence of gizzard shad in the Hudson River is it that it may be derived from inland populations, as suggested by Carl George (Smith 1985).

Gizzard shad is becoming more abundant in the tidal Hudson River (Figure 3). It is now common in large and small tributaries in the spring and summer, although there are no reports of it spawning in these areas. Commercial fishers have reported that catches of gizzard shad in American shad nets have reached nuisance status. Based on the results of the HRMP, gizzard shad are spawning in the river, although the numbers of larvae remain modest and are concentrated in the estuary around Albany. It is possible that spawning occurs in the Mohawk River and larvae moving downriver may enhance the population in the lower river.

Table 1.—Species richness of fish in the Hudson River, 1842–2002. Data are from DeKay (1842), Bean (1903), Greeley (1935, 1937), and Beebe and Savidge (1988). The numbers for the 1990s represent information from researchers actively working with the Hudson River and from museum specimens. Percentage change is computed between values from the 1930s and 1990s.

	1842	1902	1930s	1980s	1990s	% increase
Species in drainage			114		202	77
Species in lower Hudson system			99	140	187	89
Species in main channel	38	44	68		123	81
Freshwater species in channel	31	37	54	71	80	48
Native freshwater species in channel	29	32	41	48	50	21
Alien freshwater species in channel	2	5	13	23	30	130

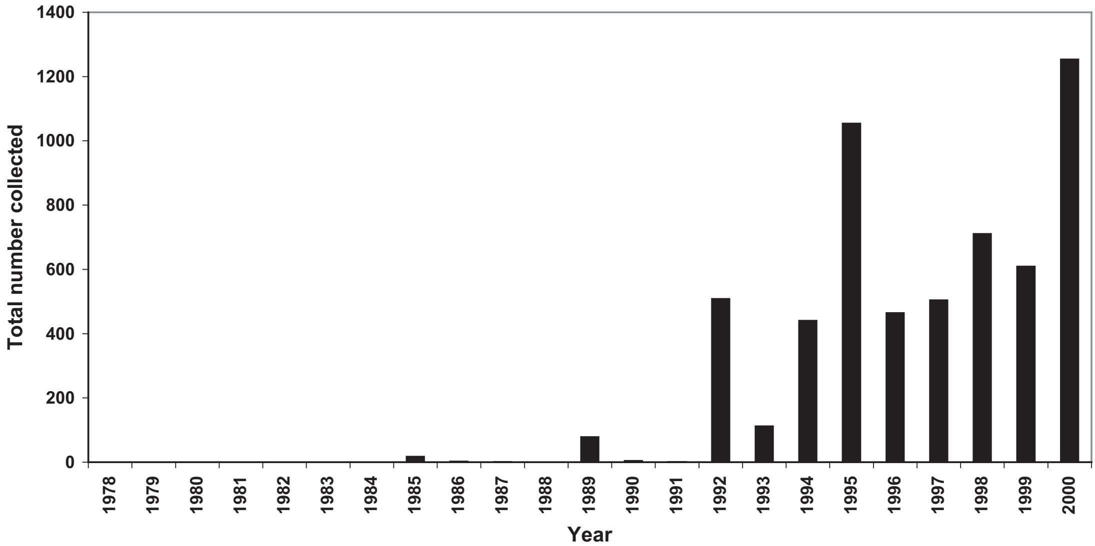

Figure 3.—Number of gizzard shad yolk sac larvae caught in ichthyoplankton tows in the Hudson River, New York, 1974–2000. Data are from the utilities sponsored Long River Ichthyoplankton survey.

Gizzard shad are small-particle feeders and facultative detritivores, and as such, large populations could affect the phytoplankton and microzooplankton populations in the Hudson River Estuary, but we are unaware of any effort to document the effect of the spread of this species.

Channel catfish has become increasingly common in the river during the last decade. A few specimens were taken before 1985, and the earliest Hudson River capture was in 1974 (Smith and Lake 1990). The origin of this species in the Hudson River is not known, but it is available from commercial fish suppliers. Beginning 10 years ago, channel catfish were common in the Sturgeon Pool and contiguous areas in the Wallkill River, a major, mid-basin tributary (R. Pierce, NYS DEC, personal communication); this pattern suggests that channel catfish was illegally released into the drainage before then. Such releases could easily explain the establishment of this species in the Hudson River. A second possible explanation is that channel catfish moved into the system from the Saint Lawrence River drainage, via the Barge Canal.

We (R.E.S., R.A.D.) have collected channel catfish in marshes and tidal tributaries, mostly in the northern part of the estuary. Channel catfish grows to a larger size than the native white catfish and could potentially displace the latter. Trawl surveys show increasing numbers of channel catfish (Jordan et al. 2004), which ultimately may lead to a decline in the native white catfish, a situation that has been observed in the Delaware and Connecticut rivers.

Although not reported in Beebe and Savidge (1988), freshwater drum have been taken from the river since 1978. Reports of this species have become more common in recent years, primarily from anglers in bass tournaments. These anglers have reported 2–4-kg fish taking jigs fished for bass. The abundance of this species may be underreported if it inhabits deep, difficult to sample areas of the estuary. Small numbers of early life stages were collected as early as 1985 in the Long River Ichthyoplankton survey, but based on these tows, spawning in the river appears limited. The invasion of zebra mussel provided an abundant food source for this molluscivorous fish, and the presence of this new forage base may account for increasing numbers of freshwater drum.

Northern pike *Esox lucius*, norlunge (*E. lucius* × muskellunge *E. masquinongy)*, and walleye *Sander vitreus* have been stocked in the Hudson River or its tributaries to establish a sport fishery. These large, piscivorous fish have become increasingly abundant in the estuary. The esocids have been taken at several upriver localities, and R.E.S. caught a spawning pair of northern pike at the head of tide in Coxsackie Creek in April 1999. Northern pike young of year have been reported from the estuary in recent years (K. Hattala, NYS DEC, personal communication.). We have a single report of walleye young of year in the tidal Hudson River (W. Gilchrest, Norrie Point Environmental Laboratory, personal communication), but we have no evidence that walleye spawn in the tidal Hudson.

Fathead minnow *Pimephales promelas* is becoming increasingly common in the watershed. This species is widely sold as bait and as forage for largemouth bass stocked in farm ponds. Although no adults have been reported from the main channel, larvae are common in drift samples taken at the mouths of tributaries. Fathead minnow was absent from 16 tributary mouths in 1988 (Schmidt and Limburg 1989), but was abundant in Stockport Creek 5 years later (Schmidt and Stillman 1994) and in Moordener Kill and Coxsackie Creek (Schmidt and Lake 2000).

Alien fishes affect the native fish assemblage directly by interspecific interactions, such as competition and predation. Other alien components of the community also affect the fish assemblage. Water chestnut was first reported in the Hudson River drainage in 1884 (Mills et al. 1997). The large beds that currently dominate river shallows from the Troy Dam to Iona Island (rkm 71) have altered the habitat available to fishes by increasing the amount of cover and spatial complexity throughout the littoral zone and have affected the dynamics of dissolved oxygen and nutrients (Caraco and Cole 2002).

The arrival of the zebra mussel is the best illustration of the effect of an alien species on the Hudson River fish assemblage (Strayer et al. 2004). The zebra mussel invasion was associated with large, pervasive changes in young-of-year fish in the Hudson (Figure 4). Abundance of many littoral species rose, with populations of several species more than doubling. In contrast, populations of openwater species showed no pervasive changes, although numbers of postyolk sac larvae of *Alosa* spp. declined sharply (Strayer et al. 2004). The distribution of fish within the Hudson also shifted following the zebra mussel invasion. As hypothesized, populations of open-water species generally shifted downriver at the same time that populations of littoral species shifted upriver. Many of these shifts were large (more than twofold). Finally, apparent growth rates of almost all open-water fish species fell after the zebra mussel invasion. Apparent growth rates rose for

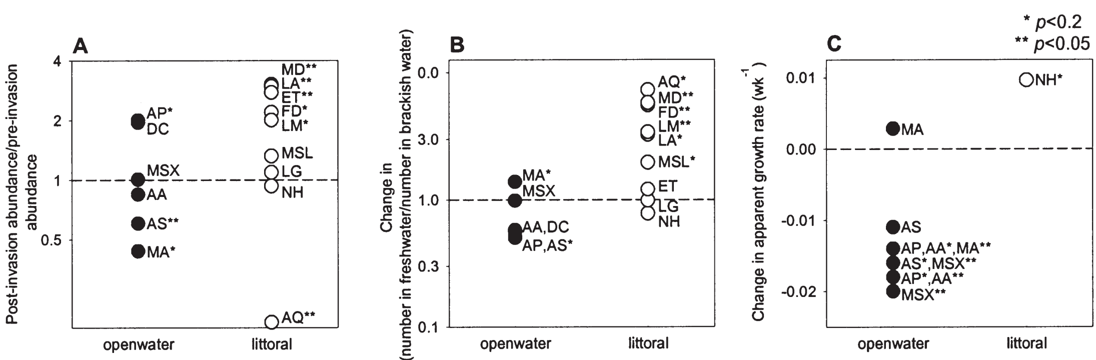

Figure 4.—Changes in abundance, distribution, and apparent growth of young-of-year fish in the Hudson River associated with the zebra mussel invasion. A. Changes in estimated riverwide number of age-0 fish. B. Changes in distribution of age-0 fish within the Hudson River. Values above 1 indicate net shifts upriver and values below 1 indicate net shifts downriver. C. Changes in apparent growth rates of age-0 fish. Several species are represented by two data points because two independent data sets were used for this analysis (see text). For reference, the mean preinvasion apparent growth rate over all species was 0.06/week. The heavy dashed line is the no-change line; that is, preinvasion = postinvasion. Species abbreviations: AA = *Alosa aestivalis*, AP = *A. pseudoharengus*, AQ = *Apeltes quadracus*, AS = *Alosa sapidissima*, DC = *Dorosoma cepedianum*, ET = *Etheostoma olmstedi*, FD = *Fundulus diaphanus*, LA = *Lepomis auritus*, LG = *L. gibbosus*, LM = *L. macrochirus*, MA = *Morone americana*, MD = *Micropterus dolomieu*, MSL = *M. salmoides*, MSX = *Morone saxatilis*, NH = *Notropis hudsonius*. Analyses are based on beach-seine data from late summer to early fall. Modified from Strayer et al. (2004).

spottail shiner, the only littoral species for which sufficient data were available. Changes in apparent growth rates were large (>25%) compared to preinvasion growth rates in many cases.

Related to the observations of Strayer et al. (2004), ongoing studies of the trophic effects of zebra mussels on juvenile blueback herring show a dramatic change in the role of the latter in the Hudson food web following mussel invasion. In the 1980s the diet of juvenile blueback herring consisted almost entirely of pelagic zooplankton (Limburg and Strayer 1987; Grabe 1996). Today, their diet contains nearly no *Bosmina leydmani* (formerly a primary component) and littoral/benthic macroinvertebrates dominate the diet (K.E.L., unpublished data). The composition of dietary items mirrors the findings of Strayer et al. (2004), suggesting that blueback herring are compensating somewhat for the loss of pelagic prey by foraging in macrophyte-associated habitats. This is suggestive of a possible regime change in production pathways in the Hudson, mediated by the strength of zebra mussel filtration of the water column.

Changes in the abundance and macrodistribution of native fishes have also been reported. Rainbow smelt is anadromous in the Hudson River and there are historical records of spawning runs in many tributaries (Smith 1985). Rose (1993), based on ichthyoplankton surveys, found no evidence of a declining population between 1974 and 1991, although Daniels (1995) showed a decline in adult catches between 1974 and 1989.

The last tributary run of rainbow smelt that we (R.E.S., K.E.L.) observed was in Rondout Creek in 1988. Rose (1993) suggested that rainbow smelt enter tributaries during high adult-population years, but spawn every year in the main channel of the river. A crude analysis of the ichthyoplankton data, extending Rose's (1993) assessment to the end of the century, shows a very different picture (Figure 5). After 1995, smelt essentially disappeared from the Hudson River ichthyoplankton. We show data for the post-

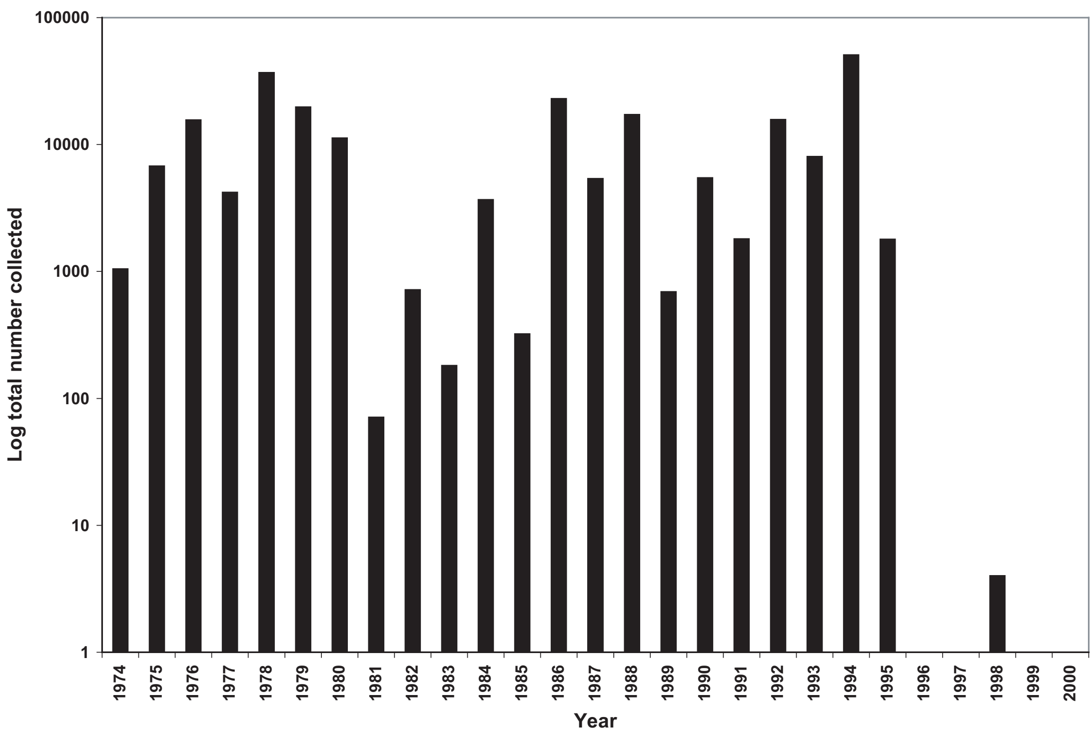

Figure 5.—Number of rainbow smelt post-yolk-sac larvae caught in the Hudson River, New York, 1974 through 2000. Data are from the utilities-sponsored Long River Ichthyoplankton survey.

yolk sac life history stage, but the other stages (egg, yolk sac, young of year, older) show the same pattern. Although there has been variation in the number of samples taken in this survey (1,561–3,684 tows/year), there were 2,329–2,437 tows/year in the last 5 years of the data set, so this disappearance is not an artifact of a change in effort.

The Hudson River is home to the only anadromous member of the family Gadidae on the North American Atlantic Coast. A population of Atlantic tomcod is largely contained in the lower tidal portions of the river, surrounding bays of the lower estuary, and in the outer bay and coastal habitats. Historically, tomcod was reported as far south as Virginia (Bigelow and Schroeder 1953), but there are no recent reports of spawning in any drainage south of the Hudson River (Stewart and Auster 1987). The fact that Hudson River tomcod are at the southernmost boundary of the species' spawning distribution may foretell future reductions in its population with warming climate.

Collections of Hudson River tomcod from 1974 to 2000 made by the HRMP, which entail estimates of abundance for all life stages, suggest cyclical change in tomcod abundance (Figure 6). It is noteworthy that the HRMP data for the most recent years (1997–2000) show tomcod abundance, quantified here as an index for the feeding age 0 stages, to be on a protracted decline and with the lowest values in the 27-year time series occurring in 2000. More recent collections by us (R.C.C.) of adult tomcod from spawning areas near Garrison, New York (rkm 82) in the winters of 2000–2001 and 2001–2002, and of juveniles in the mid to lower reaches of the tidal Hudson River during the summers of 2000–2002, reveal a continuation of extraordinarily low numbers.

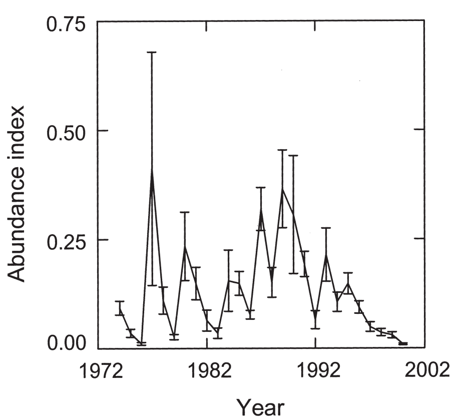

Figure 6.—Abundance index (mean ± SE) for post-yolk-sac larval and young-of-year juvenile Atlantic tomcod in the Hudson River from 1974 through 2000. The abundance index is derived by collapsing the weekly standing crop indices for the regions of the estuary that were sampled (Battery to Albany) over the period from approximately May through early July for each year. Source of data is the utilities-sponsored Long River survey.

Fourspine stickleback populations appear to be declining in the tidal Hudson River (Figure 7). Historically, this estuarine species was found upriver into the nontidal stretches upstream of the Troy Dam, where it was described as locally common (Greeley 1935). More recent collections were confined to the tidal portion downstream of Catskill Creek (rkm 177; Smith 1985). Pop-net samples in water chestnut beds in Tivoli South Bay showed this species to be one of two dominant fishes (Pelczarski and Schmidt 1990; Hankin and Schmidt 1991; Gilchrest and Schmidt 1997). Water chestnut provides cover, food items of appropriate size, and structure for nest building. This plant became abundant beginning in the late 1970s when chemical control efforts ceased (Hankin and Schmidt 1991). The pop-net surveys show a decline in the number of fourspine stickleback from 75% of the catch in 1989 to 1% of the catch in 2002 (Figure 7). In addition, Strayer et al. (2004) documented a 99% decline in the abundance of fourspine stickleback between 1974 and 1999 in the utility-sponsored beach seine survey.

The abundance pattern displayed by goldfish *Carassius auratus* is one of decline and re-establishment. Goldfish flourished in the Hudson River and supported a commercial fishery until 1979–1980 when an epidemic of furunculosis led to a catastrophic decline in numbers (Smith 1985). Recent pop-net surveys indicate that numbers are rising again (Figure 7).

Abundance of other species seems to be little changed, but other aspects of fish life history appear to have been affected by environmental changes of the last half-century. Spottail shiner has

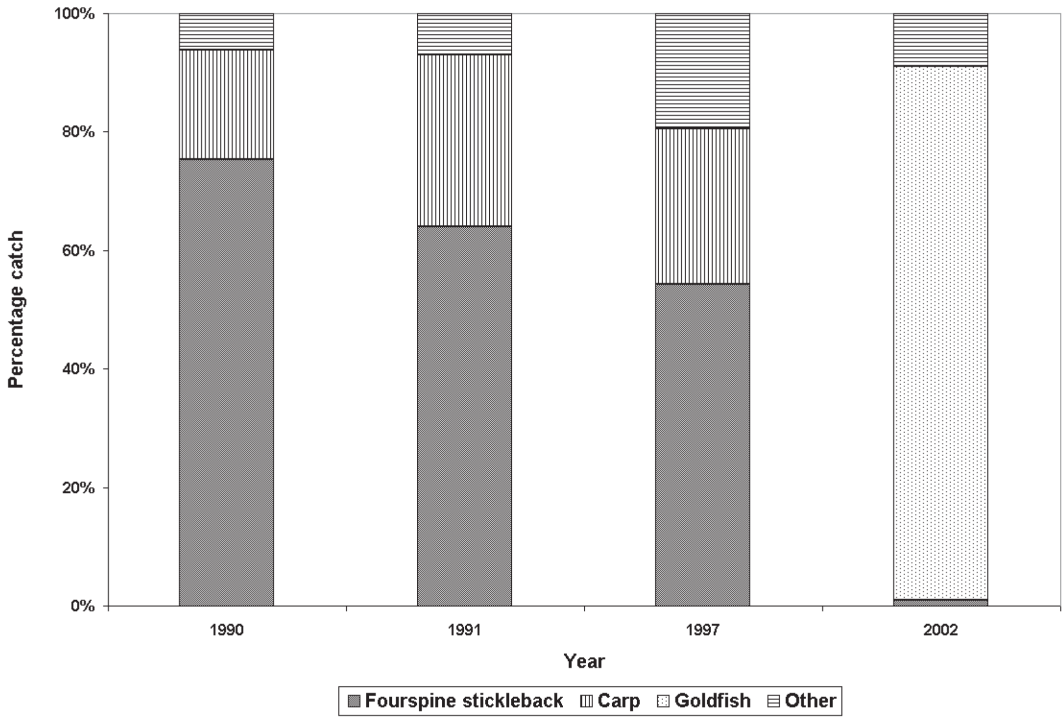

Figure 7. Relative abundance of fourspine stickleback, common carp, goldfish, and other species caught in pop nets from Tivoli South Bay, Hudson River, New York, in 1990, 1991, 1997, and 2002.

always been one of the most abundant species in the tidal Hudson River and we have no evidence that its numbers have changed. Instead, age structure of the population appears to have changed. In the late 1980s, R.E.S. and Tom Lake (NYS DEC, personal communication) independently began looking for rainbow smelt in tributaries using small-mesh gill nets (1.2-cm bar). Efforts to catch rainbow smelt in Hudson River tributaries were unsuccessful, but runs of large spottail shiners adults (total length [TL] > 110 mm) were common in the spring. Lake and Schmidt (1997) documented a substantial spawning run of these large spottail shiner in Quassaic Creek (rkm 97) and conservatively estimated that 2,800 individuals were observed. No spawning run was observed in a similar study conducted the following year in the same creek (Lake and Schmidt 1998). We have seen no further runs of large spottail shiner even though we continue to catch larvae in the drift (Schmidt and Lake 2000). A change in age structure in spottail shiner may negatively affect the status of this species in the Hudson River.

Discussion

The Hudson River fish assemblage is rich, diverse, and dynamic. Although the marine species that enter the river are an interesting component of the assemblage, many of these are listed based on a single collection. In contrast, the resident freshwater and estuarine species and the diadromous species are the key components to the Hudson River assemblage. Changes in the abundance, distribution, or life history of these species have the greatest effect on the overall assemblage. Nothing is known about the character of the pre-1800 fish assemblage. Mitchill's (1815) treatment of New York fish unfortunately fails to include consistent information on distribution within the state. DeKay (1842) is the first to include zoogeographic information.

It is difficult to accurately assess the change in the number of indigenous freshwater or diadromous species in the Hudson River since the middle years of the 19th century, although there appears to be nearly a twofold increase (Table 1). However, the 29 native species identified by DeKay (1842) is a conservative number; it is based on species identified as present in the Hudson River by DeKay (1842) who did not always provide information on the distribution of species. Undoubtedly, some species present in the Hudson River were not included in DeKay's count, simply because he did not mention the Hudson River in his commentary. Changes in nomenclature and taxonomy also affect DeKay's (1842) count; many of the minnow species not listed by DeKay (1842) had yet to be described. Bean (1903) provided more information on distribution and the taxonomy of fishes was better developed. Still, his count was less than all later 20th century counts. There also are some curious omissions from the lists published by DeKay (1842) and Bean (1903) (Table 1). DeKay (1842) did not include blueback herring, bay anchovy *Anchoa michelli*, white perch, and redbreast sunfish, and he included only five species of native minnow. Bean (1903) failed to list blueback herring, American shad, bay anchovy, rainbow smelt, and tessellated darter. These species were included in all later 20th century lists; several of these species are among the most frequently encountered species in the river in the 20th century and were obviously present in the 19th century; for example, there was an active commercial fishery for American shad in the Hudson River before 1900. Despite the differences in actual numbers, the native freshwater and diadromous species in the Hudson River make up a core assemblage that arguably has varied little since the earliest records, dating back almost 200 years.

What has changed is the number of freshwater alien species now established in the tidal Hudson River (Table 1). DeKay (1842) noted only two aliens: common carp and rock bass. Since then, there has been a 15-fold increase in the number of established alien species in the river and a doubling in the last six decades alone. Many of the new arrivals are large, predatory species, like channel catfish, northern pike, smallmouth and largemouth bass, and walleye. The establishment of several of these predatory species coincides with the decline of the small, tributary species (e.g., bridle shiner *Notropis bifrenatus*, common shiner *Luxilus cornutus,* satinfin shiner *Cyprinella analostana*) that once inhabited the nearshore areas of the main channel (Daniels 1995). Based on presence-absence information, the assemblage of the late 20th century differs from that of the early 19th century. The size and composition of the alien component of the assemblage has increased, but it is not the only change affecting the assemblage.

Large, widespread changes in fish populations were associated with the zebra mussel invasion in the Hudson. These changes were consistent with what was expected from observed changes in the Hudson's forage base, with large losses of open-water forage (zooplankton and deepwater macrobenthos) and simultaneous increases in littoral forage (Pace et al. 1998; Strayer and Smith 2001). Consequently, open-water fish (especially *Alosa* spp.) declined in abundance, apparently grew more slowly, and shifted in distribution downriver into brackish sections of the Hudson where zebra mussels are scarce or absent (Figure 4; Strayer et al. 2004). At the same time, littoral fish (especially the centrarchids) became more abundant, apparently grew more quickly, and shifted in distribution upriver into the sections of the Hudson most affected by zebra mussels. Many of these changes were large (>50%).

Abiotic factors also have affected the assemblage, although it is often difficult to identify the extent of these impacts based on available information. Habitat modification in the tidal Hudson River has been extensive: maintenance of a 10-m deep ship channel by dredging, filling in of shorelines by dredge spoils and as a result of railroad construction, creation of wetlands by shoreline railroad construction, and the stabilization of flows by dam construction upstream have all affected the abundance and distribution of fish in the river (Jackson et al. in press). Most of these changes occurred before synoptic surveys of fish were undertaken; however, the changes have been so drastic that changes in the relative importance of species is likely. The small forms that are still common in the tributaries, but are now rare in the main channel are likely to be particularly affected by these changes. Species like bridle shiner, cutlip minnow *Exoglossum maxillingua*, and blacknose dace *Rhinichthys atratulus* may not find suitable habitat in the main channel to sustain prolonged residence or through which to migrate to other tributaries. There is a negative correlation between the number of alewife larvae exiting Hudson River tributaries and the degree of watershed urbanization (Limburg and Schmidt 1990). Overfishing of stocks has led to the decline of once abundant commercially important species (e.g., Bain et al. 2000; Limburg et al. in press).

The Hudson River population of rainbow smelt is at the southern extreme of the reproductive range (Lee et al. 1980), although historically it occurred farther south (Smith 1985). The abrupt decline in rainbow smelt early life stages in the ichthyoplankton may result from global warming. Ashizawa and Cole (1994) documented the trend of slowly increasing water temperature in the Hudson River. The rainbow smelt runs in the coastal streams of western Connecticut have drastically declined or disappeared simultaneously with the decline in the Hudson River population (S. Gephard, Connecticut Department of Environmental Protection, personal communication).

Perhaps the most important explanation of the recent decline of Atlantic tomcod in the Hudson River is the thermal environment it has experienced. Atlantic tomcod is at the southern extreme of its geographic range in the Hudson River (Lee et al. 1980). Grabe (1978), Klauda et al. (1988a), McClaren et al. (1988), and the data collected by the HRMP suggest that growth of tomcod is reduced as temperatures warm in the summer. Experimental work has confirmed a temperature-dependent growth and condition response of juveniles as temperatures surpass 22°C (R.C.C., D. A. Witting, unpublished data). Atlantic tomcod experiences such temperatures regularly in July and August in the Hudson River. The degree and extent of critical temperatures have been more limiting during the last several summers, which have been exceptionally warm and dry. The decrease in frequency of reports, during the last century, of tomcod from bays to the south of the Hudson River is consistent with a retreating southern range boundary, although the contribution of habitat alterations to the decline of tomcod in these systems cannot be dismissed.

Alternatively, rather than one factor directly affecting smelt or tomcod populations, an interaction of factors may be at play in what appears to be a significant reduction in the abundance of both species in the Hudson River. For example, contaminants may be important in understanding the reduction of tomcod abundance in the Hudson River. Congener-specific analyses have demonstrated that levels of PCBs, dioxins, and furans in livers and eggs of tomcod from the Hudson River are much higher than in conspecifics from elsewhere (Wirgin et al. 1992; Courtenay et al. 1999; Roy et al. 2001; Yuan et al. 2001). Further work is needed in order to determine the degree to which molecular- and individual-level effects of toxic substances are manifested in population- and community-level responses.

We present data that indicate that the Hudson River fish assemblage is rich and dynamic. Given the number and intensity of environmental change in the drainage, the fish assemblage has demonstrated itself to be remarkably resilient. We argue that the causes affecting change are varied and include an increase in the number of alien fishes in the drainage, the arrival and establishment of alien invertebrates and abiotic factors associated with land-use practices, urbanization, nonpoint source pollution, and global warming.

Of particular interest are two factors that may foster an increase in richness in the Hudson River system. Global warming may trigger increases in the number of marine strays entering the estuary. Some of these species (e.g., Atlantic croaker and black drum *Pogonias cromis*), which now occur in estuaries that are more southern, but were once more common in New York (Bean 1903), may be able to utilize the Hudson River Estuary as a nursery or as temporary feeding grounds. Other species, such as the striped shiner *Luxilus chrysocephalus*, may use the Erie or Champlain canals to enter the Hudson River drainage. Daniels (2001) argued that the modern canals provide suitable migratory routes since they are large, flowing systems that actually include the river channels for most of their courses. Marsden et al. (2000) reviewed the status of brook silverside *Labidesthes sicculus* and suggested that it used the canal system to gain access to the lower Hudson River and Lake Champlain. Documentation of changes in ranges of species resulting from changing temperature and movement through canals should be an important research goal in future studies of river fishes. Continued monitoring of changes in the Hudson River fish assemblage will allow more rigorous testing of many of the observations and relationships examined here.

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Appendix A.—Fishes reported from the Hudson River drainage, New York. The drainage is divided into three units: the lower Hudson is tidal and runs from Troy, New York to the Battery at the tip of Manhattan Island; the Mohawk is a tributary system that enters the Hudson just upstream of Troy; the upper watershed is that portion upstream of Troy, excluding the Mohawk River and its tributaries. Presence (denoted by x) in 1842 is based on DeKay (1842), in 1902 on Bean (1903), and in 1936 on Greeley (1937). A date in the early specimen column refers to the oldest museum specimen collected prior to 1925; a ? denotes an early, undated specimen exists. We searched for specimens in NYSM, AMNH, and USNM. An x in the 1970–2002 column signifies that the species has been verified from the main channel of the lower Hudson River during those years. An x in the distribution columns indicates that the species has been reported from the watershed. Three species have been reported from the drainage (see Carlson and Daniels, 2004), but no specimens have been accessioned into any collection to allow verification. If established in the drainage, *Acipenser fulvescens*, *Ameiurus melas,* and *Esox masquinongy* are alien.

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
silver lamprey												
Ichthyomyzon unicuspis						x	x		freshwater	rare	St. Lawrence	first record 1937
American brook lamprey												
Lampetra appendix	x			1909		x			freshwater	rare		
sea lamprey												
Petromyzon marinus	x		x	?	x	x	x		anadromous	common		rare in upper drainage
smooth dogfish												
Mustelus canis						x			marine	rare		no voucher specimen
spiny dogfish												
Squalus acanthias			x			x			marine	rare		
little skate												
Raja erinacea						x			marine	rare		single specimen, 1987
barndoor skate												
R. laevis			x			x			marine	rare		single specimen, 1932
shortnose sturgeon												
Acipenser brevirostrum	x		x		x	x			anadromous	common		federal endangered
Atlantic sturgeon												
A. oxyrinchus	x		x	1878	x	x			anadromous	rare, increasing		
longnose gar												
Lepisosteus osseus					x	x			freshwater	rare	unknown	first record 1989
bowfin												
Amia calva						x			freshwater	rare	unknown	first record 1988
ladyfish												
Elops saurus						x			marine	rare		
bonefish												
Albula vulpes						x			marine	rare		
American eel												
Anguilla rostrata	x	x	x		x	x	x	x	catadromous	common		

Appendix A.—continued

Common and Scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if exotic	Comments
conger eel												
Conger oceanicus					x	x			marine	rare		transforming leptocephali
blueback herring												
Alosa aestivalis			x		x	x		x	anadromous	abundant		
hickory shad												
A. mediocris					x	x			marine	rare		
alewife												
A. pseudoharengus	x	x	x		x	x		x	anadromous	common		rare in Mohawk
American shad												
A. sapidissima	x		x		x	x		x	anadromous	common		rare in Mohawk, extirpated from upper drainage by 1850s
Atlantic menhaden												
Brevoortia tyrannus			x		x	x			marine	episodically common		
Atlantic herring												
Clupea harengus					x	x			marine	rare		
gizzard shad												
Dorosoma cepedianum					x	x		x	freshwater	common, increasing	unknown	first record in lower drainage 1972, recent range expansion
round herring												
Etrumeus teres						x			marine	rare		
striped anchovy												
Anchoa hepsetus					x	x			marine	rare		
bay anchovy												
A. mitchilli			x		x	x			estuarine	abundant		
central stoneroller												
Campostoma anomalum								x	freshwater	common	Mississippi	widely distributed in Mohawk and central tributaries, recent range expansion

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
goldfish												
Carassius auratus		x	x		x	x	x	x	freshwater	once common, increasing	Europe	first record 1842, earlier introduction
redside dace												
Clinostomus elongatus								x	freshwater	rare, declining		tributaries
lake chub												
Couesius plumbeus							x	x	freshwater	rare		
grass carp												
Ctenopharyngodon idella					x	x			freshwater	rare	Asia	escapees from introduction, 1988 no reproduction
satinfin shiner												
Cyprinella analostana						x		x	freshwater	rare		tributaries
spotfin shiner												
C. spiloptera			x		x	x	x	x	freshwater	common		tributaries
common carp												
Cyprinus carpio	x	x	x		x	x	x	x	freshwater	common	Europe	first record 1840s
cutlip minnow												
Exoglossum maxillingua		x		1921	x	x	x	x	freshwater	common		
brassy minnow												
Hybognathus hankinsoni					x	x	x	x	freshwater	rare		tributaries
eastern silvery minnow												
H. regius		x	x		x	x	x	x	freshwater	common		
common shiner												
Luxilus cornutus	x	x	x	1883	x	x	x	x	freshwater	abundant		tributaries
pearl dace												
Margariscus margarita						x	x	x	freshwater	rare		tributaries
hornyhead chub												
Nocomis biguttatus								x	freshwater	rare	St. Lawrence	first record 1900s
golden shiner												
Notemigonus crysoleucas	x	x	x	1909	x	x	x	x	freshwater	common		
comely shiner												
Notropis amoenus		x	x		x	x			freshwater	rare	Delaware	first record 1930s

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
emerald shiner												
N. atherinoides					x	x	x	x	freshwater	common	St. Lawrence	first record 1930s
bridle shiner												
N. bifrenatus			x		x	x	x	x	freshwater	rare, declining		
blackchin shiner												
N. heterodon							x		freshwater	rare, declining		
blacknose shiner												
N. heterolepis							x	x	freshwater	rare, declining		
spottail shiner												
N. hudsonius	x	x	x	1875	x	x	x	x	freshwater	abundant		
sand shiner												
N. stramineus						x			freshwater	rare	St. Lawrence	tributaries, first record 1985
rosyface shiner												
N. rubellus					x	x	x	x	freshwater	common		
northern redbelly dace												
Phoxinus eos						x	x	x	freshwater	rare		
finescale dace												
P. neogaeus							x		freshwater	rare		
bluntnose minnow												
Pimephales notatus					x	x	x	x	freshwater	abundant		
fathead minnow												
P. promelas					x	x	x	x	freshwater	abundant, increasing	unknown	first record in lower drainage, 1930s
blacknose dace												
Rhinichthys atratulus	x	x	x	1883	x	x	x	x	freshwater	abundant		tributaries
longnose dace												
R. cataractae			x		x	x	x	x	freshwater	abundant		tributaries
bitterling												
Rhodeus sericeus						x			freshwater	rare, may be extirpated	Europe	first record 1923
rudd												
Scardinius erythrophthalmus					x	x			freshwater	rare, increasing	Europe	first record 1930s
creek chub												
Semotilus atromaculatus		x	x	1881	x	x	x	x	freshwater	abundant		tributaries

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
fallfish												
S. corporalis	x	x	x	1921	x	x	x	x	freshwater	common		
longnose sucker												
Catostomus catostomus						x	x	x	freshwater	rare, declining		tributaries
white sucker												
C. commersonii	x	x	x	1924	x	x	x	x	freshwater	abundant		tributaries
creek chubsucker												
Erimyzon oblongus	x	x	x			x		x	freshwater	rare		tributaries
northern hog sucker												
Hypentelium nigricans			x		x	x		x	freshwater	rare		tributaries
shorthead redhorse												
Moxostoma macrolepidotum		x			x	x		x	freshwater	rare		first record in lower 1999, expanding range
pirapatinga												
Piaractus brachypomus						x		x	freshwater	rare	aquarium release	first record 1990s
white catfish												
Ameiurus catus	x	x	x		x	x			freshwater	common		
yellow bullhead												
A. natalis					x	x	x	x	freshwater	rare		
brown bullhead												
A. nebulosus	x	x	x	1902	x	x	x	x	freshwater	abundant		
channel catfish												
Ictalurus punctatus					x	x			freshwater	rare, increasing	stocked	first record 1976
stonecat												
Noturus flavus								x	freshwater	common		
tadpole madtom												
N. gyrinus						x	x	x	freshwater	rare		tributaries
margined madtom												
N. insignis							x	x	freshwater	rare	Delaware	first record 1930s
brindled madtom												
N. miurus								x	freshwater	rare	St. Lawrence	first record 1980s
redfin pickerel												
Esox americanus		x	x	1913	x	x	x	x	freshwater	common		
northern pike												
E. lucius					x	x	x	x	freshwater	rare, increasing	St. Lawrence	first record 1840s, and later introductions

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
chain pickerel												
E. niger	x		x	1920	x	x	x	x	freshwater	common		
central mudminnow												
Umbra limi					x	x		x	freshwater	common	unknown	first record 1932, range expansion
eastern mudminnow												
U. pygmaea	x	x		1855	x	x			freshwater	common		tributaries
rainbow smelt												
Osmerus mordax	x		x		x	x	x	x	anadromous	rare, declining		stocked in upper drainage, Mohawk
cisco												
Coregonus artedi							x	x	freshwater	rare		stocked in Mohawk, native in upper
lake whitefish												
C. clupeaformis						x	x	x	freshwater	rare		stocked in lower and Mohawk, native in upper, first record in lower drainage 1936
rainbow trout												
Oncorhynchus mykiss						x	x	x	freshwater	common	Pacific rim	stocked, tributaries
sockeye salmon												
O. nerka					x	x	x		freshwater	rare	Pacific rim	first record 1974
Chinook salmon												
O. tshawytscha						x			freshwater	rare	Pacific rim	first record 1988
round whitefish												
Prosopium cylindraceum							x	x	freshwater	rare		stocked in Mohawk, native in upper, state endangered in NY
Atlantic salmon												
Salmo salar	x		x			x	x	x	freshwater	rare	stocked	numerous stockings beginning in 1880s, tributaries, lakes, alien in upper, Mohawk, possibly native in lower

Appendix A— continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
brown trout												
S. trutta			x		x	x	x	x	freshwater	common	Europe	stocked, tributaries
brook trout												
Salvelinus fontinalis	x		x	1902		x	x	x	freshwater	common		tributaries
lake trout												
S. namaycush						x	x	x	freshwater	rare	unknown	stocked widely
inshore lizardfish												
Synodus foetens					x	x			marine	rare		
trout-perch												
Percopsis omiscomaycus		x			x	x	x	x	freshwater	rare		
fourbeard rockling												
Enchelyopus cimbrius					x	x			marine	rare		
Atlantic cod												
Gadus morhua						x			marine	rare		
burbot												
Lota lota							x		freshwater	extirpated	St. Lawrence	single record, reported 1842
silver hake												
Merluccius bilinearis					x	x			marine	rare		
Atlantic tomcod												
Microgadus tomcod	x	x	x		x	x			estuarine	common, declining		
pollock												
Pollachius virens						x			marine	rare		
red hake												
Urophycis chuss					x	x			marine	rare		
spotted hake												
U. regia					x	x			marine	common		
white hake												
U. tenuis						x			marine	rare		
striped cusk-eel												
Ophidion marginatum					x	x			marine	rare		
oyster toadfish												
Opsanus tau						x			marine	rare		
goosefish												
Lophius americanus						x			marine	rare		

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
Atlantic needlefish *Strongylura marina*			x		x	x			anadromous	common		
houndfish *Tylosurus crocodilus*						x			marine	rare		single record, 1989
sheepshead minnow *Cyprinodon variegatus*						x			marine	rare		
banded killifish *Fundulus diaphanus*	x	x	x	1859	x	x	x	x	freshwater	common		
mummichog *F. heteroclitus*			x	1883	x	x			estuarine	common		
spotfin killifish *F. luciae*						x			estuarine	rare		first noted 2000
striped killifish *F. majalis*					x	x			marine	common		
western mosquitofish *Gambusia affinis*						x			freshwater	rare	unknown	first record 1992
brook silverside *Labidesthes sicculus*					x	x		x	freshwater	common, increasing	St. Lawrence	first record 1998 in lower, 1930s in Mohawk
rough silverside *Membras martinica*					x	x			marine	rare		common in areas of high salinity
inland silverside *Menidia beryllina*			x		x	x			estuarine	rare		common in areas of high salinity
Atlantic silverside *M. menidia*			x	1858	x	x			marine	rare		
fourspine stickleback *Apeltes quadracus*	x		x		x	x			estuarine	declining		
brook stickleback *Culaea inconstans*				1909		x		x	freshwater	common		tributaries

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
threespine stickleback												
Gasterosteus aculeatus	x	x	x		x	x			anadromous?	rare		
ninespine stickleback												
Pungitius pungitius			x			x			anadromous?	rare		
bluespotted cornetfish												
Fistularia tabacaria					x	x			marine	rare		
lined seahorse												
Hippocampus erectus	x				x	x			marine	rare		
northern pipefish												
Syngnathus fuscus	x				x	x			marine	common		
flying gurnard												
Dactylopterus volitans						x			marine	rare		
northern searobin												
Prionotus carolinus					x	x			marine	rare		
striped searobin												
P. evolans					x	x			marine	rare		
slimy sculptin												
Cottus cognatus				1903		x	x	x	freshwater	common		tributaries
sea raven												
Hemitripterus americanus						x			marine	rare		
grubby												
Myoxocephalus aenaeus					x	x			marine	rare		abundant in areas of high salinity
longhorn sculpin												
M. octodecemspinosus					x				marine	rare		
lumpfish												
Cyclopterus lumpus						x			marine	rare		
Atlantic seasnail												
Liparis atlanticus					x	x			marine	rare		
white perch												
Morone americana		x	x	1921	x	x		x	estuarine	abundant		
white bass												
M. chrysops					x	x		x	freshwater	rare	Mississippi	first record 1975
striped bass												
M. saxatilis	x	x	x		x	x			anadromous	common, increasing		

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
black seabass												
Centropristis striata					x	x			marine	rare		
gag												
Mycteroperca microlepis						x			marine	rare		
rock bass												
Ambloplites rupestris	x		x		x	x	x	x	freshwater	common	St. Lawrence	first record 1840s
bluespotted sunfish												
Enneacanthus gloriosus						x			freshwater	rare		
banded sunfish												
E. obesus							x			freshwater	rare	state threatened in NY, single record 1936
redbreast sunfish												
Lepomis auritus		x	x	?	x	x	x	x	freshwater	common		
green sunfish												
L. cyanellus						x		x	freshwater	rare, increasing	stocked	first record 1936
warmouth												
L. gulosus					x	x			freshwater	rare	stocked?	first record 1936
pumpkinseed												
*L. gibbosus*x		x	x		x	x	x	x	freshwater	abundant		
bluegill												
L. macrochirus			x	1855	x	x	x	x	freshwater	common	stocked	
smallmouth bass												
Micropterus dolomieu		x	x		x	x	x	x	freshwater	common	stocked	first record 1830s
largemouth bass												
M. salmoides		x	x	1882	x	x	x	x	freshwater	common	stocked	first record 1830s
white crappie												
Pomoxis annularis					x	x		x	freshwater	rare	stocked	
black crappie												
P. nigromaculatus			x		x	x	x	x	freshwater	common	stocked	
greenside darter												
Etheostoma blennioides								x	freshwater	common		

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
fantail darter												
E. flabellare								x	freshwater	common		
tessellated darter												
E. olmstedi	x		x	1903	x	x	x	x	freshwater	abundant		
yellow perch												
Perca flavescens	x	x	x	1902	x	x	x	x	freshwater	common		
log perch												
Percina caprodes			x		x	x	x	x	freshwater	common	St. Lawrence	first record 1932
shield darter												
P. peltata			x		x	x			freshwater	rare	Delaware	first record 1936
walleye												
Sander vitreus			x		x	x	x	x	freshwater	common	stocked	first record 1893
short bigeye												
Pristigenys alta						x			marine	rare		
bluefish												
Pomatomus saltatrix	x	x	x	1881	x	x			marine	common		seasonal
cobia												
Rachycentron canadum		x	x			x			marine	rare		single record 1876
sharksucker												
Echeneis naucrates	x			1854	x	x			marine	rare		
crevalle jack												
Caranx hippos	x		x		x	x			marine	episodically common		
Atlantic moonfish												
Selene setapinnis					x	x			marine	rare		
lookdown												
S. vomer					x	x			marine	rare		
permit												
Trachinotus falcatus						x			marine	rare		
gray snapper												
Lutjanus griseus						x			marine	rare		
spotfin mojarra												
Eucinostomus argenteus						x			marine	rare		
pigfish												
Orthopristis chrysoptera						x			marine	rare		

Appendix A.—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
pinfish												
Lagodon rhomboides						x			marine	rare		
scup												
Stenotomus chrysops					x	x			marine	rare		
freshwater drum												
Aplodinotus grunniens					x	x			freshwater	rare, increasing	St. Lawrence	
silver perch												
Bairdiella chrysoura					x	x			marine	rare		
weakfish												
Cynoscion regalis					x	x			marine	episodically abundant		
spot												
Leiostomus xanthurus	x		x	1917	x	x			marine	episodically abundant		
northern kingfish												
Menticirrhus saxatilis					x	x			marine	rare		
Atlantic croaker												
Micropogonias undulatus					x	x			marine	rare		
foureye butterflyfish												
Chaetodon capistratus						x			marine	rare		single record
spotfin butterflyfish												
C. ocellatus						x			marine	rare		
striped mullet												
Mugil cephalus					x	x			marine	rare		
white mullet												
M. curema					x	x			marine	rare		
northern sennet												
Sphyraena borealis						x			marine	rare		
guaguanche												
S. guachancho						x			marine	rare		
tautog												
Tautoga onitis					x	x			marine	rare		
cunner												
Tautogolabrus adspersus					x	x			marine	rare		
rock gunnel												
Pholis gunnellus					x	x			marine	rare		

Appendix A.— continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
northern stargazer												
Astroscopus guttatus					x	x			marine	rare		
feather blenny												
Hypsoblennius hentz						x			marine	rare		
freckled blenny												
H. ionthas						x			marine	rare		
American sand lance												
Ammodytes americanus					x	x			marine	rare		larvae common early in season
fat sleeper												
Dormitator maculatus					x	x			marine	rare		
highfin goby												
Gobionellus oceanicus						x			marine	rare		single record 2000
naked goby												
Gobiosoma bosc					x	x			marine	common		
seaboard goby												
G. ginsburgi					x	x			marine	common		
Atlantic cutlassfish												
Trichiurus lepturus						x			marine	rare		
Atlantic makerel												
Scomber scombrus					x	x			marine	rare		
Spanish mackerel												
Scomberomorus maculatus					x	x			marine	rare		
butterfish												
Peprilus triacanthus			x		x	x			marine	rare		
Gulf Stream flounder												
Citharichthys arctifrons					x	x			marine	rare		
smallmouth flounder												
Etropus microstomus					x	x			marine	rare		
summer flounder												
Paralichthys dentatus			x		x	x			marine	common		
fourspot flounder												
P. oblongus					x	x			marine	rare		
windowpane												
Scophthalmus aquosus					x	x			marine	rare		

Appendix A—continued

Common and scientific names	1842	1902	1936	Early specimen	1970–2003	Distribution within drainage: Lower	Upper	Mohawk	Life history	Abundance status	Origin, if alien	Comments
winter flounder												
Pseudopleuronectes americanus			x		x	x			marine	common		
yellowtail flounder												
Pleuronectes ferrugineus					x	x			marine	rare		
northern tonguefish												
Symphurus pusillus						x			marine	rare		
hogchocker												
Trinectes maculatus	x	x	x		x	x			estuarine	common		
orange filefish												
Aluterus schoepfi						x			marine	rare		
planehead filefish												
Monacanthus hispidus						x			marine	rare		
scrawled cowfish												
Acanthostracion quadricornis					x	x			marine	rare		single specimen, 1999
striped burrfish												
Chilomycterus schoepfi						x			marine	rare		
smooth puffer												
Lagocephalus laevigatus				1848		x			marine	rare		single specimen, 1848
northern puffer												
Sphoeroides maculatus					x	x			marine	rare		