Biological Invasions in the Hudson River: An Inventory and Historical Analysis

Edward L. Mills and Mark D. Scheuerell

Department of Natural Resources
Cornell University Biological Field Station
900 Shackelton Point Road
Bridgeport, New York 13030

James T. Carlton

Maritime Studies Program
Williams College - Mystic Seaport
Mystic, Connecticut 06355

David Strayer

Institute of Ecosystem Studies
Millbrook, New York 12545

INTRODUCTION

Introduced, exotic or non-indigeneous species, defined as successfully reproducing organisms transported by human related activities into areas where they did not previously exist (Mills *et al.* 1993) represent one of the most damaging effects on the world's ecosystems (Elton 1958, Kornberg and Williamson 1986, Mooney and Drake 1986, Drake *et al.* 1989, Hengeveld 1989, Pieterse and Murphy 1990). As anthropogenic activities increasingly lead to the introduction of species outside of their natural range, portions of the earth's biota are rapidly becoming "homogenized" (Lodge 1993). Exotic plant species typically characterize 10-30% of the flora of most regions and within these regions, exotic plants may comprise 90-100% of plant biomass (Heywood 1989). The effects of these biological invasions on native communities can be dramatic and wide-ranging and include changes in species composition, biomass, and distributions, and in nutrient cycling and energy transfer pathways and rates. Large indirect effects of species invasions can be transmitted through communities and ecosystems to impact biota at different trophic levels (Mills *et al.* 1987). Furthermore, exotic species may have extensive societal impacts including economic, industrial, and human health.

Nearly four centuries of European colonization and commercial development in northeastern North America have set the stage for fundamental biological alterations and modifications of the Hudson River system. These modifications largely fall into two categories: 1) the destruction and eradication of natural habitats and native flora and fauna through urbanization, industrialization, and exploitation and 2) the introduction of non-native species. Furthermore, these anthropogenic environmental alterations are closely linked to the introduction of exotic species (Mooney and Drake 1986, Drake *et al.* 1989). In the Great Lakes, for example, human-mediated environmental activities have led to the introduction of more than 139 species of exotic animals and plants, many of which now dominate local communities (Mills *et al.* 1993). Increasing industrialization and commercialization have indirectly led to increased rates of invasions, such that over one-third of the non-indigenous species in the Great Lakes have been discovered in the past 30 years, a trend coinciding with the opening of the Saint Lawrence Seaway in 1959 (Mills *et al.* 1993).

In this paper we focus on the Hudson River, a large North American river ecosystem whose waters flow into the Atlantic Ocean. We define the Hudson River as being from the "Battery" in New York City (River Mile [RM] 0) north to the Federal Lock and Dam at Troy, New York (RM 150) (Figure 1). We base this definition upon the portion of the River navigable to larger vessels. Hydrographically and topographically the river flows 506 km from its source, Lake Tear of the Clouds in the Adirondacks, to Manhattan. Tidal influence is detected as far north

as Troy, New York. Adams (1981) notes that others define the Hudson as reaching north to Glen Falls, a distance of an additional 32 km. The entire Hudson River basin is much larger (34,615 km^2) and drains parts of five states (New York, New Jersey, Massachusetts, Connecticut, and Vermont) as well as six physiographic regions (the Canadian Shield, the Folded Appalachians, the Catskills, the Hudson Highlands, the New England Upland, and the New Jersey Lowland) (Kammen, 1975).

The Hudson River ecosystem includes both salt and fresh water. Ristich *et al.* (1977) divided the River estuary into four reaches: a polyhaline zone (18 - 30 ppt) extending from the Battery in the summer to RM17 in the late fall, a mesohaline zone (5 to 18 ppt) reaching from RM8 in early summer to RM58 (the Newburgh region) in late summer, an oligohaline zone (0.5 to 5 ppt) reaching from RM42 in the early summer to RM60 in the late summer, and a fresh water zone reaching its furthest southern extent in the spring at RM20. While a description of the River Valley's climate is beyond our present scope, it is worth noting that the lower valley acts as a temperature moderator of, and corridor for, warmer maritime air masses. Iona Island at RM45 (north of Peekskill, New York) marks the normal upper boundary of warmer air penetration, and is thus a general upriver boundary for plants with southern affinities (Kammen, 1975).

The focus of the present study is on the aquatic plants and animals of the oligohaline and freshwater reaches of the Hudson River drainage basin (Figure 2). We exclude the marine invaders that occur in Long Island Sound south of the Battery (examples include the European green crab *Carcinus maenas*, the Japanese orange-striped sea anemone *Haliplanella lineata*, the European periwinkle *Littorina littorea* and the southern U.S. barnacle *Balanus subalbidus* (Carlton, in prep.)). Although exotic species have been successfully invading the Hudson River for several centuries, there has been no previous attempt to review and analyze the history of biological invasions in the region. Previous studies have identified exotic species within certain taxonomic groups (e.g., Countryman 1970, Smith 1985, Kiviat 1987, Strayer 1987, Smith and Lake 1990) but no comprehensive list of aquatic non-indigenous species has been compiled. Here we present such an inventory for the Hudson River basin.

MECHANISMS OF INTRODUCTION OF EXOTIC SPECIES INTO THE HUDSON RIVER BASIN

History of Dispersal Mechanisms. The Hudson River Basin offers a classic example of a New World ecosystem subjected to four centuries of European exploration, colonization, and intensive urbanization, and the associated activities that have lead to the accidental or intentional release of exotic species from around the world. From the earliest colonial visits in the 17th century, which brought the seeds of marsh plants in livestock feed and fouling hydroids on carrack hulls (Carlton 1992c; Carlton and Hodder 1994) to the late 20th century release of ballast water from huge ocean-going bulk carriers (Carlton 1985; Carlton and Geller 1993), the Hudson has been the continuous site for the release and successful establishment of non-indigenous aquatic plants and animals.

Early Viking explorations aside, the Hudson River system was potentially first regularly exposed to the invasion of European organisms in the late 15th and early 16th centuries, when explorers such as Cabot (in 1498) and Gomes (in 1525) visited the River's mouth, and when Verrazano sailed far enough inland in 1524 to see the outline of the Palisades (Bruce 1907; Kammen 1975). On the bottoms of their sailing vessels were European fouling organisms, and in their holds, potentially discardable into the River, were dry ballast, dunnage, and spoiled foodstuffs. Exploration and colonization increased dramatically in the 17th century. Henry Hudson sailed all the way to present-day Albany in 1609, and numerous European vessels visited the River system in the decades to follow. For hundreds of the years, the River remained the major transport corridor for the region. In 1609 the River was described (Kammen 1975) as follows: "The Road is very neere [to the banks], and very good for all winds, save an east north-east wind", leading Kammen to note that "For generations to come, 'the road' would refer to the ships' channel, for these were waterborne communities." There is little doubt that a number of the common marsh weeds we list in this paper entered the New York region in these first few centuries of commerce. However, no scientific descriptions of the botany or zoology of the River system are available until two centuries later -- and thus knowledge of all these early presumed invasions is lost.

The thousands of vessels that visited New York in the 1600s, 1700s, and 1800s, carrying aquatic organisms in moist, solid ballast in their holds (and after the 1880s, water ballast), human and livestock food stuffs, and fouling and boring organisms on and in their hulls, thus led to many of the invasions discussed below. The opening of the Champlain Canal in 1819, the Erie Canal in 1825, and the creation, improvement, and expansion of many other smaller regional canals lead to greatly increased shipping activity in New York by the mid-19th century, as the Hudson River

became one of the most important gateways into America's heartland (Bruce 1907; Adams 1981). The improvement of the New York State Barge Canal in 1918 and the modern renovation of the Port of Albany in 1932, accomodating sea-going vessels of 27 foot draft (Adams 1981), further enhanced New York's strategic position as a major port system (Figure 3) and has played a major role in facilitating the movement of fish species (C.L. Smith 1985).

Coincident with the development of agriculture and cities along the Hudson corridor were focused activities that led to the intentional introduction of non-native species. Plants were intentionally brought in for stock forage or for urban gardens and ponds. Fish were brought in and released to improve local fisheries. With increased affluence and urban stabilization, the use of animals as aquarium pets increased. Intentional introductions often led to these organisms secondarily escaping or being released into the wild.

METHODS

In this monograph, we follow the methods of Mills *et al.* (1993). For the Hudson River basin, however, we have been forced to restrict our analyses of the non-indigenous biota to aquatic plants (macrophytes) and fish and, among the invertebrates, largely to mollusks and crayfish. The absence of historical information, limited biogeographic studies, and a severe dearth of modern faunistic and systematic studies for many taxa in the Hudson River basin, placed extensive restrictions on the analysis of the non-molluscan, non-crayfish exotic invertebrate biota of the basin. For the Hudson River basin, there was no historical information on the lower trophic levels including algae, crustacean zooplankton, rotifers, and nematodes. Data collection and analysis included first date and location of release or collection, the most probable mechanism(s) of introduction, and geographic origin; these data are included in Tables 2 and 3 for animals and plants respectively, and introduction mechanism definitions and codes are given in Table 1.

Dates of Introduction. Dates of introduction are reported as one of three categories: (1) the date of first recorded release (usually based upon a literature record), (2) the date of the first recorded collection (based upon literature or museum records, or upon a personal communication); we use first "sighting" and first "discovery" as synonyms of first collection, or (3) the date of first publication. In the literature, first "recording" has been used to refer to both categories (2) and (3), which we distinguish here. Examples of category (3) are the records of DeKay (1842) or Goode (1903): in these and similar cases we assume that the actual date of release or collection is prior to the date of publication, as it is unlikely that the first actual record is in fact the same date as the

monograph in question. Thus we have always indicated these dates as "prior to" (<) the date of publication. In instances where the literature does not provide precise dates or locations (referring instead to a general period (such as "mid 1800s") or a general location (such as "eastern New York") we have attempted to ascertain a more specific date or location. In most cases, the first collection (category 2) is sometime after the actual date of introduction into the River basin.

Mechanisms of Introduction. The mechanism or probable mechanism of introduction (entry vector) is defined as the known or the most probable means by which an organism gained access to the River basin. We have assigned an entry vector to each species based upon literature records, communications with relevant workers, and by analysis of the species' habitat. In addition, we have used known or suspected dispersal vectors from related taxa to infer a probable vector for species where a mechanism of introduction has been previously clearly stated. Thus, if several species in a genus were introduced by escaping from cultivation, we suggest that an additional congener may have been introduced by the same means. For some species the mechanism of introduction remains unknown or multiple mechanims may apply, as noted below.

We divided introduction mechanisms into the following five broad categories (Table 1): deliberate release, unintentional release, shipping activities, canals, and a combination of these (i.e. multiple). We assign letter codes (Table 1) to each of these for use in the summary tables. Deliberate releases include the intentional release of organisms into an area with the goal of establishing a viable population. Unintentional releases are defined as the release of organisms without the intention of creating established populations. These include (Carlton 1992a; 1993) the intentional release of aquarium animals and plants, the accidental escape of plants from cultivation, the release of unused bait or non-target fish with stocked fish, and the accidental release of organisms in any other manner. Shipping activities include (Carlton 1989) fouling organisms on ships' hulls, the transport of solid ballast, and the movement of water ballast. Canals include the "natural" movement of organisms through canals (as opposed to on barge hulls, which would be included under Shipping activities). Finally, a number of species have been introduced by more than one vector leading to a multiple mechanism category. Further descriptions of these mechanisms are provided by Mills *et al.* (1993).

Geographical Origin. Regional, continental, or subcontinental categories are used to describe geographic origin. These are: Holarctic, Eurasia (including Europe), Asia, North American Atlantic Coast, North American Pacific Coast, Southern United States, Interior Basin, and Unknown. We combine Europe and Eurasia because many authors fail to distinguish between these geographic regions. While the North American Atlantic Coast covers the region from Florida

to northern Canada, we considered this geographic category as a source region outside of the Hudson River basin. Thus, species that are believed to have naturally occurred only to the north or to the south of the Hudson River system, but whose modern-day occurrence in the Hudson is due to human mediated transport, are scored as originating in the North Atlantic region. Southern United States refers to waters either in the interior south or to the Gulf of Mexico. The Interior Basin is a broad category that includes the area between the Rocky Mountains and the Appalachian Mountains. Some exotic species were introduced from a secondary origin. For example, the snail *Cipangopaludina chinensis malleata* is native to Asia, but was almost certainly transported from the Pacific Coast, to where it was first introduced to North America.

RESULTS

Aquatic Fauna

Fishes

Studies of the fishes of New York have a long historical tradition; C. L. Smith (1985) provides an excellent historical synopsis of Hudson River fishes. The earliest monograph to include the fishes of the Hudson River basin was James E. DeKay's *The Zoology of New York or The New York Fauna; Part IV. The Fishes* published in 1842. In 1903, Tarleton H. Bean's *Catalogue of the Fishes of New York* was the first study to separate the Hudson River from other locations in the state. The first comprehensive surveys of the Hudson River basin fish fauna were initiated by the New York State Conservation Department in 1932-1936 (Greeley and Bishop 1933, Greeley 1935, Greeley 1937). After almost 40 years, the need for a more recent survey was realized and Bath *et al.* (1976) conducted a survey of the main channel of the Hudson River during the summer of 1976. Several recent works have further documented the Hudson River fish fauna (Smith 1985, Beebe and Savidge 1988, Smith and Lake 1990). The names of fish listed below follow those given by Robins *et al.* (1991). A summary of introduced fish in the Hudson River basin is summarized in Table 2. We have also included a list of fish species with single sightings in the Hudson (Table 3) which we consider as potential exotics but we have not included in the Table 2.

Petromyzontidae

Ichthyomyzon unicuspis Silver Lamprey

Silver lamprey are generally distributed along the Great Lakes, Saint Lawrence River, and in the larger tributaries of the Mississippi and Ohio Rivers (Lee *et al.* 1980, Smith 1985). The first silver lamprey caught in the Hudson River was collected off a traveling screen of the Niagara Mohawk Power Corporation at RM 142 near Albany, New York in June 1974 (Reider 1979b).

Reider (1979b) and George (1985) attribute its presence in the Hudson River to its passing through the Champlain Canal since Greeley (1930) found it moderately common in Lake Champlain where it is a native species.

Amiidae

Amia calva Bowfin

Bowfin occur throughout the central plains area from Wisconsin to Texas, down the Mississippi and Ohio River basins, and up the Atlantic coast from Florida to southern Pennsylvania (Lee *et al.* 1980; Smith 1985). George (1981) indicates that bowfin had not been reported in the Hudson River as of 1980, but in 1988 they were present in the lower Hudson River (Smith and Lake 1990). They may have moved through the Champlain Canal where they have been established for at least 60 years (Greeley 1930).

Clupeidae

Dorosoma cepedianum Gizzard Shad

Gizzard shad occur in the Great Lakes, Mississippi and Ohio River basins, the Mohawk River, and Atlantic coastal drainages as far north as New York harbor and Long Island (DeKay 1842, Greeley 1935, 1937; Lee *et al.* 1980, Smith 1985). Dew (1973) reports the first gizzard shad taken from the Hudson-Mohawk system were in October 1972 from power plant discharge water and intake screens. George (1983) also notes that specimens were taken from Collins Lake, a tributary of the Mohawk River in Schenectady County in June 1976. George (1983) notes that the incidence of larger, more mature fish in the Mohawk system and the absence of similar fish in the Hudson River as evidence for their movement down through the Erie Canal. Smith and Lake (1990) also believe its occurrence in the Hudson River results from its movement through the Mohawk Canal since it is common there and uncommon in the New York harbor area.

Ictaluridae

Noturus miurus Brindled Madtom

Brindled madtoms range from Lake Erie and Lake Ontario down through the Ohio River basin and the lower one-half of the Mississippi River basin to the Gulf of Mexico (Lee *et al.* 1980, Smith 1985). Taylor (1969) does not list any records of brindled madtoms east of Oneida Lake, but Smith (1985) lists several specimens taken near lock 7 (Schenectady, New York) and Smith and Lake (1990) report specimens taken as far up the river as lock 9 (Rotterdam Junction, New York) of the Erie Canal. Based on the eastward progression of collections over time (Smith

1985), we believe the brindled madtom moved into the Mohawk River and Hudson River basin via the Erie Canal.

Cyprinidae

Carassius auratus Goldfish

Goldfish are native to eastern Asia (Lee *et al.* 1980) and were widely introduced into North America prior to 1832 (Smith 1985). By 1842 they were known to be in the Hudson River (DeKay 1842). They were also introduced into the United States from Japan in 1874 by Admiral Daniel Ammon of the United States Navy (Hervey and Hems 1948). Initially imported as ornamental fish, many releases of goldfish into private ponds had occurred by the turn of the century (Lachner *et al.* 1970) and they were the first exotic fish species to establish reproducing populations in open waters of North America (Courtenay and Stauffer 1990). They have been introduced into the Hudson River by a wide variety of transport vectors including intentional introductions by the former U.S. Fish Commission, hatchery and outdoor pond escapes, and aquarium and unused bait releases (Lee *et al.* 1980).

Ctenopharyngodon idella Grass Carp

Grass carp are endemic to eastern Asia from the Amur River Basin to the West River and southward to the Chu River (Greenfield 1974, Lee *et al.* 1980). Grass carp were originally considered for importation as a possible means for controlling aquatic macrophytes (Swingle 1957). They were first introduced into the United States in 1963 at Auburn University in Alabama (Lee *et al.* 1980) and were soon spread rapidly by researchers, agency stockings to reduce aquatic macrophytes, interstate importation by private hatcheries, and escape from hatching sites. Grass carp have since been banned from importation and release in 35 states including New York because of their potential harmful impacts on aquatic environments (Smith 1985). Two ponds in the Hudson River basin have been stocked with grass carp from private hatcheries (Smith 1985). In June 1992 three grass carp, including one gravid female, were caught in the Hudson River near RM 113 and shortly thereafter, another grass carp was caught in the same area (Walt Keller, New York State Department of Environmental Conservation (NYSDEC) and Bob Daniels, New York Biological Survey Laboratory, pers. comm.).

Cyprinus carpio Common Carp

Common carp are native to Europe and temperate Asia (Smith 1985). DeKay (1842) reported that common carp were first introduced into the United States by a private citizen, Henry Robinson, in 1832 when he brought them back with him on a trip from France. After cultivating them in his ponds "for several years", he began intentionally releasing from one to two dozen carp

every spring into the Hudson River near his residence in Newburgh, New York. DeKay is unclear about the initial date of this activity, which we here arbitrarily set as 1832. At some point after that Mr. Robinson stated, "They have increased so much that our fishermen frequently take them in their nets" (Dekay 1842). Common carp have since been introduced into many areas of North America (Lee *et al.* 1980, Smith 1985) and are considered by many people to be a nuisance.

Rhodeus sericeus Bitterling

Bitterling are native to northern Europe and central and northeastern Asia (Lee *et al.* 1980, Smith 1985). On 16 September 1923, Dr. W. C. Kendall captured some bitterling in the Saw Kill, Tarrytown, Westchester County, New York (Dence 1925, Myers 1925). Bade (1926) reported a bitterling taken from a small brook near Tarrytown, New York approximately two years earlier. He stated, "It is very probable that, about ten years ago when the hobby of raising and breeding fish had its humble beginning, a fancier imported a number of these fish, placing them into this tiny stream where they have been able to multiply unhindered." Schmidt *et al.* (1981) argue that since the only breeding populations of the bitterling occur in two New York rivers, they must be the result of a single introduction prior to 1923. Courtenay and Stauffer (1990) also classify the bitterling as an aquarium release.

Scardinius erythrophthalmus Rudd

Rudd are native to Europe and western Asia (Lee *et al.* 1980, Smith 1985) and were first found in the United States in 1897 in Central Park, New York City (Bean 1897, 1903). They were introduced into the Roeliff-Jansen Kill in southeastern New York and were established there by 1936 (Greeley 1937). The American Museum of Natural History (AMNH) had specimens sent to them by Mr. Clive Brown on 11 November 1916 while he was at Unity Lodge, Copake Lake, Columbia County. It is likely that Mr. Brown released the rudd in the Copake Lake region, possibly both in the lake and in the stream (C. L. Smith, AMNH, pers. comm.). Courtenay and Stauffer (1990) list the rudd as an aquarium trade release. The release of rudd has also likely occurred with discarded fish bait; many New York bait dealers in the Hudson River basin had rudd mixed in with the golden shiners they were selling as bait during the spring and summer of 1990 (Paul Geoghegan, Normandeau Associates Incorporated, pers. comm.). Because rudd will hybridize with native golden shiners (*Notemigonous chrysoleucas*), the genetic pool of golden shiners could be altered (Anonymous 1993).

Campostoma anomalum Central Stoneroller

Central stonerollers are widely distributed in the United States from Wisconsin to New York and south into Georgia and Mexico (Lee *et al.* 1980, Smith 1985). On 7 October 1976, a

AMNH survey captured a central stoneroller in Schoharie Creek (Smith and Lake 1990), a tributary of the Mohawk River. Smith and Lake (1990) report it as quite common there now and they attribute its presence in the Hudson River basin to canals with access to the Great Lakes.

Nocomis biguttatus Hornyhead Chub

Hornyhead chub range from western New York through the Great Lakes and down the Mississippi and Ohio River basins (Lee *et al.* 1980, Smith 1985). Bean (1903) is the first to list it for the Hudson River basin, but gives no specific collection dates. George (1981) and Smith (1985) indicate that hornyhead chub probably came through the Erie Canal.

Notropis atherinoides Emerald Shiner

Emerald shiners occur in southern Canada from the Saint Lawrence River to the Northwest Territory and south through the Mississippi River basin to the Gulf of Mexico (Lee *et al.* 1980, Smith 1985). Its occurrence in the Hudson River may be due to access through the Erie and Barge Canals (Snelson 1968, George 1981, Smith 1985, Smith and Lake 1990). Greeley (1935) listed the emerald shiner in the Mohawk River in the 1934 survey, but it was not found below Catskill, New York in the Hudson River during the 1936 survey (Greeley 1937). Beebe and Savidge (1988) note that the emerald shiner was common in the lower Hudson River in later surveys and if it had colonized the Hudson-Mohawk system after the last glacial period, it should have been collected during the 1936 survey.

Notropis stramineus Sand Shiner

Sand shiners are widespread through the central United States and southern Canada from the Saint Lawrence River to the Rocky Mountains and south to Texas (Lee *et al.* 1980, Smith 1985). Smith (1985) reported an isolated introduced population in the Shawangunk Kill in southern New York. Its absence in the Delaware drainage (Smith and Lake 1990) indicates that it most likely did not move through the Delaware-Hudson Canal into the Hudson River. This exotic fish may be a bait bucket introduction (George 1981).

Salmonidae

Oncorhynchus mykiss (=*Salmo gairdneri*) Rainbow Trout

Rainbow trout are native to the Pacific Ocean drainages of North America from northern Mexico to Alaska (Lee *et al.* 1980, Smith 1985). They were introduced into New York in 1874 when Seth Green transferred eggs from the McCloud River in northern California to his hatchery in Caledonia, New York (Wales 1939, MacCrimmon 1971). These eggs were subsequently hatched and the fry distributed to many areas within the Hudson River basin. As a result of this

and many subsequent introductions, rainbow trout can now be found throughout the Hudson River basin wherever there is suitable habitat (Smith 1985).

Salmo trutta Brown Trout

Brown trout are an Old World species ranging throughout Europe, western Asia, and northern Africa (Lee *et al.* 1980, Smith 1985). The first brown trout to enter the United States came from eggs sent from Germany in 1883 and were delivered to the Northville Hatchery, Michigan (Mather 1889b, Goode 1903). Subsequent shipments of eggs made between 1884 and 1887 were raised at the U. S. Fish Commission station in Caledonia, New York, and these fish were stocked in various New York waters including some streams in the Hudson River basin (Goode 1903). Goode (1903) does not specify a date of first release; we arbitrarily choose prior to 1887. Brown trout are now abundant in most of the Hudson River tributaries (Smith 1985; Smith and Lake 1990).

Umbridae

Umbra limi Central Mudminnow

Central mudminnows occur from southern Canada, the Great Lakes and the Upper Mississippi River to the Saint Lawrence River and south into Tennessee and Arkansas (Lee *et al.* 1980, Smith 1985). In New York they are abundant in the Erie Canal (Smith and Lake 1990) and since 1967 have been collected at several locations within the Hudson River (Beebe and Savidge 1988). Mudminnows were first found in the Hudson River basin in the 1934 Mohawk River survey (Greeley 1935); they most likely moved into the Mohawk River from the Great Lakes via the Erie Canal (Greeley 1935, Smith 1976, 1985; Smith and Lake 1990). They are now common in the Hudson River basin and since they are often used as bait (George 1981), they may have been introduced into other areas of the river through bait bucket releases.

Esocidae

Esox lucius Northern Pike

Northern pike are a holarctic species generally restricted to waters north of a line from the Saint Lawrence River through the Great Lakes and upper Mississippi and Missouri Rivers (Lee *et al.* 1980, Smith 1985). Except for Lake Champlain and perhaps a few other large lakes (e.g. Lake George) in northern New York where they are glacial relicts, northern pike are introduced in the state (George 1981). During the 1840s, Sandford Lake and Henderson Lake, located in Essex County, New York on the upper Hudson River, were stocked with northern pike taken from Schroon Lake which had been previously taken from Lake Champlain (Clarke 1852, George 1981). They were found in the upper Hudson River basin in 1932 (Greeley 1933) and in the

Mohawk River in 1934 where they were believed to be Erie Canal immigrants (Greeley 1935). They were collected in the lower Hudson River in 1976 (Bath *et al.* 1976). Smith (1985) and Smith and Lake (1990) list several records of northern pike in tributaries of the Mohawk and upper Hudson Rivers. Northern pike have also been stocked and are established in several lakes in the lower Hudson River basin (e.g., Fourth Binnewater Lake, Ulster County) (D. Strayer).

Esox lucius x *Esox masquinongy* Tiger Muskellunge

Tiger muskellunge, also known as norlunge, are a hybrid of northern pike and muskellunge and are typically stocked as game fish because of their rapid growth and absence of reproductive potential (Smith 1985). The New York State Department of Environmental Conservation has been stocking tiger muskellunge in the Mohawk River since 1980 (Norm McBride, NYSDEC, pers. comm.) where they have moved downstream into the Hudson River. Smith and Lake (1990) list one specimen caught as far south as RM 29 of the Hudson River in April 1987. Although tiger muskellunge are sterile and therefore cannot reproduce, their continued stocking in these waters merits attention because they can reduce native fish stocks through predation.

Poeciliidae

Gambusia affinis affinis Mosquitofish

Mosquitofish occur in Gulf of Mexico drainages from Alabama to Florida and north up the Atlantic coast to southern New Jersey; *G. affinis affinis* is the midwestern form (Lee *et al.* 1980, Smith 1985). In July 1992, mosquitofish were discovered in Sparkill Creek near the New Jersey border and in Sparkill's skating rink located near the creek's mouth in the Hudson River (Hamilton and Schmidt 1992); this was the first recorded capture in the Hudson River drainage. Robert Schmidt (Bard College, pers. comm.) believes that they may have escaped from one or more ponds on a golf course that is upstream from their capture site. He also indicated that these fish could have been unintentionally released from nearby New Jersey which stocks them for mosquito control. Either of these scenarios can be classified as an unintentional release.

Percichthyidae

Morone chrysops White Bass

Smith (1985) and Lee *et al.* (1980) describe the range of white bass as mid-continental, spanning from the Saint Lawrence River through the Great Lakes to the Red River of the North and down the Mississippi and Ohio River basins. The 1934 New York State biological survey found white bass in Oneida Lake, but nowhere east of there in the Hudson-Mohawk system (Greeley 1935, 1937). Beebe and Savidge (1988) note that white bass have been collected in the

Hudson River since 1975 and they believe they probably moved out of Oneida Lake through the Erie-Barge Canal. Texas Instruments caught a white bass at river mile 42 of the Hudson River on 18 January 1976 (Smith and Lake 1990). Smith (1985) and Smith and Lake (1990) also suggest that the presence of the white bass in the Hudson River results from their movement through the Erie Canal.

Centrarchidae

Ambloplites rupestris Rock Bass

The original range of the rock bass has been greatly extended due to introductions (Trautman 1981). Lee *et al.* (1980) and Smith (1985) indicate that the rock bass occurs from New England through southern Canada and south through the Mississippi and Missouri River basins and east into the Tennessee River system. DeKay (1842) states, "This species occurs abundantly in the Great Lakes, and the larger streams in the western counties of the state. Since the completion of the Erie and Champlain canals, it has made its appearance in the Hudson River." Rock bass were collected throughout the Hudson River basin during the 1932 (Greeley and Bishop 1933), 1934 (Greeley 1935), and 1936 (Greeley 1937) New York State biological surveys. At present, they are abundant in freshwater habitats in all parts of the Hudson River basin (Smith 1985, Smith and Lake 1990).

Lepomis cyanellus Green Sunfish

Green sunfish originally ranged through east-central North America including the Great Lakes basin west of the Appalachian Mountains and the Mississippi River drainage (Lee *et al.* 1980, Smith 1985). In New York, it was initially only found in the Great Lakes drainage, but has since been introduced into the New Croton Reservoir (Greeley 1937). On 25 July 1936, a green sunfish was caught in Campfire Creek Pond near Millwood, New York (Smith and Lake 1990). These green sunfish were stocked into Campfire Creek Pond in 1936 in hopes of establishing a sport fishery (Greeley 1937). These species apparently spread from there into the main channel of the Hudson River, although no records appear to exist prior to 1976 (Bath *et al.* 1976).

Lepomis gulosus Warmouth

Historically warmouth ranged from Wisconsin and Ohio east to southern Pennsylvania and south down the Mississippi basin to Texas and east to Florida (Lee *et al.* 1980, Smith 1985). According to Greeley (1937), the first warmouth to enter the Hudson River basin were accidentally introduced with a shipment of green sunfish (*Lepomis cyanellus*) that were stocked in Campfire Creek Pond in 1936. Subsequently, warmouth were caught in August 1936 in the Saw Kill near Annandale, New York (Smith and Lake 1990). They have also been introduced into Woodbury

Creek, a tributary of Moodna Creek, and in the Saw Kill near Tivoli (Smith and Lake 1990). They were collected again in the Hudson River in 1976 (Bath *et al.* 1976).

Micropterus dolomieui — Smallmouth Bass and
Micropterus salmoides — Largemouth Bass

Early accounts of these fish (e.g. DeKay 1842, Seymour *et al.* 1869, Cheney 1897a) often treated them as one species, the black bass. We address them together with respect to their invasions of the Hudson River basin. Smallmouth bass and largemouth bass originally ranged throughout the north-central part of the United States and southern Canada, the Saint Lawrence drainage and the Mississippi basin, and also extended into Mexico and Florida (Lee *et al.* 1980, Smith 1985). In the beginning of the nineteenth century there were no black bass in any interior waters of New York (Cheney 1897a). Seymour *et al.* (1869) listed the Champlain Canal as the means through which black bass entered the Hudson River. However, according to Cheney (1897a), the completion of the Erie Canal in 1825 "brought black bass from Lake Erie to the Hudson River and to the waterways having connection with the canal." The black bass that entered the Erie Canal were subsequently used to stock other lakes in New York, many of which are in the Hudson River basin (George 1981). By 1903, both smallmouth and largemouth bass were collected in the Hudson River basin (Bean 1903). Greeley and Bishop (1933) reported that both species were present in the upper Hudson in 1932; they were also present in the Mohawk in 1934 (Greeley 1935). At present, both fish occur throughout the Hudson River basin; the smallmouth bass usually prefers cool, clear water with rocky substrate whereas the largemouth bass prefers warm, weedy areas (Smith 1985).

Pomoxis annularis — White Crappie

White crappie occur from southern Ontario and western New York to the Mississippi River basin and south to the Gulf of Mexico (Lee *et al.* 1980, Smith 1985). They were first collected in 1934 at sites in the lower Mohawk River (Greeley 1935). Greeley (1935) believed that white crappie were stocked in the Hudson-Mohawk system, but George (1981) believed, based on their original Mississippian range, that they entered through the Erie Canal. Smith and Lake (1990) also list the white crappie as a canal immigrant now common in the Mohawk River and the upper part of the Hudson River estuary. They were captured in the Hudson River in 1976 (Bath *et al.* 1976).

Pomoxis nigromaculatus — Black Crappie

Black crappie originally ranged from the Saint Lawrence River basin west through the Great Lakes to the Mississippi and Missouri River basins, south to the Gulf of Mexico, and north up the Atlantic coast as far as northern Virginia (Lee *et al.* 1980, Smith 1985). Greeley (1935)

indicated that black crappie were stocked in the Mohawk River basin in the early 1900s by the U.S. Bureau of Fisheries. This may have been after 1903, as Bean (1903) did not list them for the Mohawk River basin. However, Smith and Lake (1990) attribute their presence in the Hudson River basin to their passing through canals. The Erie Canal may have been the route, given their original range in western and northern New York and their present distribution throughout the Hudson River (Smith 1985).

Percidae

Percina caprodes Logperch

Logperch originally ranged from the Hudson Bay drainages south through the Great Lakes and the Mississippi River basin to the Gulf of Mexico (Lee *et al.* 1980, Smith 1985). Neither DeKay (1842) nor Bean (1903) mentions the presence of the logperch in the Hudson River basin although they both indicate that it was very common in Lake Champlain. Greeley and Bishop (1933) and Greeley (1935, 1937) list it in the Hudson River basin with a first collection date of 1932. The logperch probably made its way into the Hudson River via the Champlain Canal. It is also likely that they were transported directly into areas by humans as they have been found in the Shawangunk Kill, Ulster County, at a site that is separated from the Hudson River by four impassible dams or waterfalls (D. Strayer).

Percina peltata Shield Darter

The shield darter is native to Atlantic coastal drainages from the Delaware River south to North Carolina (Lee *et al.* 1980, Smith 1985). It was first collected in 1936 in Rondout Creek, a tributary of the Hudson River by the New York State Biological Survey (Greeley 1937). Shield darters are common there now (Smith 1985). Rondout Creek was used as part of the passage for the Hudson-Delaware Canal and *Percina peltata* could have gained access to Rondout Creek and the Hudson River basin through this canal (Beebe and Savidge 1988).

Stizostedion vitreum vitreum Walleye

Walleye range through the central part of North America from the MacKenzie River to Quebec and south through the Great Plains to northern Texas, Alabama, and Georgia, although their original distribution has been extended through introductions (Trautman 1981, Smith 1985). The Fisheries, Forest, and Game Commission of New York began stocking walleye into many lakes, rivers, and streams in 1893 (Cheney 1897b), several of which were either tributaries of the Hudson or Mohawk Rivers or into the rivers themselves. Walleye have since become widespread throughout the state and are considered a valuable game fish.

Mollusca

The molluscan fauna of the Hudson River basin has benefited from a long history of research (e.g. Lewis 1856, 1860, 1872; Marshall 1895, Townes 1937, Smith 1982, 1983) but it was not until Strayer's (1987) paper that the fauna was treated as a whole. Our list builds upon that presented by Strayer (1987) and includes some recently invading species. Exotic mollusks have entered the Hudson River basin through a number of vectors including canals, unintentional release, deliberate release, and ships' ballast (Table 2). The common names of mollusks listed below follow those given by Turgeon *et al.* (1988).

Class: Gastropoda

Valvatidae

Valvata piscinalis European Stream Valvata

The European Stream Valvata was first collected in North America at Charlotte and Summerville near the mouth of the Genesee River on Lake Ontario in 1897 (Baker 1898). The first specimens known from the Hudson River basin were collected by Strayer (1987) in 1985. *Valvata piscinalis* has been collected from various sites between Albany (RM 145) and Poughkeepsie (RM 75) along the tidal portion of the Hudson River (Strayer 1987, Jokinen 1992). According to Latchford (1914, 1925, 1930) the snail was probably introduced to the Great Lakes with packaging used in ships transporting fragile merchandise from Europe. It could have also entered the Hudson River via the Erie or Champlain Canal.

Viviparidae

Viviparus georgianus Banded Mystery Snail

This snail is native to the Mississippi River basin and southeastern United States (Clench 1962, Clench and Fuller 1965) and is now widespread in lakes and rivers in the Hudson River basin (Simpson *et al.* 1984, Strayer 1987). James Lewis successfully introduced them in 1867 when he brought them from Illinois and planted them into the Erie Canal at Mohawk (Lewis 1872). This initial colony was very successful as the snails now have viable populations at various locations in the Mohawk and upper Hudson Rivers (Strayer 1987) and also lakes in the basin (Jokinen 1992). Its spotty occurrence in the basin suggests additional movements by humans as aquarium releases.

Cipangopaludina chinensis malleatus Chinese Mystery Snail

The Chinese Mystery Snail was introduced into North America in San Francisco in 1892 from Asia (Wood 1892) and is now widely distributed throughout North America (Clench and Fuller 1965, Jokinen 1982). It was discovered in the Hudson River basin at Niskayuna, in 1920