NOAA Technical Memorandum NMFS-NE-121

Habitat Use and Requirements of Important Fish Species Inhabiting the Hudson River Estuary: Availability of Information

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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Habitat Use and Requirements of Important Fish Species Inhabiting the Hudson River Estuary: Availability of Information

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September 1999

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

[f]McEachran, J.D.; Dunn, K.A. 1998. Phylogenetic analysis of skates, a morphologically conservative clade of elasmobranchs (Chondrichthyes: Rajidae). *Copeia* 1998(2):271-290.

[g]ISO [International Organization for Standardization]. 1981. ISO standards handbook 3: statistical methods. 2nd ed. Geneva, Switzerland: ISO; 449 p.

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Acronyms

GIS = geographical information system
NEFSC = Northeast Fisheries Science Center
SUNY = State University of New York
TL = total length

EXECUTIVE SUMMARY

The objective of our project was to determine the extent and availability of information that is adequate for: 1) assessing basic habitat requirements of selected fishery resources of the Hudson River estuary; 2) relating those requirements to habitat availability in that estuary; and 3) developing priorities for projects that will enhance, restore, or maintain productivity of those resources. We used a three-step process to determine if sufficient information is available on habitat requirements of selected fish species. First, we selected 11 fish species that are considered important and representative of the fish community in the Hudson River estuary. Second, we examined alternative definitions of habitat and selected one for evaluating the role of habitat in the life history strategies of the 11 species. Third, we assessed the availability of information necessary to evaluate habitat requirements and use in the Hudson River estuary for each of the 11 species.

We assembled a list of close to 1,000 publications up to 1995 containing information that may be relevant to habitat requirements and use by the selected fish species inhabiting the Hudson River estuary, then sorted those publications by species and life stage. To determine the amount of information that would likely be available for a full-scale study of habitat use by the 11 selected species, we made two evaluations of the collected publications: 1) the availability of published information on site-specific **distribution** within the Hudson River estuary of each life stage (*i.e.*, spawning, egg, larva, juvenile, subadult, and adult) for each selected species; and 2) the availability of published information on **habitat requirements** of each life stage for each selected species. We evaluated the two types of information separately because evaluations of habitat requirements and use usually begin by locating the organisms within the water body, then determining why they are there; locational information is usually much easier to obtain, as was apparent in our study.

We conclude that the available information is insufficient to conduct a full-scale, detailed study of the importance of Hudson River habitats to the selected fish species. Although our evaluation of the available information suggests that little would be gained from a full-scale study, we do not recommend total abandonment of the project; our review of the literature revealed a wealth of information on a number of areas related to the natural history of the Hudson River estuary and the alteration of the estuary through human activities.

We suggest that the next step towards identifying important habitats for Hudson River fishes would be to begin assembling the data on life stage distributions and habitats of the Hudson River estuary into a geographic-based information system (GIS). By using GIS, gaps in the information base will become more clear, and priorities for collection of additional information will become more evident. Because of the immensity of this task, no single governmental or nongovernmental organization should be expected to undertake such a project for the Hudson watershed singlehandedly -- a cooperative effort among federal, state, and local agencies is needed where all parties contribute and all parties benefit.

INTRODUCTION

Since 1963, the Hudson River estuary has been the focus of one of the most ambitious environmental research and assessment programs ever performed (Barnthouse *et al.* 1988), and nowhere has the conflict between society and the environment been so intense (Smith 1988). The estuary supports major commercial and recreational fisheries, serves as a major transportation corridor, and is surrounded by one of the most densely populated metropolitan areas in North America (Figure 1). In spite of efforts by government agencies and nongovernment organizations to protect the fishery resources of the river, threats -- including sediment-laden contaminants, municipal and industrial water withdrawals and discharges, channel dredging, and nonpoint-source runoff -- continue in this estuarine habitat.

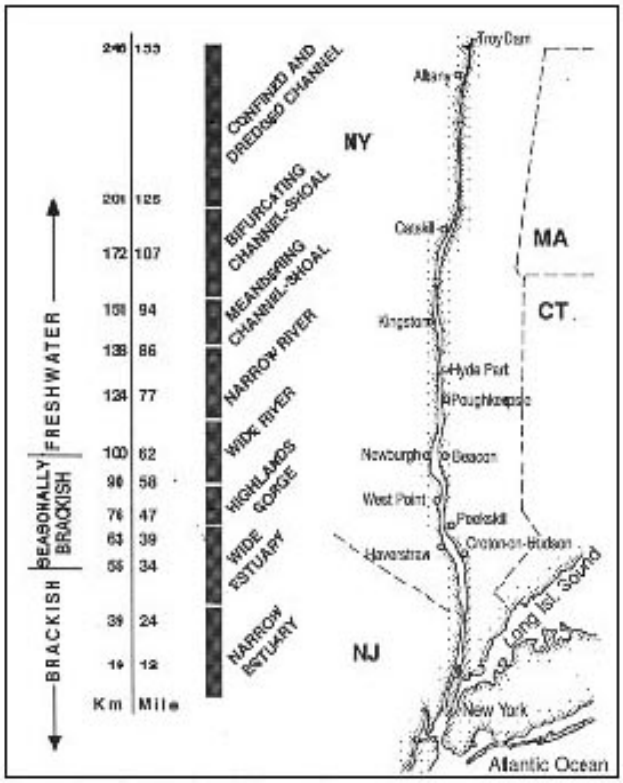

Figure 1. Geographical, geomorphological, and salinity characteristics of the Hudson River estuary. (From Haley (1999).)

Before major programs are initiated to protect, enhance, and restore the fishery resources of the Hudson River estuary through habitat improvements, an understanding is needed of the relationship between habitat characteristics of the estuary and basic habitat requirements of the fishery resources, as recommended in the "Habitat Research Plan of the National Marine Fisheries Service" (Thayer *et al.* 1996). Information used to gain that understanding also needs to be in a form that is useful in determining: 1) the types of habitat restoration projects that are feasible, and 2) the short-term and long-term benefits of these projects. However, establishing baseline habitat requirements for fishery resources of the Hudson River estuary is not as straightforward as it may seem. In some instances, the habitat requirements of a prey species may be the important factor in productivity of a fishery resource; for example, productivity of bluefish may depend on the abundance of bay anchovy in the estuary. Furthermore, the amount of available habitat may be limited more by the abundance of competitor species than by the spatial scale of the habitat itself. Thus, determining linkages between habitat characteristics and fishery resource productivity requires an appreciation for, and understanding of, the complexities of interactions among members of the fish community, specifically among predators, competitors, and prey during all life stages present in the system.

By 1981, an estimated $40-50 million had been spent on basic fisheries research in the Hudson River (Smith 1988), and $3-4 million has been spent per year since then on research and monitoring by the Hudson River utilities and the Hudson River Foundation. Because of these enormous expenditures, a dogma exists within the environmental community that sufficient data now exist for informed management of the Hudson River resources and their habitats. This is simply not the case, as evidenced in recent criticism of the draft environmental impact statement prepared by the Hudson River utilities (ESSA Technologies, Ltd., and Deriso 1994).

Much of the information gathered on Hudson River fishes has been specifically for evaluating impacts of power plant operations (see Barnthouse *et al.* 1984). Habitat-related studies in the Hudson River estuary have been chiefly site-specific or species-specific, such as the work being performed by the State University of New York (SUNY) at Stony Brook on the effects of cadmium-contaminated sediments on the aquatic fauna at Foundry Cove (Knutson *et al.* 1987), or by the Institute for Ecosystem Studies on the invasion and subsequent distribution of zebra mussels in the upper estuary (Strayer *et al.* 1994). No program has been undertaken to define habitat use and habitat requirements of Hudson River fishes on an estuary-wide basis; this is a fundamental void that needs to be filled for development of remedial actions and restoration plans for habitats.

The objective of our project was to determine the extent and availability of information that is adequate for: 1) assessing basic habitat requirements of selected fishery resources of the Hudson River estuary; 2) relating those requirements to habitat availability in that estuary; and 3) developing priorities for projects that will enhance, restore, or maintain productivity of those resources.

METHODS

Two approaches could be used, either independently or jointly, as first-order approximations to understand the linkage between habitat requirements and the well-being of

fishery resources. One approach would be to determine the minimum habitat requirements necessary to support selected fishery resources, and then to map areas where any one or a combination of these factors would exclude use by the selected resources. A tool to accomplish this task would be a geographic-based information system (GIS). A second approach would be to determine the historical extent of habitat use in the estuary by selected fishery resources, compare to the current extent, and determine what factors might be causing any differences. Both approaches are data hungry, requiring an extensive amount of information from field collections and controlled laboratory experiments. The extent to which the data exist and are available will determine success of either approach in assessing habitat requirements and, ultimately, in setting priorities for habitat restoration projects in the estuary.

We used a three-step process to determine if sufficient information is available on habitat requirements of selected fish species. First, we selected 11 fish species that are considered important and representative of the fish community in the Hudson River estuary. Second, we examined alternative definitions of habitat and selected one for evaluating the role of habitat in the life history strategies of those 11 species. Third, we assessed the availability of information necessary to evaluate habitat requirements and use in the Hudson River estuary for each of the 11 species.

SELECTION OF SPECIES

The Hudson River estuary extends for 243 km from the Battery on Manhattan Island north to the Troy Dam (Cooper *et al.* 1988), and is tidal over its entire length, with the greatest tidal amplitudes occurring at both ends. The magnitude of tidal flow within the estuary is 10-100 times greater than the freshwater inflows, causing a reversal in the current pattern twice each day (Busby 1966, cited in Cooper *et al.* 1988). The estuary is generally considered freshwater (<0.3‰) above river kilometer (Rkm) 80 to 100, which may extend to Rkm 40 during high inflow periods (spring and fall). The oligohaline zone (0.3-5‰) extends from Rkm 80 to 40, but may reach Rkm 19, and the mesohaline zone (5-18‰) generally occurs from Rkm 45 into New York Harbor (Cooper *et al.* 1988; Haley 1999).

A total of 140 species of fish have been collected within the Hudson River estuary, a listing of which by river region can be found in Beebe and Savidge (1988, Table 6). Of the 140 species, 50 have been found in all three salinity zones of the estuary, and two species have been found only in the polyhaline zone (Yonkers and Tappan Zee sampling regions, Figure 2). The 140 fish species also embody a variety of life history strategies, which can largely be described by four patterns: **anadromous** (spawning and nursery areas in freshwater, oligohaline, and/or mesohaline zones of the Hudson River estuary, most of adult life in the marine environment); **freshwater-oligohaline nonmigratory** (entire life cycle in freshwater and/or oligohaline zones); **euryhaline nonmigratory** (entire life cycle within the Hudson River, but across all salinity zones); and **oceanic/coastal spawners** (spawning in highest salinity zone of the Hudson River estuary and surrounding coastal waters, early life stages enter lower salinity zones of the estuary). Anadromous can be further subdivided into the group of species that spawns in the **tributaries** -- if not also the river proper -- of the Hudson River estuary, and the group that spawns exclusively in the **river** proper. We chose 11 fish species that represent the four life history strategies (Table 1), and that are also important to the Hudson River estuary economically or ecologically. Synopses of the life histories of the 11 selected species are presented in Appendix A.

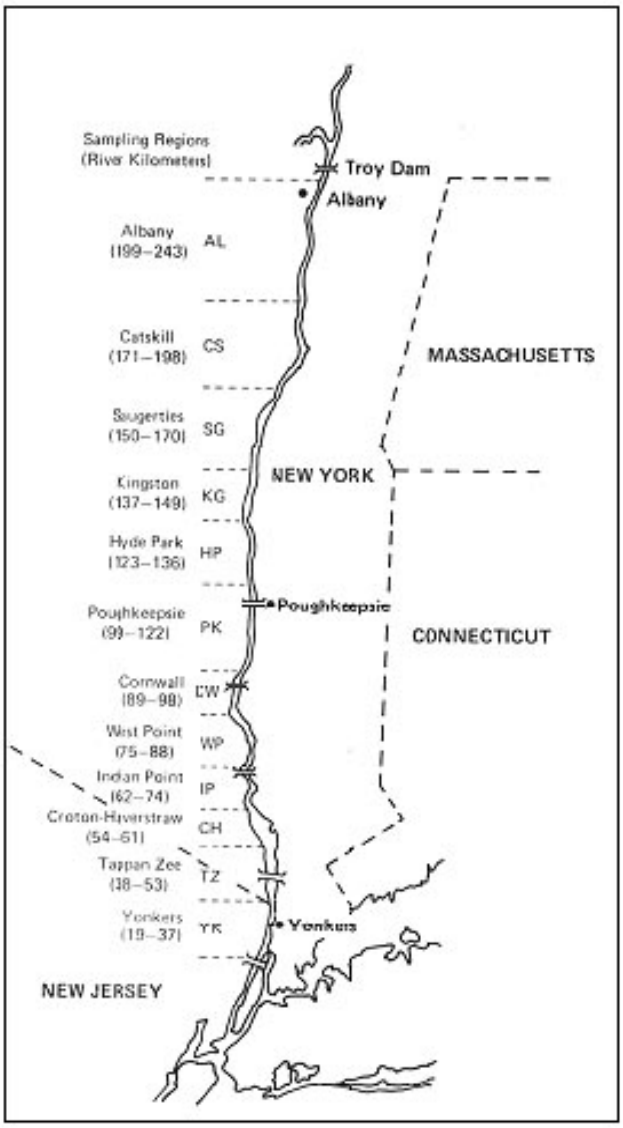

Figure 2. Sampling regions used by the Hudson River utility companies for their ichthyoplankton survey programs. (From Boreman and Klauda (1988).)

Table 1. Fish species selected for assessing the availability of information on habitat use and preference in the Hudson River estuary

Life History Strategy	Species
Anadromous:	
Tributary spawners	Alewife (*Alosa pseudoharengus*)
	Blueback herring (*A. aestivalis*)
River spawners	Striped bass (*Morone saxatilis*)
	American shad (*A. sapidissima*)
	Atlantic sturgeon (*Acipenser oxyrhynchus*)
Freshwater-oligohaline nonmigratory	Largemouth bass (*Micropterus salmoides*)
Euryhaline nonmigratory	Shortnose sturgeon (*A. brevirostrum*)
	Atlantic tomcod (*Microgadus tomcod*)
	White perch (*Morone americana*)
Oceanic/coastal spawners	Bluefish (*Pomatomus saltatrix*)
	Bay anchovy (*Anchoa mitchilli*)

HABITAT DEFINITION

The term "habitat" needs to be defined before assessing the availability of information related to habitat use by important fish species inhabiting the Hudson River estuary. We thoroughly reviewed definitions of habitat that have appeared in the literature (Odum 1971; Partridge 1978; Pimm and Rosenzweig 1981; Rosenzweig 1981, 1991; Van Horne 1983; Boesch and Turner 1984; Rosenzweig and Abramsky 1985; Bell and Westoby 1986; Brown and Rosenzweig 1986; Bell *et al.* 1987; CBLRFT 1987; Morris 1987a,b; McIvor and Odum 1988; Govoni *et al.* 1989; Sogard and Able 1991; Peters and Cross 1992; Hoss and Thayer 1993; Able and Kaiser 1994). We subsequently settled on one that seems to be most appropriate for Hudson River estuary fishes: Habitat is that part of the environment required for the survival (*i.e.*, survival to successful reproduction) of individuals of a species, consisting of biological and nonbiological parameters which differ among species, as well as among life stages within a species, and which are affected either seasonally or change as a result of other environmental factors.

ASSESSMENT OF INFORMATION AVAILABILITY

Given our working definition of habitat, we assembled information that might be used to determine the importance of habitats in the Hudson River estuary to the 11 selected fish species. We surveyed the published and unpublished (gray) literature ("publications") available through agencies and organizations involved with research on Hudson River resources. We also contacted a number of investigators and organizations that might possess unpublished information, such as databases and specimen collections, that also might be relevant (Appendix B).

We used a software package for database retrieval called FileMaker Pro Unlimited® (available in Windows and MacIntosh versions from FileMaker, Inc., 5201 Patrick Henry Dr., P.O. Box 58168, Santa Clara, CA 95054-8168) to organize the publications in a manner that allowed us to search those publications. The publications could be searched by the following: author, year, title, report type, publisher, geography, fish species, and/or keyword(s). This database is available for public access and use. See Appendix C ("Users Guide to the Database") of this report for the several formats of the database which have been prepared for public access and use.

RESULTS

We assembled a list of close to 1,000 publications containing information that may be relevant to habitat requirements and use by the selected fish species inhabiting the Hudson River estuary (Appendix D), then sorted those publications by species and life stage. Approximately 120 of the publications are available from us in hard copy. Unpublished materials are also available through personal, agency, and nongovernmental organization contacts. (See the "Remarks" column in Appendix B.)

To determine the amount of information that would likely be available for a full-scale study of habitat use by the 11 selected species, we made two evaluations of the collected publications: 1) the availability of published information on site-specific **distribution** within the Hudson

Table 2. Evaluation of the relative availability of published information on the life stage **distributions** of 11 fish species inhabiting the Hudson River estuary, based on the publications listed in Appendix D. (Key: A = information available for Hudson River population; Al = information available for Hudson River population, but limited; N = information available from neighboring system; Ua = information unavailable, but attainable within 3 yr; Uu = information unavailable and unattainable within 3 yr; and X = not applicable for Hudson River population.)

	Life History Stage					
Species	**Spawning**	**Egg**	**Larva**	**Juvenile**	**Subadult**	**Adult**
Alewife	Al,N	A	A	Al	X	Al,N
American shad	Al,N	A	A	Al	X	Al,N
Atlantic sturgeon	Al	Ua	Ua	Al	X	Al
Atlantic tomcod	Al,N	A	A	A	Al	Al,N
Bay anchovy	Al,N	Al,N	Al,N	Al,N	Al	Al,N
Blueback herring	Al,N	A	A	Al	X	Al,N
Bluefish	X	X	X	Al	Al	Al
Largemouth bass	A	A	A	Ua	Ua	Al?
Shortnose sturgeon	Al,N	Ua	Ua	Al	Al,N	Al,N
Striped bass	A	A	A	Al	Al	Al
White perch	Al	Al	A	Al	Al	Al

River estuary of each life stage (*i.e.*, spawning, egg, larva, juvenile, subadult, adult) for each selected species (Table 2); and 2) the availability of published information on **habitat requirements** of each life stage for each selected species (Table 3). Habitat requirements information includes tolerances and preferences for environmental parameters (salinity, temperature, turbidity, depth, vegetation, bottom type, etc.) and trophic inter-relationships. We evaluated the two types of information separately because evaluations of habitat requirements usually begin by locating the organisms within the water body, then determining why they are there; locational information is usually much easier to obtain, as was apparent in our study. For each life stage of each species, we noted whether information on distribution or habitat requirements is: 1) available for the Hudson River population (**A** in Tables 2 and 3); 2) available for the Hudson River population, but limited either geographically or temporally (**Al**); 3) not available for the Hudson River population, but available for a population of the species in a neighboring system (**N**); 4) unavailable, but attainable within 3 yr assuming adequate funding (**Ua**); 5) unavailable and would not be attainable within 3 yr even if funding were adequate (**Uu**); or 6) inapplicable because the life stage is not present in the Hudson River estuary (**X**). The evaluations contained in Tables 2 and 3 are based on our judgments; others may draw different conclusions after reviewing the publications contained in the database.

The most complete information on distribution of the 11 selected species in the Hudson River estuary is for the planktonic life stages (egg and larva) of alewife, American shad, Atlantic tomcod, blueback herring, and striped bass. This result is not surprising, since all 11 selected species, except the largemouth bass, have been targeted for collection in the riverwide surveys conducted by the utility companies as part of their impact assessment programs. Although the utilities' surveys covered the entire estuary over a number of years, the spatial resolution of the data is limited to the 12 regions designated by the survey design (Figure 2). Their surveys also varied in coverage of depth zones.

The distribution of spawners, eggs, and larvae of the largemouth bass has been well documented in a special study of the species conducted by David Green and his coworkers (*e.g.*, see Nack and Cook 1987; Hopkins and Green 1988; Green *et al.* 1988, 1989; Nack *et al.* 1993). Information on the distributions of other life stages of largemouth bass and on Hudson River populations of the

Table 3. Evaluation of the relative availability of published information on the life stage **habitat requirements** of 11 fish species inhabiting the Hudson River estuary, based on the publications listed in Appendix D. (Key: A = information available for Hudson River population; Al = information available for Hudson River population, but limited; N = information available from neighboring system; Ua = information unavailable, but attainable within 3 yr; Uu = information unavailable and unattainable within 3 yr; and X = not applicable for Hudson River population.)

	Life History Stage					
Species	**Spawning**	**Egg**	**Larva**	**Juvenile**	**Subadult**	**Adult**
Alewife	Ua,N	Ua	Ua	Ua	X	Ua
American shad	Ua,N	Ua,N	Ua,N	Ua,N	X	Ua,N
Atlantic sturgeon	Ua	Ua	Ua	Ua	X	Ua
Atlantic tomcod	Ua	Al	Al	Al	Ua	Al
Bay anchovy	Ua,N	Ua,N	Ua,N	Ua,N	Ua,N	Ua,N
Blueback herring	Ua,N	Ua	Ua	Ua	X	Ua
Bluefish	X	X	X	Al	Ua	Ua
Largemouth bass	Al	Al	Al	Al	Ua	Al
Shortnose sturgeon	Ua	Ua	Ua	Ua	Ua	Ua
Striped bass	N	N	N	N	N	N
White perch	Al,N	N	N	N	Ua,N	Ua,N

other species is also generally available, although limited geographically or temporally.

Information on habitat requirements for the 11 selected species is much more limited than information on their distributions. For striped bass, white perch, bay anchovy, and American shad, substantial information exists on habitat requirements in neighboring systems, primarily Chesapeake Bay, that may be transferrable to the Hudson River estuary. Transferring habitat requirements information among estuarine systems, however, may not withstand the scrutiny of litigation. Generally, information on habitat requirements is unavailable for most species, but attainable within the short-term (3 yr or so) if sufficient funding is available to test the species' preference or tolerance for key habitat variables. The variables may include, depending on the species and life stage, water temperature, salinity, conductivity, sediment type, vegetation or other shelter, and turbidity. We are assuming that the individual life stages need to be tested under controlled conditions, and recognize that techniques for rearing and maintaining the fish for purposes of experimentation have not yet been developed for all life stages.

CONCLUSIONS AND RECOMMENDATIONS

Based on our assembly of close to 1,000 publications, and on our contacts with a number of individuals, agencies, and nongovernmental organizations involved with collection of information on Hudson River fishes, we conclude that the available information is insufficient to conduct a full-scale, detailed study of the importance of Hudson River habitats to the selected fish species. If a full-scale study proceeds, the following findings are likely:

1. Distributions will be available for the egg through juvenile life stages of most of the 11 species, but the spatial resolution of the distributions will not be adequate for evaluating use of specific areas within the estuary.

2. Few studies have been conducted on the distributions of subadult and adult life stages within and adjacent to the estuary, in and out of spawning season. The distributions will have to be based on

anecdotal information from recreational and commercial harvesters, and on results of studies presently being planned or conducted on striped bass, American shad, the sturgeons, and bay anchovy.

3. Specific habitat requirements related to key environmental variables will be largely unknown for the Hudson River populations of the 11 species. Studies in other systems (Chesapeake Bay, Delaware River, and Connecticut River) may provide some information, but transferability of the information from the neighboring systems to the Hudson River estuary will be suspect. Efforts should be made to compare extant data among these systems to determine transferability.

4. Tributaries to the Hudson River estuary probably serve a more important role in the life history of the eleven fish species than previously thought.

5. Most life stages of the eleven fish species are probably not associated with a specific habitat, such as cobble bottom or mussel bed, but are at the mercy of freshwater discharge and tidally-driven circulation in the estuary. For planktonic life stages, such as eggs and larvae of striped bass, salinity, temperature patterns, and turbidity may be more important to survival than substrate or vegetation.

Although our evaluation of the available information suggests that little would be gained from a full-scale study, we do not recommend total abandonment of the project. Our review of the literature revealed a wealth of information on a number of areas related to the natural history of the Hudson River estuary and on the alteration of the estuary through human activities; some of the information has already been synthesized in literature reviews and atlases. However, such syntheses have limited utility. Experience has shown that the efforts of the U.S. Fish and Wildlife Service and NOAA related to coastal wetlands mapping and estuarine inventories do not meet needs when attempts are made to use their information on a site-by-site basis, which is where both agencies expend most of their resource-advising efforts. This concern is especially critical as federal and state agencies move towards ecosystem-level management of aquatic and terrestrial systems.

We suggest that the next step towards identifying important habitats for Hudson River fishes would be to begin assembling data on life stage distributions and habitats of the Hudson River estuary into a GIS. By using GIS, gaps in the information base will become more clear, and priorities for collection of additional information will become more evident. The GIS approach retains flexibility in its use and analysis, addresses the needs of ecosystem-level management, and takes advantage of new and developing technologies as recommended in the "Habitat Research Plan of the National Marine Fisheries Service" (Thayer *et al.* 1996). Giles and Nielsen (1992) give examples of how GIS can be used in watershed research and management:

- bibliographic references to site-specific conditions and ecological phenomena
- standard reports, texts, and tables for various reports and purposes
- ongoing research and development projects
- factual information (such as that provided by the Fish and Wildlife Information System)
- numerical datasets (*e.g.*, daily precipitation)
- models (statistical, mathematical)
- records of materials collections (plants, fish, wildlife, soil, water, etc.)
- map databases that link all of the above

For a system as large and complex as the Hudson River estuary, both in terms of its physical attributes and the resource management system that oversees it, more than the current piecemeal approach to identifying resource distributions and habitat use is necessary. A GIS for the Hudson River estuary should contain the following dataset layers at a minimum:

- fish, wildlife, and plant distributions and abundances
- harvesting profiles (location, type, and density of effort, catch, and access)
- water body characteristics (depth and current profiles, physical and chemical features, wetted perimeter, locations and types of blockages, and hydrologic features)
- sources and fates of environmental contaminants
- sediment characteristics and substrate types for the main channel and its tributaries
- town zoning plans and bylaws
- density distribution of human population
- locations of parks, open space, and other recreational areas
- daily records of the amount and chemical composition of precipitation
- snow accumulation and chemical composition
- climatic information such as temperature, photoperiod, cloud cover, and barometric pressure
- upland characteristics such as soil and bedrock types and properties, slope, and land-use cover

Because of the immensity of this task, no single governmental or nongovernmental organization should be expected to undertake such a project for the Hudson watershed single-handedly -- a cooperative effort among federal, state, and local agencies is needed where all parties contribute and all parties benefit.

Concurrent with development of the GIS database, we recommend initiation of studies on life stages of the selected fish species that would be expected to associate

with key habitat variables such as bottom type, vegetation, structures, circulation patterns (eddies, plumes, etc.), and geomorphological characteristics (wetlands, tributaries, etc.). Information generated from these studies would be immediately useful in planning habitat restoration programs. We recommend placing initial focus of the studies on the juvenile, post-planktonic life stages of the 11 selected species, examining the importance of shore zones, shelter created by vegetation or structure, and tributaries and their outfalls. We speculate that it is the juvenile life stage that is probably the least tolerant of habitat alteration and loss in the Hudson River estuary.

ACKNOWLEDGMENTS

We thank all of the people listed in Appendix B for helping us locate information pertaining to the fish resources of the Hudson River. In particular, we thank Hayes Batten, Nancy Steinberg, Karl von Kries, John Waldman, and Robert Schmidt for their assistance and advice during the course of this study. Useful comments on an earlier draft were provided by John Waldman, Gordon Thayer, and Tom Halavik. This study was supported, in part, under a contract with the National Oceanic and Atmospheric Administration, and with funds provided by the Hudson River Foundation.

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APPENDIX A

Life History Synopses for Selected Fish Species Inhabiting the Hudson River Estuary

Understanding habitat requirements of the selected fish species in the Hudson River estuary requires an understanding of the distribution and environmental limitations for each life stage found in the estuary. A synopsis of the life history of each selected species reveals that a variety of habitats and regions of the Hudson River estuary are utilized; it also reveals some disagreement in the literature, as well as a general lack of information on specific habitat requirements for all life stages. Included in this appendix are 11 complementary figures (Figures A1-A11) for the 11 selected species which schematically present spatial distribution by life stage. References cited in this appendix are listed in the "References Cited" section of this document.

ATLANTIC STURGEON

The Atlantic sturgeon, *Acipenser oxyrhynchus*, is an anadromous species of the Hudson River. The following account of life history is summarized from Bain *et al.* (1995). Adult Atlantic sturgeon live along the Atlantic coastline for approximately 10 yr before migrating into coastal rivers. Males enter the Hudson River in early April, before the females. Atlantic sturgeon do not spawn annually, with 2-5 yr between spawning events. Spawning occurs well upstream from the salt front; larvae are known to be intolerant of euryhaline environments.

Eggs are demersal and adhesive. The larvae remain close to the river bottom for some time. Juveniles are fairly evenly distributed in the Hudson River during summer, with their highest concentration between Kingston and Haverstraw Bay (Rkm 140 and 63, respectively). After summer, when water temperatures fall below 20°C, juveniles are found in high numbers between the Bear Mountain Bridge and the George Washington Bridge (Rkm 74 and 19, respectively). This tighter distribution is thought to represent an overwintering area for juvenile Atlantic sturgeon. Juveniles move back upstream in early spring, and do not migrate out of the Hudson River until 2-6 yr of age. Adults spend approximately 10 yr at sea before maturation and subsequent inland migration. Males and females mature at different ages, approximately 12 and 15 yr of age, respectively.

SHORTNOSE STURGEON

The shortnose sturgeon, *A. brevirostrum*, is considered to be a nonmigratory, euryhaline fish. In the Hudson and other large rivers, adult shortnose sturgeon overwinter in deep polyhaline water downstream from the spawning grounds to which they will travel in the following spring when water temperatures reach 8-9°C (Dadswell *et al.* 1984). In the Hudson River, spawning occurs in April and May between Coxsackie and Troy (Dadswell *et al.* 1984; Hoff *et al.* 1988). Detailed information on spawning habitat is available for shortnose sturgeon of the Savannah River, South Carolina (Smith *et al.* 1993), which may or may not apply to those of the Hudson River. Adults are thought to move downstream in May and June, after spawning (Hoff *et al.* 1988).

Eggs of the shortnose sturgeon are demersal and adhesive (Dadswell *et al.* 1984). Larvae and juveniles are probably benthic, remaining in deep water where currents are strong (Dadswell *et al.* 1984; Hoff *et al.* 1988). As a result, little is known about the early life stages. In addition, identification of young specimens (eggs, larvae, and juveniles) is extremely difficult because of overall similarity to young Atlantic sturgeon (Hoff *et al.* 1988). Some workers (*i.e.*, Hoff *et al.* 1988) believe that the larvae disperse downstream during summer, whereas others (*i.e.*, Dadswell *et al.* 1984) believe that young shortnose sturgeon remain above the salt front until they reach 45 cm total length (TL). Upon attaining adult size (45-50 cm TL), shortnose sturgeon move downriver in fall, and back upriver in spring (Dadswell *et al.* 1984).

Sexual maturation is thought to be at 3-4 yr of age for males, and probably 6-8 yr of age for females, in the Hudson River (Dadswell *et al.* 1984). The age of maturation for females is based on age at first spawning. It is unknown how frequently shortnose sturgeon in the Hudson River spawn; in Canada, females spawn every 3 yr, and males every other year (Dadswell *et al.* 1984).

ALEWIFE

The alewife, *Alosa pseudoharengus*, is an anadromous species of the Hudson River (Schmidt and Stillman 1994). Adult alewife spend most of the year in coastal Atlantic waters, migrating into the Hudson River (and other estuaries) to spawn. Alewife probably return to their natal river to spawn (Klauda *et al.* 1991). Alewife usually enter the Hudson River in early spring, prior to mid-May (Schmidt *et al.* 1988).

Spawning usually occurs in freshwater tributaries, in relatively shallow water with a slow current (Schmidt *et al.* 1988); in fact, the alewife is the only anadromous fish species commonly found in freshwater tributaries of the Hudson River (Schmidt and Stillman 1994). Eggs and larvae are not morphologically distinguishable from those of blueback herring (*A. aestivalis*), and for this reason, the two species are typically referred to as "river herring"

(Dovel 1981; Schmidt *et al.* 1994). The role of blueback herring in tributaries is still unclear; however, because adult alewife are frequently sampled from freshwater tributaries during the spawning season, it has been assumed that most, if not all, of the eggs and larvae found in the freshwater tributaries are alewife (Schmidt *et al.* 1994). This contradicts earlier findings in which alewife eggs and larvae were presumed to be present in the main river channel (Boreman 1981). In addition to the differences in spawning location, larvae and eggs can also be distinguished by their temporal distribution, because alewife spawn about a month earlier than blueback herring (Hildebrand and Schroeder 1928; Schmidt *et al.* 1988).

Eggs are essentially pelagic, somewhat adhesive, and demersal in still water (Hildebrand 1963; Norden 1967; Lippson and Moran 1974; Klauda *et al.* 1991). In the Chesapeake Bay area, alewife larvae and juveniles may move further upstream to avoid intrusion of saltwater (Klauda *et al.* 1991). Larvae and juveniles remain in the freshwater tributaries of the Hudson River until June. At this time, juvenile alewife move out of the nursery areas of the tributaries and make their way downstream to the lower Hudson River and into the Atlantic Ocean (Schmidt *et al.* 1988), although capture of yearlings suggests some may overwinter in the estuary during the first year of life.

Alewife feed primarily on amphipods, mysids, copepods, small fish, and fish eggs (Leim and Scott 1966).

BLUEBACK HERRING

The blueback herring, *A. aestivalis*, is an anadromous fish of the Hudson River (Klauda *et al.* 1991). Adults remain in coastal waters of the Atlantic Ocean and migrate upriver to spawn, as do alewife. Blueback herring usually spawn later in the spring than alewife, and in different habitat (Schmidt *et al.* 1988). Blueback herring prefer to spawn in relatively deep freshwater with swift currents on hard substrates of either gravel or sand (Schmidt *et al.* 1988; Klauda *et al.* 1991). It has been noted that this habitat preference is mainly seen in northern populations where blueback herring are sympatric with alewife, and, conversely, southeastern blueback herring spawn in lentic as well as lotic water (Klauda *et al.* 1991). It has been observed that blueback herring do not move as far upstream in tributaries as alewife (Loesch 1968, 1969), and recent studies in the Hudson River suggest that blueback herring spawn mainly in the main channel of the estuary, whereas alewife spawn more in tributaries (Schmidt *et al.* 1994). The single peak, seen in late May, in the temporal distribution of "river herring" eggs in the main channel (Boreman 1981) may therefore represent eggs of blueback herring.

Eggs of the blueback herring are pelagic, somewhat adhesive, and demersal in still water (Hildebrand 1963; Norden 1967; Lippson and Moran 1974; Klauda *et al.* 1991). "River herring" larvae found in the main channel of the Hudson River estuary are thought to be blueback herring; larvae probably remain in nearshore habitat (Schmidt *et al.* 1994). Juveniles move downriver in July, later than alewife (Boreman 1981; Schmidt *et al.* 1988).

Food of blueback herring consists mainly of plankton, copepods, pelagic shrimp, and early life stages of small fishes (Scott and Crossman 1973).

AMERICAN SHAD

The American shad, *A. sapidissima*, is a highly migratory species of the Hudson River, and is often cited as a classic example of an anadromous fish. Adults move into the Hudson River from Atlantic waters in early spring, usually beginning in March or April (Boreman 1981), depending on the water temperature of the river, which must be 12°C or above before the shad begin their run (Bigelow and Schroeder 1953). Adult American shad do not eat when running or spawning, and will not do so until they begin the postspawning downriver migration to the Atlantic, eating along the way (Bigelow and Schroeder 1953). Spawning occurs mainly at night (Bigelow and Schroeder 1953; Ross *et al.* 1993), in shallow freshwater of moderate current (Schmidt *et al.* 1988), and on various substrates (Bigelow and Schroeder 1953).

Eggs are demersal and nonadhesive (Bigelow and Schroeder 1953), and hatch after 2-17 days, depending on water temperature (Boreman 1981). Bigelow and Schroeder (1953) report that eggs raised in water at 12°C hatch between 12 and 15 days. Eggs are found in the spawning areas (Boreman 1981), and are not associated with any particular habitat type (Ross *et al.* 1993). In a 1974 study, egg abundance peaked in May (Boreman 1981); yolksac larval abundance has also been reported to peak in May (Schmidt *et al.* 1988). Yolksac larvae absorb their yolk in 4-5 days in water at 17°C (Boreman 1981). Larvae are reported to frequent riffle pools where water is of moderate depth and variable velocity and direction (Ross *et al.* 1993). Both feeding and yolksac larvae are planktonic; dispersal therefore occurs by passive transport (Boreman 1981; Schmidt *et al.* 1988). Juveniles are found downriver from the spawning grounds (Boreman 1981) beginning in June, with peak abundance in July (Schmidt *et al.* 1988). Juvenile habitat preference in the Hudson River seems to be positively correlated with depth, turbidity, and current velocity, possibly as an effect of food distribution (Ross *et al.* 1993). Most juveniles complete their migration from freshwater into the Atlantic by late fall or early winter (Bigelow and Schroeder 1953; Boreman 1981; Schmidt *et al.* 1988).

Adult American shad overwinter in the deep water of the Atlantic and Gulf of Maine (Boreman 1981). They move closer to their natal river in the spring, due to their strong homing ability (Boreman 1981). Adult American shad are

euryhaline, but only enter freshwater to spawn (Bigelow and Schroeder 1953).

ATLANTIC TOMCOD

The Atlantic tomcod, *Microgadus tomcod*, is a euryhaline fish of the Hudson River estuary. It is not considered to be migratory *per se*, but does show significant, seasonal, upriver/downriver movement within the estuary. Spawning of Atlantic tomcod takes place under ice, mainly from December to January (Bigelow and Schroeder 1953; Boreman 1981; Klauda, Moos, and Schmidt 1988; McLaren *et al.* 1988; Dew and Hecht 1994). The winter spawning occurs upriver mainly in fresh and possibly in brackish water (Boreman 1981; Klauda, Moos, and Schmidt 1988; Dew and Hecht 1994).

Eggs are demersal (Bigelow and Schroeder 1953; Boreman 1981; Klauda, Moos, and Schmidt 1988). The state of adhesion or nonadhesion of eggs is unknown, due to the difficulty of winter collection; conflicting opinions range from nonadhesive (Boreman 1981), to probably adhesive (Klauda, Moos, and Schmidt 1988), to adhesive (Bigelow and Schroeder 1953). Hatching occurs in freshwater (Dew and Hecht 1994) after 24-60 days in February and March (Klauda, Moos, and Schmidt 1988; Dew and Hecht 1994). Yolksac larvae reach peak abundance in mid-March, and post-yolksac larvae reach peak abundance in mid-April (Klauda, Moos, and Schmidt 1988). The yolksac larval period is approximately 4 wk, and the feeding larval period is approximately 6 wk (Boreman 1981). Larvae disperse downriver to Rkm 19-53 by mid-May (Klauda, Moos, and Schmidt 1988). The lower Hudson River is considered to be a nursery area for young Atlantic tomcod (McLaren *et al.* 1988). Juveniles are thought to peak in mid-May, mainly in the Tappan Zee and Yonkers regions (Klauda, Moos, and Schmidt 1988), although earlier reports show that juveniles did not appear until early August (Boreman 1981). They move upriver in mid-spring (Dew 1995), possibly to remain in brackish water as the salt front moves upriver (Klauda, Moos, and Schmidt 1988).

In the Hudson River, males and females both sexually mature between 11 and 12 mo, during their first fall (Boreman 1981; Klauda, Moos, and Schmidt 1988; McLaren *et al.* 1988). Adult Atlantic tomcod therefore spawn in their first year. Atlantic tomcod are not thought to move out of the Hudson River estuary during their life span, although they are found frequently in mouths of estuaries when not spawning (Bigelow and Schroeder 1953).

BAY ANCHOVY

The bay anchovy, *Anchoa mitchilli*, is a coastal species which enters the lower Hudson River in April as adults (Woodhead *et al.* 1992). Adults are present in the lower estuary in high numbers in the summer, and are absent from the estuary in the winter (Woodhead *et al.* 1992). Egg collections suggest spawning occurs in the lowest regions of the Hudson River and probably out into coastal waters (Boreman 1981). Spawning is typically in water less than 20 m deep (Richards 1959); spawning activity in the lower Hudson River occurs from early June to mid-August and perhaps beyond, as suggested by a study of anchovy spawning in nearby Long Island Sound (Richards 1959). Since the minimum age at maturity is 2.5 mo at a size between 30 and 40 mm (Stevenson 1958), it is likely that bay anchovies spawn in their first year of life.

Eggs are pelagic (Klauda *et al.* 1991) and hatch in about 24 hr; yolksacs are absorbed in another 24 hr (Boreman 1981). Anchovy eggs have been collected in the Hudson River estuary up to Rkm 88 (Boreman 1981). The distribution of young anchovy shifts upriver as development progresses through summer. Post-yolksac larvae metamorphose in August and September (Woodhead *et al.* 1992). Juveniles in Chesapeake Bay prefer freshwater habitats (Klauda *et al.* 1991); this may also be the case for juveniles in the Hudson River as suggested by the upriver shift in distribution mentioned earlier. In the Hudson River, juvenile anchovy emigrate to sea in the fall; few remain in the estuary after November (Woodhead 1991).

Although no tagging studies have been conducted on Hudson River bay anchovy, studies elsewhere suggest that oceanic movements are limited to inshore-offshore migrations (Hildebrand 1963). Bay anchovy feed on detrital material and small planktonic animals in the Hudson River estuary (Boyce Thompson Institute for Plant Research 1977).

BLUEFISH

Bluefish (*Pomatomus saltatrix*) are ocean spawners; larval and early juvenile development also occurs offshore. Bluefish first appear in estuaries as juveniles and, in the Northeast, usually arrive in the lower Hudson in late summer and fall (Boyle 1968). The distribution of larvae offshore is fairly well studied (Kendall and Walford 1979), but that of early juveniles is less known. Very little information is available on habitat requirements, food habits, or multispecies interactions in the oceanic phase. Juvenile bluefish generally appear in nearshore coastal waters in two waves, one in spring and another in summer, suggesting two spawning periods or a protracted spawning season offshore (Sargent and Boreman 1984).

In estuaries, juvenile bluefish are piscivorous, feeding on a wide variety of prey items (Marks and Conover 1993). Juvenile bluefish in the Hudson River feed on bay anchovy, white perch, American shad, river herring, and striped bass (Texas Instruments 1976b; Juanes *et al.* 1993).

LARGEMOUTH BASS

The largemouth bass, *Micropterus salmoides*, is a freshwater-oligohaline, nonmigratory species inhabiting the Hudson River. When preparing to spawn, adult largemouth bass select appropriate sites in which to construct nests and to fertilize and deposit eggs. In the Hudson River, spawning and nesting habitat typically consists of protected coves and bays, and almost never exposed shoreline (Nack *et al.* 1993). Miller and Kramer (1971) found high mortality rates for eggs and larvae due to exposure to wind-induced waves, which explains why largemouth bass seem to prefer lentic habitat. Also, while specific effects of tidal action on developing eggs are unknown, stable water levels are associated with high recruitment (Von Geldern 1971). Nesting in coves and bays may slightly mitigate effects of tidal action. Temperature may be an important environmental cue for the timing of spawning because the early season nests seem to be in areas of warmer water (Nack *et al.* 1993).

Eggs are adhesive, sticking to one another in a mass and to the substrate upon which they are laid, such as gravel or roots (Breder and Rosen 1966). Male largemouth bass guard the nests, even after the eggs have hatched (Breder and Rosen 1966). Larvae and juveniles use the area around nesting sites as nursery habitat (Green *et al.* 1988; Green *et al.* 1989; Nack *et al.* 1993). Presumably, these preadult life stages remain in the tributaries where they would be protected from waves, unstable water levels, as well as some predators.

Adult largemouth bass also prefer lentic water in protected areas, especially in winter (Carlson 1992). Largemouth bass are believed to seek shelter from tide-affected areas in winter when their metabolic rates are low (Carlson 1992). Largemouth bass tend to leave overwintering sites when water temperature rises to 10°C (Nack *et al.* 1993).

STRIPED BASS

Striped bass (*Morone saxatilis*) spawn in the fresh-brackish reach of the Hudson River, concentrating between Rkm 54 and 88, from early May through June (Boreman 1981). Striped bass eggs are semibuoyant (Hardy 1978). The yolksac larval stage runs 3-6 days, and the feeding (post-yolksac) larval stage may last 4 wk (Boreman and Fletcher 1993). The distribution of the early life stages in the river has been well documented (*e.g.*, see Boreman and Klauda 1988), showing that the fish distribute both upriver and downriver as they develop. Timing of movement of juveniles out of estuarine nursery areas varies among stocks; in the Hudson River, age 0 fish move out of the river to estuaries in Long Island Sound and New Jersey. By age 1, these fish are participating in coastal migrations. Temperature is usually implicated in triggering migrations, but further studies relating movement and environmental conditions or prey availability seem warranted. Coastal movement of striped bass tagged in the Hudson River is extensive, but concentrated between Cape May and Cape Cod (McLaren *et al.* 1981).

Food habits studies conducted in the estuary (Texas Instruments, Inc. 1976a) suggest that age-0 striped bass feed primarily on harpacticoid, calanoid, and cyclopoid copepods, *Gammarus* spp., and chironomid larvae, progressing to fish as they age. Striped bass greater than 75 mm feed on bay anchovies, and striped bass greater than 116 mm feed on clupeids, Atlantic tomcod, mummichogs, *Morone* spp., and banded killifish. White perch, bluefish, Atlantic tomcod, largemouth bass, and smallmouth bass have been reported as potential predators on striped bass larvae (McFadden *et al.* 1978).

WHITE PERCH

In the Hudson River, the white perch, *M. americana*, is a nonmigratory euryhaline species which is widely distributed throughout the river. Spawning occurs from April to June (Bigelow and Schroeder 1953; Klauda, McLaren, *et al.* 1988) or July (Boreman 1981), with peak egg deposition in mid-May to early June in the upper Hudson (Klauda, McLaren, *et al.* 1988). Spawning takes place mainly in freshwater (Englert and Sugarman 1988; Klauda, McLaren, *et al.* 1988) in a variety of protected habitats, such as shallow flats, embayments, and tidal creeks (Klauda, McLaren, *et al.* 1988).

Eggs are demersal and adhesive (Bigelow and Schroeder 1953), and hatch after only 1.5-2 days (Boreman 1981). Yolksac larvae are found in the same areas as the eggs, probably as a result of the short duration of the larval stages (3-5 days) (Klauda, McLaren, *et al.* 1988). Feeding larvae are more widely distributed due to their higher mobility, and disperse downriver in July (Klauda, McLaren, *et al.* 1988). This finding on post-yolksac larval distribution conflicts with earlier sampling data from the 1970s which indicated that both egg and larval stages are widely distributed in the Hudson, with larval stages found between Rkm 39 and 201 (Boreman 1981). Juveniles first appear in June, dispersing downriver and into the shorezone during the end of summer; juveniles were mainly found close to shore in October, but then moved into deeper water by December (Klauda, McLaren, *et al.* 1988).

Adult white perch sexually mature at age 4 in males, and age 5 in females (Klauda, McLaren, *et al.* 1988). There is no known habitat preference for adults; they are widely distributed in the Hudson River in both brackish and freshwater habitats (Klauda, McLaren, *et al.* 1988), but remain in the river for their entire life span (Boreman 1981).

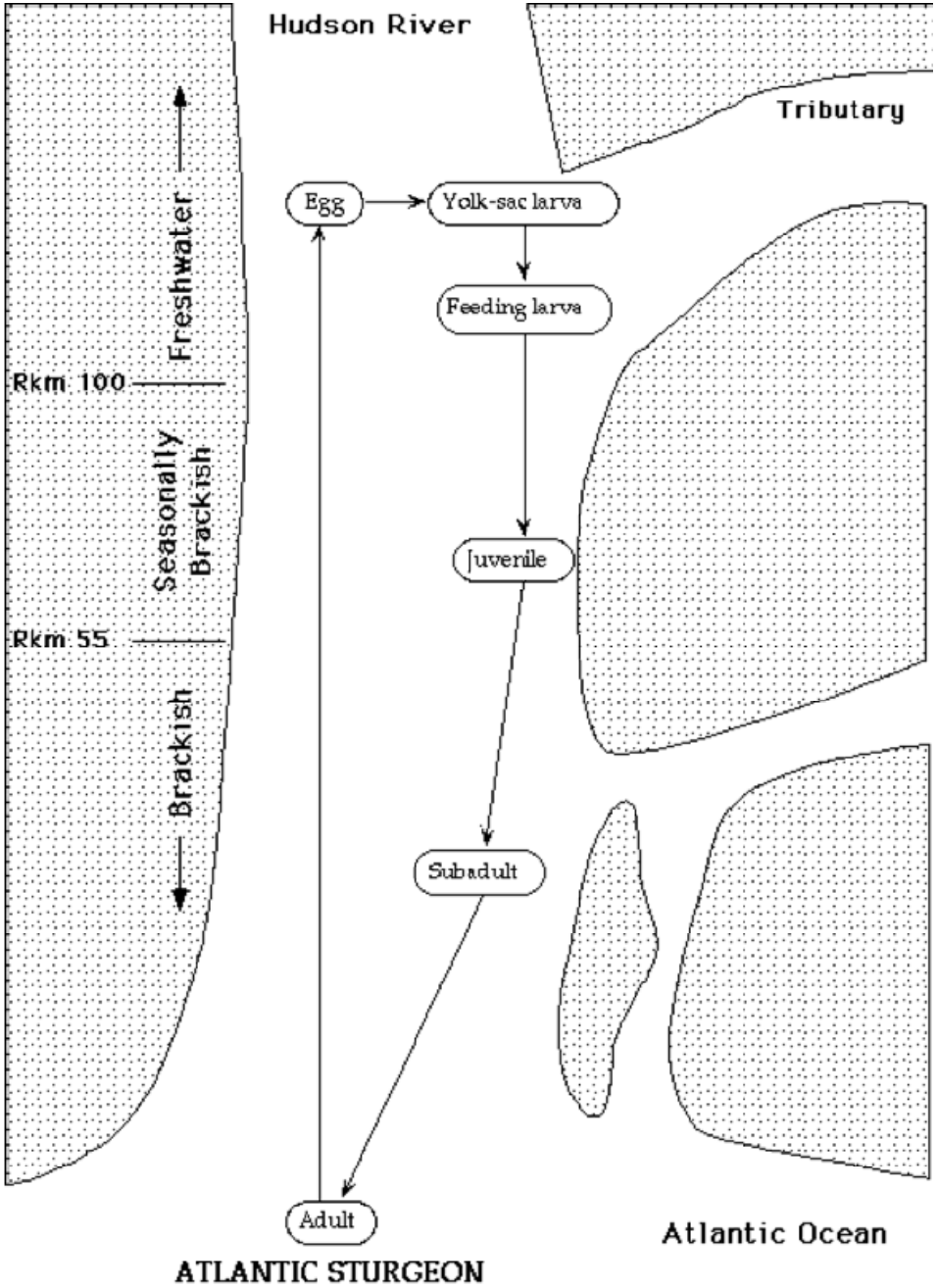

Figure A-1. Spatial representation of the life history of the Atlantic sturgeon in the Hudson River estuary

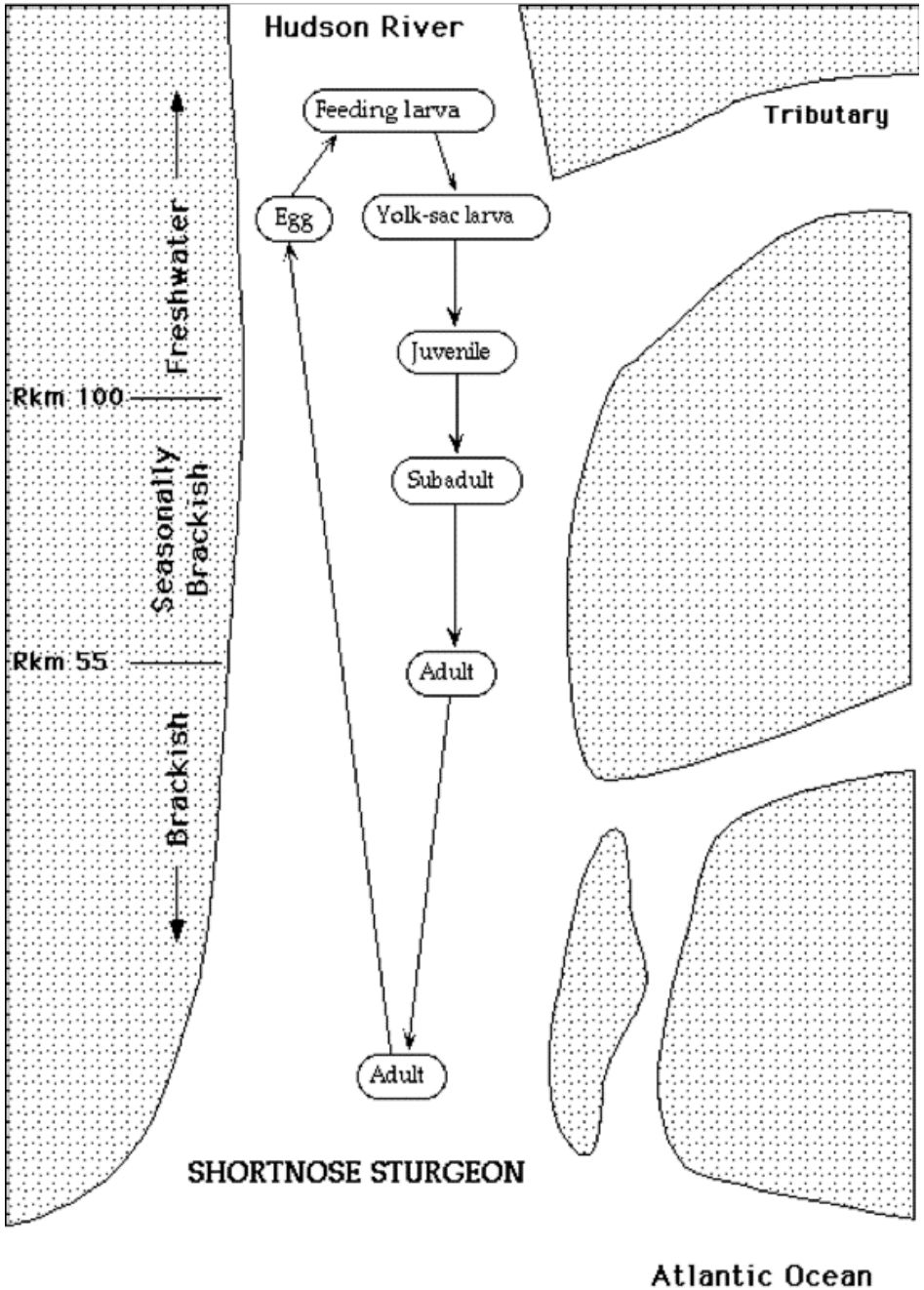

Figure A-2. Spatial representation of the life history of the shortnose sturgeon in the Hudson River estuary

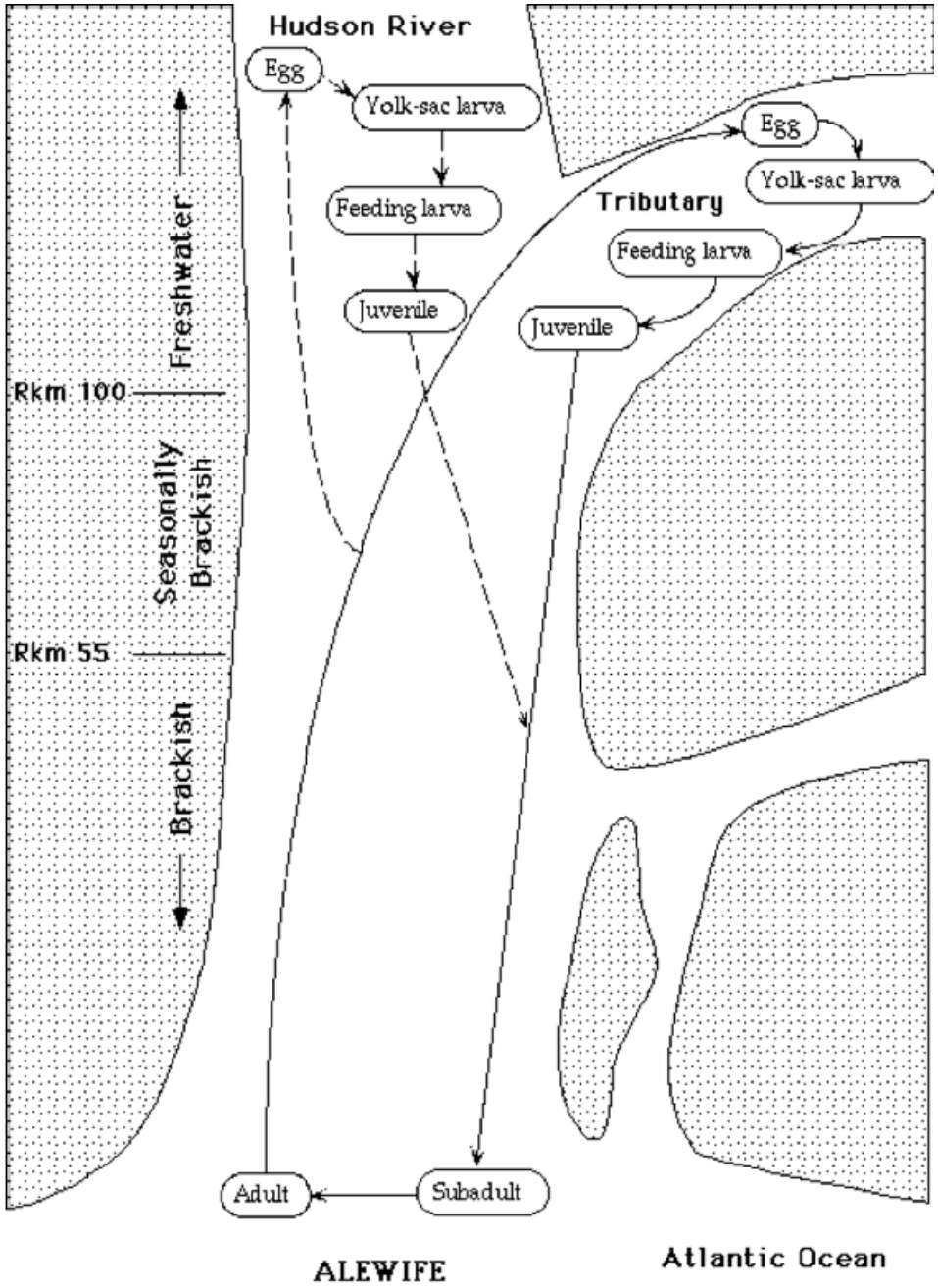

Figure A-3. Spatial representation of the life history of the alewife in the Hudson River estuary

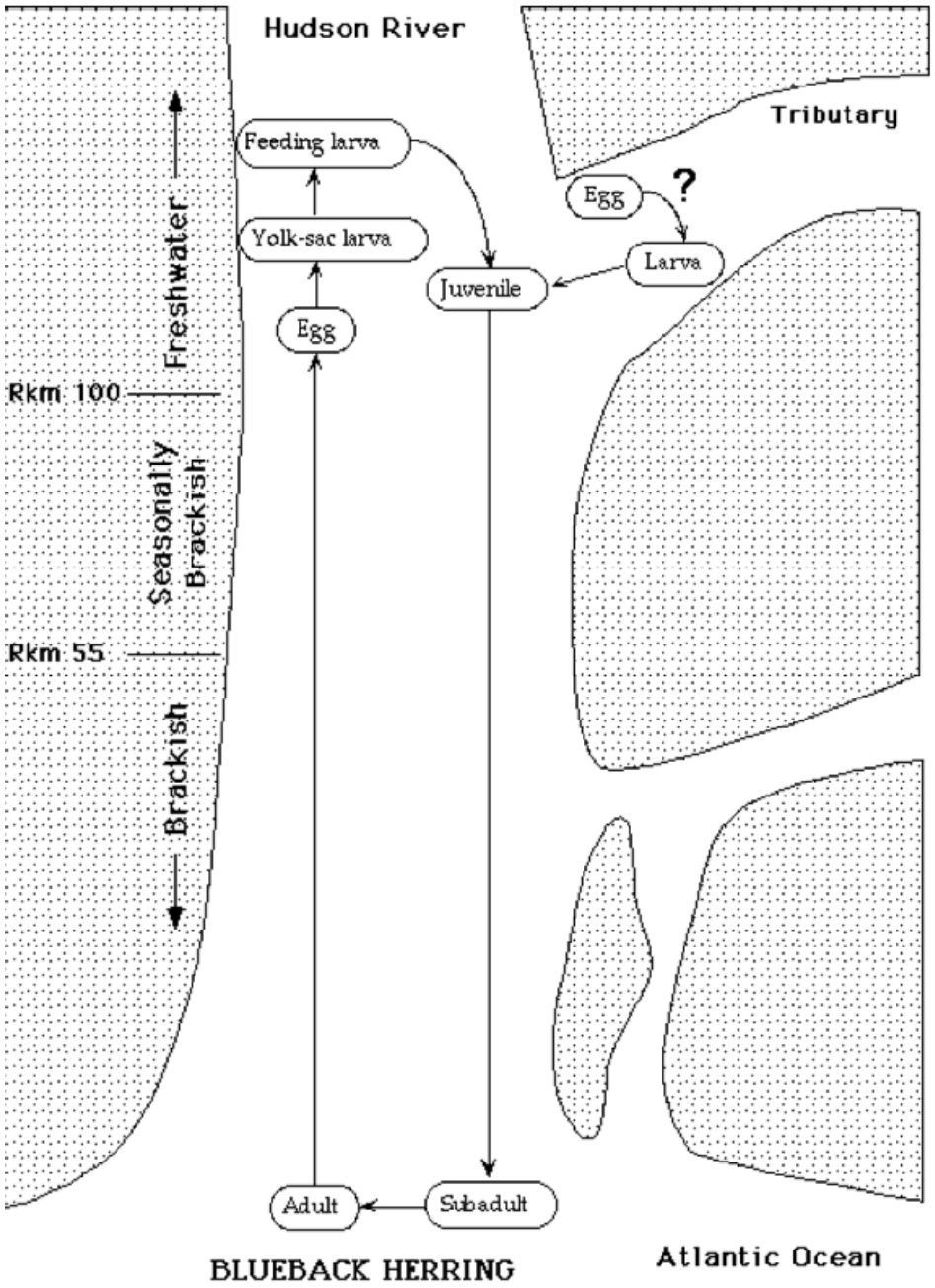

Figure A-4. Spatial representation of the life history of the blueback herring in the Hudson River estuary

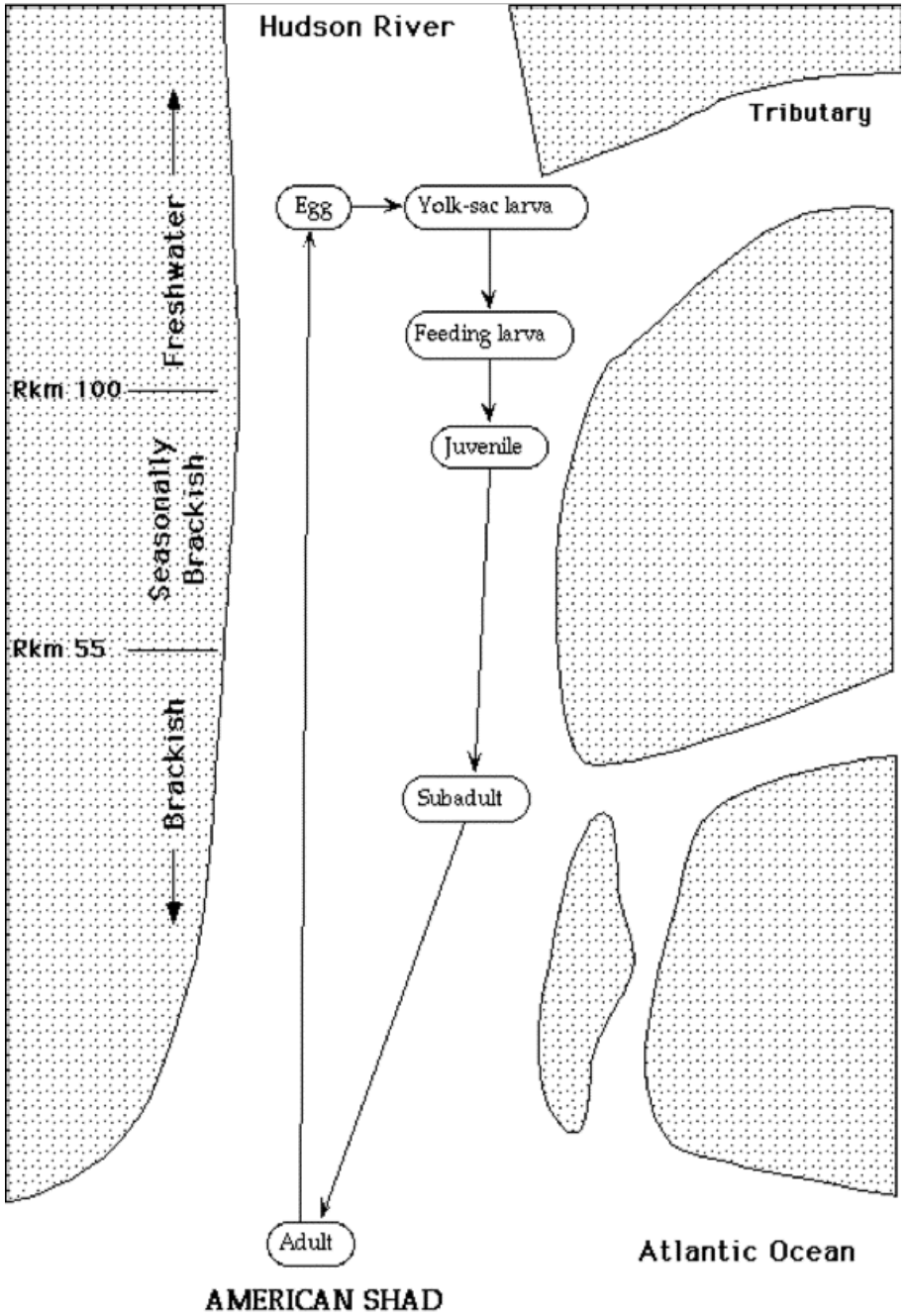

Figure A-5. Spatial representation of the life history of the American shad in the Hudson River estuary

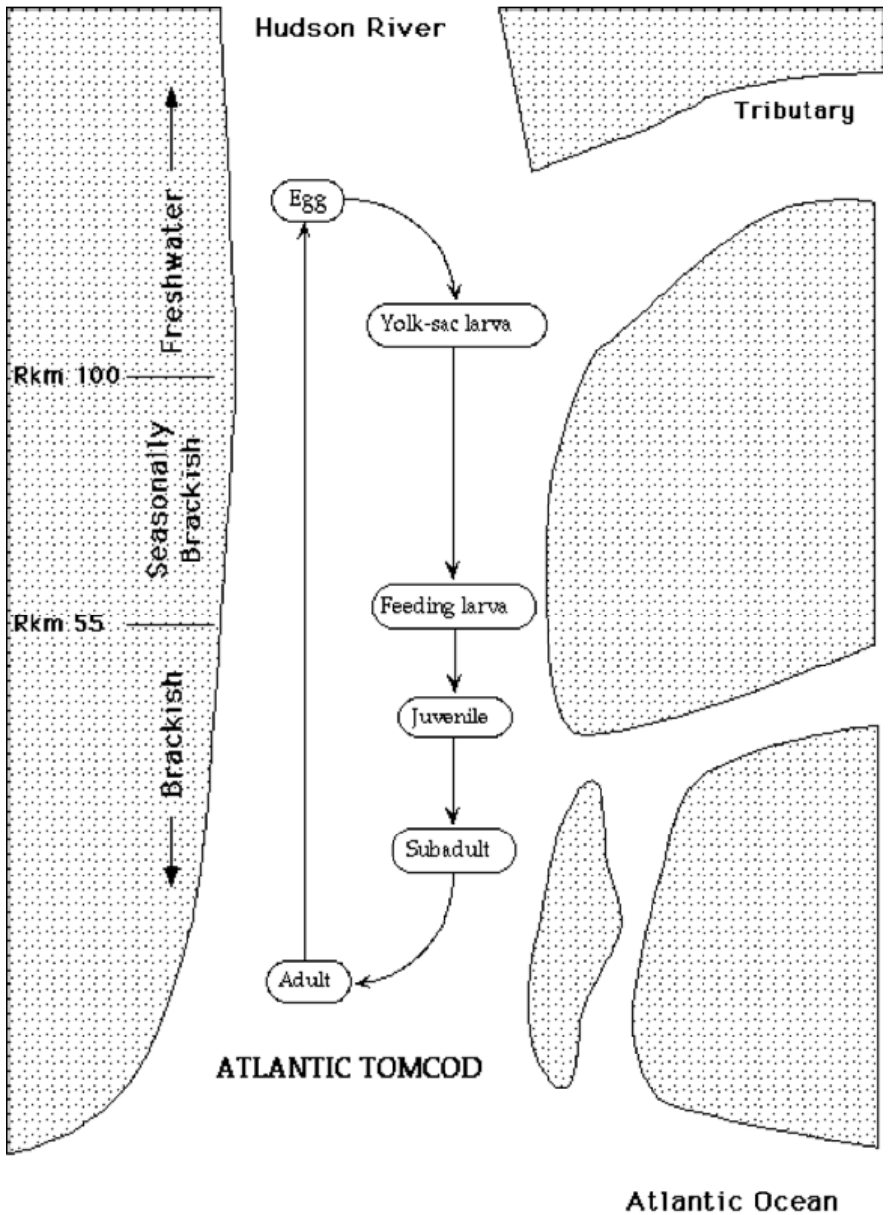

Figure A-6. Spatial representation of the life history of the Atlantic tomcod in the Hudson River estuary

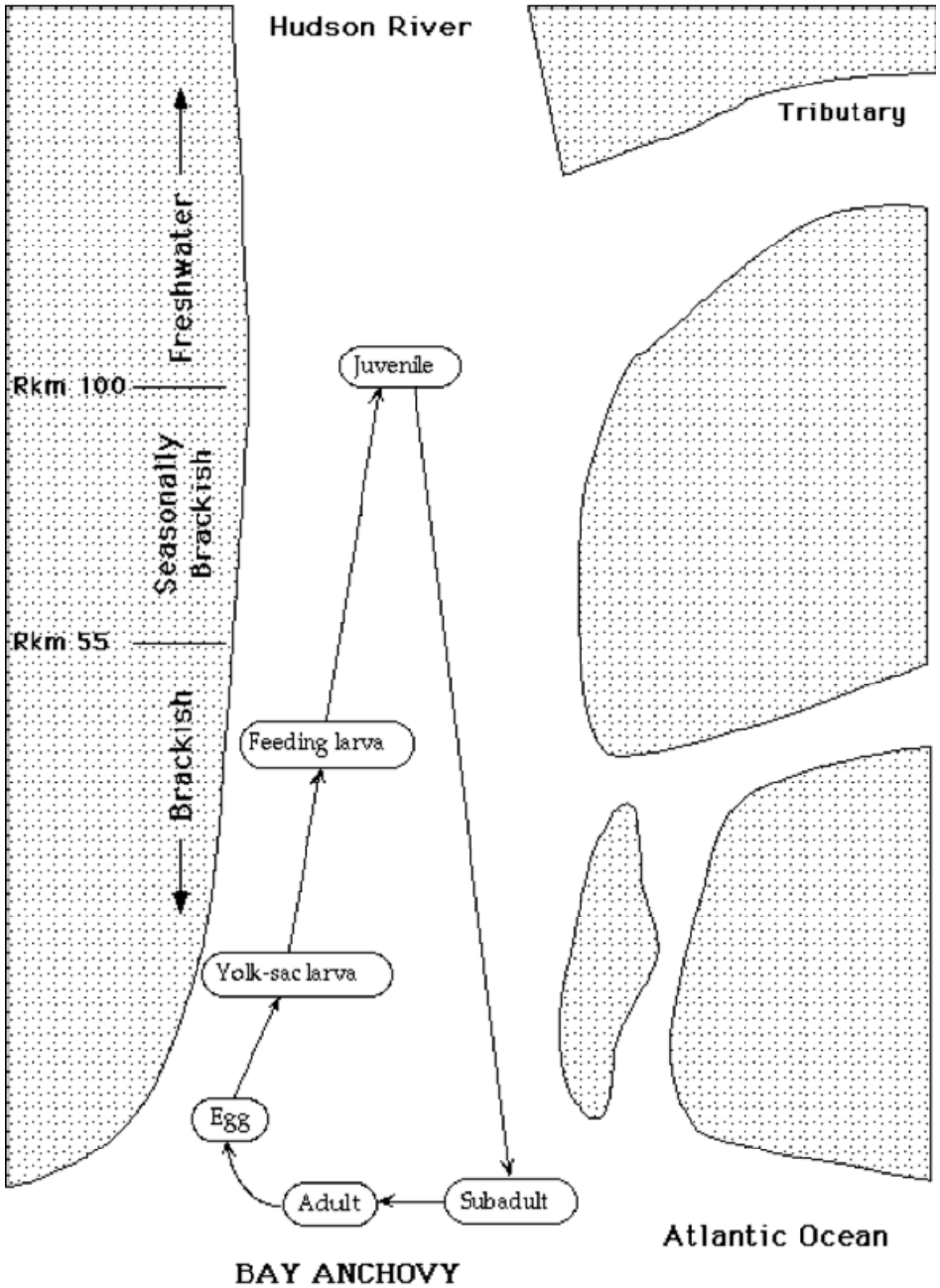

Figure A-7. Spatial representation of the life history of the bay anchovy in the Hudson River estuary

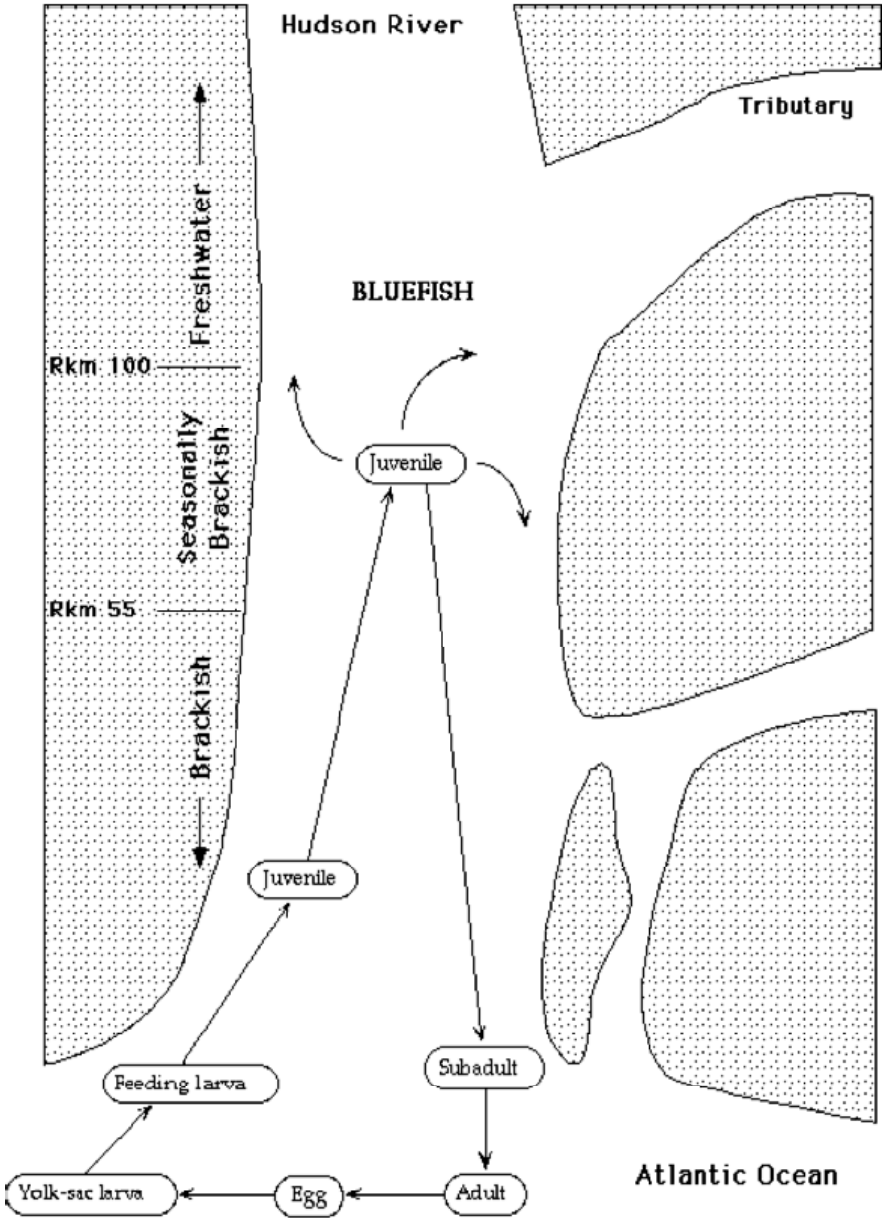

Figure A-8. Spatial representation of the life history of the bluefish in the Hudson River estuary

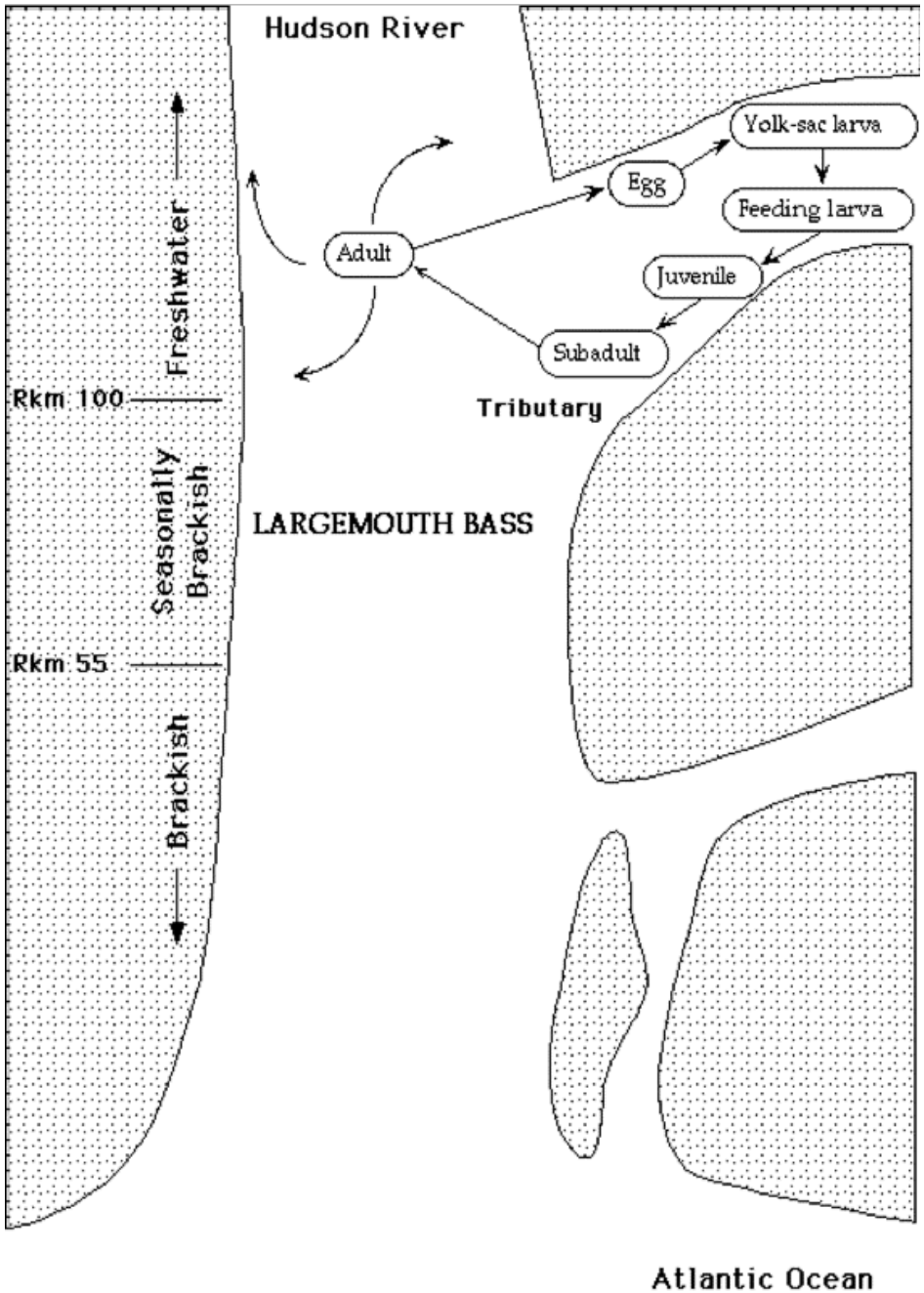

Figure A-9. Spatial representation of the life history of the largemouth bass in the Hudson River estuary

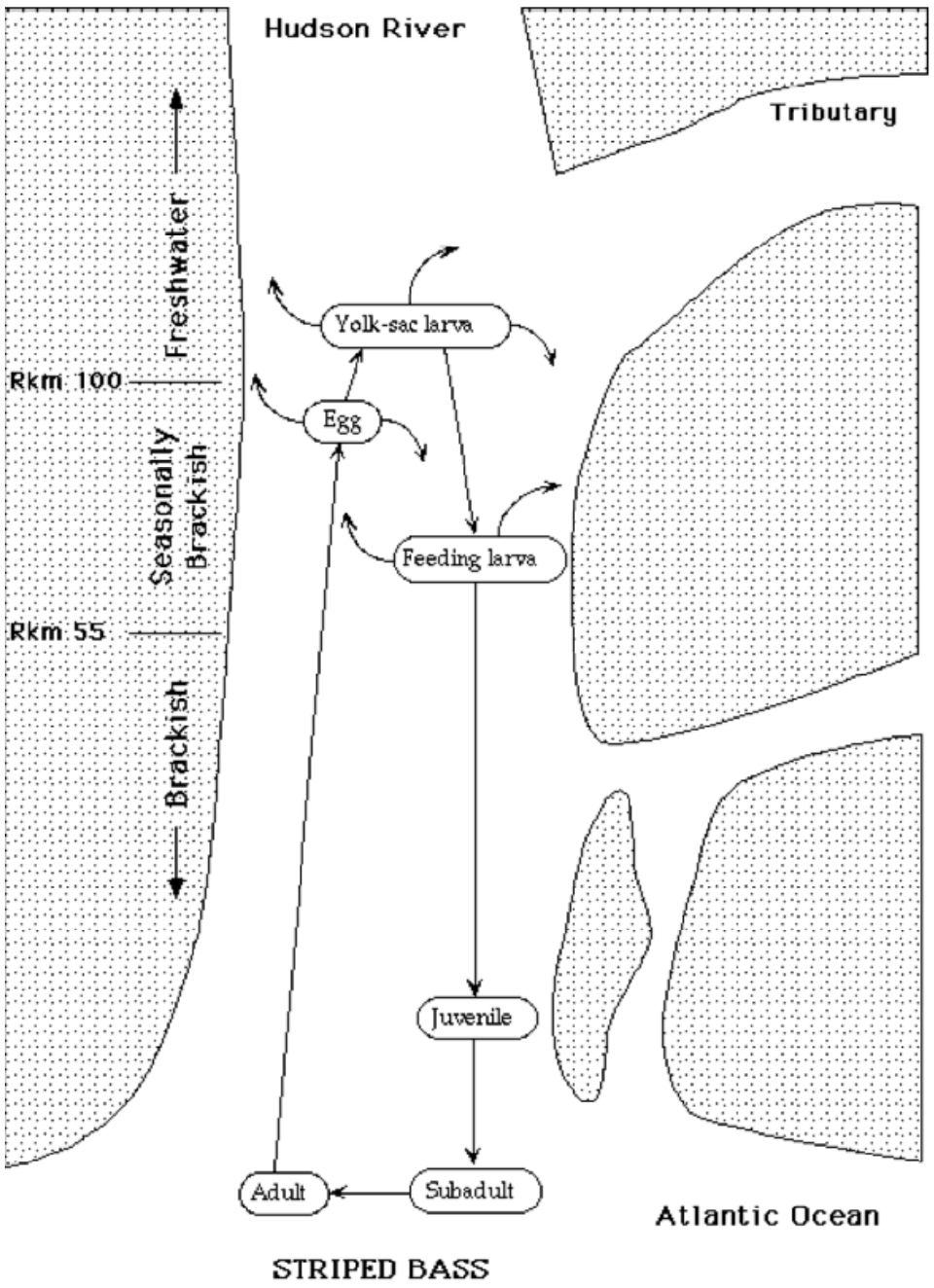

Figure A-10. Spatial representation of the life history of the striped bass in the Hudson River estuary

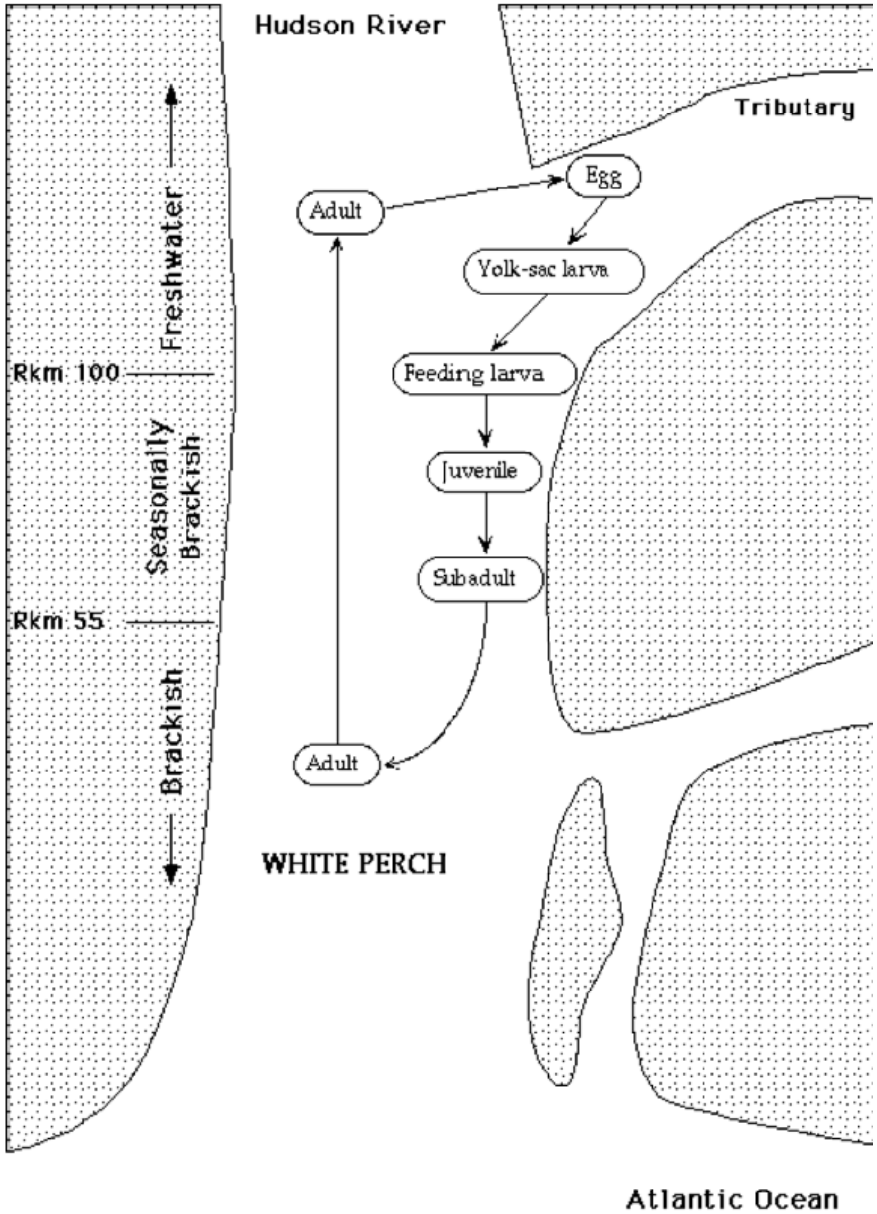

Figure A-11. Spatial representation of the life history of the white perch in the Hudson River estuary

APPENDIX B

List of Agencies, Organizations, and Individuals Contacted to Determine the Extent of Unpublished Information Related to Habitat Use by the Selected Fish Species Inhabiting the Hudson River Estuary

AGENCIES AND ORGANIZATIONS

American Museum of Natural History
Bard College
Central Hudson Gas and Electric
Consolidated Edison Co.
Cornell University
Hudson River Foundation
Hudson River National Estuarine Research Reserve
Hudson River Sloop *Clearwater*
Hudson Riverkeeper
Hudsonia, Ltd.
Institute of Ecosystem Studies
Lawler, Matusky and Skelly Engineers
Maryland Department of Natural Resources
National Marine Fisheries Service
New York State Museum
New York Power Authority
New York State Department of Environmental Conservation
New York State Department of State
Orange and Rockland Utilities
Rutgers University
Scenic Hudson, Inc.
Simon's Rock College
State University of New York at Stony Brook
The River Project
U.S. Army Corps of Engineers
U.S. Fish and Wildlife Service
University of Maryland Chesapeake Biological Laboratory
University of Massachusetts
University of South Alabama

INDIVIDUALS

Name & Mailing Address at Time of Contact	Remarks
Kenneth Able Marine Field Station Institute of Marine and Coastal Sciences Rutgers University 800 Great Bay Blvd. Tuckerton, NJ 08087	Research on striped bass in the Hudson River
Mark B. Bain Department of Natural Resources Cornell University Ithaca, NY 14853-3001	Research on shortnose sturgeon in the Hudson River

Barbara Brown Department of Ichthyology American Museum of Natural History Central Park West & 79th St. New York, NY 10024	Detailed information available on cataloged specimens from the Hudson River; all 11 species represented by most life stages
Jeffrey A. Buckel Marine Science Research Center State University of New York at Stony Brook Stony Brook, NY 11794	Research on bluefish in the Hudson River
Gregory L. Capobianco Coastal Program New York State Department of State 162 Washington Ave., 4th Fl. Albany, NY 12231	Head of Significant Habitat Unit; has worked on Hudson River significant habitat
John Catena Northeast Regional Operations Office National Marine Fisheries Service 1 Blackburn Dr. Gloucester, MA 01930	
David Conover Marine Science Research Center State University of New York at Stony Brook Stony Brook, NY 11794	Research on bluefish in the Hudson River
James Cowan Department of Marine Science University of South Alabama Mobile, AL 36688	Research on bay anchovy in Chesapeake Bay
John Cronin P.O. Box 130 Garrison, NY 10524	Hudson Riverkeeper
Robert A. Daniels Biological Survey Laboratory New York State Museum 145 Jordan Rd. Troy, NY 12180	Information available on cataloged specimens from the Hudson River; all 11 species represented, mainly young-of-the-year and adult stages
Cathy Drew The River Project 67 Vestry St. New York, NY 10013	Executive Director
Dennis Dunning New York Power Authority 123 Main St. White Plains, NY 10601	Research on striped bass in the Hudson River
Fran Dunwell New York State Department of Environmental Conservation 21 S. Putt Corners Rd. New Paltz, NY 12561-1696	Information on the Hudson River as it pertains to New York State government

David M. Green Biological Field Station Cornell University 900 Shakelton Point Rd. Bridgeport, NY 13030	Research on largemouth bass in the Hudson River
Thomas Halavik Coastal Ecosystems Project U.S. Fish and Wildlife Service Shoreline Plaza, Rt. 1A P.O. Box 307 Charlestown, RI 02813	Senior biologist heading study on "Significant Habitat and Habitat Complexes of the New York Bight Watershed"
Len Houston Environmental Analysis Branch New York District U.S. Army Corps of Engineers 26 Federal Plaza New York, NY 10278	This office is putting together, along with the New York State Department of Environmental Conservation, a restoration plan for the Hudson River
Francis Juanes Department of Forestry and Wildlife University of Massachusetts Amherst, MA 01003	Research on bluefish in the Hudson River; recruitment and feeding, in particular
Andrew W. Kahnle Hudson River Fisheries Unit New York State Department of Environmental Conservation 61 Yankee Folly Rd. New Paltz, NY 12561	Hudson River fisheries for the New York State Department of Environmental Conservation; New York state sturgeon regulations, 1992; research on American shad and striped bass in the Hudson River
Eric Kiviatt Hudsonia, Ltd. Bard College Field Station Annandale, NY 12504	Research on natural and social science aspects of Hudson River management
Ronald J. Klauda Research & Monitoring Division Tidewater Administration - Chesapeake Bay Maryland Department of Natural Resources 580 Taylor Ave., B2 Annapolis, MD 21401	Research on striped bass, white perch, shortnose sturgeon, American shad, Atlantic tomcod, and alewife in the Hudson River
Tom Lake *Hudson River Almanac* New York State Department of Environmental Conservation 3 Steinhaus Ln. Wappinger Falls, NY 12590	
Cara Lee Scenic Hudson, Inc. 9 Vassar St. Poughkeepsie, NY 17601	Environmental Director; also Director of Hudson River Improvement Fund

Karin Limburg Institute of Ecosystem Studies Box AB Millbrook, NY 12545	Research on alewife, blueback herring,American shad, and general fish ecology in the Hudson River
Wayne Mancroni Central Hudson Gas and Electric 284 South Ave. Poughkeepsie, NY 12602	
Kim McKown Marine Resources New York State Department of Environmental Conservation 205 Belle Meade Rd. East Setauket, NY 11733	Research on striped bass in the Hudson River; sturgeon regulations with Andrew W. Kahnle
Andrew Milliken Coastal Ecosystems Project U.S. Fish and Wildlife Service Shoreline Plaza, Rt. 1A P.O. Box 307 Charlestown, RI 02813	
William Neider Hudson River National Estuarine Research Reserve Bard College Field Station Annandale, NY 12504	Research coordinator for the reserve
Michael Pace Institute of Ecosystem Studies Box AB Millbrook, NY 12545	Research on striped bass in the Hudson River
William D. Sasken Orange and Rockland Utilities 1 Blue Hill Plaza Pearl River, NY 10965	
Robert Schmidt Simon's Rock College Great Barrington, MA 01230	Research on alewife and blueback herring in the Hudson River with particular knowledge of freshwater tributary habitat
David H. Secor Chesapeake Biological Laboratory University of Maryland P.O. Box 38 Solomons, MD 20688	Research on striped bass and Atlantic sturgeon in the Hudson River
C. Lavett Smith Department of Ichthyology/Herpetology American Museum of Natural History Central Park West & 79th St. New York, NY 10024	Editor of several books on Hudson River fishes

Nancy Steinberg Hudson River Foundation 40 West 20th St. New York, NY 10011	Research on young-of-the-year bluefish in the Hudson River;head of library at the Hudson River Foundation
Dennis Suzskowski Hudson River Foundation 40 West 20th St. New York, NY 10011	
John Waldman Hudson River Foundation 40 West 20th St. New York, NY 10011	Research on striped bass and Atlantic sturgeon in the Hudson River
Alan Wells Lawler, Matusky and Skelly Engineers 1 Blue Hill Plaza P.O. Box 1509 Pearl River, NY 10965	
John Young Consolidated Edison Co. 4 Irving Place New York, NY 10003	

APPENDIX C

User's Guide to the Database

ABOUT THE DATABASE

Literature references, representing mostly published papers and unpublished reports, for 11 fish species which are considered important and representative of the fish community of the Hudson River estuary, have been assembled into a database. The 11 fish species are: Atlantic sturgeon, *Acipenser oxyrhynchus*; shortnose sturgeon, *A. brevirostrum*; American shad, *Alosa sapidissima*; alewife, *A. pseudoharengus*; blueback herring, *A. aestivalis*; bay anchovy, *Anchoa mitchilli*; bluefish, *Pomatomus saltatrix*; Atlantic tomcod, *Microgadus tomcod*; striped bass, *Morone saxatilis*; white perch, *M. americana*; and largemouth bass, *Micropterus salmoides*. The record of each literature reference in the database includes 18 fields, among which are fields for "fish species," "geography," and "(other) keywords" (Table C-1). The 62 "other keywords" which were most often used in the database to describe the habitat use and requirements of the 11 species are listed in Table C-2.

DATABASE ACCESS AND USE

The database currently exists in three formats to enable public access and use, and will eventually exist in a fourth format for such purposes. The first format of the database is an annotated bibliography of the literature references which is presented in a paper printing of this report. Each entry in that bibliography is annotated with keywords on fish species, geography, and "other" keywords. That annotated bibliography is Appendix D ("List of Published and Unpublished Works Containing Information That May Be Relevant to Habitat Requirements and Use by the Selected Fish Species Inhabiting the Hudson River Estuary") of this report.

The second format of the database is the same annotated bibliography as presented in the paper printing, but is one which has been electronically posted. The electronic posting is part of the HTML and PDF publishing of this report on the Northeast Fisheries Science Center's (NEFSC's) Internet webpage on "Reports and Publications" (*http://www.nefsc.nmfs.gov/nefsc/publications/*). The HTML version can be searched with the search engine associated with the user's Internet access software (*e.g.*, Netscape Navigator, Microsoft Internet Explorer).

The third format of the database is one prepared with FileMaker® database software (FileMaker, Inc., 5201 Patrick Henry Dr., P.O. Box 58168, Santa Clara, CA 95054-8168). To access and use this format, one must have either FileMaker 4 or 5 software installed on his/her computer, and must request the actual data to be sent as an e-mail attachment from the NEFSC's Editorial Office (*Jon.Gibson@noaa.gov*). The FileMaker database contains complete instructions -- through its "Help" menu -- for the user, and permits searches on either single or multiple items (*i.e.*, fish species, "other" keywords, and authors).

The fourth format of the database, which will not be available until several years after the first three formats have been prepared, will be the tagging of the annotated bibliography with XML. The XML-tagged bibliography will be part of an XML-based system for searching and retrieving a wide array of information from an extensive collection of NEFSC-produced scientific works.

Table C-1. Fields associated with records in the database on habitat use and requirements of important fish species inhabiting the Hudson River estuary

Field Name	Content
Author:	Name(s) of the author(s) of the particular document.
Year:	Year of publication, or year of completion if unpublished.
Title:	Title of the particular document.
Type:	Type of document, *i.e.*, whether it is a journal article, thesis, etc. For example, since bibliographic format differs for a book by one or more authors, as opposed to an edited book which contains several papers by different authors, this field allows the database program to identify the different types of books (*i.e.*, "Book Type I" and "Book Type II") so that the program can set up the proper bibliographic output.
Title of Type:	Title of the type of document, only where the title of the type of document differs from the title of the document itself; *i.e.*, for journal articles, this would include the title of the journal where an article is published.
Volume:	Volume number, when applicable.
Pages:	Either the page numbers, or number of pages, for the particular document, when known.
Editors:	Editors for the document, when applicable.
Publisher:	Publisher for the particular document, when applicable.
Geography:	One or more items pertaining to the locality (or localities) discussed in, or pertinent to, the document.
Fish Species:	Fish species discussed in the document, especially for those 11 species of particular interest. In papers discussing fish species other than the 11, not all species are necessarily included in this field. In most cases, the genus and species, as well as the common name, are entered for each fish.
Hardcopy Y or N:	Whether a hardcopy of the document was on hand when the database was created. The papers with "Yes" written in this field are now in a small library under the care of John Boreman. (See new affiliation and e-mail address noted earlier.)
Hardcopy #:	Number assigned to the hardcopy, for easy reference.
Notes:	Originally intended to contain notes on papers that were read. Mostly, this field has been left blank.
Source:	From what paper, person, or place the document was originally found.
Output:	Bibliographic format for the document.
Keywords:	Keywords for the document. For papers for which a hardcopy is available, keywords are taken from both the text and title. For papers for which a hardcopy is not available, keywords are taken from only the title.

Table C-2. Keywords most often used in the database on habitat use and requirements of important fish species inhabiting the Hudson River estuary

abundance
adult
age
anadrom (for "anadromy" or "anadromous")
behavior
benthos
biology
chemistry
community
contamin (for "contaminant" or "contamination")
development
dissolved oxygen
distribution
ecology
ecosystem
egg
embryo
entrain
environment
estuary
feeding
fisher (for "fishery" or "fisheries")
food
freshwater
growth
habitat
history
impinge
juvenile (also, see "young")
larva (for "yolksac and post-yolksac/feeding larva"; also, see "young")
life history
loading
management
mark (for "mark and recapture")
marsh
migration
mortality
movement
nursery
nutrient
otolith
PCB (polychlorinated biphenyl)
physiology
plankton
pollut (for "pollution" or "pollutant")
population
power (for "power plant")
predat (for "predation" or "predator")
recruitment
reproduc (for "reproduce" or "reproduction")
salinity
season
sediment
spawn
stock
temperature
tide (or "tidal")
toxic
turbidity
vegetation
wastewater
young (for "young" and "young-of-the-year"; also, see "larva" and "juvenile")

APPENDIX D

List of Published and Unpublished Works Containing Information That May Be Relevant to Habitat Requirements and Use by the Selected Fish Species Inhabiting the Hudson River Estuary

*Editor's Note: To insure consistency between the content of the following bibliography and the content of the FileMaker database created by this report's authors, none of the bibliographic data (*i.e., *author(s), date, title, and publishing information) in this bibliography have been edited by this series' editorial staff. Some formatting and styling have been performed for the sake of consistency among issues in the* NOAA Technical Memorandum NMFS-NE *series.*

Able, K.W.; Kaiser, S.C. 1994. Synthesis of summer flounder habitat parameters. *NOAA Coastal Ocean Program Decision Anal. Ser.* 1. Silver Spring, MD: NOAA Coastal Ocean Office; 167 p. Keywords: North America habitat, egg, larva, juvenile, adult summer flounder.

Abood, K.A. 1974. Circulation in the Hudson River estuary. *Annals NY Acad. Sci.* 250:39-111. Keywords: Hudson River, water circulation.

Abood, K.A. 1977. Evaluation of circulation in partially stratified estuaries as typified by the Hudson River. [Ph.D. dissertation.] New Brunswick, NJ: Rutgers University. Keywords: Hudson River, New York, evaluation, circulation, stratification, estuary.

Abood, K.A.; Apicella, G.A.; Wells, A.W. 1992. General evaluation of Hudson River freshwater flow trends. *In*: C.L. Smith, ed. Estuarine Research in the 1980s: Hudson River Environmental Society, 7th Symposium on Hudson River Ecology. Albany, NY: State University of New York Press; p. 3-28. Keywords: Hudson River, freshwater.

Abood, K.A.; Konrad, K.A.; Shirk, J.; McCroddy, P. 1973. Effects of power plants on physical and chemical water quality parameters with specific attention to temperature, dissolved oxygen, and chlorine distributions. *In*: Proceedings of 3rd Symposium of Hudson River Ecology. New Paltz, NY: Hudson River Environmental Society. Keywords: Hudson River, New York, effects, power plants, water quality, chemistry, temperature, dissolved oxygen, chlorine.

Abood, K.A.; Maikish, E.A.; Kimmel, R.R. 1976. Field and analytical investigations of ambient temperature distribution in the Hudson River: *In*: Boesch, D.F., ed. Proceedings of the 4th Symposium on Hudson River Ecology. New Paltz, NY: Hudson River Environmental Society. Keywords: Hudson River, New York, temperature distribution.

Adams, A.G. 1981. The Hudson: a guidebook to the river. Albany, NY: State University of New York Press; 424 p. Keywords: Hudson River, New York, guidebook, reference.

Adams, P.B. 1980. Life history patterns in marine fishes and their consequences for fisheries management. *Fish. Bull. (U.S.)* 78:1-12. Keywords: life history, fisheries, marine fishes, management.

Adams, S.M. 1976. The ecology of eelgrass, *Zostera marina* (L.), fish communities: I. Structural analysis. *J. Exp. Mar. Biol. Ecol.* 22:269-291. Keywords: ecology, eelgrass, fish community, habitat, vegetation.

Adams, S.M. 1976. The ecology of eelgrass, *Zostera marina* (L.), fish communities: II. Functional analysis. *J. Exp. Mar. Biol. Ecol.* 22:293-311. Keywords: ecology, eelgrass, fish community, function, habitat, vegetation.

Adams, S.M.; DeAngelis, D.L. 1987. Indirect effects of early bass-shad interactions on predator population structure and food web dynamics. *In*: Kerfoot, W.C.; Sih, A., eds. Predation: direct and indirect impacts on aquatic communities. Hanover, NH: University Press of New England; p. 103-117. Keywords: interactions, predation, predator, prey, population structure, food web, adult, largemouth bass, American shad.

Albrecht, A.B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. *Calif. Fish Game J.* 50:100-113. Keywords: observations, factors, survival, eggs, larvae, striped bass.

Allen, D.M.; Barker, D.L. 1990. Interannual variations in larval fish recruitment to estuarine epibenthic habitats. *Mar. Ecol. Prog. Ser.* 65:113-125. Keywords: interannual, variations, larvae, fish recruitment, metamorphosis, estuary, epibenthic habitats.

Alperin, I.M. 1966. Dispersal, migration, and origins of striped bass from Great South Bay, Long Island. *NY Fish Game J.* 13:79-112. Keywords: Long Island, Great South Bay, dispersal, migration, adult, striped bass.

Alperin, I.M. 1966. Occurrence of yearling striped bass along the south shore of Long Island. *NY Fish Game J.* 13:113-120. Keywords: Long Island, Atlantic Ocean, population, yearling, young, striped bass.

Alsop, R.G.; Forney, J.L. 1962. Growth and food of white perch in Oneida Lake. *NY Fish Game J.* 9:133-136. Keywords: Oneida Lake, New York, growth, food, feeding, adult, white perch.

Ammerman, J.W. 1989. Microbial breakdown of organic phosphates in the Hudson River, 1 August, 1987 - 31 July, 1988. [Final report.] New York, NY: Hudson River Foundation; 30 p. Keywords: Hudson River, New York, microbe, microbial breakdown, organic, phosphates.

Ammerman, J.W. 1991. Role of ecto-phosphohydrolases in phosphorus regeneration in estuarine and coastal ecosystems. *In*: Chrost, R.J., ed. Microbial enzymes in aquatic

environments. New York, NY: Springer-Verlag; p. 164-185. Keywords: ecto-Phosphohydrolases, phosphorus, estuary, coastal, ecosystem.

Anderson, A.B.; Schmidt, R.E. 1989. A survey of larval and juvenile fish populations in water-chestnut (*Trapa natans*) beds in Tivoli South Bay, a Hudson River tidal marsh. *In*: Blair, E.A.; Waldman, J.R., eds. Polgar Fellowship reports of the Hudson River National Estuarine Research Reserve Program, 1988, Section VII. New York, NY: Hudson River Foundation; 34 p. Keywords: Tivoli South Bay, Hudson River, survey, fish, larvae, juvenile, populations, water-chestnut beds, tidal marsh, habitat.

Anderson, E.D. 1980. A preliminary assessment of the bluefish (*Pomatomus saltatrix*) along the Atlantic coast of the United States. *NOAA/NMFS Woods Hole Lab. Ref. Doc*. 80-30; 29 p. Keywords: Atlantic Coast, Atlantic Ocean, preliminary assessment, survey, population, adult, bluefish.

Anderson, H.G. 1970. Annotated list of parasites of the bluefish. *Bur. Sport Fish. Wildl. Tech. Pap.*. 54; 15 p. Keywords: annotated list, parasites, adult, bluefish.

Anderson, R.D. 1978. Feeding and spawning of bluefish. *Sea Frontiers* 24:335-339. Keywords: food, feeding, spawning, adult, bluefish.

Anonymous. 1994. Scientific publications about the Hudson River National Research Reserve and environments. Unpublished; 13 p. Keywords: Hudson River, publications, references, estuary, environment.

Armstrong, R.W.; Sloan, R.J. 1980. Trends in levels of several known chemical contaminants in fish from New York State waters. *DEC Bur. Environ. Protect. Wildl. Tech. Rep.* 80-2, v. iii; 77 p. Keywords: New York, Hudson River, estuary, lakes, bays, sounds, rivers, trends, chemical, contaminants, fish.

Armstrong, R.W.; Sloan, R.J. 1981. PCB patterns in Hudson River fish: I. Resident/freshwater species. *In*: Proceedings of Hudson River Environmental Society. New Paltz, NY: Hudson River Environmental Society. Keywords: Hudson River, New York, PCB patterns, fishery, freshwater species.

Armstrong, R.W.; Sloan, R.J. 1988. PCB patterns in Hudson River fish: I. Resident freshwater species. *In*: Smith, C.L., ed. Fisheries research in the Hudson River. Albany, NY: State University of New York Press; p. 304-324. Keywords: Hudson River, PCBs.

Ashizawa, D.; Cole, J.J. 1994. Long-term temperature trends of the Hudson River: a study of the historical data. *Estuaries* 17(1B):166-171. Keywords: Hudson River, temperature, history.

Atkinson, C.E. 1951. Feeding habits of adult shad (*Alosa sapidissima*) in fresh water. *Ecology* 32:556-557. Keywords: feeding, food, adult, American shad.

Taub, S. 1990. Fishery management plan for Atlantic sturgeon. *Atl. States Mar. Fish. Comm. Fish. Manage. Rep.* 17; 73 p. Keywords: fishery, management, Atlantic sturgeon.

AuClair, R.P. 1956. The white perch, *Morone americana* (Gmelin) [in] Sebasticook Lake, Maine. [M.S. thesis.] Orono, ME: University of Maine; 84 p. Keywords: Maine, Sebasticook Lake, adult, white perch.

AuClair, R.P. 1960. White perch in Maine. Augusta, ME: Department of Inland Fisheries and Game. Keywords: Maine, adult, white perch.

Auld, A.H.; Schubel, J.R. 1978. Effects of suspended sediment on fish eggs and larvae: a laboratory assessment. *Estuar. Coastal Mar. Sci*. 6:153-164. Keywords: suspended sediment, fish eggs, eggs, laboratory experiment.

Austin, H.K.; Findlay, S. 1987. The contribution of bacteria to benthic processes in the Hudson River estuary. *In*: Blair, E.A.; Cooper, J.C., eds. Polgar Fellowship reports of the Hudson River National Estuarine Research Reserve Program, 1986, Section V. New York, NY: Hudson River Foundation; 48 p. Keywords: Hudson River, benthos, bacteria.

Austin, H.K.; Findlay, S. 1989. Benthic bacterial biomass and production in the Hudson River estuary. *Microbial Ecol.* 18:105-116. Keywords: Hudson River, benthos, bacteria.

Austin, M.P. 1987. Models for the analysis of species? Response to environmental gradients. *Vegetatio* 69:35-45. Keywords: model, species, environment, gradient.

Ayres, R.U.; Ayres, L.W.; McCurley, J.; Small, M.; Tarr, J.A.; Widgery, R.C. 1985. An historical reconstruction of major pollutant levels in the Hudson-Raritan basin 1880-1980. Pittsburgh, PA: Variflex Corp. Keywords: Hudson River, Raritan River, New York, New Jersey, basin, history, pollutants, pollution, 1880, 1980, 1880-1980.

Ayres, R.U.; Ayres, L.W.; McCurley, J.; Small, M.; Tarr, J.A.; Widgery, R.C. 1988. An historical reconstruction of major pollutant levels in the Hudson-Raritan Basin: 1880-1980 (3 volumes). *NOAA Tech. Memo. NOS OMA* 43. Keywords: Hudson River, New York, Raritan River, New Jersey, Hudson - Raritan Basin, estuary, history, reconstruction, pollutants, pollutant levels, 1880-1980.

Ayres, R.U.; Rod, S.R. 1986. Patterns of pollution in the Hudson River. *Environment* 28:14-20, 39-43. Keywords: Hudson River, Raritan Bay, pollution, wastewater, contaminants, loadings.

Bain, M.B.; Bain, J.L. 1982. Habitat suitability index model: coastal stocks of striped bass. *U.S. Fish Wildl. Serv. Rep. FWS/OBS* 82/10.1; 47 p. Keywords: model, habitat, coastal, stocks, adult, striped bass.

Bain, M.B.; Boreman, J.; Nack, S.; Haley, N. 1995. Techniques for evaluating the population status of Atlantic sturgeon. [Proposal.] Stony Brook, NY: New York Sea Grant Institute; 27 p. Keywords: Hudson River, habitat, distribution, juvenile, adult, sampling, mark and recapture, Atlantic sturgeon.

Barclay, B. 1993. Hudson River angler survey. [Final report.] New York, NY: Hudson River Foundation; 66 p. Keywords: Hudson River, sport fishery, angler.

Barger, L.E. [year unknown.] Age and growth of the bluefish, *Pomatomus saltatrix* (Linnaeus), from the northern Gulf of Mexico and the southeastern United States. *NOAA/*

NMFS Panama City Lab. Rep.; 10 p. Keywords: northern Gulf of Mexico, Gulf of Mexico, southeastern United States, age, growth, adult, young, bluefish.

Barnthouse, L.W.; Boreman, J.; Christensen, S.W.; Goodyear, C.P.; Van Winkle, W.; Vaughan, D.S. 1984. Population biology in the courtroom: the Hudson River controversy. *BioScience* 34:14-19. Keywords: Hudson River, population biology, courtroom, controversy.

Barnthouse, L.W.; Klauda, R.J.; Klauda, R.L. 1988. Assessing ecological impacts of power plants: Lessons from the Hudson River case. *Am. Fish. Soc. Monogr*. 4. Keywords: Hudson River, New York, ecology, impacts, power plants.

Barnthouse, L.W.; Klauda, R.J.; Vaughan, D.S. 1988. What we didn't learn about the Hudson River, why, and what it means for environmental assessment. *Am. Fish. Soc. Monogr*. 4:1-8. Keywords: Hudson River, New York, environmental assessment.

Barnthouse, L.W.; Van Winkle, W. 1988. Analysis of impingement impacts on Hudson River fish populations. *Am. Fish. Soc. Monogr*. 4:182-190. Keywords: Hudson River, New York, impingement, power plant, fish population.

Barnthouse, L.W.; Van Winkle, W.; Vaughan, D.S. 1983. Impingement losses of white perch at Hudson River power plants: magnitude and biological significance. *Environ. Manage*. 7:355-364. Keywords: Hudson River, New York, impingement, mortality, power plants, biology, egg, larva, juvenile, white perch.

Bason, W.H. 1971. Ecology and early life history of striped bass, *Morone saxatilis*, in the Delaware estuary. Middletown, DE: Ichthyological Associates. *Ichthyol. Assoc. Bull*. 4:112. Keywords: Delaware, Delaware River, Delaware Bay, Delaware estuary, estuary, ecology, early life history, striped bass.

Battelle Marine Research Laboratory. 1983. 1980 and 1981 year class report for the Hudson River Estuary Monitoring Program. [Report.] New York, NY: Consolidated Edison Co.; 350 p. Keywords: Hudson River, New York, 1980, 1981, year class report, estuary, monitoring program, adult, striped bass, white perch, Atlantic tomcod.

Bath, D.W.; O'Connor, J.M. 1982. The biology of white perch, *Morone americana*, in the Hudson River estuary. *Fish. Bull. (U.S.)* 80:599-610. Keywords: Hudson River, New York, estuary, biology, adult, white perch.

Bath, D.W.; Beebe, C.A.; Ryder, R.H.; Hecht, J.H. 1976. A list of common and scientific names of fishes in the Hudson River. *In*: Boesch, D.F., ed. Proceedings of the 4th Symposium on Hudson River Ecology. New Paltz, NY: Hudson River Environmental Society; 6 p. Keywords: Hudson River, New York, fishes, names, common, scientific.

Bath, D.W.; O'Connor, J.M. 1981. Development and identification of larval Atlantic sturgeon (*Acipenser oxyrhynchus*) and shortnose sturgeon (*Acipenser brevirostrum*) from the Hudson River estuary, New York. *Copeia* 1981:711-717. Keywords: Hudson River, development, identification, estuary, larvae, Atlantic sturgeon, shortnose sturgeon.

Bayless, J.D. 1972. Artificial propagation and hybridization of striped bass, *Morone saxatilis* (Walbaum). Columbia, SC: South Carolina Marine Resources Dept.; 135 p. Keywords: propagation, hybridization, adult, striped bass.

Beaven, M.; Mihursky, J. 1980. Food and feeding habits of larval striped bass: an analysis of larval striped bass stomachs from 1976 Potomac estuary collections. *Chesapeake Biol. Lab. Ref. No. [UMCEES]* 79-45-CBL; 27 p. Keywords: Potomac River, estuary, feeding, habits, behavior, larvae, stomachs, analysis, 1976, striped bass.

Beebe, C.A.; Savidge, I.R. 1988. Historical perspective on fish species composition and distribution in the Hudson River estuary. *Am. Fish. Soc. Monogr*. 4:25-36. Keywords: Hudson River, distribution.

Bell, J.D.; Westoby, M. 1986. Variations in seagrass height and density over a wide spatial scale: effects on fish and decapods. *J. Exp. Mar. Biol. Ecol*. 104:275-295. Keywords: seagrass, fish community, habitat, decapods.

Bell, J.D.; Westoby, M.; Steefe, A.S. 1987. Fish settling in seagrass: do they discriminate between beds of different leaf density? *J. Exp. Mar. Biol. Ecol*. 111:133-144. Keywords: seagrass, fish habitat.

Belton, T.; Roundy, R. 1985. A study of toxic hazards for urban subsistence and recreational fishermen. [Final report.] New York, NY: Hudson River Foundation; 48 p. Keywords: Hudson River, toxic, PCBs, pesticides, fish tissue analysis, fishermen, adult, striped bass, white perch, bluefish.

Belton, T.; Ruppel, B.E.; Lockwood, K.; Boriek. M. 1983. PCBs in selected finfish caught within New Jersey waters, 1981-1982 (with limited chlordane data). Trenton, NJ: New Jersey Department of Environmental Protection; 36 p. Keywords: New Jersey, adult, PCB, bluefish, striped bass.

Bennett, G.W. 1974. Ecology and management of largemouth bass, *Micropterus salmoides*. Overharvest and management of largemouth bass in small impoundments. *Am. Fish. Soc. Spec. Pub*. No. 3. Keywords: ecology, management, adult, largemouth bass.

Benz, G.W.; Jacobs, R.P. 1986. Practical field methods of sexing largemouth bass. *Prog. Fish-Cult*. 48:221-225. Keywords: field methods, sexing, adult, largemouth bass.

Berg, D.L.; Levinton, J.S. 1985. The biology of the Hudson-Raritan estuary with special emphasis on fishes. *NOAA Tech. Memo. NOS OMA* 16; 170 p. Keywords: Hudson River, New York, Raritan River, New Jersey, estuary, biology, fishes.

Berggren, T.J.; Lieberman, J.T. 1978. Relative contribution of Hudson, Chesapeake and Roanoke striped bass, *Morone saxatilis*, stocks to the Atlantic coast fishery. *Fish. Bull. (U.S.)* 76:335-345. Keywords: Hudson River, Chesapeake Bay, Roanoke River, Atlantic Ocean, contribution, stocks, population, fishery, Atlantic coast, adult, striped bass.

Bero, A.S.; Gibbs, R.J. 1990. Mechanisms of pollutant transport in the Hudson estuary. *Sci. Total Environ*. 97/98:9-22. Keywords: Hudson River, pollutant transport, sediment, PCB, pesticides, trace metals.

Bigelow, H.B.; Schroeder, W.C. 1953. Alewife. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):101-106. Keywords: Gulf of Maine, distribution, biology, growth, adult, spawning, food, fishery, alewife.

Bigelow, H.B.; Schroeder, W.C. 1953. American shad. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):108-112. Keywords: Gulf of Maine, adult, distribution, food, spawning, reproduction, egg, larva, growth, fishery, American shad.

Bigelow, H.B.; Schroeder, W.C. 1953. Bay anchovy. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):118-119. Keywords: Gulf of Maine, adult, distribution, bay anchovy.

Bigelow, H.B.; Schroeder, W.C. 1953. Blueback herring. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):106-107. Keywords: Gulf of Maine, adult, distribution, spawning, blueback herring.

Bigelow, H.B.; Schroeder, W.C. 1953. Bluefish. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):383-389. Keywords: Gulf of Maine, adult, behavior, spawning, egg, larva, juvenile, distribution, fishery, bluefish.

Bigelow, H.B.; Schroeder, W.C. 1953. Short-nose sturgeon. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):84-85. Keywords: Gulf of Maine, Maine, distribution, spawning, adult, short-nose sturgeon.

Bigelow, H.B.; Schroeder, W.C. 1953. Striped bass. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):389-405. Keywords: Gulf of Maine, Maine, biology, adult, behavior, food, migration, spawning, egg, larva, growth, fishery, population, abundance, striped bass.

Bigelow, H.B.; Schroeder, W.C. 1953. Tomcod. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):196-199. Keywords: Gulf of Maine, adult, spawning, egg, larva, food, behavior, distribution, fishery, Atlantic tomcod.

Bigelow, H.B.; Schroeder, W.C. 1953. White perch. *In*: Fishes of the Gulf of Maine. *U.S. Fish Wildl. Serv. Fish Bull*. 74(53):405-407. Keywords: Gulf of Maine, adult, distribution, spawning, egg, larva, fishery, white perch.

Blackford, C.M. 1916. The shad: a national problem. *Trans. Am. Fish. Soc*. 46:14-May. Keywords: adult, American shad.

Blair, B.; Neider, W.C. 1993. Mapping the Hudson River National Estuarine Reserve: Creating tools for tidal wetlands research, management, and education. [Final report.] New York, NY: Hudson River Foundation; 6 p. Keywords: Hudson River, wetland, tidal, tide, research, management, education.

Boesch, D.F.; Turner, R.E. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. *Estuaries* 7:460-468. Keywords: marsh habitat, food, refuge.

Bohne, C.; Schmidt, R.E. 1989. Larval fish flux between a freshwater tidal marsh and the Hudson River estuary. *In*: Blair, E.A.; Waldman, J.R., eds. Polgar Fellowship reports of the Hudson River National Estuarine Research Reserve Program, Section VII. New York, NY: Hudson River Foundation; 22 p. Keywords: Hudson River, larvae, movement, marsh habitat, freshwater.

Bokuniewicz, H.J.; Ellsworth, J.M. 1986. Sediment budget for the Hudson River system. *Northeast Geol*. 8:156-163. Keywords: Hudson River, New York, sedimentation, sediment, geology.

Bokuniewicz, H.J.; Ullman, D. 1995. Turbidity distribution in the Hudson River estuary. Stony Brook, NY: Marine Science Research Center, *Spec. Sci. Rep*. 109 (Reference 95-02); 42 p. Keywords: Hudson River, turbidity.

Bonn, E.W.; Bailey, W.M.; Bayless, J.D.; Erickson, K.E.; Stevens, R.E., editors. 1976. Guidelines for striped bass culture. Bethesda, MD: American Fisheries Society (Southern Division); 103 p. Keywords: guidelines, culture, eggs, striped bass.

Booth, R.A. 1967. A description of the larval stages of the tomcod, *Microgadus tomcod*, with comments on its spawning ecology. [M.S. thesis.] Storrs, CT: University of Connecticut; 53 p. Keywords: larval stages, larvae, spawning, ecology, tomcod.

Bopp, R.F. 1979. The geochemistry of polychlorinated biphenyls in the Hudson River. [Ph.D. dissertation.] New York, NY: Columbia University. Keywords: Hudson River, New York, geochemistry, PCBs.

Bopp, R.F.; Simpson, H.J. 1984. Persistent chlorinated hydrocarbon contaminants in the New York Harbor complex. [Final report.] New York, NY: Hudson River Foundation. Keywords: Hudson River, New York Harbor, contaminants, loadings.

Bopp, R.F.; Simpson, H.J. 1988. Sources and trends of persistent contaminants in the New York Harbor complex. [Final report.] New York, NY: Hudson River Foundation; 54 p. Keywords: Hudson River, contaminants, sediments, radionuclides, PCBs, chlorinated hydrocarbon pesticides, trace metals, cadmium.

Bopp, R.F.; Simpson, H.J. 1989. Contamination of the Hudson River - the sediment record. *In*: National Research Council, ed. Contaminated marine sediments assessment and remediation. Washington, DC: National Academy Press; p. 401-416. Keywords: Hudson River, New York, contaminant, sediment, pollution.

Bopp, R.F.; Simpson, H.J.; Chillrud, S.N.; Robinson, D.W. 1993. Sediment-derived chronologies of persistent contaminants in Jamaica Bay, New York. *Estuaries* 16:608-616. Keywords: Jamaica Bay, New York, sediment, contaminants.

Bopp, R.F.; Simpson, H.J.; Deck, B.L. 1985. Release of polychlorinated biphenyls from contaminated Hudson River sediments. [Final report.] Albany, NY: New York State Department of Environmental Conservation. Keywords: Hudson River, New York, release, polychlorinated biphenyls, PCB, contamination, sediments.

Bopp, R.F.; Simpson, H.J.; Olsen, C.R.; Kostyk, N. 1981. Polychlorinated biphenyls in the sediments of the tidal Hudson River, New York. *Environ. Sci. Technol*. 15:210-216. Keywords: Hudson River, New York, polychlorinated biphenyls, PCBs, sediments, tide.

Bopp, R.F.; Simpson, H.J.; Olsen, C.R.; Trier, R.M.; Kostyk, N. 1982. Chlorinated hydrocarbons and radionuclide chronologies in sediments of the Hudson River and estuary. *NY Environ. Sci. Technol*. 16:666-676. Keywords: Hudson River, New York, estuary, chlorinated hydrocarbons, radionuclide, chronologies, sediments.

Boreman, J. 1979. Spatial distributions of entrainable life stages of six Hudson River fish populations. *In*: Boreman, J., *et al*. Entrainment impact estimates for six fish populations inhabiting the Hudson River estuary. Testimony submitted during the EPA, Region II, adjunctory hearing in the matter of NPDES permits for Bowline Point, Indian Point, and Roseton generating stations. Exhibit EPA-200; Chapter III. Keywords: Hudson River, entrainment, distribution.

Boreman, J. 1981. American shad stocks along the Atlantic Coast. *NOAA NMFS Woods Hole Lab. Ref. Doc*. 81-40. Keywords: Atlantic Coast, population, stocks, adult, American shad.

Boreman, J. 1981. Life histories of seven fish species that inhabit the Hudson River estuary. *NOAA NMFS Woods Hole Lab. Ref. Doc*. 81-34; 97 p. Keywords: Hudson River, Long River, spawning, egg, larvae, juvenile, adult, trophic relationships, ecology, striped bass, white perch, blueback herring, alewife, American shad, Atlantic tomcod, bay anchovy.

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