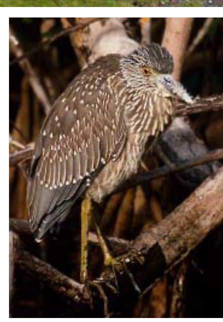
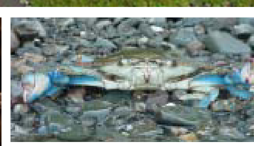
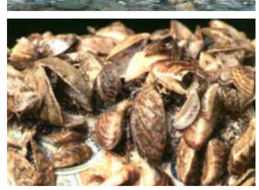
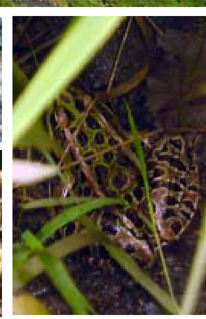
Ecological Profile of the Hudson River National Estuarine Research Reserve









Ecological Profile of the Hudson River National Estuarine Research Reserve

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PREFACE

The Hudson River National Estuarine Research Reserve, designated in 1982, is one of 26 estuarine reserves included within the National Oceanic and Atmospheric Administration's National Estuarine Research Reserve System (NERRS). As part of the NERRS program, each reserve is required to develop a site profile, which describes the estuarine and terrestrial ecosystems represented within the site; outlines ongoing research, monitoring, and education programs; and identifies site-specific research needs and priorities.

This site profile includes an introduction to the Reserve; an environmental overview of the Hudson River Estuary; a description of ecological community types that occur among the four individual Reserve site components; an overview of the Reserve's programs and partnerships; a summary of basic and applied research conducted within the past 20 years at the Reserve; and suggestions for future research and monitoring activities.

This document is intended to provide guidance for the future direction of the Reserve's research and monitoring programs and will be made available to a wide range of potential users, including scientists, natural resource managers, local planners, elected officials, and environmental educators.

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ACKNOWLEDGEMENTS

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We also thank Dr. Stuart Findlay and Dr. Erik Kiviat for reviewing previous drafts of the profile. We thank Linda Beckwith McCloskey and Kathy Schmidt for providing illustrations of the Reserve's flora and fauna, respectively. Chastity Miller produced the Reserve vegetation maps. Patricia Brown compiled the species list (**Appendix B**). Cover photos were provided by the New York State Department of Environmental Conservation and the Institute of Ecosystem Studies in Millbrook, NY. We thank Laurie Fila for cover design.

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LIST OF ACRONYMS

μS/cm	microsiemens per centimeter
2,4-D	2,4-dichlorophenoxyacetic acid
BOCES	Board of Cooperative Educational Services
BOD	biochemical oxygen demand
CDMO	Central Data Management Office
cm	centimeter
cm/yr	centimeters per year
CSO	combined sewer outfall
Cu	copper
DDT	dichloro diphenyl trichloroethane
DO	dissolved oxygen
DOC	dissolved organic carbon
ERD	Estuarine Research Division
ESA	Endangered Species Act
FCI	functional capacity index
g	gram
GIS	geographic information system
GRF	Graduate Research Fellowship
ha	hectare
Hg	mercury
HREP	Hudson River Estuary Program
HRF	Hudson River Foundation
HRHR	Hudson River Habitat Restoration
HRNERR	Hudson River National Estuarine Research Reserve
IES	Institute of Ecosystem Studies
II	Iona Island
ind./ha	individuals per hectare
IRIS	Institute for Resource Information Systems
ISSR	Inter-Sample Sequence Repeat
kg	kilogram
km	kilometer
m	meter
m^3/s	cubic meters per second
mg/L	milligrams per liter
MLW	mean low water
N	nitrogen
NEIWPCC	New England Interstate Water Pollution Control Commission, Inc.
NERRS	National Estuarine Research Reserve System
ng/g	nanograms per gram
NJ	New Jersey
NOAA	National Oceanic and Atmospheric Administration
NY	New York
NYC	New York City
NYS	New York State

NYSDEC	New York State Department of Environmental Conservation
NYSDOS	New York State Department of State
NYSG	New York Sea Grant
NYSOGS	New York State Office of General Services
OPRHP	Office of Parks, Recreation, and Historical Preservation
P	phosphorus
Pb	lead
PBDE	polybrominated diphenyl ethers
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo dioxins
PCDF	polychlorinated dibenzo furans
pg/g	picograms per gram
PIPC	Palisades Interstate Park Commission
PM	Piermont Marsh
ppt	parts per thousand
SAV	submerged aquatic vegetation
SC	Stony Creek
SF	Stockport Flats
SK	Saw Kill
SP	Sparkill Creek
SPI	sediment profile imagery
ST	Stockport Creek
SWMP	System-Wide Monitoring Program
TN	Tivoli North Bay
TNB L	Tivoli North Bay, lower intertidal
TNB M	Tivoli North Bay, middle intertidal
TNB U	Tivoli North Bay, upper intertidal
TS	Tivoli South Bay
TSS	total suspended solids
U.S.	United States
USACE	U.S. Army Corps of Engineers
USACE-NYD	U.S. Army Corps of Engineers, New York District
USEPA	U.S. Environmental Protection Agency
WRDA	The Water Resources and Development Act
YOY	young-of-year
Zn	zinc

INTRODUCTION

The Hudson River National Estuarine Research Reserve (the Reserve), designated in 1982, encompasses 1,958 ha of brackish and freshwater tidal wetlands, tidal swamps, submerged plant beds, mudflats, forests, and meadows distributed among four component sites: Piermont Marsh, located at river km 38-42 in Rockland County, NY; Iona Island, located at river km 72-74 in Rockland County, NY; Tivoli Bays, located at river km 98-100 in Dutchess County, NY; and Stockport Flats, located at river km 192-200 in Columbia County, NY (**Figure 1**).

The Reserve is administered by The New York State Department of Environmental Conservation (NYSDEC), in cooperation with the New York State Office of Parks, Recreation, and Historic Preservation (OPRHP), the New York State Department of State (NYSDOS), the New York State Office of General Services (NYSOGS), and the Palisades Interstate Park Commission (PIPC). The Reserve headquarters is located at the Bard College Field Station, in Annandale-on-Hudson, NY.

The Reserve is part of National Oceanic and Atmospheric Administration's (NOAA) National Estuarine Research Reserve System (NERRS), which includes 26 reserves located among 20 coastal states and Puerto Rico. The reserve system was established to promote informed management of the Nation's estuaries and coastal habitats by the Coastal Zone Management Act (CZMA) of 1972, as amended, 16 U.S.C. Section 1461, to augment the Federal Coastal Zone Management (CZM) Program. As stated in the NERRS regulations, 15 C.F.R. Part 921.1(a), the National Estuarine Research Reserve System mission is:

> *The establishment and management, through Federal-state cooperation, of a national system of Estuarine Research Reserves representative of the various regions and estuarine types in the United States. Estuarine Research Reserves are established to provide opportunities for long-term research, education, and interpretation.*

Federal regulations, 15 C.F.R. Part 921.1(b), provide five goals for the NERRS:

- Ensure a stable environment for research through long-term protection of National Estuarine Research Reserve resources;
- Address coastal management issues identified as significant through coordinated estuarine research within the System;
- Enhance public awareness and understanding of estuarine areas and provide suitable opportunities for public education and interpretation;
- Promote Federal, state, public and private use of one or more Reserves within the System when such entities conduct estuarine research; and
- Conduct and coordinate estuarine research within the System, gathering and making available information necessary for improved understanding and management of estuarine areas.

Reserve Mission

The mission of the Reserve is to improve the health and vitality of the Hudson River Estuary by protecting estuarine habitats through integrated education, training, stewardship, restoration, and monitoring and research programs. Since acceptance of the national designation in 1982, New York State has made a strong commitment to developing an estuarine research and education program; preserving tidal wetlands through acquisition, stewardship, and management of public use; and ensuring the long-term availability of Reserve sites as natural field laboratories for research, education, and environmental monitoring in the Hudson River Estuary. The Reserve sites provide for public access and recreational opportunities as long as these activities are compatible with resource protection.

The specific goals of the Reserve are to:

- Increase scientific understanding of Hudson River Estuary habitats;
- Increase estuarine literacy to promote active stewardship and environmentally sustainable behaviors and decisions;
- Increase informed decision-making to protect and enhance Hudson River Estuary habitats; and
- Enhance stewardship of the land and water ecosystems within the Reserve.

The Reserve's research objectives include:

- Mapping/inventory of all Hudson River aquatic and shoreline habitats to document their location and characteristics;
- Characterization of habitat functions for selected estuarine habitats in support of resource management decisions;
- Characterization of spatial and temporal change in estuarine habitats and tributaries to Reserve sites;
- Gather additional information about human impacts on Hudson River habitats and ways to reduce these impacts;
- Provide access to original and synthesized scientific information about the Reserve and Hudson River habitats to scientists, managers and educators; and
- Conduct research at Reserve sites and on Reserve priority topics elsewhere in the estuary.

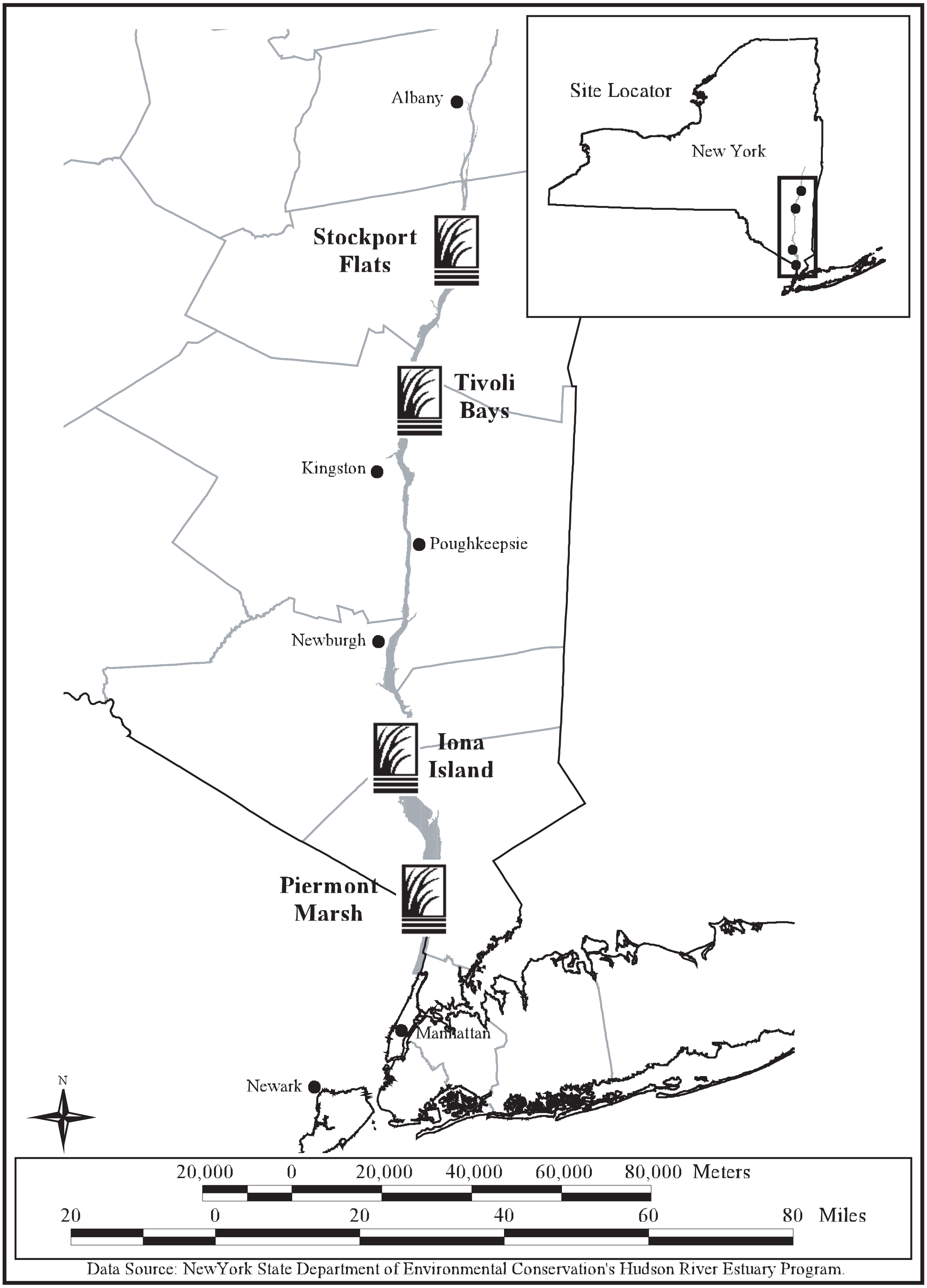


Figure 1: Hudson River National Estuarine Research Reserve Locator Map.

HUDSON RIVER ENVIRONMENTAL SETTING

The Hudson River originates at Lake Tear of the Clouds in the Adirondack Mountains and flows south 507 km to its confluence with Upper New York Bay (**Figure 2**). The Hudson River Valley lies almost entirely within the state of New York, except for its last 35 km, where it serves as the boundary between New York and New Jersey. Tributaries to the river drain small portions of Connecticut, Massachusetts, New Jersey, and Vermont. The 247 km tidal estuary portion extends north from the southern tip of Manhattan Island to the Troy Dam, north of Albany, NY (Limburg and Moran, 1986; Cooper et al., 1988).

The entire Hudson River drainage basin covers 33,835 km^2 and includes three major sub-basins: the Upper Hudson (11,987 km^2), the Mohawk (8,972 km^2), and the Lower Hudson/Hudson River Estuary (12,876 km^2). The stream elevation gradient for the Hudson River Estuary is slight, dropping only 1.5 m from Albany to Manhattan. The river bottom at Albany is at sea level (Cooper et al., 1988). Flowing in almost a straight southerly direction, the estuary is bounded on the west by the Catskill Mountains and on the east by the Taconic Mountains. A major topographic feature of the central portion of the estuary is the Hudson Highlands, whose cliffs rise directly from the river's edge.

Climate

Long, cold winters and short, warm summers characterize the climate of the Hudson River Valley. The mean annual temperature for this region is approximately 4 degrees Celsius (˚C). The normal annual temperature during the winter months is about -4 ˚C, and ranges from 21 ˚C to 24 ˚C during the summer months. Annual precipitation (in rainfall) for this region is approximately 100 centimeters (cm). The mean annual snowfall for the entire Hudson River Basin varies from about 250 cm in the northern Hudson Valley to about 50 cm near New York City (USACE, 1995).

Geology

The Hudson River Valley is a north-south trending linear lowland extending from New York City to the Adirondack Mountains. Although the Hudson River is considered an antecedent stream, many changes in the river's course appear to be controlled by fault zones or by contact with erosion-resistant rocks (USACE, 1995).

From just south of Albany to Kingston the Hudson River Valley is relatively narrow and steep-walled. The Catskill Mountains lie to the west and the lower Taconic Mountains lie to the east. This section of the river valley is predominantly underlain by Ordovician shale and sandstone with some chert and siltstone. Some Cambrian shale, conglomerate, and limestone are also present.

South of Kingston, the valley widens and the river deepens. The most common rocks underlying the valley from Kingston to just below Poughkeepsie are Ordovician graywacke, shale, siltstone, chert, and argillite of the Austin Glen, Indian River, Mt. Merino, and Normanskill Formations.

At Cornwall-on-Hudson the river valley narrows into a deep steep-sided gorge as the river enters the the Hudson Highlands. This region is underlain predominantly by

Precambrian and Cambrian metamorphic rocks.

After passing through the Hudson Highlands the river widens again. From Stony Point south, the river follows the contact between the Triassic rocks of the Newark Basin and the Lower Paleozoic/Precambrian rocks of the Manhattan Prong until it reaches New York Bay.

Tidal and Riverine Hydrodynamics

The Hudson River is a tidal estuary from its confluence with Upper New York Bay to the Federal Dam at Troy. Hudson River tides are semi-diurnal, with two highs and two lows occurring within a 25-hour period. The mean tidal range is 1.37 m at the Battery, 0.80 m at West Point, and 1.56 m at Albany (Cooper et al., 1988). The mean tidal amplitude at Albany increased from 1890 to 1950 from approximately 0.8 m to it's present-day amplitude as a result of navigation channel dredging which increased the river's cross-sectional area (Cooper et al., 1988).

Freshwater flow in the Hudson estuary follows a typical seasonal pattern, with highest flow during the spring and lowest flow during late summer and early fall. The upper Hudson and Mohawk watersheds contribute nearly 80% of the annual freshwater flow through the estuary, with the drainage basin located below Troy contributing the remainder (Cooper et al., 1988). The estimated average annual freshwater flow in the lower Hudson is 540-570 m^3/s. Flushing time is estimated to be 126 days, faster than many other large east-coast estuaries (Limburg and Moran, 1986).

Salinity Regime

The Hudson River Estuary can be divided into four salinity zones: polyhaline (18-30 ppt), mesohaline (5-18 ppt), oligohaline (0.5-5 ppt), and freshwater tidal (<0.5 ppt). Salinity zones in the Hudson are determined by a combination of hydrographic factors, primarily the tidal surge of saline water upriver from the ocean and the magnitude of freshwater flow into the upper estuary. Under an average runoff regime the salt front (0.5 ppt) reaches Newburgh by late summer/early fall. During conditions of high freshwater runoff, usually during spring, the salt front may be pushed downriver as far as the Bronx. Under low flow conditions, vertical mixing of salt water and freshwater is high, with only a 10% difference between surface and bottom water salinity. This differential may be as high as 20% under high flow conditions (Limburg and Moran, 1986).

Human Effects and Alterations

The Hudson River Estuary has a long history of environmental perturbation, including shoreline modifications, dredging impacts/channelization, and pollution. Many habitats are impacted or threatened by toxic chemicals, increased sedimentation and turbidity, and non-point source pollution from agricultural and residential watersheds. Treated sewage effluent is discharged into many Hudson River tributaries by towns and villages. Many older municipalities have aging sewage treatment systems with clay pipes, along with inadequate pump stations and treatment plants. This decaying infrastructure permits raw sewage to enter the estuary under conditions of heavy rainfall (Cooper at al., 1988). In the lower estuary, combined sewer outfalls (CSOs) discharge during storm events, contributing a pulse of nutrients and other contaminants

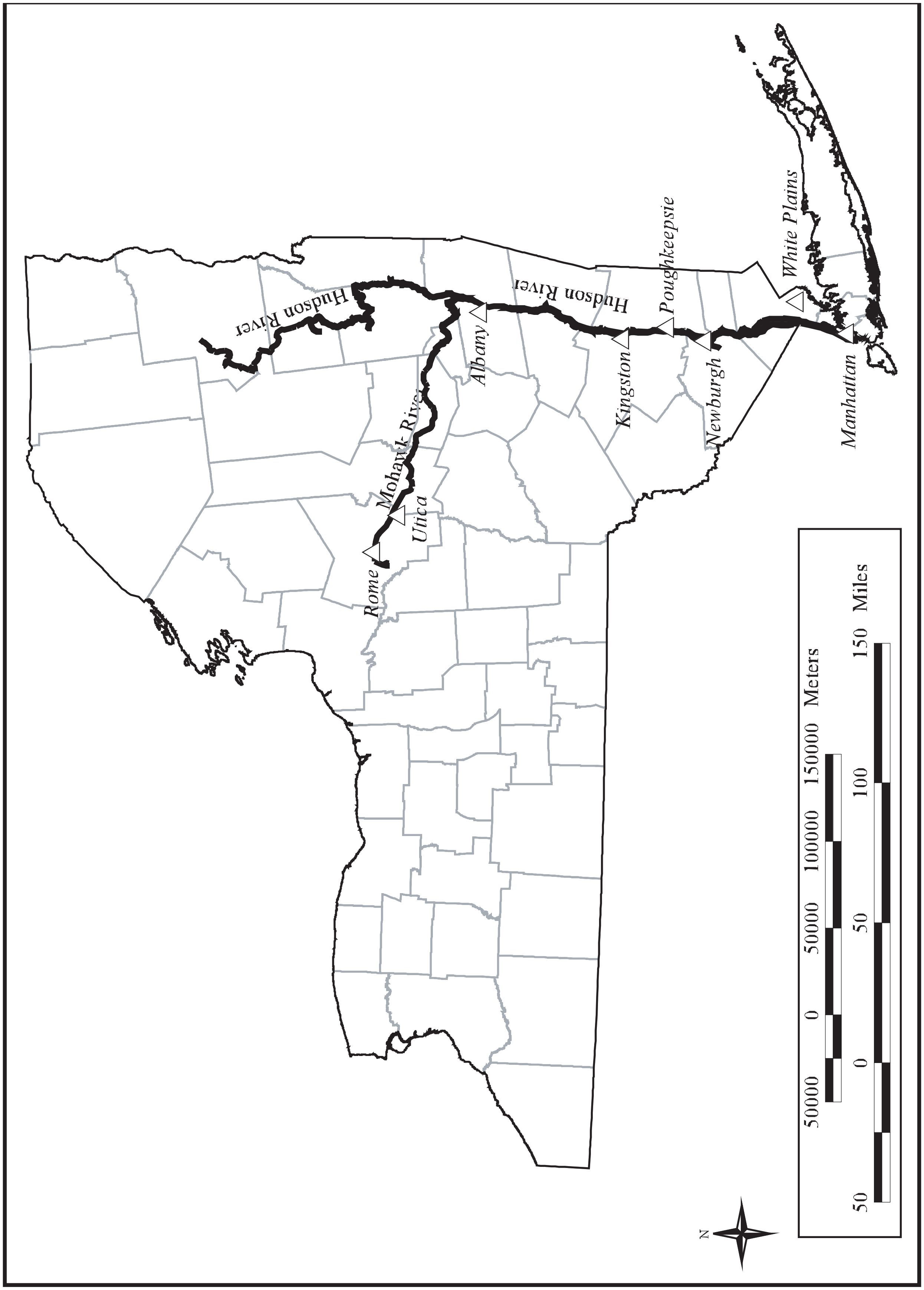


Figure 2: Map depicting the location of the Hudson River within New York State.

(e.g., grease, oil, floatable debris). However, recent funding initiatives, authorized by the New York State Clean Water/Clean Air Bond Act of 1996, have made significant progress towards improvement of older wastewater infrastructure in many municipalities along the Estuary.

Many Hudson River tributaries have historically been dammed for industrial use, eliminating access to spawning habitat for many anadromous fish, notably alewife (*Alosa pseudoharengus*). Construction of rail beds along both shores has had major impacts on the tributary mouths and has isolated numerous shallow coves and bays from the mainstem of the river, resulting in greatly accelerated accumulation of sediments (Squires, 1992).

Shoreline modifications to the Estuary began in the late 18th century, with the construction of a dam at the head of Papscanee Island in 1790, intended to divert river flow away from the island and into the main channel. Between 1790 and 1823, a series of dams were constructed between New Baltimore and Troy, NY. By connecting existing islands in the upper estuary to one another, it was believed that the currents would intensify and deepen the main channel. The completion of the Erie Canal in 1825 further increased the need for a navigable Hudson River. A plan for a shipping canal to run parallel with the river was rejected at this time; however, a series of longitudinal dikes was constructed from 1836 to 1845 (USACE, 1995).

By the 1850s, it was evident that the channel was deepening; however, shoals and bars were forming downstream of the project areas, requiring dredging. Dikes continued to be built until 1890 and the U.S. Army Corps of Engineers (USACE) began to place dredged material behind the dikes, accelerating deposition, which occurred when the natural flow of sediment into the river was impeded. By 1925, miles of stone and timber dikes lined the shores of the upper Hudson River Estuary. Expansive tidal flats were developing around islands, and many of the channels between islands had become closed off by dredged material placement and natural siltation. Entrances to many backwater areas were blocked off by dikes or shoals. In 1925, Congress authorized deepening of the Hudson River Navigation Channel to 8.2 m. In 1954, the channel was further deepened to 9.8 m. and remains so today (USACE, 1995).

Toxic Substances

Polychlorinated Biphenyls (PCBs)

PCBs are a class of organic chemical compounds used in industrial manufacturing and characterized by a high resistance to biological degradation processes (Nadeau and Davis, 1976). PCBs were manufactured in the United States from 1929 to 1977 by Monsanto and sold under the trade name Aroclor. During the interval 1951-1977, two electrical capacitor manufacturing facilities discharged approximately 270,000 kg of PCBs, primarily Aroclor 1016 and Aroclor 1242, into the Upper Hudson River (Sloan et al., 1983). The vast majority of PCBs accumulated in the sediments directly downstream of the point sources. In October 1973, a dam at Fort Edward was removed, allowing approximately 1,000,000 m^3 of PCB laden sediment to be transported downstream. This resulted in a significant increase in PCB loadings throughout the system, including the estuary from Troy to New York Harbor.

PCBs were first identified as an environmental hazard in 1966, by Soren Jensen, a Swedish chemist who incidentally encountered PCBs while conducting bioassays on pesticide-contaminated fish. Although his results were published at the time, it was not until a decade later that PCBs were widely recognized as an environmental and human health hazard in the Hudson River (Limburg, 1986).

In 1975, a public warning was issued by the NYSDEC against consumption of Hudson River fish due to PCB contamination. In 1976, a settlement was negotiated between General Electric and NYSDEC; PCB discharge was terminated the following year and General Electric was required to fund $4,200,000 for PCB related research and mitigation costs (Brown et al., 1985; Limburg, 1986).

In 1983, the U.S. Environmental Protection Agency (USEPA) listed the Hudson River on its Superfund National Priority List. In 1984, the USEPA decided not to take action to remove PCBs from the Hudson. In 1989, the USEPA reevaluated its 1984 decision and initiated a series of studies on Hudson River PCBs to support future actions. In 2000, the USEPA released a $500,000,000 plan to dredge nearly 2,000,000 m^3 of PCB-contaminated sediments in the Hudson River above the Troy Dam. In 2002, the USEPA signed a Record of Decision to implement the dredging program (USEPA, 2002).

Striped bass (*Morone saxatilis*), an extremely popular gamefish along the east coast and elsewhere, was commercially harvested from the Hudson River until 1976 when the fishery was closed due to PCB contamination; the commercial fishery remains closed to this day. Despite PCB contamination, there is no evidence of a population level impact on the fishery (Wirgin and Waldman, 1998). The striped bass population in the Hudson is estimated to have grown at a rate of 8% per year since closure of the commercial fishery and an active and regionally profitable recreational fishery has developed (Waldman, 2005).

Other Toxic Substances
PCBs are not the only contaminant of concern in the Hudson River Estuary. High concentrations of dichloro-diphenyl-trichloroethane (DDT) have been identified in some Hudson River tributaries. The sources of this harmful pesticide are difficult to pinpoint, but may be related to old agricultural practices. Airborne mercury, a byproduct of coal combustion, is deposited along the estuary and can accumulate to harmful levels in fish and other aquatic biota.

Cadmium is another contaminant of concern in the Hudson River Estuary. During 1952-1979, a nickel-cadmium battery manufacturing facility located in Cold Spring, NY, discharged over 179,000 kg of cadmium-enriched waste into Foundry Cove, a freshwater intertidal wetland. This site was considered the most heavily cadmium-polluted location in the world, with sediment cadmium concentrations of 500 to 225,000 ppm (Knutson et al., 1987). Foundry Cove was designated a Super Fund site by the USEPA in 1983. A $91,000,000 sediment remediation and habitat restoration project was conducted at the site in 1994. Following completion of the remediation/restoration project, sediment cadmium concentrations ranged from 10 to 100 ppm (Junkins and Levinton, 2003).

Emerging or newly recognized contaminants such as poly-brominated-diphenyl-ethers (PBDEs), a class of chemicals used in developing fire-retardant industrial materials, are receiving attention in the Hudson River Estuary and its tributaries, as are the effects of pharmaceutical chemicals (including anti-depressants, birth-control drugs, and caffeine) (Strandberg et al., 2001; Kolpin et al., 2002; Buerge et al., 2003).

Non-Indigenous and Invasive Species

Water Chestnut

Water chestnut is an annual aquatic plant, native to Eurasia and Africa, which grows in dense floating mats, shading out native submerged aquatics (Kiviat and Hummel, 2004). The growth form is characterized by a distinctive rosette of floating leaf clusters with air bladders. A slender cord-like stem attaches the plant to a large barbed seed buried in the substrate. The seeds are considered edible, but the plant is not related to the common Chinese water chestnut (*Eleocharis dulcis*) used in Asian-American cuisine.

Water Chestnut
(Trapa natans)

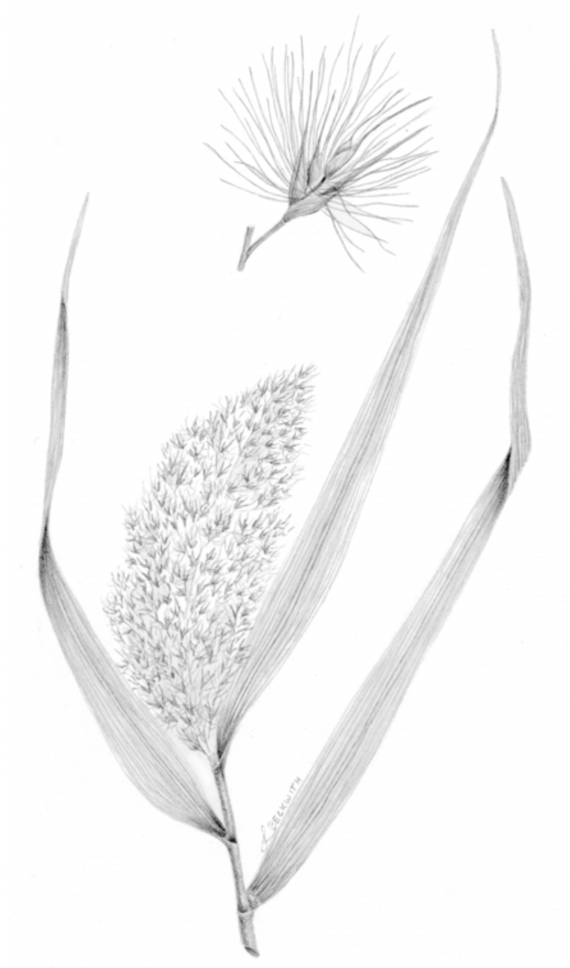
Water chestnut was intentionally planted in Collins Lake (formerly Sanders Lake), Scotia, NY in 1884 (Kiviat and Hummel, 2004). Subsequent flooding of the New York Barge Canal transported water chestnut into the Mohawk River, where it was well established by 1920. Water chestnut was established in the Hudson River at Cohoes, NY by the late 1930s. By the 1950s, it was widespread in the mid-upper Hudson River Estuary. Transportation of the plant or its seed has been illegal in New York State since 1949.

Proliferation of water chestnut can alter the physical, chemical, and biological characteristics of shallow subtidal habitats. Plant biomass and the rapid accumulation of organic matter in areas of dense water chestnut growth results in marked increases in biochemical oxygen demand (BOD) and localized anoxia/hypoxia. Dissolved oxygen (DO) concentrations in the largest water chestnut beds typically remain below 2.5 mg/L up to 30% of the time (Caraco and Cole, 2002). In contrast, DO concentrations in native Hudson River submerged aquatic vegetation (SAV) beds rarely drop below 5.0 mg/L. Larval and juvenile fish communities associated with native submerged plant beds may be negatively impacted by water chestnut, due to changes in the physical structure of their submersed habitat and changes in the availability and composition of invertebrate prey (Schmidt and Kiviat, 1988). Additionally, the aesthetic and recreational qualities of the estuary may be significantly reduced, as the dense floating water chestnut mats are a nuisance and potential hazard to boaters and anglers.

For many years, proliferation of water chestnut in the Hudson River (and elsewhere) was controlled by application of the herbicide 2,4-dichlorophenoxyacetic acid (2,4-D). This practice ceased in 1976 after Federal regulations limited the use of 2,4-D in water bodies. Since then, water chestnut has spread throughout shallow, low-energy areas along the Hudson River, from the Troy Dam south to Constitution Island (Nieder et al., 2004). Scattered patches can be found as far south as Iona Island; however, salinity limits water chestnut growth (Schmidt and Kiviat, 1988). Hand pulling and mechanical harvesting are used to remove water chestnut in some local areas. The tough, barbed seeds may remain viable for years buried in soft sediments or accumulate in piles along the high-tide line. Potential vectors of water chestnut seed dispersal in the Hudson River include Canada geese (*Branta canadensis*), mute swans (*Cygnus olor*), boats and trailers, nets, tides, and construction/dredging equipment.

Common Reed
Intertidal wetlands in the Hudson River are increasingly undergoing changes due to the proliferation of common reed (*Phragmites australis*). This species has the potential to spread rapidly within brackish and intertidal freshwater wetlands, especially in the mid- to upper-intertidal zone, where it out competes native species such as narrow-leaved cattail (*Typha angustifolia*), spotted jewelweed (*Impatiens capensis*), and Olney-threesquare (*Scirpus americanus*).

Common Reed
(Phragmites australis)



During the 1900s, common reed expanded its range in many parts of North America, invading fresh and brackish wetlands (Saltonstall, 2002). This successful invasion may have been in part driven by human activities such as habitat alteration, sedimentation, and eutrophication of marsh and wetland areas. The recent spread of common reed is also believed to be in part due to the proliferation of a more aggressive European genotype in North America (Saltonstall, 2002). A new native subspecies (*Phragmites australis* subsp. *americanus*) is now recognized as genetically distinct from both the European genotypes and the Gulf Coast North American lineages (Saltonstall et al., 2004).

It is believed that invasive common reed first appeared at the Piermont Marsh component of the Hudson River Reserve as early as 1791–1858. Expansion of common reed occurred exponentially since that time, with an average expansion rate of five ha per year. There was a long interval of stability from 1964-1980, with a rapid increase by 1991. Common reed replaced narrow-leaved cattail, Olney-threesquare, and salt-meadow cordgrass (*Spartina patens*) at Piermont Marsh and now dominates the site (Winogrond and Kiviat, 1997).

The dominant mechanism for expansion at Piermont Marsh was linear clonal growth along creekbanks. Creekbanks may be an optimum area for initial invasion since they are subject to a variety of natural disturbances including ice shear, wave action, and muskrat burrowing (Winogrond and Kiviat, 1997) and are most likely to be colonized first by water-borne propagules (Lathrop et al., 2003).

A similar pattern of expansion has occurred at the Iona Island Reserve component, originally an oligohaline cattail marsh, which is now nearly dominated by common reed. Initial colonization by common reed at Iona Island Marsh is believed to have occurred as recently as the mid-1960s (Winogrond and Kiviat, 1997). Common reed stands at the Tivoli Bays and Stockport Flats Reserve components are in a much earlier stage of invasion and exhibit a slower expansion rate, approximately 0.1 ha per year.

A number of detrimental effects have been attributed to common reed. In the upper Chesapeake Bay and in southern New Jersey (Delaware Bay), it has been shown that common reed has altered intertidal wetland topography and hydrology by rapidly accreting biomass and trapping soils, elevating the wetland and reducing flooding depth and duration (Windham and Lathrop, 1999; Rooth and Stevenson, 2000). Wetland microtopographic features, such as shallow pools and intertidal rivulets, are obscured (Weinstein and Balleto, 1999) and dead stems and leaves (litter) form a dense organic mat on the marsh surface (Angradi et al., 2001).

In addition to reducing the biodiversity of the native plant community, use of the marsh by resident finfish may be diminished as a result of invasion by common reed (Able and Hagan, 2000, 2003; Raichel et al., 2003). Larval and juvenile fish abundance is significantly lower in common reed stands and dense stands may restrict the movement of fish and other natant macrofauna across the marsh surface, fragmenting marsh communities (Weinstein and Balleto, 1999).

Common reed expansion may be excluding several wildlife species from the structure of the native community, which they depend on for refuge and nesting (e.g., rails and other small wading birds) (Benoit and Askins, 1999). Muskrats (*Ondatra zibethicus*) and several insect species are among the few animals that can eat the tough common reed leaf. Muskrats also use live and dead common reed stems to build lodges (Kiviat, 2005).

The influence of common reed colonization on the ecological function of intertidal marshes appears to be determined by maturity of the reed stand and distribution within the marsh landscape (areal coverage, patch configuration, stand orientation) (Lathrop et al., 2003). The deleterious effects of common reed invasion appear to be much greater when common reed occupies dynamic locations (e.g., creekbanks) and/or when a common reed monoculture occupies the majority of the marsh plain and patches coalesce in later stages of invasion (Lathrop et al., 2003).

Some recent studies have attributed ecosystem benefits to common reed stands, including a superior capacity for nutrient retention relative to native intertidal wetland vegetation, habitat for terrestrial insects, and utilization by a wider range of bird species than previously thought (Meyerson et al., 2000; Kiviat and MacDonald, 2004). Some wading birds use common reed stems and leaves as nest building material. Recent surveys conducted in Tivoli North Bay have documented less singing and breeding activity in common reed stands relative to narrow-leaved cattail; however, several species roosted in the reed beds at night in significant numbers [e.g., tree swallow (*Iridoprocne bicolor*), bank swallow (*Riparia riparia*), barn swallow (*Hirundo rustica*), Eastern kingbird (*Tyrannus tyrannus*), red-winged blackbird (*Agelaius phoeniceus*), common grackle (*Quiscalus quiscula*), rusty blackbird (*Euphagus carolina*), bobolink (*Dolichonyx oryzivorus*), brown-headed cowbird (*Molothrus aler*), and European starling (*Sturnus vulgaris*)] (Kiviat, 2005).

Large populations of phytophagous mites, aphids, and scale insects occupy reed stands and attract insect predators, such as ladybugs (Coccinellidae). These are in turn preyed upon by spiders and birds, such as marsh wrens (*Cistothorus palustris*), black-capped chickadees (*Parus atricapillus*), and American goldfinches (*Carduelis tristis*). White-tailed deer (*Odocoileus virginianus*) and Eastern cottontails (*Sylvilagus floridanus*) will bed in common reed stands during winter. Small mammals occupying reed stands are preyed upon by marsh hawks and foxes.

Some studies of fish communities in wetlands undergoing invasion by common reed do not support the theory that nekton use is impaired, at least in terms of use by adult fish (Fell et al., 1998; Meyerson et al., 2000). Feeding habits of resident fish in Connecticut tidal marshes undergoing invasion by common reed were similar to those in marshes dominated by native salt marsh vegetation (Fell et al., 2003), although it was not clear if the marshes in question were in an early or advanced state of invasion.

Given similar flooding dynamics, fish use among common reed and native salt marsh vegetation [e.g., smooth cordgrass (*Spartina alterniflora*)] is similar (Osgood et al., 2003). At Iona Island Marsh, resident fish abundance did not differ among common reed vs. narrow-leaved cattail stands across a gradient of elevation and flooding duration; however, the abundance of juvenile fish was significantly greater in narrow-leaved cattail stands, indicating that nursery function of the intertidal marsh surface may be reduced following common reed invasion (Osgood et al., in press). A comparison of larval mummichog (*Fundulus heteroclitus*) distribution at Iona Island documented similar abundances of early life stage mummichogs in cattail and small, more recently established common reed stands; significantly fewer mummichogs were collected within older, more expansive reed sands, supporting the contention that larger, older stands experience hydrogeomorphic changes which result in reduced spawning success (increased elevation, reduced tidal flooding). Larval fish abundance was positively correlated to greater depth of tidal flooding. An unusually high density of larval and juvenile mummichogs was observed at low tide in shallow subtidal pools containing SAV adjacent to common reed stands; therefore, it was hypothesized that reduced habitat suitability in common reed stands may displace early life stage mummichogs to the shallow subtidal zone (Harm et al., 2003). Iona Island Marsh is at a relatively early state of common reed invasion in comparison to Piermont Marsh.

Purple Loosestrife

Purple loosestrife (*Lythrum salicaria*) occurs in Hudson River tidal wetlands from Troy to

Piermont Marsh. This species first appeared in the Hudson Valley around 1800, perhaps arriving in ship ballast or deliberately introduced as an ornamental, and was widespread in the region by 1900 (Kiviat 1996). Purple loosestrife is very common in tidal and non-tidal freshwater wetlands and meadows throughout the U.S., especially in the northeast and in southern Canada.

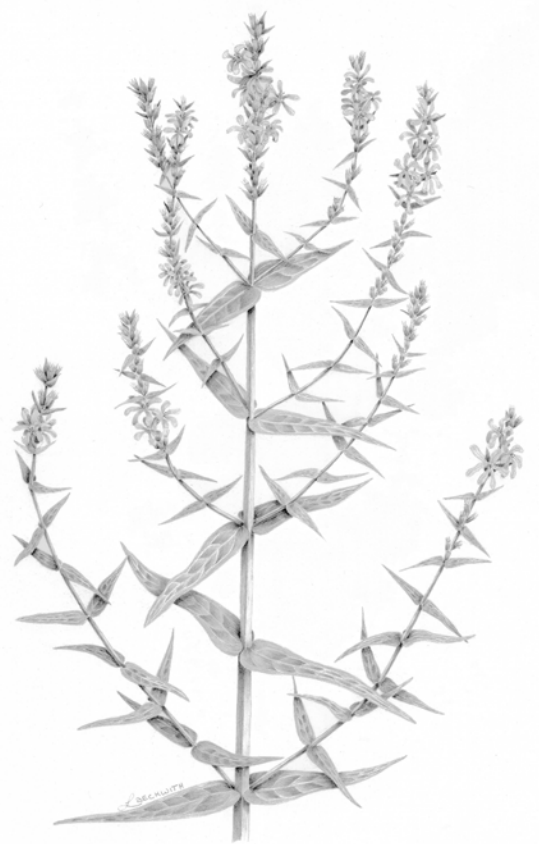
Most breeding marsh birds will not nest in purple loosestrife, with the exception of certain songbirds, such as red-winged blackbird, common grackle, swamp sparrow (*Melospiza georgiana*), song sparrow (*Melospiza melodia*), marsh wren, and American goldfinch (Kiviat, 1996). The cecropia moth (*Hyalophora cecropia*) and polyphemus moth (*Antheraea polyphemus*) are known to eat purple loosestrife, and pollinating insects are attracted to purple loosestrife flowers (Barbour and Kiviat, 1997). In an attempt to find a biological control agent, Cornell University researchers are experimenting with two species of European leaf-eating beetles (*Galerucella calmariensis* and *G. pusilla*), a root-mining weevil (*Hlyobius transversovittatus*), and a flower-eating weevil (*Nanophyes marmoratus*). These insects were released at several locations in the lower Hudson River Valley during 1994-1995 (Blossey and Nuzzo, 2004). The insects have sucessfully reduced the abundance of purple loosestrife in many locations; however, in some of these locations other invasives such as common reed or reed canary-grass (*Phalaris arundinacea*) have expanded as loosestrife is controlled (Blossey et al., 2001).

Zebra Mussel

Zebra mussels (*Dreissena polymorpha)*, originally described from the Caspian Sea and Ural River in Eurasia, were first discovered in North America in 1988 in the Canadian waters of Lake St. Clair. By 1990,

Purple Loosestrife

(Lythrum salicaria)



they had spread throughout the Laurentian Great Lakes (Pace et al., 1998). The likely vector for introduction of zebra mussels to the Great Lakes was ballast water discharge. Rapid expansion of this species in the Mississippi and other drainages is attributed to barge traffic and recreational boat trailering.

Zebra mussels were first identified in the Hudson River in 1991, with current population estimates ranging from 50-550 billion individuals. The population is cyclic, with strong year classes every 4-5 years. Zebra mussels initially colonized rocky bottom habitats, but are now spreading to soft bottom areas as mud-sand substrate is being converted to shell-gravel.

Within 17 months of detection, zebra mussels accounted for over 50% of the heterotrophic biomass in the Hudson River Estuary (Strayer et al., 1999). Water column phosphate concentrations increased and average DO levels declined. An increase in SAV growth in the littoral zone may have moderated the reduction in DO to some degree (Caraco et al., 2000).

Significant declines in phytoplankton (80-90%), zooplankton (70%), and deepwater zoobenthos occurred rapidly following the Hudson River zebra mussel invasion. Microzooplankton (tintinnid ciliates, rotifers, and copepod nauplii) declined markedly in 1992 and continued to decline thereafter, probably due to direct ingestion by zebra mussels. Adult copepods and most cladoceran species have not declined measurably (Pace et al., 1998).

It was hypothesized that these system changes would lead to a decrease in the abundance of open water fishes [e.g., American shad (*Alosa sapidissima*), white perch (*Morone americana*), striped bass] and an increase in littoral zone fishes [e.g., black bass (*Micropterus* spp.), sunfish]. Feeding studies of Hudson River centrarchids indicate that at least two species, pumpkinseed (*Lepomis gibbosus*) and redbreast sunfish (*L. auritus*), consume zebra mussels (Schmidt et al., 1995). Analysis of long-term data on young-of-year (YOY) fish collected by NYSDEC is consistent with this hypothesized change. Populations of open water fish species declined 28% and shifted their distributions downriver in response to the zebra mussel invasion. Populations of littoral zone species increased by 97%. Alosids and centrarchids seem to exhibit the strongest response to the zebra mussel invasion. Growth rates of juvenile American shad have declined by as much as 20% since 1992, as zebra mussels

Zebra mussel
(Dreissena polymorpha)

have removed critical food resources (phytoplankton) from the water column (Strayer et al., 2004). Although water column nutrients increased as a result of the zebra mussel invasion, phytoplankton growth did not increase and light penetration only increased modestly in the shallows; overall water column transparency in the Hudson River is controlled by inorganic particulates (silt) in the water column rather than phytoplankton blooms. (Strayer et al., 2004).

Deep-water benthic macroinvertebrates, which depend on recently sedimented phytoplankton as a primary food source, declined 33% during 1991-1995; however, in shallow littoral areas, benthic macroinvertebrate density increased by 25%, presumably due to an indirect positive effect of increased water clarity and increased macrophyte/algal production resulting from zebra mussel filter-feeding (Strayer et al., 1998).

Native suspension-feeding bivalves (Unionidae: *Elliptio complanata*, *Anodonta implicata*, and *Leptodea ocracea*) have also declined in the Hudson due to the decrease in phytoplankton. Since 1992, native unionid densities have declined by 56%, and recruitment of YOY unionids has declined by 90% (Strayer and Smith, 1996; Strayer et al., 1998).

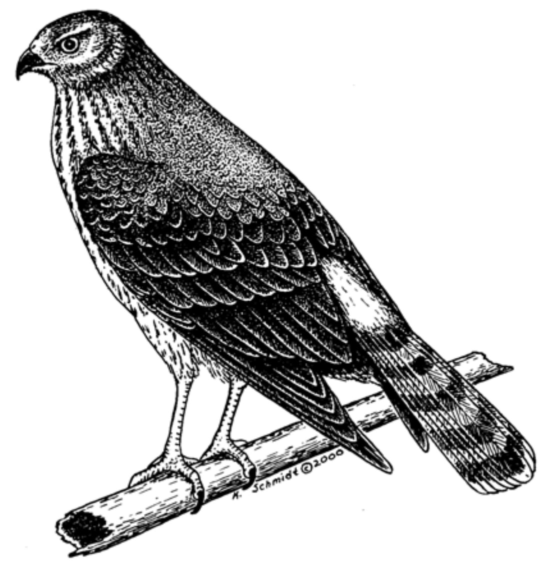
COMPONENT SITE DESCRIPTIONS

Piermont Marsh

Location: Rockland County; River km 38 – 42
Area: 412 ha
Salinity and Tidal Range: 0-12 ppt; 1.0 m.

Description: Piermont Marsh is a brackish tidal wetland complex, bordered on the north by Piermont Pier and on the west by the 50 m cliffs and talus slopes of the Palisades Ridge in southeastern Rockland County. Sparkill Creek drains 29 km^2 of a predominantly urban watershed and discharges into the north end of the marsh. A few well-defined but relatively shallow tidal creeks traverse the marsh. Extensive shallows border the east side of the marsh. Most of the Reserve site is within the boundaries of Tallman Mountain State Park.

Northern Harrier
(Circus cyaneus)



Piermont Marsh sediments are predominantly peat and organic silt, with an estimated deposition rate of approximately 0.26 cm/yr (Wong and Peteet, 1999). Peat deposits are at least 12 m deep in the western part of the marsh, which has been developing for over 4,000 years. Landward soils are primarily derived from glacial till.

Piermont Marsh habitats include brackish tidal marsh, shallows, and intertidal mudflats. The emergent marsh is dominated by common reed (>80 %); however, portions of the marsh interior are vegetated by mixed stands of Olney-threesquare, salt-meadow cordgrass, salt-grass (*Distichlis spicata*), narrow-leaved cattail, and rose-mallow (*Hibiscus moscheutos*).

Smooth cordgrass occurs along portions of the marsh edge. Offshore shallows are largely unvegetated mud/sand, although water celery, curly pondweed (*Potamogeton crispus*), sago pondweed (*Potamogeton pectinatus*), and horned pondweed (*Zannichellia palustris*) occur in sparse beds.

The upland forest at the base of the Palisades Ridge has abundant and large American beech (*Fagus grandifolia*), tulip tree (*Liriodendron tulipifera*), Northern red oak (*Quercus rubra*), cherry birch (*Betula lenta*), and flowering dogwood (*Cornus florida*).

Common fish and macrocrustaceans which occur in Piermont Marsh include dagger-blade grass shrimp (*Palaemonetes pugio*), fiddler crab (*Uca minax*), blue crab (*Callinectes sapidus*), mummichog, and striped bass. Muskrats build lodges in the marsh interior. Snapping turtles (*Chelydra serpentina*) and diamondback terrapins (*Malaclemys terrapin terrapin*) reside within the marsh and can be observed basking along the Piermont Pier. Wading and shore birds include green-backed heron (*Butorides striatus*), American bittern (*Botaurus lentiginosus*) and semipalmated sandpiper (*Calidris pusilla*). Piermont Marsh has been designated as part of the Atlantic Flyway for seasonally migrating birds and is used by many threatened and endangered species such as least bittern (*Ixobrychus exilis*), osprey (*Pandion haliaetus*), Northern harrier (*Circus cyaneus*), bald eagle (*Haliaeetus leucocephalus*), and peregrine falcon (*Falco peregrinus*).

Native American sites in Rockland County and the surrounding area date back 5,000-6,000 years. The Tappan tribe had fishing villages at each end of the marsh, on Tallman Mountain and at Sneden's Landing. Dutch settlers moved into the New York area in the early 1600s and by 1640, settlements such as Tappan were present. Sparkill Creek was the first sea-level break in the Palisades north of New York City and served as an important access route inland as the first mile of the waterway was navigable by the flat-bottomed sloops of the 17th and 18th centuries.

By the early 19th century, development of larger sloops with deeper drafts made the use of Sparkill Creek impractical. To solve this problem, the 1.6 km long pier was constructed in 1839 at the terminus of the Erie railroad. The pier still stands today and is used by local residents for access to the Hudson River. Most of Piermont Marsh is managed by the PIPC as a state park, but NYSDEC owns a small portion of the site. Recreational activities permitted at Piermont Marsh include boating, fishing, crabbing, hiking, and bird watching.

The urban setting of this site and the continued dominance of the marsh plant community by common reed are two factors driving research and monitoring efforts. Future research needs include:

- Conduct a marsh breeding bird survey;
- Conduct a rare and threatened plant survey;
- Continue monitoring marsh plant communities at 5-10 year intervals;
- Determine if any native common reed clones exist;
- Determine the feasibility of controlling common reed, especially where high marsh habitat is being lost or threatened by reed expansion;
- Continue to support research addressing the ecological effects of common reed expansion;
- Identify sources of chloride in the watershed and document changes/trends in chloride loadings;
- Establish a water quality datalogger station on Piermont Pier in collaboration with Columbia University;
- Expand paleoecology studies to the northern and southern portions of the marsh;
- Monitor the recently documented spotfin killifish (*Fundulus luciae*) population; and
- Update the 1994 land cover/land use digital database.

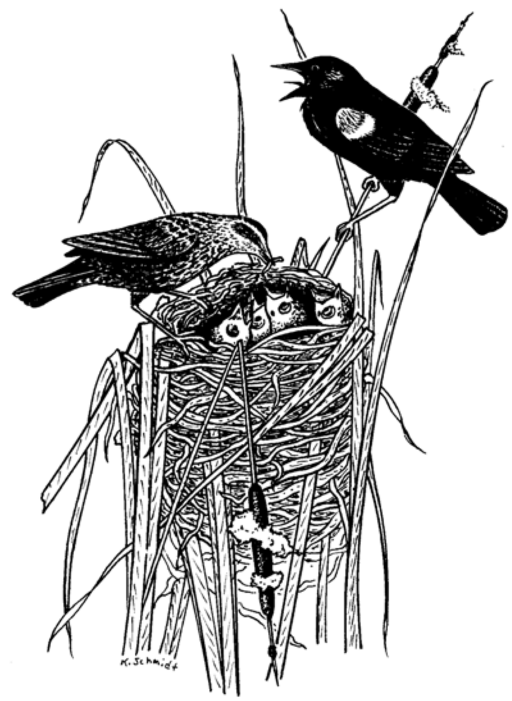
Iona Island Marsh

Location: Rockland County; River km 72-74
Area: 225 ha
Salinity and Tidal Range: 0-6 ppt; 0.9 m

Site Description: Iona Island Marsh is one of the largest, undeveloped, tidal wetlands on the Hudson River, located between Iona Island and the western shore of the Hudson River, in the Town of Stony Point, Rockland County. The site is primarily oligohaline intertidal marsh, dominated by common reed and narrow-leaved cattail. Tidal mudflats, SAV beds, and small areas of rocky uplands also occur in the area. Iona Island Marsh receives freshwater from Doodletown Brook, a small, high-gradient stream that drains a small (7.5 km^2), predominantly forested watershed. The marsh is hydrologically connected to the Hudson River through openings in the railroad bank at each end of Iona Island. Iona Island Marsh is located within Bear Mountain State Park and is owned by the PIPC. A causeway provides vehicular access to the island from the mainland; however, this becomes flooded during extreme high tides.

Sediments in the tidal marshes and shallows consist of peat and silt. According to radiocarbon analysis of the peat, the marsh began to form at least 6,000 years ago, behind Iona Island, in what is believed to have been an old channel of the Hudson River. Some sediments under the marsh are as old as 12,500 years. Soils on Iona Island and the mainland are derived from glacial till and are very shallow, acidic, and nutrient poor. A network of tidal creeks dissects the marsh and Doodletown Brook enters the western edge of the marsh north of the road causeway. In Doodletown Bight, the northern portion of the marsh, extensive mudflats are visible at low tide.

Red-winged Blackbird
(Agelaius phoeniceus)



The dominant species of SAV in the brackish tidal shallows are water celery and European water-milfoil. Sparse growth of water chestnut occurs in Doodletown Bight, representing the farthest downriver location of this invasive species. Plants in the lower intertidal zone include arrow-arum (*Peltandra virginica*), pickerel-weed (*Pontederia cordata*), and arrowhead (*Sagittaria* sp.). The upper intertidal zone is dominated by narrow-leaved cattail and common reed, with rose-mallow. Wooded swamps occur in the southwest corner, north of the causeway, and west of railroad tracks.

Rocky woodland communities occur on each side of the causeway and include oaks (*Quercus* spp.), ashes (*Fraxinus* spp.), birches (*Betula* spp.), willows (*Salix* spp.), red maple (*Acer rubrum*), and elms (*Ulmus* spp.). The woodlands are maintained for their value as cover, perch sites, and buffer zones.

Iona Island Marsh provides favorable habitats for a variety of fish and wildlife species. Shallow areas and tidal creeks provide spawning and nursery habitat for anadromous and resident estuarine fishes, including alewife, blueback herring (*Alosa aestivalis*), white perch, striped bass, and mummichog. Blue crabs are also common in the shallows and tidal creeks.

Iona Island Marsh is especially important for marsh-nesting birds. Probable or confirmed breeding species include green-backed heron, least bittern, Canada goose, mallard (*Anas platyrhynchos*), wood duck (*Aix sponsa*), Virginia rail (*Rallus limicola*), sora (*Porzana carolina*), belted kingfisher (*Ceryle alcyon*), marsh wren, red-winged blackbird, and swamp sparrow. Large concentrations of herons, waterfowl and shorebirds also occur in Iona Island Marsh during spring and fall migrations (March-April and September-November, respectively). Other resident wildlife species in the area include muskrat, white-tailed deer, snapping turtle, painted turtle (*Chrysemys picta*), Northern water snake (*Nerodia sipedon*), and green frog (*Rana clamitans melanota*). Five-lined skinks (*Eumeces fasciatus*) can occasionally be found on the rock outcrops overlooking the marsh.

The original inhabitants of Iona Island were Native Americans who hunted and fished there. Evidence of human occupation of the marshes and Iona Island date back about 5,500 years ago. Stephanus van Cortland acquired the property in 1683 and named it Salisbury Island. The site was re-named Iona by C.W. Grant, who purchased the property in 1849 and cultivated the Iona grape. The U.S. Navy purchased Iona Island in 1899 and constructed a military complex, which included nearly 150 buildings, plus an assortment of concrete bunkers. Iona Island was acquired by the PIPC in 1965. The present causeway to the island was originally built in 1911 and rebuilt in 1983.

The primary coastal management concern at Iona Island Marsh is the rapid loss of marsh plant diversity caused by the expansion of common reed since 1970. The area of Iona Island Marsh dominated by common reed increased from 16 ha (31%) to 30 ha (56%) during the interval 1991-1997. Research has focused on identifying ecosystem effects of this expansion (e.g., fish use of the marsh, marsh breeding bird populations) and future research should include the following:

- Monitor marsh breeding birds every five years;
- Continue monitoring marsh plant communities at 5-10 year intervals;
- Determine the feasibility of controlling common reed;
- Continue to support research addressing the ecological effects of common reed expansion;
- Develop a hydrological model for the tidal marshes;
- Establish a continuous water quality datalogger station and a weather station; and
- Initiate a paleoecology study, similar to that conducted at Piermont Marsh.

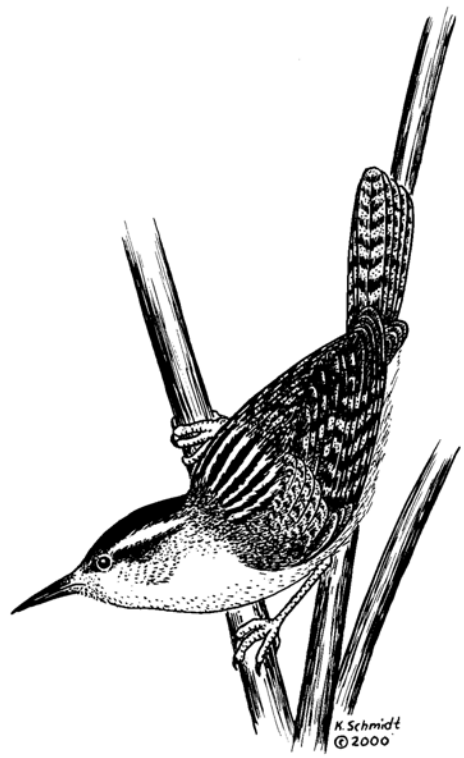
Tivoli Bays

Location: Dutchess County; River km 98-100
Area: 697 ha
Salinity and Tidal Range: Freshwater; 1.2 m.

Site Description: The Tivoli Bays consists of two large river coves partially surrounded by wooded clay bluffs encompassing two miles along the eastern shore of the Hudson River between the villages of Tivoli and Barrytown, in Dutchess County, NY. The bays are partially isolated from the main channel of the Hudson River by a railroad causeway built on fill in approximately 1850. Tivoli North Bay encompasses approximately 170 ha and Tivoli South Bay encompasses approximately 117 ha. Two 15-20 m wide openings in the rail bed and three culverts permit tidal exchange with North Bay. Three openings, approximately 20-30 m, currently permit tidal exchange with South Bay (a fourth opening was closed circa 1950). Tivoli North Bay's intertidal marsh has a well-developed network of tidal creeks and pools. A similar network of creeks and pools began to form in Tivoli South Bay's shallows and mudflats during the 1970s. The site also includes Cruger Island and Magdalen Island, two bedrock islands located west of the railroad. A road built on fill connects Cruger Island with the mainland. Extensive tidal shallows lie north and south of Cruger Island, although just west of the island the main river is 15 m deep. The main tributaries are the Stony Creek and the Saw Kill, which drain a combined watershed of about 124 km^2. The Reserve is headquartered at the Bard College Field Station on South Bay, near the mouth of the Saw Kill.

Freshwater tidal marshes at Tivoli North Bay are dominated by narrow-leaved cattail, with spatterdock (*Nuphar advena*) and

Marsh Wren
(Cistothorus paulstris)



pickerel-weed occurring in the lower to middle intertidal zone. Two NY state-listed rare plants, goldenclub (*Orontium aquaticum*) and heartleaf plantain (*Plantago cordata*), are known to occur in North Bay.

Invasive purple loosestrife and common reed both occur within North Bay. Aerial mapping conducted in 1997 indicated that some 30 ha of Tivoli North Bay were occupied by purple loosestrife, representing nearly 18% of the vegetated marsh surface. In the 1997 vegetation survey, common reed stands represented a relatively minor component of total wetland area (1.9 ha, or 1% of total marsh area), but presently continue to expand.

Subtidal shallows support communities of submerged plants, with water celery and European water-milfoil most abundant.

Freshwater intertidal mudflat and shore communities are also present. Tivoli South Bay is dominated by water chestnut, which forms dense mats covering most of the bay's surface during summer. An extensive tidal swamp located on Cruger Neck, the peninsula between the two bays, and a smaller swamp located at the mouth of Stony Creek are mixed deciduous communities, with a well-developed shrub layer and diverse moss species. The clay bluffs and rocky islands in the vicinity of the bays support mixed forests dominated by oak, hickory (*Carya* spp.), Eastern hemlock (*Tsuga canadensis*), and white pine (*Pinus strobus*).

The Tivoli Bays are an important spawning and/or nursery ground for a variety of anadromous and freshwater fish species, including black bass, white perch, and common carp (*Cyprinus carpio*). Two regionally uncommon fish species, American brook lamprey (*Lampetra appendix*) and Northern hog sucker (*Hypentelium nigricans*), are known to occur in the mouth of the Saw Kill.

A large snapping turtle population exists in Tivoli North Bay. In late June, females deposit their eggs in shallow burrows excavated in the soft sand of the rail beds. Painted turtles appear to have declined in recent years (Rozycki and Kiviat, 1996). Waterfowl use the Tivoli Bays extensively during migration and winter. Many other bird species use the site for feeding, breeding, and migratory stopovers. Marsh wren, least bittern, and Virginia rail nest in narrow-leaved cattail in North Bay.

Tivoli Bays and the associated uplands are administered by NYSDEC as a Reserve component and as a Wildlife Management Area. Activities permitted at Tivoli Bays include scientific research, nature study, hunting, trapping, boating, hiking, cross country skiing, bird watching, and fishing.

Native Americans used the Tivoli shores and Cruger Island as fishing and hunting camps as early as 2500 B.C. and archaeological sites have been excavated within the area. The original non-native inhabitant of the Tivoli Bays was Peter Schuyler, who settled there in the late 17th Century. Cruger Island was purchased in 1835 by John Church Cruger. Lavish homes were constructed on the island during the mid to late 19th Century. A series of summer camps were maintained until the mid 1900s. Cruger Island was purchased by Central Hudson Gas & Electric in 1960; NYSDEC acquired the island in 1979.

Research, inventory, and monitoring priorities at this site include:

- Develop a reliable hydrological/tidal exchange model;
- Continue monitoring resident and transient fish species;
- Continue monitoring marsh plant communities at 5-10 year intervals;
- Identify sources of chloride in the watershed and document changes/trends in chloride loadings;
- Develop a land cover/land use digital database;
- Monitor marsh breeding birds every five years;
- Initiate a paleoecology study, similar to that conducted at Piermont Marsh; and
- Monitor the response of the marsh to common reed removal.

Stockport Flats

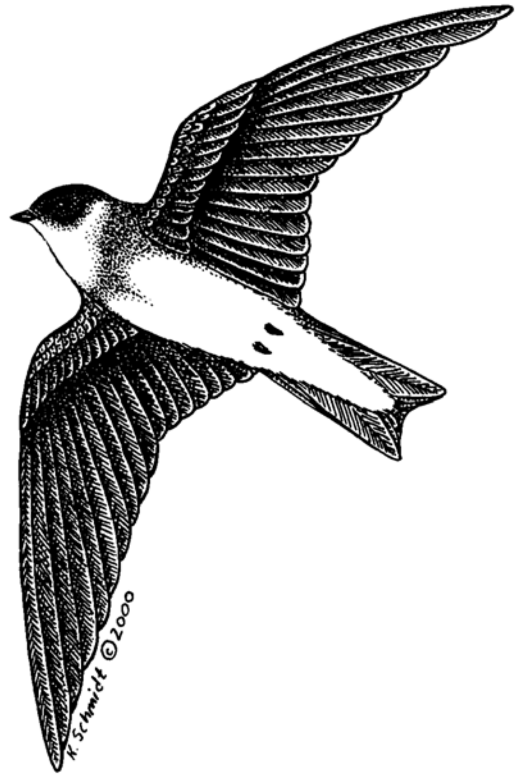
Location: Columbia County; River km 192-200
Area: 625 ha
Salinity and Tidal Range: Freshwater; 1.2 m

Site Description: Stockport Flats is an 8-km mosaic of intertidal shore, marshes, subtidal shallows, sandy islands, and tidal swamp. It is located on the eastern shore of the Hudson River in Columbia County, a few miles north of the city of Hudson, in the towns of Stockport and Stuyvesant. Most of this site lies west of the eastern shore railroad line. The site's primary geographic features, from north to south, include Nutten Hook (a bedrock outcropping), Gay's Point and Stockport Middle Ground (created during the deepening of the Federal navigation channel in the 1920s), the mouth of Stockport Creek, and Priming Hook. Stockport Creek, one of the ten largest tributaries to the lower Hudson, drains about 1,300 km^2.

Subtidal shallows at Stockport support SAV, with water celery the most abundant species present. The tidal marshes are dominated by narrow-leaved cattail, wild rice (*Zizania aquatica*), spatterdock, pickerel-weed, and purple loosestrife. Common reed stands encompassed approximately nine ha (6.5% of total marsh area) during a 1997 vegetation survey, while purple loosestrife covered 22 ha (16% of the total intertidal marsh area surveyed). Invasive common reed is estimated to be colonizing at a rate of 0.1 ha per year at Stockport (Winogrond and Kiviat, 1997). Tidal and floodplain swamps at Stockport support a mixed deciduous forest community.

The bluffs along the south side of Stockport and east of the main marsh are covered by deciduous forest with oaks and other species, as well as localized stands of white pine. The sandy islands and peninsulas have abundant cottonwood (*Populus deltoides*), black locust (*Robinia pseudoacacia*), red cedar (*Juniperus virginiana*), staghorn sumac (*Rhus typhina*), oaks, and other species.

Bank Swallow
(Riparia riparia)



State-listed rare plants known to occur at Stockport Flats include Southern estuarine beggar-ticks (*Bidens bidentoides*), salt-marsh bittercress (*Cardamine longii*), Fernald's sedge (*Carex merritt-fernaldii*), Schweinitz's flatsedge (*Cyperus schweinitzii*), kidneyleaf mud-plantain (*Heteranthera reniformis*), sharpwing monkey-flower (*Mimulus alatus*), goldenclub, swamp lousewort (*Pedicularis laneceolata*), heartleaf plaintain, spongy arrowhead (*Sagittaria calycina* subsp.

spongiosa), and Hudson sagittaria (*Sagittaria subulata*).

Stockport Flats is a spawning and/or nursery ground for anadromous and freshwater fish species including alewife, blueback herring, American shad, striped bass, yellow perch (*Perca flavescens*), and largemouth bass (*Micropterus salmoides*). Stockport Creek and its tributaries represent an important spawning area for smallmouth bass (*Micropterus dolomieu*) (Schmidt and Stillman, 1994; 1998).

Waterfowl use the site as both a migration staging area and wintering ground, when not frozen. Wading, shore, and songbirds use it for feeding and breeding. Bank swallows and belted kingfishers nest in the sand cliffs on the southwestern shore of Stockport Middle Ground and Gay's Point peninsula.

Nutten Hook was the site of the R & W Scott Ice Company (circa 1885), which was one of the largest independently-owned icehouses on the Hudson River, now on the National Register of Historic Places. With portions of the foundations and the powerhouse chimney remaining, this site is the most intact and interpretable ruin associated with the ice industry on the Hudson River.

Nearly the entire Stockport Flats component is in New York State ownership under the jurisdiction of NYSDEC, the OPRHP, and the OGS. Three small parcels are in private ownership.

Stockport Flats likely contains some of the youngest tidal marsh habitat on the Hudson River because of the recent and continued movement of sediments. Many upland habitats at this site were created by disposal of dredged material from the navigation channel. This material is primarily sand and is continually shifting and eroding. Pertinent management issues for this site are the influence of visitors on the erosion of the shoreline and the stability of the underwater lands and dredged material islands. Future research needs include:

- Identify sources of chloride in the watershed and document changes/trends in chloride loadings;
- Initiate a paleoecology study, similar to that conducted at Piermont Marsh;
- Monitor marsh breeding birds every five years;
- Continue monitoring marsh plant communities at 5-10 year intervals;
- Develop a land cover/land use digital database;
- Conduct a cultural resources study at Nutten Hook;
- Determine the status of Cerulean warbler (*Dendroica cerulea*) use of dredged material habitats (upland and wetland forests); and
- Describe the dynamic nature of the bathymetry along the Hudson River channel through Stockport Flats.

HUDSON RIVER NATIONAL ESTUARINE RESEARCH RESERVE PROGRAMS

Research and Monitoring Programs

Research policy at the Reserve is designed to fulfill the NERRS goals, authorized under Section 315 of the Coastal Zone Management Act of 1972 (NERRS Regulations: Title 15, Part 921 of the Code of Federal Regulations). These include:

- Addressing coastal management issues identified as significant through coordinated estuarine research within the system;

- Promoting Federal, state, public and private use of one or more reserves within the system when such entities conduct estuarine research; and

- Conducting and coordinating estuarine research within the system, gathering and making available information necessary for improved understanding and management of estuarine areas.

The goal of the Hudson River Reserve's research and monitoring program is to increase scientific knowledge and understanding of natural and human processes, ecological interrelationships, and trends occurring at the Reserve sites, within their watersheds, and throughout the Hudson River Estuary. To further this goal, the Reserve will:

- Promote the use of the Reserve by researchers representing public and private research entities for research projects consistent with local and national research priorities and protection of estuarine resources;

- Continue the development of long-term, continuous data sets to be used to test research hypotheses, identify short-term variability and long-term trends in estuarine ecosystem health, and provide a source of hypotheses on fundamental ecological relationships and coastal management questions;

- Develop and maintain facilities, equipment, tools, a reference library, data-bases, and other resources necessary to facilitate research and monitoring;

- Disseminate scientific information to researchers, resource managers, and local decision-makers to promote improved coastal management and stewardship of the Hudson River Estuary and its watershed; and

- Coordinate and manage research projects at the Reserve sites in order to streamline scientific efforts and avoid research site conflicts and disturbances.

Current key research priorities include:

- Assess ecological functions of aquatic habitats (e.g., SAV, tidal marsh and swamp, benthic habitats);

- Inventory estuarine aquatic habitats and document their spatial distribution within the estuary;

- Investigate effects of invasive plant and animal species on ecosystem structure and function;

- Initiate habitat restoration studies;

- Continue development and verification of the Hudson River Wetland Functional Assessment Method to guide restoration planning and evaluation;

- Advance the knowledge base on restoring freshwater tidal wetland habitats; and

- Identify watershed sources of point and non-point surface water pollutants.

Education Programs

The Reserve offers a wide spectrum of education programs designed to increase awareness and understanding of estuarine habitats and promote sound stewardship of these resources. Programs for the general public include guided canoe trips at three of the Reserve's component sites, interpretive programs and a monthly lecture series at the Tivoli Bays Visitor Center, representation at regional Hudson River events and a variety of on-site field trips and off-site presentations. Interpretive panels and brochures describe the ecological, cultural and recreational aspects of the Reserve's component sites. A network of trails at two of the Reserve's component sites allows visitors to explore the uplands adjacent to tidal habitats.

Formal education programs serve teachers and their K-12 classes, as well as undergraduate and graduate students. The Reserve is currently targeting middle school science classes in the Tivoli Bays area, exploring ways to link them with Hudson River research. The program under development will utilize distance learning technology, supplemented by classroom visit and site visit components. Future work will build on this pilot program to reach out to middle schools adjacent to the other three Reserve sites and to expand services to elementary and high school science classes.

Another primary focus of the Reserve's education program is the development of collaborative workshops that will assist decision makers in the Hudson Valley in managing and protecting the estuary's resources, including its watershed area, by providing science-based training and information, access to technology and a forum for networking with colleagues throughout the estuary.

The Reserve augments its educational impact by supporting a variety of other educational programs in the Hudson River Estuary. Other organizations using Reserve sites for educational purposes include Bard College, the Dutchess County's Waterman Bird Club, and local chapters of the Sierra Club and the National Audubon Society. More active field support is given to organizations such as Clearwater, Rockland County Board of Cooperative Educational Services (BOCES), the Museum of the Hudson Highlands, the Stony Kill Farm Environmental Center, and the Trailside Museum of Bear Mountain State Park. The Reserve is working in close collaboration with the NYSDEC's Hudson River Estuary Program (HREP) to help develop a Hudson Valley K-12 curriculum and synchronize with its education goals (HREP, 2002).

Effectively incorporating findings of the Reserve's research and monitoring programs into all its educational outreach and training programs is critical to fulfilling its mission of promoting improved coastal management. Over the next five years, the Reserve will focus on the following topics:

- Anthropogenic sources of chlorides to aquatic systems;

- Ecological costs/benefits of controlling invasive common reed in Hudson River estuarine wetlands;

- The role of Hudson River tidal wetlands in processing dissolved inorganic nitrogen and phosphorus;

- Application of Hudson River ecological functional assessment methods to Hudson River estuarine restoration;

- Effective management and protection of Hudson River estuarine aquatic habitats (e.g., benthic, SAV, and tidal wetland habitats);

- Use of water quality monitoring data for classroom and/or community education; and

- Continued implementation of the SAV volunteer monitoring program.

Fellowship Programs

Three graduate and undergraduate fellowship programs have contributed greatly to the body of estuarine research conducted at the Hudson River Reserve: the Tibor T. Polgar Fellowship Program, the NOAA/NERRS Graduate Research Fellowship Program (GRF), and the New York Sea Grant (NYSG) / Hudson River NERR Cooperative Fellowship Program.

The Tibor T. Polgar Fellowship program was established in 1985 and is a cooperative program between the Reserve and the Hudson River Foundation for Science and Environmental Research. To date, over 160 undergraduate and graduate fellows have been supported under the Polgar Fellowship Program to conduct original research in the Hudson River Estuary. Research topics include life cycles and trophic dynamics of estuarine biota; water quality, sediment and nutrient exchanges between tidal wetlands and the river; vegetation communities; pollution impacts; archaeological investigations; watershed and land use studies; and public policy research. Many of the Polgar projects have been conducted within one or more Reserve component sites.

The NOAA/NERRS GRF is intended to support research in the reserves by providing graduate students with hands-on experience in research, coastal zone management and monitoring. This competitive fellowship program provides graduate students with funding for one to three years to conduct their own research projects while receiving training in ecological monitoring and coastal management. GRF projects must address coastal management issues identified as having regional or national significance, relate them to the NERRS research priorities listed, and be conducted at least partially within one or more designated Reserve sites.

The Reserve and NYSG co-sponsor a graduate fellowship program which provides annual funding for one student to conduct research within one or more of the four Reserve components. Current research priorities are to:

- Develop evaluation techniques to measure restoration success and/or remediation techniques to restore disturbed coastal environments and habitat;

- Determine functional impacts/importance of introduced and native species on estuarine wetland ecosystem functioning and develop effective detection and control mechanisms;

- Identify and/or evaluate anthropogenic effects on estuarine wetland ecosystem functions; and

- Identify and/or evaluate relationships between wetland ecosystems and the drainage basin.

Although research in these areas is preferred, other topics, including socio-economic research relevant to the missions of NYSG and Reserve programs may also be considered.

Water Quality Monitoring

In 1991, a long-term water quality-monitoring program was initiated at he Reserve. The goal of the program is to take monthly measurements of physical and chemical components of the marsh and tributary surface waters of the Reserve sites. Since then, this program has been carried out continuously and has resulted in a 13-year database.

The monitoring program includes field measurements of DO, specific conductivity, temperature, and salinity, as well as collection of whole water samples for nutrient analysis (nitrate, phosphate, chloride and sulfate) and long-term (April through December) deployment of electronic dataloggers at four marsh and five tributary monitoring stations among the Reserve components. Each instrument package measures depth, DO, water temperature, specific conductivity, salinity, pH, and turbidity. Episodic event and base flow data have been collected in order to assess seasonal variations and to determine the response of tributaries to storm events.

Monitoring tributary water quality is important to document the effects of urban and residential land use practices on Reserve site watersheds. Since residential coverage continues to increase, it is hoped that the intensive monitoring of the surface waters in these watersheds will identify trends associated with this rapid development.

The NERRS System-Wide Monitoring Program

The NERRS has a System-wide Monitoring Program (SWMP), which provides standardized data on national estuarine environmental trends while allowing the flexibility to assess coastal management issues of regional or local concern. The principal mission of the SWMP is to develop quantitative measurements of short-term variability and long-term changes in the integrity and biodiversity of representative estuarine ecosystems and coastal watersheds for the purposes of contributing to effective coastal zone management. The program is designed to enhance the value and vision of the reserves as a system of national references sites. Data collected by the NERRS monitoring program are compiled electronically at a central data management "hub." The centralized data management office (CDMO) at the Belle W. Baruch Institute for Marine Biology and Coastal Research of the University of South Carolina provides additional quality control for data and metadata. The Reserve participates in the SWMP via data collection at the Tivoli South Bay, Tivoli North Bay, Saw Kill, and Stony Creek long-term water quality monitoring sites.

Long-Term Meteorological Data Collection

Meteorological data have been collected at the Tivoli Bays component since July 1999.

Measurements of air temperature, relative humidity, barometric pressure, precipitation, photosynthetically active radiation, and wind speed and direction are taken from a weather station, located at the Bard College Ecology Field Station, adjacent to the confluence of the Saw Kill and Tivoli South Bay.

Plant Community Inventory and Trends

The Reserve has been monitoring marsh plant communities of each component site and has completed two community inventories, in 1991 and 1997 (**Appendix A**). This has enabled the Reserve to identify trends in plant community coverage, including the spread of invasive plant species such as common reed and purple loosestrife. The results of the community mapping study are being used by the Reserve to direct research efforts on the ecology and potential control of these and other invasive species.

SAV Inventory and Trends

Through a collaborative partnership with Cornell University, The Institute of Ecosystem Studies (IES), New York Sea Grant, and Hudson River Estuary Program, the Reserve has mapped the distribution of SAV in the Hudson River along a 200-km study area from Troy, NY south to Yonkers, NY using 1995, 1997, and 2002 aerial photography. Four broad categories were used in the classification: 1) water celery/other SAV, 2) water chestnut, 3) open water, and 4) upland/intertidal. No attempt was made to distinguish among individual SAV species within the first category, although approximately 20 occur in the study area. Light penetration is the primary determinant of SAV distribution in the Hudson River, and the increase in light penetration resulting from enhanced filtration of the estuary water column by invasive zebra mussels in recent years is believed to be changing the distribution of SAV in the estuary (Strayer et al., 1999).

Hudson River Benthic Mapping Project

The Reserve, working with several private, state, and Federal partners, is mapping the submerged lands of the Hudson River Estuary with a suite of geophysical tools. Multibeam swath bathymetry, side-scan sonar, and sub-bottom profiling using "chirp" sonar and ground-penetrating radar were used to collect information on bottom contours, submerged structures, and shallow geophysical features from NY/NJ Harbor to the Federal Dam at Troy, NY. The geophysical data collection has been supplemented with sediment profile imagery (SPI) and characterization of benthic communities by sediment core/grab sampling. This study represents the first modern attempt to map the bottom of the Hudson River Estuary, as the last comprehensive bathymetric survey of the river was conducted in the 1930s.

Data products include acoustic images, mosaics, and several interpreted geographic information system (GIS) data layers. These layers include anthropogenic deposits, recently deposited fine-grained sediments, sediment grain size, bedforms, and river bottom morphology.

The benthic mapping project has yielded a wealth of new information on the bottom features of the Hudson River Estuary, including cultural and historic resources. Historic oyster beds have been mapped in the Tappan Zee and ten-foot high sand waves were observed to be extensive in the Kingston-Saugerties region. Sediment lobes at the mouths of major tributaries were mapped in Newburgh Bay.

This information will be used to classify and manage benthic habitats, and to monitor and manage sediment and contaminant transport within the estuary. The images and GIS database will prove useful in documenting temporal and spatial change in the estuary, guiding future research and enforcing the laws that govern human activity in the estuary.

Tivoli Bays Fish Community Surveys

In 2001, the Reserve partnered with Simon's Rock College to establish a long-term fish community monitoring program at the Tivoli Bays Reserve component. The purpose of this program is to assess inter-annual variability and document long-term trends in resident fish populations and anadromous fishes that are using the Tivoli Bays.

Monitoring takes place at several stations in both Tivoli North and South Bays. Additional samples are collected along the inner shore of Magdalen and Cruger Islands. Anadromous fish and larvae are sampled at the mouths of Stony Creek and the Saw Kill tributaries to South and North Bays, respectively. Rectangular drift nets are used to sample larval fish at night on ebb tides. A pop net was used to collect fish from the dense water chestnut beds in South Bay during summer 2002. Adult fish are sampled at mouths of the Saw Kill and Stony Creek on occasion using a backpack electroshocker.

Restoration Science Program

The Reserve has developed a Restoration Science Program, which involves regional planning and collaboration with several local agencies and research institutions, including the NYSDEC Hudson River Estuary Program; Hudsonia, Ltd.; Cornell University; and IES. The program focuses on several key restoration priorities in the Hudson River, including:

- Restoration of migratory fish passage within Hudson River tributaries;
- Development of an understanding of the functional shifts associated with managing invasive common reed;
- Softening of hardened shorelines along the estuary;
- Conversion of dredged material uplands to intertidal and subtidal freshwater wetlands;
- Developing a reference set of wetlands and data to guide freshwater tidal wetland restoration; and
- Determining the limiting factors controlling the establishment and distribution of SAV in freshwater tidal habitats.

Partners

A key ingredient in the success of the Reserve's research, monitoring, and education programs is the partnerships that have been established and strengthened over the past 15 years. Partners include: NOAA's Estuarine Reserves Division (ERD), HREP, IES, Cornell University's Institute for Resource Information Systems (IRIS), Bard College, Hudson River Foundation (HRF), Columbia University; Hudsonia, NYSG, the Greenway Conservancy for the Hudson River Valley, and the New England

Interstate Water Pollution Control Commission (NEIWPCC). These partnerships have been critical for directing the Reserve's research focus, attracting research scientists and funding, extending research and monitoring results to coastal management programs, and implementing research, monitoring, and education programs in the most effective manner.

DESCRIPTION OF SIGNIFICANT AQUATIC HABITATS WITHIN THE RESERVE

The Reserve includes many distinct ecological communities and significant habitats, including tidal deepwaters, shallow bays and coves, intertidal mudflats, emergent tidal wetlands, tidal swamps, forested uplands, and both the tidal and non-tidal portions of Hudson River tributaries. Reschke (1990) developed a classification scheme for ecological communities in New York State. This scheme arranges community types by systems and sub-systems. For example within the system "Estuarine" there exist three subsystems (subtidal, intertidal, and cultural). Each subsystem includes several community types (e.g., tidal marsh, tidal mudflat, etc.). Each community type is further subdivided by salinity regime (e.g., brackish vs. freshwater). The following community descriptions are based upon Reschke's classification.

System: Estuarine
Sub-system: Subtidal

Tidal River
Reschke (1990) divides the tidal river community type into two depth strata. The shallow zone includes areas less than 2 m deep that lack rooted aquatic vegetation. The deepwater zone includes areas over 2 m in depth at low tide. This zone is generally too deep to support growth of aquatic macrophytes. Swift currents and sandy or rocky bottoms characterize many Hudson River tidal deepwater habitats. Characteristic fish species of the deepwater zone include Atlantic tomcod (*Microgadus tomcod*), bay anchovy (*Anchoa mitchilli*), and hogchoker (*Trinectes maculatus*). Characteristic fish of the shallow zone include striped bass, American shad, and white perch.

Tidal Creek
Tidal creeks are the permanent drainage features of brackish or freshwater intertidal marshes. Water levels in a creek fluctuate twice daily with the tides and many secondary tidal creek bottoms are exposed at low tide. With the exception of those that were channelized, most tidal creeks exhibit a characteristic sinuous pattern, due to the flat topography of the low-lying tidal marshes, which they drain. Characteristic SAV species of tidal creeks include widgeon-grass (*Ruppia maritima*) in brackish creeks, and water celery in freshwater tidal wetlands. The non-native European water-milfoil and water chestnut commonly occur in freshwater tidal creeks as far south as Iona Island. Characteristic fish species of brackish tidal creeks in the Hudson Estuary include Atlantic silverside (*Menidia menidia*) and mummichog. Characteristic fish species of freshwater tidal creeks include banded killifish (*Fundulus diaphanus*), spottail shiner (*Notropis hudsonius*), and tessellated darter (*Etheostoma olmstedi*). Tidal creeks are used as nursery areas by several estuarine-dependent species, including striped bass and bluefish (*Pomatomus saltatrix*).

Brackish and Freshwater Subtidal Aquatic Bed
This shallow subtidal zone occurs above deepwater, but below mean low water (MLW). Typically, this zone occurs in narrow bands along the shoreline or in broad shallow flats. In the upper estuary, this zone may also be present in shallow bays such as Tivoli South Bay. Water celery is the most

common SAV species of the upper estuary. Additional species include water-weeds (*Elodea canadensis* and *E. nuttallii*), naiads (*Najas guadalupensis* and *N. minor*), pondweeds, and the non-native water chestnut and European water-milfoil. Brackish SAV communities occur in Haverstraw Bay and in the Tappan Zee. Historically, SAV was abundant at the mouth of the Croton River and throughout Croton Bay.

Characteristic SAV species of the lower estuary include water-weeds, water celery, coontail (*Ceratophyllum demersum*), naiads, sago pondweed, horned pondweed, and widgeon-grass.

System: Estuarine
Sub-system: Intertidal

Brackish and Freshwater Intertidal Shore
Intertidal shore communities include sparsely vegetated gravel or sandy shorelines and the extensive railroad embankments, which occur along both shores of the Hudson. Characteristic plant species occurring along intertidal shores include knotweeds (*Polygonum* spp.), tidewater hemp (*Amaranthus cannabinus*), heartleaf plantain, and Northern estuarine beggar-ticks (*Bidens hyperborea*) (USFWS, 1997).

Intertidal Brackish and Freshwater Mudflats
Intertidal mud flats are sparsely vegetated, depositional environments which occur in tributary mouths or behind islands, where wave and current energy is relatively low. Some 440 ha of brackish and intertidal mud flats are present throughout the estuary. Extensive brackish intertidal mud flats occur behind Iona Island and Constitution Island, in the oligohaline portion of the estuary. Significant areas of freshwater intertidal mud and sand flats occur at the Tivoli Bays and Stockport Flats (USFWS, 1997).

Characteristic mud flat vegetation in the mid-Hudson River Estuary includes European water-milfoil, arrowheads (*Sagittaria subulata, S. calycina*), and kidneyleaf mud-plantain. In the upper estuary, bulrushes (*Scirpus* spp.) may occur on intertidal sand flats.

Intertidal Brackish and Freshwater Marshes
The Hudson River Estuary contains approximately 1800 ha of intertidal brackish and freshwater tidal marshes; both broadleaf and graminoid community types are well-represented. There are very few intertidal marshes in the lower estuary, with the notable exception of Piermont Marsh. Freshwater tidal marshes are widely distributed throughout the mid- and upper-Hudson River Estuary.

Although Hudson River freshwater tidal marshes perform many of the same functions as tidal saltwater or brackish marshes, their floral and faunal composition is similar to that of non-tidal freshwater wetlands. In contrast to salt marshes, in which plant distribution and zonation is usually dominated by one or two species (e.g., *Spartina* sp.), freshwater tidal marshes frequently include mixed communities of many species, including grasses, shrubs, and forbs. Floristic intertidal zonation occurs along an elevation gradient, but may not be as sharply defined as in saline coastal marshes. Seasonal variation in plant community composition may be pronounced, with annual and perennial plant species alternating both in aerial extent and biomass.

Characteristic plants of the lower freshwater intertidal marsh include spatterdock and pickerel-weed. In the mid to upper reaches of the marsh, both annuals and perennials are encountered, including arrow-arum, wild rice, narrow-leaved and hybrid cattail (*Typha angustifolia*, *Typha X glauca*), common arrowhead (*Sagittaria latifolia*), knotweeds, beggar-ticks (*Bidens* spp.), rice cut-grass (*Leerzia oryzoides*), and sweet flag (*Acorus calamus*). Seed availability and germination potential may, in part, determine the distribution of plants across the marsh landscape. Various species are restricted to upper intertidal locations as a result of intolerance to extended periods of inundation (Leck and Simpson, 1987). Competition and shading may also contribute to the determination of plant zonation, vegetative growth patterns, and distribution patterns. Many freshwater tidal marshes in the mid-upper Hudson River estuary are undergoing invasion by common reed.

Freshwater Tidal Swamp

Freshwater tidal swamp, a regionally and globally rare community type, can be found in select locations within the upper Hudson River Estuary, including the Tivoli Bays Reserve (Cruger Island Neck). Some 600 ha of freshwater tidal tree/shrub swamp occurs within the mid-upper Hudson River Estuary. Tidal swamps provide habitat for a variety of nesting birds, mammals, reptiles, and amphibians. Characteristic plant species of freshwater tidal swamps include red maple, green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), and willows. Shrub species may include Bell's honeysuckle (*Lonicera* X *bella*), silky dogwood (*Cornus amomum*), smooth alder (*Alnus serrulata*), common buttonbush (*Cephalanthus occidentalis*), and Northern spice-bush (*Lindera benzoin*). Typical plants of the tidal swamp understory include purple loosestrife, spotted jewelweed, sensitive fern (*Onoclea sensibilis*), knotweeds, and skunk cabbage (*Symplocarpus foetidus*) (USFWS, 1997).

System: Estuarine
Sub-system: Cultural

Dredged Material Habitats

Dredged material islands and uplands are a common landscape feature in the upper Hudson River Estuary. Most of these were constructed from 1860 to 1925, as navigation improvements were implemented to deepen the Federal navigation channel in the upper reaches of the estuary, between Hudson and Albany. Significant portions of the Stockport Flats Reserve component are comprised of dredged material habitats.

Reschke (1990) describes several dredged material community types, including estuarine/marine dredge spoil shore, dredge spoil wetland, and dredge spoils. Stevens (2001) further divides these into the following sub-communities: dredge spoil tidal swamp/tidal supra swamp, dredge spoil shore meadow, dredge spoil forest, dredge spoil floodplain forest, dredge spoil dry meadow, dredge spoil bluff slope, and dredge spoil vernal pool. Reschke (1990) suggests that dredged material habitats contain relatively few plant and animal species and that vegetation cover is minimal; however, Stevens (2001) documented a fairly diverse assemblage of species at Stockport Flats and nearby. Given sufficient time (years to decades), succession by a variety of plant and animal species is likely to occur on these man-made habitats.

Riprap/Artificial Shore

This community type represents the vegetation and biota associated with rocks, wooden bulkheads, and concrete structures placed to stabilize shorelines and control erosion. Much of the shoreline of the upper Hudson River Estuary (north of the city of

Hudson) is characterized by wooden bulkheading, some constructed as early as the late 18th century, intended to stabilize dredged material islands and other man-made shoreline features. Vegetative cover and species diversity tends to be low in association with rip/rap bulkheaded structures as compared to natural shoreline substrates.

System: Riverine
Sub-system: Natural Streams

Hudson River Tributaries
Hudson River tributaries provide a source of sediments and nutrients to the main stem of the estuary, influencing both its physical and biological attributes. Some Hudson River tributaries may contain relatively swift currents, with considerable lateral erosion and a well-defined pool, riffle, and run geomorphology. Others may be dominated by clearly defined meanders and considerable deposition. Characteristic fish species of Hudson River tributaries include creek chub (*Semotilus atromaculatus*), blacknose dace (*Rhinichthys atratulus*), and tessellated darter. Rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) have been introduced in the upper reaches of some tributaries. The lower non-tidal sections of Hudson River tributaries provide important overwintering areas for smallmouth bass and largemouth bass. The non-tidal portions of tributaries also provide essential spawning habitat for anadromous fish, notably alewife.

System: Terrestrial
Sub-system: Forested Uplands

Upland Forest
Reschke (1990) defines a forested upland as those upland communities with more than 60% canopy cover of trees occurring on substrates with less than 50% rock outcrop or shallow soil over bedrock. Characteristic trees of the Hudson Valley region include oaks, maples (*Acer* spp.), birches, American beech, Eastern hemlock, and white pine. Dry rocky slopes in the vicinity of Iona Island support Northern red oak and rock chestnut oak (*Quercus prinus*). Areas with moist, deeper soils, typically found in the mid to upper Hudson Valley, support oaks, sugar maple (*Acer saccharum*), tulip tree, sweet birch (*Betula lenta*), American beech, Eastern hemlock, and flowering dogwood (USFWS, 1997). Shrubs, ferns, lichens, and mosses are common among the forest understory. Successional northern hardwood communities occur in areas that have been cleared (for agriculture or logging) or otherwise disturbed. The upland forest community adjacent to the estuary shoreline provides habitat for a variety of mammals, birds, reptiles, and amphibians. Characteristic species known to occur within the Reserve include white-tailed deer, wild turkey (*Meleagris gallopavo*), red-bellied woodpecker (*Melanerpes carolinus*), Eastern garter snake (*Thamnophis sirtalis sirtalis*), Eastern box turtle (*Terrapene carolina carolina*), American toad (*Bufo americanus*), and Eastern red-backed salamander (*Plethodon cinereus*).

Arrow-arum
(Peltandra virginica)

Pickerel-weed
(Pontederia cordata)

Spatterdock
(Nuphar advena)

Narrow-leaved Cattail
(Typha angustifolia)

ECOSYSTEM PROCESSES AND BIOTIC COMMUNITIES

Long-Term Water Quality Monitoring

Since 1991, the Reserve's long-term water quality monitoring program has provided a nearly continuous time series of basic water quality parameters [salinity, total suspended solids (TSS), DO, pH] and nutrient concentrations (nitrate and phosphate) within the four Reserve components and their principal tributaries. While basic water quality conditions throughout the Reserve are generally representative of conditions in a temperate estuary, and therefore unremarkable, monitoring of nutrients has identified some areas of concern and potential sources of organic enrichment. In addition, monitoring of sulfate and chloride has identified elevated concentrations of the latter within the Reserve components and their tributaries. Along with nutrient enrichment, chloride pollution is linked to the increasing urbanization of the site component's individual watersheds. Sulfate levels have decreased within the past 15 years among the Reserve components, consistent with a decreasing trend in atmospheric sulfate deposition regionally. The long-term data record generated by the Reserve's monitoring program can be used to compare temporal trends and spatial patterns in water quality among the individual Hudson River component sites, between the Reserve components and the Hudson River mainstem and among the Hudson River Reserve and other reserves located throughout the U.S.

Salinity

From NYC to Troy, salinity decreases as the distance from the mouth of the Hudson River increases (**Figure 3**). The average salinity at Iona Island Marsh (II) is approximately one-half that of Piermont Marsh (PM). At these two sites, salinity in winter and spring is approximately one-fourth that of summer and fall. Ebb-tide measurements often reflect lower salinity than the main channel due to the influence of the major tributary at each site. Tivoli South Bay (TS), Tivoli North Bay (TN), and Stockport Flats (SF) always exhibit freshwater conditions. Mean concentrations of chloride and sulfate follow the same spatial pattern as salinity at the marsh sites.

Nitrate

Nitrate concentrations in the tributaries are related to activities within the watersheds (**Figure 4**). Stockport Creek, Stony Creek and the Saw Kill all have watersheds classified as low-density residential. However, nitrate concentrations in the Saw Kill and Stony Creek are higher than in Sparkill Creek, which is located within a primarily urban watershed. Septic systems in the watershed contribute nitrate to the Saw Kill. A municipal sewage treatment plant discharges nitrate-laden effluent in the upstream reaches of Stony Creek. Discernible spikes in nitrate concentrations occur at this site, primarily during low-flow conditions.

Nitrate concentrations in Piermont Marsh and Stockport Flats are similar to concentrations in the tributaries. At both sites, the tributary does not flow through an extensive marsh system prior to entering the river. Nitrate concentrations are similar among Iona Island Marsh, Tivoli South Bay, and Tivoli North Bay. Concentrations at these three sites are more similar to the river than to the dominant tributary. These three marshes not only intercept nutrients being exported from the watershed; they are also removing nutrients from the tidal waters of the Hudson River mainstem.

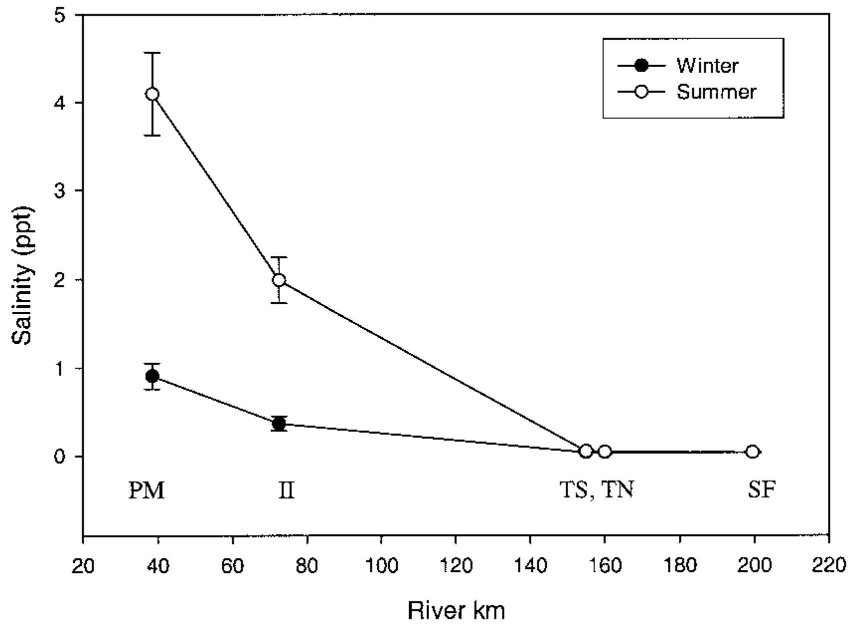


Figure 3: Mean salinity at HRNERR marsh sites in the winter/spring and summer/fall seasons. Means are derived from monthly measurements from June 1991- May 1992 and from June 1996-December 2003. Error bars represent one standard error of the mean.

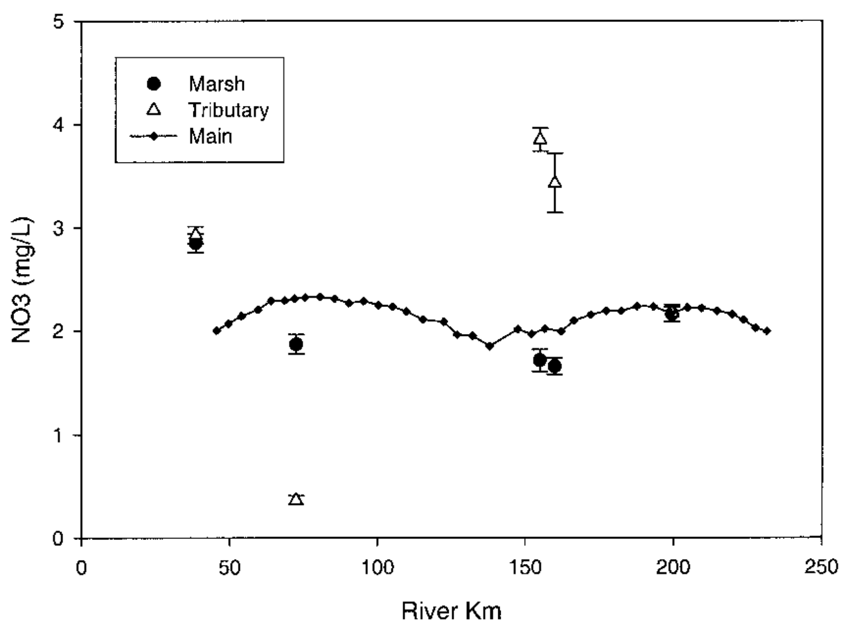


Figure 4: Mean nitrate concentrations in ebb-tide water from HRNERR tidal marshes, their associated tributaries and the main channel of the Hudson River by location (The Battery = River km 0). Mean concentrations at HRNERR sites are derived from data collected monthly from May 1991- December 2003 (a break in data collection in the marsh sites occurred from June 1992 – May 1996). Error bars represent one standard error of the mean. Mean concentrations in the main channel are derived from data collected bi-weekly during May through October from 1993-2003 (N.F. Caraco and J. J. Cole, unpublished data).

At all marsh sites, nitrate and DO are lowest in the summer, due to increased biological activity (**Figure 5**). Decomposition in the fall leads to higher nitrate concentrations relative to summer, while DO remains the same. Concentrations of nitrate and DO are higher in the winter and spring, likely due to limited biological activity during these seasons.

When invasive water chestnut is at maximum biomass in Tivoli South Bay, nitrate removal during a tidal cycle is evident (**Figure 6**). Late ebb-tide concentrations are less than 20% of flood tide values. This removal is either due to uptake by the plants (Tsuchiya and Iwakuma, 1993; Kiviat and Hummel, 2004) or denitrification in the hypoxic sediments, created in the water under the plant canopy. Nitrate removal during a tidal cycle is much less before the water chestnut beds achieve peak biomass (June) and after the water chestnut beds have senesced (November) (**Figure 7**).

Phosphate
Phosphate concentrations in Stony Creek are affected by discharge of effluent from a municipal sewage treatment plant located in the adjacent village of Tivoli. Discernible spikes in phosphate concentrations occur at this site, primarily during low-flow conditions. Higher concentrations of phosphate in Sparkill Creek relative to the Saw Kill and Stockport Creek are likely due to the greater degree of development within the watershed (**Figure 8**).

Concentrations of phosphate in Piermont Marsh and Iona Island Marsh are similar to main channel concentrations. Concentrations at Iona Island Marsh are less than Piermont Marsh, but greater than all of the freshwater tidal sites. Higher concentrations in the southernmost sites may be due to greater population density and sewage inputs or release of phosphate from sediments in the summer (Lampman et al., 1999). Phosphate concentrations in Tivoli North Bay and Tivoli South Bay are similar to main channel concentrations and phosphate concentrations in Stockport Flats are more similar to concentrations in Stockport Creek than to concentrations in the main channel.

Total Suspended Solids
Mean concentrations of total suspended solids at the Reserve marsh sites (ebb-tide measurements) are similar to mean concentrations at nearby locations in the main channel (**Figure 9**). Concentrations in Piermont Marsh and Stockport Flats are likely influenced by tributary input. Of all the tributaries, Stockport Creek has the highest mean concentration of suspended solids, due in part to the size of the drainage.

Dissolved Oxygen and pH
In both Tivoli South Bay and Tivoli North Bay, as depth decreases (ebb-tide), DO and pH decrease (**Figure 10**). As depth increases (flood tide), DO and pH increase again. Biological activity in both Tivoli Bays sites appears to remove DO from the water and the change in pH likely results from CO_2 addition. These effects are less obvious in the early spring and late fall/early winter due to reduced biological activity and colder temperatures.

Among all Reserve marsh sites, yearly mean DO percent saturations (from monthly measurements) are lowest at Tivoli North Bay and Tivoli South Bay (**Figure 11**, **Figure 12**). This is likely due to high biological activity in the marsh at Tivoli North Bay and the presence of the water chestnut beds in Tivoli South Bay during the summer and fall. Yearly mean dissolved oxygen saturation is highest in Stockport

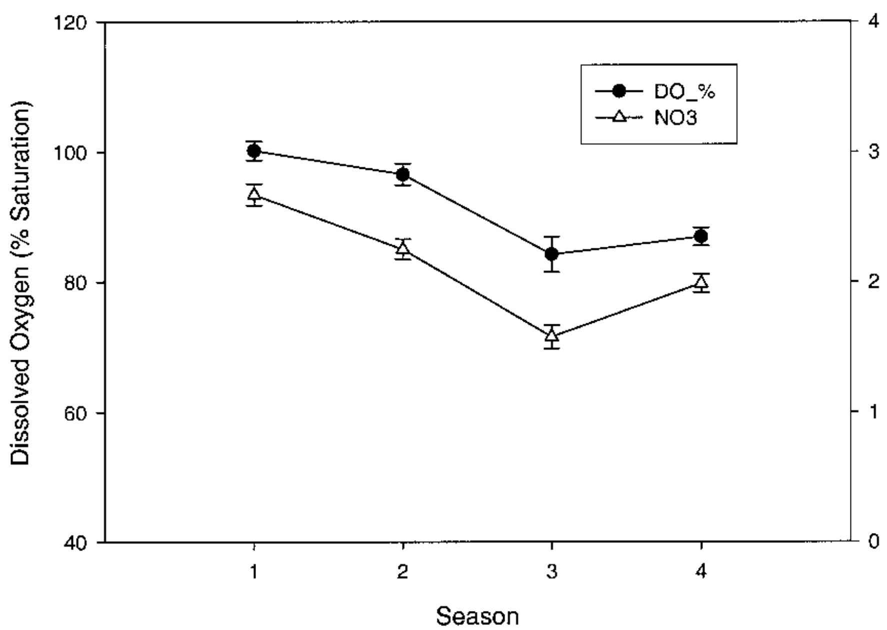


Figure 5: Seasonal patterns of mean nitrate concentrations and percent saturation of dissolved oxygen at all HRNERR marsh sites (Winter = 1, Spring = 2, Summer = 3, Fall = 4). Means include monthly measurements from 1991-1992 and from 1996-2003. Error bars represent one standard error of the mean.

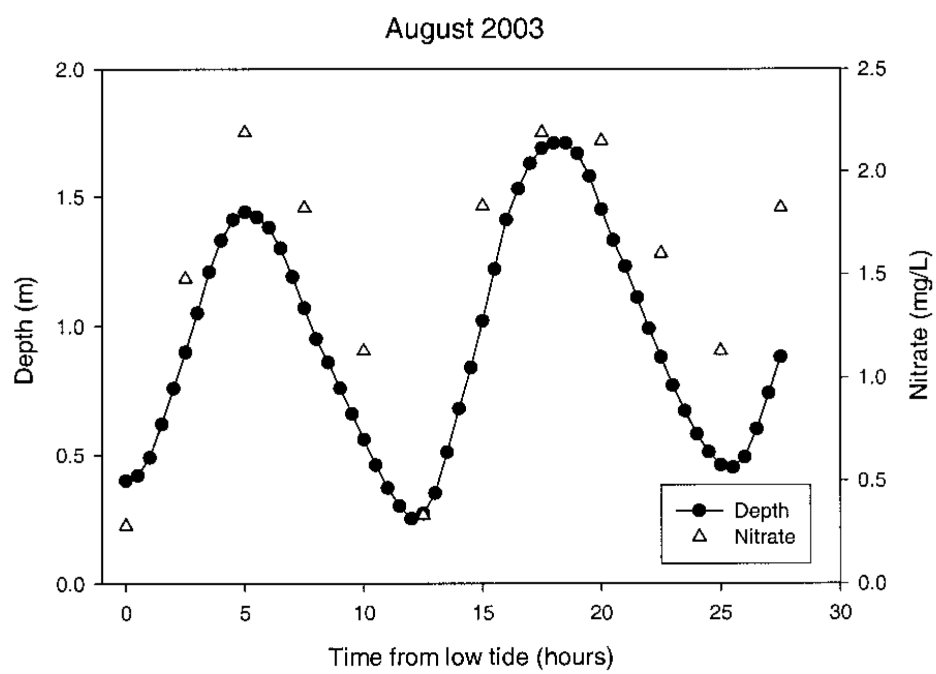


Figure 6: Relationship between nitrate and tide stage at Tivoli South Bay during a diel sampling in August 2003. Depth data were recorded by a datalogger every 30 minutes and a water sample was collected by an autosampler every 2.5 hours over a 27.5-hour period.

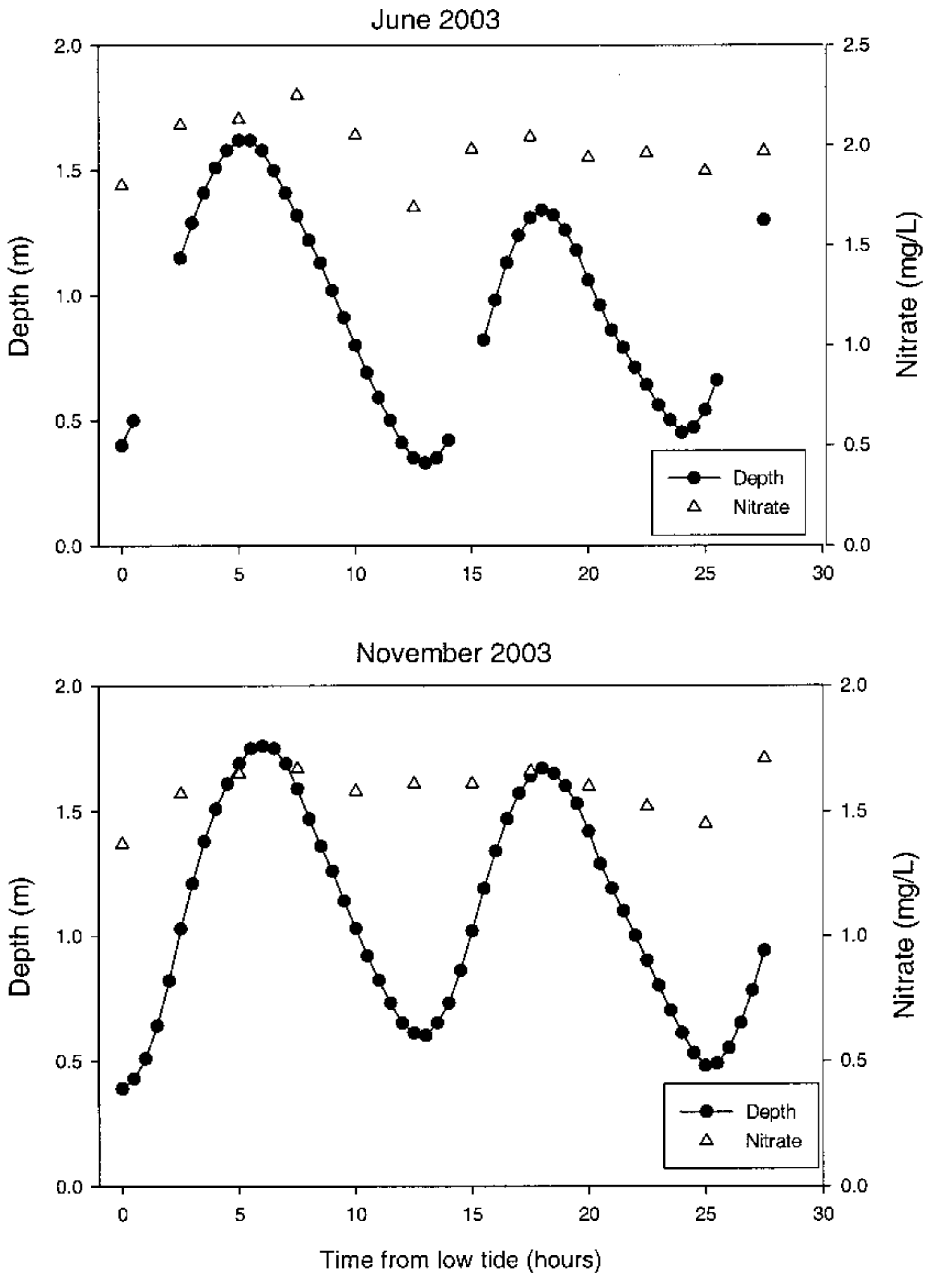


Figure 7: Relationship between nitrate and tide stage at Tivoli South Bay during diel sampling events in June and November 2003. Depth data were recorded by a datalogger every 30 minutes and a water sample was collected by an autosampler every 2.5 hours over a 27.5-hour period.

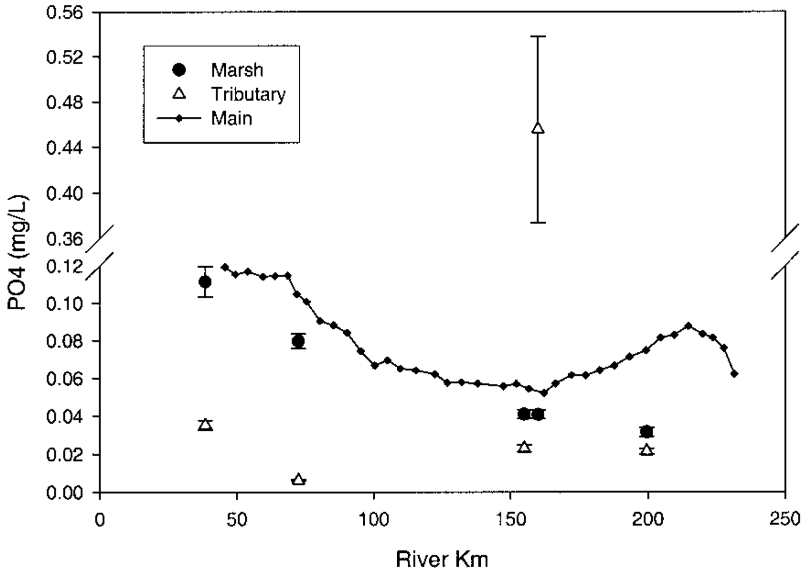


Figure 8: Phosphate (PO_4) concentrations in HRNERR tidal marshes, their associated tributaries and the main channel of the Hudson River by location (The Battery = River km 0). Main concentrations at HRNERR sites are derived from data collected monthly from May 1991-December 2003 (a break in data collection in the marsh sites occurred from June 1992-May 1996). Error bars represent one standard error of the mean. Mean concentrations in the main channel are derived from data collected biweekly during May through October from 1992-2003 (N.F. Caraco and J.J. Cole, unpublished data).

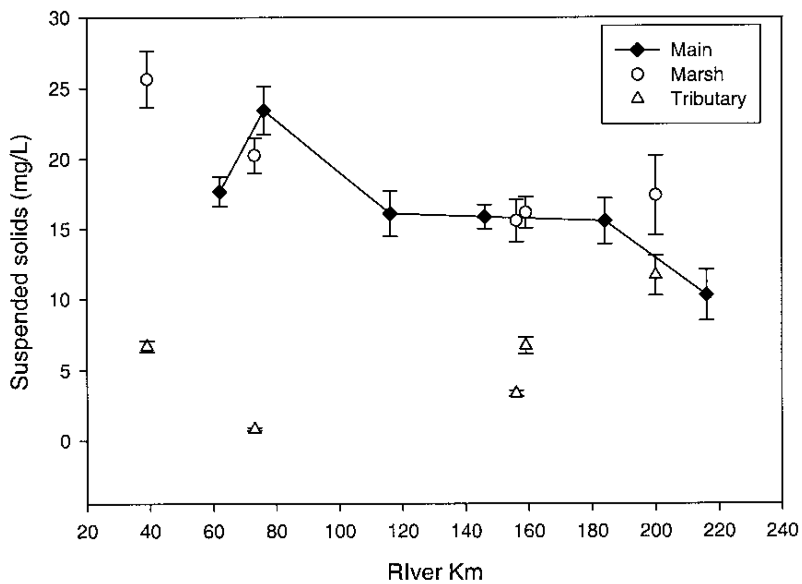


Figure 9: Concentrations of suspended solids in HRNERR tidal marshes, their associated tributaries and the main channel of the Hudson River by location (The Battery = River km 0). Mean concentrations at HRNERR sites are derived from data collected monthly from May 1991-December 2003 (a break in data collection in the marsh sites occurred from June 1992-May 1996). Error bars represent one standard error of the mean (S.E.G. Findlay, unpublished data).

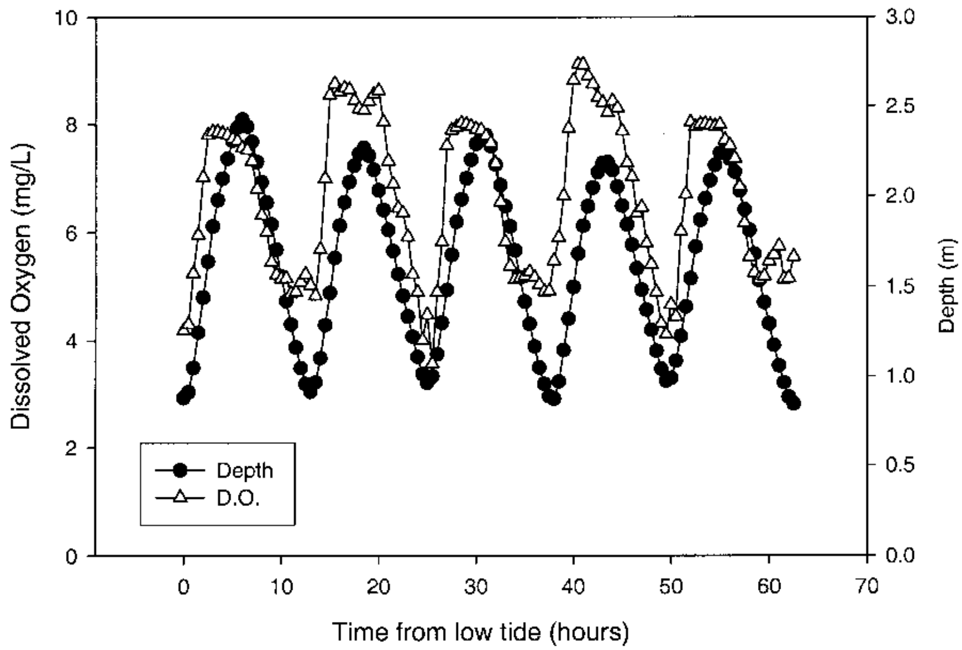


Figure 10: Relationship between DO concentrations and tide stage in Tivoli North Bay in the summer. DO and depth data were observed by a datalogger every 30 minutes.

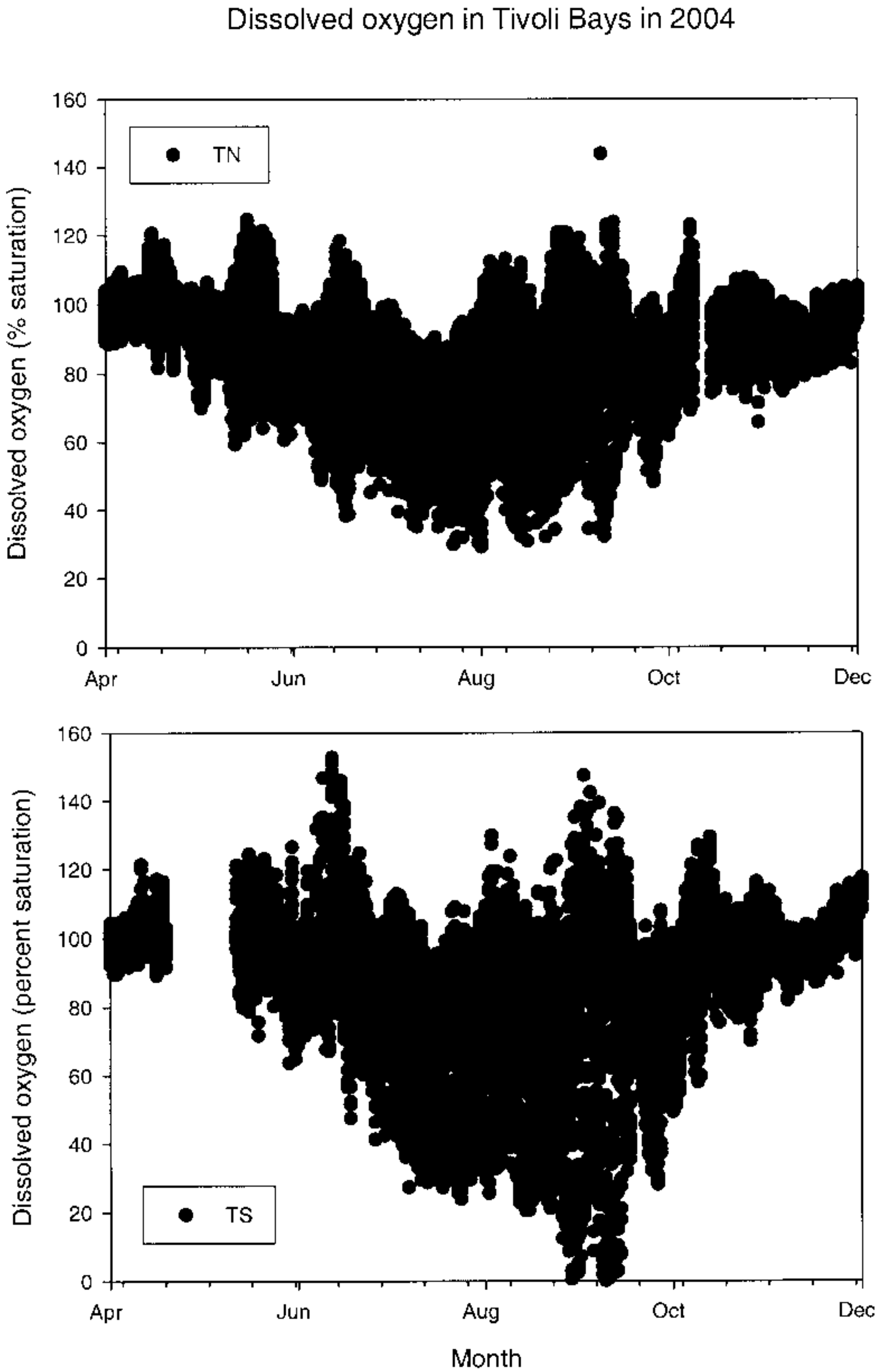


Figure 11: Percent saturation of DO in Tivoli North Bay (TN) and Tivoli South Bay (TS) in 2004. DO data were collected every 30 minutes by dataloggers from late March through late December.

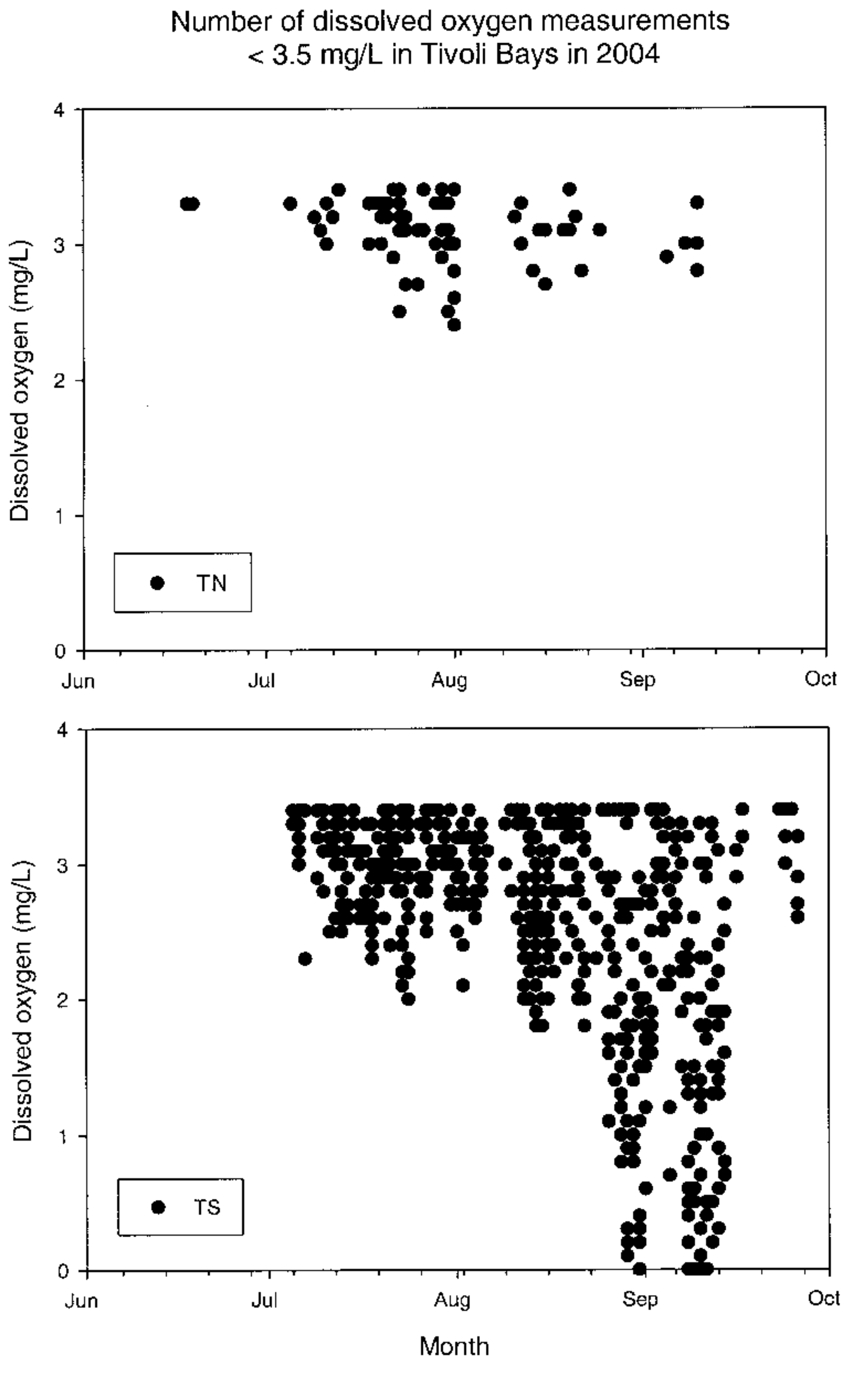


Figure 12: Number and timing of DO measurements <3.5 mg/L in Tivoli North Bay (TN) and Tivoli South Bay (TS) in 2004. DO date were collected every 30 minutes by dataloggers every 30 minutes from late March through late December.

Flats and Iona Island Marsh, perhaps due to the presence of SAV at these sites. DO saturation at Piermont Marsh, where SAV is scarce and largely restricted to the shallow flats offshore of the marsh, is intermediate.

Chloride and Sulfate

Differences in chloride and sulfate concentrations and specific conductivity reflect the degree of development within the watersheds and localized inputs. Sparkill Creek (SP) has a predominantly urban watershed (70%) and Doodletown Brook has a small, forested watershed. The Saw Kill (SK), Stony Creek (SC), and Stockport Creek (ST) have low-density residential watersheds. Development in the Saw Kill watershed is increasing, which may be affecting chloride concentrations and specific conductivity. Stony Creek receives effluent discharge from a sewage treatment plant upstream from the sampling site, which may contribute to the higher specific conductivity and sulfate concentrations relative to the other low-density residential sites.

An increase in chloride concentrations was evident in four out of five Reserve tributaries from 1991-2003 (**Figure 13**). The highest concentrations and greatest increase in yearly mean concentrations (40-110 mg/L) were documented in Sparkill Creek. A seasonal pattern, with spikes in chloride concentrations in the winter months, is evident at this site. This suggests that road salt likely influences chloride concentrations. Yearly mean concentrations have doubled in the Saw Kill since 1991 (**Figure 14**). There is a strong inverse relationship of chloride concentrations to flow at this site, suggesting that chloride is entering the groundwater. Possible sources include road salt, septic systems, and water softeners. Yearly mean concentrations have increased in Stony Creek since 1991, but the increase is not as dramatic (<10 mg/L). However, spikes in chloride concentrations are concurrent with spikes in nitrate and phosphate concentrations, suggesting the possible influence of the sewage treatment plant discharge at this site. Yearly mean concentrations have also increased in Stockport Creek since 1991 (16-23 mg/L), but sources are more difficult to distinguish due to the large area of the watershed (1326 km^2).

Yearly mean sulfate concentrations have decreased in all five Reserve tributaries from 1991-2003 (**Figure 15**). The total decrease in concentration ranges from 20-40%. A similar decrease (approximately 33%) in sulfate concentrations in wet deposition has been recorded by the National Atmospheric Deposition Program monitoring station in West Point, NY. Rainfall appears to affect sulfate concentrations in all Reserve tributaries, with higher concentrations occurring during dry years. In Doodletown Brook, atmospheric deposition is likely the major source of sulfate. Sewage treatment plants on Sparkill Creek and Stony Creek may contribute to sulfate concentrations at Piermont Marsh and Tivoli North Bay.

Hydrology

Hydrologic processes have been studied at three of the four Reserve component sites. Hydrologic exchange between Tivoli North Bay and the Hudson River mainstem has been estimated using a water budget. Tidal inflow accounts for approximately 90% of the total volume of water inflow, and tidal outflow accounts for nearly all of the water leaving the marsh (Lickus and Barten, 1991). Examining the influence of tidal exchange allows identification of long-term trends in the water quality of the Hudson River Estuary and the potential inputs to the estuary from the Reserve sites.

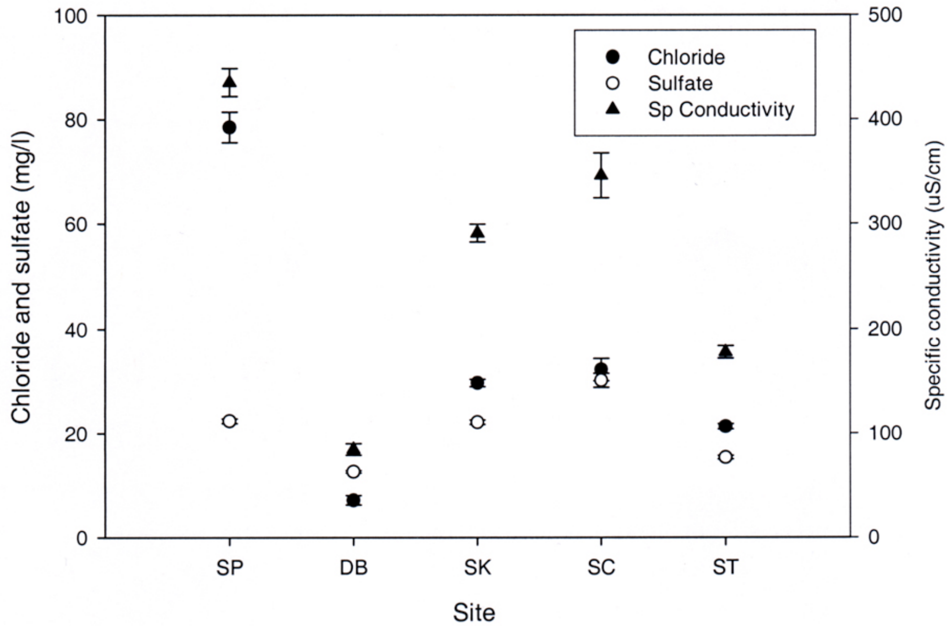


Figure 13: Mean concentrations of chloride and sulfate and mean specific conductivity in all HRNERR tributaries. Means were derived from monthly measurements from May 1991-December 2003. Error bars represent standard error of the mean.

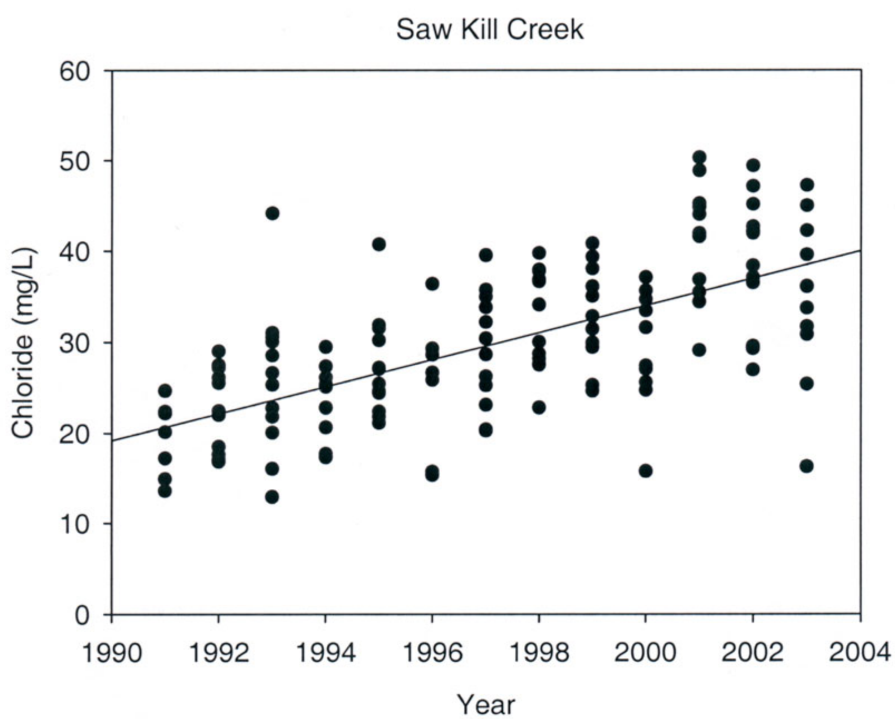


Figure 14: Increase in chloride concentrations in the Saw Kill from 1991-2003. The mean monthly concentrations (two replicates) are shown for each year. The yearly mean chloride concentration has doubled over a 12-year period.

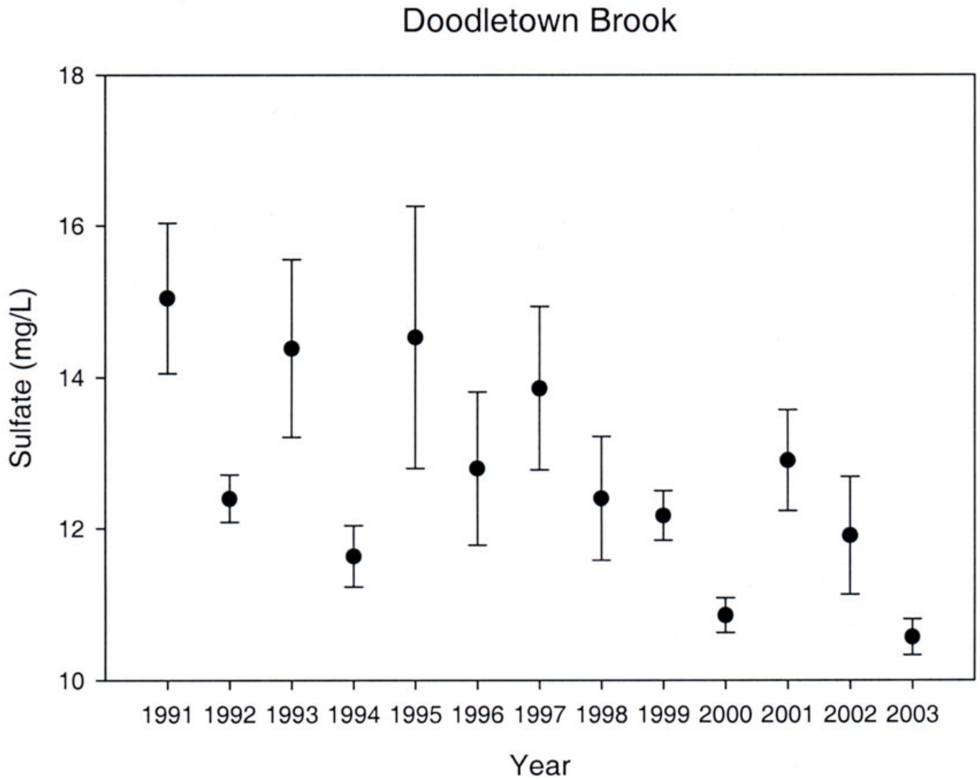


Figure 15: Yearly mean sulfate concentrations in Doodletown Brook from 1991-2003. Mean concentrations are from monthly measurements for the entire year. Error bars represent standard error of the mean.

A comparison of tidal inundation patterns was conducted among narrow-leaved cattail and common reed stands occurring across a range of elevations at Iona Island Marsh, and across an elevation gradient (creekbank to interior) at Piermont Marsh, in association with a study of habitat utilization of common reed stands by resident finfish and macrocrustaceans within the Reserve (Osgood et al., in press). Iona Island marsh flooded more frequently (approximately 50-80% of high tides inundated the marsh) than Piermont Marsh, where an average of 30% and 45% of high tides inundated the marsh surface each month at the high and low elevations, respectively (**Figure 16**). Flooding duration and frequency were significantly different between elevations at Iona Island Marsh, but did not differ with elevation at Piermont Marsh. Flooding depth, duration, and frequency were similar between common reed and narrow-leaved cattail stands occurring at similar elevations at Iona Island Marsh.

Greater depth of flooding did not translate into longer duration of flooding at Piermont Marsh. This phenomenon has also been observed among common reed stands in a Connecticut salt marsh (Osgood et al., 2003). One possible explanation for the incongruity of flooding depth and duration may be ponding in interior sections of marsh that increases duration of flooding relative to the creekbank or marsh edge.

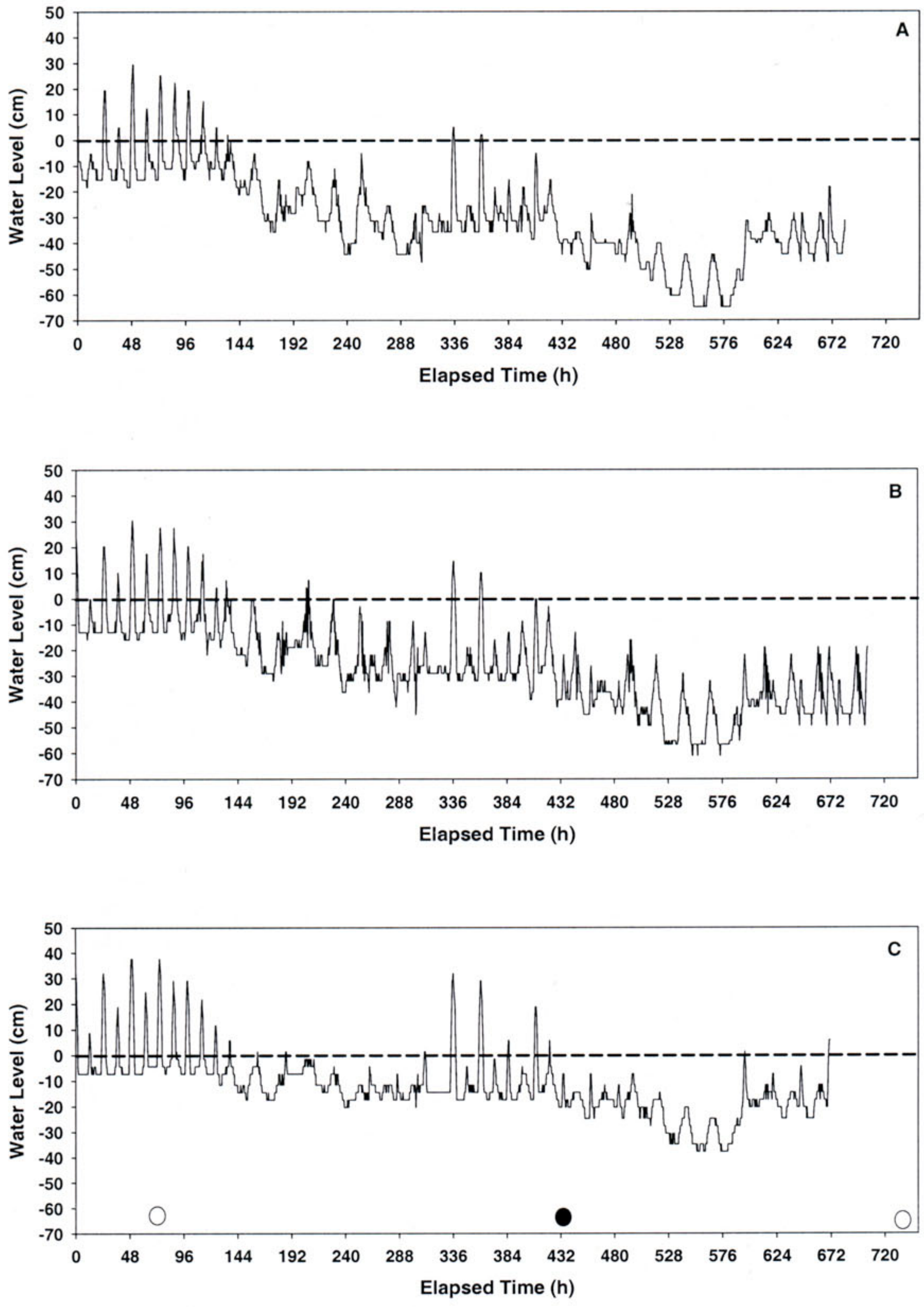


Figure 16: Water level relative to the marsh surface (dashed line) from common reed at Piermont Marsh (A), common reed at Iona Island Marsh (B) and narrow-leaved cattail at Iona Island (C) from July 28-August 26, 2000. Data points were recorded at 24-minute time intervals. Times of new moon (empty circle) and full moon (filled circle) are depicted on the graph.

Biogeochemistry

Various aspects of sediment biogeochemistry have been studied within the Hudson River Reserve. Sedimentation rates for Tivoli South Bay range from 0.59-2.92 cm per year (Benoit et al., 1999). The mean is 1.16 cm per year, which exceeds the current rate of sea level rise, suggesting that the bay will fill in within the next century. Sources of sediment include tidal exchange from the main channel of the Hudson, epsiodic storm events, and sediment input from the Saw Kill. Subtidal areas have lower sedimentation rates, compared to intertidal areas, due to a lack of deposition of organic matter. Burial rates of nitrogen range from 8-19 g of nitrogen m^{-2} per year and 1.1-3.6 g of phosphorus m^{-2} per year in marsh sediments (Merrill, 1999).

There exist four principal sources of nutrients to Hudson River tidal marshes: 1) incoming tides, 2) tributaries, 3) re-mineralization of organic nutrients during the decomposition of organic matter, and 4) atmospheric deposition of nitrogen. Tidal inputs dominate and inorganic nitrogen and phosphorus concentrations are high in the Hudson River mainstem (Lampman et al., 1999). Nitrate concentrations measured in ebbing tidewaters are lower than mean nitrate concentrations in the mainstem, suggesting that Hudson River tidal marshes function as sinks, not sources of nitrogen. The considerable phosphorus uptake requirements of marsh plants suggests a large source of phosphate in incoming tidewaters and phosphorus concentrations in tributary waters are high, likely as a result of treated sewage effluent. Phosphorus concentrations in ebb and flood tide are similar among Reserve marshes.
Denitrification is moderate to high in spring and relies on nitrification of reduced nitrogen, rather than uptake of nitrate from the water column. It is estimated that the Tivoli Bays remove 10,500 kg of particulate nitrogen and 2,000 kg of particulate phosphorus on an annual basis. As surface water salinity increases downriver, sulfate reduction increases. Conversely, denitrification increases as surface water salinity decreases along an estuarine gradient to freshwater habitats upriver (Gould and Findlay, 1991).

Interstitial sulfate concentrations are higher in South Bay than in the river mainstem. The occurrence of methane gas in bubbles from agitated sediments from South Bay indicates substantial anaerobic respiration (McCarron and Findlay, 1989). Consumption and production of methane in South Bay is greater than in North Bay (Goldman and Groffman, 1994).

Porewater nutrients represent a large nutrient pool, and this is considered to be the immediate source of nutrients for emergent marsh vegetation. Enclosed tidal marshes typically exhibit 2-3 times higher concentrations of porewater nitrogen and phosphorus in comparison to sheltered (semi-enclosed) or fringing marshes. The rate of emergent plant nutrient uptake is great enough to completely turnover porewater nutrient pools several times within a single growing season. At Tivoli North Bay, porewater phosphate is significantly lower in purple loosestrife stands during summer, in comparison to that of common reed and narrow-leaved cattail stands (Templer et al., 1998). Porewater ammonium does not differ among the three species.

Common reed sequesters nearly twice the amount of nitrogen per unit marsh area in above-ground plant tissues, than that of narrow-leaved cattail. Sediment microbial biomass on cattail and reed litter is dominated by fungi, and fungal nitrogen accounts for 25% of total nitrogen associated with litter (Findlay et al., 2002). Microbial biomass is similar in water chestnut, narrow-leaved cattail, and spatterdock communities. Production is significantly lower in sandy Hudson River shoreline communities dominated by *Scirpus pungens* (Austin and Findlay, 1989).

Tivoli North Bay and Tivoli South Bay export dissolved organic carbon (DOC) into the Hudson River. Flux studies have determined the primary source of DOC within Tivoli South Bay to be sediment pore water diffusion driven by a concentration gradient between the surface water and pore water. The Saw Kill is not considered to be a major source of DOC as it was determined to have a lower DOC concentration than the Hudson River mainstem. In North Bay, a portion of the total exported DOC diffuses from subtidal sediments; however, the majority of North Bay-derived DOC leaches from narrow-leaved cattail leaf litter and is exported to the Hudson River via ebb tides. North Bay sediment porewater supported the highest rate of bacterial productivity in bioassays; however, since the primary source of DOC in North Bay is leaf litter, the bioavailability of North Bay DOC may be relatively low, in comparison to South Bay (Raphael and Findlay, 1996).

Sediment Contaminants

The Hudson River Estuary has a long and well-documented history of environmental perturbation, including the input of chemical contaminants form a variety of sources. The Reserve sites have been the setting for a number of studies intended to document the distribution of contaminants in estuarine and wetland sediments.

Cores samples form all four Reserve components were analyzed for polychlorinated dibenzo-dioxins (PCDDs) and polychlorinated dibenzo-furans (PCDFs). These samples were supplemented with air, soil, rain, and storm runoff samples from nearby locations. PCDDs and PCDFs were found at all four component sites down to 60 cm. Average PCDD and PCDF concentrations ranged from 800-47,900 pg/g. Average concentration across the Reserve was 9,800 pg/g. The relative contribution of each was about 90% PCDDs and 10% PCDFs. The historical record indicates that PCDD/PCDF deposition was very low prior to 1945; after 1945, concentrations increased rapidly, reaching a maximum between 1950 and 1980 and then declined to values of 4,100-5,600 pg/g by the early 1990s. The primary mechanism of entry to wetlands and adjacent upland soils is atmospheric deposition (Smith et al., 1996).

A time series of sediment and associated pollutant deposition within the estuary was established by inputting the history of radionucleides associated with known releases from the Indian Point nuclear reactor located in Westchester, NY. A core from Iona Island was chosen for detailed analysis; PCB, DDT, and trace metal concentrations were found to be declining (Peller and Bopp, 1986).

Sediment concentrations of lead (Pb), copper (Cu), and zinc (Zn) at Tivoli South Bay are well correlated with each other, as determined by 210Pb dating, implying a common source for the three metals (Wang and Benoit, 1993). Mercury (Hg) enters tidal marshes through atmospheric deposition (Stevenson et al., 1986). However, relatively high mercury concentrations of 190-1070 ng/g-Hg have been reported from Tivoli South Bay, suggesting an additional (non-atmospheric) source of contamination, the most likely source being tidal transport of sediments from the Hudson River mainstem (Zelewski and Armstrong, 1997). Removal of the dam at Fort Edwards in 1973, which resulted in a pulse of PCB contamination to the estuary, is also the likely upstream source of mercury. This event correlates with the occurrence of the highest mercury concentrations in Tivoli South Bay sediment profiles. Deposition rates have declined since this time; this is attributed to a general improvement in water and sediment quality as a result of the passage and implementation of the Clean Water Act of 1972.

Plant Communities

Phytoplankton

The most common of Hudson Estuary phytoplankton fall under four categories: diatoms, blue-green algae, green algae, and flagellates. *Asterionella formosa* is the most common species of pennate diatom found in the freshwater tidal Hudson. *A. japonica* is a marine species typically found downriver. *Coscinodiscus excentricus* is widely distributed along the entire estuary. *C. lineatus* is found in the lower estuary and *C. lustris* and *C. rothii* are found north of the Tappan Zee. *Cyclotella* is widely distributed throughout the estuary. A spring and fall bloom of *C. aliquantale* is common. *C. atommus* occurs following the spring bloom of *C. aliquantale*. Other species of *Cyclotella* in the Hudson include *C. boadnica, C. kutingiana, C. gloema*, *C. ocellata, C. pedostelligera*, and *C stylorum*. Another common diatom in the Hudson Estuary is the genus *Melosira*. *M. ambigua* is abundant in spring and early summer. *M. disan*, *M. granulata*, and *M. italica* also occur in the estuary. *M monoliformis* and *M. sulcata* are typically present south of the Tappan Zee, but have been reported as far north as Bear Mountain. *Skeletonema costatum* is common, occurring in late summer and early fall (Boyce Thompson Institute, 1977).

Free-floating green algae (Chlorophyta) include *Pediastrum,* which are abundant in the mid-estuary during summer. Typical species include *P. biradiatum*, *P. duplex*, *P. simplex*, and *P. tetras*. Over 20 species of *Scenedesmus* occur in the estuary, including *S. quafirausa*, *S. bijuga*, *S. dimorphus*, *S. obliqus*, and *S. opoliensis*. North of the Tappan Zee, the genus *Ankistrodesmus* is encountered, with *A. falcatus* the most common species. Others include *A. barunii*, *A. convilus*, *A. fracus*, and *A. siralis.*

Dinoflagellates are an important component of the Hudson River phytoplanton community. Typical species include *Ceratium hinunella* and *C. tripos*. *Procentumis micans* is a marine species found in the lower estuary.

Blue-green algae (cyanobacteria) are common in estuarine waters and under certain conditions, some species may form harmful blooms toxic to fish and human bathers. *Anacystis*, a fresh to brackish water colonial genera is represented by two species in the Hudson, *A. aeriginusa* and *A. incerta*. Another toxin-producing blue green alga is *Anabena*, which may occur in a free floating or colonial form. *A cicinalis*, *A. flos-aquae*, and *A. siroides* are common in the Hudson Estuary.

A total of 62 phytoplankton taxa were identified during summer sampling at Stockport Flats (Campbell and Dexter, 1987). Freshwater diatoms representing 32 genera and 25 genera of colonial and single-celled green algae achieve peak abundance in the freshwater tidal portion of the estuary during June and early July.

SAV and Water Chestnut

The areal extent of SAV in the Hudson River Estuary from Hastings to Troy is 1,802 ha. This represents some 6% of the total river bottom and approximately 18% of the tidal shallows (Nieder et al., 2004). Water chestnut covers 575 ha and represents 2% of the total river bottom and 6% of the shallows. In the most densely vegetated reach of the river (approximately Hyde Park to Stockport), the combined coverage of SAV and water chestnut approaches 25% of the river area. From Albany north to the Federal Dam at Troy, there are frequent occurrences of very narrow linear beds of water celery located adjacent to the shoreline. These beds are generally less than three meters wide and occur in waters less than two meters in depth.

It is believed that other factors besides light penetration can play a significant role in determining the distribution of SAV in the Hudson River Estuary. These factors may include substrate type, flow velocities, ice scour, bioturbation (by carp and snapping turtles), and grazing by waterfowl and muskrat. Longitudinal distribution patterns of SAV in certain reaches of the estuary have implications for distribution of early life stages of organisms which rely on SAV as critical habitat (e.g., larval and juvenile fish) and may result in differential habitat encounter rates for transient fish that seek out SAV habitat for feeding or predator avoidance. In general, fishes moving towards shore will encounter SAV habitat before encountering water chestnut. Because of the high visibility of the floating water chestnut beds to the casual river observer, it is difficult to appreciate the fact that SAV habitat is actually three times more abundant in the estuary.

More than 20 studies have been conducted on water chestnut, which has thrived in the Hudson River since the 1930s. The body of research has included studies of the life cycle of the water chestnut, distribution and trophic dynamics of the fish and invertebrate populations that live within the water chestnut beds, and comparisons of water chestnut beds with other SAV communities. Most of the research has been conducted within Tivoli South Bay, which is almost entirely covered with water chestnut during the summer months.

Stems and rosettes of the water chestnut develop in late spring. By the end of June, water chestnut reaches its maximum coverage of shallow areas of the estuary. By July, water chestnut reaches its greatest biomass. The plants undergo rapid senescence and decomposition during September and October (Schmidt and Kiviat, 1988). The decline of the water chestnut beds in August-September correlates with a decline in the export of organic seston, indicating that water chestnut decomposes in the bay, with the majority of the organic biomass consumed by bacteria and fungi (Goldhammer and Findlay, 1988; Findlay et al., 1990).

Negative effects of the water chestnut beds include: extirpating rare and native species, out-competing waterfowl food plants, increasing sedimentation in areas where beds flourish, modifying water chemistry and BOD, decreasing DO, altering the fish species composition of an area, and interfering with recreation and navigation (Anderson and Schmidt, 1989).

Three food webs exist within the water chestnut beds. Larval and juvenile fish feed on epiphytic invertebrates, which in turn feed on the algae growing on the leaves and stems of the plants; a benthic system of decomposers thrives on the water chestnut detritus and sediments; and the water-lily leaf beetle (*Galerucella nymphaeae*) feeds on the upper surface of the leaves and is fed on by a predatory ladybug (*Coleomegilla macolata*). Juvenile fish, including spottail shiners, common carp, golden shiners (*Notemigonus crysoleucas*), banded killifish, and fourspine sticklebacks (*Apeltes quadracus*), feed upon a variety of epiphytic microcrustaceans and insect larvae associated with the water chestnut plants.

Emergent Intertidal

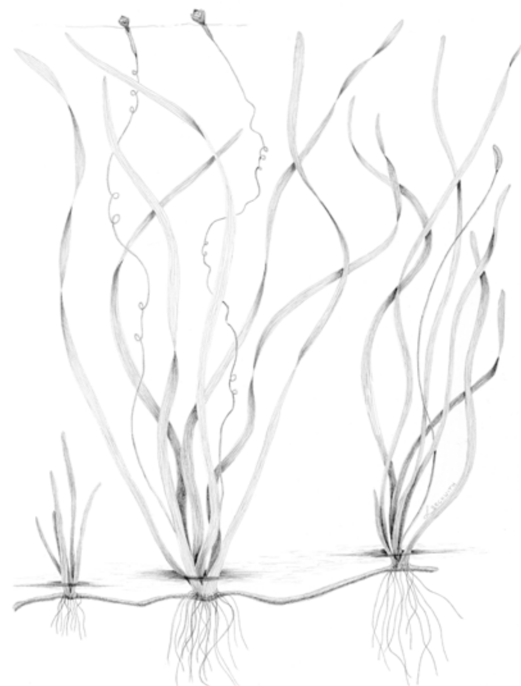
Primary production and aboveground macrophyte standing crop in freshwater tidal wetlands is among the highest reported for wetlands (Odum et al., 1984; Odum, 1988). Soils of Hudson River freshwater tidal wetlands are predominantly fine silts and clays with organic matter content of 8-12% in shallow subtidal environments, and up to 25-45% in vegetated mid-upper intertidal locations (Kiviat and Beecher, 1991). These values are similar to those reported from marshes in the Delaware River and Chesapeake Bay. Some differences noted between the Hudson River freshwater tidal marshes and those occurring in more southern estuaries are that narrow-leaved cattail appears to occupy a greater portion of the upper intertidal zone and purple loosestrife is more prevalent in the Hudson.

The Reserve has completed plant community maps for each component site using aerial photographs taken during summer 1991 and repeated in 1997. These large-scale maps (1"=200'), produced in both black and white and color, accurately depict the wetland vegetation communities.

The 1991 surveys consisted of over 100 land cover classes, which were subsequently recoded to match the 20 classes used in the 1997 survey.

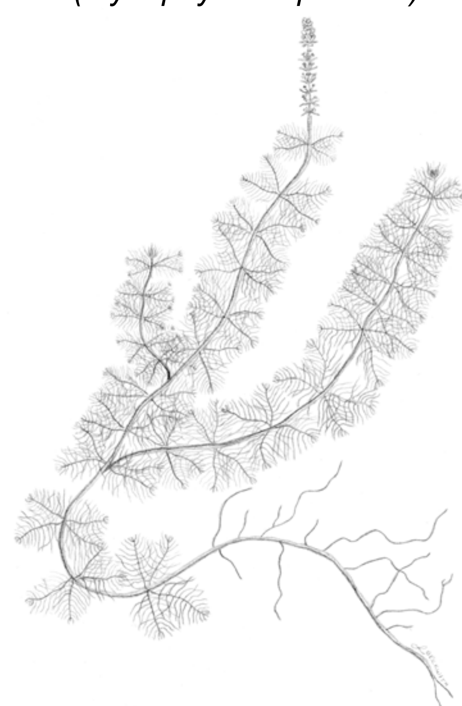
Water Celery

(Vallisneria americana)



European Water-milfoil

(Myriophyllum spicatum)



Water celery, European water-milfoil, and water chestnut dominate subtidal habitats within Tivoli North Bay. Spatterdock dominates the lower third of the intertidal zone and creek bank edge habitat supports a mixed community of spotted jewelweed, rice cut-grass, arrow-arum, purple loosestrife, and narrow-leaved cattail. The upper portion of the intertidal zone is dominated by narrow-leaved cattail and common arrowhead. Aboveground biomass of narrow-leaved cattail is similar to that reported from freshwater tidal wetlands in other estuaries, but aboveground biomass of spatterdock is lower than reported elsewhere (Kiviat and Beecher, 1991).

Some changes in the vegetation dynamics of the Tivoli Bays are occurring. Since the mid-1970s, muskrat clearings have been re-invaded by narrow-leaved cattail, and common reed has become established in at least six distinct stands. Water celery populations have increased at the expense of European water-milfoil. Water chestnut was able to re-invade the Tivoli Bays when NYSDEC discontinued application of the herbicide 2,4-D in 1976. Purple loosestrife expanded throughout Tivoli North Bay during the 1970s, 1980s, and 1990s, especially along the rail causeway. Sweet flag, previously considered rare in the Tivoli Bays, has increased in certain areas. Many of these changes have been attributed to the decline of the muskrat population in the Tivoli Bays, as many of the aforementioned species (sweet flag and cattail) were favored muskrat food items. Kiviat and Beecher (1991) determined that elevation was the primary environmental variable controlling the production and accumulation of organic matter by rapidly growing, flood-tolerant, marsh perennials which tend to have large underground storage organs and/or standing dead aerial parts, and which persist through the winter. Physical and biological disturbance along creekbanks and pool edges prevents establishment of narrow-leaved cattail stands, allowing a mixed community to thrive, contributing to greater species richness and community evenness.

Tidal Swamp
A total of 226 plant species, representing 142 genera and 66 families have been reported from Cruger Island Neck and the Big Bend Swamp at the Tivoli Bays. The most common tree species are green ash, black ash (*Fraxinus nigra*), and red maple. Common shrubs include willow, Bell's honeysuckle, silky dogwood, red-osier dogwood (*Cornus sericea*), spice-bush, and swamp-rose (*Rosa palustris*). Understory vegetation is dominated by spotted jewelweed, purple loosestrife, and sensitive fern (Westad and Kiviat, 1986). A total of 57 species of mosses and liverworts have been identified in the area (Leonardi and Kiviat, 1990).

Invertebrate Communities

Zooplankton
Zooplankton communities have been studied at three of the Reserve sites. At Piermont Marsh, the summer zooplankton assemblage is dominated by copepod nauplii. Adult harpacticoid copepods and barnacle nauplii are also abundant. Spatial and temporal variations in zooplankton distribution at Piermont Marsh are determined by variables such as tributary flow, tidal mixing and re-suspension, and storm events (Nemazie and Dexter, 1988).

A total of 33 zooplankton taxa have been reported from the Tivoli Bays component. The copepod *Eurytemora affinis*, and the cladoceran *Bosmina longirostris* are the dominant species. Nighttime densities are 2-5 times greater than daytime, indicating a net import from the river mainstem to the bays at night (Drill and Schmidt, 1988).

A total of 22 zooplankton taxa have been reported from the Stockport Flats component. The assemblage is dominated by microcrustaceans (cladocerans, cyclopoid copepods, and ostracods). Rotifers are abundant in most samples with at least seven genera represented. Sheltered (semi-enclosed) embayments support the greatest abundance and diversity of zooplankton, relative to open waters (Campbell and Dexter, 1987).

Benthic and Epiphytic Invertebrates

Benthic invertebrate communities associated with the intertidal common reed stands at Iona Island and Piermont Marsh are dominated by annelids (Tubificidae, Enchytraidae), insect larvae (Diptera) and molluscs (Sphaeriidae and Hydrobiidae). Macroinvertebrate taxa richness is greater at Iona Island Marsh relative to Piermont Marsh. Taxa richness is lowest among the common reed stands at Piermont Marsh, but similar among common reed and narrow-leaved cattail stands at Iona. Intertidal common reed stands in Hudson River tidal marshes appear to support abundant and diverse macroinvertebrate communities, indicating that this particular function may not necessarily be impaired in intertidal wetlands experiencing invasion by common reed (Osgood et al., in press).

The benthic and epiphytic invertebrate communities associated with the water chestnut beds in Tivoli South Bay have been studied in considerable detail. The surfaces of water chestnut leaves in Tivoli South Bay are colonized mostly by chironomids (*Endochironomus*, *Dicrotendipes*, *Tanytarsus*, *Ablabesmyia*, and *Polypedilum*), tanypodine larvae (*Procladius*), and Orthocladinae (*Cricotopus*). Other insects and invertebrates present include aquatic bugs (Hemiptera), beetles (Coleoptera), gastrotrichs, bryozoans (Cristatellidae and Plumatellidae), leeches (Hirudinea), amphipods (Talitridae and Gammaridae), and gastropods (Lymnaeidae, Ancylidae, Physidae, and Planorbidae) (Findlay et al., 1989; Yozzo and Odum, 1993).

Characteristic microcrustacean taxa associated with the water chestnut beds of South Bay include several common littoral cladocerans (*Sida crystallina*, *Holopedium gibberum*, *Bosmina longirostris, Ceriodaphnia* sp., and *Alona* sp.), the cyclopoid copepod *Eucyclops agilis* and several species of ostracods, including *Cypridopsis vidua, Darwinula stevensoni, Candona* sp., and *Physocypria* sp. (Yozzo and Odum, 1993). From June-August, epiphytic invertebrates in Tivoli South Bay are relatively more abundant than benthic invertebrates, suggesting the importance of the summer water chestnut beds as habitat for epifauna (Schoeberl and Findlay, 1988).

A marked decline in epiphytic invertebrate abundance (especially chironomids) occurs during July in Tivoli South Bay (Wagner and Findlay, 1987). Possible explanations for this decline include predation by juvenile fishes and other invertebrates (e.g. damselfly larvae, predaceous chironomids), changes in habitat structure and suitability resulting in a reduction in available surface area for colonization, competition among the various chironomid species, and emergence of adult insects. Predator exclusion experiments did not establish an effect of juvenile fish predation on epiphytic microcrustacean communities in Tivoli South Bay; however, ostracods, cyclopoid copepods, cladocerans, and early instar chironomid larvae are numerically important prey items in the guts of juvenile and adult banded killifish, and several other resident fish species in the study area (Yozzo and Odum, 1993).

Oligochaetes, chironomids, *Sida*, and *Hydra* are the most common epiphytic invertebrates found on leaves and stems of water celery, which also occurs in Tivoli South Bay, primarily in deeper channels where water chestnut growth is sparse or along the edges of the water chestnut beds (Lutz and Strayer, 2001).

In South Bay sediments, chironomids are most abundant, with two dominant genera, *Tanytarsus* and *Polypedilum*. *Chironomus* sp., *Harnischia*, the tanypodine midge *Procladius*, and the naidid oligochaetes *Stylaria*, *Chaetogaster*, and *Dero* are also common. Additional sediment-dwelling invertebrates include gastropods, cladocerans, and ostracods. Densities of benthic invertebrates in Tivoli South Bay are comparable to infaunal densities from non-tidal freshwater habitats (Findlay et al., 1989; Yozzo and Diaz, 1999).

Reference wetland characterization studies conducted at Tivoli North Bay have documented patterns of benthic macroinvertebrate abundance and distribution across the intertidal zone and among seasons (Yozzo et al., 1999). Benthic macroinvertebrate taxa richness is greatest in the mid-intertidal in July and greatest in the upper-intertidal in September. Total macroinvertebrate density is greatest in the lower-intertidal zone in July and greatest in the upper-intertidal zone in September. Total biomass is greatest in the lower intertidal zone in July and greatest in the upper-intertidal zone in September (**Table 1**, **Table 2**).

Both sediment-dwelling and epiphytic ostracods occur among a variety of habitat types at the Stockport Flats component, including emergent low marsh, unvegetated shallows, and water chestnut beds. The fauna is dominated by one species (*Physocypria* sp.) and several other widely distributed taxa are common (*Darwinula stevensoni, Candona* sp., and *Cypridopsis vidua*). Less common taxa include *Candona caudata*, *Limnocythere* sp., and *Ilyocypris gibba*. Although comprehensive surveys of freshwater ostracods are rare, it is believed that ostracod faunas of freshwater tidal wetlands may be species-poor relative to those of non-tidal freshwater habitats. (Yozzo and Steineck, 1994).

Terrestrial Invertebrates

Terrestrial invertebrate communities have received limited attention at the Reserve. Two early studies focused on the distribution and life history of Lepidoptera at Tivoli North Bay (Barbour and Kiviat, 1986) and the ecology of the water-lily leaf beetle (*Galerucella nymphaeae*) in Tivoli South Bay (Schmidt, 1986). A more recent study compared the distribution and abundance of terrestrial insects among common reed, purple loosestrife, and narrow-leaved cattail stands in Tivoli North Bay (Krause et al., 1997).

Some 30 species of diurnal Lepidoptera, 25 butterflies and five moths, are known from edge habitats (e.g., road, railbed) within the Tivoli North Bay - Cruger Neck area of the Tivoli Bays. The most common are the cabbage butterfly (*Pieris rapae*) and the silver-spotted skipper (*Epargyreus clarus*). A total of 27 species of nocturnal moths have been identified in the Reserve, but only two occur in large numbers: the pearly wood nymph (*Eudryas unio*) and the dusky groundling (*Condica vecors*). Nectar sources for moths and butterflies in the Tivoli Bays include pickerel-weed, purple loosestrife, joe-pye-weed (*Eupatorium* spp.), dogwoods, bur-marigold (*Bidens cernua*), and spotted knapweed (*Centaurea biebersteinii*). Bird

Table 1: Percent abundance of dominant macroinvertebrate taxa (> 5% of the total) collected at Tivoli North Bay sites, July and September 1997 (TNB L = lower intertidal; TNB M = middle intertidal; and TNB U = upper intertidal) (adapted from Yozzo et al., 1999).

July

Taxa	TNB L	TNB M	TNB U
Annelida			
Tubificidae sp.	50.1	26.7	70.4
Quistadrilus multisetosus	14.8		
Bivalvia			
Pisidium sp.			9.9
Diptera			
Ceratopogonidae sp.		50.1	5.3
Chironomidae			
Tanytarsus sp.	11.9		

September

Taxa	TNB L	TNB M	TNB U
Annelida			
Tubificidae sp.	51.7	39.8	42.3
Quistadrilus multisetosus	9.4		
Lumbriculidae sp.			6.7
Gastropoda			
Ancylidae sp.		8.8	
Bivalvia			
Sphaeriidae sp.			9.5
Pisidium casertanum			7.8
Amphipoda			
Gammarus sp.		5.1	
Diptera			
Ceratopogonidae sp.	6.5	13.0	5.6
Chironomidae			
Procladius sp.		6.5	
Tanypus sp.	5.9		

Table 2: Total number, mean density, and biomass of dominant macroinvertebrate taxa collected at Tivoli North Bay sites, July and September 1997 (Adapted from Yozzo et al., 1999).

July

Station	Total No. Taxa	Mean Density No./m^2 (S.E.)	Biomass g/m^2 (S.E.)
TNB L	32	36000 (13447)	1.01 (0.67)
TNB M	38	6420 (1623)	0.07 (0.01)
TNB U	30	28545 (45583)	1.51 (0.89)
		23655 (13134)	0.86 (0.73)

September

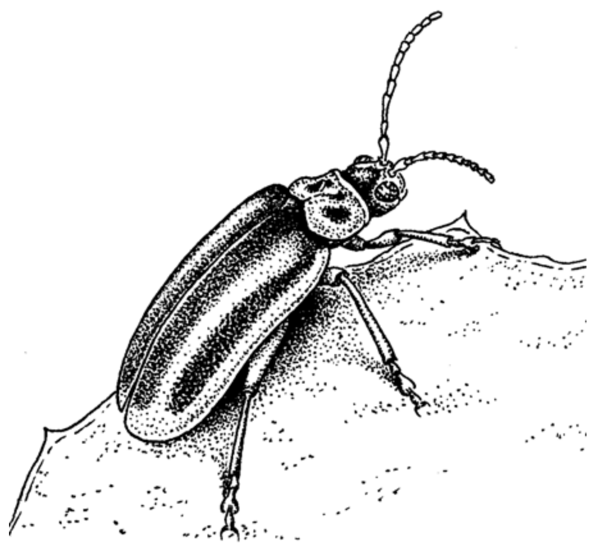
Station	Total No. Taxa	Mean Density No./m^2 (S.E.)	Biomass g/m^2 (S.E.)
TNB L	24	14591 (2562)	0.20 (0.05)
TNB M	25	9818 (2372)	0.34 (0.11)
TNB U	38	16318 (5161)	2.05 (0.66)
		13576 (900)	0.86 (0.59)

predation has been observed on tiger swallowtail (*Papilio glaucus*), red admiral (*Vanessa atalanta*), and viceroy (*Limenitis archippus*) at the Tivoli Bays. Larvae of the fall webworm (*Hyphantria cunea*) were the most abundant. Early life stages of five butterflies and six moths were found, suggesting that those species are lifetime residents. Willow, wild black cherry (*Prunus serotina*), choke-cherry (*P. virginiana*), common elder (*Sambucus canadensis*), spice-bush, and Bell's honeysuckle host larval populations. Defoliation activities along the railroad right-of-way have limited plant species available to butterfly and moth larvae. The most abundant butterfly in the area, the cabbage butterfly, is found primarily along the right-of-way.

The water-lily leaf beetle occurs in close association with water chestnut, spatterdock, and purple loosestrife. The beetles overwinter under logs, moss, and leaf litter. The eggs are laid on the mature leaves of the water chestnut. The beetles can withstand submersion to a certain degree, during storms and high tide. Red-winged blackbirds, cedar waxwings (*Bombycilla cedrorum*), marsh wrens, and least bitterns are known to feed on water-lily leaf beetles in Tivoli North Bay. A damselfly, the big bluet (*Enallagma durum*), is commonly found among water chestnut beds.

In Tivoli North Bay, at least ten insect species, representing seven orders (Coleptera, Diptera, Homoptera, Hymenoptera, Lepidoptera, Collembola, and Thysanoptera), are known to occur on purple loosestrife, common reed, and narrow-leaved cattail. The most abundant insect species is the homopteran *Chaetoccus phragmitis,* representing 74% and 60% of total insect biomass on common reed in spring and summer, respectively. The lepidopteran *Lymnaecia phragmitella* is seasonally abundant, representing 85% and 29% of total insect biomass on narrow-leaved cattail in spring and summer, respectively. Bumble bees (*Bombus* spp.) and honeybees (*Apis mellifera*) are common among purple loosestrife.

Water-lily Leaf Beetle
(Galerucella nymphaeae)



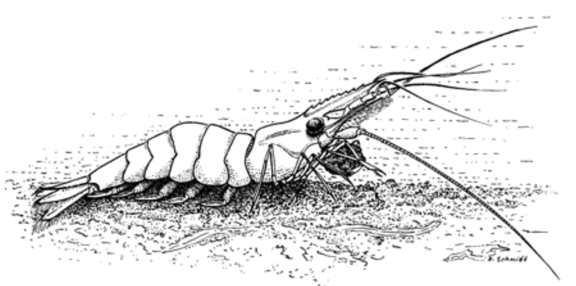
Fish Communities

Marsh/Estuarine Resident Species
Marsh resident fish species are those which utilize intertidal marshes for most or all of their life history (Kneib, 1997). Examples of marsh residents in northeastern U.S. tidal wetlands include the various killifishes (*Fundulus* spp.). A number of studies in the Reserve have focused specifically on the ecology of marsh resident fish species.

The abundance of marsh resident species at Piermont Marsh and Iona Island Marsh has been estimated using intertidal lift nets. Nekton densities have been related to continuous measurements of tidal hydrology on the marsh surface and observations of marsh geomorphic properties at the marsh edge and interior locations. Marsh resident species at Iona Island include the ubiquitous mummichog; while at Piermont marsh, mummichogs and dagger-blade grass shrimp comprise the majority of the resident nekton community, although densities are generally low in the dense common reed stands (Hanson et al., 2002; Osgood et al., in press).

Dagger-blade Grass Shrimp

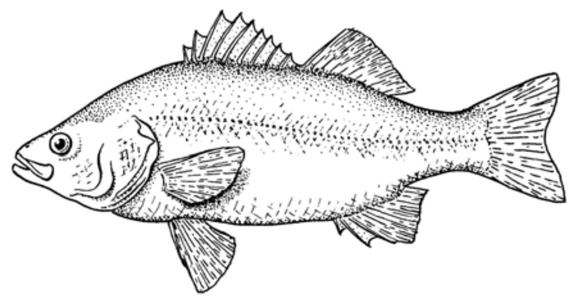
(Palaemonetes pugio)



At Iona Island Marsh, a comparison of larval and juvenile mummichog distribution among cattail, and large vs. small patch sizes of invasive common reed, found significantly fewer mummichog YOY within the large common reed patches relative to the narrow-leaved cattail, but discerned no significant difference in abundance between cattail vs. the smaller common reed patches. A positive correlation was observed between YOY abundance and intertidal flooding depth. In addition, large numbers of YOY were observed to congregate in shallow intertidal pools in the adjacent creek beds. It is hypothesized that common reed invasion may alter YOY distribution patterns with fish selecting creek bed refugia over intertidal marsh surfaces, which have converted from narrow-leaved cattail to common reed (Harm et al., 2003).

White Perch

(Morone americana)



Differences in the transient fish populations of tidal creeks draining common reed and narrow-leaved cattail stands have been observed within the Reserve. At Iona Island Marsh, creeks draining common reed stands are characterized by reduced light penetration in the water column and sparse growth of SAV. Creeks draining narrow-leaved cattail stands support more luxuriant growth of SAV. A recent comparison of two tidal creeks at Iona Island (common reed vs. narrow-leaved cattail) yielded a total of fourteen fish species from the common reed creek, while the narrow-leaved cattail creek yielded only five species. Total abundance of fish collected was similar between both creeks. The most common resident species, mummichog, represented 84% of total fish collected and was equally abundant between both creek types. White perch and blue crab were also common in both creeks. Gut fullness was comparable among fish foraging in both creeks, but prey composition differed. Aquatic worms, insects and grass shrimp were the most common food items in fish guts from the creeks draining common reed. Worms, insects, amphipods, and fish were the most common food items in creeks draining narrow-leaved cattail stands (Lewis, 2001).

Recent examination of the resident fish community associated with common reed stands in Tivoli North Bay suggest that while utilization of common reed habitat by resident fishes was still comparable to adjacent narrow-leaved cattail habitat, these stands will eventually expand in area and accrete vertically, thereby decreasing flooding frequency, depth and duration and restricting fish access (Yozzo and Cianciola, 2002).

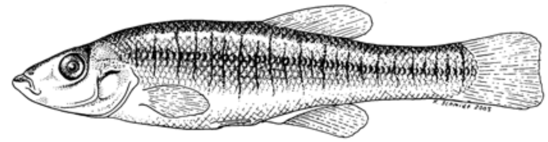
Recently, several new distribution records for the spotfin killifish (*Fundulus luciae*) were reported in the northeastern U.S., including Piermont Marsh (Yozzo and Ottman, 2003). This represents the first collection of this species in the Hudson River drainage, although they are known to inhabit high intertidal marshes along the Atlantic coast from southeastern Massachusetts (Narragansett Bay drainage) to Georgia (Jorgenson, 1969; Hartel et al., 2002). Spotfin killifish may not necessarily be rare, but their cryptic lifestyle and preference for high salt and brackish marshes may have precluded their collection in previous studies.

Freshwater Species

The fish assemblages in the Tivoli Bays are determined primarily by vegetation type and water depth. The water chestnut mats in South Bay support many species of larval and juvenile fish. Three common species (golden shiner, carp, and banded killifish) represent 95% of the larval fish community. The dense vegetation provides protective cover from bird and fish predators and hosts a diverse assemblage of small invertebrates such as chydorid cladocerans, harpacticoid copepods, and chironomid midge larvae (Sidari and Schmidt, 1990; Yozzo and Odum, 1993). Dense areas of the water chestnut beds typically support greater numbers of larval and juvenile fish and are more diverse than sparse cover (Anderson and Schmidt, 1989). However, greater fish biomass (e.g., larger individuals) is found

Banded Killifish

(Fundulus diaphanus)



along the edges of the beds (Frenzel and Limburg, 2004).

The edge areas of the water chestnut mats are inhabited by different species including white sucker (*Catostomus commersoni*), juvenile spottail shiner, and tessellated darter. Unvegetated shallows in South Bay are occupied by cyprinids, white perch, and juvenile striped bass (Gilchrest and Schmidt, 1998). Fourspine stickleback are common among water chestnut in South Bay in some years and seemingly rare in others (Pelczarski and Schmidt, 1991; Gilchrest and Schmidt, 1998; Kelley and Schultz, 2003).

South Bay does not appear to be a source or a sink for alewife or white perch larvae, although the two species may feed in the bay. Alewife larvae are most abundant during diurnal flood tides; carp and bluegill (*Lepomis macrochirus*) larvae are abundant during nocturnal ebb tides; white perch larvae are not correlated with any particular tidal or diel stage (Bohne and Schmidt, 1989).

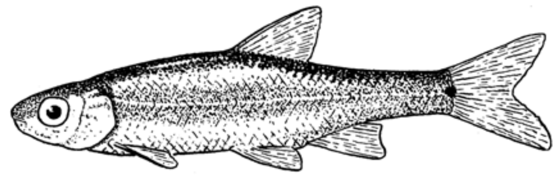
Common carp are an important component of the fish community of Tivoli South Bay (Gilchrest and Schmidt, 1998). Carp feed on detritus, chironomid midges, and snails. South Bay is used primarily by adult carp as a spawning site, and larval carp emigrate to the main channel on the ebb tides. Adult carp can often be observed rising to the surface in South Bay, moving their mouths and making popping noises, possibly gasping for oxygen (Montgomery and Schmidt, 1993).

Tivoli North Bay is also regarded as an important nursery area for fish. Water celery and European water-milfoil beds in North Bay, and in shallow subtidal channels behind Magdalen and Cruger Islands, support a variety of species, including golden shiner, redbreast sunfish, goldfish (*Carassius auratus*), and largemouth bass. Banded killifish, spottail shiners, white perch, and tessellated darters prefer shallow intertidal areas within North Bay, while herrings (blueback herring, alewife, and American shad) are found in deeper channels (Schmidt, 1986; Schmidt and Kiviat, 1988).

Banded killifish are one of the most common species present in Tivoli North Bay throughout the year. They have been described as "the freshwater ecological equivalent of the saltwater mummichogs" (Richard and Schmidt, 1987), although the two species co-occur in North Bay and in Hudson River tidal wetlands south of the Tivoli Bays. Evidence of hybridization between these two fundulids has been documented in the freshwater tidal Hudson River (Mugue and Weis, 1995). Important prey items for small killifish, which forage on the flooded marsh surface at high tide, include cladocerans and copepods; as they grow larger, ostracods and chironomid larvae constitute more of their diet. Killifish serve as an important trophic link in the food web of North Bay, as they are preyed upon by larger piscivorous fish and wading birds (e.g., great blue heron (*Ardea herodias*), green-backed heron, and least bittern).

Tessellated darters are common in the intertidal shallows and among the water celery beds of North Bay (Hankin and Schmidt, 1992). Juvenile tessellated darters

Spottail Shiner
(Notropis hudsonius)



feed on chironomid larvae, cladocerans, and copepods. As the YOY darters grow throughout the summer, the relative importance of the different invertebrate prey changes, with chironomids becoming more important to larger fish. Almost all darters collected in North Bay are juveniles, indicating possible movement of mature fish into the main channel (Duryea and Schmidt, 1987).

Goldfish were once abundant throughout the freshwater tidal Hudson, but experienced a decline during the 1980s and 1990s. Recent results of the Reserve's fish monitoring program suggest that this species may be on the increase in the Tivoli Bays (Schmidt et al., 2002a; 2002b; 2004).

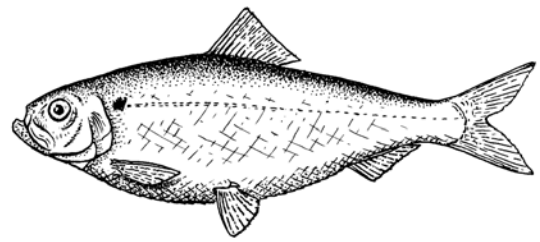
Passive hydroacoustic technology has recently been employed to further characterize the fish communities of the Tivoli Bays (Anderson et al., 2004). During 2003, a total of eighteen distinct sounds were recorded in the Tivoli Bays, five of which were considered fish sounds (although no specific species could be identified) and eight additional unidentified biological sounds. Potential soniforous species occupying the Tivoli Bays include channel catfish (*Ictalurus punctatus*) and brown bullhead (*Ameiurus nebulosus*).

Black bass (largemouth bass and smallmouth bass) populations have increased in the Hudson River Estuary in recent years. This has been attributed in part to an increase in the spatial extent of vegetated littoral habitat as a result of the zebra mussel invasion of the early 1990s (Strayer et al., 1999). The majority of largemouth bass present in the Hudson River are either produced in the mainstem of the river or enter the mainstem very early in development (Hopkins and Green, 1989). At Stockport Flats, bass prefer protected areas such as bays, pools, impoundments, and creek outlets (Nack and Cook, 1987). Submerged vegetation is an important determinant of nest site selection (Green et al., 1988). Most bass nests are found in areas with at least some vegetative cover. Shallow river shorelines, subject to strong wave, wind, or current action, are not likely to be used as nest sites. Many of the largemouth bass that winter in tidal creek mouths will move into the main channel during spring as water temperature increases.

Drift of smallmouth bass fry from Stockport Creek suggests potamodromy (migration for reproduction within freshwater) in this population (Schmidt and Stillman, 1998). The estimated magnitude of the drift is large enough to be a significant addition to the estuarine smallmouth bass population in the Hudson River mainstem. Other species known to be potamodromous in the Hudson River include white sucker, spottail shiner, yellow perch, and white perch (Schmidt and Stillman, 1994).

Migratory Species
The life history and trophic dynamics of various herring species (alewife, American shad, and blueback herring) have been studied within the Reserve and within the mainstem of the Hudson River. These migratory fish represent an important trophic link between the semi-isolated tidal wetlands and embayments and the open waters of the Hudson River mainstem. All three species migrate up into the freshwater tidal portion of the estuary to spawn in early

Alewife
(Alosa pseudoharengus)



spring and the larvae are commonly encountered in the shallow backwaters and bays throughout the summer. However, the alewife is the only herring species that consistently spawns in Hudson River tributaries in substantial numbers (Schmidt and Lake, 2000). Alewife spawning runs have consistent temporal patterns and tributaries in the upper reaches of the estuary have unimodal runs with a mid-May maximum.

Larval alewife and blueback herring feed on cladocerans, copepods, ostracods, rotifers, protozoa, and phytoplankton in Tivoli North and South Bays. Juvenile shad feed on a variety of arthropods including midges, ants, beetle larvae, and copepods. Juvenile blueback herring feed primarily on microcrustaceans, specifically the cladoceran *Bosmina longirostis* (Limburg and Strayer, 1988).

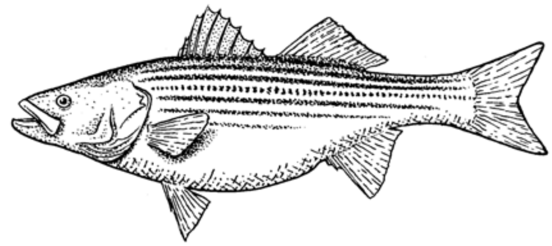
Hudson River herring populations have experienced a dramatic decline within the past several years, and it is feared the cause of this decline may be related to increased zebra mussel filtration of zooplankton food sources for juvenile herring and other pelagic fish species in the Hudson (Schmidt et al., 2002a; 2002b; 2004). Preserving water and habitat quality of the tributaries is critical to maintaining the integrity of these populations and Hudson River fisheries scientists have recommended installation of fish ladders on significant spawning tributaries to help manage and enhance the stock.

Striped bass have ben intensively studies in the mainstem (Rathjen and Miller, 1957; McLaren et al., 1981; Waldman et al., 1990), but have received little attention within the Reserve. Juvenile striped bass are known to occur within each of the component sites and during certain times of the year (e.g., late spring – early summer) can be particularly abundant, especially among the deeper channels and pools of Tivoli South Bay. The Hudson River stock is the northernmost of the three main migratory stocks (along with Chesapeake Bay and Delaware River) that support an intensive recreational fishery along the northeastern U.S. coastline. Striped bass spawn in the mid to upper reaches of the estuary (above the salt front) from early May through June, and are regarded as the most popular gamefish in the Hudson River Estuary (Waldman, 2005).

American eels (*Anguilla rostrata*) are catadromous, spawning offshore in the Sargasso Sea. Larvae (leptocephali) migrate into estuaries, including the Hudson during early Spring. Eels are an important component of the Hudson River fish community and have been observed at densities greater than 13,000 ind./ha in the mouths of some tributaries (Petersson and Schmidt, 2004). The total annual run of YOY American eels (elvers) in the Saw Kill is estimated to range from 850-10,000 YOY eels (Schmidt and Lake, 2003; 2004).

Atlantic sturgeon (*Acipenser oxyrhynchus*) and the endangered shortnose sturgeon (*A. brevirostrum*) rarely enter tributaries to spawn, preferring deep, freshwater tidal mainstem habitats. Atlantic sturgeon are

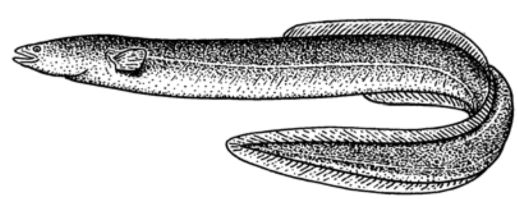
Striped Bass
(Morone saxatilis)



currently protected under a fishing moratorium that may extend until 2038. Shortnose sturgeon have been protected since the U.S. Endangered Species Act (ESA) of 1973; however, the Hudson River population appears to be recovering and may be a candidate for de-listing under the ESA (Waldman, 2005). Shortnose sturgeon are sometimes encountered by anglers in the vicinity of the Tivoli Bays.

Other than alewife, the only diadromous species currently known to spawn in Hudson River tributaries is the sea lamprey (*Petromyzon marinus*); however, adult specimens or ammocoetes are only rarely encountered in surveys, and none have been collected in tributaries within the Reserve (Waldman, 2005). Rainbow smelt (*Osmerus mordax*) were once abundant in many Hudson River tributaries and supported an intensive recreation net fishery. The population declined rapidly during the late 1900s, with the last significant tributary runs occuring in 1979. Rainbow smelt are now considered to be extinct in the Hudson River Estuary (Waldman, 2005).

American Eel
(Anguilla rostrata)



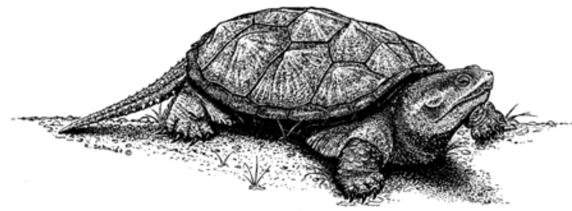
Wildlife

Reptiles and Amphibians

Few studies of reptile and amphibian populations have been conducted in estuarine habitats and the environmental factors that control their abundance and distribution in tidal habitats are not particularly well understood. Salinity, ice scouring, and water level fluctuation are some of the factors that may limit reptile and amphibian populations in estuarine wetlands (Rubbo and Kiviat, 1999). For amphibians, the most important breeding habitat in freshwater tidal marshes are supratidal pools which may occur at the marsh/terrestrial interface. These ephemeral habitats support breeding populations of amphibians such as American toad, spring peeper (*Hyla crucifer*), Northern leopard frog (*Rana pipiens*), spotted salamander (*Abystoma maculatum*), and red-spotted newt (*Notophthalmus viridescens viridescens*).

Only fourteen reptile and amphibian species, of the nearly 50 species known to occur in the Hudson Valley, have been recorded in the freshwater intertidal wetlands of Tivoli Bays. Thirteen of these species are considered rare to absent, and only the snapping turtle is commonly encountered among the Reserve marshes (Rubbo and Kiviat, 1999), with the exception of Piermont Marsh, where this species may be limited by high salinity (Kiviat, 1998). Adult snapping turtles become active in the Tivoli Bays from mid-April to early-May and feed upon resident fish, especially killifish, as well as on benthic invertebrates and plants. Nesting activity begins in mid-late June. A suitable nest site needs soft soil and ample sunlight and many snapping turtles lay their eggs along the railroad embankments separating the tidal marshes from the Hudson River mainstem. There are typically 20 to 50 eggs in a clutch. Bioturbation by snapping turtles can be significant. Kiviat (1980) estimated that snapping turtles in Tivoli North Bay disturbed up to 1% of the marsh substrate to a depth of 15 cm by burrowing and 20-25% to a depth of 2-7 cm by treading.

Snapping Turtle
(Chelydra serpentina)



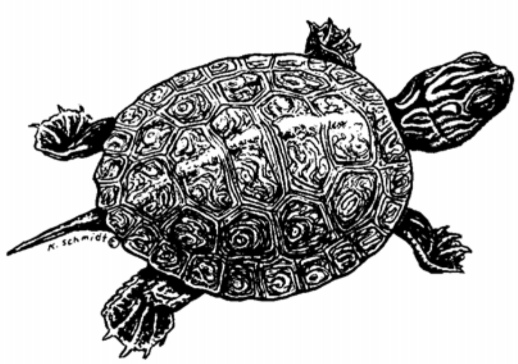
Along with the snapping turtle, the wood turtle (*Clemmys insculpta*) occurs at the Tivoli Bays and Stockport Flats Reserve components (New York Natural Heritage Program, 1996a; 1996b). The first report documenting the wood turtle in freshwater tidal wetlands of the Hudson River included twelve occurrences at four sites, two of those within the Reserve (Kiviat and Barbour, 1996).

The Hudson River has the only documented estuarine population of the map turtle (*Graptemys geographica*). Interestingly, this species is not generally found in non-tidal waters in the Hudson Valley. Other (non-tidal) New York locations for this species include the Susquehanna River, Lake Erie, Lake Ontario, and Lake Champlain (Kiviat, 1998). In the Hudson River, map turtles occupy broad, open shallows, containing exposed logs, rocks, or other suitable basking sites. Elsewhere, map turtles feed upon molluscs and crayfish, and it is presumed that they exhibit similar feeding habits in the Hudson River. Map turtles move into tidal marshes and females nest on the rail embankments and on islands (Kiviat, 1998).

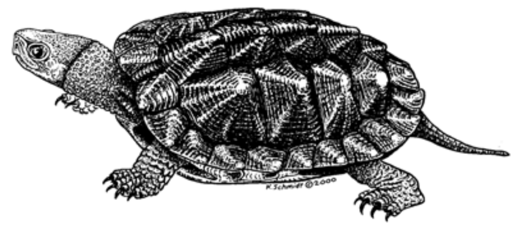
The diamondback terrapin has been the focus of recent research within the Reserve. Diamondback terrapins were hunted to near extinction at the turn of the last century and are beginning to show signs of population recovery in the Hudson River and other northeastern estuaries. At Piermont marsh, terrapins are subject to drowning in crab traps, and their eggs and young may be preyed upon by raccoons.

A preliminary population survey conducted during the summer of 1997 identified eight terrapins (six males, two females) at Piermont Marsh. Although diamondback terrapins were utilizing the marsh system, it was unclear whether or not they were nesting in the Reserve; dense stands of common reed might reduce the availability of suitable nesting areas at Piermont Marsh (Simoes and Chambers, 1998). A follow-up study (Wiktor and Chambers, 2001) determined that the Piermont Marsh terrapins were not genetically distinct from other populations sampled in Connecticut, Rhode Island, and New Jersey, as indicated by Inter-Sample Sequence Repeat (ISSR) analysis.

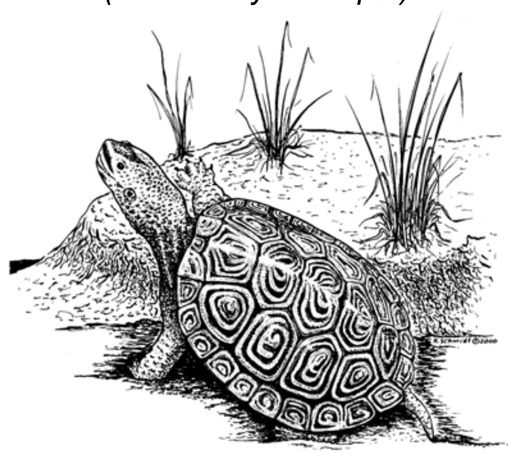
Map Turtle
(Graptemys geographica)



Wood Turtle
(Clemmys insculpta)



Diamondback Terrapin
(Malaclemys terrapin)



Birds
The bird communities of the Reserve have received considerable attention, with surveys dating back to the early 1970s. Most studies have focused on characterization of breeding habitat, threatened and endangered species, and the effects of ecosystem alteration resulting from the proliferation of invasive plants on nesting and foraging habitat.

The freshwater tidal wetlands of Tivoli North Bay provide valuable habitat for a diverse avifauna, with over 135 species documented (New York Natural Heritage Program, 1996a). Least bittern, Virginia rail, and marsh wren nest among the dense stands of narrow-leaved cattail. Purple loosestrife and shrub vegetation provide habitat for red-winged blackbird, American goldfinch, swamp sparrow, song sparrow, willow flycatcher (*Empidonax traillii*), yellow warbler (*Dendroica petechia*), and common yellowthroat (*Geothlypis trichas*). Tree swallows, bank swallows, European starlings, red-winged blackbirds, and common grackles feed in uplands by day and roost in North Bay at night. Avian food resources present in the bay include seeds of wild rice, rice cut-grass, water-millet (*Echinochloa walteri*), and knotweed, as well as water celery, larvae of the cattail moth (*Lymnaecia phragmitella*), water-lily leaf beetles, snails, goldfish, and killifish.

The freshwater tidal wetlands and mudflats of the Stockport Flats component also provide valuable habitat for a diverse avifauna. Belted kingfisher, American black duck (*Anas rubripes*), Canada goose, common tern (*Sterna hirundo*), great blue heron, house wren (*Troglodytes aedon*), song sparrow, tree swallow, willow flycatcher, marsh wren, red-winged blackbird, swamp sparrow, and yellow warbler are present in the freshwater tidal marshes. Killdeer (*Charadrius vociferus*) and spotted sandpiper (*Actitis macularia*) frequent both the intertidal mudflats and the intertidal gravel shores.

A completed bald eagle nest was identified off Gay's Point (Stockport Flats) in 1995 (New York Natural Heritage Program, 1996b). Selectivity of perch and forage sites by two pairs of bald eagles known to be breeding within the Reserve (Stockport Flats and Tivoli Bays) was monitored in spring and summer 1999 (Thompson and McGarigal, 2000). The eagles preferentially selected forested areas adjacent to marshes or tidal flats that were exposed during low tide with minimal human disturbance.

Bald Eagle
(Haliaeetus leucocephalus)

Breeding bird surveys conducted at Stockport Marsh, Tivoli North Bay, and Iona Island Marsh in 1986 identified 22 species considered likely to breed in Hudson River marshes (Swift, 1987; 1989). Breeding birds can be grouped on the basis of habitat use: those which nest in the deeply flooded marsh interior (e.g., marsh wren, least bittern), those which nest in open marsh with some purple loosestrife or woody vegetation present (e.g., willow flycatcher, red-winged blackbird, American goldfinch, song sparrow), and those which primarily use tidal swamp or upland edge habitat and occasionally stray into the intertidal marsh [e.g., gray catbird (*Dumetella carolinensis*), rose-breasted grosbeak (*Pheucticus ludovicianus*)]. A fourth category, waterfowl, could be considered; however, nesting activities of waterfowl are limited by tidal flooding. The most common species of waterfowl observed in the marshes and tidal shallows of the Reserve are mute swan, Canada goose, mallard, American black duck, wood duck, green-winged teal (*Anas crecca*), and blue-winged teal (*Anas discors*). Common merganser (*Mergus merganser*) and canvasback (*Aythya valisneria*) also occur within the Reserve, but are much less common. The ten most abundant species in Swift's study, accounting for almost 95% of all sightings, included marsh wren, red-winged blackbird, swamp sparrow, Virginia rail, yellow warbler, song sparrow, willow flycatcher, common yellowthroat, least bittern, and American goldfinch. Both woody vegetation and purple loosestrife stands supported a relatively large number of species and total number of birds.

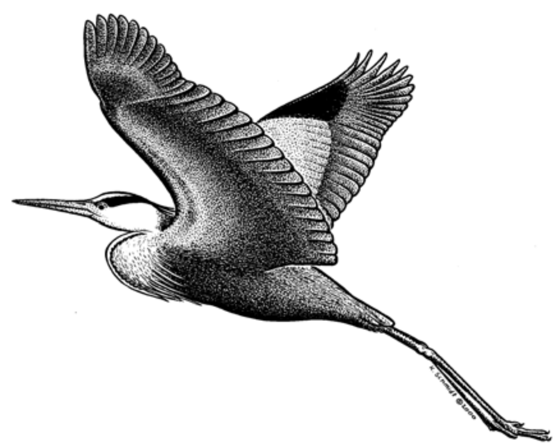
Among non-passerine birds, Virginia rail, least bittern, and mallard are the most likely to nest in Hudson River marshes. Virginia rails were observed more often in the vicinity of narrow-leaved cattail stands in close proximity to uplands, while terrestrial passerine species preferred upper intertidal areas with woody emergent vegetation. Least bittern and marsh wren were more commonly associated with regularly flooded cattail stands.

An observed decline in species richness, and in the numbers of least bittern, Virginia rail, marsh wren, and swamp sparrow was documented at Iona Island Marsh during a re-survey conducted in 2004. Red-winged blackbird populations have doubled, as narrow-leaved cattail stands have been replaced by common reed. Additional species known to nest in common reed stands in the Hudson Reserve include barn swallow, tree swallow, bank swallow, and European starling. Although the proliferation of common reed was a likely cause of the decrease in avian species richness, it may not represent the only factor. Behavioral interactions between species such as marsh wren and red-winged blackbird may have also played a roll in the decline (LMS Engineers, 2005).

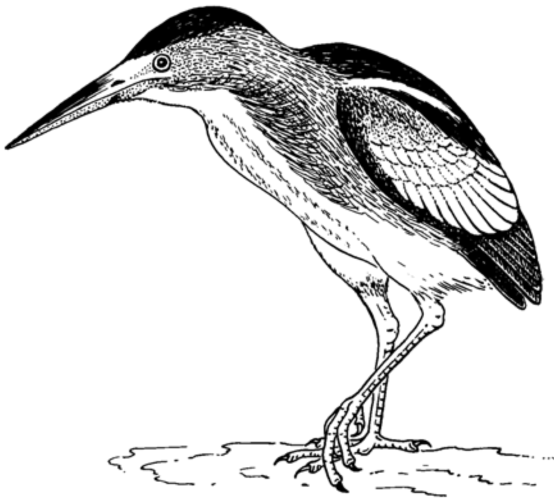
An interesting and somewhat unique nesting habitat occurs primarily at the Stockport Flats Reserve site. Eroding scarps of old dredged material deposits support large nesting populations of bank swallows and belted kingfishers (Kiviat et al., 1985).

Osprey
(Pandion haliaetus)

Great Blue Heron
(Ardea herodias)



Least Bittern
(Ixobrychus exilis)



Mammals
Several mammal species are conspicuous residents of the Reserve marshes. A prime example is the muskrat, known for its burrowing, feeding, and lodge building activity. Muskrats are the primary vertebrate consumer of intertidal marsh vegetation. While muskrat grazing does not appear to markedly affect plant species composition or richness, it does increase soil nitrification rates through increased aeration (Connors et al., 2000). Additionally, muskrat lodge construction contributes to the structural complexity of the intertidal marsh surface, providing nesting and feeding habitat for marsh birds and other vertebrates at all four Reserve component sites. Other mammal species, such the meadow vole (*Microtus pennsylvanicus*), may be present but rarely noted due to their cryptic lifestyles. Beaver (*Castor canadensis*) populations appear to be increasing at the Reserve sites since the 1980s. Only a handful of studies have focused on the ecology of mammal populations at the Reserve.

The proliferation of invasive plant species, including common reed and purple loosestrife, may affect the distribution and abundance of mammal species in Tivoli North Bay; however, data to support this contention is lacking. One common small mammal, the white-footed mouse (*Peromyscus leucopus*), shows no preference for either common reed, purple loosestrife, or cattail habitats (McGlynn and Ostfeld, 2000).

Muskrat
(Ondatra zibethicus)

ROLE OF THE HUDSON RIVER RESERVE IN REGIONAL HABITAT RESTORATION

The habitat restoration program at the Hudson River Reserve focuses on several key priorities: These include:

- Restoration of migratory fish passage within Hudson River tributaries;
- Development of an understanding of the functional shifts associated with managing invasive common reed;
- Softening of hardened shorelines along the estuary;
- Conversion of dredged material uplands to intertidal and subtidal freshwater wetlands;
- Developing a reference set of wetlands and data to guide freshwater tidal wetland restoration; and
- Determining the limiting factors controlling the establishment and distribution of SAV in freshwater tidal habitats.

Restoration Planning, Information Transfer, and Regional Science Coordination

In June 1998, the Reserve sponsored the first Hudson River Restoration Round Table, held at the Norrie Point Environmental Center in Staatsburg, NY. Attending were 35 participants representing state and Federal agencies, non-governmental organizations, and consultants. The round table was co-hosted by NYSG and the NYSDOS. At this meeting the working group began to form the elements of a comprehensive Hudson River Estuary Restoration Plan and achieved consensus on defining the goals and objectives of the plan, which identified restoration science and educational programs as key elements.

In July 2000, a restoration coordinator was hired with the support of the Hudson River Estuary Program. The position is primarily responsible for authoring the "Hudson River Estuary Restoration Plan." The Plan will detail a science-based restoration and decision making process that will strive to coordinate restoration efforts throughout the estuary toward a set of specific ecosystem goals. Additionally, through this position, the Hudson River National Estuarine Research Reserve (HRNERR) provides technical support for local, state and Federal restoration planning and implementation. The program also manages several research initiatives, both inside and beyond Reserve boundaries, intended to provide valuable information to improve the quality of restoration projects throughout the estuary.

The Reserve sponsored an Advanced Habitat Restoration Training course in June 1998. The participants included 24 state agency staff involved with implementing aquatic habitat restoration under the NYS Bond Act. The participants received training in determining habitat restoration goals and objectives, incorporating an ecological perspective in restoration planning, development of restoration monitoring programs, and applying the principles of adaptive management to habitat restoration projects.

Hudson River Habitat Restoration (HRHR) Project

The U.S. Army Corps of Engineers, New York District (USACE-NYD), in cooperation with NYSDEC, NYSDOS, OPRHP, and the Nature Conservancy, proposes to restore intertidal freshwater wetlands within the Hudson River Estuary as part of a comprehensive Hudson River habitat restoration progam. The project is currently in the feasibility/planning stages. Two proposed sites are located on Schodack-Houghtaling Island, an island/wetland complex in the upper Hudson River Estuary, some 12 miles south of Albany, NY. The third site is a large freshwater tidal wetland located along Mill Creek, a Hudson River tributary, near Stuyvesant, NY. The islands were created by filling in tidal wetlands and shallows for navigation channel construction and maintenance during the early to mid 20th century.

The HRHR project focuses on removing dredged material fill to restore intertidal and shallow subtidal habitat. Areas of existing intertidal wetlands are to be the basis of the restoration. Existing wetland habitats will be enhanced, increasing ecosystem function. The goals of the project are to improve/provide bird and fish habitat, provide corridors for wildlife, improve water quality, and provide habitat for threatened and endangered species. A USACE-NYD reconnaissance study evaluated the potential for restoration of Hudson River tidal wetlands and determined the ecological significance of such restoration. Factors in the site selection process included: anthropogenic stress, functions lost, need/availability of habitats within the region, cost/benefit studies, and logistics, such as proximity to active dredged material placement areas and land ownership. Specific restoration activities may involve re-grading of upland dredged material deposits to intertidal elevations, removal/control of invasive plant species (e.g., common reed, purple loosestrife), removal of derelict bulkheading, and excavation of silted-in channels to increase tidal exchange.

Baseline environmental data (vegetation, fish, benthic macroinvertebrates, soil chemistry) were collected at project and reference sites (including Tivoli North Bay) during 1997-98. These data documented existing conditions at project and reference sites and provided project managers with information needed to specify target ranges for select ecological variables. Project funding sources include the New York State Clean Water/Clean Air Bond Act, and Federal funds made available to the USACE-NYD, under the Water Resources and Development Act (WRDA).

Fish Passage Restoration

The Sleepy Hollow dam is located on the Pocantico River, at the historic estate of Philipse Manor, in Sleepy Hollow, NY. This working mill dam has been identified as a barrier to the upstream migration of anadromous fish, specifically river herring (*Alosa* spp.). The herring species most likely to be encountered in the Pocantico River is the alewife. This species enters Hudson River tributaries from approximately late March through May. Other herring species, which may be present in the study area, include American Shad, blueback herring, and possibly hickory shad (*Alosa mediocris*). Reserve staff have been working with the site to identify fish passage solutions which could restore the fishery resource while minimizing the impact on the historic site. Recent fisheries surveys corroborated anecdotal reports by workers at the mill dam of river herring migrating to the base of the dam, unable to reach upstream spawning areas.

Because the mill is currently functional, and located at a site of historical/cultural significance, it is not feasible to remove the dam or permanently alter its appearance. Therefore, alternatives to dam removal/modification are being evaluated. The Reserve is currently evaluating the installation of a removable fish ladder, such as a steeppass or denil fishway, at the dam to facilitate migration of herring to upstream spawning areas.

Functional Assessment of Freshwater Tidal Wetlands

The Hudson River Reserve participated in the development of a functional assessment procedure for evaluating the success of freshwater tidal wetland restoration projects based on the USACE's Hydrogeomorphic approach (Brinson, 1993; Smith et al., 1995; Shafer and Yozzo, 1998). Fifteen reference wetlands, representing a gradient of severely disturbed to relatively undisturbed habitats, were sampled to develop a reference dataset for the evaluation of a suite of ecosystem functions during 1997-1998. The data were used to develop a set of functional capacity indices (FCIs), which can be used to assess pre-project condition and post-project outcomes. This project has direct application to restoration science in the Hudson River Estuary, and elsewhere, by providing a means of evaluating and prioritizing potential restoration projects, as well as a means of determining the success of ongoing and completed projects (Findlay et al., 2002; Mihocko et al., 2003).

RECOMMENDATIONS FOR FUTURE RESEARCH AND MONITORING

For more than 20 years, the research and monitoring conducted at the Reserve has contributed greatly to our understanding of the Hudson River Estuary ecosystem. The work supported by the reserve has augmented that done by other research institutions and together this knowledge has aided the coastal management community in better protecting and managing the natural resources of this system. However, as with any large natural system much still needs to be understood to address ongoing and new coastal management information needs. It is difficult to predict what research will need to be done in the future but we have a good understanding of what additional information is needed at the time of this publication. For example, there are gaps in our knowledge on restoration methods and ecosystem responses to restoration, temporal and spatial variability of habitats and species, driving forces of change in the estuary, and long-term effects of development and global climate change.

It is a priority of the Reserve to continue the monitoring programs focusing on long-term change and short-term variability. These include marsh plant community mapping, the SAV and water chestnut inventory, long-term water quality and meteorological monitoring, marsh breeding bird monitoring, rare and threatened plant surveys, and the resident and transient fish monitoring at Tivoli Bays. All of these programs have contributed greatly to our understanding of the estuary and have also been instrumental in identifying coastal management issues requiring our immediate attention.

In the next few years, the Reserve will expand components of the SWMP program to the other sites, especially Iona Island and Piermont Marsh. Improvements to hydrological models for Tivoli Bays will enable us to better predict the effect of the marshes on water-borne nutrients and contaminants. Better coordination of our monitoring efforts with other state and Federal agencies will improve the ability of coastal managers to observe and predict estuarine conditions. The resident fish monitoring program should be expanded to the other Reserve sites, especially Piermont Marsh were the population of spotfin killifish could be threatened by the continued expansion of common reed.

Earlier in this document, we identified specific research and monitoring needs for each site. The following list summarizes these and includes additional general research needs:

- Expand ongong paleoecological studies to all Reserve sites;
- Identify sources of chloride and determine the causes of increase in surface water concentrations;
- Determine the ecological effects of common reed expansion and removal on nutient cycling, carbon and detrital cycling, and vertebrate and invertebrate communities;
- Develop and maintain land use/landcover digital databases for the Reserve watersheds;
- Continue to monitor plant communities every 5-10 years using aerial photography or other comparable remote sensing method;

- Determine why higher vertebrates (i.e, muskrat, mink, river otter, harbor seal, some marsh birds) are either absent or declining in the Hudson River Estuary;

- Determine what factors drive the large variability in resident marsh fish populations (i.e., four-spine sticklebacks);

- Determine and predict the response of Hudson River estuarine aquatic habitats to invasions of non-indigenous species;

- Characterize the terrestrial invertebrate communities associated with the emergent macrophyte stems and litter (including common reed, cattail, other species);

- Determine the role marsh mammal communities have on limiting or causing spread of invasive plant species (e.g., common reed, purple loosestrife); and

- Survey marsh breeding bird populations every five years at all Reserve sites.

Addressing these information needs will require the commitment and support of funding organizations, legislators, government and local officials and resource managers. Given the economic, recreational, and commercial value of the Hudson River Estuary and it's natural resources, we need to continue to educate and remind all of the key constituents of the need to better understand, manage, and protect the Hudson River ecosystem through research and monitoring programs such as those being conducted at the Hudson River Reserve.

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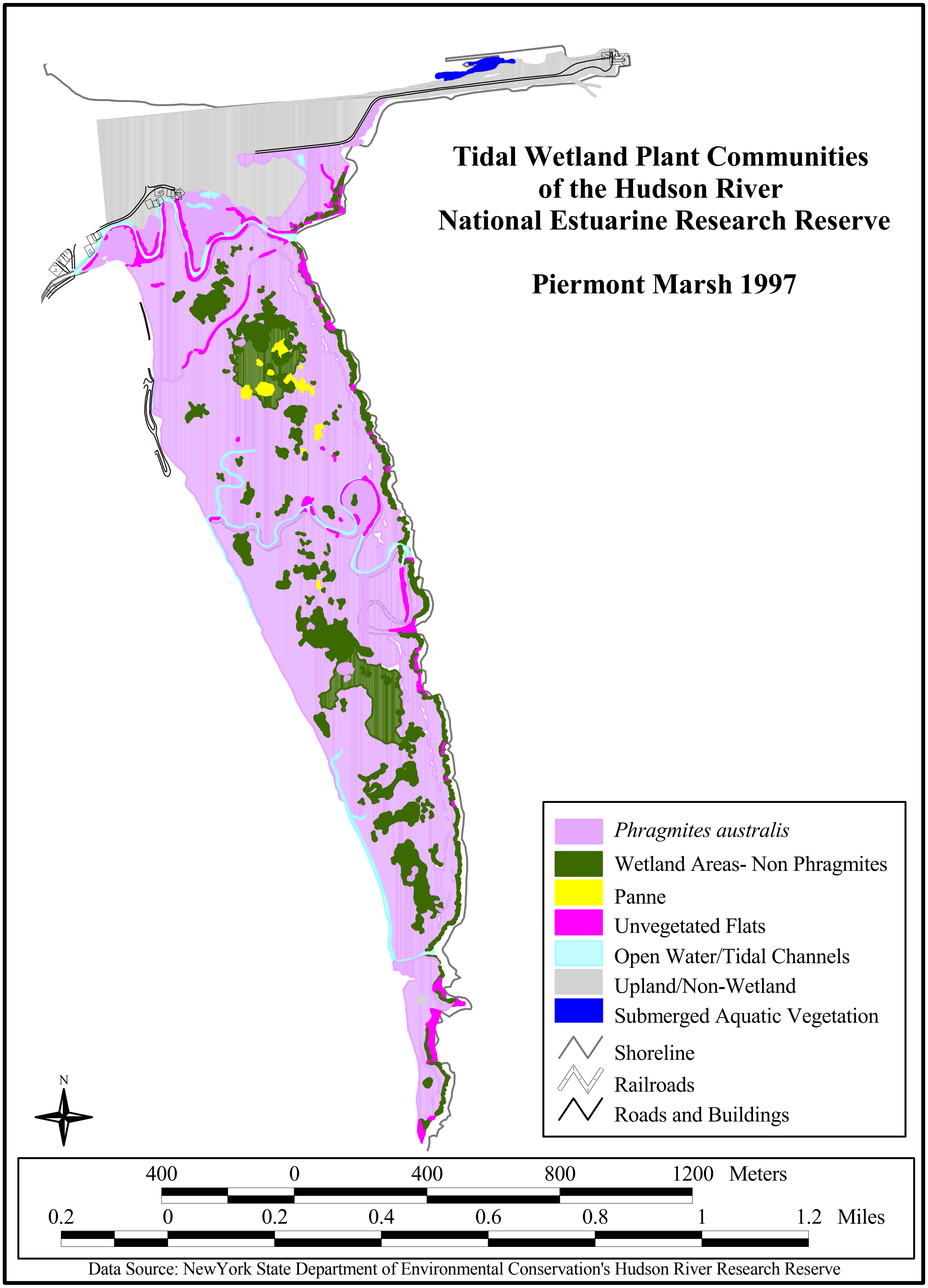
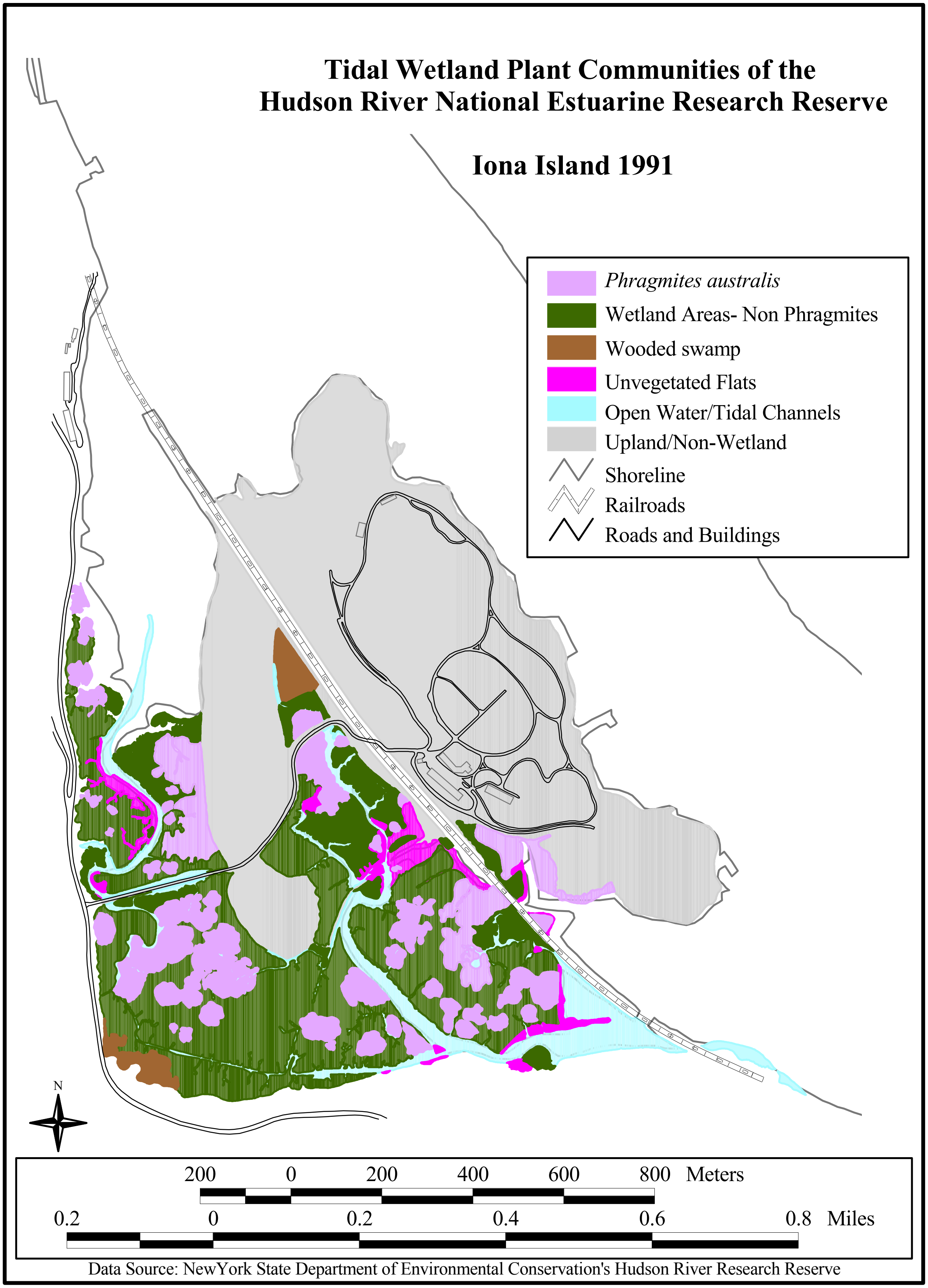
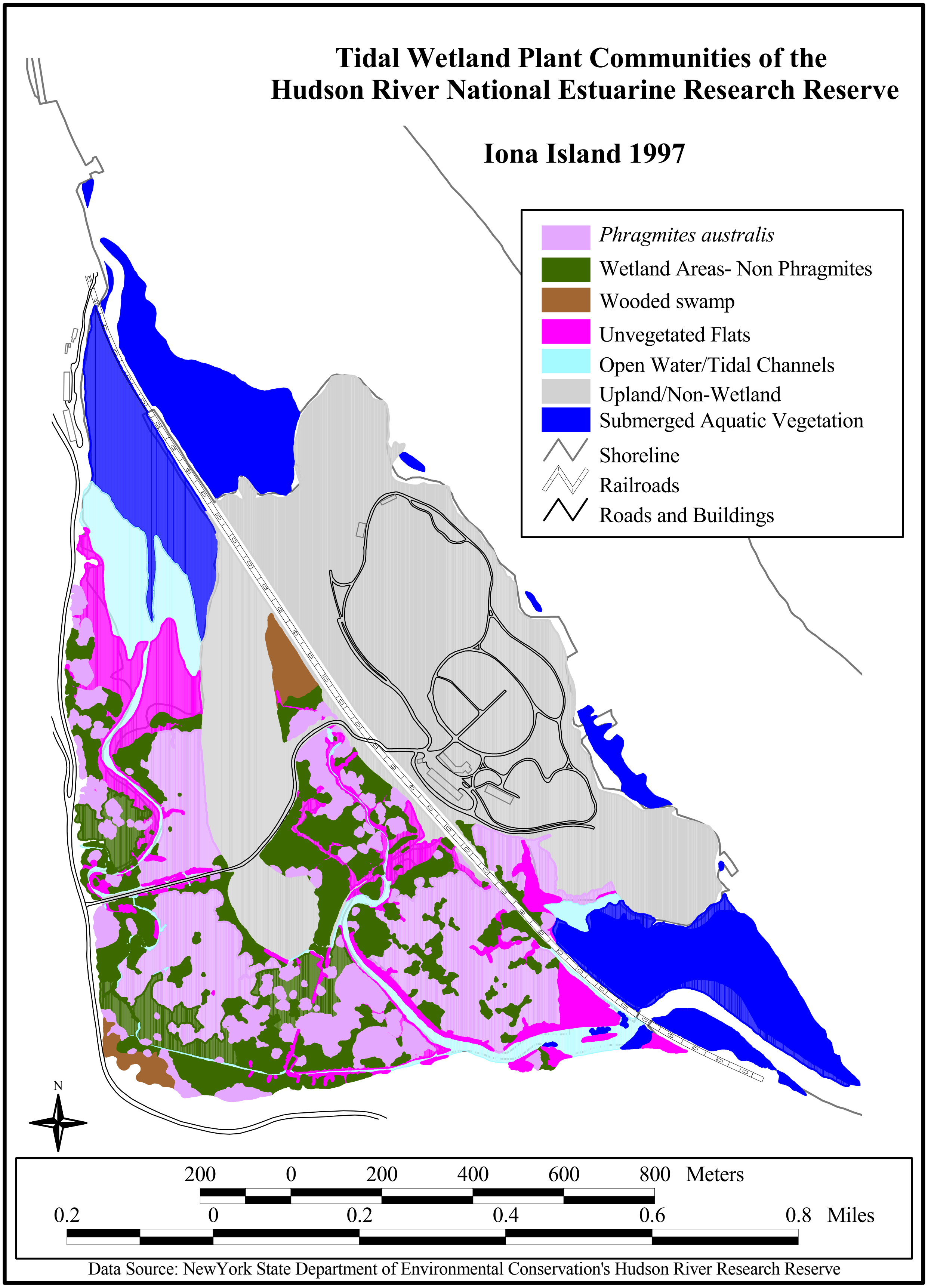
APPENDICES

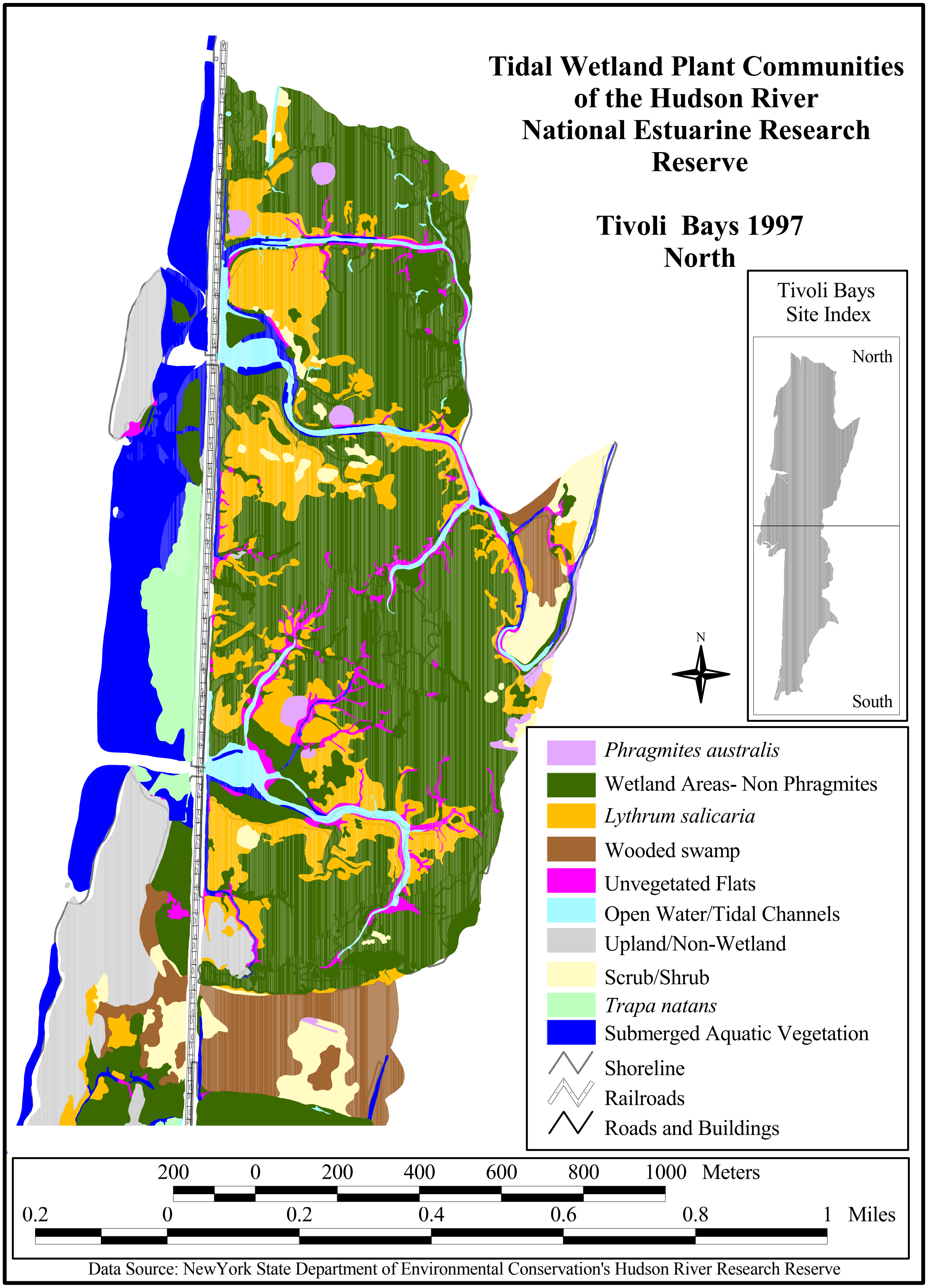
APPENDIX A
Plant Community and Submerged Aquatic Vegetation Maps

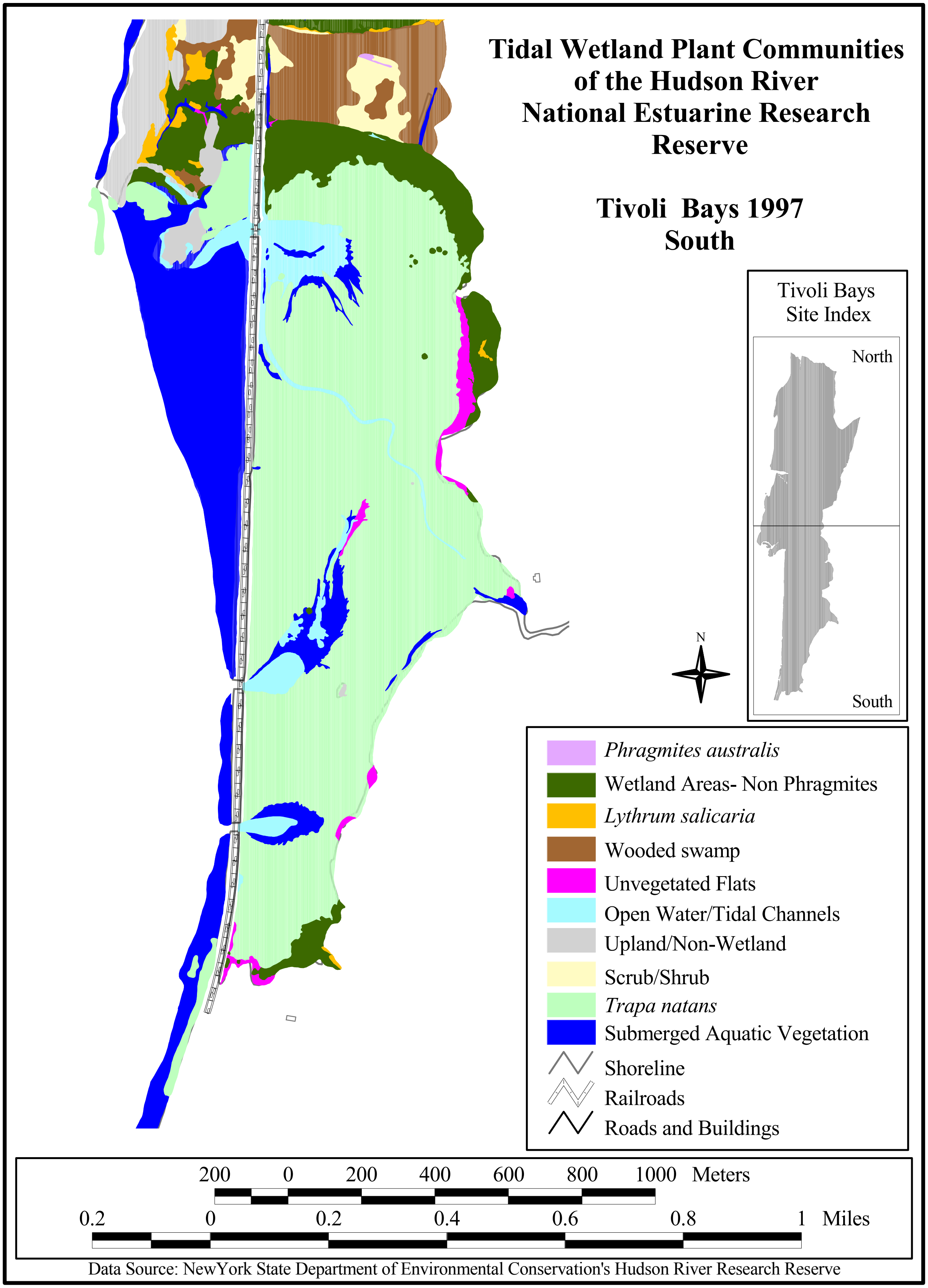

Tidal Wetland Plant Communities
of the Hudson River
National Estuarine Research Reserve
Piermont Marsh 1997
Phragmites australis
Wetland Areas- Non Phragmites
Panne
Unvegetated Flats
Open Water/Tidal Channels
Upland/Non-Wetland
Submerged Aquatic Vegetation
Shoreline
Railroads
Roads and Buildings
N
400 0 400 800 1200 Meters
0.2 0 0.2 0.4 0.6 0.8 1 1.2 Miles
Data Source: NewYork State Department of Environmental Conservation's Hudson River Research Reserve


Tidal Wetland Plant Communities of the
Hudson River National Estuarine Research Reserve
Iona Island 1991
Phragmites australis
Wetland Areas- Non Phragmites
Wooded swamp
Unvegetated Flats
Open Water/Tidal Channels
Upland/Non-Wetland
Shoreline
Railroads
Roads and Buildings
N
200 0 200 400 600 800 Meters
0.2 0 0.2 0.4 0.6 0.8 Miles
Data Source: NewYork State Department of Environmental Conservation's Hudson River Research Reserve



Tidal Wetland Plant Communities of the
Hudson River National Estuarine Research Reserve
Iona Island 1997
Phragmites australis
Wetland Areas- Non Phragmites
Wooded swamp
Unvegetated Flats
Open Water/Tidal Channels
Upland/Non-Wetland
Submerged Aquatic Vegetation
Shoreline
Railroads
Roads and Buildings
N
200 0 200 400 600 800 Meters
0.2 0 0.2 0.4 0.6 0.8 Miles
Data Source: NewYork State Department of Environmental Conservation's Hudson River Research Reserve


Tidal Wetland Plant Communities
of the Hudson River
National Estuarine Research
Reserve
Tivoli Bays 1997
North
Tivoli Bays
Site Index
North
South
N
Phragmites australis
Wetland Areas- Non Phragmites
Lythrum salicaria
Wooded swamp
Unvegetated Flats
Open Water/Tidal Channels
Upland/Non-Wetland
Scrub/Shrub
Trapa natans
Submerged Aquatic Vegetation
Shoreline
Railroads
Roads and Buildings
200 0 200 400 600 800 1000 Meters
0.2 0 0.2 0.4 0.6 0.8 1 Miles
Data Source: NewYork State Department of Environmental Conservation's Hudson River Research Reserve


Tidal Wetland Plant Communities
of the Hudson River
National Estuarine Research
Reserve
Tivoli Bays 1997
South
Tivoli Bays
Site Index
North
South
N
Phragmites australis
Wetland Areas- Non Phragmites
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Wooded swamp
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Open Water/Tidal Channels
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Scrub/Shrub
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Shoreline
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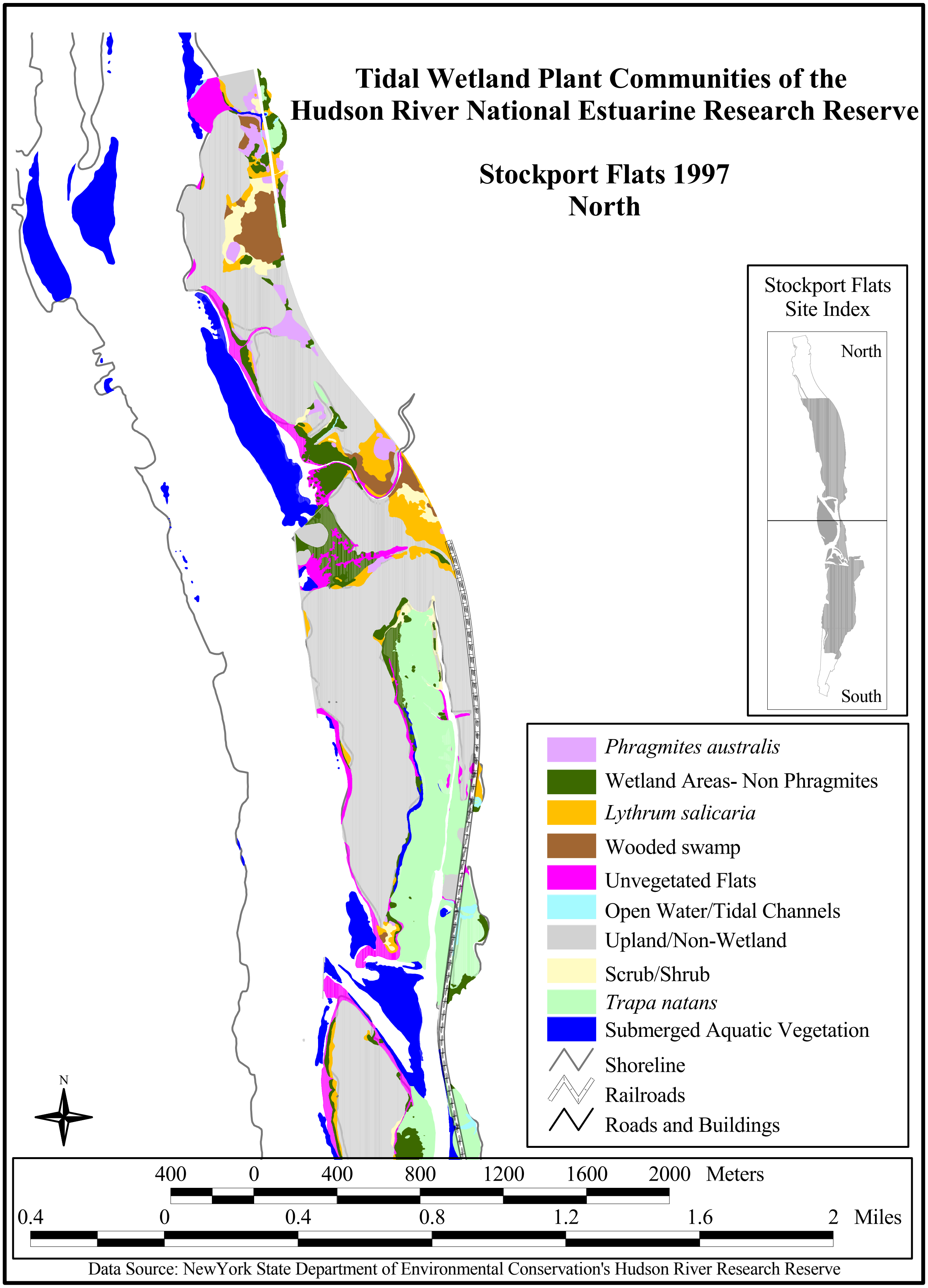
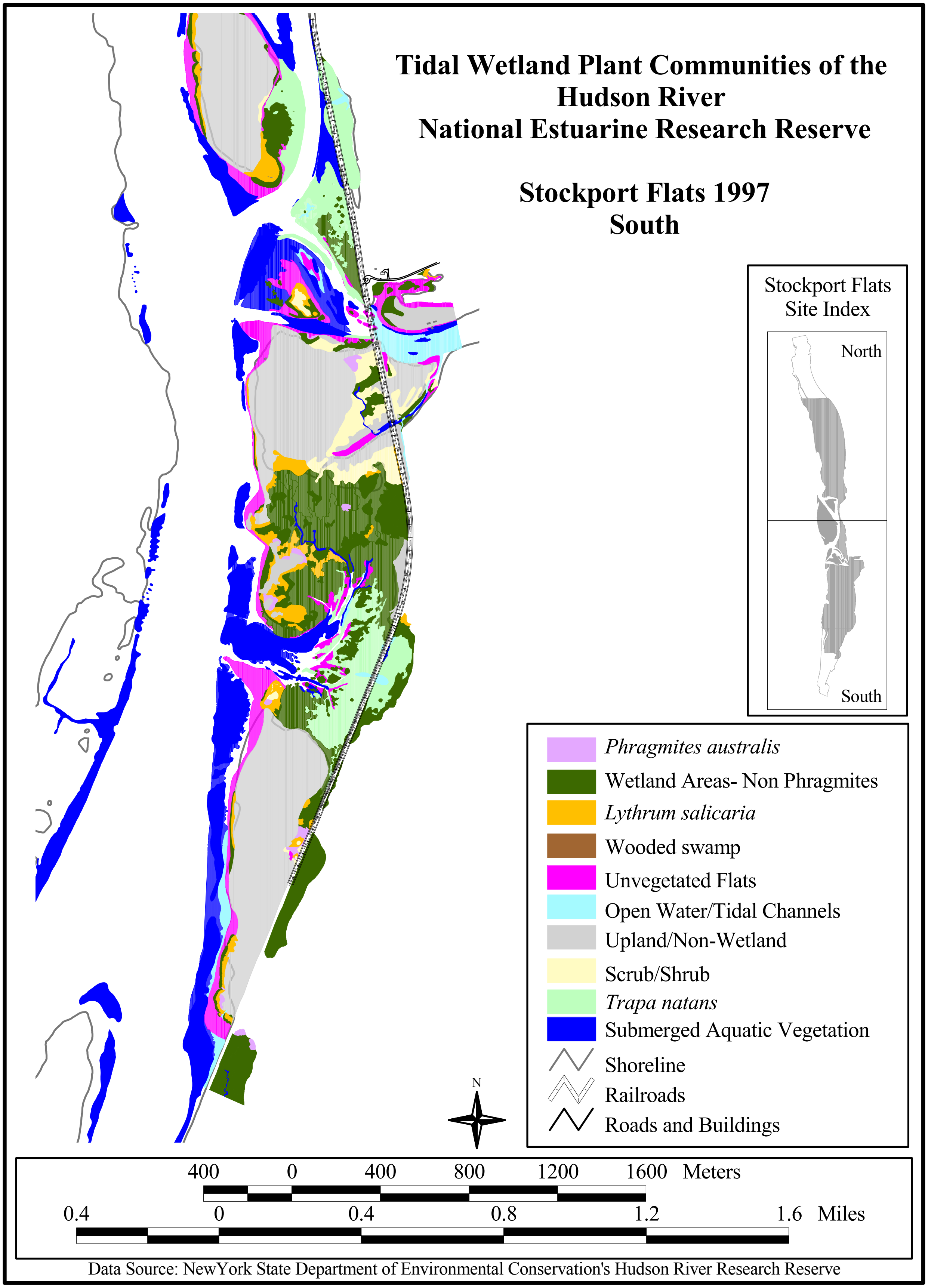
Roads and Buildings
200 0 200 400 600 800 1000 Meters
0.2 0 0.2 0.4 0.6 0.8 1 Miles
Data Source: NewYork State Department of Environmental Conservation's Hudson River Research Reserve



Tidal Wetland Plant Communities of the
Hudson River National Estuarine Research Reserve
Stockport Flats 1997
North
Stockport Flats
Site Index
North
South
Phragmites australis
Wetland Areas- Non Phragmites
Lythrum salicaria
Wooded swamp
Unvegetated Flats
Open Water/Tidal Channels
Upland/Non-Wetland
Scrub/Shrub
Trapa natans
Submerged Aquatic Vegetation
Shoreline
Railroads
Roads and Buildings
N
400 0 400 800 1200 1600 2000 Meters
0.4 0 0.4 0.8 1.2 1.6 2 Miles
Data Source: NewYork State Department of Environmental Conservation's Hudson River Research Reserve


Tidal Wetland Plant Communities of the Hudson River National Estuarine Research Reserve
Stockport Flats 1997
South
Stockport Flats Site Index
North
South
Phragmites australis
Wetland Areas- Non Phragmites
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Wooded swamp
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Submerged Aquatic Vegetation
Shoreline
Railroads
Roads and Buildings
N
400 0 400 800 1200 1600 Meters
0.4 0 0.4 0.8 1.2 1.6 Miles
Data Source: NewYork State Department of Environmental Conservation's Hudson River Research Reserve

APPENDIX B
List of Plants, Fish, Reptiles, Amphibians, Birds, and Mammals Occurring in the Reserve

Appendix B: List of plants, fish, reptiles, amphibians, birds, and mammals occurring in the Reserve. Major sources of information include: Kiviat and Beecher (1991), Leonardi and Kiviat (1989), Lewis (2001), LMS (2005), New York Natural Heritage Program (1996a, 1996b), Osgood et al. (in press), Schmidt (1986), Schmidt et al. (2001), Schmidt et al. (2002a, 2002b), Schmidt et al. (2003), Senerchia-Nardone et al. (1986), Stevens (2001), Swift (1987, 1989), USDOC (1984), Westad and Kiviat (1985), Westad (1987), and Yozzo et al. (1999). Vascular plant species names follow Gleason and Cronquist (1991).

Liverworts and Mosses		Stockport	Tivoli	Iona	Piermont
Amblystegiaceae					
Juratzk's Amblystegium Moss	*Amblystegium juratzkanum*		X		
Hydroamblystegium Moss	*Hygroamblystegium tenax*	X	X		
Streamside Leptodictyum Moss	*Leptodictyum riparium*		X		
Tributary Moss	*L. trichopodium*		X		
Anomodontaceae					
Anomodon Moss	*Anomodon attenuatus*	X	X		
Anomodon Moss	*A. minor*		X		
Anomodon Moss	*A. rostratus*		X		
Aulacomniaceae					
Ribbed Bog Moss	*Aulacomnium palustre*	X			
Bartramiaceae					
Philonotis Moss	*Philonotis muehlenbergii*		X		
Brachytheciaceae					
Cedar Moss	*Brachythecium oxycladon*		X		
Cedar Moss	*B. rutabulum*		X		
Cedar Moss	*B. salebrosum*		X		
Cedar Moss	*B. turgidum*		X		
Beautiful Beaked Moss	*Eurhynchium pulchellum*		X		
Steerecleus Moss	*Rhynchostegium serrulatum*		X		

Liverworts and Mosses		Stockport	Tivoli	Iona	Piermont
Bryaceae					
Silver Moss	*Bryum argenteum*		X		
Dry Calcareous Bryum Moss	*B. caespiticium*		X		
Common Green Bryum Moss	*B. pseudotriquetrum*		X		
Pohlia Moss	*Pohlia* sp.		X		
Rose Rhodobryum Moss	*Rhodobryum roseum*		X		
Climaciaceae					
Tree Moss	*Climacium americanum*		X		
Dicranaceae					
Silky Fork Moss	*Dicranella heteromalla*	X			
Montane Dicranum Moss	*Dicranum montanum*		X		
Ditrichaceae					
Burned Ground Moss	*Ceratodon purpureus*		X		
Entodontaceae					
Sedusctive Entodon Moss	*Entodon seductrix*		X		
Fissidentaceae					
Plume Moss	*Fissidens adianthoides*		X		
Bryoid Fissidens Moss	*F. bryoides*		X		
Fissidens Moss	*F. fontanus*		X		
Fissidens Moss	*F. taxifolius*	X	X		
Hypnaceae					
Callicladium Moss	*Callicladium haldanianum*		X		
Lindberg's Hypnum Moss	*Hypnum lindbergii*		X		
Platygyrium Moss	*Platygyrium repens*		X		
Taxiphyllum Moss	*Taxiphyllum taxirameum*	X	X		

Liverworts and Mosses		Stockport	Tivoli	Iona	Piermont
Leskeaceae					
Bryohaplocladium Moss	*Bryohaplocladium microphyllum*		X		
Bryohaplocladium Moss	*Haplocladium microphyllum*	X	X		
Leskea Moss	*Leskea gracilescens*	X	X		
Leskea Moss	*L. polycarpa*		X		
Lindbergia Moss	*Lindbergia brachyptera*		X		
Mniaceae					
Rhizomnium Moss	*Mnium punctatum*		X		
Woodsy Moss	*Plagiomnium cuspidatum*	X	X		
Orthotrichaceae					
Ohio Orthotrichum Moss	*Orthotrichum ohioense*		X		
Orthotrichum Moss	*O. pumilum*		X		
Orthotrichum Moss	*O. sordidum*		X		
Stellate Orthotrichum Moss	*O. stellatum*		X		
Plagiotheciaceae					
Plagiothecium Moss	*Plagiothecium cavifolium*		X		
Polytrichaceae					
Spine Leaf Moss	*Atrichum undulatum*		X		
Polytrichum Moss	*Polytrichum commune*		X		
Pottiaceae					
	Barbula unguiculata		X		
Obtuse Leaf Desmatodon Moss	*Desmatodon obtusifolius*		X		
Thuidiaceae					
Delicate Thuidium Moss	*Thuidium delicatulum*		X		
Cyrto-hypnum Moss	*T. minutulum*		X		

Liverworts and Mosses		Stockport	Tivoli	Iona	Piermont
	Brynia novae-angliae		X		
Aneuraceae					
	Aneura pinguis		X		
Conocephalaceae					
Great Scented Liverwort	*Conocephalum conicum*		X		
Geocalycaceae					
	Lophocolea heterophylla	X	X		
Jubulaceae					
	Frullania eborocensis		X		
Porellaceae					
	Porella pinnata		X		
Leafy Liverwort	*P. platyphylla*		X		
Ricciaceae					
Slender Riccia	*Riccia fluitans*		X		
Trichocoleaceae					
	Trichocolea tomentella		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Aceraceae					
Boxelder	*Acer negundo*	X	X		
Red Maple	*A. rubrum*	X	X	X	
Silver Maple	*A. saccharinum*	X	X		
Sugar Maple	*A. saccharum*		X		
Acoraceae					
Sweet Flag	*Acorus calamus*	X	X	X	
Adiantaceae					
Northern Maidenhair Fern	*Adiantum pedatum*		X		
Alismatacae					
Southern Water-plantain	*Alisma subcordatum*		X	X	X
Arrowhead	*Sagittaria* sp.	X	X	X	
Common Arrowhead	*S. latifolia*	X	X	X	X
Sessile-fruited Arrowhead	*S. rigida*	X	X		
Spongy Arrowhead	*S. calycina* ssp. *spongiosa*	X		X	
Hudson Sagittaria	*S. subulata*	X	X	X	X
Amaranthaceae					
Tidewater Hemp	*Amaranthus cannabinus*	X	X	X	X
Anacardiaceae					
American Smoketree	*Cotinus coggygria*		X		
Squaw-bush	*Rhus aromatica*	X			
Smooth Sumac	*R. glabra*		X		
Staghorn sumac	*R. typhina*	X	X		
Poison ivy	*Toxicodendron radicans*		X	X	
Poison sumac	*T. vernix*				X

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Apiaceae					
Purplestem Angelica	*Angelica atropurpurea*		X		
Bulb-bearing Water-hemlock	*Cicuta bulbifera*		X	X	
Common Water-hemlock	*C. maculata*		X		
Honewort	*Cryptotaenia canadensis*		X		
Lilaeopsis	*Lilaeopsis chinensis*				X
Bland Sweet Cicely	*Osmorhiza claytonii*		X		
Atlantic Mock Bishop-weed	*Ptilimnium capillaceum*				X
Black Snakeroot	*Sanicula marilandica*		X		
Water-parsnip	*Sium suave*	X	X	X	X
Aquifoliaceae					
Winterberry	*Ilex verticillata*		X	X	
Araceae					
Green Dragon	*Arisaema dracontium*	X			
Jack-in-the-pulpit	*A. triphyllum*		X		
Goldenclub	*Orontium aquaticum*	X	X		
Arrow-arum	*Peltandra virginica*	X	X	X	X
Skunk-cabbage	*Symplocarpus foetidus*	X	X	X	
Araliaceae					
Wild Sarsaparilla	*Aralia nudicaulis*		X		
Aristolochiaceae					
Wild Ginger	*Asarum canadense*		X		
Asclepiadaceae					
Swamp Milkweed	*Asclepias incarnata*		X	X	
Common Milkweed	*A. syriaca*		X		
Black swallow-wort	*Vincetoxicum nigrum*	X			

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Aspleniaceae					
Lady Fern	*Athyrium filix-femina*		X		
Marginal Woodfern	*Dryopteris marginalis*		X		
Marsh Fern	*Thelypteris palustris*		X	X	X
Asteraceae					
Giant Ragweed	*Ambrosia trifida*		X		
Aster	*Aster* sp.		X	X	
Bristly Aster	*A. puniceus*		X		
Annual Saltmarsh Aster	*A. subulatus*				X
Beggar-ticks	*Bidens* sp.	X			X
Southern Estuarine Beggar-ticks	*B. bidentoides*	X	X	X	
Bur-marigold	*B. cernua*	X	X		
New England Estuarine Beggar-ticks	*B. eatonii*		X		
Devil's Beggar-ticks	*B. frondosa*		X		
Northern Estuarine Beggar-ticks	*B. hyperborea*		X		
Showy Bur-marigold	*B. laevis*	X	X		
Spotted Knapweed	*Centaurea biebersteinii*		X		
Ox-eye Daisy	*Chrysanthemum leucanthemum*		X		
Fireweed	*Erechtites hieraciifolia*			X	X
Annual Fleabane	*Erigeron annuus*		X		
Philadelphia Daisy	*E. philadelphicus*		X		
Spotted Joe-pye-weed	*Eupatorium maculatum*		X		
Boneset	*E. perfoliatum*	X	X		
Purple-node Joe-pye-weed	*E. purpureum*		X		
Common Sneezeweed	*Helenium autumnale*	X	X	X	
Jerusalem-artichoke	*Helianthus tuberosus*		X		
Maritime Marsh-elder	*Iva frutescens*				X
Climbing Hempweed	*Mikania scandens*		X	X	X
Marsh-fleabane	*Pluchea purpurascens*			X	X
Black-eyed Susan	*Rudbeckia hirta*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Asteraceae					
Cut-leaf Coneflower	*Rudbeckia laciniata*		X		
Heart-leaved Groundsel	*Senecio aureus*		X		
Goldenrod	*Solidago* sp.	X	X	X	
Common Goldenrod	*S. altissima*		X		
Smooth Goldenrod	*S. gigantea*		X		
Common Flat-topped Goldenrod	*S. graminifolia*		X		
Seaside-goldenrod	*S. sempervirens*				X
Common Dandelion	*Taraxacum officinale*		X		
Common Cocklebur	*Xanthium strumarium*	X			
Balsaminaceae					
Touch-me-not	*Impatiens* sp.			X	
Jewelweed	*I. capensis*	X	X	X	X
Berberidaceae					
Japaneese Barberry	*Berberis thunbergii*		X		
Common Barberry	*Berberis vulgaris*		X		
May-apple	*Podophyllum peltatum*	X			
Betulaceae					
Speckled Alder	*Alnus rugosa*			X	
Smooth Alder	*A. serrulata*	X	X	X	
Yellow Birch	*Betula alleghaniensis*		X		
Cherry Birch	*B. lenta*				
White Birch	*B. papyrifera*		X		
Grey Birch	*B. populifolia*		X		
Swamp Birch	*B. pumila*		X		
Hornbeam	*Carpinus caroliniana*	X	X		
American Hazel-nut	*Corylus americana*		X		
Hop-hornbeam	*Ostrya virginiana*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Bignoniaceae					
Southern Catalpa	*Catalpa bignonioides*		X		
Northern Catalpa	*C. speciosa*	X			
Boraginaceae					
Blue-weed	*Echium vulgare*			X	
Forget-me-not	*Myosotis* sp.	X	X	X	
Smaller Forget-me-not	*M. laxa*		X		
Brassicaceae					
Garlic Mustard	*Alliaria petiolata*		X		
Yellow Rocket Winter-cress	*Barbarea vulgaris*		X		
Northern Winter-cress	*B. orthoceras*		X		
Spring cress	*Cardamine rhomboidea*	X			
Salt-marsh Bittercress	*C. longii*	X			
Pennsylvania Bittercress	*C. pensylvanica*		X		
Cuckoo-flower	*C. pratensis*		X		
Toothwort	*Dentaria* spp.		X		
Dame's Rocket	*Hesperis matronalis*	X	X		
Marshcress	*Rorippa palustris*		X		X
Caesalpiniaceae					
Northern Wild Senna	*Cassia hebecarpa*	X			
Honey-locust	*Gleditsia triacanthos*			X	
Callitrichaceae					
Water starwort	*Callitriche* sp.				X
Water starwort	*C. verna*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Caprifoliaceae					
Bell's Honeysuckle	*Lonicera* X *bella*	X	X		
Common Elder	*Sambucus canadensis*	X	X	X	
Dockmackie/ Flowering Maple	*Viburnum acerifolium*		X		
Arrow-wood	*V. dentatum*	X	X	X	
Nannyberry	*V. lentago*		X		
Guelder-Rose	*V. opulus*		X		
Black Haw	*V. prunifolium*			X	
Campanulaceae					
Marsh-bellflower	*Campanula aparinoides*		X		
Cannabaceae					
Hops	*Humulus lupulus*		X		
Caryophyllaceae					
Giant Chickweed	*Stellaria aquatica*		X		
Celastraceae					
Oriental Bittersweet	*Celastrus orbiculata*		X		
American Bittersweet	*C. scandens*		X		
Ceratophyllaceae					
Coontail	*Ceratophyllum demersum*	X	X	X	
Chenopodiaceae					
Spearscale	*Atriplex patula*				X
Goosefoot	*Chenopodium* sp.		X		
Pigweed	*C. album*			X	

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Clethraceae					
Sweet Pepperbush	*Clethra alnifolia*			X	
Clusiaceae					
Marsh St. John's-wort	*Triadenum virginicum*			X	
Commelinaceae					
Common Day-flower	*Commelina communis*	X	X		
Convolvulaceae					
Hedge Bindweed	*Convolvulus sepium*		X		
Cornaceae					
Silky Dogwood	*Cornus amomum*	X	X	X	
Flowering Dogwood	*C. florida*	X			
Northern Swamp Dogwood	*C. racemosa*		X		
Red-osier Dogwood	*C. sericea*		X		
Cucurbitaceae					
Bur-cucumber	*Echinocystis lobata*	X			
Star-cucumber	*Sicyos angulatus*	X			
Cupressaceae					
Red Cedar	*Juniperus virginiana*	X			
Northern White Cedar	*Thuja occidentalis*	X	X		
Cuscutaceae					
Dodder	*Cuscuta* sp.			X	
Buttonbush Dodder	*C. cephalanthi*	X			
Common Dodder	*C. gronovii*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Cyperaceae					
Bebb's Oval Sedge	*Carex bebbii*		X		
Craford's sedge	*C. crawfordii*		X		
Fringed sedge	*C. crinita*		X		
Gray's Sedge	*C. grayii*		X		
Necklace Sedge	*C. hormathodes*				X
Porcupine Sedge	*C. hystericina*		X		
Common Lake Sedge	*C. lacustris*		X		
Shallow Sedge	*C. lurida*		X		
Fernald's Sedge	*C. merritt-fernaldii*	X			
Rosy Sedge	*C. rosea*		X		
Deflexed Bottle-brush Sedge	*C. rostrata*		X		
Common Fox Sedge	*C. stipata*		X	X	
Straw Sedge	*C. straminea*		X		
Common Tussock Sedge	*C. stricta*		X	X	
Awl-fruited Oval Sedge	*C. tribuloides*		X		
Galingale	*Cyperus rivularis*		X	X	
Yellow Flatsedge	*C. flavescens*				X
Schweinitz's Flatsedge	*C. schweinitzii*	X			
False Nutsedge	*C. strigosus*		X		
Three-way Sedge	*Dulichium arundinaceum*		X		
Dwarf Hairgrass	*Eleocharis acicularis*	X			
Blunt Spike-rush	*E. ovata*	X	X		
Spike-rush	*E. diandra*	X	X	X	
Common Spike-rush	*E. palustris*	X	X		X
Little Spike-rush	*E. parvula*				X
Hardstem Bulrush	*Scirpus acutus*	X	X		
Olney-threesquare	*S. americanus*	X	X	X	X
Black Bulrush	*S. atrovirens*		X		
Saltmarsh-bulrush	*S. cylindricus*			X	X
Wool-grass	*S. cyperinus*			X	

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Cyperaceae					
River Bulrush	*Scirpus fluviatilis*	X	X		X
Alkali-bulrush	*S. maritimus*				X
Common Threesquare	*S. pungens*			X	X
Saltmarsh Bulrush	*S. robustus*			X	X
Bluntscale Bulrush	*S. smithii*	X	X	X	
Softstem-bulrush	*S. tabernaemontani*	X	X	X	X
Dennstaedtiaceae					
Bracken Fern	*Pteridium aquilinum*		X		
Dioscoreaceae					
Wild yam	*Dioscorea villosa*		X		
Elantinaceae					
Waterwort	*Elatine triandra*	X	X		
Equisetaceae					
Horsetail	*Equisetum* sp.	X	X		
Field horsetail	*E. arvense*		X		
Water horsetail	*E. fluviatile*		X		
Marsh horsetail	*E. palustre*		X		
Ericaceae					
Wintergreen	*Gaultheria procumbens*		X		
Highbush-blueberry	*Vaccinium corymbosum*		X		
Eriocaulaceae					
Pipewort	*Eriocaulon parkeri*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Fabaceae					
False indigo	*Amorpha fruticosa*		X	X	
Hog-peanut	*Amphicarpaea bracteata*		X	X	
Groundnut	*Apios americana*		X	X	
Marsh-Pea	*Lathyrus palustris*	X	X		
White Sweet Clover	*Melilotus alba*			X	
Woolly Bean	*Strophostyles helvula*			X	
Fagaceae					
Chestnut	*Castanea dentata*		X		
American Beech	*Fagus grandifolia*	X			
White Oak	*Quercus alba*		X		
Swamp White Oak	*Q. bicolor*	X	X		
Rock Chestnut Oak	*Q. prinus*		X		
Northern Red Oak	*Q. rubra*		X		
Black Oak	*Q. velutina*		X		
Gentianaceae					
Bottle Gentian	*Gentiana andrewsii*		X		
Bottle Gentian	*G. clausa*	X			
Geraniaceae					
Wild Geranium	*Geranium maculatum*		X		
Grossulariaceae					
Eastern Black Current	*Ribes americanum*		X		
Haloragaceae					
European Water-milfoil	*Myriophyllum spicatum*	X	X	X	X
Whorled Water-milfoil	*Myriophyllum verticillatum*	X			

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Hamamelidaceae					
Witch-hazel	*Hamamelis virginiana*		X		
Sweet Gum	*Liquidambar styraciflua*				X
Hydrocharitaceae					
Common Water-weed	*Elodea canadensis*	X	X	X	
Free-field Water-weed	*E. nuttallii*	X	X	X	X
Water celery	*Vallisneria americana*	X	X	X	X
Iridaceae					
Yellow Flag	*Iris pseudacorus*	X	X	X	
Northen Blue Flag	*I. versicolor*	X	X	X	
Blue-eyed Grass	*Sisyrhynchium* sp.			X	
Isoetaceae					
Riverbank-quillwort	*Isoetes riparia*		X		
Juglandaceae					
Pignut-hickory	*Carya glabra*		X		
Shagbark-hickory	*C. ovata*		X		
Mockernut-hickory	*C. tomentosa*		X		
Butternut	*Juglans cinerea*		X		
Black Walnut	*J. nigra*		X		
Juncaceae					
Tapered Rush	*Juncus acuminatus*		X		
Small-headed Rush	*J. brachycephalus*		X		
Black Grass	*J. gerardii*			X	
Path Rush	*J. tenuis*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Lamiaceae					
Northern Horse-balm	*Collinsonia canadensis*		X		
Gill-over-the-ground	*Glechoma hederacea*		X		
American Water-horehound	*Lycopus americanus*		X		
European Water-horehound	*L. europaeus*		X		
Stalked Water-horehound	*L. rubellus*		X		
Virginia Water-horehound	*L. virginicus*		X		
Northern Water-horehound	*L. uniflorus*		X		
Mint	*Mentha* sp.	X		X	
Field-mint	*M. arvensis*		X		
Marsh-skullcap	*Scutellaria galericulata*			X	
Skullcap	*S. lateriflora*		X		
Hispid Hedge-nettle	*Stachys hispida*		X		
Hedge-nettle	*S. palustris*		X		
American Germander	*Teucrium canadense*				X
Lauraceae					
Spice-bush	*Lindera benzoin*	X	X		
Sassafras	*Sassafras albidum*		X		
Lemnaceae					
Lesser Duckweed	*Lemna minor*	X	X	X	X
Greater Duckweed	*Spirodela polyrhiza*	X	X	X	
Water-meal	*Wolffia columbiana*		X		
Liliaceae					
Onion	*Allium* sp.			X	
Prairie Onion	*A. stellatum*		X		
Field-garlic	*A. vineale*		X		
Trout-lily	*Erythronium americanum*	X			
Day-lily	*Hemerocallis fulva*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Liliaceae					
Wild Yellow Lily	*Lilium canadense*		X		
False Soloman's Seal	*Smilacina racemosa*		X		
Trillium	*Trillium* sp.		X		
False Hellbore	*Veratrum viride*		X		
Campanulaceae					
Cardinal-flower	*Lobelia cardinalis*	X	X	X	
Great Blue Lobelia	*L. siphilitica*		X		
Lythraceae					
Purple Loosestrife	*Lythrum salicaria*	X	X	X	X
Magnoliaceae					
Tulip tree	*Liriodendron tulipifera*		X		
Malvaceae					
Rose-mallow	*Hibiscus moscheutos*		X	X	X
Menyanthaceae					
Little Floating Heart	*Nymphoides cordata*		X		
Myricaceae					
Sweet Fern	*Comptonia peregrina*		X		
Najadaceae					
Northern Water-nymph	*Najas flexilis*	X	X	X	
Southern Water-nymph	*N. guadalupensis*	X		X	X
Eutrophic Water-nymph	*N. minor*	X	X		
Hudson River Water-nymph	*N. muenscheri*	X	X	X	

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Nymphaeaceae					
Spatterdock	*Nuphar advena*	X	X	X	
Water-lily	*Nymphaea odorata*		X		
Oleaceae					
Ash	*Fraxinus* sp.			X	
White Ash	*F. americana*		X		
Black Ash	*F. nigra*	X	X		
Green Ash	*F. pennsylvanica*	X	X		
Common Privet	*Ligustrum vulgare*		X		
Onagraceae					
Common Enchanter's Nightshade	*Circaea lutetiana*		X		
Willow-herb	*Epilobium* sp.			X	
American Willow-herb	*E. adenocaulon*		X		
Easterm Willow-herb	*E. coloratum*		X		
Northern Willow-herb	*E. glandulosum*		X		X
Common Water-purslane	*Ludwigia palustris*	X	X		X
Evening-primrose	*Oenothera* sp.	X	X		
Onocleaceae					
Ostrich-fern	*Matteuccia struthiopteris*	X			
Sensitive Fern	*Onoclea sensibilis*	X	X	X	
Orchidaceae					
Helleborine	*Epipactis helleborine*		X		
Osmundaceae					
Cinnamon-fern	*Osmunda cinnemomea*		X	X	
Interrupted Fern	*O. claytoniana*			X	
Royal Fern	*O. regalis*		X	X	

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Pinaceae					
Red Pine	*Pinus resinosa*		X		
Red Spruce	*P. rubens*	X			
White Pine	*P. strobus*	X	X		
Eastern Hemlock	*Tsuga canadensis*	X			
Plantaginaceae					
Heartleaf Plantain	*Plantago cordata*	X	X		
Plantanaceae					
Sycamore	*Platanus occidentalis*	X			
Poaceae					
Bent-grass	*Agrostis* sp.			X	
Ticklegrass	*A. hyemalis*		X		
Creeping Bent-grass	*A. stolonifera*				X
Bluejoint	*Calamagrostis canadensis*		X		
Woodreed	*Cinna* sp.			X	
Common Woodreed	*C. arundinacea*		X		
Salt-grass	*Distichlis spicata*				X
Barnyard-grass	*Echinochloa crusgalli*		X		
Water-millet	*E. walteri*		X	X	X
Virginia Wild Rye	*Elymus virginicus*		X	X	
Fowl-mannagrass	*Glyceria striata*		X		
Rice cut-grass	*Leersia oryzoides*	X	X	X	
White Grass	*L. virginica*	X	X		
Panic-grass	*Panicum* sp.	X	X	X	
Witch-grass	*P. capillare*	X			
Panic-grass	*P. dichotomiflorum*	X	X		
Switchgrass	*P. virgatum*			X	X
Reed Canary-grass	*Phalaris arundinacea*	X	X	X	

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Poaceae					
Common Reed	*Phragmites australis*	X	X	X	X
Wood Bluegrass	*Poa alsodes*		X		
Smooth Cordgrass	*Spartina alterniflora*				X
Big Cordgrass	*S. cynosuroides*			X	X
Salt-meadow Cordgrass	*S. patens*				X
Prairie Cordgrass	*S. pectinata*		X	X	
Wild Rice	*Zizania aquatica*	X	X	X	
Polygonaceae					
Knotweed	*Polygonum* sp.	X	X	X	
Halberd-leaved Tearthumb	*P. arifolium*		X	X	X
Smartweed	*P. cespitosum*		X		
Japanese Knotweed	*P. cuspidatum*	X			
Seaside Knotweed	*P. glaucum*				X
Water-pepper	*P. hydropiper*		X		
False Water-pepper	*P. hydropiperoides*		X	X	
Lady's Thumb	*P. persicaria*		X		
Dotted Smartweed	*P. punctatum*	X	X	X	X
Coarse Smartweed	*P. robustius*		X		
Arrow-leaved Tearthumb	*P. sagittatum*	X	X	X	
Jumpseed	*P. virginianum*		X		
Curly Dock	*Rumex crispus*		X		
Dock	*R. salicifolius*			X	
Water-dock	*R. verticillatus*		X		
Pontederiaceae					
Kidneyleaf Mud-plantain	*Heteranthera reniformis*	X	X		X
Pickerel-weed	*Pontederia cordata*	X	X	X	
Water Star-grass	*Zosterella dubia*	X	X	X	

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Portulacaceae					
Spring-beauty	*Claytonia virginica*		X		
Potamogetonaceae					
Curly Pondweed	*Potamogeton crispus*		X	X	X
Ribbonleaf Pondweed	*P. epihydrus*	X	X		
Leafy Pondweed	*P. foliosus*	X	X	X	
Longleaf Pondweed	*P. nodosus*	X	X		
Sago Pondweed	*P. pectinatus*	X		X	X
Redhead-grass	*P. perfoliatus*	X	X	X	X
Slender Pondweed	*P. pusillus*	X			
Richardson's Pondweed	*P. richardsonii*	X	X	X	
Flatstem Pondweed	*P. zosteriformis*	X	X		
Primulaceae					
Fringed Loosestrife	*Lysimachia ciliata*	X	X		
Moneywort	*L. nummularia*		X		
Bulbil-loosestrife	*L. terrestris*		X		
Water-pimpernel	*Samolus floribundus*			X	X
Ranunculaceae					
Doll's Eyes Baneberry	*Actaea alba*		X		
Red Baneberry	*A. rubra*	X	X		
Wild Columbine	*Aguilegia canadensis*		X		
Marsh-marigold	*Caltha palustris*	X	X		
Virgin's Bower	*Clematis virginiana*	X	X		
Round-lobed Hepatica	*Hepatica americana*		X		
Small-field Crowfoot	*Ranunculus abortivus*		X		
Cursed Crowfoot	*R. sceleratus*		X		X
Buttercup	*R. septentrionalis*	X	X		
Tall meadow-rue	*Thalictrum polygamum*	X	X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Rhamnaceae					
Common Buckthorn	*Rhamnus catharticus*		X		
Rosaceae					
Shadbush	*Amelanchier* spp.		X		
White Avens	*Geum canadense*		X		
Rough Avens	*G. laciniatum*		X		
Ninebark	*Physocarpus opulifolius*		X	X	
Wild Black Cherry	*Prunus serotina*		X		
Choke-cherry	*P. virginiana*		X		
Multiflora-rose	*Rosa multiflora*		X		
Swamp-rose	*R. palustris*		X	X	
Bramble	*Rubus* spp.		X		
Swamp-dewberry	*R. hispidus*		X		
Meadowsweet	*Spiraea alba*		X	X	
Hardhack	*S. tomentosa*			X	
Rubiaceae					
Buttonbush	*Cephalanthus occidentalis*		X	X	
Rough Bedstraw	*Galium asprellum*		X		
Bluntlf-bedstraw	*G. obtusum*			X	
Marsh-bedstraw	*G. palustre*		X		
Northern Three-lobed Bedstraw	*G. trifidum*		X		
Salicaceae					
Cottonwood	*Populus deltoides*	X	X	X	X
Big-tooth Aspen	*P. grandidentate*		X		
Quaking Aspen	*P. tremuloides*		X		
Willow	*Salix* sp.	X	X		
White Willow	*S. alba*		X		
Crack Willow	*S. fragilis*		X		
Black Willow	*S. nigra*	X		X	
Basket Willow	*S. purpurea*			X	
Rigid Willow	*S. rigida*		X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Saxifragaceae					
Ditch-stonecrop	*Penthorum sedoides*		X		
Scrophulariaceae					
White Turtlehead	*Chelone glabra*		X	X	
Atlantic Mudwort	*Limosella subulata*	X	X		
False Pimpernel	*Lindernia dubia*	X	X		X
Nuttall's Mudwort	*Micranthemum micranthemoides*		X		
Sharpwing Monkey-flower	*Mimulus alatus*	X			
Allegheny Monkey-flower	*M. ringens*		X		
Swamp-lousewort	*Pedicularis lanceolata*	X	X		
Smilacaceae					
Greenbrier	*Smilax* sp.		X		
Smooth Carrionflower	*S. herbacea*		X		
Bristly Greenbrier	*S. hispida*		X		
Solanaceae					
Bittersweet	*Solanum dulcamara*		X		
Sparganiaceae					
Bur-reed	*Sparganium americanum*		X		
Giant Bur-reed	*S. eurycarpum*	X	X		
Staphyleaceae					
Bladder-nut	*Staphylea trifolia*		X		
Taxaceae					
American Yew	*Taxus canadensis*		X		
Tiliaceae					
Basswood	*Tilia americana*	X	X		

Vascular Plants		Stockport	Tivoli	Iona	Piermont
Trapaceae					
Water chestnut	*Trapa natans*	X	X	X	
Typhaceae					
Narrow-leaved Cattail	*Typha angustifolia*	X	X	X	X
Hybrid Cattail	*T.* x. *glauca*	X	X	X	X
Ulmaceae					
Elm	*Ulmus* sp.		X		
American elm	*U. americana*	X	X	X	
Slippery Elm	*U. rubra*		X		
Urticaceae					
False Nettle	*Boehmeria cylindrica*		X	X	
Fibrous-rooted Nettle	*Laportea canadensis*	X	X		
Clearweed	*Pilea* sp.	X			
Clearwood	*P. fontana*			X	
Clearweed	*P. pumila*	X	X		
Erect Nettle	*Urtica dioica*	X			
Violaceae					
Blue Violet	*Viola* sp.		X	X	
Blue Marsh-violet	*V. cucullata*		X		
Vitaceae					
Virginia creeper	*Parthenocissus quinquefolia*	X	X		
Grape	*Vitis* sp.	X	X		
Fox-grape	*V. labrusca*		X		
Zannichelliaceae					
Horned Pondweed	*Zannichellia palustris*	X	X	X	X

Fishes		Stockport	Tivoli	Iona	Piermont
Acipenseridae					
Shortnose Sturgeon	*Acipenser brevirostrum*	X	X	X	X
Atlantic Sturgeon	*A. oxyrhynchus*				X
Anguillidae					
American Eel	*Anguilla rostrata*	X	X	X	X
Atherinidae					
Inland Silverside	*Menidia beryllina*		X		X
Atlantic Silverside	*M. menidia*				X
Belonidae					
Atlantic Needlefish	*Strongylura marina*				X
Carangidae					
Crevalle Jack	*Caranx hippos*			X	X
Catostomidae					
White Sucker	*Catostomus commersoni*	X	X	X	X
Creek Chubsucker	*Erimyzon oblongus*				X
Northern Hog Sucker	*Hypentelium nigricans*	X	X		
Centrarchidae					
Rock Bass	*Ambloplites rupestris*		X		
Bluespotted Sunfish	*Enneacanthus gloriosus*		X	X	
Redbreast Sunfish	*Lepomis auritus*	X	X	X	X
Pumpkinseed	*L. gibbosus*	X	X	X	X
Warmouth	*L. gulosus*		X		
Bluegill	*L. macrochirus*	X	X	X	X
Smallmouth Bass	*Micropterus dolomieu*	X	X	X	
Largemouth Bass	*M. salmoides*	X	X	X	X
Black Crappie	*Pomoxis nigromaculatus*		X		

Fishes		Stockport	Tivoli	Iona	Piermont
Clupeidae					
Blueback Herring	*Alosa aestivalis*		X	X	X
Alewife	*A. pseudoharengus*	X	X	X	
American Shad	*A. sapidissima*	X	X	X	X
Atlantic Menhaden	*Brevoortia tyrannus*			X	
Gizzard Shad	*Dorosoma cepedianum*			X	
Cottidae					
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*				X
Cyprinidae					
Goldfish	*Carassius auratus*	X	X	X	
Satinfin Shiner	*Cyprinella analostana*		X		
Spotfin Shiner	*C. spiloptera*	X	X		
Common Carp	*Cyprinus carpio*	X	X	X	
Cutlips Minnow	*Exoglossum maxillingua*		X		
Eastern Silvery Minnow	*Hybognathus regius*	X	X		
Common Shiner	*Luxilus cornutus*	X	X		
Golden Shiner	*Notemigonus crysoleucas*	X	X	X	X
Comely Shiner	*Notropis amoenus*		X		
Bridle Shiner	*N. bifrenatus*	X	X		
Spottail Shiner	*N. hudsonius*	X	X	X	X
Blacknose Dace	*Rhinichthys atratulus*		X		X
Rudd	*Scardinius erythrophthalmus*		X		
Creek Chub	*Semotilus atromaculatus*		X		
Fallfish	*S. corporalis*	X	X		
Cyprinodontidae					
Banded Killifish	*Fundulus diaphanus*	X	X	X	X
Mummichog	*F. heteroclitus*	X	X	X	X
Spotfin Killifish	*F. luciae*				X
Striped Killifish	*F. majalis*				X

Fishes		Stockport	Tivoli	Iona	Piermont
Engraulidae					
Bay Anchovy	*Anchoa mitchilli*				X
Esocidae					
Redfin Pickerel	*Esox americanus*	X	X	X	X
Northern Pike	*E. lucius*	X			
Chain Pickerel	*E. niger*		X		
Gadidae					
Atlantic Tomcod	*Microgadus tomcod*			X	X
Gasterosteidae					
Fourspine Stickleback	*Apeltes quadracus*	X	X	X	X
Threespine Stickleback	*Gasterosteus aculeatus*			X	
Ictaluridae					
White Catfish	*Ameiurus catus*	X	X		X
Yellow Bullhead	*A. natalis*				X
Brown Bullhead	*A. nebulosus*	X	X	X	
Channel Catfish	*Ictalurus punctatus*		X		
Labridae					
Tautog	*Tautoga onitis*				X
Osmeridae					
Rainbow Smelt	*Osmerus mordax*	X	X		
Percichthyidae					
White Perch	*Morone americana*	X	X	X	X
Striped Bass	*M. saxatilis*	X	X	X	X
Percidae					
Tessellated Darter	*Etheostoma olmstedi*	X	X	X	X
Yellow Perch	*Perca flavescens*	X	X	X	

Fishes		Stockport	Tivoli	Iona	Piermont
Petromyzontidae					
American Brook Lamprey	*Lampetra appendix*		X		
Sea Lamprey	*Petromyzon marinus*		X		
Pomatomidae					
Bluefish	*Pomatomus saltatrix*			X	X
Salmonidae					
Rainbow Trout	*Oncorhynchus mykiss*		X		
Brown Trout	*Salmo trutta*	X	X		
Brook Trout	*Salvelinus fontinalis*		X		
Sciaenidae					
Weakfish	*Cynoscion regalis*				X
Serranidae					
Black Seabass	*Centropristis striata*				X
Soleidae					
Hogchoker	*Trinectes maculatus*		X		X
Syngnathidae					
Northern Pipefish	*Syngnathus fuscus*				X
Umbridae					
Central Mudminnow	*Umbra limi*		X		
Eastern Mudminnow	*U. pygmaea*				X

Reptiles		Stockport	Tivoli	Iona	Piermont
Chelydridae					
Snapping turtle	*Chelydra serpentina*	X	X	X	X
Colubridae					
Northern water snake	*Nerodia sipedon*	X	X	X	X
Brown snake	*Storeria dekayi*	X	X		
Eastern garter snake	*Thamnophis sirtalis sirtalis*	X	X	X	
Eastern ribbon snake	*T. sauritus*		X		
Eastern hognose snake	*Heterodon platyrhinos*			X	
Ringneck snake	*Diadophis punctatus*	X	X		
Black racer	*Coluber constrictor*		X	X	X
Smooth green snake	*Opheodrys vernalis*	X			
Black rat snake	*Elaphe obsoleta*			X	
Milk snake	*Lampropeltis triangulum*		X		
Emydidae					
Spotted turtle	*Clemmys guttata*	X	X		
Wood turtle	*C. insculpta*	X	X		
Eastern box turtle	*Terrapene carolina carolina*		X	X	
Diamondback terrapin	*Malaclemys terrapin*			X	X
Map turtle	*Graptemys geographica*	X	X		
Painted turtle	*Chrysemys picta*	X			
Kinosternidae					
Stinkpot	*Sternotherus odoratus*	X			
Iguanidae					
Eastern fence lizard	*Sceloporus undulatus*			X	
Skincidae					
Five-lined skink	*Eumeces fasciatus*			X	
Viperidae					
Copperhead	*Agkistrodon contortrix*	X			

Amphibians		Stockport	Tivoli	Iona	Piermont
Ambystomatidae					
Marbled Salamander	*Ambystoma opacum*	X			
Jefferson Salamander	*A. jeffersonianum*		X		
Blue-spotted Salamander	*A. laterale*	X			
Spotted Salamander	*A. maculatum*	X	X	X	
Bufonidae					
American Toad	*Bufo americanus*	X	X	X	
Hylidae					
Spring Peeper	*Hyla crucifer*	X	X	X	X
Gray Treefrog	*H. versicolor*	X	X	X	
Plethodontidae					
Dusky Salamander	*Desmognathus fuscus*		X	X	X
Eastern Red-backed Salamander	*Plethodon cinereus*	X	X	X	X
Slimy Salamander	*P. glutinosus*		X	X	X
Four-toed Salamander	*Hemidactylium scutatum*	X			
Red Salamander	*Pseudotriton ruber*				X
Two-lined Salamander	*Eurycea bislineata*		X		X
Proteidae					
Mudpuppy	*Necturus maculosus*		X		
Ranidae					
Bullfrog	*Rana catesbeiana*	X	X	X	X
Green Frog	*R. clamitans melanota*	X	X	X	X
Wood Frog	*R. sylvatica*	X	X	X	X
Northern Leopard Frog	*R. pipiens*	X	X		
Pickerel Frog	*R. palustris*		X	X	
Salamandridae					
Red-spotted Newt	*Notophthalmus viridescens viridescens*	X	X	X	X

Birds		Stockport	Tivoli	Iona	Piermont
Accipitridae					
Northern Harrier	*Circus cyaneus*	X	X	X	X
Red-tailed hawk	*Buteo jamaicensis*	X	X	X	X
Rough-legged hawk	*B. lagopus*	X	X	X	X
Bald eagle	*Haliaeetus leucocephalus*	X	X	X	X
Golden eagle	*Aquila chrysaetos*		X	X	X
Alaudidae					
Horned lark	*Eremophila alpestris*	X	X	X	X
Alcedinidae					
Belted kingfisher	*Ceryle alcyon*	X	X	X	X
Anatidae					
Mute swan	*Cygnus olor*	X		X	X
Tundra swan	*C. columbianus*	X	X		
Snow goose	*Chen caerulescens*	X	X	X	X
Greater white-fronted goose	*Anser albifrons*				X
Canada goose	*Branta canadensis*	X	X	X	X
Brant	*B. bernicla*	X	X	X	X
Fulvous whistling duck	*Dendrocygna bicolor*		X		
American black duck	*Anas rubripes*	X	X	X	X
Gadwall	*A. strepera*	X	X	X	X
Mallard	*A. platyrhynchos*	X	X	X	X
Northern pintail	*A. acuta*	X	X	X	X
American wigeon	*A. americana*	X	X	X	X
Eurasian wigeon	*A. penelope*		X		
Wood duck	*Aix sponsa*	X	X	X	
Northern shoveler	*Anas clypeata*	X	X		

Birds		Stockport	Tivoli	Iona	Piermont
Anatidae					
Blue-winged teal	*Anas discors*	X	X	X	X
Green-winged teal	*A. crecca*	X			
American green-winged teal	*A. crecca carolinensis*	X	X	X	X
White-winged scoter	*Melanitta deglandi*	X	X	X	X
Surf scoter	*M. perspicillata*	X	X	X	X
Black scoter	*M. nigra*	X	X	X	
Oldsquaw	*Clanqula hyemalis*	X	X	X	X
Canvasback	*Aythya valisineria*	X	X	X	X
Redhead	*A. americana*	X	X	X	
Ring-necked duck	*A. collaris*	X	X	X	X
Lesser scaup	*A. affinis*	X	X	X	X
Greater scaup	*A. marila*	X	X	X	X
Common goldeneye	*Bucephala clanqula*	X	X	X	X
Bufflehead	*B. albeola*	X	X	X	X
Ruddy duck	*Oxyura jamaicensis*		X	X	X
Common merganser	*Mergus merganser*	X	X	X	X
Red-breasted merganser	*M. serrator*	X	X	X	X
Hooded merganser	*Lophodytes cucullatis*	X	X	X	X
Apodidae					
Chimney swift	*Chaetura pelagica*	X	X	X	X
Ardeidae					
Great blue heron	*Ardea herodias*	X	X	X	X
Little blue heron	*Florida caerulea*	X	X	X	X
Tricolored heron	*Egretta tricolor*				X
Great egret	*Casmerodius albus*	X	X	X	X
Snowy egret	*Egretta thula*	X	X	X	X
Cattle egret	*Bulbulcus ibis*	X			

Birds		Stockport	Tivoli	Iona	Piermont
Ardeidae					
Black-crowned night-heron	*Nycticorax nycticorax*	X	X	X	X
Yellow-crowned night-heron	*N. violacea*				X
Green-backed heron	*Butorides virescens*	X	X	X	X
Least bittern	*Ixobrychus exilis*	X	X	X	X
American bittern	*Botaurus lentiginosus*	X	X	X	X
Bombycillidae					
Cedar waxwing	*Bombycilla cedrorum*	X	X	X	X
Caprimulgidae					
Common nighthawk	*Chordeiles minor*	X	X	X	X
Whip-poor-will	*Caprimulgus vociferus*	X	X	X	X
Certhiidae					
Brown creeper	*Certhia familiaris*	X	X	X	X
Charadriidae					
Black-bellied plover	*Pluvialis squatarola*		X		X
Lesser golden plover	*P. dominica*		X		
Ruddy turnstone	*Arenaria interpres*		X		X
Semipalmated plover	*Charadrius semipalmatus*	X	X		X
Killdeer	*C. vociferus*	X	X	X	X
Columbidae					
Mourning dove	*Zenaida macroura*	X	X	X	X
Rock dove	*Columbia livia*	X	X	X	X
Corvidae					
Fish crow	*Corvus ossifraqus*	X	X	X	X
American crow	*C. brachynhynchos*	X	X	X	X
Northern raven	*C. corax*		X	X	
Blue jay	*Cyanocitta cristata*	X	X	X	X

Birds		Stockport	Tivoli	Iona	Piermont
Cuculidae					
Yellow-billed cuckoo	*Coccyzas americanus*	X	X	X	X
Black-billed cuckoo	*C. erythrophthalmus*	X	X	X	X
Falconidae					
American kestrel	*Falco sparverius*	X	X	X	X
Merlin	*F. columbarius*		X	X	X
Peregrine falcon	*F. peregrinus*		X	X	X
Gyrfalcon	*F. rusticolus*		X		
Fringillidae					
Lapland longspur	*Calcarius lapponicus*		X		
Chestnut-collard longspur	*C. ornatus*		X		
Northern junco	*Junco hyemalis*	X	X	X	X
Snow bunthing	*Plectrophenax nivalis*	X	X	X	X
Northern cardinal	*Cardinalis cardinalis*	X	X	X	X
Red crossbill	*Loxia curvirostra*		X		
White-winged crossbill	*L. leucoptera*		X	X	
Common redpoll	*Acanthis flammea*	X	X	X	X
Hoary redpoll	*A. hornemanni*		X		
House finch	*Carpodacus mexicanus*	X	X		X
Purple finch	*C. purpureus*	X	X	X	X
Pine grosbeak	*Pinicola enucleator*		X	X	X
Evening grosbeak	*Hesperiphona vespertina*	X	X	X	X
American goldfinch	*Carduelis tristis*	X	X	X	X
Pine siskin	*C. pinus*	X	X	X	X
Blue grosbeak	*Guiraca caerulea*		X		
Indigo bunting	*Passerina cyanea*	X	X	X	X
Rose-breasted grosbeak	*Pheucticus ludovicianus*	X	X	X	X
Rufous-sided towhee	*Pipilo erythrophtalmus*	X	X	X	X
White-throated sparrow	*Zonotrichia albicollis*	X	X	X	X
White-crowned sparrow	*Z. leucophrys*	X	X	X	X
Chipping sparrow	*Spizella passerina*	X	X	X	X

Birds		Stockport	Tivoli	Iona	Piermont
Fringillidae					
Field sparrow	*Spizella pusilla*	X	X	X	X
Swamp sparrow	*Melospiza georgiana*	X	X	X	X
American tree sparrow	*Spizella arborea*	X	X	X	X
Lark sparrow	*Chondestes grammacus*				X
Grasshopper sparrow	*Ammodramus savannarum*		X		X
Fox sparrow	*Passerella iliaca*	X	X	X	X
Song sparrow	*Melospiza melodia*	X	X	X	X
Vesper sparrow	*Pooecetes gramineus*		X	X	X
Lincoln's sparrow	*Melospiza lincolnii*	X	X	X	X
Savanna sparrow	*Passerculus sandwichensis*	X	X	X	X
Henslow's sparrow	*Ammodramus henslowii*		X		
Sharp-tailed sparrow	*Ammospiza caudacuta*		X		X
Seaside sparrow	*A. maritima*				X
Gaviidae					
Common loon	*Gavia immer*	X	X	X	X
Red-throated loon	*G. stellata*	X	X	X	X
Gruidae					
Sandhill crane	*Grus canadensis*		X		
Hirundinidae					
Purple martin	*Progne subis*	X	X	X	X
Cliff swallow	*Petrochelidon pyrrhonota*	X	X	X	X
Barn swallow	*Hirundo rustica*	X	X	X	X
Tree swallow	*Tachycineta bicolor*	X	X	X	X
Rough-winged swallow	*Stelgidopteryx ruficollis*	X	X	X	X
Bank swallow	*Riparia riparia*	X	X	X	

Birds		Stockport	Tivoli	Iona	Piermont
Icteridae					
Red-winged blackbird	*Agelaius phoeniceus*	X	X	X	X
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*		X		
Brown-headed cowbird	*Molothrus aler*	X	X	X	X
Rusty blackbird	*Euphagus carolinus*	X	X	X	X
Common grackle	*Quiscalus quiscula*	X	X	X	X
Bobolink	*Dolichonyx oryzivorus*	X	X	X	X
Eastern meadowlark	*Sturnella magna*	X	X	X	X
Orchard oriole	*Icterius spurius*	X	X		X
Northern oriole	*I. galbula*	X	X	X	X
Laniidae					
Northern shrike	*Lanius excubitor*		X		X
Loggerhead shrike	*L. ludovicianus*		X		X
Laridae					
Glaucous gull	*Larus hyperboreus*	X		X	X
Iceland gull	*L. glaucoides*	X		X	
Herring gull	*L. argentatus*	X	X	X	X
Ring-billed gull	*L. delawarensis*	X	X	X	X
Black-legged kittiwake	*Rissa tridactyla*		X		
Great black-backed gull	*Larus marinus*	X	X	X	X
Laughing gull	*L. atricilla*		X	X	X
Bonaparte's gull	*L. philadelphia*	X	X	X	X
Sandwich tern	*Sterna savicensis*				X
Royal tern	*S. maximus*	X			X
Caspian tern	*S. caspia*		X		X
Least tern	*S. albifrons*				X
Common tern	*S. hirundo*	X	X	X	X
Forster's tern	*S. forsteri*				X
Roseate tern	*S. dougallii*				X
Black tern	*Chlidonias niger*	X	X	X	X
Sooty tern	*Sterna fuscata*	X		X	X

Birds		Stockport	Tivoli	Iona	Piermont
Meleagrididae					
Wild turkey	*Meleagris gallopavo*	X	X		
Motacillidae					
Water pipit	*Anthus spinoletta*	X	X	X	X
Mimidae					
Brown thrasher	*Toxostoma rufum*	X	X	X	X
Gray catbird	*Dumetella carolinensis*	X	X	X	X
Northern mockingbird	*Mimus polyglottos*	X	X	X	X
Pandionidae					
Osprey	*Pandion haliaetus*	X	X	X	X
Paridae					
Black-capped chickdee	*Parus atricapillus*	X	X	X	X
Boreal chickadee	*P. hudsonicus*	X	X		X
Tufted titmouse	*P. bicolor*	X	X	X	X
Parulidae					
Northern parula warbler	*Parula americana*	X	X	X	X
Yellow-throated warbler	*Dendroica dominica*		X		
Black-throated green warbler	*D. virens*	X	X	X	X
Prothonotary warbler	*Protonotaria citrea*	X	X		X
Black-and-white warbler	*Mniotilta varia*	X	X	X	X
Blackpoll warbler	*Dendroica striata*	X	X	X	X
Black-throated blue warbler	*D. caerulescens*	X	X	X	X
Cerulean warbler	*D. cerulea*	X	X	X	X
Magnolia warbler	*D. magnolia*	X	X	X	X
Yellow-rumped warbler	*D. coronata*	X	X	X	X
Canada warbler	*Wilsonia canadensis*	X	X	X	X
Cape May warbler	*Dendroica tigrina*	X	X	X	
Chestnut-sided warbler	*D. pensylvanica*	X	X	X	X

Birds		Stockport	Tivoli	Iona	Piermont
Parulidae					
Bay-breasted warbler	*Dendroica castanea*	X	X	X	X
Blackburnian warbler	*D. fusca*	X	X	X	X
American redstart	*Setophaga ruticilla*	X	X	X	X
Pine warbler	*Dendroica pinus*	X	X	X	
Prarie warbler	*D. discolor*	X	X	X	X
Palm warbler	*D. palmarum*	X	X	X	
Blue-winged warbler	*Vermivora pinus*	X	X	X	X
Yellow warbler	*Dedroica petechia*	X	X	X	X
Worm-eating warbler	*Helmitheros vermivorus*		X	X	X
Tennessee warbler	*Vermivora peregrina*	X	X	X	X
Orange-crowned warbler	*V. celata*		X		X
Wilson's warbler	*Wilsonia pusilla*	X	X	X	X
Hooded warbler	*W. citrina*		X	X	X
Golden-winged warbler	*Vermivora chrysoptera*		X	X	
Nashville warbler	*V. ruficapilla*		X	X	X
Connecticut warbler	*Oporornis agilis*		X		
Mourning warbler	*O. Philadelphia*		X		
Kentucky warbler	*O. formosus*		X		X
Common yellowthroat	*Geothlypis trichas*	X	X	X	X
Yellow-breasted chat	*Icteria virens*		X	X	X
Northern waterthrush	*Seiurus noveboracensis*	X	X	X	X
Louisiana waterthrush	*S. motacilla*	X	X	X	X
Ovenbird	*S. aurocapillus*	X	X	X	X
Phalacrocoracidae					
Double-crested cormorant	*Phalacrocorax auritus*	X	X	X	X
Great cormorant	*P. carbo*				X
Phasianidae					
Ring-necked pheasant	*Phasianus colchicus*	X	X	X	X
Gray partridge	*Perdix perdix*		X		

Birds		Stockport	Tivoli	Iona	Piermont
Picidae					
Red-headed woodpecker	*Melanerpes erythrocephalus*		X		
Pileated woodpecker	*Dryocopus pileatus*	X	X	X	X
Northern flicker	*Colaptes auratus*	X	X	X	X
Red-bellied woodpecker	*Melanerpes carolinus*	X	X		X
Yellow-bellied sapsucker	*Sphyrapicus varius*	X	X	X	X
Downy woodpecker	*Picoides pubescens*	X	X	X	X
Hairy woodpecker	*P. villosus*	X	X	X	X
Black-backed three-toed woodpecker	*P. arcticus*		X		
Ploceidae					
House sparrow	*Passer domesticus*	X	X	X	X
Podicipedidae					
Horned grebe	*Podiceps auritus*	X	X	X	X
Pied-billed grebe	*Podilymbus podiceps*	X	X	X	X
Red-necked grebe	*Podiceps grisengena*	X	X	X	
Psittacidae					
Monk parakeet	*Myiopsitta monachus*				X
Rallidae					
Virginia rail	*Rallus limicola*	X	X	X	X
King rail	*R. elegans*	X	X	X	X
Clapper rail	*R. longirostris*				X
Sora	*Porzana carolina*	X	X	X	X
American coot	*Fulica americana*	X	X	X	X
Common Moorhen	*Gallinula chloropus*	X	X	X	X

Birds		Stockport	Tivoli	Iona	Piermont
Scolopacidae					
American woodcock	*Philohela minor*	X	X	X	X
Common snipe	*Capella gallinago*	X	X	X	X
Short-billed dowitcher	*Limnodromus griseus*		X		X
Long-billed dowitcher	*L. scolopaceus*				X
Red knot	*Calidris canutus*				X
Willet	*Catoptrophorus semipalmatus*				X
Greater yellowlegs	*Tringa melanoleuca*	X	X	X	X
Lesser yellowlegs	*T. flavipes*	X	X	X	X
Solitary sandpiper	*T. solitaria*	X	X		X
Sanderling	*Calidris alba*		X		X
Upland sandpiper	*Bartramia longicauda*			X	X
Pectoral sandpiper	*Calidris melanotos*	X	X		X
Dunlin	*C. alpina*	X	X		X
Spotted sandpiper	*Actitis macularia*	X	X	X	X
Least sandpiper	*Calidris minutilla*	X	X		X
Semipalmated sandpiper	*C. pusillus*		X		X
Western sandpiper	*C. mauri*				X
White-rumped sandpiper	*C. fuscicollis*				X
Northern phalarope	*Lobipes lobatus*			X	X
Sittidae					
White-breasted nuthatch	*Sitta carolinensis*	X	X	X	X
Red-breasted nuthatch	*S. canadensis*	X	X	X	X
Sturnidae					
European starling	*Sturnus vulgaris*	X	X	X	X
Sulidae					
Northern gannet	*Sula bassanus*		X		
Sylviidae					
Ruby-crowned kinglet	*Regulus calendula*	X	X	X	X
Golden-crowned kinglet	*R. satrapa*	X	X	X	X
Blue-gray gnatcatcher	*Polioptila caerulea*	X	X	X	X

Birds		Stockport	Tivoli	Iona	Piermont
Tetraonidae					
Ruffed grouse	*Bonasa umbellus*	X	X	X	
Thraupidae					
Summer tanager	*Piranga rubra*		X		
Scarlet tanager	*P. olivacea*	X	X	X	X
Threskiornithidae					
Glossy ibis	*Plegadis falcinellus*		X		X
Trochilidae					
Ruby-throated hummingbird	*Archilochus colubris*	X	X	X	X
Troglodytidae					
House wren	*Troglodytes aedon*	X	X	X	X
Winter wren	*T. troglodytes*	X	X	X	X
Carolina wren	*Throyothorus ludovicianus*	X	X		X
Marsh wren	*Cistothorus palustris*	X	X	X	X
Sedge wren	*C. platensis*				X
Turdidae					
Eastern bluebird	*Sialia sialia*	X	X	X	X
American robin	*Turdus migratorius*	X	X	X	X
Northern wheatear	*Oenanthe oenanthe*		X		
Swainson's thrush	*Catharus ustulata*	X	X	X	X
Hermit thrush	*C. guttata*	X	X	X	X
Veery	*C. fuscescens*	X	X	X	X
Wood thrush	*Hylocichla mustelina*	X	X	X	X
Tyrannidae					
Eastern kingbird	*Tyrannus tyrannus*	X	X	X	X
Western kingbird	*T. verticalis*		X		
Great crested flycatcher	*Myiarchus crinitus*	X	X	X	X
Eastern phoebe	*Sayornis phoebe*	X	X	X	X
Eastern pewee	*Contopus virens*	X	X	X	X

Birds		Stockport	Tivoli	Iona	Piermont
Tyrannidae					
Olive-sided flycatcher	*Nuttallornis borealis*		X	X	
Acadian flycatcher	*Empidonax virescens*		X		
Yellow-bellied flycatcher	*E. flaviventris*		X	X	
Least flycatcher	*E. minimus*	X	X	X	X
Willow flycatcher	*E. traillii*	X	X	X	X
Alder flycatcher	*E. alnorum*		X		
Tytonidae and Strigidae					
Short-eared owl	*Asio flammeus*	X			X
Common screech owl	*Otus asio*	X	X	X	X
Long-eared owl	*Asio otus*		X		X
Great horned owl	*Bubo virginianus*	X	X	X	
Barred owl	*Strix varia*		X	X	
Barn owl	*Tyto alba*	X			
Snowy owl	*Nyctea scandiaca*				X
Saw-whet owl	*Aegolius arcadius*	X	X		
Vireonidae					
Red-eyed vireo	*Vireo olivaceus*	X	X	X	X
Warbling vireo	*V. gilvus*	X	X		X
Philadelphia vireo	*V. philadelphicus*		X		X
Yellow-throated vireo	*V. flavifrons*	X	X	X	X
White-eyed vireo	*V. griseus*		X	X	
Solitary vireo	*V. solitarius*	X	X	X	X

Mammals		Stockport	Tivoli	Iona	Piermont
Canidae					
Red fox	*Vulpes vulpes*	X	X	X	
Coyote	*Canis latrans* var.	X	X		
Castoridae					
Beaver	*Castor canadensis*	X	X	X	X
Cervidae					
White-tailed deer	*Odocoileus virginianus*	X	X	X	X
Cricetidae					
Deer mouse*	*Peromyscus maniculatus*				
White-footed mouse	*P. leucopus*	X	X	X	
Eastern woodrat	*Neotoma floridana*			X	X
Meadow vole	*Microtus pennsylvanicus*	X	X	X	
Southern bog lemming*	*Synaptomys cooperi*				
Delphinidae					
Common dolphin	*Delphinus delphis*		X		
Didelphidae					
Common opossum	*Didelphis marsupialis*	X			
Erethizontidae					
Porcupine	*Erethizon dorsatum*		X		
Felidae					
Bobcat	*Felis rufus*		X		

Mammals		Stockport	Tivoli	Iona	Piermont
Leporidae					
Eastern cottontail	*Sylvilagus floridanus*	X	X	X	X
Muridae					
House mouse	*Mus musculus*		X		
Norway rat	*Rattus norvegicus*		X	X	
Southern red-backed vole	*Clethrionomys gapperi*				
Muskrat	*Ondatra zibethicus*	X	X	X	X
Pine vole	*Microtus pinetorum*				
Mustelidae					
Long-tailed weasel	*Mustela frenata*		X		
Ermine	*M. erminea*		X		
Fisher	*Martes pennanti*			X	
Mink	*Mustela vison*		X	X	
Striped skunk	*Mephitis mephitis*	X	X	X	
River otter	*Lutra canadensis*	X	X	X	
Procyonidae					
Raccoon	*Procyon lotor*	X	X	X	X
Sciuridae					
Eastern chipmunk	*Tamias striatus*	X	X	X	X
Gray squirrel	*Sciurus carolinensis*	X	X	X	X
Red squirrel	*Tamiasciurus hudsonicus*	X	X	X	
Southern flying squirrel	*Glaucomys volans*		X	X	
Woodchuck	*Marmota monax*	X	X	X	

Mammals		Stockport	Tivoli	Iona	Piermont
Soricidae					
Masked shrew	*Sorex cinereus*				
Short-tailed shrew	*Blarina brevicauda*		X	X	
Smokey shrew	*Sorex fumeus*	X			
Talpidae					
Star-nosed mole	*Condylura cristata*	X	X		
Eastern mole	*Scalopus aquaticus*	X			
Hairy-tailed mole	*Parascalops breweri*	X			
Ursidae					
Black bear	*Ursus americanus*		X		X
Vespertilionidae					
Big brown bat	*Eptesicus fuscus*	X	X		
Red bat	*Lasiurus borealis*		X		
Hoary bat	*L. cinereus*				
Little brown bat	*Myotis lucifuqus*	X	X		
Keen's bat	*M. keenii*		X		
Indiana bat*	*M. sodalis*				
Eastern pipistrelle	*Pipistrellus subflavus*				
Zapodidae					
Meadow jumping mouse	*Zapus hudsonius*		X		
Woodland jumping mouse	*Napaeozapus insignis*				

Notes:

*Species identified, but location not noted due to T/E status.