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Hackensack Meadowlands, New Jersey, Biodiversity:

A Review and Synthesis

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Corrections and Updates to:

Hackensack Meadowlands, New Jersey, Biodiversity: A Review and Synthesis

By Erik Kiviat and Kristi MacDonald, Hudsonia Ltd.

We will occasionally add information to this section of the report instead of frequently changing the report itself. This section last changed 23 June 2003 by EK.

Corrections:

P. 40: The laboratory work of J. Weis comparing reed and cordgrass detritus did not use mummichogs, only fiddler crabs and grass shrimp.

P. 93: The correct year of publication for Labriola is 2000. Labriola should precede Langan.

P. 97: The Yuhas 2001 thesis was prepared at New Jersey Institute of Technology, not Rutgers University.

Table 4: American coot should be indicated (*) as water or wetland-associated; barn-owl should not be.

Updates:

P. 32: In July 2002, an apparent family group of northern harrier (Endangered) was observed on multiple days at the Carlstadt-Moonachie marshes (Empire tract), indicating breeding at that location. Thus the Empire tract and the Berry's Creek marshes are the two known breeding localities for this species in the Meadowlands.

P. 65: To the best of our knowledge, this clam-shrimp species is known from only about 10 localities in its global range. If this species were reviewed by the State Natural Heritage Program it would be ranked G1 S1. The Meadowlands population therefore may have considerable significance for conservation.

Table 1: Additional species in the Meadowlands flora are *Cuscuta pentagona, Menispermum canadense, Penstemon digitalis,* and *Tradescantia virginiana.*

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INTRODUCTION: AN URBAN ESTUARY

The Hackensack Meadowlands[1] are about 16 kilometers (about 10 miles) long north to south, and cover an area of about 83 square kilometers or 8,300 hectares (about 32 square miles or 21,000 acres) that was once almost all wetlands (see Quinn 1997, Day et al. 1999). The official Hackensack Meadowlands District comprises 7,889 hectares (19,485 acres). Wetlands and waters now cover about 3,200 hectares (about 8,000 acres) in the Meadowlands (Meadowlands Environmental Research Institute [MERI], personal communication to EK, 2002). The land is mostly at sea level, with isolated knolls that include the ca. 53 meter (ca. 175 foot) high Laurel Hill and a few 30 meter (100 foot) high landfills (Day et al. 1999). Extensive common reed marshes, more than anything else, characterize the Meadowlands environment which lies isolated and surrounded by rocky ridges and urban centers. The marshes are crisscrossed by high-speed highways, dotted with hills of covered garbage, and broken by industrial archipelagoes. In 2001, based on the threat of urban development, the Hackensack River was ranked number 12 of the 13 "Most Endangered Rivers" of the U.S. (American Rivers 2001, Anonymous 2001). Yet the Meadowlands have been called a *de facto* "urban wildlife refuge" (R. Kane, statement at U.S. Fish and Wildlife Service workshop, 31 October 2001), and are 1 of 5 clusters of estuarine open space lands in the New York City area (A. Appleton, statement at USFWS workshop, 31 October 2001). In the Meadowlands, development, rare birds, invasive plants, pollution in the sediments, and ecological restoration projects vie for space in seeming ecological contradiction.

The Meadowlands might not stand out among estuaries but for its location within one of the most heavily industrialized and densely populated regions of the world, northeastern New Jersey. With Manhattan looming less than three miles away, the Meadowlands is a diorama of residential development and factories, automobile and air traffic, and landfills, contrasted with expanses of tall reeds, tidal creeks, mudflats, rivers, and abundant wildlife. This remarkable landscape has persisted despite centuries of draining and ditching, dumping and chemical pollution. The considerable values of the Meadowlands for fauna and flora, and for the 20 million human residents of the New York metropolitan area, require a comprehensive assessment of existing information and research needs. This review and synthesis about the Meadowlands ecosystem will provide some of the scientific information needed to make sound planning, management, and restoration decisions.

In 1968, the New Jersey State Legislature enacted a law creating the Hackensack Meadowlands Development Commission (Kraus and Bragin 1988). In 2001, this agency was officially renamed New Jersey Meadowlands Commission (NJMC); we use this name regardless of the time period, except for literature references which we present verbatim. The NJMC was given broad regulatory power over land use and economic development in 14 municipalities which lie within the boundaries of the Hackensack Meadowlands District in Bergen and Hudson

[1] Excluding the narrow extension along the Hackensack River north of Teterboro.

counties (Kraus and Bragin 1988) (Figure 1). The three principal mandates of the NJMC are: 1. To support orderly development; 2. To administer solid waste disposal; and 3. To protect the ecosystem.

The Nature of Estuaries

Most estuaries are semi-enclosed coastal water bodies which have free connections with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage (Pritchard 1967). Estuaries are zones of biogeochemical, faunal, and floral mixing and they are considered to be one of the most highly productive ecosystems on the planet (Day et al. 1989). Due to this environmental diversity, estuaries support a high diversity of living components. Schelske and Odum (1962) give several reasons for this high productivity. First, estuaries contain three types of photosynthesizing organisms: marsh grass, benthic algae, and phytoplankton. Thus, light energy from the sun can be captured in all seasons. Second, the ebb and flow of tides, and the influx of water from rivers and other areas of the estuary continuously bring large amounts of nutrients in and out of the system. Finally, there is a high rate of regeneration and storage of nutrients in the estuarine system through the activities of microorganisms and filter-feeding invertebrates.

Estuaries have a number of other important characteristics. The benthic fauna is the myriad of organisms that resides within and upon the sediments, plants, and other submerged surfaces. This includes crustaceans, insects, mollusks, oligochaetes, polychaetes, protozoa, and others. Within estuaries, it is generally accepted that species richness decreases as one moves from high-salinity ocean waters to low-salinity waters upstream (references cited in Day et al. 1989). The abundance of benthic organisms per unit area of the estuarine bottom, however, exceeds the numbers in marine environments by 1 or 2 orders of magnitude (Day et al. 1989). Patterns of estuarine community structure in relation to salinity remain an active topic of research and scientific debate (Day et al. 1989).

Drifting within the water column is the plankton community, which is composed of phytoplankton, bacterioplankton, and zooplankton. Zooplankters are small organisms that are passively transported by water currents or that swim too weakly to avoid the influence of the currents (Day et al. 1989). Copepods, immature invertebrates and chordates, eggs, larvae, and juveniles of adult nekton (see below), and sexual stages of hydrozoan and scyphozoan coelenterates are examples of zooplankton found in estuaries (Day et al. 1989).

Nekton comprises all of the free-swimming pelagic organisms of the estuary, including mostly fishes but also squids, scallops, crabs, lobsters, turtles, and marine mammals (Day et al. 1989). The biomass of these organisms in estuaries is among the greatest biomass at higher trophic levels found in natural ecosystems anywhere in the world (Day et al. 1989). Because many species of marine fishes require estuaries for spawning or as nursery grounds, estuaries are an integral habitat for the maintenance of marine fish stocks (Day et al. 1989). Brackish tidal marshes are generally considered important components of the environment of East Coast fisheries, not only due to the functions of the marshes as spawning, nursery, and foraging habitats, but also because the organic matter and animals exported from marshes to estuary form the base of many fishery food chains.

Estuaries support a high diversity of birds, mammals and reptiles (Day et al. 1989). There are also amphibian species that occur there but they are not abundant due to problems with osmoregulation in saline environments and their requirement for freshwater for spawning. Species composition and abundance changes seasonally as well as diurnally with the tides. Muskrat occurs year-round at high densities in estuarine marshes, using large amounts of plant material for direct consumption and for building their conical houses. Sandpipers and other shorebirds stop over in estuaries during spring and fall to obtain nutrients and energy to fuel their migration to and from their Arctic breeding grounds. They exploit the abundance of benthic fauna that becomes available during low tides on exposed mudflats and in marsh shallows. Large numbers of wading birds breed in the estuary or nearby, and feed on benthic fauna and fish. Rails and bitterns nest in the marsh vegetation during spring and summer. Songbirds such as red-winged blackbirds and marsh wrens occur in high numbers in estuaries where they nest in tall vegetation such as common reed and exploit the high productivity of the tidal marshes. A single breeding pair of marsh wrens consumed 20% of the standing crop of insects and spiders in their territory per day, equal to 3500 kcal for the entire breeding season (Kale 1965). An unintended consequence of large-scale mosquito ditching in most eastern U.S. estuaries was that dredged material along ditches provided a drier habitat where shrubs such as marsh-elder could grow (Day et al. 1989) and which supports activities of terrestrial animals. Northern diamondback terrapins are present in high numbers in the tidal creeks and they and other turtle species deposit their eggs in these spoil banks and other dry areas. Birds also use the vegetation on the spoil banks for perching and nesting.

Purpose and Methods of this Review

Many decisions about environmental planning, management, and restoration are being made for the Meadowlands and the larger estuarine system (the New York – New Jersey harbor estuary complex). Public officials, scientists, stakeholders, and the public need information on the biology and ecology of the region in order to make informed decisions. Much of the existing information is not integrated or readily available, and information is lacking on many aspects of Meadowlands science. The purpose of our report is to synthesize information about the Meadowlands into a form that is easy to find and use, and to identify those aspects of the region that need further study or synthesis.

Information about Meadowlands biology exists in several forms, especially formal scientific literature, popular literature, "gray" literature (e.g. agency reports, consulting reports), theses, maps, and the minds and files of scientists, naturalists, and outdoorspeople. We searched the scientific literature by means of commercial and library electronic databases. We located popular literature via library databases such as WorldCat and Reader's Guide to Periodical Literature. We searched the gray literature using WorldCat, the Meadowlands Environmental Research Institute (MERI) database "Digital Meadowlands" (http://digitalmeadowlands.org) and the references cited in major environmental documents (e.g. NJTA 1986, USACOE 2000), as well as by talking with biologists and planners who have worked in the region. We also searched databases for Ph.D. theses and Master's theses. The gray literature on the Meadowlands is extensive, and many documents are difficult to obtain and have relatively low information content. Therefore, we focused on acquiring a representative sample of recent information that was most relevant to our questions, as well as older references with particular relevance to certain issues.

We studied maps of the region, including the U.S. Geological Survey 7.5 minute topographic map quadrangles (Elizabeth N.J.-N.Y. 1995, Hackensack N.J. 1997, Jersey City N.J.-N.Y. 1967 [Photorevised 1981], Orange N.J. 1955 [Photorevised 1970], Weehawken N.J.-N.Y. 1967, Yonkers N.J.-N.Y. 1956). We also contacted a selection of the biologists and naturalists who are most experienced in the Meadowlands, but time limitations did not allow an exhaustive survey of "oral" natural history despite its apparently high value. We generally assumed the accuracy of our information sources except where one source contradicted another, or there was some reason to think the information was incomplete or inaccurate (e.g. by comparison to our own observations in the Meadowlands or our knowledge of similar environments elsewhere in the northeastern states). In this respect, we accorded more weight to information that was consistent from one source to another, and to professional scientists, naturalists, and Ph.D. candidates with long experience working in eastern estuaries or intensive experience of the Meadowlands.

Our task in finding, compiling, and analyzing information was to extract meaning from fragmentary and limited sources. Kiviat's long experience (30 years) studying the Hudson River provided a valuable counterpoint. We anticipate that this report will require revisions as we gain access to more information and are better able to judge the accuracy and value of specific data and ideas. There has been an intensive focus on water and marsh birds in many of the studies we reviewed (due to the importance of the Meadowlands for rare birds and game birds, and the regulatory significance of birds). Therefore our report treats these groups in more detail than the other biota. In contrast, most other animals, plants, fungi, microorganisms, and ecological processes have received little study or none.

Many literature references on the Meadowlands are old, or for other reasons do not use current nomenclature for plant and animal species. We have updated scientific names of species to current nomenclature as found in Gleason and Cronquist (1991) for vascular plants and American Ornithologists' Union (1998) for birds. We have used common names that are either current standard names (e.g. for birds, see American Ornithologists' Union [1998]) or which we believe to be in widespread use by biologists and naturalists in the northeastern coastal regions. In some cases, only common names are used in literature references and we have equated these to species as best we could;

where doubt exists, this is noted in the text or a common name is partly or entirely enclosed in square brackets "[ ]" indicating uncertainty. "Mulberry" and "poplar" in Kane and Githens (1997) are, respectively, white mulberry (*Morus alba*), and quaking aspen (*Populus tremuloides)* with less frequent eastern cottonwood (*Populus deltoides)* (R. Kane, New Jersey Audubon, personal communication to EK, 2001). Occasionally we have included outdated scientific names or alternative common names where these appear prominently in the literature of the Meadowlands. We provide both common and scientific names in the text at first mention of a species; subsequently only the common name is used (scientific names of fishes and birds, however, are presented only in Appendix Tables 2-3). Only scientific names are given in the Metropolitan Flora Project database (Table 1), and we have not attempted to provide common names or conform these scientific names to any single botanical manual. "Endangered" or "Threatened" is noted parenthetically after mention of state-listed animal and plant species to call attention to this status; in cases where breeding and nonbreeding populations of a bird species are listed differently, we have used the appropriate status term.

This report underwent peer review by four biologists at local institutions (Joan Ehrenfeld, Rich Kane, Lisamarie Windham, and an anonymous reviewer) who have conducted research in the Meadowlands and are familiar with Meadowlands ecology and environmental issues. Following revision, the report was reviewed by four scientists at the Meadowlands Environmental Research Institute (MERI) (Francisco Artigas, Kirk Barrett, Brett Bragin, and Christine Hobble) and then was revised again. We take responsibility for any errors that remain in this report.

ENVIRONMENTAL SETTING AND CONDITIONS

Geology

The Hackensack Meadowlands are within the Northern Triassic Lowlands (Newark Basin), a subdivision of the Piedmont physiographic province in northeastern New Jersey. Triassic red shale and sandstone comprise the underlying bedrock (Newark Formation), which formed when sediments were depositied in the rift valley that existed in this area 200 million years ago (Schuberth 1968). Depth to bedrock ranges from 8 to 81 meters (25 to 265 feet) below the wetland surfaces (Widmer 1964). The Hackensack River Valley, in which the Meadowlands lie, is separated from the Passaic River Valley on the west by a low sandstone ridge, and from the Hudson River on the east by a narrow ridge of igneous rock (Palisades diabase, locally called "traprock") (Day et al. 1999). Associated diabase bedrock is exposed at Laurel Hill (Snake Hill) and Little Snake Hill in Secaucus (Sipple 1972). The Palisades diabase contains variable proportions of the silicate minerals plagioclase, pyroxene, and olivine (Wolfe 1977). These minerals can vary in their content of calcium, magnesium, iron, sodium, and aluminum (Pough 1953). The Granton diabase sill, at the eastern edge of the Meadowlands in North Bergen, is a small igneous intrusion similar to the Palisades sill but separated from it by 107 m (350 feet) of Stockton sandstones and shales and

Lockatong shales and argillites (Wolfe 1977). Hornfels bedrock is exposed at the Granton Quarry (van Houten 1969); hornfels occurs at the contact zones of igneous and sedimentary rocks and varies in mineral composition (Pough 1953). Elevations of wetlands in the Meadowlands range from sea level to about 3 meters above sea level (with the exception of a few ponds atop closed landfills). Bedrock outcrops at Laurel Hill rise to about 53 meters; several landfills reach about 30 meters above sea level (Day et al. 1999).

During the Wisconsin glaciation, an ice sheet extended from the northern latitudes to a terminal moraine just south of the Meadowlands. At the end of the Pleistocene, about 10,000 years ago, when the glacier began to melt and retreat northward, the terminal moraine of the glacier, extending from Staten Island in the east and through Perth Amboy, impounded glacial meltwater creating glacial Lake Hackensack (Heusser 1963, Day et al. 1999). Lake Hackensack covered a low-lying area that extended from the terminal moraine in Rahway to Tappan, New York (Reeds 1933 in Tedrow 1986). During the 2,500 to 3,000 years of the lake's existence, thin alternating layers of silt and clay (varves) were deposited seasonally (Antevs 1928). Beds of clay up to 30 m (100 feet) thick underlie wetland sediments (Reeds 1933 in Tederow 1989). Clays are overlain by stratified sand and gravel that reach a thickness of approximately 10 feet (Reeds 1933 in Tedrow 1989). Clay bluffs 30 m high occur near the Meadowlands (Bosakowski 1983).

It is postulated that the lake ceased to exist as a result of breaching of the barrier dam (terminal moraine) to the south from gradual uplifting of the lake bottom as the land adjusted to decreased pressure from the retreating glacier (Heusser 1963). Draining of Lake Hackensack coincided with a postglacial rise in sea level of about 3 meters in the last 2,000 years, which allowed encroachment of sea water and eventually the formation of tidal marsh (Heusser 1963). The harbor estuary currently experiences a rise in sea level of about 2.7 millimeters per year (Hartig 2002).

Vermeule (1897 in Tedrow 1989) described surficial deposits in the Meadowlands as consisting of blue mud or clay with portions covered by peaty soils. Sipple (1972) described soil in the Meadowlands as predominantly peat or muck with mineral material overlying the glaciolacustrine clays. The organic soils contain the remains of aquatic plants, including logs, roots, and stumps, that accumulated in the wetlands over thousands of years. Marsh soils range from peats to mineral soils with high organic matter content, and the "peats" vary greatly in organic matter and mineral matter composition (J. Ehrenfeld, personal communication to EK and KM, 2001). Natural mineral soils also occur in limited upland areas (Sipple 1972). On the "East Site" of the proposed Meadowlands Arena, thicknesses of soil strata from top to bottom were: fill, 1.2-4.9 m (4-16 feet); dark brown peat, "meadow mat," or organic silt 1.2-3.0 m (4-10 feet); fine sand with some silt, 0.3-0.8 m (1-2.5 feet); varved clay and silt with some sand,4.0-7.2 m (13-23.5 feet); and glacial till, 0.3-4.6 m (1-15 feet). Decomposed shale occurred 8.2-13.3 m, maximum 19.8 m (27-43.5 feet, maximum 65 feet) below Mean Sea Level (McCormick & Associates 1978).

The Bergen County soil survey described soils of the Meadowlands as “Urban land” and “Sulfihemists and Sulfaquents, frequently flooded”; the soil descriptions below are based on Goodman (1995). Urban land in the Meadowlands was described as Udorthents (cut-and-fill soils) with either a loamy substratum or a wet substratum and highly variable. The Sulfihemists and Sulfaquents map unit was described as very deep, levelor nearly level (0-1% slope), very poorly drained soils. Sulfihemists (organic soils) in the Meadowlands have at least 41 cm (16 inches), and usually more than 130 cm (51 inches) of organic material overlying mineral material. The top 30 cm (12 inches) of organic material is dark colored (gray, reddish brown, brown, or black) and highly decomposed. Below 30 cm the organic material is less decomposed but may be interbedded with highly decomposed material. The underlying mineral material is varved and ranges in texture from very gravelly sand to clay. Depth to bedrock typically exceeds 3 m (10 feet) in the Sulfihemists. The Sulfaquents (hydric mineral soils) of the Meadowlands have a surface layer of either organic material less than 41 cm thick (dark reddish brown or black, and highly decomposed) or mineral material 10-30 cm thick (dark reddish brown, very dark brown, or black silt loam or fine sandy loam with organic content less than 20%). The underlying mineral material is varved with a wide range of color and with textures in the same range as those of the material underlying the Sulfihemists. Depth to bedrock exceeds 1.8 m in the Sulfaquents. Both Sulfihemists and Sulfaquents have high available water capacity. The organic material is characterized by rapid or very rapid permeability, and the mineral material has variable permeability. Both soils have very slow runoff. Both soils are neutral or slightly acidic throughout when moist; however, when dried these soils are strongly acidic or very strongly acidic. The Sulfihemists and Sulfaquents have severe limitations (wetness, flooding) for building site development and “sanitary facilities” (i.e. sewage treatment systems and sanitary landfills) (Goodman 1995).

Little seismic activity has been associated with the Newark Basin in recent history. The epicenter of one earthquake during the period 1962-1977, shown by Aggarwal and Sykes (1978), was in, or close to, the Meadowlands.

Paleoecology

Much evidence for the development of plant communities has been gained through studies of pollen, spores, other plant remains, and foraminifera in peat core samples as well as historical accounts of the vegetation. There is significant evidence that wetlands that developed on the lake sediments were dominated by freshwater plant associations for thousands of years. Analysis of pollen and other plant remains in peat core samples from Secaucus demonstrate that there was a progression of plant communities over several thousand years, reflecting climatic and salinity changes in the Meadowlands (Heusser 1963, Harmon and Tedrow 1969). The oldest peat samples taken from Secaucus were dated at 2,025 ± 300 years B.P. (Heusser 1963). Peat cores in the Meadowlands indicate that the organic material was deposited by freshwater plants (Heusser 1963, Harmon and Tedrow 1969). Salt marsh peat later developed over these freshwater peats (Tedrow 1989).

The first postglacial wetland community in the area was dominated by black ash (*Fraxinus nigra*) and then a mixture of black ash and northern peatland species including tamarack (*Larix laricina)* and black spruce (*Picea mariana)*. More than 500 years ago, Atlantic white cedar (*Chamaecyparis thyoides*) moved into the area. Atlantic white cedar had been established in more southern areas of New Jersey for thousands of years (e.g. Rosenwinkel 1964). Finally, the peat cores show that the Atlantic white cedar wetlands were encroached upon from the periphery by marsh composed of Olney three-square *(Scirpus americanus [S. olneyi])*, black rush (*Juncus gerardii,* also called "black grass"), and narrowleaf cattail (*Typha angustifolia)*, all either salt or brackish marsh species, according to Heusser (1963). A core taken just west of the Hackensack River on the north side of Route 3 showed a discontinuity between a basal clay and the oldest organic deposit radiocarbon dated at 2,610 ± 130 years before present (YBP) (Carmichael 1980). Above the clay were 100 cm of alder (*Alnus*) peat, then 160 cm of sedge (Cyperaceae) peat, and finally 120 of silty reed (*Phragmites*) muck. The alder-sedge transition was dated 2,060 ± 120 YBP, and the sedge-reed transition lay between dates of 810 ± 110 YBP and 240 ± 110 YBP. The reed muck was characterized by various weedy plants associated with human disturbance (Carmichael 1980).

The harvest of salt hay (primarily saltmeadow cordgrass [*Spartina patens*]*)* in the Meadowlands at least as early as 1697 (Quinn 1997), and old maps showing salt marsh, indicate that salt marsh occupied fairly extensive areas of the Meadowlands at that time. However, surveys conducted in the early 1800s (Torrey 1819) did not report significant coverage by brackish marsh species in the Meadowlands. Common reed (*Phragmites australis)* was not reported by Torrey in 1819, though it may have been present as indicated by its occurrence in nearby Elizabethtown (now Elizabeth) (Sipple 1972). In a list of species found in New Jersey published in 1877, common reed is listed as occurring in the Hackensack Meadows (Willis 1877 in Yuhas 2001). Interestingly, peat profiles published by Waksman (1942) show common reed occurred widely in lowland peat deposits in New Jersey, including at least one site in the Meadowlands, at depths where the reed materials must have been deposited in pre-Columbian times. Harshberger and Burns (1919) describe salt marsh vegetation along the creeks and the river. In addition, they report extensive areas of brackish marsh covered by common reed and less brackish areas dominated by cattails. Vermeule's maps indicate that islands of cedar swamp still existed between lower Berry's Creek and the Hackensack River and in areas of Carlstadt, East Rutherford, and Ridgefield until the late 1800s (Tedrow 1989). Therefore, evidence suggests that the extensive brackish and salt marsh communities of the Meadowlands of today and the now-ubiquitous common reed were present before European settlement but it is unclear how extensive different plant communities were at various times. The apparent contradictions among different sets of palaeoecological and historic evidence concerning Meadowlands vegetation may be due to the temporal and spatial variation in plant community coverage as well as to the inherently coarse scale and potential sources of error in the methods of both paleoecology and environmental history. The distribution of brackish marsh and common reed is related to the context of colonial settlement and changes that occurred during the last three centuries.

Fire may have also had an impact on the development of plant communities. As organic materials from plants accumulate in marshes and peatlands, surface elevation gradually increases above the water table (Harmon and Tedrow 1969). After these dried peats are burned, the surface elevation is substantially decreased. Harmon and Tedrow (1969) found buried ash in soil cores suggesting that ancient fires may have been fairly common in the Meadowlands.

Environmental History

The first human inhabitants, Paleoindians, occupied the Northeast from 14,000 to 10,000 years ago (Quinn 1997). It is not known exactly when the Lenape arrived in the region but they were present by 9,000 years ago in the Hackensack valley. The word "Hackensack" probably derives from one of two Lenape phrases: *Hackink Saquik* (a stream that unites with another on low ground) or *Hocquan Sakuwit* (hooked mouth of a river) (Quinn 1997). At the time of European colonization, the Lenape lived in small, permanent settlements (Kraft 1986). Henry Hudson's arrival in 1609 marked the beginnings of Dutch colonization and Lenape-Dutch trade (Quinn 1997). The area remained sparsely populated with a few scattered villages, plantations, and farms until as late as 1680. By the early 1700s, however, the area had been rapidly settled (Quinn 1997).

With settlement came land use practices that profoundly shaped the Meadowlands ecosystems as we know them today. Settlers practiced burning of woods and fields in fall and spring (Thayer 1964) which may have lead to subsidence of peat marshes and decline of Atlantic white cedar forests. The cedar was harvested for a variety of purposes, including a supply of timber for shipmasts for the British navy (Quinn 1997). By the late 1700s, the first attempts at building roads across the marshes used Atlantic white cedar planks (Mattson 1970). The locations of these roads now support Bellville Pike and Paterson Plank Road (Mattson 1970). By 1821, people were brought in by rail to pick "huckleberries" (*Gaylussacia* or *Vaccinium*) in the Meadowlands (Mattson 1970). The 1800s saw many projects attempting to drain and dike the Meadowlands. The goals were to prevent tidal inundation and reduce muskrats in order to make the marshes suitable for agriculture. The most notable of these endeavors was the Iron Dike Land Reconstruction, which erected a dike enclosing a large area from the Passaic River north into Sawmill Creek in 1867 (Mattson 1970, Sipple 1972). The dike effectively cut off tidal water and drained the diked area, probably resulting in the loss of a large section of Atlantic white cedar swamp (Sipple 1972). Furthermore, the project failed in its attempt to reclaim land for agriculture because the decrease in inundation of the underlying peats caused uneven subsidence, up to 1.1 meters (3.5 feet), which prevented uniform irrigation and farming (Waksman 1942, Mattson 1970). Drainage probably also made the remaining cedar swamps more vulnerable to fire. Lowering of the water table, higher salinity, fire, and harvest eliminated the cedar forests (Kraus 1988).

While most agricultural reclamation endeavors failed in one way or another, the harvesting of salt hay required no reclamation although it benefited from decreased frequency of tidal flooding (Quinn 1997). Salt hay farming began as early as the late 1600s and remained successful and active until the 1950s when pollution and common reed invasion reportedly brought this industry to an end (Quinn 1997). Because of uncertainties about the actual coverage of high salt marsh (salt meadow) vegetation at different historical periods (see Paleoecology, above), it is difficult to say how extensive salt hay harvesting areas may have been in any historical period. The muskrat, once considered a pest because it burrowed beneath crops and consumed plant roots, became an increasingly valuable commodity. By 1918, muskrat pelts were more valuable than any crop and muskrat persistence in the Meadowlands was encouraged (Quinn 1997).

In the early 1900s, tidal marsh drainage and diking projects for mosquito control began in the Meadowlands. Under the leadership of mosquito biologist Thomas Headlee (1945), diking, ditching, and tidegating on a massive scale severely altered the hydrology of the Meadowlands (Quinn 1997). The building of dikes and drainage features probably facilitated the spread of common reed (Sipple 1972). Quinn (1997) mentions that mats of common reed, which was already ubiquitous in the northern Meadowlands, were used by workers to cross wet areas in these early diking projects. Headlee (1945:280-281) pointed out that both dead and living common reed materials were used to create and strengthen dikes for mosquito control in the Meadowlands. Hydrological changes were exacerbated by the building of the Oradell Dam on the Hackensack River in 1922. The dam cut off most of the freshwater flow to the Meadowlands, allowing brackish water to intrude farther upriver (Sipple 1972).

The ramifications of widespread agricultural and mosquito control projects, coupled with sea level rise, were the decline of freshwater wetland communities and the rapid expansion of brackish and salt marsh communities throughout the Meadowlands (Sipple 1972). Peatlands that were cut off from tidal inundation in some cases dried and subsided. In addition, in 1950 a major storm breached many of the water control structures in the Meadowlands, allowing brackish tides to flood these areas (Black 1970).

While these major hydrological alterations were occurring, the region was on its way to being one of the largest urban-industrial centers in the world. In the late 1700s, there was already a leather tanning industry in the Newark area (Crawford et al. 1994). During the 1800s and 1900s, paint, textile, petroleum, chemical, plastics, and pharmaceutical industries became established and expanded rapidly (Crawford et al. 1994). Many of the waste products from these industries, as well as raw sewage from the large urban population, were dumped directly into creeks, rivers, and wetlands (Crawford et al. 1994). Overharvesting coupled with severe declines in water quality caused decreases in fish populations as early as 1885, and by 1926 fish life was considered “destroyed” (Crawford et al. 1994). The Meadowlands currently have 1,012 hectares (2,500 acres) of solid waste landfills, the result of more than a century of dumping garbage from the large population and industrial activities of the New York metropolitan area (Quinn 1997). Today all but one of the landfills have been closed or are inactive (J. Quinn, personal communication to EK, 2001); the single remaining landfill is used for construction and demolition debris.

With increasing industrialization and population growth came the need for improved transportation in the Meadowlands. Dredging of shipping channels in the Hackensack River has occurred frequently since 1900 (Crawford et al. 1994), and most of the dredged material (spoil) was presumably deposited in the marshes and shallows. The seemingly insurmountable task of traversing the Meadowlands was due to the soft muck, over 30 m (100 feet) deep in some places (Sullivan 1998). A modest railway had already been built in the Meadowlands from Paterson to New York by 1830 (Quinn 1997). By the early 1900s, railroads on filled and graded beds traversed the Meadowlands, again affecting hydrology (Quinn 1997). There were many small roads, ferries, and drawbridges that allowed travel through the Meadowlands but journeys were time-consuming until the opening of the massive Pulaski Skyway in 1932, which connected Jersey City and the Holland Tunnel to Newark (Sullivan 1998). The New Jersey Turnpike, which bisects the Meadowlands from north to south, was in operation by the early 1950s (Quinn 1997).

Filling of wetlands to build railroad and road beds and to reclaim land for industrial and residential development was extensive during the past 150 years, resulting in further decreases in wetland area and changes in hydrologic function. In recent decades alone, filling of wetlands in the area has reduced their extent from 8,100 hectares (20,000 acres) to about 3,400 hectares (8,400 acres) (Day et al. 1999). Contradictions in the literature regarding vegetation history of the Meadowlands may be due to the complex mosaic of plant communities in space and time. Natural and human disturbance has created an ecological palimpsest, and the fragmentary views afforded by paleoecological and historic methods may be detecting different communities at different places and times. An ongoing historical study by Tamara Shapiro (Rutgers University) addresses these issues. The Hackensack Meadowlands have been referred to in older literature as the Hackensack Meadows or the Newark Marshes (e.g. Abbott 1907).

Hydrology

The Hackensack River Basin extends 55 km (34 miles) from its source at Haverstraw, New York, to its confluence with Newark Bay, and drains an area of 488 square kilometers (188.3 square miles) (NJTA 1986). The Hackensack Meadowlands contain 3,400 ha (8,450 acres) of tidal saline, brackish, and freshwater wetlands in addition to limited, mostly artificial, uplands located along the Hackensack River. There are 5.6 km (3.5 miles) of maintained (dredged) shipping channel 90 to 150 meters (300 to 500 feet) wide and 9.0 meters (30 feet) deep. From Little Ferry to Hackensack, there is a 3.3 meter (11 feet) deep navigation channel. Between the dredged reaches the river is naturally 6.5 meters (21 feet) deep on average (Day et al. 1999). The major tributaries to the mainstem of the

Hackensack River in the Meadowlands are Losen Slote, Moonachie Creek, Berry's Creek, Kingsland Creek, and Sawmill Creek on the western bank, and Penhorn Creek, Mill Creek, Cromakill Creek, and Bellman's Creek on the eastern bank.

Mean tidal range is 1.59 meters (5.2 feet) at Kearny Point near the mouth of the river (NOAA, *fide* Meadowlands Environmental Research Institute [MERI]) and 0.5 meter (1.6 feet) at Little Ferry (Day et al. 1999) near the upstream limit of the tides. The Hackensack River connects with Newark Bay just north and east of where the Passaic River empties into the Bay. Tidal waters reach the Hackensack River from Newark Bay, which receives tidal fluxes from the Arthur Kill and from New York Bay via the Kill van Kull. The Hackensack Meadowlands is a somewhat atypical estuary in that its connection to marine waters is through a constricted opening at the northern portion of Newark Bay and another constricted opening where Newark Bay debouches into New York Harbor, unlike a more typical estuary in which a wide river mouth opens directly into the ocean (J. Ehrenfeld, Rutgers University, personal communication to EK and KM, 2001).

The present hydrologic patterns are the result of sea level rise and climatic changes as well as extensive anthropogenic changes to tidal circulation caused by the building of dikes, tide gates, dams, and road beds and the subsequent breaching of water control structures in some places. From the 1920s to the 1950s, ditches and flap gates (tide gates) were build extensively in the Meadowlands. Perhaps the most notable hydrologic feature of the Hackensack Meadowlands is the loss of creek morphology and the morphology of creek networks (i.e., loss of dendritic drainage patterns) that occurred from centuries of ditching and draining (J. Ehrenfeld, Rutgers University, personal communication to EK and KM, 2001). Furthermore, these structures drained fresh water from many areas and prevented salt water intrusion. Many drained areas were subsequently filled and developed, resulting in loss of flood storage capacity. Drainage structures for mosquito control were not adequate to prevent flooding of developed areas. In "upstream" areas, e.g. Teterboro, flooding from rain is a problem, whereas in "downstream" areas estuarine storm surges are more of a problem. The U.S. Army Corps of Engineers plans to address flooding problems by enlarging existing ditches, repairing (tightening) leaky tide gates, improving existing pump stations, and installing new pumps to allow more pumping of stormwater discharge over the tide gates (Kerry Anne Donohue, personal communication to KM, 2001). USACOE is developing a hydraulic model of the Hackensack River to address questions about flooding (H. Wine, statement at USFWS workshop, 31 October 2001; MERI, personal communication to EK, 2002).

Water Quality and Air Quality

Salinity in the Hackensack River ranges from 0 to 16 ppt (parts-per-thousand). The reach of the river from the mouth to Cromakill Creek is a moderate salinity (mesohaline) zone supporting both marine and estuarine invertebrates, fishes, and turtles. The river above Cromakill Creek to just upriver of Hackensack is a low salinity (oligohaline) zone supporting both estuarine and freshwater invertebrates, fish, and turtles (Day et al. 1999). Reduction of freshwater discharge below the Oradell Dam, coupled with inputs of treated sewage effluent, caused the upper reach of the Hackensack River estuary to be more brackish (John Quinn, NJMC, personal communication to EK, 2001). Salinity is generally highest in late summer and fall and lowest in spring (Kraus and Bragin 1988).

Conditions within the estuary seem to have improved since the early 1970s as evidenced by recovery of aquatic biota and birds in the area (Crawford et al. 1994). Although environmental legislation (e.g., the Federal Clean Water Act) has greatly decreased the amounts of chemicals released directly into rivers in the region, there remain many point and non-point source inputs of many pollutants into the Meadowlands (Crawford et al. 1994, Huntley et al. 1995). Furthermore, because this is a tidal system, pollutants entering Newark Bay from the heavily polluted Passaic River, Arthur Kill, and New York Bay may be transported "upstream" into the Hackensack River and its marshes.

Pollution of the marshes, waterways, and upland areas in the Meadowlands represents the lingering consequences of past as well as present-day activities. There are reported to be about 50-60 active industrial discharges (MERI, personal communication to EK, 2002), 3 power generating plants, 7 sewage treatment plants, 32 combined sewer outflows, and 12 emergency overflows within the Meadowlands District (Day et al. 1999). MERI (personal communication to EK 2002) disagrees with some of the Day et al. numbers cited in this paragraph, and we have not been able to confirm the data independently. As of 2000, the U.S. Environmental Protection Agency had identified 7 National Priorities List (Superfund) sites within about 3 kilometers (2 miles) of the Meadowlands proper (U.S. Fish and Wildlife Service, New Jersey Field Office, map dated 2001).

The Keegan landfill, now inactive, still leaches about 246,000 liters (65,000 gallons) of contaminated liquids per day into Kearny Marsh (Quinn 1997). The EPA has documented the presence of mercury, lead, chromium and polychlorinated biphenyls (PCBs) at Kearny Marsh and motor oils and heavy metals join the list at other sites. In total, some 1.4 million liters (375,000 gallons) of liquid leachate per acre of Meadowlands landfills flow into the Hackensack and Passaic Rivers each year (Quinn 1997). Given the large number of petroleum refinery and storage facilities, chemical manufacturers, combined sewer overflows, sewage treatment facilities, and confirmed or suspected hazardous waste sites located within the Meadowlands and its surroundings, it is not surprising that the area is intensely affected by chemical pollution. What is striking is that the Meadowlands continue to support a high level of biological diversity and abundance.

Accidental petroleum and chemical spills occur in the Hackensack River periodically (Gunster et al. 1993). Heavy metals such as lead, mercury, and zinc, as well as industrial chemicals including PCBs, polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, and DDT metabolites, remain in the soils, submerged sediments, water column, and aquatic biota of the Hackensack Meadowlands, often at levels considered toxic to aquatic organisms by federal (NOAA) standards (Bonnevie et al. 1993, Crawford et al. 1994, Gillis et al. 1995, Huntley et al. 1993, 1995, HMDC 1997, 2002, Durell and Lizotte 1998). The highest concentration of mercury in the major tributaries of Newark Bay was found in the Hackensack River in the Meadowlands and is attributed to a chemical facility located on Berry's Creek (Iannuzzi and Wenning 1995). In the Berry's Creek area, mercury concentrations were 3.6-262 ppm dry weight in the upper 10 cm (4 inches) of soil, with only 4 of 20 values < 10 ppm (McCormick & Associates 1978). Very high levels of metals were found in tidal wetland sediments at Mill Creek. In some samples, chromium or lead exceeded 15,000 parts-per-million (ppm) and mercury reached 13 ppm (Hartz Mountain Industries 1978). Levels of metals in Meadowlands waters are also high (HMDC 2002).

Until the late 1960s, most of the sewage discharged into the Hackensack River and other Newark Bay tributaries remained untreated (ISC 1967). Many industries discharged their wastes directly into the rivers (Crawford et al. 1994). As recently as the late 1970s, dissolved oxygen levels, a principal indicator of sewage-related contamination, as low as 0.1 mg per liter in the Hackensack River (Mytelka et al. 1981). Coliform and fecal coliform bacteria counts were high (Foote 1983). Water quality is poorest in summer due to reduced freshwater inputs, high water temperatures, and low dissolved oxygen levels (Kraus and Bragin 1988). A recent year-round sampling program recorded annual temperatures in the Hackensack River of 3 to 37 °C (37 to 99 °F) and an annual range of dissolved oxygen concentrations from 1.0 to 15.5 mg per liter (Day et al. 1999).

A nitrogen budget was estimated for Mill Creek during a single tidal cycle (approximately dawn to dusk) at the season of peak (summer) plant productivity, 4 days after any rain, in 1974 (HMDC 1974). At the study site, a point on Mill Creek ca. 650 meters (2,200 feet) map distance downstream of the Secaucus sewage treatment plant outfall and 350 meters (1,200 feet) upstream of the Hackensack River, Mill Creek drains 108 hectares (267 acres) of marsh characterized by HMDC (1974) as cordgrass-reed-cattail marsh (these marshes may have largely shifted to reed dominance by the time the Hartz Mountain and Mill Creek mitigation projects were initiated about 17 and 3 years ago, respectively). The concentration of total nitrogen in Mill Creek reached a maximum of 10.8 mg per liter at the sampling station during the study. During the tidal cycle, 46 kg of nitrogen were discharged into Mill Creek by the sewage treatment plant. It was calculated that 4,348 kg of nitrogen entered Mill Creek from downstream (i.e. from the Hackensack River), and 4,130 kg of nitrogen left Mill Creek during the tidal cycle. The 5.45% difference (238 kg of nitrogen) was presumed to have been removed from the creek water by the marsh. Dissolved oxygen in the creek water was higher on the outgoing tide than on the incoming tide (HMDC 1974). Thus, despite the input of 46 kg of nitrogen from treated sewage, the water leaving Mill Creek was of better quality (lower nitrogen, higher dissolved oxygen) than the water entering Mill Creek. Marsh "treatment" of polluted waters in the Meadowlands may explain why water quality (e.g. nitrate, dissolved oxygen, total suspended solids; see below) is not worse.

Since 1993, NJMC has monitored approximately 25 water quality parameters quarterly at 14 stations on the Hackensack River estuary, tidal tributaries, and impoundments (HMDC 2002). We examined the data from 6 of these stations selected to represent sites discussed in this report or stations expected to show better and worse conditions: Hackensack River just below Route 46 (near the confluence with Overpeck Creek), Sawmill Creek, Berry's Creek, upper Cromakill Creek, Kearny Marsh [West], and Belleville Pike Drainage Lagoon. All stations are slightly to moderately brackish, with mean salinities ranging from 10.8 ppt at Sawmill Creek to 1.0 ppt at upper Cromakill Creek. Fecal coliform means, respectively, for the 6 stations are 2,700, 1,019, 1,087, 6,615, 863, and 5,314 counts per 100 ml, with maxima of 5,000-16,000. pH ranges from 5.3 to 8.4 standard units (means for the 6 stations 7.2-7.4). Mean nitrate ranges from 0.2 to 0.5 mg per liter, and mean ammonium ranges from 1.7 to 17.8 mg per liter. Phosphorus has not been monitored. Total suspended solids means range from 24 to 63 mg per liter, with maxima of 96-836 mg per liter (the highest maximum was measured in the Belleville Pike Drainage Lagoon). Total dissolved solids means range from 1,103 to 10,273 mg per liter. Dissolved oxygen means are 5.1-7.8 mg per liter, and minima are 1.0-3.2 mg per liter. Data on oxygen saturation are not available. Clearly, the Hackensack River estuary system is characterized by degraded, urban-industrial water quality (see Kraus 1989).

Prevailing winds in the Meadowlands are from the west; however, winds from all directions, including east, occur (Willis et al. 1973). In 1970, the following average annual concentrations of air pollutants were reported for the Meadowlands (New Jersey Department of Environmental Protection data summarized in Willis et al. 1973): particulates, 113.3 micrograms per cubic meter; sulfur dioxide, 0.043 parts-per-million (ppm); carbon monoxide, 4.24 ppm; hydrocarbons, 2.09 ppm; and nitrogen oxides, 0.113 ppm. Continuous weather and air quality monitoring data are posted on the MERI web site at http://cimic.rutgers.edu/meri/ems_data/index.html.

VEGETATION AND HABITAT TYPES IN THE MEADOWLANDS

The wetlands of the Hackensack Meadowlands have been studied more than the (largely fill) uplands; among the wetlands, the herbaceous wetlands (marshes and wet meadows) have been studied more than the remnant wooded swamps. Common reed-dominated vegetation has received a lot of attention in the literature of the Meadowlands, yet even those areas have not been described in detail. Along with reed–dominated areas, the Hackensack Meadowlands contain many kinds of freshwater and brackish wetlands, rivers, creeks and upland habitats. At the proposed site of the Meadowlands Arena, for example, McCormick & Associates (1978) mapped vegetation on 291 (720 acres) which included 53% reed stands, 29% barren recent fill and waste, and 13% goldenrod-ragweed on fill. The vegetation zonation of tidal marshes is largely determined by elevation, drainage, and soil type (Day et al. 1989), and similar factors, along with fire, animal activities, and distribution of plant propagules, shape vegetation patterns in other Meadowlands habitats. The following descriptions of the major vegetation (habitat) types are based closely on HMDC (1984) and USFWS et al. (2000).

WETLAND AND WATERWAY HABITATS

Tidal and nontidal wetlands are the predominant habitats in the Hackensack Meadowlands. Marshes, especially tidal marshes, are the areas of most concentrated primary productivity in the estuarine system. The wide range of habitat types, their complex interspersion, and the occurrence of many large blocks of habitat (e.g. more than 40 hectares [100 acres]) contribute to the importance of the Meadowlands region to wildlife.

Subtidal Habitats

Estuarine Deep Water: These tidally influenced areas are permanently submerged by at least 2 meters of water at low tide. Estuarine deep water occurs in the Hackensack River and major tidal creeks. This is an important habitat for adult and juvenile estuarine fishes and migrating and wintering waterfowl. Mud crabs **(*Rhithropanopeus*)** and other invertebrates are abundant in estuarine deep water. Unlike most other habitats in the Meadowlands, estuarine deep water areas lack vascular vegetation.

Estuarine Shallow Water: The substrate elevations of these areas are between Mean Low Water (MLW) and 2 meters below MLW. Estuarine shallow water habitats are typically located between areas of estuarine deep water and mudflats. The mid-channel habitats of many of the smaller creeks and the upper reaches of the larger creeks in the Meadowlands are estuarine shallow water. These areas support aquatic vascular plants, algae, and benthic invertebrates that are important food sources for all life stages of fish as well as for waterfowl, wading birds, and migratory shorebirds.

Intertidal Habitats

Salt Marshes

Salt marsh is a general category that includes a diversity of habitat types and vegetation assemblages, including mudflats, salt panne, low marsh, and high marsh. There is a gradient of vegetation assemblages within the salt marsh with shallow water occurring at low elevation or adjacent to creeks, mudflats between creeks and adjacent to shallow water, then low marsh and high marsh occurring with increasing elevation. (It should be noted that, in common usage among East Coast ecologists, low and high marsh in tidal salt marshes refer respectively to the zone between mean sea level and Mean High Water [MHW] and to the zone between MHW and the elevation of higher high tides. In freshwater tidal marshes, however, low marsh refers approximately to the lower half of the intertidal zone or between MLW and mean sea level, whereas high marsh refers to the upper intertidal zone between mean sea level and MHW.) Salt pannes are non-vegetated or sparsely vegetated areas of hypersalinity that form on the high salt marsh where most vascular plants are unable to grow. We differentiate Meadowlands "salt" marshes from "brackish" marshes by vegetation (e.g. salt marshes have communities dominated by saltmarsh cordgrass, saltmeadow cordgrass, saltgrass, black rush, or glasswort) as is the practice of many East Coast biologists; in reality, all the tidal marshes of the Meadowlands are brackish.

Mudflats: Mudflats are exposed at low tide and flooded at high tide. They lack vascular vegetation or support a low biomass of vascular plants (e.g., dwarf spikerush [*Eleocharis parvula*]); however, mudflats typically support productive and diverse mats of mud algae (also called benthic microalgae or microphytobenthos). Diatoms are prominent components of this algal community. Mudflats typically occur between areas of shallow water and low marsh. These areas, along with shallow open water, attain the second highest salinities of the estuarine system (salt pannes being the highest). When high tide waters travel up the river and into creeks, they transform mudflats into shallow open water. Then as low tide approaches, water levels drop and the mudflats are exposed. Mudflats support a variety of mollusks, crustaceans, and other invertebrates. Exposed mudflats are particularly important foraging areas for migratory shorebirds. Additionally, mudflats provide feeding areas for dabbling ducks and wading birds. While inundated at high tide, mudflats provide habitat for juvenile fish. Shallow open water and mudflats comprise approximately 379 hectares (936 acres) of the Hackensack Meadowlands. The most significant area of this type of habitat exists in the Sawmill Creek Wildlife Management Area (WMA). There are smaller shallow bays and mudflats located throughout the Meadowlands.

Low Salt Marsh: Low salt marshes are vegetated areas that receive regular tidal inundation twice daily. The dominant vegetation in these areas in the northeastern U.S. is saltmarsh cordgrass (*Spartina alterniflora*), which often grows 1.2-2.1 meters (4-7 feet) tall. Other species that commonly occur in the low salt marshes of the Meadowlands include marsh-fleabane (*Pluchea odorata [P. purpurascens]*), dwarf spike-rush, and glasswort (*Salicornia*; Labriola [2000] reported *Salicornia europaea* but most authors have not identified the species). The low salt marsh is a major source of primary productivity in the estuary. Low salt marshes support a variety of fishes including juvenile anadromous species, estuarine dependent species, and forage species. Low salt marsh borders much of the Hackensack River and its tributary tidal creeks, although these borders may be very narrow upriver. The largest areas of low salt marsh lie to the north and south of Sawmill Creek. There are also significant areas of this habitat surrounding lower Berry's Creek in Lyndhurst and Rutherford (HMDC 1984). In the northern end of the estuary, saltmarsh cordgrass is found at salinities that are 50-75% of the Sawmill area salinity. Saltmarsh cordgrass is believed to have colonized these historically low-salinity areas as a result of increased salinities that occurred due to alteration (damming) of freshwater sources. There are ca. 342 hectares (845 acres) of low salt marsh in the Meadowlands.

High Salt Marsh: High salt marsh areas are mainly flooded during monthly spring (full moon and new moon) tides and during storm and wind-driven tides. Local variation in elevation, soil type and disturbance creates a mosaic of plant associations within the high marsh. Native high marsh consists of a salt meadow community dominated by saltmeadow cordgrass, spike grass *(Distichlis spicata)* and black rush; a dwarf salt marsh cordgrass zone; a sparsely vegetated salt panne zone dominated by glasswort; and an upland fringe shrub zone dominated by groundsel-tree (*Baccharis halimifolia*), marsh-elder or high-tide bush (*Iva frutescens*), switchgrass (*Panicum virgatum*), and seaside goldenrod (*Solidago sempervirens*). High marsh provides habitat for birds, reptiles, and mammals. There may be as few as 22 hectares (55 acres) of this habitat type in the Meadowlands (HMDC 1984).

Brackish Marshes

Brackish (mesohaline and oligohaline) marshes in the middle reaches of estuaries are subject to a wide range of salinity levels, ranging from fresh (due to precipitation and springtime river discharge) to saline or nearly saline (in late summer and early fall). There are 713 hectares (1,760 acres) of this habitat type in the Meadowlands (HMDC 1984), making it the largest mesohaline marsh complex in northern New Jersey (Tiner 1985). Most of this marsh type is locally dominated by common reed, but some brackish marshes also contain remnant stands of narrowleaf cattail (now rare), big cordgrass (*Spartina cynosuroides*), and Olney three-square. Princess tree (*Paulownia tomentosa*), an exotic, is frequently found growing on dikes and levees within brackish marshes.

Brackish marsh is found predominantly northward from Route 3 in Lyndhurst, continuing to Overpeck Creek in Ridgefield on both sides of the Hackensack River. Diking previously excluded tidal flow in these areas and allowed common reed to spread vigorously. Tidal flow has since returned to some areas and there the communities are changing. Even in areas seemingly dominated by common reed, other plants often grow among the reeds (HMDC 1984). Creek edges have stands of saltmarsh cordgrass, big cordgrass, and tidemarsh water-hemp (*Amaranthus cannabinus [Acnida cannabina]*). Dwarf spikerush, cordgrass, softstem bulrush (*Scirpus tabernaemontani [S. validus]*), and tidemarsh water-hemp are found in isolated pools. There is an area north of the WNEW radio tower in Carlstadt where one can see saltmarsh cordgrass growing beside softstem bulrush (a freshwater sedge).

Freshwater Tidal Marshes

Freshwater emergent wetlands occur along tidal freshwater rivers; small remnants persist in the Meadowlands, generally above MHW and behind naturally occurring levees. Common reed dominates disturbed sites, while sweet flag (*Acorus calamus* s.l.), narrowleaf cattail (rare), pickerelweed, purple loosestrife (*Lythrum salicaria*), marsh-fleabane, sedges (*Carex* spp.), and bulrushes (*Scirpus* spp.) may also be present. Giant ragweed (*Ambrosia trifida*) is abundant along natural and artificial levees, along with goldenrods (*Solidago* spp.).

Because of the reduction in freshwater discharge into the Hackensack River estuary caused by the Oradell Dam, and probably also due to the small size of this estuarine system and the dredging that has occurred "downstream," e.g. in Newark Bay, even areas far up the Hackensack River estuary are subject to oligohaline or mesohaline conditions during dry seasons. For example, salinity at Hackensack River County Park just north of Route 4, on 3 September 2001, was estimated to be 8 ppt (parts-per-thousand) (Joseph Labriola, personal communication to EK), and mean salinity in the Hackensack River just above Overpeck Creek is 4.4 ppt (HMDC 2002). This suggests that true freshwater tidal marshes are very limited in extent in the Meadowlands and presumably occur only where fresh surface or groundwater enters tidal marshes. A small, slightly brackish tidal marsh on the north side of the von Steuben House (historic site) at New Bridge Landing (on the Hackensack River but above the Hackensack Meadowlands District) is dominated by common reed and purple loosestrife, with jewelweed (*Impatiens capensis*), arrowleaf tearthumb (*Polygonum sagittatum*), iris (probably *Iris pseudacorus*), and arrow arum (*Peltandra virginica*) common, and at least 20 other species of vascular plants (EK, personal observation, 2001).

Wild-rice (*Zizania aquatica*) is a conspicuous plant of many freshwater tidal marshes in the northeastern states. Wild-rice was evidently at least locally abundant in the Meadowlands 100 years ago (Chapman 1900; also see Brooks 1957). The last record of wild-rice in the Metropolitan Flora database is from 1948 (Table 1). Populations of this annual grass are apparently sensitive to water quality and consumption by animals.

Non-Tidal Habitats

Brackish Impoundments: Brackish impoundments form when tidal flow is restricted by diking but limited flow of brackish water continues through leaking dikes. One such area is north of Route 7 and south of Sawmill Creek WMA. There is also the 40 hectare (100 acre) Kingsland Impoundment in Bergen County where significant numbers of wading birds and shorebirds stop during migration. Common reed often dominates the vegetation of brackish impoundments. As a result of salinity intrusion into impoundments, however, most of the common reed and duckweed (*Lemna minor)* have died in some areas. There are now 168 hectares (414 acres) of brackish impoundment in the Hackensack Meadowlands.

Freshwater Marshes and Impoundments: Various depths of freshwater cover certain areas of the marsh where flows of creeks have been impeded by diking and salt water is not able to penetrate with the tides. There are 200 hectares (494 acres) of freshwater marsh in the Hackensack Meadowlands. Three substantial freshwater marshes exist in the Hackensack Meadowlands: at Kearny Marsh, in the Penhorn Creek Basin, and in North Bergen. There are also numerous smaller pockets of freshwater marsh scattered throughout the Meadowlands. Kearny Marsh West (also called "Kearny Marsh" or Kearny Freshwater Marsh) was once densely vegetated with common reed but in 1975 became inundated with an additional 0.6-0.9 meter (2-3 feet) of water so that the average water depth is now 1.2-1.5 meters (4-5 feet) according to HMDC (1984). (However, water depths measured at 15 sediment sampling stations in April 1999 ranged from 2.0-5.0 feet, with a mean of 3.17 feet [Langan 1999].) These high water levels created large freshwater ponds interspersed with stands of common reed; duckweeds (Lemnaceae), purple loosestrife, and marsh-fleabane are abundant. Rose mallow (*Hibiscus moscheutos [H. palustris]*) occurs along the channels in these freshwater marshes. Other important plants include water shield (*Brasenia schreberi*), arrow arum (*Peltandra virginica*), purple loosestrife (*Lythrum salicaria),* white water-lily (*Nymphaea odorata*), mild water-pepper (*Polygonum hydropiperoides*), pickerelweed (*Pontederia cordata*), broadleaf cattail (*Typha latifolia*), and spatterdock (*Nuphar*). Such areas offer important foraging grounds for waterfowl and wading birds, as well as breeding habitat for marsh and water birds. Although Kearny Marsh West is considered a freshwater impoundment, mean salinity is actually 1.8 ppt at the MERI monitoring station and a maximum salinity of 4 ppt has been recorded (HMDC 2002).

Forested Wetlands: Forested wetlands lie along the headwaters of rivers and streams in the Meadowlands and are characterized by the presence of woody vegetation taller than 6 meters (20 feet). These forests consist of red maple (*Acer rubrum*), silver maple (*Acer saccharinum*), gray birch (*Betula populifolia*), eastern cottonwood (*Populus deltoides*), princess tree, pin oak (*Quercus palustris*), American elm (*Ulmus americana*), slippery elm (*Ulmus rubra*), black cherry (*Prunus serotina*), sweetgum (*Liquidambar styraciflua*), black willow (*Salix nigra*), and other trees. American hornbeam (*Carpinus caroliniana*) and arrowwood (*Viburnum dentatum* s.l.) are common understory trees. The shrub layer is well-developed and includes common elderberry (*Sambucus canadensis*), spicebush (*Lindera benzoin*) and alder (*Alnus*). Vines are abundant and include poison ivy (*Toxicodendron radicans*), riverbank grape (*Vitis riparia*), Virginia creeper (*Parthenocissus quinquefolia* s.l.), and common greenbriar (*Smilax rotundifolia*). Historically, coniferous swamps dominated by Atlantic white cedar covered large areas in the Meadowlands, but these forests were eliminated by hydrological alteration with associated salinity intrusion, harvesting, and fire. Many species of today's hardwood swamps would also be sensitive to more than very modest levels of salinity.

Swamp forests occupy small areas in the Meadowlands. The most notable remnants of this forest type are in several riparian corridors along the Hackensack River north of the official Meadowlands District and also include the forests at Teterboro Airport, at the headwaters of Losen Slote, and in Schmidt's Woods in Secaucus. Forested wetlands are important for migrating and nesting forest songbirds. Other aspects of these habitats have apparently not been studied; we would expect mammals, reptiles, amphibians, invertebrates, and plants that do not occur elsewhere in the Meadowlands.

Ponds on Landfills: Ca. 1.6 hectares (4 acres) of (presumably freshwater) ponds have formed on top of closed landfills. These ponds are important habitat for shorebirds and waterfowl, especially gadwall broods (Day et al. 1999).

Upland Habitats

Upland Meadow and Shrubland Communities: Upland herb (meadow) and shrub (shrubland) habitats in the Meadowlands are located principally along roadsides, on abandoned lots, on dredge spoil and other fill, and on the slopes of landfills. Meadow and shrubland may be intermingled in patches. Meadow communities are often dominated by exotic warm-season grasses with other herbaceous plants. Commonly occurring native grasses are switchgrass, broomsedge or big bluestem (*Andropogon virginicus*), and Indian grass (*Sorghastrum nutans*), with planted areas of big bluestem, little bluestem (*Schizachyrium scoparium*), and Canada wild-rye (*Elymus canadensis*) at some sites. Patches of dense, short, spindly common reed may occur. Common meadow forbs include yarrow (*Achillea millefolium*), common milkweed (*Asclepias syriaca*), Queen Anne's lace (*Daucus carota*), and black-eyed Susan (*Rudbeckia hirta*). Shrubs can be locally diverse and include gray dogwood (*Cornus racemosa [C. foemina]*), smooth sumac (*Rhus glabra*), staghorn sumac (*Rhus typhina*), steeplebush (*Spiraea tomentosa*), groundsel-tree, and common elderberry. Upland meadow may be floristically rich; McCormick & Associates (1978) described "aster/ragweed forb land" with common ragweed (*Ambrosia artemisiifolia*), Indian hemp (*Apocynum*), aster (*Aster*), pigweed (*Chenopodium album*), Mexican tea (*Chenopodium ambrosioides*), thistle (*Cirsium*), Queen Anne's lace, fleabane (*Erigeron canadensis*), fescue (*Festuca ?elatior*), sunflower (*Helianthus annuus*), evening-primrose (*Oenothera biennis*), panic grass (*Panicum dichotomiflorum*), common reed, pokeweed (*Phytolacca americana*), Pennsylvania smartweed (*Polygonum pensylvanicum*), foxtail grass (*Setaria*), goldenrod (*Solidago*), common mullein (*Verbascum thapsus*), cocklebur (*Xanthium [strumarium]*, tree-of-heaven, bittersweet (*Celastrus [orbiculatus]*, [white] mulberry, princess tree, eastern cottonwood, black cherry, bramble (*Rubus*), and common elderberry.

Much of the 648 hectares (1,600 acres) (Kane and Githens 1997) of inactive landfill is developing upland meadow and shrubland habitats. Restoration of native forests is being undertaken on several old landfills (see Robinson and Handel 2000). Meadow and shrubland are especially important to butterflies and other terrestrial insects, and to breeding grassland and shrubland birds. Fruits of sumacs are important food for birds in winter and spring, e.g. at

DeKorte Park (EK, personal observation, 2001), and we expect that fruits of common elderberry and gray dogwood, as well as grass and forb seeds, are also important fall, winter, and spring foods for birds and mammals. Upland meadows may also be important foraging habitats for raptors preying on meadow vole (*Microtus pennsylvanicus*) or other "upland" animals. Rawson (1993) found 15 species of birds and 6 of mammals in upland habitats (mugwort [*Aremisia vulgaris*], reed, "range" [meadow], and trees) on the Old Lyndhurst Landfill.

An example of upland meadow and shrubland, apparently on dredge spoil, is in the northwestern part of Oritani Marsh along Berry's Creek Canal. A large herbaceous and shrubby meadow, apparently on fill, is between the Meadowlands Convention Center and the Turnpike in Secaucus. An area of dry meadow, shrubland, and hardwood forest on natural sandy soil, unusual in the Meadowlands, is located in Hackensack River County Park (Boro of Hackensack), north of the official Meadowlands District. Some of the species in this area are pin oak, gray birch, black locust (some of which is stunted and shrub-like), bayberry (*Myrica pensylvanica*), yarrow, blue curls (*Trichostema dichotomum*), sandbur (*Cenchrus longispinus*), and a flatsedge (*Cyperus lupulinus*) (EK and other participants in Torrey Botanical Society field trip 2 September 2001, personal observations).

Rights-of-way and Margins of Developed Areas: Corridors of habitat associated with land uses such as highways and pipelines, as well as the margins of parking areas, building sites, and highways, have not been described in the literature on the Meadowlands. Many of the larger trees of the region, for example, occur in these habitats, and these trees may have a high value to birds, insects, and fungi.

Non-vegetated areas: Non-vegetated upland areas in the Hackensack Meadowlands include portions of railroad embankments, road and pipeline berms, and dikes, as well as surfaces of landfills and dredge spoil disposal areas that have not yet become vegetated with vascular plants. In these areas, soils are often droughty at the surface. Non-vegetated areas provide exposed soil or fill that may be important habitat for nesting diamondback terrapin, least tern (Endangered), spotted sandpiper, killdeer, horned lark, and other birds, as well as resting, basking, dustbathing, and foraging habitat for upland species that also utilize marsh habitats, e.g., ring-necked pheasant, snakes, and small mammals. Non-vegetated areas potentially support rare insect species that have affinities for sandy soils or other specialized habitats.

Buildings and Other Artificial Stuctures: The myriad of buildings, bridges, towers, and other built structures in the Meadowlands, both active and abandoned, provides a variety of habitat functions for certain species. Least tern (Endangered), common nighthawk, and killdeer potentially nest on gravel rooftops. Peregrine falcon (Endangered) nests on bridges and a large building in the region. Double-crested cormorant, several raptors, and swallows, among other species, use towers and wires for perching and roosting. Northern rough-winged swallow nests in artificial structures such as drain pipes in bridges, and presumably does so in the Meadowlands. Barn-owl, barn swallow, eastern phoebe, and bats may nest or roost on bridges or in abandoned buildings. Guy wires of the many radio towers may be a collision hazard for peregrine falcon (Endangered) (Wander and Wander 1995), and radio towers as well as other elevated structures that are illuminated at night are a potential collision hazard for nocturnally migrating birds. We have seen no data on bird mortality at towers and tall illuminated structures in the Meadowlands.

SITE DESCRIPTIONS

In this section the sites are listed in the same order as in Appendix Table 3, i.e. in a loop that goes from south to north on the west side of the Hackensack River then from north to south on the east side of the river. The description of each site is based primarily on the reference(s) cited at the end. The differences in the numbers of plant species listed for different sites may be due more to uneven treatment in the literature than to real differences among sites; one should not assume that a particular site is more or less species-rich than another based on our descriptions. Analysis of the attainment of goals of the mitigation projects at e.g. Cromakill-Mill Creek, Harrier Meadow, TransCo ("Meadowlands Mitigation Bank" in the Carlstadt-Moonachie marshes), and Skeetkill Marsh is not included in our purview for this report, and we lack adequate field experience and sufficient access to data and reports from monitoring programs to conduct such an analysis.

Kearny Marsh: This site is a largely non-tidal marsh consisting of common reed stands, marsh-fleabane, and open water (NJTA 1986). Cattail occurs in small patches. There is permanent standing water. Dense duckweed (Lemnaceae) exists in some places, especially in late summer. The major water source is runoff from adjacent areas. A pipeline berm and a roadway impound water here. The site also contains meadow, shrubland, and trees growing on landfills (NJTA 1986). Abbott (1907) described a deepwater, ponded marsh with extensive cattail-duckweed stands and an exceptionally rich breeding marsh bird community, reached by walking along the railroad from Newark; this may have been Kearny Marsh West or a nearby area.

Kearny Marsh East (Kearny Brackish Marsh). Kearny Marsh East is located west of the S-curve in the Hackensack River in Kearny. It stretches from the river on the east to the triangle formed by the New Jersey Turnpike Western Spur and Belleville Pike on the west. It is bounded on the north by the Conrail railroad, below the Sawmill Creek WMA. The southeastern boundary is the Amtrak railroad. Brackish water enters the marsh through intake pipes at the Hackensack River. There is always at least a small patch of open water in the winter. Shallow reed marsh is interspersed with large areas of open water, ideal for many breeding marsh and water birds. An island where subadult night herons roost is a potential rookery site. The WMCA radio towers are a potential nesting site for double-crested cormorant. This marsh is important for flood control and has been called the best unprotected wetland in the Meadowlands (Kane and Githens 1997). Management of water levels may be required in the future.

Kearny Marsh West (Kearny Freshwater Marsh). This well-known site lies west of the Turnpike Western Spur and Belleville Pike (Route 7) which divides Kearny West from Kearny East. The 142 hectare (350 acre), triangular marsh is surrounded by railroad embankments which isolate it hydrologically. (NJMC considers the area of this marsh to be 126 hectares [311 acres].) There is brackish water intrusion from a broken tide gate, and the area has become more brackish recently, causing changes in the fish community and vegetation. Several old landfills adjacent to the railroad embankments and the marsh are changing from dominance by mugwort, pokeweed, Japanese knotweed, common elderberry, and other shrubs to poplar, white mulberry, princess tree, tree-of-heaven, and wild cherry. Kearny Marsh West formerly supported a large black-crowned night-heron (Threatened) rookery that is apparently no longer present. The site now has a yellow-crowned night-heron (Threatened) rookery on an old railbed in mid-marsh, and is used by both night-herons for foraging (Kane and Githens 1997).

To the northwest and west of Kearny Marsh West are two large landfills covering ca. 182 hectares (450 acres); slightly more than 8 hectares (20 acres) were in recent use. Most of the other ca. 430 acres is revegetating with grasses and forbs. The small mammals of the landfills and other disturbed upland areas support an abundance and diversity of hawks and owls throughout the year, especially in winter, and these habitats also provide important migration and nesting habitat for a variety of passerine birds (Day et al. 1999).

Sawmill Creek: Located predominantly between the Hackensack River and the Turnpike Western Spur (a portion is west of the Turnpike), this site extends from the Erie-Lackawanna Railroad on the north to the Conrail tracks across the Hackensack River from Laurel Hill on the south. This is a prime site for migrant waterfowl with flyway-level significance, as well as an important site for wintering waterfowl (Kane and Githens 1997), and a large area is protected as Sawmill Creek State Wildlife Management Area. This 304 hectare (751 acre) tidal marsh area contains low salt marsh, open bay, and mudflat habitats (NJTA 1986). Closer to the Turnpike, much of the wetland is dominated by common reed and cordgrass. Both saltmarsh and saltmeadow cordgrasses are present but saltmarsh cordgrass predominates as clumps and narrow fringes along the reed-mudflat edge and along ditches. Near the Boonton Branch railroad, [saltmarsh] cordgrass becomes much more abundant, occupying major expanses, especially along the Hackensack River (NJTA 1986).

Around 1920, this area was diked and drained for mosquito control. The area was subsequently dominated by common reed. A severe northeastern storm in 1950 washed out the dikes and tide gates and restored tidal flooding to the area. Common reed began to die off in all but the higher dredge spoil islands. Saltmarsh cordgrass established itself at the tidal flat edges and spread throughout the area. There is now a patchwork of large mudflats interspersed with stands of cordgrass (Smith 1974). In 2000, we saw a complex pattern of saltmarsh cordgrass, common reed, and mudflats. Over the long term, cordgrass should continue to increase with sea level rise and increasing salinity

(Kane and Githens 1997). The strong tendency of common reed for vegetative (colonial) dominance presumably slows the change from reed marsh to saltmarsh cordgrass and mudflats.

Harrier Meadow: This tidal marsh was dominated by common reed and had sparse populations of saltmarsh cordgrass (Hartman and Smith 1999) at the initiation of mitigation activities. There were also areas of exposed mudflats prior to mitigation (NJTA 1986). The Harrier Meadow Wetland Mitigation Site encompasses 31 hectares (77.5 acres) (Hartman 2001a). Restoration goals include return of tidal flow to the interior, control of common reed and purple loosestrife, creation of open water areas, and establishment of native vegetation along upland-wetland edges (Hartman 2001a). The mitigation "resulted in the creation of approximately 22.2 acres of open water-mudflat, 16.7 acres of low-high marsh, 3.7 acres of scrub-shrub border, and 8.02 acres of enhanced uplands" (Hartman 2001a). Vegetation sampling in the low-high marsh zone demonstrated that two species dominated the site, spike grass and black rush (Hartman 2001a). The scrub-shrub zone of the site was dominated by groundsel-tree and black rush (Hartman 2001a). Common reed dominated 9.25 acres of the site (Hartman 2001a).

Kingsland Marsh: This large site is bordered by the Conrail railroad and the Berry's Creek marsh on the north, the Belleville Pike on the south, the Turnpike Western Spur on the east, and a railroad and development in North Arlington on the west. The site includes the NJMC buildings, the Kingsland Impoundment (40 hectares [100 acres]), a large tidal flat (at least 283 hectares [700 acres]), a large active landfill, and several overgrown, inactive landfills (NJTA 1986, Kane and Githens 1997). In the south, the site overlaps Sawmill Creek WMA. Kingsland Marsh contains low salt marsh (NJTA 1986). In Richard W. DeKorte Park, the sides of one landfill have been planted with flowers, shrubs, and pines. Maples and sycamores (*Platanus occidentalis*) have been planted on the road to the environment center. There are trails on the landfill and a long boardwalk through the impoundment (Kane and Githens 1997, Anonymous no date a). The Kingsland Marsh area contains a confusing complex of jurisdictions and facilities, including the Richard W. KeDorte Park, Lyndhurst Nature Reserve, NJMC offices, and the Hackensack Meadowlands Environment Center.

Berry's Creek Marsh: This site is located on the west side of the river and extends from the Lyndhurst Corporate Park, on the west, to the river on the east, and from Route 3 on the north, to the Erie-Lackawanna railroad (Conrail) on the south, just south of the Jersey City Aqueduct. The site includes Berry's Creek (southern portion), Berry's Creek Canal, and Oritani Marsh. The site consists of marshlands interspersed with fill, some of which is becoming forested (Kane and Githens 1997). Most of the wetlands are tidal except for some common reed and cattail patches, which occur in non-tidal, ponding depressions. Both high and low salt marsh occur (NJTA 1986). Most of the wetland is common reed marsh though [saltmarsh] cordgrass occurs as a multitude of clumps and a few large stands. Much of the northern portion of this area does not flood during spring high tides, whereas most of the southern portion does (NJTA 1986).

Along Berry's Creek and tidal ditches, patches of [saltmarsh] cordgrass are frequently encountered but common reed is dominant in many places. The areas away from the water courses are "hyperdominant" (dense, near-pure stands, *sensu* Kiviat submitted b) common reed with an occasional rose mallow. Along the open water edge, saltmarsh cordgrass may dominate instead of common reed. There are several large pockets of saltmeadow cordgrass, rush (*Juncus*), spikerush, orache (*Atriplex patula*), marsh-fleabane, and a blue-green "alga" (blue-green bacterium). These are usually connected to larger canals or creeks and are sites of intense muskrat activity including denning. NJTA (1986) refers to wetlands with relatively deep standing water through the year that are densely covered by duckweed in late summer.

Oritani Marsh (a portion of Berry's Creek Marsh) is in the triangle bordered by the Hackensack River, the New Jersey Transit railroad (Bergen County line), and Berry's Creek Canal. Oritani Marsh includes tidal common reed marsh, saltmeadow cordgrass stands (uncommon), non-tidal common reed stands, and upland meadows. Tidal areas are drained by mosquito control ditches. Areas of [saltmarsh] cordgrass mainly exist along the river and ditches (NJTA 1986). Plant diversity is highest in the large common reed stand south of Berry's Creek Canal. At higher elevations there is an herbaceous layer beneath the continuous common reed canopy with marsh fern (*Thelypteris palustris*), sensitive fern (*Onoclea sensibilis*), jewelweed (*Impatiens [capensis]*), rush, and composites (Asteraceae) being common. There are patches of cattail, spikerush (*Eleocharis* sp.), and water-plantain (*Alisma*) adjacent to a gas pipeline fill, and scattered stands of common elderberry and groundsel-tree. West of the pipeline, common reed dominates, with small patches of other emergents including cattails, spikerush, water-plantain, and marsh-marigold (*Caltha palustris*). East of the Turnpike there is a saltmarsh cordgrass section along a small ditch and Mary Ann's Ditch (Mary Ann Creek), with groundsel-tree, glasswort, and orache on the edges (Kane and Githens 1997).

Meadow vegetation occurs along the landfill road north of Berry's Creek, the TransCo pipeline easement that runs parallel to the Turnpike, the service road north of Berry's Creek Canal, the Conrail railroad right-of-way, and on the two dumps north of Berry's Creek. Dredged material from the canal has been deposited on the south bank of the canal. In some places, the dredge spoils were deep enough to have shifted the plant community from marshland to mesic meadow and shrubland. Stands of tree-of-heaven, staghorn sumac, aspen (*Populus*), and shining sumac (*Rhus copallina)* are common (NJTA 1986). Other plants on the upland portions of the site include sunflower, mugwort, wormwood, occasional shrubs such as common elderberry, and stands of princess tree, tree-of-heaven, [quaking aspen], wild cherry, and white mulberry (Kane and Githens 1997). The corporate center at the edge of the site has some wetlands and planted conifers.

The marshes around Berry's Creek are heavily used by wintering raptors. The last confirmed northern harrier (Endangered) nest site in the Meadowlands and a harrier winter roost are located here (Bosakowski 1983, NJTA 1986, Kane and Githens 1997). The nest successfully fledged young in 1995 and 1996 when observations were last made. The site is also important because it links the lower river marshes with the upper marshes at Route 3 and provides continuous habitat through the middle of the district (Kane and Githens 1997).

Walden Swamp: This site is located farther north along Berry's Creek (mostly between Berry's Creek and the west side of the Meadowlands Sports Complex). Walden Swamp is highly contaminated with mercury. The marshes are dominated by common reed (Sullivan 1998; EK, personal observation 2001).

Eight Day Swamp: This site is still farther north along Berry's Creek. It is apparently being fragmented by development. Vegetation is primarily common reed, with a small area of upland meadow on fill (P. Weis, personal communication to EK, 2002). Sediment levels of mercury, chromium, lead, copper, and zinc are high but small annelids and other invertebrates are abundant (P. Weis and J. Weis, personal communications to EK, 2002).

Carlstadt-Moonachie Site (in part, "Empire Tract"): This site is bounded by Route 120 (Washington Avenue) on the west, Route 3 on the south, Moonachie Avenue and Empire Boulevard on the north, and the Hackensack River on the east. The site contains one of the largest remaining expanses of wetlands in the Meadowlands, linking the upper and lower river marshes on the west side of the river (Kane and Githens 1997). Included are Bashes, Moonachie, and Doctor's Creeks, a diked freshwater area, tidal reed wetland, and, near the Hackensack River, an area dominated by common reed and [saltmarsh] cordgrass. The upland reed stands grade into reed marsh and the tidal common reed association dominates (NJTA 1986). Saltmeadow cordgrass and saltgrass were reported from several of the 16 stations studied by Grossmueller (2001), suggesting remnant salt meadows may be present. Water levels fluctuate depending on rainfall and stormwater runoff (HMDC 1984). In dry years, flooding is restricted to the creek and ditch channels. But during exceptionally wet years, fresh water ponds and pools form across the area (HMDC 1984). The area flooded in 1968-71 with construction of the Turnpike (HMDC 1984). The numerous creeks and ditches allow tidal inundation of some of the interior areas, especially during spring tides and storm surges. Areas west of the Turnpike are minimally tidal due to fill adjacent to the Turnpike (NJTA 1986) and to tide gates. Common reed is dominant along the river with some areas of cordgrass. In some common reed wetlands, common plants of high elevation marshes, such as sensitive fern (*Onoclea sensibilis*) and blue vervain (*Verbena hastata*), co-occur with the reed (NJTA 1986). An extensive mosaic of reed patches interspersed with patches dominated by bluejoint grass (*Calamagrostis canadensis*) is located west of the TransCo "Paterson Lateral" gas pipeline, and a small area north of Paterson Plank Road where reed has been harvested annually has high floristic diversity (EK and KM, personal observations). Extensive portions of the reed burned on 23 April 1994 (Kane and

Githens 1997), and a smaller fire occurred in 2000. There are stands of [quaking aspen], tree-of-heaven, and princess tree on filled portions (Kane and Githens 1997). East of the Turnpike is an extensive mitigation project known as the Meadowlands Mitigation Bank; fill has been removed and the marsh surface lowered to increase the frequency of tidal flooding and partially replace reed with other plant communities (Terry Doss, Louis Berger Group, Inc., personal communication 2002). West of the Turnpike is the site of the proposed Meadowlands Mills development (USACOE 2000). The Carlstadt-Moonachie site supports a variety of breeding and non-breeding birds, some of which are listed species in New Jersey, including yellow-crowned night-heron (Threatened), northern harrier (Endangered), and least tern (Endangered) (Kane and Githens 1997, U.S. Army Corps of Engineers 2000; also see Kiviat 2000).

Losen Slote: This site is bounded by Losen Slote on the west, the Hackensack River on the east, and the Boro of Little Ferry on the north. It includes the Bergen County Utility Authority property, a large pond, and a well developed forest of pin oak with white oak, red oak, black gum (*Nyssa sylvatica*), sweet gum, and red maple. Part of this land is in Losen Slote Creek Park, which is mostly forested but includes field, marsh and a portion of Losen Slote Creek. Shrubs include dogwood (*Cornus*), blueberry (*Vaccinium*), spicebush, and arrowwood. Vegetation on the forest floor includes netted chain fern (*Woodwardia areolata*), cinnamon fern (*Osmunda cinnamomea*), Canada mayflower (*Maianthemum canadense*), trout lily (*Erythronium americanum*), violet (*Viola*), bellwort (*Uvularia*), Turk's cap lily (*Lilium superbum*), and other woodland herbs. Portions of the meadow are overgrown by gray birch. The site is an oasis for migrant neotropical songbirds. Only 5.7 hectares (14 acres) of forest remain, but this is one of the few forest remnants in the Meadowlands (Kane and Githens 1997). Losen Slote is spelled "Losen Slofe" on the U.S. Geological Survey Weehawken quad.

Power Plant Peninsula: This peninsula is located at the confluence of the Hackensack River and Overpeck Creek, includes the west and east edges of the river, extends east along Overpeck Creek to the New Jersey Turnpike, and south to the Losen Slote site. CSX and Public Service Electric & Gas (PSE&G) own this site. The area is very developed, but the mudflats and the mouth of the creek are heavily used for foraging by migrant and resident birds (Kane and Githens 1997).

Teterboro Airport Forest: This area contains large remnants of lowland forest, mostly with young trees, and dominated by gray birch and pin oak with a variety of other species. The forest has been extensively ditched which has resulted in much drier soils.

Overpeck Creek and Hackensack River: The Overpeck Creek area east of the Turnpike is common reed marsh. Upland common reed stands are adjacent to the marsh (NJTA 1986).

Skeetkill Marsh and Bellman's Creek Marsh: Located east of the Hackensack River opposite Losen Slote, this site extends from the Hackensack River and the New Jersey Turnpike on the west to the Conrail tracks and developments in Ridgefield and Fairview on the east. It is marshland with intruding development. The southern end of the site is at a narrow point at the creek mouth. The north end of the site is at a cemetery and power substation. One side of the creek is vegetated with shrubs, including common elderberry and groundsel-tree. Bulrush (*Scirpus* sp.), rose mallow, and spikerush were reported in the wetlands. This area is notable for its nesting marsh birds (Kane and Githens 1997). Hartman and Smith (1999) describe the Skeetkill Marsh as dominated by common reed with sparse areas of saltmarsh cordgrass. A 16.3 acre portion of this site is part of an ongoing restoration project to create open water and mudflat, upland, and enhanced wetland habitats (Hartman 2001b) (restoration of the wetland portion has been completed; MERI, personal communication to EK 2002). Control but not complete eradication of common reed was a stated goal of the mitigation (Hartman 2001b). In the enhanced wetland areas, dwarf spikerush and marsh-fleabane covered 46% and 42%, respectively (Hartman 2001b).

Cromakill Creek Marsh: This site is located east of the Hackensack River in Secaucus and is bounded on the west by the Eastern Spur of the New Jersey Turnpike, on the north by development in North Bergen, on the east by the North Bergen [rail] Yards, and on the south by a development north of Paterson Plank Road. The fills are overgrown with [quaking aspen], tree-of-heaven, and princess tree (Kane and Githens 1997). Kane and Githens (1997) say that diamondback terrapin and fiddler crab are common; MERI (personal communication to EK, 2002) has not observed this. Cromakill Creek Marsh contains extensive reed marsh that is at least partly tidal. Areas of common reed were removed in the Hartz Mountain mitigation project (see Mill Creek, below). Northwest of the Meadowlands Convention Center is a large meadow on fill dominated by groundsel-tree, stunted mugwort, dense low grass (unidentified), patches of stunted reed, and groves of eastern cottonwood (EK, personal observation, 2002).

Mill Creek: The site is located east of the Hackensack River in Secaucus, and is bounded by the river on the west, Cromakill Creek on the north, the Turnpike Eastern Spur on the east, and by Route 3 and Park Place on the south (Kane and Githens 1997; MERI, personal communication to EK 2002). Part of this area, the Mill Creek wetland enhancement site (Hartz Mountain Industries), encompasses 84 hectares (207 acres). In the falls of 1984 and 1985, the area was treated with an herbicide, glyphosate, to kill common reed. Then, the elevation of the marsh was lowered by removing fill, and channels were dredged. The low areas were planted with saltmarsh cordgrass. Elevated islands were created with dredge spoil and were planted with salt-tolerant shrubs. The goal was to create shallow subtidal areas, mudflats, lower-intertidal brackish marsh, and a variety of upland habitats (TAMS 1985). Vegetation on the mitigation site includes tidemarsh water-hemp, saltmarsh cordgrass, marsh-fleabane, groundsel-tree, and pilewort. Except for the mitigation area, the marshes are mostly dominated by common reed.

The artificial islands retain some open sandy areas. Waterfowl nest on the islands, and the area is important for migrant green-winged teal (Kane and Githens 1997). The islands are also used by raptors, killdeer, gulls, and songbirds (Wargo 1989, USEPA and Gannett Fleming 1992). Certain bird species may be taking advantage of sparsely vegetated, upland soils to nest and roost. Soils of the islands are acidic and contaminated with metals (L. Windham, personal communication to EK and KM, 2001), which has evidently inhibited development of vegetation. Some of the islands have become densely overgrown with gray birch (EK, personal observations).

A second mitigation project to restore about 56 hectares (138 acres) of wetland adjacent to the Hartz Mountain site was initiated in 1999 and has been completed (Yuhas 2001; MERI, personal communication to EK, 2002). The goals of this mitigation project were to increase open water areas through the creation of impoundments and tidal channels, re-establish tidal flow, enhance upland and emergent fringe vegetation and create nesting habitat for least tern (*Sterna antillarum*), an endangered species in New Jersey (Hartman 2001c). Monitoring of various ecological parameters, including vegetation development, is ongoing at the site (Hartman 2001c).

Anderson Creek Marsh: This site is dominated by common reed. There are some mudflats exposed at low tide and half the site is inundated at high tide (USEPA and Gannett Fleming 1992).

Laurel Hill (Snake Hill) and Little Snake Hill: This is a mass of diabase bedrock which rises ca. 53 meters (ca. 175 feet). Laurel Hill originated as a volcanic neck (Manspeizer and Olsen 1981). The mountain was extensively mined from the late 1800s until 1982. It now supports areas of open-canopy forest, meadows, and nearly bare rock some areas of which are graffiti-covered. Tree species include chestnut oak (*Quercus montana*), red oak, hackberry, and black cherry (Quinn 1997). Tree-of-heaven, white mulberry, white ash, princess tree, and eastern red cedar are also present (EK, personal observation, 2002). A small area of chestnut oak woodland with dense low grasses on the northeastern knoll of Laurel Hill appears to represent “natural” vegetation on a non-quarried area (EK, personal observation, 2002). Labriola ([2000]) referred to a chestnut oak - hairgrass (*Deschampsia flexuosa*) community.

The Torrey Botanical Society reported 115 vascular plants and NJMC reported 145 species from Laurel Hill (Quinn 1997). One of the species was wafer-ash or hop-tree (*Ptelea trifoliata*) which is listed as Endangered in New Jersey and ranked G5 S1 by the New Jersey Natural Heritage Program, i.e. globally secure but very rare in the state. Wafer-ash was reported as recently as 1999 on Laurel Hill (Labriola [2000]). A single individual was observed then, raising the possibly that wafer-ash was planted, along with other ornamental species (e.g. paper-mulberry [*Broussonetia papyrifera*]) that occur on Laurel Hill (W. Standaert, personal communication to EK, 2002). Wafer-ash should be protected until its origin can be determined through recourse to historical documents or other information. Violet bush-clover (*Lespedeza violacea s.s.*), ranked S3S4 in New Jersey, was provisionally identified on Laurel Hill, also in 1999 (W. Standaert, personal communication to EK, 2001). Among other interesting native species reported at Laurel Hill are starry campion (*Silene stellata*) and Virginia mountain mint (*Pycnanthemum virginianum*) (Labriola [2000]).

In February 2002, EK found several species of lichens on Laurel Hill (see Fungi and Lichens, below). A dry meadow on fill or mine tailings (and possibly crushed stone from railroad ballast) at the southwest foot of Laurel Hill bears a community of small eastern cottonwoods, staghorn sumac, mullein, mugwort, white mulberry, switchgrass, and other herbs (EK, personal observation). Labriola ([2000]) reported sessile tooth-cup (*Ammania robusta*), from a meadow at the base of Laurel Hill.

Southeast of Laurel Hill is Little Snake Hill, a smaller diabase knob 24 meters high (Widmer 1964). Little Snake Hill has not undergone much alteration; in 2002 there were the remains of a large billboard (see Brooks 1957) on the summit, a small area (perhaps 100 m^2) that appeared to have been excavated, very limited off-road vehicle use, and graffiti on rocks (EK, personal observations). Little Snake Hill has extensive bedrock outcrops, and there are talus slopes on the east and north. The most common woody plants were black cherry, chestnut oak, other oaks (*Quercus*), winged sumac, choke cherry (*Prunus virginiana*), and dewberry (*Rubus flagellaris*). The flora was diverse and included basswood (*Tilia americana*), sassafras (*Sassafras albidum*), post oak (*Quercus stellata*), switchgrass, wild sarsaparilla (*Aralia nudicaulis*), blue toadflax (*Linaria canadensis*), and pale corydalis (*Corydalis sempervirens*) (EK, personal observations, 2002). Snake Hill (Laurel Hill) was reported to have served as a winter denning area for snakes that frequented the surrounding wetlands (Waldman 1999); this was presumably true of Little Snake Hill as well. Ledges on Little Snake Hill contain fissures potentially suitable for bat roosting.

The New Jersey Transit Authority is removing rock from the eastern slopes of Laurel Hill to reduce hazards of falling rock to the Turnpike below. An equipment road and parking area, as well as the rock removal activities, are causing loss of vegetation and soil (Bill Sheehan, personal communication to EK, 2002; EK, personal observation). We do not know if wafer-ash or violet bush-clover is threatened by these activities.

Penhorn Creek Marsh: Penhorn Creek Basin is a large freshwater marsh where tidal flow has been restricted by a tide gate on the mouth of Penhorn Creek (HMDC 1984). There are extensive stands of common reed (MERI, personal communication to EK, 2002). Accumulation of pollutants in the lower and middle reaches of the creek has created anoxic conditions; however, the headwaters of the creek are less affected (HMDC 1984).

Riverbend Marsh: The site is highly dominated by common reed. It also has several patches of high marsh vegetation, including saltmeadow cordgrass, spikegrass, and glasswort (Bart and Hartman 2000).

PLANTS AND FUNGI

Vascular Plants

Because the landscape of the Meadowlands has been highly altered and polluted, many of the plants are common, weedy species, and many species that are rare or uncommon in northeastern New Jersey appear to be absent. There is, nonetheless, a rich flora in the Meadowlands, including many native species. A list of plants of the Meadowlands is in Table 1, derived from the database of the Brooklyn Botanic Garden Metropolitan Flora Project. Other lists of the Meadowlands flora include an original flora and compilation from other sources in Sipple (1972) and a compilation in USACOE (2000). Because many areas of the Meadowlands are difficult of access, we expect that additional botanical surveys will discover species not included in Table 1 or other flora lists. Two rare species, wafer-ash and violet bush-clover, occur at Laurel Hill (see Site Descriptions, above). Other rare native species (e.g. rare grasses, sedges, rushes, dodders, composites, mustards) may yet be found by careful field work. Urban-industrial influences do not preclude the occurrence of rare plants, many of which currently occur in New York City, for example.

Common Reed and other Invasive Plants

A review of Meadowlands biology would not be complete without a discussion of invasive plants. We use the term "invasive plants" to denote either native or introduced species that establish and spread aggressively at the expense of native plants and plant communities, and that have the potential to significantly alter ecological functions including habitat functions for other biota and ecological processes such as nutrient cycling, energy flow, and disturbance regimes. Plants may also be considered invasive because they alter aesthetic or scenic values of the landscape, or rapidly change plant communities to which people are accustomed. Plant invasions are considered of great importance because they may threaten rare or endangered plant and animal species and affect economic productivity associated with, for example, agriculture, fisheries, and public health.

Those invasive plants of greatest concern in the Meadowlands (USFWS et al. 2000) include common reed, purple loosestrife, mugwort, tree-of-heaven, and Japanese knotweed (*Fallopia japonica [Polygonum cuspidatum* or *Reynoutria japonica]*). Mugwort occurs mostly on artificial mineral soils (e.g. fill) at an early stage of vegetation development. Japanese knotweed does not seem especially abundant in the Meadowlands and does not seem to be invading marshes there; it is mostly a weed of roadsides and vacant lots (EK, personal observations 1999-2001). In addition to Japanese knotweed, the similar *Polygonum sacchalinense* also occurs in the Meadowlands (EK, personal observation). Common reed appears to be the most abundant plant overall in the Meadowlands and probably accounts for the greatest number of stems and highest peak standing crop and annual production of any herbaceous vascular plant there. There is a prevalent perception in the Meadowlands and elsewhere in the northeastern U.S. that common reed has only negative impacts on animals (especially fishes and birds) and in general lacks values to society. The text that follows questions prevalent interpretations of common reed ecology in the Meadowlands, and offers a brief summary of recent research and observations on the ecological functions and values of reed stands that are relevant to Meadowlands biodiversity. The purpose of this discussion is to provide a perspective for our review of the biota of the Meadowlands, much of which has a direct or indirect relationship to common reed. This discussion is adapted from Kiviat (2000; submitted b) and is intended to present important recent findings but is not a comprehensive review.

Plant communities dominated by common reed are found throughout the Meadowlands (Sipple 1972). Common reed is a native species in New Jersey including the Meadowlands; it has been found deep in peat profiles, indicating it was a member of the local flora in pre-European times (see Waksman 1942), probably since the early Holocene. Reed became much more abundant and dominant in the Meadowlands during the 1900s, as also occurred in many other areas of the northeastern U.S. There is recent genetic evidence indicating that a majority of the reed stands in the northeastern states represent a genotype of introduced European origin (Kristin Saltonstall, Yale University, 2001 personal communication to EK). The extent to which the invasion of reed in the past century has been due to human impacts on the environment or to recently introduced genotypes is unclear (see Kiviat and Hamilton 2001). Both genetics and environment must be considered in order to understand and manage this species.

The plant diversity and species composition of common reed stands in the Meadowlands and elsewhere vary greatly depending upon salinity, duration of tidal inundation, muskrat activities, and site history (among other factors). On portions of the Carlstadt-Moonachie site, for example, in 2000 and 2001 we found reed stands that were virtually pure, i.e. there were only scattered occurrences of other vascular plants beneath the reed canopy and many hypothetical one-square-meter plots would have contained only reed. At other locations, reed occurred in mixed stands. On the west side of the Paterson Lateral gas pipeline road in the northern end of the site, common reed formed a matrix complexly interspersed with patches dominated by bluejoint grass and supporting several forb species. On the north side of Paterson Plank Road, in an area where reed had been cut annually for years (see Human Use, below) and had also burned as recently as about March 2000, there were at least 18 other plant species beneath a dominant reed canopy. At other sites, we have seen reed stands containing a low density of woody plants, such as tree-of-heaven, princess tree, and common elderberry. Reed at wetland edges (e.g. the western edge of Kearny Marsh West) is commonly colonized by vines of many species. McCormick & Associates (1978) described "common reed / marsh fleabane grassland" with common reed, marsh-fleabane, water-hemp, orache(?), saltmarsh cordgrass, and American threesquare (*Scirpus pungens [S. americanus]*). The factors shaping reed stands cause them to vary through time as well as across space; stands in which reed is highly dominant today may become more diverse in the future (or vice versa) depending on deposition and erosion of sediments, fire, changes in hydrology and salinity, and other factors. The variety characterizing different reed stands has been omitted from most discussions of common reed in the Meadowlands. This variation is especially important in any consideration of common reed as habitat for birds and other animals.

Interspersion of emergent vegetation and “open” water is an important stand characteristic affecting habitat functions. Variation in substrate elevation (flooding depth) is also important. Creeks, ditches, impoundments, erosion and deposition of sediments, animal activities, off-road vehicle tracks, and fires all influence interspersion. Reed stands that appear homogeneous from the edge may have pools, ditches, depressions, berms, and other hidden features important to plant and animal community structure. The Carlstadt-Moonachie site has ditches, creeks, ponding associated with creeks, off-road vehicle tracks, and variations in substrate elevation, most of which can be discerned only by walking through the reed stands (B. Sheehan, personal communication to EK, 2000; EK and KM, personal observations, 2000-2001). Kearny Marsh West, deeply flooded by accidental impoundment, is undergoing fragmentation of the reed stands apparently due to stress from deep water, wind waves, and consumption of reed underground parts by European carp and muskrat (*Ondatra zibethicus*). Where patches of reed have died, peat has rafted to the water surface and is being colonized by marsh-fleabane and purple loosestrife (EK and KM, personal observations, 2000).

Reed stands are capable of producing large quantities of organic matter, much of which may accumulate *in situ* as litter and ultimately peat beneath the stand (Windham 2001). Reed stands may also cause increased deposition of organic and mineral suspended solids from waters flowing through the stand (Rooth and Stevenson 2000). Substrate elevation may thus increase relatively rapidly beneath reed stands, resulting in reduced depth and duration of flooding by tides or runoff (Berger 1992 referred to this process in the Meadowlands without documentation). Increasing elevation may eventually result in “terrestrialization” of reed stands, that is, a shift from wetland to non-wetland (this process has not been rigorously documented in North America as far as we know). In theory, a marsh surface should reach an equilibrium of deposition of organic and mineral matter vs. decomposition and erosion; however, this dynamic has not been studied in the Meadowlands and is presumably subject to human alterations of the hydrological, sedimentary, and fire regimes, as well as the potentially different time scales of different processes. Decreased flooding is believed to result in less export of marsh plant detritus to estuarine waters, thus shifting organic matter and food web interactions from the open water estuarine system to the marsh soils. In East Coast tidal marshes, however, patterns of exchange of organic matter between tidal marshes and estuarine waters are highly variable (J. Ehrenfeld, personal communication to EK and KM, 2001), and it is unclear what patterns would be normal in the Meadowlands. Presumably export of detritus occurs even now during severe flooding from storms, and the relative importance of this process needs study in the Meadowlands.

Living and dead organic matter of reeds supports food webs in the reed stands. Components of these food webs include terrestrial and aquatic organisms that feed on living reed (e.g. mealy plum aphid [*Hyalopterus pruni*], reed scale [*Chaetococcus phragmitis*], broadwing skipper [*Poanes viator*], muskrat) and dead reed material (e.g. fungi, terrestrial sowbug, chironomid midges, other invertebrates), as well as animals eating the primary consumers and each other (presumably ladybugs, fiddler crabs, grass shrimp [*Palaemonetes*], mummichog (*Fundulus heteroclitus*) and other marsh fishes, northern harrier, many marsh and water birds, etc.). Limited research indicates that reed detritus is as good or better than saltmarsh cordgrass detritus as food for major detritus-feeding tidal marsh animals (fiddler crab, grass shrimp, and mummichog), and that these animals do not consistently select one plant community over the other in laboratory experiments (Weis 2000, Weis and Weis 2000).

Reed is more effective at immobilizing metals than is saltmarsh cordgrass. Saltmarsh cordgrass accumulates copper, chromium, lead, and zinc from contaminated sediments. Release of these four metals from cordgrass leaves was greater than from reed leaves in both laboratory and field (at a Meadowlands site) (Burke et al. 2000). Also, cordgrass accumulated higher levels of chromium and lead in its leaves than reed, therefore cordgrass is expected to mobilize these metals more through decomposition of leaves (Burke et al. 2000). In the laboratory, allocation of lead was greater in aboveground biomass in saltmarsh cordgrass and greater in belowground biomass in common reed, indicating that reed is sequesters more lead belowground which would lead to permanent burial rather than remobilization during decomposition of plant tissues (Windham et al. 2001).

Reed stands burn readily, especially in spring. Stalter (1984) studied plant communities on garbage landfills in New York City, and implied that reed stands burn more intensely than other landfill vegetation. These fires kill woody plants and help maintain reed vegetation (Stalter 1984). Some reed fires in the Meadowlands also threaten buildings and create smoke that is a hazard to motorists on high-speed highways such as the Turnpike (e.g. Wakin 2001). Research is needed on the relative frequency and intensity of fires in reed, and the fire hazard to buildings and other cultural features, associated with reed stands compared to other wetland or upland plant communities in the Meadowlands. Because fires on organic soils ignite methane generated from soil organic matter, fires on marshes with organic soils burn intensely irrespective of plant community (E. Hartig, personal communication to EK, 2002). Spring fires remove the previous year's standing dead reed stems, making burned patches accessible to animals that forage, roost, or nest on bare soil or in sparse low vegetation. Spring burns may diversify the structure of reed stands. Summer burns that have been studied in other regions (e.g. the Delta Marshes of Manitoba, Ward [1942]) burn into soil and reed underground parts, lowering substrate elevation and killing patches of reed. We do not know if this occurs in the Meadowlands. The potential for fire to change characteristics of vegetation, soil, hydrology, and animal use in reed stands suggests that fire management should be studied as a component of reed management.

The dense aboveground parts of common reed retard water flows and absorb energy from storm waters during floods. Reed is a highly productive and nutrient "hungry" species that binds nutrients in living and dead plant matter (Meyerson et al. 2000). That reed is excellent for amelioration of surface water quality is evidenced by its frequent use (outside the Meadowlands) in wetlands constructed for wastewater treatment. Values of reed stands in modulating flood flows and ameliorating water quality have not been measured for the Meadowlands but are likely considerable (see e.g. HMDC 1974). Uptake and sequestration of nutrients from waters by reed would depend on patterns of water flow (J. Ehrenfeld, personal communication to EK and KM, 2001). Reed stands separated from tidal flow by flood control berms, dikes, or other features will not normally remove nutrients from tidal waters; however, nutrient removal from stormwater runoff may still occur.

Common reed traps and accumulates mineral and organic matter efficiently, and in a Chesapeake Bay study area was better than saltmarsh cordgrass at stabilizing soils and preventing erosion and marsh loss (Rooth and Stevenson 2000). Reed stands along the Hackensack River mainstem and major tributaries presumably help bind soils and maintain integrity of banks. Soil stability in the Meadowlands will become a more important concern as sea level continues to rise, and also if motorized recreational boating increases. The high production of living and dead organic matter by reed stands, and the accumulation of portions of this material in soils beneath reed (Windham 2001), suggest that reed might be important as a carbon sink. Carbon accumulation in sediments vs. losses to air and water may vary greatly (J. Ehrenfeld, personal communication), and carbon balance has not been studied in Meadowlands marshes.

There has been remarkably little research on habitat functions of common reed in North America, and virtually all of this work has been conducted in tidal marshes rather than nontidal marshes or upland reed stands. Furthermore, many studies are limited by lack of replication at the level of the stand or the site (i.e. these studies have been conducted in very limited areas). Dense reed stands obstruct vision and movement of observers (e.g. Wander and Wander 1995), discouraging biological studies of stand interiors. Nonetheless, a picture of the habitat functions of reed has begun to emerge.

Invertebrates. Most studies of invertebrate use of reed stands in North America have begun recently, and to date most quantitative work has been done in tidal marshes. Several studies of reed stands in New York and New England indicate favorable habitat for mollusks, spiders, phytophagous mites, and certain insects (reviewed in Meyerson et al. 2000). Terrestrial insects associated with reed in North America were reviewed by Schwarzlander and Hafliger (1999); however, little research has been conducted on the insect fauna of reed on this continent.Trial sampling of litter in reed and narrowleaf cattail in a Hudson River fresh-tidal marsh suggests mites, springtails, and other invertebrates are abundant and diverse in both plant communities (E. Kiviat, unpublished data). In a Chesapeake Bay study, Meyer et al. (2001) found that 3 important decapod crustaceans (blue crab [*Callinectes* *sapidus*], mud crab, and grass shrimp) ranked about equally in abundance and biomass in reed compared to saltmarsh cordgrass samples in May, July, and October. An uncommon crab (*Dyspanopeus sayi*), however, was found only in cordgrass. In brackish marshes of the Hudson River, blue crab was equally abundant in reed and alternate plant communities at similar marsh surface elevations (D. Yozzo, personal communication to EK, 2001). Grass shrimp was more abundant in reed stands than in cattail on tidal marshes of the Connecticut River (Fell et al., submitted). Reed had a more diverse benthic macroinvertebrate community than saltmarsh cordgrass, whereas abundance of invertebrates was equal in both plant communities, at a Meadowlands site (Weis et al., submitted). Robertson and Weis (2002) found that saltmarsh cordgrass supported a higher density of epifauna than reed at sites in the Meadowlands and on Long Island. Cordgrass supported more harpacticoid copepods than reed, and at one site reed supported more mites. Woolcott and Weis (2002) found equal abundance of grass shrimp and blue crab in reed vs. saltmarsh cordgrass at Sawmill Creek in the Meadowlands. In the laboratory, two species of fiddler crabs (*Uca pugnax* and *U. pugilator*) and grass shrimp performed equally on diets of reed vs. saltmarsh cordgrass (Weis et al. 2002).

Fish. Although one group of studies has shown greater abundance and diversity of fishes in saltmarsh cordgrass compared to common reed (Able 1999, Able and Hagan 2000), and it has been hypothesized that common reed invasion smooths microtopography (Windham and Lathrop 1999), making tidal marshes less suitable as fish habitat (Weinstein and Balletto 1999), studies by Fell et al. (1998), Wainright et al. (2000), Weinstein et al. (2000), Weis (2000), Weis and Weis (2000), Able et al. (2001), Meyer et al. (2001), and others indicate that some tidal reed marshes are good fish habitat, fish use of common reed and alternate plant communities does not differ greatly, and reed contributes substantially to fish food chains in some areas. These studies have used field surveys, laboratory and field experiments, historical surveys, and stable isotope analyses to demonstrate the comparability of reed and alternate plant communities as fish habitat. Able (submitted), however, has stated that generally juvenile and adult fish use of reed and saltmarsh cordgrass stands is similar, and that mummichog spawns in both reed and cordgrass stands, but that mummichog larvae do not thrive in reed stands. Twice as many subadult and adult mummichogs were found in saltmarsh cordgrass compared to reed in Sawmill Creek (Meadowlands) (Woolcott and Weis 2002). Because the mummichog is highly dominant in the upper intertidal zone and supratidal zone fish community of northeastern tidal marshes across a broad range of salinity, a negative influence on mummichog population dynamics could have substantial ramifications through the ecosystem. Research on fish use of reed compared to alternate plant communities has not been conducted in nontidal marshes.

Birds: Many bird species have been reported breeding in common reed stands in North America (Meyerson et al. 2000; Kiviat et al., submitted b). In a few cases, reed stands have been described as less or more favorable for certain bird species than alternate plant communities, but little quantitative information is available. Notably, in high salt marsh communities of southern New England, 3 species of habitat-specialists (saltmarsh sharp-tailed sparrow, seaside sparrow, and willet) breed in saltmeadow cordgrass but do not breed in reed (Benoit and Askins 1999, Shriver and Vickery 2001). The great height of reed compared to other marsh graminoids (cordgrasses, cattails, etc.) provides a different habitat for birds; reed in vigorous stands in the Meadowlands may be 3.6-4.5 m tall (Bontje 1988). Reed stands in the Meadowlands are, in fact, used by many species of breeding and nonbreeding birds (USEPA and Gannett Fleming 1992, Quinn 1997, USACOE 2000, Kane 2001a, b). The bird fauna of Meadowlands reed stands includes populations of common and rare species, some of considerable regional significance. Extensive reed stands lacking pools or mudflats are unfavorable foraging habitat for peregrine falcon (Endangered) (Wander and Wander 1995).

Mammals. Reed stands can be favorable habitat for muskrat (e.g. Quinn 1997; Kiviat et al. submitted a and references cited therein), as well as for other small mammals (Svihla 1929, 1930, Holland and Smith 1980, McGlynn and Ostfeld 2000). Large mammals may also use reed stands; these species include white-tailed deer (*Odocoileus virginianus*), black bear (*Ursus americanus*), and others (Kiviat et al., submitted a). Although muskrat is the most prominent reed mammal in New Jersey, other species that use reed stands in the Meadowlands include opossum (*Didelphis marsupialis*), raccoon (*Procyon lotor*), white-footed mouse (*Peromyscus leucopus*), meadow jumping mouse (*Zapus hudsonius*), Norway rat (R*attus norvegicus*), house mouse (*Mus musculus*), and eastern cottontail (*Sylvilagus floridanus*) (Rawson 1993, Quinn 1997; Berger Group 2001, M. A. Thiesing, personal communication to EK, 1999; EK, personal observations). We have seen no data on relative population density or productivity of Norway rat or house mouse in reed compared to alternate plant communities in the Meadowlands; this comparison could have implications for public health.

Plants. Reed can form either mixed stands or dense, highly dominant stands. Dense stands may contain few other vascular plants (e.g. Meyerson et al. 2000). Therefore, it is believed that reed dominance reduces plant diversity. Some alternate plant communities (e.g. cattail marsh, low salt marsh) are also typically hyperdominant and have few other plant species, whereas other communities (e.g. salt meadows, freshwater wet meadows) may have high species richness of vascular plants. In some estuaries (e.g. Connecticut River) reed is considered a threat to rare plant species. There are examples of rare plants in the edges of reed stands in New York where the rare species appear to be facilitated by reed (EK, personal observations). In most cases it is not known whether underlying problems, such as hydrological alteration, pollution, or intensive livestock grazing, caused the loss of rare plants or native plant communities before or during reed invasion. In the Meadowlands, it is possible that habitat alteration and pollution were as important, or more important, than reed in the elimination of most rare plant species that may once have occurred. (To date, very few state-listed rare plants have been found in the Meadowlands, and we have found no evidence that rare plants are more likely to occur in alternate plant communities than in reed stands.). Reed may also not be the only, or the ultimate, cause of the loss of salt meadow communities in the Meadowlands; changes in hydrology, salinity, water quality, livestock grazing, other fauna, mosquito ditching, or salt hay harvesting, may have played a role. Nonetheless, reed invasion of salt meadows may be one of the most important negative impacts reed has on native biological diversity.

Reed reduces accessibility of certain areas to people, and this can benefit wildlife by creating *de facto* refuges. Reed can also inhibit access by larger predatory mammals and birds, which can help smaller animals including some of the wetland-dependent bird species. Reed is beneficial to some animals and detrimental to others, and this varies according to characteristics of the reed stands and other characteristics within and between sites.

Human use. Common reed was one of the herbaceous plants most highly used by North American Indians (Kiviat and Hamilton 2001). A historical exhibit in the Hackensack Meadowlands Development Commission headquarters shows Native Americans with a fish net woven from common reed, but we were unable to discover the source of this information. Hasidic Jews (and possibly other Jews) annually harvest common reed for thatching *succot* (ceremonial shelters used in the Feast of Tabernacles) (Anonymous 1993; B. Sheehan, personal communication to EK). Some or all of this harvest occurs on the Carlstadt-Moonachie site north of Paterson Plank Road. There is an area of floristically diverse mixed reed at this location that may be the result of the harvest and associated disturbances. It is unclear whether the reed at this location, due to repeated harvest, has properties particularly suitable for thatching. Reed was used historically in the Meadowlands as matting to support weight on marsh surfaces and in construction of berms and dikes for mosquito control projects (Headlee 1945). A border of reed was retained along the river margin at the Hartz Mountain reed removal project at Mill Creek to keep logs and other debris from rafting into, and damaging, the cordgrass plantings (K. Dunn, statement at 20 October 1998 NJMC wetland mitigation workshop). Gertler (1992) believed that extensive reed stands “soften” the appearance of the landfills of the Meadowlands, and Brooks (1957) related that extraneous industrial and agricultural odors were not noticeable when standing beneath the reeds.

Other invasive plants are also important components of the Meadowlands landscape. Tree-of-heaven may well be the most abundant woody plant. The ecology of tree-of-heaven has not been studied in the Meadowlands, and is poorly understood elsewhere in its non-native range in North America. Tree-of-heaven is abundant on mineral soil fill where the soil is either dry or wet (but not deeply flooded). The ability of this species to grow in wetland edges and wet meadows has not been well reported in the literature (see Kiviat submitted a). A good example of tree-of-heaven on wet substrates is at the tidal edge of the southern dike (trail) at Kingsland Impoundment in DeKorte Park (Lyndhurst). Here the tree bases are wet by brackish water at high tide. Tree-of-heaven is often found growing among common reed in wet meadows and on dry upland soils. Tree-of-heaven is apparently fire-sensitive (EK, personal observation) and it is easy to find dead, charred stems among thriving reed colonies. Some of these dead trees-of-heaven support macrofungi which in turn provide habitat for insects and other arthropods. Tree-of-heaven is browsed by cottontails during the dormant season (see Mammals, below), and seeds are eaten by northern cardinal (EK, personal observation). Some tree-of-heaven stands are being killed by a naturally-occurring fungus *Verticillium dahliae* in New York City (Emmerich et al. 1998); this phenomenon should be expected in the Meadowlands where it could effect important changes in the vegetation.

Bryophytes

Usually few species of bryophytes survive in urban-industrial areas, and occurrence of mosses appears limited in the Meadowlands. In 2000-2001, EK collected mosses that appeared locally common on dry, disturbed soils, for example near the parking area of the New Jersey Turnpike Vince Lombardi service area, at the edges of the Paterson Lateral gas pipeline road at the Carlstadt-Moonachie site, in a dry dredge spoil meadow at Oritani Marsh, and on Laurel Hill. Specimens were identified by Nancy Slack (Russell Sage College). Several specimens were *Ceratodon purpureus* which is evidently common on dry, disturbed or artificial, mineral soils. Also on Laurel Hill were *Brachythecium salebrosum*, *Bryum argenteum*, and *Dicranella* sp. McCormick & Associates (1978) reported *Dicranella* from the site of the proposed Meadowlands Arena. We observed that moss cover was well-developed locally on soil in a common reed stand and a purple loosestrife stand, both on floating peat, at Kearny Marsh West in 2001. None of the mosses observed were sphagnums, which generally are intolerant of high nutrient levels and pollution. Mosses may be locally important soil binders and microhabitat for invertebrates in the Meadowlands. There has been little recent study of the moss flora of New Jersey; of 247 taxa, 40% are known only from historical collections (Karlin and Schaffroth 1992).

Algae

Little has been written about "algae" (including blue-green bacteria) in the Meadowlands, although these small organisms are undoubtedly important components of biological communities in the waters, on the soil surface, and on the bases of higher plant stems (including tree-of-heaven and reed; EK, personal observations). Mud algae, in particular, are likely to be important components of tidal marsh ecosystems due to the formation of large, productive mats on mudflats and creekbanks. Suspended algae were studied in the upper Hackensack River estuary (Foote 1983). Of 232 species found, minute centric diatoms were abundant in winter and green algae were prominent in summer. Species were those tolerant of organic pollution and low concentrations of salt. Utberg and Sutherland (1982) report that "warm summer temperatures were accompanied by a proliferation of submergent vegetation, particularly the green algae *Cladophora* sp. and *Enteromorpha* sp." in a brackish marsh in Bergen County.

Fungi and Lichens

We have found no literature on fungi or lichens of the Hackensack Meadowlands. Casual collections by EK from dead stems and stumps of tree-of-heaven in 2001 revealed oyster mushroom (*Pleurotus sapidus [P. ostreatus]*), *Trichaptum biforme*, and *Schizophyllum commune* (specimens identified by Dwane Decker and Bill Bakaitis, Hudsonia Ltd.). These are common and widespread species outside the Meadowlands (E. Varney, personal communication to KM).

Certain lichens are good ecological indicators because of narrow habitat affinities, limited dispersal capabilities, and sensitivity to air quality (Hunter and Webb 2002), and lichens tend to be absent or rare in urban environments. In 2001, EK observed a foliose lichen on tree-of-heaven in the Kingsland Impoundment (DeKorte Park). EK also collected the foliose lichens *Physciella chloantha* from the base of an elm just above MHW at Hackensack River County Park, and *Phaeophyscia imbricata* from a large eastern cottonwood near Overpeck Creek. He found the fruticose lichen *Cladonia polycarpoides* in a dry dredge spoil meadow at Oritani Marsh, and *C. polycarpoides* as well as *C. cristatella* (British soldiers) on dry quarry tailings or dredge spoil at Laurel Hill. EK also collected *Xanthoparmelia plittii* from soil, and observed 2 crustose lichen species at Laurel Hill. Lichen specimens were identified by Robert Dirig (Bailey Hortorium, Cornell University). Macrofungi and a lichen on tree-of-heaven are interesting finds because of the limited ecological knowledge of this tree and its great abundance in the Meadowlands.

ANIMALS OF THE MEADOWLANDS

The Meadowlands are significant for concentrations of federal trust species including waterfowl, wading birds, shorebirds, raptors, anadromous and estuarine fishes, and diamondback terrapin (Day et al. 1999). The most species-rich vertebrate groups in the Meadowlands are fishes and birds. Eighty-eight Species of Special Emphasis (U.S. Fish and Wildlife Service 1997) occur in the Meadowlands, primarily fishes and birds. Twenty state-listed endangered or threatened species occur there (Table 4). Forty-two species considered rare in the urban core of the New York metropolitan region, and 49 species rare in the New York Bight ecosystem, are found in the Meadowlands (Day et al. 1999).

Mammals

A mammal survey conducted along the New Jersey Turnpike corridor prior to Turnpike expansion in the late 1980s and early 1990s provides much of the available information on mammal distribution within the Hackensack Meadowlands. A total of 16 species was found (NJTA 1986). A total of 12 species was found at Oritani Marsh in two studies in the 1980s and 1990s (Berger Group 2001).

Muskrat occurs throughout the Meadowlands (NJTA 1986). Kingsland Marsh, Kearny Marsh, Sawmill Creek WMA, and the marshes around Berry's and Overpeck creeks are among the locations where muskrats are abundant (NJTA 1986, Kane and Githens 1997). Muskrat uses common reed marshes (NJTA 1986) as well as a variety of other wetland habitats. Brooks (1957) opined that the "unhealthy environment" of the Meadowlands reduced predation pressure by mammals and snakes, allowing muskrats to thrive. This large rodent may be considered a keystone species due to the changes it causes in the vegetation, soils, marsh topography, and animal habitats by its feeding and building activities. Muskrat lodges built of emergent vegetation may provide a substrate for nesting birds, especially geese and ducks (e.g. Kiviat 1978). Grazing by muskrats may be important in opening up common reed habitat by thinning or creating clearings. Grazing and digging may also increase rates of nitrogen mineralization in the soil, as occurs in cattail marshes (see Daiber 1982, Kiviat 1989, Connors et al. 2000). Muskrat effects on biogeochemistry may be important in the Meadowlands because of high nutrient levels and locally or periodically dense muskrat populations. Muskrat depredation of plantings was a problem in the Hartz Mountain mitigation project (Berger 1992).

Beaver (*Castor canadensis*) is not currently known in the Meadowlands (Anne Galli, NJMC, personal communication to KM, 2001); however, beaver expansion into tidal wetlands and urban-fringe areas in the Hudson Valley suggest the Meadowlands may eventually be colonized. Beaver could have large influences on ecosystems by selective feeding on certain plant species, construction of lodges, burrows, and canals, and local alteration of water levels.

Several mammals are found predominantly along road and rail beds, pipeline corridors, and other elevated areas as well as in the marshes and meadow habitats of the Meadowlands. In addition to muskrat, rodent species found in the Meadowlands include white-footed mouse, meadow vole, house mouse, Norway rat, eastern chipmunk (*Tamias striatus*), and eastern gray squirrel (*Sciurus carolinensis*) (NJTA 1986). White-footed mouse was found around Berry's Creek and Oritani marshes and in the area around Blackman's and Cedar creeks (NJTA 1986). Meadow vole was found around Berry's Creek and Oritani Marsh (NJTA 1986). The introduced house mouse and Norway rat are probably most abundant in developed areas and around landfills but have also been observed in marshes, including the Sawmill Creek WMA, Kearny Marsh, and Oritani Marsh (NJTA 1986). We expect that white-footed mouse and meadow vole are common and widespread in the Meadowlands. McCormick & Associates (1978) found meadow vole in common reed – marsh fleabane vegetation and probably meadow vole sign in a reed stand burned the previous year. Norway rat and house mouse have been prominently associated with landfills, garbage, buildings, and (presumably) farms in the Meadowlands. Norway rat has declined with the closing of many landfills (Quinn 1997). Seven captures of meadow jumping mouse (*Zapus hudsonius*) in Oritani Marsh (in cordgrass, reed, and "old field" habitat) resulted from a recent survey (Berger Associates 2001).

Gray squirrel was found at Berry's Creek, Oritani Marsh, and around Blackman's and Cedar Creeks (NJTA 1986). An eastern chipmunk was found near Berry's Creek (NJTA 1986). Woodchuck (*Marmota monax*) is found in elevated areas where burrowing is possible, such as roadbeds (Quinn 1997) and the Paterson Lateral gas pipeline road (EK, personal observation). This species should be common on landfill cover, dredge spoil, and other sandy or gravelly fill soils.

Masked shrew (*Sorex cinereus*) and eastern mole (*Scalopus aquaticus*) were found along roads and the TransCo pipeline easements at Sawmill Creek WMA, Oritani Marsh, and the Berry's Creek area (NJTA 1986). Little brown bat (*Myotis lucifugus*) has been observed near Berry's Creek Canal, Blackman's Creek, and Cedar Creek (NJTA 1986).

Eastern cottontail was found in the areas of Berry's Creek, Oritani Marsh, Moonachie Creek and in the marshes around Blackman's and Cedar Creeks (NJTA 1986). Cottontail sign was common in aster-ragweed meadow and in the margins of common reed marsh at the proposed Meadowlands Arena site (McCormick and Associates 1978). Cottontails were common around the edges of the Carlstadt-Moonachie site in spring 2001 where they were extensively browsing bark from sapling-size tree-of-heaven stems, and cottontail feeding on tree-of-heaven twigs was also seen on Laurel Hill in February 2002 (EK, personal observations). Although New England cottontail (*Sylvilagus transitionalis*) is almost indistinguishable from eastern cottontail in the field, it is unlikely that New England cottontail occurs in the Meadowlands because of its geographic distribution and habitat affinities; therefore we refer all Meadowlands cottontails to the eastern cottontail (*Sylvilagus floridanus*). Eastern cottontail appears widespread and common in the Meadowlands (EK, personal observations).

Raccoon, opossum, and striped skunk are widespread in the Meadowlands, but often go undetected due to their nocturnal habits (Quinn 1997). Raccoon was abundant at Kingsland Marsh, Oritani Marsh and around Berry's Creek (NJTA 1986, Kane and Githens 1997). Opossum was observed near Berry's Creek and Moonachie Creek (NJTA 1986). A striped skunk (*Mephitis mephitis*) was seen near Berry's Creek (NJTA 1986); striped skunk and raccoon occur on the Carlstadt-Moonachie site (M.A. Thiesing, personal communication, 1998). Feral cats and dogs were also observed along roads, at landfills, and near developed areas in the Meadowlands (NJTA 1986). Uncommon mammals include red fox (*Vulpes vulpes*) and mink (*Mustela vison*) (Quinn 1997). Recently, a river otter (*Lutra canadensis*), once a common resident of northern New Jersey, was found at an old landfill on Overpeck Creek but was believed to have escaped from a nearby zoo (Quinn 1997). A harbor seal (*Phoca vitulina*) was observed in the Hackensack River by William Schultz, a staff member of the Marine Mammal Stranding Center ca. 1 March 2001, and a harbor seal was also photographed in the late 1980s in Teaneck and reported in *The Record* (Hugh Carola, Hackensack Riverkeeper, personal communication to EK, 2002). An unidentified seal (probably a harbor seal) was photographed in Mill Creek 8 April 2002 (MERI, personal communication to EK, 2002). These are the only Hackensack River records we know of, although harbor seal occurrence has increased in the Hudson River in recent years (Kiviat and Hartwig 1994 and unpublished data).

White-tailed deer is rare in the Meadowlands where they are associated with remnant forests in northern areas (Rich Kane, personal communication to EK, 2000). The population explosion of deer in many areas of New Jersey and New York during the last three decades, however, suggests this species may become more common in the Meadowlands. Scats apparently of eastern coyote (*Canis latrans* var.) were found at Laurel Hill, and near the Cromakill, in 2002 (EK, personal observations); this species has also increased greatly in the Northeast. Other mammals that might occur in the Meadowlands but were not reported in the NJTA (1986) studies include short-tailed shrew (*Blarina brevicauda*), Keen's bat (*Myotis keenii*), small-footed bat (*Myotis leibii*), big brown bat (*Eptesicus fuscus*), long-tailed weasel (*Mustela frenata*), and gray fox (*Urocyon cinereoargenteus*) (US ACOE 2000). (Small-footed bat [eastern small-footed myotis] is ranked as G3 S1 U, or apparently very rare but poorly understood, by the New Jersey Natural Heritage Program.)

Birds

Two hundred twenty-five bird species are known to occur in the Meadowlands (Black 1970, Kane 1974, Wargo 1989). Wargo (1989) reported 52 bird species (39 wetland-dependent) at the Mill Creek marsh mitigation site in 1987 and 1988. Forty-seven species (38 wetland-dependent) were at the Sawmill Creek WMA (Wargo 1989). The TAMS bird study at the Carlstadt-Moonachie site (USACOE 2000) suggests the complexity of the Meadowlands bird fauna; even so, modifications of survey techniques and data analysis would likely have demonstrated greater species richness of birds and a larger number of rare species breeding at that site (see Kiviat 2000). A checklist of Meadowlands birds, with seasonal and abundance annotations, was compiled by NJMC (HMDC no date).

The large freshwater and brackish wetlands interspersed with upland areas provide a wide range of habitats that support large populations of resident, migrant (spring and fall), breeding (summer), and wintering birds. Waterfowl and shorebirds occur in large numbers during spring and fall migrations, and waterfowl are also abundant in winter, which makes the Hackensack Meadowlands one of the critical sites identified by Federal and State agencies and non-governmental organizations for conservation of these bird groups (Dunne et al. 1989, Kane and Githens 1997, Quinn 1997, Day et al. 1999, U.S. Fish and Wildlife Service et al. 2000). In addition, there are important breeding populations of ducks. Several species of hawks and owls use the area as a feeding and wintering ground. One of only 2 pairs of northern harriers (Endangered) confirmed breeding in the urban core of New York City nests in the Meadowlands (Day et al. 1999). Extent of available reed marshes may limit harrier breeding as this appears to be an area-sensitive species (Kiviat et al., submitted b). Many species of songbirds migrate through the Meadowlands, and both resident and Neotropical migrant songbirds breed in the marshes and remnant upland forests. Waterfowl, rallids, many shorebirds, gulls, terns, and several raptors and songbirds are dependent upon a variety of wetland habitats in the Meadowlands. The distribution, seasonality, abundance, and habitat requirements of these groups are outlined below.

Table 3 provides an outline of data from several sources on the distribution and seasonal use by bird species for which the Meadowlands provide important habitat. However, several shortcomings in presenting such data should be pointed out. First, not all areas within the Meadowlands have been sampled equally. Table 3 shows where and when species have been present but does not identify conclusively where they were absent. Gaps in the table may represent gaps in our knowledge, and more study is needed. Nonetheless, the table suggests which species are widespread and which areas are important habitat within the Meadowlands.

Waterfowl: The Meadowlands is designated an area of special concern under the North American Waterfowl Management Plan (Day et al. 1999). Waterfowl includes diving ducks, dabbling ducks, and geese. The Meadowlands are important for wintering, breeding, and migrating waterfowl. These species use both freshwater and brackish marshes. Many ducks that breed in the Arctic regions winter in the coastal and inland wetlands of the warmer, temperate latitudes. The creeks, shallow open water areas such as shallow bays and impoundments, mudflats, and salt marshes of the Meadowlands provide food resources such as submerged pondweeds and protection from harsh weather and predators during winter and breeding season. Tidal creeks dominated by common reed and other emergent vegetation are used by breeding birds, and also provide important shelter for wintering waterfowl such as green-winged teal (Rich Kane, personal communication to EK 2000).

Canada goose, American black duck, mallard, canvasback, greater scaup, gadwall, ruddy duck, green-winged teal, and northern pintail are the species most abundant in winter in the Hackensack Meadowlands (Day et al. 1999). Mid-winter aerial survey counts of waterfowl on the New York Harbor estuary average 80,000 birds (Day et al. 1999). Daily winter counts in the Meadowlands average 2,000 birds. Aerial waterfowl counts on the Hackensack River between routes 3 and 46 flown September to January, 1972-1975, by the New Jersey Division of Fish and Game found 2-4 species and 195-1530 individuals per count, with species in approximate order of decreasing abundance American black duck, mallard, northern pintail, green-winged teal, Canada goose, blue-winged teal, canvasback, scaup, northern shoveller (McCormick & Associates 1978). A major flock of ruddy ducks winters on the Hackensack River (Day et al. 1999). Hundreds of northern pintails and canvasback are present in the Sawmill Creek area during winter (Kane and Githens 1997, Day et al. 1999). Mill Creek, Cromakill Creek, and other small creeks have abundant green-winged teal during fall and winter (Day et al. 1999).

Breeding waterfowl are concentrated in common reed stands along creeks and ditches, and in open water areas (NJTA 1986, Kane and Githens 1997). Tidal open water – mudflat complexes are used for foraging by a variety of waterfowl. Species that breed in the Hackensack Meadowlands in significant numbers include Canada goose, blue-winged teal, mallard, gadwall, American black duck, and ruddy duck (NJTA 1986, Wargo 1989, Kane and Githens 1997, Day et al. 1999; Paul Castelli, NJDEP, personal communication to KM 2001). In the late 1980s and 1990s, gadwall was the most common breeding duck in the Meadowlands (Rich Kane, personal communication to EK, 2000), and breeding areas are fairly widespread in the Meadowlands. In 1990, a pond on top of a landfill held 144 gadwall ducklings (Day et al. 1999). Locations of particular importance include Kearny Marsh (East and West), the marshes around Moonachie, Mill, Cromakill, Bellman's, and Berry's creeks, Sawmill Creek WMA, Kingsland Marsh, Oritani Marsh, and Losen Slote. Regionally rare breeding populations of ruddy duck, a species that in New Jersey nests only in reed marshes (Kane 2001b), occur at Kearny Marsh and Kingsland Marsh (NJTA 1986, Day et al. 1999). Kingsland Marsh supports one of the largest breeding populations of this species in the state (NJTA 1986). Kingsland Impoundment had 2,000 waterfowl during a survey in July 1994 (Day et al. 1999). Wood duck broods have been observed in Kearny Marsh West, but as there are no large trees in the immediate vicinity, the nest sites are a mystery (Rich Kane, personal communication to EK, 2000).

The Meadowlands are visited by a number of waterfowl species during spring and fall migration. The most numerous species include gadwall, mallard, northern shoveler, green-winged teal, northern pintail, all three mergansers, greater and lesser scaups, American wigeon, common goldeneye, canvasback, American black duck, blue-winged teal, and Canada goose. Important locations include Kearny Marsh, the marshes around Mill, Bellman's, and Moonachie creeks, Losen Slote, and Power Plant Peninsula (Kane and Githens 1997, USACOE 2000).

Wading birds: Several species of wading birds nest, forage and roost in the Meadowlands (Day et al. 1999). The wading birds common in the Meadowlands include black-crowned night-heron (Threatened), American bittern (Endangered), glossy ibis, great egret, green heron, least bittern, snowy egret, great blue heron, and yellow-crowned night-heron (Threatened) (NJTA 1986, Kane and Githens 1997, Day et al. 1999, USACOE 2000). In addition to the local breeding populations, wading birds come from breeding sites in the New York Harbor estuary complex to forage. These include black-crowned night-heron (Threatened), snowy egret, glossy ibis, and great egret (Day et al.

1999). In mid to late summer, the Meadowlands are heavily used as a foraging area during post-breeding dispersal of adult and juvenile egrets, herons, ibis, and other aquatic birds (Day et al. 1999). Furthermore, the Meadowlands provide roosting habitat (nighttime resting sites) for these species at that season (Day et al. 1999). In 1995, the Harbor Herons Rookery Complex, "downstream" of the Meadowlands in the Arthur Kill and Kill van Kull, supported 1,400 nesting pairs of nesting herons, egrets, and ibises (US Fish and Wildlife Service 1997). Sawmill Creek has been identified as a main foraging area for these "Harbor Herons."

Least bitterns breed in Kearny Marsh and Kingsland Marsh (NJTA 1986, Kane and Githens 1997). Kearny Marsh had 35 adult least bitterns during breeding seasons in the 1970s and 1980s (Day et al. 1999). There is still a black-crowned night-heron (Threatened) rookery located there (Day et al. 1999), and green herons breed there (NJTA 1986, Kane and Githens 1997). In summer, egrets and herons use this area as a feeding and roosting site (Kane and Githens 1997). Both least bittern and American bittern (Endangered) were reported to breed in a deepwater cattail marsh in the Kearny area in 1905 (Abbott 1907).

Yellow-crowned night-heron (Threatened) and green heron are resident at the Carlstadt-Moonachie site (Kane and Githens 1997). Several species use the site in spring, summer and fall (USACOE 2000). Black-crowned night-heron (Threatened), American bittern (Endangered), least bittern (1 sighting), great blue heron, great egret, and snowy egret have also been seen there (USACOE 2000).

The wetland mitigation site between Mill Creek and Cromakill Creek contains open water habitat, mudflats, intertidal salt marsh, and small islands that attract wading birds (Day et al. 1999). The mudflats at Power Plant Peninsula are used by snowy egrets (Kane and Githens 1997). Other important locations for migrant wading birds are in the areas around Bellman's, Cromakill, and Berry's creeks (Kane and Githens 1997). The Berry's Creek area probably supports breeding American bittern (Endangered) (NJTA 1986, Kane and Githens 1997). The tidal flats and marshes at Kingsland Marsh and Sawmill Creek WMA are heavily used by herons (NJTA 1986).

Rallids: In spring, summer, and fall Virginia rail and sora were considered "common," clapper rail and king rail "infrequent," and common moorhen "abundant," in the area of the Sports Complex (McCormick & Associates 1978). American coot is among the most abundant birds in the Meadowlands during winter (Day et al.1999). Kearny Marsh supports nesting American coot and common moorhen (Kane and Githens 1997). Coot also breeds at Kingsland Impoundment (NJTA 1986). Common moorhen breeds in the marshes at Berry's Creek, and was also found in the Moonachie Creek area during the 1994 breeding season (NJTA 1986, Kane and Githens 1997). Moorhens breed in the common reed within tidal open water - mudflat areas at Oritani Marsh (NJTA 1986). In 1905, moorhen was a common breeding bird in a cattail marsh near Newark that may have been Kearny Marsh (Abbott 1907).

The Carlstadt-Moonachie site had Virgina rail in 1994 (Kane and Githens 1997). In addition, clapper rail and Virginia rail are there in spring, summer and fall (USACOE 2000). King rail is present in summer, suggesting it may be nesting onsite (USACOE 2000). The Mill Creek site had breeding clapper rail in 1994 (Kane and Githens 1997). One of the last reported nesting sites for clapper rail in northern New Jersey was at Kingsland Marsh (NJTA 1986).

Virginia rail was observed at Oritani Marsh during the Turnpike expansion surveys and may have been nesting (NJTA 1986). A Virginia rail was observed foraging in a creek at the Sawmill Creek WMA in April 1999 (L. Windham, Lehigh University, personal communication to EK and KM). Virginia rails bred in an area of cattail that developed in Kearny Marsh West (R. Kane, personal communication to EK, 2000). Sora was recorded in September, once each at Sawmill Creek WMA and Mill Creek (Wargo 1989). Sora was found at the Moonachie site during fall surveys (USACOE 2000). Chapman (1900) mentioned soras feeding on wild-rice in the Meadowlands during fall migration. Sora may have formerly bred in the Meadowlands, but does not do so now (Rich Kane, personal communication to EK, 2000).

Shorebirds: The Meadowlands are considered one of the most important stopovers for shorebirds migrating between South America and Arctic nesting grounds (Day et al. 1999). The Meadowlands are one of 11 critical migration corridors in New Jersey as identified by Dunne et al. (1989). Thirty-one species of shorebirds have been found in the Meadowlands during migration (Day et al. 1999); during fall migration 31 species visit the Kingsland site complex alone (Kane 1983). Tidal mudflats and impoundments are important habitats within the Meadowlands and are used as feeding sites by thousands of migrating shorebirds (Day et al. 1999). The most common fall migrants include semipalmated sandpiper, lesser yellowlegs, short-billed dowitcher, and dunlin (Day et al. 1999). At one site in the Meadowlands [Kingsland Impoundment?], maximum daily counts of sandpipers have exceeded 5,000 in most years (Day et al. 1999). Wilson's phalarope is a regularly seen migrant (Day et al. 1999). Some of the rarer fall migrants include buff-breasted sandpiper, Hudsonian godwit, and red-necked phalarope (Day et al. 1999).

Kingsland Marsh had 31 species of shorebirds on the tidal flat between July and November 1971-1980 (Kane 1983). Eight thousand semipalmated sandpipers were recorded in the impoundment 23 July 1994 (Kane and Githens 1997). Shorebirds use the mudflats exposed during drawdown of the impoundment. Other shorebirds using the impoundments include both species of yellowlegs (Kane and Githens 1997). Kane (1983) points out the importance of managing the impoundment at this site from July through November to provide the shallow water and mudflats needed for resting and feeding by shorebirds at times of high tide (see Kane 1983). The area of the impoundment nearest the Turnpike is used as a high-tide roost by migrating shorebirds in fall (NJTA 1986). Tidal mudflat habitat in this location is also important as a feeding area for shorebirds (14 species seen) and is one of the most important areas in the state for migrating shorebirds in fall (NJTA 1986).

Sawmill Creek WMA has an abundance of shorebirds at low tide (Kane and Githens 1997, Day et al. 1999). The wetland mitigation site between Mill Creek and Cromakill Creek contains open water, mudflats, intertidal saltmarsh, and small islands that attract shorebirds.

Migrants at the Carlstadt-Moonachie marshes included yellowlegs, common snipe, least and semipalmated sandpipers, and short-billed dowitcher (Kane and Githens 1997). Tidal areas there provide feeding habitat for shorebirds (NJTA 1986). Common snipe was found there in all seasons except winter (USACOE 2000). Greater yellowlegs (spring, summer, fall), and less commonly the lesser yellowlegs, semipalmated sandpiper, and solitary sandpiper were found there (USACOE 2000).

The mudflats at Power Plant Peninsula are important for migrating shorebirds, including spotted sandpiper, greater yellowlegs, and semipalmated sandpiper (hundreds in late July - early August) (Kane and Githens 1997). Migrants using the Bellman's Creek area included greater and lesser yellowlegs and semipalmated plover (Kane and Githens 1997). During fall migration in 1995, greater yellowlegs and semipalmated sandpiper were seen at the Mill Creek site (Kane and Githens 1997). Among the migrating shorebirds seen in 1995 were least and semipalmated sandpipers, short-billed dowitcher, and greater yellowlegs (Kane and Githens 1997). In the Oritani Marsh area, shorebirds use some areas near the Turnpike as a high-tide roost (NJTA 1986). A variety of shorebirds visit the tidal marsh, including greater and lesser yellowlegs, least and semipalmated sandpipers, common snipe, and killdeer (NJTA 1986). A Wilson's phalarope (rare in New Jersey) was seen there in August 1985 (NJTA 1986).

Spotted sandpipers breed at widespread locations within the Hackensack Meadowlands. Breeding sites for this species include Kearny Marsh, the headwaters of Losen Slote, and the marshes surrounding Bellman's, Berry's, Mill, Cromakill, and Moonachie creeks (NJTA 1986, Kane and Githens 1997, USACOE 2000)). Killdeer have been documented breeding at Kingsland Marsh and the marshes around Moonachie and Bellman's creeks (Kane and Githens 1997, USACOE 2000). Two biologically anomalous sandpipers, American woodcock and common snipe, occur in the Meadowlands. Woodcock is declining in the eastern U.S. Woodcock breeds in quaking aspen patches on landfill cover (Rich Kane, personal communication to EK, 2000). Common snipe was found at the Moonachie Creek site in all seasons except winter, and therefore may have bred there (USACOE 2000).

Gulls and terns: Least tern0000 (Endangered) has nested on dredged material deposits and may be roosting on roofs of commercial buildings in the Meadowlands (Day et al. 1999). North of the Vince Lombardi Service Area, a large sandy area provided nesting habitat for the least tern (NJTA 1986), but this site is believed to be no longer in use (Rich Kane, personal communication to EK, 2001).

Kearny Marsh is a feeding site for gulls, least tern (Endangered), and black skimmer (Endangered) (Day et al. 1999, NJTA 1986). Least and Forster's terns use the marsh as a feeding site in summer (Kane and Githens 1997). Species using the Kingsland Impoundment include least and Forster's terns, great black-backed and herring gulls by the thousands, and the lesser black-backed, glaucous, and Iceland gulls (Kane and Githens 1997). Least terns (Endangered) that breed in the Meadowlands congregate there with their fledged young (NJTA 1986). Black skimmers (Endangered) have been seen feeding there (NJTA 1986). Sawmill Creek WMA has hundreds of herring, great black-backed, and ring-billed gulls during migration (Kane and Githens 1997). Non-breeding visitors at the Carlstadt-Moonachie site during summer also included least tern (Endangered), and migrants included Forster's tern and least tern (Kane and Githens 1997). Tidal areas provide feeding habitat for least tern (NJTA 1986), as well as great black-backed gull, laughing gull, and ring-billed gull (USACOE 2000). The mudflats at Power Plant Peninsula are important for migrating species including least tern (Endangered), Forster's tern, and ring-billed gull (Kane and Githens 1997). During migration in 1995, the Mill Creek area had Forster's and least terns (Endangered) (Kane and Githens 1997). The Cromakill Creek site had breeding ring-billed gull and least tern (Endangered) (Kane and Githens 1997).

Other water birds: Kearny Marsh is a nesting and wintering area for pied-billed grebe (Endangered) (Kane and Githens 1997) as well as a feeding site for double-crested cormorant (Kane and Githens 1997, Day et al. 1999). Horned and red-necked grebes use the area during migration (Kane and Githens 1997). Pied-billed grebe was recorded breeding in the Kearny area in 1905 (Abbott 1907). Kingsland Impoundment has breeding pied-billed grebe (Endangered) (NJTA 1986) and the mudflats created during drawdown are heavily used by double-crested cormorants and pied-billed grebes (Kane and Githens 1997). Double-crested cormorants were present in the Moonachie Creek area during spring and summer (USACOE 2000). Cormorants use the mudflats at Power Plant Peninsula, as well as the Berry's Creek area during migration (Kane and Githens 1997).

Birds of prey: Raptors use a variety of wetland and upland habitats in the Meadowlands for breeding, hunting, and roosting (Day et al. 1999). Species of hawks and owls commonly seen include northern harrier (Endangered), rough-legged hawk, red-tailed hawk, Cooper's hawk (Threatened), American kestrel, short-eared owl, and long-eared owl (Threatened) (Day et al. 1999). The Meadowlands are an important wintering area for several raptor species (Bosakowski 1983). Habitat characteristics favoring raptors in the Meadowlands include the large extent of the marshes, little direct human disturbance, and an abundance of prey (fish, small birds, small rodents, depending upon the raptor species).

One of only 2 pairs of northern harriers (Endangered) confirmed nesting in the urban core of New York City nests at the Berry's Creek Marsh in the Meadowlands (NJTA 1986, Kane and Githens 1997, Day et al. 1999). This represents a remnant population of the 1-3 pairs of harriers (Day et al. 1999) and possibly 4 pairs (Kane 1974) that once nested there. Common reed stands in the area are important as feeding and nesting habitat for harriers (NJTA 1986). Harrier was considered "common" in spring, fall, and winter, and "infrequent" in summer near the proposed Meadowlands Arena site (McCormick & Associates 1978). In addition to the marshes within the Berry's Creek breeding territory, harriers forage in many locations throughout the Meadowlands, including Kearny Marsh, Oritani Marsh, Moonachie Creek marshes, and around Bellman's and Cromakill creeks (NJTA 1986, Kane and Githens 1997). Wargo (1989) reported northern harriers at both Sawmill Creek WMA and at Mill Creek. The Carlstadt-Moonachie site (Empire Tract) had a pair of northern harriers (Endangered) acting territorial in April and May 1995, always in the same spot, suggesting a potential breeding location (Kane and Githens 1997). Northern harriers are commonly observed there hunting over the common reed (NJTA 1986, USACOE 2000). Furthermore, there is still a winter roost for harriers at Berry's Creek (Kane and Githens 1997).

The common reed marshes and landfills of the Meadowlands provide important habitat for populations of wintering raptors, especially northern harriers, rough-legged hawks, red-tailed hawks, American kestrel, short-eared owls and long-eared owls (Threatened) (Bosakowski 1983, 1986). Berry's Creek, Kearny Marsh, Sawmill Creek WMA, and Moonachie Creek are among the areas important as feeding and roosting sites for many raptor species (NJTA 1986, Day et al. 1999). American kestrel visits the landfills (NJTA 1986); McCormick & Associates (1978) considered kestrel "uncommon" all year at the Sports Complex site. A variety of raptors has been seen at the Carlstadt-Moonachie site including short-eared owl, which probably uses this large area of habitat in winter. American kestrel, northern harrier, and red-tailed hawk are commonly seen there (USACOE 2000). Rough-legged hawk is present in winter and spring (USACOE 2000). Several species considered transient have also been observed, including merlin, Cooper's hawk (Threatened), sharp-shinned hawk, and red-shouldered hawk (Threatened) (USACOE 2000). Wintering raptors use the Berry's Creek site intensively, including rough-legged and red-tailed hawks, northern harrier, long-eared and short-eared owls, peregrine falcon (Endangered), American kestrel, northern goshawk (Endangered) and Cooper's hawk (Threatened) (Kane and Githens 1997). Wargo (1989) reported northern harrier, sharp-shinned hawk, and American kestrel at Sawmill Creek, and at the Mill Creek mitigation site, harrier, kestrel, and once an osprey (Threatened).

Observations of hawk activity during winter demonstrated that northern harriers hunt predominantly in common reed wetlands whereas rough-legged hawks hunt around landfills (Bosakowski 1983). A large communal roost of northern harriers was located in a common reed marsh in consecutive years (Bosakowski 1983). The areas most notable for wintering long-eared and short-eared owls are Berry's Creek and Moonachie Creek (NJTA 1986, Kane and Githens 1997, Day et al. 1999). McCormick & Associates (1978) referred to short-eared owl as "uncommon" in spring, summer, and fall, implying possible breeding in the vicinity of the Sports Complex.

In addition to marshes, the areas around landfills are used for hunting by wintering short-eared owls (Bosakowski 1983, NJTA 1986). Studies of long-eared and short-eared owl pellets collected from roost sites near Berry's Creek in the Meadowlands were conducted by Anderson (1977) and Bosakowski (1982). Anderson identified meadow vole (*Microtus pennsylvanicus)* as the primary food source for long-eared owl (Threatened) followed by Norway rats, house mice, and small birds. However, Bosakowski found that house mouse was the major prey for long-eared owl. Bosakowski explains this unusual phenomenon as being possibly due to snow cover making it difficult to capture meadow voles. Bosakowski identified house mice, birds, and Norway rats as the main prey items in short-eared owl pellets. Roost sites preferred by short-eared owls are in large conifer trees adjacent to the open expanses of marsh and field where they forage (Bosakowski et al. 1989). Short-eared owls roost in planted conifers or on the ground in common reed stands (Bosakowski 1986). Long-eared and short-eared owls have overall experienced a severe decline as breeding birds in the state (Bosakowski et al. 1989).

Osprey (Threatened) has been observed at Kearny Marsh, which represents a potential breeding habitat for this species (NJTA 1986). Osprey has also been observed feeding at Kingsland Marsh and at the Moonachie Creek marshes in summer (NJTA 1986, USACOE 2000). A golden eagle was seen in the Meadowlands in January 2001 (S. Sautner, personal communication to KM). There are recent bald eagle (Endangered) sightings as well: April 2000, an immature at Little Ferry, and January 2001, an adult at New Milford (H. Carola, personal communication to EK, 2002). Bald eagles are now present year-round on the Hudson River estuary, are seen frequently, and a few pairs are nesting, thus more frequent occurrence in the Meadowlands should be expected.

Until recently, the peregrine falcon was federally listed as endangered and is still listed as endangered by New Jersey (Table 4). Bridges in and near the Meadowlands may be used as nesting sites (Day et al. 1999). Peregrine falcon pairs occur at the PSE&G building in Kearny, and at the Driscoll, Goethals, and Verrazano bridges (Kane and Githens 1997) not far outside the Meadowlands. The Driscoll Bridge, however, was not occupied by nesting peregrines in 1999 or 2000 (S. Wander, personal communication to EK, 2002). Peregrines are seen often enough in the Meadowlands, and sufficient suitable foraging habitat and prey populations are available, to indicate that some Meadowlands marshes and landfills are probably feeding sites for migrant peregrines, nonbreeding immatures, or peregrines breeding near the Meadowlands (Wander and Wander 1995). The majority of reported peregrine sightings in the Meadowlands in recent years has occurred in the Lyndhurst – North Arlington area (Wander and Wander 1995). Sawmill Creek Wildlife Management Area, among other sites, could be an important foraging area (S. Wander, personal communication to EK, 2002).

Galliform birds: Ring-necked pheasant has been observed at Berry's Creek, Moonachie Creek, and Kearny Marsh (NJTA 1986, Kane and Githens 1997, USACOE 2000). This species is widespread and fairly common in the Meadowlands; pheasants spend a lot of time in common reed stands, but are believed to nest in other habitats, e.g. upland meadows (Richard Kane, personal communication to EK 2000; EK, personal observations).

Other birds: The Meadowlands provide habitat for a variety of songbirds and other small birds during the breeding, spring and fall migration, and winter seasons (NJTA 1986, Kane and Githens 1997, Day et al. 1999). The diversity of small birds is enhanced by the presence of a diversity of habitats and vegetation types in the Meadowlands. Marsh-upland edges and rights-of-way with mixed vegetation including vines, sumacs, and other abundant upland shrubs provide late fall, winter, and early spring food. Shrub thickets and reed stands offer dense escape cover and shelter from the weather. There may be reduced pressure from terrestrial predators such as snakes, certain rodents, and certain carnivores because some species are rare or absent from the Meadowlands and others may have difficulty reaching some of the bird habitats due to highways and canals.

The species most commonly found nesting in the freshwater wetlands and salt marshes, including common reed marshes, are red-winged blackbird, marsh wren, common yellowthroat, willow flycatcher, and swamp sparrow (NJTA 1986, Kane and Githens 1997, USACOE 2000). Quinn (1997) suggested that the sedge wren (Endangered) may be returning as a breeding species in the Sawmill Creek WMA and in Kearny Marsh. Sedge wren was also reported at the Moonachie Creek area during the breeding season (USACOE 2000). However, these areas may not provide suitable habitat for the sedge wren (R. Kane, personal communication to EK and KM). Meadows of bluejoint grass (*Calamagrostis canadensis)* interspersed with reed on a portion of the Carlstadt-Moonachie marshes most closely approach the requisite short grass or sedge habitat for this species (EK, personal observations, 2001-2002). Red-winged blackbird is the songbird most commonly nesting in common reed (NJTA 1986). Areas of shrubs and trees found along ditches and canals, on landfills and other uplands, combined with upland meadows, support several breeding species, including northern flicker, downy woodpecker, eastern kingbird, tree swallow, fish crow, American robin, brown thrasher, gray catbird, northern mockingbird, yellow warbler, common grackle, northern oriole, indigo bunting, blue grosbeak (rare), American goldfinch, song sparrow, savannah sparrow, (NJTA 1986, Wargo 1989, Kane and Githens 1997). Savannah sparrow (Threatened) was found at the Moonachie site during spring, summer and fall surveys (USACOE 2000).

During fall migration, large numbers of songbirds and other small birds are found in the trees and shrubs on the uplands. In addition to the species found breeding there, some of the small birds present in fall include yellow-bellied sapsucker, eastern phoebe, purple martin, bank swallow, hermit thrush, winter wren, American pipit, ruby-crowned kinglet, and golden-crowned kinglet, warbling vireo, palm warbler, blackpoll warbler, yellow-rumped warbler, Lincoln's sparrow, and bobolink (Threatened) (Kane and Githens 1997). Historically, large nonbreeding roosts of European starling (Kalmbach and Gabrielson 1921) and swallows (tree, bank, barn, cliff, and northern rough-winged) (Chapman 1900) were reported from the Meadowlands. Roosting congregations of starling, blackbirds, and swallows probably still occur in reed stands or groves of trees.

The remnant lowland forests at Teterboro Airport, the headwaters of Losen Slote Creek, and Schmidt's Woods in Secaucus are important as stopover habitat for many songbirds, including Neotropical migrants, as well as nesting habitat for several resident and Neotropical forest songbirds. For example, the headwaters of Losen Slote Creek in Little Ferry contain forest habitat that is used by breeding species, including downy woodpecker, barn swallow, American crow, blue jay, and tufted titmouse (Kane and Githens 1997). In addition, hairy woodpecker, red-bellied woodpecker, black-capped chickadee, American robin, wood thrush, gray catbird, common grackle, and northern cardinal were present in the forests at Teterboro Airport during the breeding season in 2001 (KM, personal observation) and are probably nesting in the other forest remnants. During migration in 1995, 5 species of flycatcher, ruby-crowned kinglet, blue-gray gnatcatcher, 5 thrushes, cedar waxwing, 3 species of vireo, 18 warblers, orchard and northern orioles, rose-breasted grosbeak, bobolink (Threatened), 4 sparrow species, and American goldfinch were observed at the headwaters of Losen Slote Creek (Kane and Githens 1997).

The Meadowlands have historically provided habitat for several rare or declining species. The tidal marsh at Kingsland is one of the last reported nesting sites for sharp-tailed and seaside sparrows in northern New Jersey (NJTA 1986). Sharp-tailed sparrow was found at Mill Creek and Sawmill Creek during September and October (Wargo 1989). North of the Vince Lombardi Service Area, a large sandy area formerly provided nesting habitat for horned lark (NJTA 1986) but is believed no longer in use (R. Kane, personal communication to EK, 2001).

Notable species that winter in the Meadowlands include horned lark and American pipit (NJTA 1986). Belted kingfisher has been found at a number of sites in the Meadowlands but its nesting habitat has not been reported. Common nighthawk was "uncommon" in spring, summer, and fall in the Sports Complex area (McCormick & Associates 1978); it is not stated whether these were breeding birds or late and early migrants.

Reptiles and Amphibians

Diamondback terrapin (*Malaclemys terrapin*), mud turtle (*Kinosternon subrubrum*), snapping turtle (*Chelydra serpentina*), and painted turtle (*Chrysemys picta*) are the four turtle species found in the Meadowlands (Quinn 1997). The diamondback terrapin, unique among North American turtles in its adaptations to brackish water, has increased greatly in the Meadowlands during the past three decades (HMDC 1999). Terrapins are confined to the lower and middle reaches of the Hackensack River where salinities averaged 9.4 ppt and 5.6 ppt, respectively (Kraus and Bragin 1988). Significant numbers of this species have been seen at the Sawmill Creek WMA and

Kingsland Marsh (Kane and Githens 1997, Day et al. 1999), and the Sawmill Creek wetlands are believed to support a population of several hundred or more (HMDC 1999). Diamondback terrapins feed in estuarine shallows and wetland habitats and nest in nearby sandy habitats and along road and railbeds with sparse to moderate vegetation cover (Day et al. 1999). Barrier fences have been erected at four locations to guide terrapins beneath the New Jersey Turnpike via existing waterways rather than attempting to cross the pavement (Urffer 2002).

Snapping turtle tolerates brackish environments (Quinn 1997). In the upper reaches of the river, where salinities average 3.4 ppt, snapping turtle replaces diamondback terrapin (Kraus and Bragin 1988). Snapping turtle has been observed throughout the Meadowlands, most notably at Kearny Marsh, Sawmill Creek WMA, Oritani Marsh and near Berry's Creek (NJTA 1986). Painted turtle also tolerates brackish environments and has been seen at Kearny Marsh, Sawmill Creek WMA, and around Berry's Creek (NJTA 1986). According to Quinn (1997), mud turtle has been reported at Berry's Creek, Bellman's Creek, and Kearny Marsh. Because mud turtle is listed as endangered in New York State and is probably rare in northern New Jersey, specific documentation of its occurrence in the Meadowlands would be valuable.

Several snake species are reportedly fairly common in the Meadowlands. These include garter snake (*Thamnophis sirtalis*), northern water snake (*Nerodia sipedon*), eastern milk snake (*Lampropeltis triangulum*), and brown snake (*Storeria dekayi*) (NJTA 1986). Garter snake is fairly widespread in the Meadowlands (NJTA 1986). Water snake may be found in heavily vegetated freshwater or mildly brackish areas, such as the Kingsland Impoundment, Overpeck Creek, Losen Slote Creek (Quinn 1997), and Sawmill Creek WMA (NJTA 1986). Milk snake and brown snake occur on uplands adjacent to wetlands and on landfills (NJTA 1986).

Few amphibians occur in the Hackensack Meadowlands because of the predominance of brackish water. The green frog (*Rana clamitans*) is found at Kearny Marsh, Losen Slote Creek, and in other nontidal wetlands (Quinn 1997). The southern leopard frog (*Rana utricularia*) is found in fresh and mildly brackish creeks and impoundments, including the Kearny Marsh, Overpeck Creek, and Sawmill Creek areas (Quinn 1997) (reported as "*Rana pipiens*" which does not occur south of the Mid-Hudson Valley and southern New England [see Klemens et al. 1987]). Pickerel frog (*Rana palustris*) has been seen at Kearny Marsh (Quinn 1997).

Several other reptiles and amphibians are reported to occur in the Meadowlands (compiled in USACOE 2000; also see McCormick & Associates 1978), but documentation is lacking. Some species may have been reported based solely on field guide range maps, misidentifications, or occurrences near but outside the Meadowlands. These species are: stinkpot, spotted turtle, five-lined skink, eastern ribbon snake, eastern hognose snake, northern black racer, smooth green snake, American toad, Fowler's toad, northern cricket frog, spring peeper, "gray treefrog," (whether *Hyla versicolor* or *H. chrysoscelis* not specified; the latter is endangered in New Jersey), New Jersey chorus frog, and bullfrog. Fowler's toad (*Bufo fowleri*) was present in the Meadowlands in the late 1960s, but has apparently disappeared due to habitat loss (R. Kane, personal communication to EK and KM, 2001). The lack of documentation of American toad and bullfrog from the Meadowlands is puzzling. The apparent absence of salamanders presumably reflects brackish water influence, scarcity of undisturbed upland soils, loss of forested habitats, and fragmentation of the landscape by roads and other intensive land uses.

Fishes

A February 1987 to December 1988 study of fish in the Hackensack River and its major tributaries found 34 species (Kraus and Bragin 1988). The lower Hackensack River system was declared essential fish habitat by the National Marine Fisheries Service for six species: red hake, black sea bass, Atlantic butterfish, and three flounders (Day et al. 1999). Designation is pending for bluefish and Atlantic herring (Day et al. 1999). The most common prey items for piscivorous birds and fishes are the abundant mummichogs, striped killifish, and grass shrimp (Day et al. 1999). Atlantic tomcod, formerly listed as a threatened species in New Jersey, uses the Hackensack River from near its mouth to Sawmill Creek as a nursery, refuge, and spawning area (Kraus and Bragin 1990). The greatest numbers of adult Atlantic tomcod were captured by Kraus and Bragin (1990) in late summer and autumn.

During summer, low dissolved oxygen levels and increased suspended sediment make the waters tolerable by only a few hardy resident species (Day et al. 1999). Dominant fish species are those resident, estuarine fishes tolerant of fluctuations in salinity and water quality (Day et al. 1999), including mummichog, striped killifish, inland silverside, Atlantic silverside, white perch, brown bullhead, white catfish, European carp, common sunfish (pumpkinseed), bay anchovy, and American eel (Day et al. 1999). Ninety percent of the fish caught in summer are mummichogs (Day et al. 1999).

The most abundant fishes in the 1988 survey were the mummichog (85% of numbers), inland silverside (9.2%), white perch (2%), and brown bullhead (1.4%) (Kraus and Bragin 1988). Other fish species comprised 2.4% of the total catch for that year, the most abundant of which included striped killifish, blueback herring, Atlantic silverside, striped bass, and common sunfish (Kraus and Bragin 1988). The fish community varied seasonally, regardless of water quality. Peaks in numbers of fish caught occurred in May and October when water quality is declining and improving, respectively. The peaks correspond to spring and fall migration as well as periods when fish are using the estuary as a refuge from predators and as a spawning and nursery area (Kraus and Bragin 1988). Some of the fish species found in spring included migrants such as alewife, Atlantic tomcod, blueback herring, and striped bass as well as those seeking foraging and shelter habitat such as Atlantic menhaden and bluefish (Kraus and Bragin 1988). Atlantic menhaden and bluefish are the most common marine fishes (Day et al. 1999). Alewife and tomcod were present most of the year except July and August (Kraus and Bragin 1988). American shad is also present during spring (Day et al. 1999). Fall peaks occurred in northern weakfish and winter flounder. Resident species, present throughout the year, included mummichog, white perch, inland silverside, brown bullhead, common sunfish, European carp, and American eel. Among the less common freshwater species found in the current (2001-2002) survey are largemouth bass and goldfish; green sunfish was reported in the 1987-1988 survey (B. Bragin, personal communication to EK, 2002). Because other centrarchids or hybrids are sometimes misidentified as green sunfish (R.E. Schmidt, Hudsonia, personal communication to EK, 2002), voucher specimens of this species in the collection of MERI should be verified by a systematic ichthyologist.

In the high salinity, lower reaches of the river, 22 species were taken (7 marine, 6 diadromous, 5 estuarine, and 4 freshwater) in the first NJMC survey. In the middle reaches of the river, 21 species were taken (6 marine, 7 diadromous, 4 estuarine, and 4 freshwater). At the uppermost reaches of the river sampled, where salinity was lowest, 14 species of fish were taken (3 diadromous, 4 estuarine, 7 freshwater) (Kraus and Bragin 1988). In fall 2000, 30 striped bass were tagged in one afternoon in the river at Secaucus; in 2001 there was an even better striped bass run with many anglers catching striped bass at Laurel Hill Park, under the Turnpike bridge between Secaucus and Kearny, and at the PSEG power plant on the Hackensack River in Jersey City (H. Carola, personal communication to EK, 2002). USACOE (2000) reports a recent survey limited to 3 days of gillnetting within the creeks of the Carlstadt-Moonachie site; mummichog, European carp, brown bullhead, and common sunfish were the only species caught.

A study of larval, juvenile and adult mummichogs compared habitat use of reed and saltmarsh cordgrass-dominated marshes at Mill Creek (Raichel 2001). Larval mummichogs were significantly more abundant in cordgrass marshes than in reed marshes. However, adult mummichogs were similarly abundant in both marsh types. Differences in microtopography and prey sizes were identified as probable explanations for the observed pattern.

A list of species known or expected to occur in the Hackensack Meadowlands (NJTA 1986) is in Table 2. There is potential for all these species to occur in the Hackensack Meadowlands, but it undoubtedly is not a complete list of the Meadowlands fish fauna. We found no specific identification of spawning and nursery habitats in the literature on the Meadowlands. Also, information on fishes of the tidal creeks, ditches, and tributary streams is sparse despite the areal importance and probable trophic significance of these small waterways. The marsh waterways could support species such as eastern mudminnow (*Umbra pygmaea*) and mud sunfish (*Acantharcus pomotis*) that do not occur in the Hackensack River mainstem (R. E. Schmidt, personal communication to EK, 2002). Low dissolved oxygen minima (see Water Quality, above) presumably limit fish diversity and fish use of small waterways, and even the larger waterways, in hot summer weather. Mugue and Weis (1995) studied genetics of two subspecies of the mummichog and hybridization with banded killifish; they sampled at several Meadowlands stations as well as stations on the Hudson River estuary and the Jersey Shore. Mosquitofish (*Gambusia affinis*) and "sunfish" are introduced at unspecified locations, presumably including the Meadowlands, by the Hudson County Office of Mosquito Control (Rutgers University 2002).

MERI is conducting a two-year re-survey of fish and benthos, using the sampling stations of the 1987-88 survey in the Hackensack River mainstem and major “boatable” tributaries (Brett Bragin, personal communication to EK, 2002). Sampling was conducted monthly for the first year, and will continue quarterly during the second year.

Aquatic Macroinvertebrates

A study of aquatic fauna conducted by Bragin et al. (1988) found 53 species of invertebrates in the Hackensack River and its major tributaries. Polychaetes comprised 36% of the sample, 15% were mollusks, and 11% were amphipods. The remaining 38% of the species were spread among 13 classes of organisms. NJTA (1986) reports approximately 42 invertebrate species within the Hackensack River and its tributaries during a study from May to September 1985. Oligochaetes, polychaetes (clam worms, ampharetid worms, and mud worms), crustaceans (amphipods, shore shrimp, sand shrimp, and barnacles), insects (midges), bivalves, and gastropods (swamp hydrobia snail) were among the most abundant species. During this study and others within the Raritan to Hudson estuaries, it was noted that the greatest diversity and abundance of aquatic invertebrates occur at shallow depths (< 6 meters [< 20 feet]), because there is periodic oxygen depletion at greater depths (NJTA 1986). In general, samples included species very tolerant of pollution and low oxygen levels (e.g., certain oligochaetes and polychaetes) and those able to tolerate moderate pollution and low oxygen (e.g., certain crustaceans) (NJTA 1986). More tolerant species were dominant in subtidal (channel) areas (NJTA 1986).

Benthic macroinvertebrates were sampled at 16 stations in the tidal and nontidal marshes of the “Empire Tract” (Carlstadt-Moonachie marshes) on 8 November 2000, yielding 24 higher taxa (Grossmueller 2001). Marine oligochaetes and marine polychaetes were abundant at 2 stations. Chironomids were well represented at certain stations, and enchytraeids moderately represented at a few stations. Surveys of creeks in Carlstadt-Moonachie marshes found midge larvae (Chironominae), biting midge or no-see-um larvae (Ceratopogonidae), and dragonfly larvae (Libellulidae) (Hartman and Smith 1999).

Each spring and summer, there are large swarms of the midge, *Chironomus decorus,* in the Meadowlands (Utberg and Sutherland 1982). A study in a brackish marsh in Bergen County in 1979 demonstrated that midge populations increased with rising temperatures in spring and peaked in July (Utberg and Sutherland 1982). Quinn (2001a) discusses *Chironomus plumosus* as emerging in large swarms in the Meadowlands and serving as important food for tree swallows and other birds. Kraus (1989) noted that *Chironomus decorus* is the main food of tree swallows.

There is no information indicating that chironomid midges are an economic or health problem in the Meadowlands, although they are probably considered a nuisance at times.

The Meadowlands have historically been considered a major mosquito-producing landscape. Not only saltmarsh mosquitoes (especially *Aedes sollicitans*) but also peridomestic species can be abundant. In Headlee's (1945: Table 1) summary of the results of trapping adult female mosquitoes around the state 1932-1941, a trap operated at Secaucus yielded 2.5 times as many house mosquitoes (*Culex pipiens*) as the next most productive locality in the state. This mosquito, which breeds in organically-polluted surface waters as well as artificial containers, might have been a byproduct of the Secaucus pig farms. Headlee (1945:Table 1) reported 23 mosquito species overall from Meadowlands localities. Twenty-four species of mosquitoes occur in Hudson County (not necessarily in the Meadowlands) where the most important mosquito breeding habitats are, in decreasing order of importance, freshwater swamp, polluted water, salt marsh, fresh floodwater, woodland pool, artificial container or treehole, and snow pool (Rutgers University 2002).

As part of a study of mummichog use of common reed versus saltmarsh cordgrass marshes, Raichel (2001) sampled benthic invertebrates in mitigated and non-mitigated areas along Mill Creek. She found that copepods, ostracods, nematodes and oligochaetes were much more abundant in cordgrass than reed marshes. Gammarids and gastropods were more prevalent in reed-dominated marshes. Among the insects, chironomids were more dominant in reed marshes whereas Collembola were more dominant in cordgrass marshes. Yuhas (2001) studied benthic invertebrates in "natural" reed and saltmarsh cordgrass marshes along Sawmill Creek and at two mitigated wetlands at Mill Creek, one recently initiated and one initiated 12 years earlier (i.e., the Hartz Mountain site). Common taxa (> 1.0% of the total abundance) at the 12-year-old Mill Creek restoration site were nematodes, oligochaetes, copepods, and the sabellid polychaete *Manayunkia aestuarina.* Uncommon taxa (< 1.0% of the total abundance) at the 12-year restoration site were ostracods and gastropods. Common taxa at the recently initiated restoration site at Mill Creek were nematodes, oligochaetes, ostracods, and gastropods. Uncommon taxa at this site were copepods, chironomids, and the ampharetid polychaete *Hobsonia florida*. Common taxa at the Sawmill Creek sites combined were oligochaetes, nematodes, the sabellid polychaete *Manayunkia aestuarina*, copepods, the spionid polychaete *Streblospio benedicti*, other unknown spionid polychaetes, *Hobsonia florida*, nereid polychaetes, ceratopogonids, and the anthurid isopod *Cyanthura polita.* Uncommon taxa at Sawmill Creek included unidentified insect larvae, Turbellaria, Foraminifera, chironomics, ceratopogonids, the anthurid isopods *Edotea triloba* and *Cyathura polita*, mites, the collembolan *Anurida* sp., and the marine bivalve *Macoma balthica*. Both Raichel (2001) and Yuhas (2001) found that taxomonic diversity of the benthic community in "natural" marshes dominated by common reed was higher than both natural and mitigated cordgrass marshes. Mitigated marshes had a greater abundance of benthic invertebrates than "natural" marshes (Yuhas 2001). This could be a short term response to disturbance associated with wetland manipulation. An interesting finding by Yuhas (2001) was that the benthic community of the 12-year-old mitigated marsh at Mill Creek did not resemble the benthic community of the "natural" marshes at Sawmill Creek. This could be related to salinity differences (MERI, personal communication to EK 2002).

Mud crabs, blue crabs, and fiddler crabs) are widespread in the Hackensack River and its tributaries south of and including Overpeck Creek (NJTA 1986). A density of 1 mud crab (*Neopanope texana*) per square meter was found in Sawmill Creek WMA (Quinn 1997). Fiddler crabs are found along creeks and the rivers where the muddy banks are exposed during low tide (Quinn 1997). Fiddler crabs, considered scarce in the 1970s, have apparently rebounded from the effects of oil pollution and insecticide contamination (Quinn 1997). In one study, blue crab was confined to the lower and middle reaches of the river, where salinity averaged 9.4 ppt and 5.6 ppt, respectively (Kraus and Bragin 1988). This species is active at both the bottom and within the water column (NJTA 1986). It continues to thrive in some of the most highly stressed environments (NJTA 1986). Blue crabs are locally harvested for food despite advisories against consumption (Quinn 1997).

Zooplankton was sampled at low and high tides during fall and spring along the Hackensack River. One hundred twelve species of protozoa were identified (Jones and Isquith 1981).

On 3 September 2001, EK found a clam-shrimp that was abundant in apparently permanent rain puddles on the surface of the Paterson Lateral gas pipeline road (Carlstadt-Moonachie marshes, proposed Meadowlands Mills development site). Specimens were identified by Robert E. Schmidt (Hudsonia) as *Caenestheriella gynecia* (Branchiopoda: Cyzicidae). This species, one of only two clam-shrimps known east of the Mississippi River, has been found in Massachusetts and Pennsylvania (Smith and Gola 2001). We are unaware of any previous record of *C. gynecia* in New Jersey. Clam-shrimp are rarely found and are probably rare in the northeastern states, and *C. gynecia* merits study and conservation. We do not know if this clam-shrimp occurs only on the road, or also on the marshes at Carlstadt-Moonachie, nor do we know if it occurs elsewhere in the Meadowlands.

Terrestrial Invertebrates

"Terrestrial" invertebrates (or insects) refer to those taxa that lack an aquatic immature stage. Hartman and Smith (1999) report preliminary findings for surveys of aquatic and terrestral insects at the marsh mitigation sites located at Skeetkill Creek, Harrier Meadows, and Riverbend. Their samples included 16 families of Coleoptera (beetles), 22 families of Diptera (true flies), 4 families of Hemiptera (true bugs), 4 families of Homoptera (aphids, scale insects, leafhoppers, etc.), 6 families of Hymenoptera (ants, bees, wasps), one species of Lepidoptera (moths and butterflies; the broad-winged skipper, *Poanes viator zizaniae*), 8 species of Odonata (dragonflies and damselflies), one family of Orthoptera (grasshoppers, etc.), Psocoptera (psocids or "booklice"), and Trichoptera (caddisflies).

At 16 stations in the tidal and nontidal Carlstadt-Moonachie marshes on 5 October 2000, Grossmueller (2001) sampled macroinvertebrates in the aboveground vegetation by sweep-netting, and in leaf litter by Berlese funnel separation. Sixty orders or families were identified in the sweep net samples, including 5 spider families, 1 taxon of Opiliones (harvestman), 1 mite family, 1 isopod, and a mollusk (slug). Also represented were diverse taxa of insects, especially Aphididae (aphids), Miridae (plant bugs), Cicadellidae (leafhoppers), Culicidae (mosquitoes), Chironomidae (midges), and Platygasteridae (a family of parasitic wasps). Invertebrate richness and density in the sweep net samples were stated to be negatively correlated with reed density and relative abundance; it was not stated whether this pattern was statistically significant. Thirty-seven taxa of invertebrates were identified in the litter samples, including Nematoda, Oligochaeta, Enchytraeidae, Lumbriculidae, Gastropoda (slug), spiders, 7 genera or species of Acarina (mites), Isopoda, Diplopoda (millipedes), Chilopoda (centipedes), and the rest were insects. Mites and Collembola (springtails) were the most abundant taxa. Details of sampling techniques were not presented in this report, and the graphs are difficult to interpret because of illogical scales.

Grossmueller (2001) reported "deer tick" ("Ixodidae," no genus or species identified), 7 individuals in litter samples from 2 stations. EK has encountered no deer ticks (*Ixodes scapularis*) in the Meadowlands, and the very restricted distribution of white-tailed deer (R. Kane, personal communication to EK) suggests deer ticks would be no more than very locally distributed. EK did find ticks (provisionally identified as *Dermacentor variabilis*) on Little Snake Hill in 2001. If voucher specimens of ticks from Grossmueller's (2001) study exist, they should be submitted to a specialist for identification.

Localities in or near the Meadowlands (e.g. Newark, Secaucus, Snake Hill) are listed for a number of butterflies by Gochfeld and Burger (1997). Many old records are cited for "Newark"; however, early naturalists were sometimes imprecise about localities, and it is unclear how wide a radius around Newark might have been included. Some of the more interesting species that occurred, or may have occurred, in the Meadowlands are Edwards' hairstreak, Harris' checkerspot, silvery checkerspot, and bronze copper. There is a record from the early 1900s (Gochfeld and Burger 1997:46) of bronze copper in the marshes at Kearny. The larval food plant of bronze copper is curly dock (*Rumex crispus*) which was documented in the Meadowlands as recently as 1991 (Table 1), thus bronze copper might still occur.

Quinn (2000) describes several areas in the Hackensack Meadowlands, including abandoned landfills and Richard W. DeKorte Park in Lyndhurst, as butterfly "hotspots." The most common butterfly is the introduced cabbage white. Other species include tiger swallowtail, spicebush swallowtail, red admiral, great spangled fritillary, meadow fritillary, eastern tailed blue, common sulphur, mourning cloak, and two unidentified species of skippers (Quinn 2000). (Quinn also mentions "eastern checkerspot," which we are unable to assign to any species listed for New Jersey by Gochfeld and Burger [1997].) Several species of butterflies are mentioned in Kane and Githens (1997).

There is a population of least skipper along Berry's Creek Canal (EK, personal observation 2001); it would be interesting to know if the larvae are feeding on common reed (least skipper is a grass-feeder, and other grasses appear to be scarce in that area). None of the Fourth of July Butterfly Counts reported by the North American Butterfly Association has been conducted in the Meadowlands area; the closest count is on Staten Island (North American Butterfly Association 2002).

Bees were studied at the Kearny landfill site, comprising 6 ha of upland meadow and young trees, surrounded by common reed, tidal fresh(?) marsh, and exit 15W of the Turnpike (Yurlina 1998). A total of 51 species of mostly native bees was found at this site, including 1 species that was either undescribed or an undocumented introduction. Four "specialist pollinators" were found in association with, respectively, sunflower (*Helianthus*), ironweed (*Vernonia*; planted), swamp rose mallow, or cinquefoil (*Potentilla*). Regarding another study area on Staten Island, Yurlina (1998) stated that pre-existing cavities in stems of plants such as sumacs (*Rhus*), tree-of-heaven, sunflower, and common reed were suitable nest sites for bees of the genera *Bombus* (bumblebees), *Hylaeus*, and *Ceratina*. We infer that abundance of potential pollen and nectar sources on upland meadows, and abundance of potential nest sites in plants such as sumacs, tree-of-heaven, and reed, may make certain landfills and other filled areas in the Meadowlands suitable habitat for diverse native bee faunas.

The first confirmed location in the United States where the imported coccinellid beetle *Coccinella septempunctata* had naturalized was in the Meadowlands, in East Rutherford, adjacent to a landfill (Angalet et al. 1979). This ladybug was introduced elsewhere as a biological control of aphids during two attempts in 1958 and 1973; it is not known how the beetle became established in the Meadowlands. During this study, Angalet et al. (1979) identified 26 species of aphids and 17 species of ladybugs in the East Rutherford area. Common reed is the host plant of the mealy plum aphid (*Hyalopterus pruni*), the most abundant aphid in the Meadowlands (Angalet et al. 1979). The abundance of common reed and mealy plum aphid in the Meadowlands (HMDC 1984; EK, personal observations) presumably help make this region suitable for *C. septempunctata*. The commercial harvest of ladybugs from the Meadowlands for sale to gardeners and farmers for biological control of aphids, alluded to by Sullivan (1998), may pertain to this species. Aphids and ladybugs were prominent in samples of invertebrates from the marsh surface at the Carlstadt-Moonachie site (Empire Tract) reported in USACOE (2000). Ladybugs are food for mantids, birds, and fish (HMDC 1984, Berger 1992).

The little information available suggests that the terrestrial arthropod fauna of the Meadowlands is reasonably rich for a wetland complex in the New York City region. For example, the pearly wood nymph moth (*Eudryas unio*, Noctuidae), a fairly common grazer on purple loosestrife leaves in New York and New Jersey, was defoliating loosestrife in a common reed stand on the north side of Paterson Plank Road, 18 September 2000 (EK and KM, personal observations). We observed several species of butterflies nectaring at purple loosestrife in Kearny Marsh

West in July 2000. On 14 February 2001, EK collected egg masses of two introduced mantids, *Tenodera sinensis* and *Mantis religiosa* (identified by James [Spider] Barbour, Hudsonia Ltd.). Spiders appeared fairly common and diverse in visual observations among reed litter and stubble at the Carlstadt-Moonachie site (EK and KM, personal observations, 18 September 2000). Collections of terrestrial insects from monitoring of wetland mitigation projects are undergoing identification (J. M. Hartman, personal communication to EK, 2001).

ENDANGERED, THREATENED, AND RARE SPECIES

No species federally listed as endangered or threatened is currently known in the Meadowlands. Table 4 shows species of the Meadowlands that appear on the state list of endangered and threatened species, or on the New Jersey Natural Heritage Program list of rare species. We have included birds in Table 4 only if the New Jersey breeding population is ranked S3 or rarer. State-listed bird species are an important component of the biological diversity of the Meadowlands. Although the nonbreeding population of double-crested cormorant in the Meadowlands is not considered rare (Heritage rank S4), we expect this species to begin breeding in the Meadowlands based on recent breeding in northwestern New Jersey and on the tidal Hudson River. Saltmarsh bulrush (*Scirpus maritimus*), ranked G5 SH E (globally secure, known historically, Endangered) in New Jersey occurred historically in the Meadowlands (Day et al. 1999) at location(s) unknown to us. For additional explanation of the New Jersey Natural Heritage Program ranking system see New Jersey Natural Heritage Program (2001).

HUMAN USE OF THE MEADOWLANDS

In this section we outline the extractive and amenity values of the Meadowlands. Use for landfills, construction, and other forms of "development" is well known and is mostly not discussed here. Indirect use of the Meadowlands for water quality maintenance is undoubtedly very important but little information is available (see, however, HMDC 1974). Functions and values as animal habitat are discussed elsewhere in our report.

Current Uses

Fishing: Commercial fishing in the Newark Bay complex, which includes the Meadowlands, has been closed for many years due to contamination from industrial discharges into the rivers and bay (Shaw 1994 cited in Pflugh et al. 1999). The area is still used for recreational and subsistence fishing and crabbing on a daily basis (Quinn 1997, Pflugh et al. 1999). Fish consumption advisories ranging from do not eat, to eat no more than once per month depending on risk group, have been issued for bluefish, American eel, white perch, striped bass, white catfish and blue crab due to contamination with dioxins and PCBs (Pflugh et al. 1999). Angling for striped bass was popular and successful along the Hackensack River mainstem in 2001 (see section on Fish, above). Blue crab (blue-claw crab) thrives in the tidal water bodies, including highly stressed areas, and is harvested for food by local residents (NJTA 1986). A single bait fisher continues to trap mummichogs which are sold as live bait for sport fishing on the Jersey Shore (Quinn 2001b).

Turtle Harvest. We are not aware of any collection of snapping turtles or diamondback terrapins for food from the Meadowlands. These species are, or were until recently, widely harvested both commercially and on a subsistence basis in eastern coastal states. Probably there is a small amount of harvesting in the Meadowlands. Collection of turtles for food should not be encouraged because of the vulnerability of freshwater turtle populations to loss from the adult stage (Congdon et al. 1994), and because of the propensity of snapping turtles to accumulate contaminants (see Stone et al. 1980). There is a New York State Health Advisory against all consumption of snapping turtle tissues from the Hudson River.

Hunting: Duck hunting was common in the Meadowlands as recently as the 1960s (Quinn 1997). Baldi (1981) referred to pheasant and rabbit hunting along the Paterson Lateral gas pipeline road in the Carlstadt-Moonachie marshes. There appears to be little hunting in the Meadowlands now, although an occasional blind looks recently used. Some duck hunting still occurs in Sawmill Creek WMA (Conniff 2001).

Fur Trapping: Muskrat trapping was an important industry in the Meadowlands. Chet Mattson (cited in Quinn 1997) states that 12,000 muskrat pelts are still taken on the Meadowlands annually (this appears to refer to the 1990s but seems high). Meadowlands muskrat pelts are of high commercial quality (Brooks 1957).

Ladybug Harvest: Sullivan (1998) mentions commercial collection of ladybugs. They are sold for biological control of aphids.

Reed Harvest: Hasidic Jews from Union City, New Jersey, annually harvest common reed in later summer – early fall for thatching *succat* (ceremonial shelters used in the Feast of Tabernacles) (Anonymous 1993; B. Sheehan, Hackensack Riverkeeper, personal communication to EK, 2000). Harvest by hand-cutting with sickles has occurred at the Carlstadt-Moonachie site since at least the mid-1980s (B. Sheehan *fide* H. Carola, 2001). In 1999, Hasidim from Monsey, New York, harvested reed at this site using “weed-whackers” (MERI, personal communication to EK, 2002).

Illegal Waste Disposal: This was evidently a major historical activity in the Meadowlands. We have not seen any information on current illegal waste disposal practices.

Resources from Landfills: Methane gas is collected from closed garbage landfills and burned to generate electricity (Scarlatelli 1997, Hackensack Meadowlands Development Commission 1999, Matthews 2001). At least one company is exploring the commercial potential for producing ethanol from organic matter mined from Meadowlands landfills (B. Sheehan, Hackensack Riverkeeper, personal communication to EK, 2001).

Ecotourism, Birdwatching, and Nature Study: Tour boats ply the Hackensack River (Quinn 1997). Motorized small craft (including "personal watercraft") and canoes use the Hackensack River, and to a lesser extent its tributaries. There appears to be substantial use of public sites (e.g. Richard W. DeKorte Park at Kingsland Impoundment) by birdwatchers, school groups, and others on foot. Some of this use occurs informally (Quinn 1997; EK, personal observations) e.g. on the Paterson Lateral gas pipeline road at the Carlstadt-Moonachie site. NJMC, Hackensack Riverkeeper, Bergen County Audubon Society, New Jersey Audubon Society, Torrey Botanical Society, and other organizations lead field trips for varied audiences. There are marsh boardwalks open to the public at DeKorte Park and Mill Creek Marsh.

Miscellaneous Active Recreation: Various locations on fill in the Meadowlands support public recreation such as organized sports and model airplane flying. There is an abandoned, overgrown par course and paved recreational trail on fill northwest of the Meadowlands Convention Center. Quinn (1997) mentions off-road vehicles on dirt roads (we have seen both motorcycles and "four-wheelers"), and in 2002 there was evidence of off-road vehicle use on Laurel Hill and Little Snake Hill (EK, personal observations). Two trails are being built for hikers and cyclists (Quinn 1997, HMDC 1999). A deepwater cattail marsh in the Kearny area was formerly burned each winter to serve as a skating pond (Abbott 1907).

Mosquito Control: The Hudson County Office of Mosquito Control performs ground-based and aerial larviciding and ground-based adulticiding based on surveillance (monitoring) of mosquito larvae and adults (Rutgers University 2002). The Office also maps mosquito breeding habitats, introduces mosquitofish (*Gambusia affinis*) and "sunfish" for control of larvae, responds to complaints, and conducts public education. The Bergen County Department of Mosquito Control practices surveillance, source reduction (i.e. elimination of breeding habitats), water management, and biological and chemical control (Bergen County Department of Public Works 2002). The bacterial larvicide *Bacillus thuringiensis israelensis* (BTI) is used, and mosquitofish are stocked. "…hand labor and heavy equipment is used to clear and desilt ditches, streams and ponds to allow for free movement of water. Tide-gates and dikes are inspected and repaied to prevent flooding of low-lying areas and water in ditches and brooks are lowered to minimize mosquito breeding" (Bergen County Department of Public Works 2002). We do not know if nontarget impacts of mosquito control (e.g. stocking of larvivorous fishes, use of mosquito larvicides and adulticides, hydrological manipulation) on other Meadowlands biota have been studied.

Industrial and Transportation Uses: There is a concentration of industrial and commercial facilities sited on fill in the Meadowlands. Railroads and highways criss-cross the Meadowlands. There are two airports, Teterboro Airport at the north end, and Newark International Airport south of, the Meadowlands. A major container port is located at the mouth of the Hackensack River in the Elizabeth area. Although outside the Meadowlands *per se*, these facilities affect air quality, water quality, and noise levels in the Meadowlands. These uses of the Meadowlands exploit the large flat areas of open space, major highways, and the natural or dredged shipping channels close to the industrial and population centers of northeastern New Jersey and New York City. There are numerous commercial radio broadcast antennas in the Meadowlands (Brooks 1957) (in general, wet soil improves AM radio transmission; David Groth 2001, personal communication to EK). Legal filling of wetlands in the Meadowlands continues for commercial and residential development.

Stormwater and Wastewater: Treated sewage is discharged into some of the Meadowlands waterways. There are also stormwater retention or detention ponds e.g. on the west side of Polito Avenue in Lyndhurst and at the Meadowlands Sports Complex.

The Arts: The Meadowlands have been the subject of art photography (Mortenson 1983), visual art and site art (Potteiger and Purinton 1998); namesake of a book of poems (Glück 1966); and inspiration to other urban artists and writers. Two major recent books (Quinn 1997, Sullivan 1998) have interpreted the human and natural history of the Meadowlands for lay audiences. The search for the historic stone columns of Penn Station in the Meadowlands dumps is a story that has intrigued writers (e.g. Matthews 2001). And the Meadowlands have been the subject of jokes (Dunne 2000).

Historic and Potential Uses

Mining: The diabase of Laurel Hill was extensively quarried for construction (Quinn 1997). The Schuyler copper mine operated in North Arlington from the early 1700s to the late 1800s and possibly later (Woodward 1944). The Granton Quarry, in hornfels and diabase, is at the eastern edge of the Meadowlands in North Bergen (Van Houten 1969, Manspeizer and Olsen 1981). Granton Quarry was identified as a potential "geological natural landmark" with national significance but in serious danger due to commercial development (Butler et al. 1975). Clay mining for brick manufacture occurred on the west bank of the Hackensack River near Little Ferry (Reeds 1927, Brooks 1957) and presumably elsewhere in the Meadowlands. Willow Lake occupies a 2 ha abandoned clay pit in Little Ferry (Brooks 1957). At the northern end of Laurel Hill, a deposit of artificial material which superficially resembles sandy glacial outwash, possibly bottom ash from the old kiln, was being mined in winter 2001-2002, possibly for road work (EK, personal observation). We are not aware of any other hard rock or soil mines in the Meadowlands. Nor are we aware of any historic peat or wood mining, although these activities were likely. The existence of a large body of peat (e.g. Waksman 1942) suggests a future opportunity for peat mining depending on peat quality and demand. Fossil logs of Atlantic white cedar potentially could be mined. Depending on the scale and type of mining, these activities could be destructive to habitats as well as potentially remobilizing contaminants from sediments. Impacts of such mining would need to be examined relative to water bird habitats and other wetland functions and values. Possibly peat mining could be used selectively to lower marsh elevations and increase the hydroperiod of certain reed stands.

Agriculture and Logging: These activities were historically important in the Meadowlands, but in most cases are no longer possible or ecologically appropriate.

Edible Plants and Fungi. The presence of oyster mushroom on dead tree-of-heaven (see above) suggests an opportunity for collection of edible mushrooms. “Huckleberries” were harvested commercially in the 1800s (Mattson 1970); these presumably were *Gaylussacia* or *Vaccinium* associated with the cedar swamps. Jelly can be made from the fruits of the introduced shrubs, beach rose (*Rosa rugosa*), autumn-olive (*Elaeagnus umbellata*), and Russian-olive (*E. angustifolia*), which occur in the Meadowlands. Many other potentially edible plants are common in the Meadowlands. Metals or other contaminants could present a problem for consumption of mushrooms or plants.

Beneficial Use of Invasive Plant Biomass. Biomass from common reed, tree-of-heaven, and princess tree is abundant in the Meadowlands and potentially useful (see below under “Restoration”).

BIOLOGICAL EFFECTS OF CHEMICAL POLLUTANTS

Several studies have examined accumulation of contaminants in vertebrates in the Hackensack Meadowlands. Galluzzi (1981) studied mercury concentrations in reptiles, mammals and birds collected from different sites in the Meadowlands. Despite the presence of a geographic gradient of mercury contamination in sediments within the Meadowlands, no geographic pattern was observed among biota in that study. Santoro and Koepp (1986) found a discrepancy between the concentration of mercury in sediments from the heavily contaminated Berry’s Creek and concentrations in fish species collected there. The lack of correlation between sediment and tissue mercury levels in these studies could be related to the bioavailability of these contaminants, the mobility of many animal species, or to dietary and other differences in local populations within the Meadowlands.

In a study comparing heavy metal concentrations in sediments, water, and northern diamondback terrapin stomach contents and liver tissue between Cape May and the Hackensack Meadowlands, C. McIntyre (unpublished report) found that while the Meadowlands were more polluted, tissue from Cape May terrapins had higher concentrations of copper, zinc, and cadmium. There were dietary differences between the two areas that may explain the counterintuitive differences in metals accumulation in terrapins. Albers et al. (1986) compared PCB concentration in livers of snapping turtles from the Hackensack Meadowlands (contaminated sites) with that of turtles in Maryland (less contaminated) but did not find a difference. Turtle trapping produced no catch in Mill Creek and Berry's Creek, the most contaminated sites sampled in the Meadowlands, although snapping turtles were successfully captured at several other sites (Albers et al. 1986).

Kraus (1989) compared the accumulation of heavy metals in different tissues of embryonic and nestling tree swallows as well as midges (Chironomidae), their primary food source in the Meadowlands. Swallow eggshells contained higher concentrations of cadmium, chromium, copper, lead, and nickel than embryonic tissues. There was differential accumulation of heavy metals among tissue types (brain, liver, muscle, feather) in nestling swallows. The study demonstrated that heavy metals can move from sediments to tree swallows via their prey source, midges.

Several studies have been conducted on fish and crustaceans in Berry’s Creek, a site heavily contaminated with mercury. In a study along a distance gradient from the mercury source at the headwaters of Berry’s Creek, Santoro and Koepp (1986) found that mercury concentrations in finfish and crustaceans were elevated but were several orders of magnitude lower than mercury concentrations in local sediments. Furthermore, several species exhibited higher mercury concentrations “downstream” from the most heavily contaminated areas. Mummichog, blue crab, and fiddler crab were the only animals sampled that exhibited a positive correlation between average mercury concentrations in tissue and distance from mercury point sources on Berry's Creek. Mercury concentrations in mummichogs ranged from 0.29 $\mu g \bullet g^{-1}$ (micrograms per gram [wet weight, *fide* E. Konsevick, NJMC]) at Berry’s Creek to 0.11 $\mu g \cdot g^{-1}$ at both Overpeck and Sawmill Creek. The highest individual concentration of mercury (0.61 $\mu g \cdot g^{-1}$) was found in yellow perch and the lowest (0.10 $\mu g \bullet g^{-1}$) in bluegill, both at Overpeck Creek. A mean mercury concentration of 0.44 $\mu g \bullet g^{-1}$ was detected in American eel samples from Berry’s Creek (the only site in which this species was sampled). This study involved several hundred samples from 15 species of fishes and 5 crustaceans. Santoro and Koepp (1986) stated, “Only 2% of Berry’s Creek data (0% for other biozones) resulted in individual values in excess of the existing Food and Drug Administration > 1.0 microgram per gram guideline…However, approximately 31% of all analyses were in excess of the prior 0.5 microgram per gram guideline as follows: Berry’s (9%), Sawmill (8%), and Overpeck (14%).” Species exceeding the lower guideline included mummichog, white perch, blueback herring, sunfishes, American eel, yellow perch, European carp, and blue crab.

Weis et al. (1986) studied the effects of different environmental factors on the release of mercury from Berry’s Creek sediments and its uptake by mummichogs. They found that decreased dissolved oxygen levels (similar to summer conditions) enhanced mercury uptake but stirring (to simulate dredging) did not. Furthermore, mercury concentrations in sediment did not relate to the uptake by fish.

Toxicological studies of the physiological, behavioral and developmental effects of chemical pollutants on estuarine organisms are extensive and a review of that literature is beyond the scope of this paper. However, several studies and reviews are immediately relevant to this discussion. In a review of the literature on whether exposure to toxicants may bring about physiological acclimation or genetic tolerance in aquatic organisms, Weis and Weis (1989) provide examples of these phenomena. Furthermore, they describe a case in which acclimation to locally present forms of mercury (methyl mercury specifically) entails costs as well as benefits. Mummichogs in Piles Creek, a nearby polluted tributary of the Arthur Kill, are more tolerant to methyl mercury than individuals from more pristine estuaries. However, they exhibit signs of poor health that include decreased growth and increased mortality in adult stages. Furthermore, mummichogs in this polluted environment show signs that they are allocating larger amounts of energy to reproduction and reproducing at an earlier age than those in less contaminated locations. Weis and Weis mention that fiddler crabs and grass shrimp from Piles Creek also exhibit enhanced tolerance to methyl mercury. Weis et al. (2001) review the literature on behavioral effects of environmental toxicants and offer an illustration of the ecological consequences via a case study of mummichogs and their prey, grass shrimp, in Piles Creek as compared with a sample from a cleaner estuary. Mummichogs from the polluted estuary were slower to capture prey and escape predators. Mummichogs from the polluted site had a higher amount of detritus in their diet, reduced growth and reduced longevity as compared to the largely crustacean diet in less contaminated areas. The consequence was that grass shrimp exhibited increased population density and larger size frequency in Piles Creek than those in cleaner locations. This shows that pollutants may have indirect effects within ecological communities, which makes it difficult to predict the effects of pollutants in ecosystems. A study of the effects of petroleum hydrocarbons on phytoplankton communities in Piles Creek demonstrated a 3-fold increase in photosynthesis after exposure to phenanthrene (Kelly et al. 1999).

It is remarkable that a region as contaminated as the Meadowlands can support the fauna we have described above, and that reported contaminant levels are fairly low in water birds, snapping turtles, and other fish-eating animals. It is possible that: 1. The nekton-feeding water birds of the Meadowlands (e.g. pied-billed grebe, herons, bitterns, gulls, terns) are consuming mummichogs, fiddler crabs, or other prey that do not accumulate large amounts of contaminants (see Galluzzi 1981); 2. The studies conducted to date have missed the sites, prey species, predator species, population classes, or tissues where contamination is having a deleterious effect on top predator species; or 3. Common reed and other plants are sequestering metals, or reduced conditions in the sediments are immobilizing metals, making them unavailable to higher levels of the food chains. Yet cautions concerning the potential effects of modest levels of mercury on health of fishes (Uryu et al. 2001) and water birds (Odom 1975) may be relevant to the Meadowlands. The studies of contaminants in tissues of Meadowlands vertebrates need to be reviewed and possibly replicated for confirmation of the low levels reported, and research needs to be done on the health effects of contaminants on animals. A study of contaminants in fishes and blue crab is underway (MERI, personal communication to EK 2002). Organic contaminants (e.g. dioxins, PCBs, PAHs) have not been studied as well as metals in the Meadowlands. Knowledge of contaminant effects on animals is important for planning management of habitats that may attract animals to, or discourage them from using, the more contaminated areas of the Meadowlands.

THE MEADOWLANDS AND WILDLIFE

What makes the Meadowlands such a magnet for wildlife? We think the following features of the Meadowlands contribute to their suitability for many animals: 1. A large complex of undeveloped habitats in a vast urban-industrial area; 2. Abundant surface waters with diverse hydrology (tidal and nontidal, fresh and brackish); 3. A variety of habitats ranging from open estuarine waters to dry fill and rock; 4. Extensive areas of marsh, wet meadow, and upland meadow habitat with minimal direct human intrusion; 5. Dense stands of common reed and other plant communities that have low visibility and low penetrability (i.e. they are hard to see into and move through, *sensu* Egler 1977:111), and provide concealment and shelter for animals nesting, roosting, or foraging within the reed stands or on other habitats surrounded by reed stands; 6. Abundance of certain foods (including common reed for muskrats; small rodents and small birds for raptors; terrestrial insects and spiders, as well as adult chironomid midges, for small birds; macrobenthic invertebrates for dabbling ducks, shorebirds, and small fishes; small fishes for piscivorous fishes, turtles, cormorants, herons, diving ducks, gulls, terns, etc.; and fiddler crabs for turtles, herons, etc.); 7. Reduced levels of hunting, trapping, and fishing activities that might potentially affect nontarget species and prey species as well as legally harvested species; and 8. Possibly reduced levels of predation, competition, and herbivory (e.g. deer grazing) providing ecological "refuge" for certain animals. We think these apparent advantages to life in the Meadowlands are "traded off" differently by different animal species with the detriments of the Meadowlands environment including: 1. Intensive replacement of "natural" habitats by altered or artificial habitats; 2. Loss of connectivity with other wetland and grassland habitat complexes; 3. Loss of sensitive species that may have served as food, symbionts, habitat structure, etc.; 4. Physical hazards of motor vehicles, aircraft, buildings, radio towers, and construction equipment; 5. High anthropogenic noise and light levels; 6. Urban-type water, soil, and air quality; 7. Contamination by metals and other toxic substances; and 8. Competition or predation from a few common, urban-tolerant animals (e.g. Norway rat, raccoon). For example, salamanders may not survive in the Meadowlands because of the artificial upland soils, scarcity of forest habitat, and chemical contamination (as well as salinity), despite the abundance of wetlands. Many breeding bird species may thrive because of the abundant prey and lack of direct human disturbance, despite contamination of the environment. The species that thrive in the Meadowlands tend to be those species that are highly mobile and are presumably able to move between the Meadowlands and other habitat complexes via air and water corridors, while also being able to move among habitats within the Meadowlands and avoid hazards such as highways. Of course, in order to thrive in the Meadowlands, animals also have to be able to use the available plant communities, many of which are dominated by invasive plants.

IMPLICATIONS FOR CONSERVATION

The values of the Hackensack Meadowlands include: 1. Extensive wetlands and other green spaces within a large urban-industrial area; 2. Recreation opportunities; 3. Habitat functions for many rare birds and trust species of birds, fishes, and the diamondback terrapin, as well as for common species of native wetland biota; and 4. Ecological services (albeit studied poorly or not at all) including water quality amelioration in wetlands, storage of carbon, and flood modulation. The best case has been made for the biological values, especially for marsh and water birds and to a lesser extent fishes. These values will depend increasingly on protection of habitats and habitat complexes from degradation or destruction, maintenance or improvement of water and air quality, and remediation of landfills and hazardous contamination. Scarce habitat types (e.g. high salt marsh, low salinity tidal marsh, natural sand scrub, natural rocky ledges) especially need protection, as do specific habitat units critical to populations for reproduction, nursery, migratory "stopover," and other special functions. Large blocks of habitat are important for certain species, e.g. breeding northern harrier and certain marsh and water birds. Many of the species for which the Meadowlands are most important are relatively large and highly mobile animals such as marsh and water birds, raptors, and migratory fishes. These animals tend to use complexes of habitats within and outside the Meadowlands depending on season, weather, hydrology, disturbance, food availability, and other factors. This indicates that landscape and regional level patterns are important in addition to local habitat characteristics. We believe therefore that research, planning, and management of the Meadowlands need to consider both local and larger scale ecology in order to conserve the unusual wildlife of the region. Management and restoration of habitats and habitat complexes will play a role in this conservation. More than 400 hectares (1000 acres) of the Meadowlands are permanently protected (MERI, personal communication to EK 2002); however, several thousand acres of wetlands as well as important habitats on fill and natural uplands remain unprotected. The Hackensack Meadowlands are the largest remaining incompletely protected tidal wetland complex in the New York – New Jersey harbor estuary and one of the largest remaining contiguous blocks of open space in the New York metropolitan area (Day et al. 1999).

HABITAT MANAGEMENT AND RESTORATION

Targets for Restoration

We have described, within limits of available information, existing biological diversity of the Hackensack Meadowlands. The biodiversity of the future is inextricably related to the course of management and restoration activities in the Meadowlands. Ecological “restoration” can accomplish a variety of goals, among them restoration to a known prehistoric or historic condition, restoration of ecological processes, creation or enhancement of habitat to favor particular species of animals or plants, removal of non-native species or other organisms considered undesirable or detrimental, remediation of pollution or improvement in environmental quality (e.g. dissolved oxygen, nutrient levels, contaminant levels), or achievement of an aesthetic condition such as unobstructed views of water. Some goals of restoration may conflict; for example, providing extensive mudflats for shorebirds and having extensive robust emergent vegetation to ameliorate water quality are not necessarily compatible with each other. Restoration “targets” should be clearly defined and realistic (i.e. achievable and sustainable). Restoration should re-establish ecological integrity and ecosystem processes as well as water quality and wildlife use (Berger 1992). Key organisms and environmental factors should be monitored before and after restoration, and the results of monitoring made available to the public promptly, so that new projects can benefit from prior experiences.

The concept of restoring Meadowlands marshes to salt marsh has been criticised because salt marshes were not historically dominant in this landscape (Day et al. 1999). Salinities may not be high enough in many portions of the Meadowlands to allow plants such as saltmarsh cordgrass to compete with common reed in the long term, although large patches of saltmarsh cordgrass have persisted on the site of the first major mitigation project in the Meadowlands (the Hartz Mountain project) after 15 years. (Cordgrass on this mitigation site, however, is reported not thriving, short, and unproductive, and the soil low in organic matter [L. Windham, personal communication to EK and KM, 2001; also see Wander and Wander 1995].) Possibly sea level rise and the accompanying increase in salinity will favor salt marsh communities in the future. Restoration to Atlantic white cedar swamps, as proposed for part of the mitigation for the Meadowlands Mills development (USACOE et al. 2000), is unrealistic because the conditions required by this plant community (e.g. low fertility, acidic soils, no saline intrusions, low fire frequency) are probably unattainable (Kiviat 2000). NJMC twice attempted white cedar restoration unsuccessfully; plantings were killed by muskrats and a salinity intrusion (Waldman 1999).

One way to conceptualize effective restoration is to observe how ecosystems change. Restoration planning can grow from knowledge of, e.g., existing high quality habitat for marsh and water birds in the Meadowlands. Kearny Marsh West is a case in point. Accidentally blocked drainage turned a brackish tidal marsh into an impoundment and raised the water level. This caused a dense stand of common reed to break into fragments interspersed with shallow open water, and created some of the best habitat for breeding marsh and water birds in the Meadowlands. Use of impoundment (permanent, temporary, or controllable) to manage extensive dense reed stands and increase interspersion should be considered at certain sites. Restoration and management in the Meadowlands, of course, must be designed to reduce (or at least not aggravate) flooding of developed areas, production of nuisance and vector mosquito species and other nuisance biota, and fire hazard. Management of reed marshes as habitat should address a broad taxonomic spectrum. Because of the limits of knowledge of reed interactions with many taxa, however, our discussion of habitat focuses on birds and fishes.

Impoundment of Tidal Marshes

Impoundment can produce a stable (or controllable) water level and, if correctly designed, vegetation favorable for breeding of marsh and water birds (see above). Impoundment, however, reduces or eliminates the ability of the marsh to ameliorate estuarine water quality, export plant detritus to the estuary, and act as spawning or nursery habitat for migratory fishes. Impoundments are also vulnerable to undesirable invasions in the water (e.g. purple loosestrife, water-chestnut [*Trapa natans*], European carp) and on the dikes (tree-of-heaven, princess tree). The structure of reed stands in impoundments varies depending on water depth and probably other factors. At Kearny Marsh West, where water is deep, reed stands are fragmented, interspersed with open water, and declining. At Kingsland Impoundment, reed stands are interspersed with open water, appear to be less fragmented than at Kearny West, and may be more stable. At the Carlstadt-Moonachie Marshes, where a berm has kept tidal flow out of large areas, and standing water is shallow, of shorter duration, and restricted in extent, reed stands are more continuous, hyperdominant, and presumably stable.

Managing Water Levels

The fragmentation of common reed stands in Kearny Marsh West appears to be progressing beyond an optimal state for marsh and water bird habitat. The combination of permanent high water, poor water quality, muskrat and European carp grazing on reed rhizomes, and flotage of peat where reed has died may result in conversion of large areas of marsh from interspersed reed and open water (i.e. a deep reed marsh) to a floating purple loosestrife and marsh-fleabane marsh (EK, personal observation, 2000). Although this mixed loosestrife community may provide resources to butterflies, meadow vole, and several marsh and marsh-edge bird species, this habitat may not be good for animals of deep marsh such as common moorhen, American coot, and least bittern. It may be necessary to lower the water level permanently or seasonally to stabilize the reed stands. Additional action may be needed to break up or sink some of the floating peat mats. Detailed study of water quality, vegetation dynamics, and habitat use by birds is needed. A similar problem does not seem to exist in the Kingsland Impoundment, which is also good deep reed marsh habitat for breeding marsh and water birds. A careful comparison of these two marshes may be in order.

Drawdown of Impoundments

Seasonal drawdown (July through October) to expose mudflats in the Kingsland Impoundment would attract southward-migrating shorebirds (Kane and Githens 1997). This would provide a habitat for foraging and loafing at times of higher tides when these activities are limited in the nearby tidal marshes. Drawdowns also contribute to use by birdwatchers, important because the Meadowlands are an important birdwatching area (R. Kane, personal communication to EK and KM, 2001). Seasonal drawdowns should be considered for other impoundments as well. The potential during and following drawdowns for invasion by purple loosestrife or for excessive proliferation of common reed, or of volatilization of organic contaminants such as PCBs, needs consideration.

Removal of Tide Barriers

Tidal flow may be restored to impounded or semi-impounded areas by removal or modification of tide gates, dikes, berms, or other water control structures. This action has good potential to restore saltmarsh cordgrass stands and diversify common reed stands in some places (Day et al. 1999). Tidal barriers at Sawmill Creek WMA were breached by a storm in 1950 allowing increased tidal flooding. A decrease in common reed and an increase in mudflats and low salt marsh resulted (Day et al. 1999). It has been suggested (B. Sheehan, personal communication to EK, 2000) that the flood control berm on the Hackensack River side of the Carlstadt-Moonachie site (including the Empire Tract) could be relocated to the "landward" or developed side of the marsh, maintaining flood protection for developed areas but allowing tidal flooding of the marsh. Depending on topography, it might be necessary to create or deepen creeks and pools within the common reed matrix in the marsh to open substantial areas to tidal flow. Substrate elevation and microtopography will influence species and abundances of fishes using the marsh. Restoration of tidal flow to marshes may allow stands of reed and other marsh plants to ameliorate the quality of estuarine waters.

Reed Replacement

Reed removal by means of repeated herbicide (glyphosate) applications alone or in combination with other techniques, recontouring of the soils, and planting of preferred species such as cordgrasses has been practiced in several mitigation projects in the Meadowlands. These projects are located primarily at Mill Creek (the first major mitigation project in the Meadowlands as well as a new mitigation project), the Meadowlands Mitigation Bank (TransCo property on eastern portion of the Carlstadt-Moonachie site), Skeetkill Marsh, and Harrier Meadow. Additional sites have been identified as potential mitigation sites (including Oritani Marsh, Riverbend Marsh, and Kearny Marsh) according to an undated NJMC map labelled "Current & Potential HMDC Wetland Mitigation Sites"; however, this map does not imply that reed removal is anticipated at all those sites. The stated goals of reed removal projects in the Meadowlands are to remove common reed, lower the substrate and increase tidal flooding, establish a native plant community such as saltmarsh cordgrass, improve the ability of the marshes to ameliorate water quality, increase export of plant detritus to the estuary, make the marsh more available to estuarine nekton (fishes, crabs, etc.), create foraging habitat for shorebirds, waterfowl, and long-legged wading birds, and create opportunities for environmental education and passive recreation (K. Scarlatelli and others, "Wetland Mitigation Banking in the Hackensack Meadowlands District" workshop at NJMC, 20 October 1998). These responses, however, are in some cases not proven to result from reed removal, may be in conflict with each other, and in other cases may occur in the short term but may not be sustainable. In the 1998 workshop, Scarlatelli stated that more than 700 acres of mitigation were already completed or in progress, and 530 acres were planned, for a total of more than 497 hectares (more than 1,230 acres). Current and planned NJMC wetland "enhancement" sites encompass more than 688 hectares (1,700 acres) (HMDC 1999); this would involve 20% of the total remaining wetland area of the Meadowlands). NJMC maintains 11 mitigation sites (J. Quinn, personal communication to EK, 2001). The Environmental Improvement Program of NJMC calls for 3,400 acres (1,376 hectares) of wetland "restoration" overall (Scarlatelli 1997). The majority of these acres may be subject to reed removal. NJMC, however, has decided not to perform any new mitigation or mitigation banking, although these activities may still occur on private lands (Robert Ceberio, NJMC, personal communication to EK, 2002). A wetland enhancement project is planned for a 15 ha (38 acre) site near the Secaucus High School (L. Houston, U.S. Army Corps of Engineers, statement at U.S. Fish and Wildlife Service workshop, 31 October 2001; Anonymous, no date b). The New Jersey Transit Authority is planning a 20 ha (50 acre) reed removal project in the Penhorn Creek area near the Turnpike and Route 495 (A. Fekete, statement at USFWS workshop, 31 October 2001).

Apart from the expense of reed removal, many questions remain unanswered about nontarget impacts and sustainability. These include effects of herbicides on nontarget organisms including rare plants, habitat impacts on rare animals and plants, loss of the water quality amelioration (see Findlay et al. 2002), soil stabilization, and other key functions and values of reed marsh, remobilization of contaminants via soil disturbance and replacement of reed by saltmarsh cordgrass (see Burke et al. 2000), release of carbon dioxide and methane, and short term loading of estuarine waters with nutrients, suspended sediment, dissolved organic matter, and oxygen demand. The trading of filling and development of wetlands for enhancement of wetland via e.g. reed removal represents a net loss of wetlands (Berger 1992), although it has been argued that this process may represent a net increase in wetland function (Kraus 1988).

Findings from recent research on common reed ecology require re-examination of the scientific basis for this restoration method and these goals. There may be less intensive methods that can accomplish the stated NJMC goals as well as or better than reed removal, while maintaining many of the important functions and values of reed stands (e.g. water quality amelioration, sediment stabilization). NJMC approaches to wetland mitigation appear to be moving away from strict reed removal to a mixture of different types of treatment. Planning for any form of restoration, of course, should be preceded by thorough biological surveys and habitat assessments (R. Kane, personal communication to EK and KM, 2001). The study conducted by Berger Group (2001) of the prospective mitigation site at Oritani Marsh is a step in this direction.. Some of the sampling methodologies (e.g. mammals, birds) were not necessarily adequate to fully characterize these communities and detect any rare species. For example, only 200 Sherman trap-nights and 200(?) pitfall trap-nights were invested in the small mammal survey, and there apparently was no rare plant survey.

Replacement of reed by saltmarsh cordgrass in the Hartz Mountain mitigation project at Mill Creek resulted in establishment of a stenotopic (narrow habitat niche) bird, seaside sparrow. Bontje (1988) reported seaside sparrows on the mitigation area and none on an adjoining, reed-dominated, reference site. We do not know if seaside sparrows bred successfully or persisted at the Hartz Mountain site. Krivenko (2001) analyzed relative abundance data from bird surveys at the Mill Creek mitigation site before and after mitigation. Use of the site by waterfowl, waders, shorebirds, and gulls and terns increased, whereas use by raptors and "land birds" (i.e. passeriform birds) decreased. Mudflats, open water, and sparsely vegetated islands apparently attracted water birds post-mitigation, whereas the removal of reed stands eliminated habitat for land birds. It will be important to see if the attraction of water birds to recently-created habitats is associated with a short-term "flush" of production of invertebrate or other food, or if it is a long-lasting habitat effect. Reed replacement and partial reed replacement projects are described by e.g. Bontje (1988) and Doss (2000).

Altering Soil and Vegetation in Existing Reed Stands

Some reed stands may appropriately be managed by diversifying topography, hydrology, and vegetation without large-scale removal of reed. Possible techniques include creation of shallow ponds, thinning by means of repeated summer mowing, and planting woody species. Sparse shrubs or trees in certain Meadowlands reed stands provide important nest sites for birds (R. Kane, personal communication to EK, 2000). Wet soils, and at some sites salinity intrusion, may be unfavorable for many woody species; however, common elderberry, groundsel-tree, marsh-elder, sweet gum, and others may survive under Meadowlands conditions. These and other reed management techniques have been used in Europe and elsewhere to alter reed stands for specific goals including enhancement and maintenance of habitat for rare plants, native plant communities, rare birds, rare insects, and other species. European reed management has been discussed by Burgess et al. (1995), Hawke and José (1996), and others. Some American counterparts have been described by E. Ward (1942), P. Ward (1968), and Tesauro (2001). It may be possible to enhance fish use of reed marshes by restoring or creating the various-sized creeks and pools that are generally believed to provide access to the marsh for fish and other nekton.

Removal of Fill

There are many areas of wetland fill in the Meadowlands that are not in active, formal use. An example is the peninsula of fill projecting eastward into the Carlstadt-Moonachie marshes from the end of JoMike Court in

Carlstadt (USACOE 2000), and the large area of fill west and northwest of the Meadowlands Convention Center in Secaucus (EK, personal observation, 2002). In some areas, it may be feasible to remove fill and restore wetland soils, hydrology, and vegetation. This might be more costly than reed replacement, but has the advantage of not compromising existing wetland functions and values. Of course, the ecological tradeoff of extant functions of the ecosystems developed on fill (e.g. upland meadow and shrubland) compared to those of restored wetland would need to be evaluated. It may be timely to perform an inventory of such "idle" fill areas as potential restoration sites. Fill removal has been proposed for the northern portions of Oritani Marsh (Berger Group 2001).

Artificial or Emplaced Natural Structures for Wildlife

Creating structures for wildlife nesting and other activities generally has few ecological side-effects and can be useful alone or in combination with other habitat manipulation procedures. Appropriate structures might include: 1. Nesting boxes for eastern bluebird, tree swallow, purple martin, wood duck, eastern screech-owl, and American kestrel; 2. Nesting platforms for osprey, barn-owl, and waterfowl; 3. "Boxes" for roosting bats and wintering butterflies; and 4. Basking logs or platforms for diamondback terrapin and other aquatic reptiles. Tree swallow nesting boxes are already successful at the Kingsland Impoundment (DeKorte Park) and other sites, and there are two butterfly boxes at DeKorte Park. Osprey platforms at DeKorte are not used (J. Quinn, personal communication to EK, 2001); the reasons are unclear. Structures need to be designed and installed properly, as well as maintained and monitored, and determinations need to be made as to whether structures (e.g. nesting sites) are limiting, or other factors (e.g. human activity, turbidity, contamination, vegetation) limit populations of the target species. Construction of artificial nest foundations on platforms helps attract nesting osprey (Paul Spitzer, personal communication to EK, 1973).

Pond and Marsh Construction

Construction of ponds or marshes atop capped landfills or on other fill areas could provide habitat for birds, aquatic invertebrates including dragonflies and damselflies, and other biota. If these surface waters were underlain by impervious clay or plastic liners, it might be feasible to maintain good "perched" water quality.

Afforestation

Large areas of the Meadowlands were occupied by forests until 100-200 years ago. Although re-creation of Atlantic white cedar swamps is likely impossible, there are other types of woody plant communities that could be created on both wetland and upland soils. One possibility is afforestation of closed landfills; experiments have been conducted by Stephen Handel (Center for Urban Restoration Ecology of Rutgers University and the Brooklyn Botanic

Garden). Establishment of swamp scrub (carr) or swamp hardwood forest on high elevation wetland substrates should also be possible, provided areas are not subject to much salinity intrusion (tidal swamps occur naturally in oligohaline reaches of estuaries such as the Hudson River and the Mullica River, New Jersey). Woody species such as red maple, certain willows, gray birch, common elderberry, and alder that are native to the Meadowlands could be salvaged from legal filling of wetlands in nearby areas of New Jersey, and translocated to appropriate sites in the Meadowlands.

Fire

It should be feasible to create firebreaks around the margins of reed stands to reduce the likelihood of fires spreading from the reed stands to developed areas. Such firebreaks in wet areas could incorporate shallow open ponds or channels that would support submergent aquatic vegetation and provide foraging habitat for water birds, muskrat, and turtles. In dry areas, firebreaks could include ponds as well. Information is needed on effective size and shape of firebreaks bordering reed stands.

Livestock Grazing

Livestock grazing is widely used in Europe and less so in North America (but see Tesauro 2001) to manage species composition of vegetation (including in some instances reduction of invasive plants) and improve habitat for various animal species. For example, there may be a role for horse or sheep grazing, which can inhibit or even kill common reed, in some areas of the Meadowlands. Contaminants could be a problem for livestock.

Beneficial Use of Invasive Plant Biomass

Potential beneficial use of invasive plant biomass should be considered. For example, biomass could be combined with organic matter from landfills or with "new" waste materials (e.g. lawn and horticultural wastes) for use in methane or ethanol production for generating electricity, or as an industrial feedstock. Common reed has been used for paper pulp in Romania and home heating fuel in Sweden; many other historic and current uses are known in North America and elsewhere. Tree-of-heaven is used for fuelwood, charcoal, lumber, furniture, and cellulose (Vietmeyer et al. 1980). Princess tree is potentially valuable for wood and medicine (Ellison 2001). Harvest of plant biomass could be a component in an integrated management program for common reed or tree-of-heaven.

Garbage

Non-capped landfills and miscellaneous garbage dumps are leaching nutrients and contaminants into wetlands. One such dump, for example, is in Kearny Marsh West, one of the most important bird habitats in the Meadowlands. Remediation of sediment contamination in Kearny West is under consideration by the U.S. Army Corps of Engineers (L. Houston, personal communication to EK, 2002). Refuse may be a hazard to wildlife (e.g. plastic six-pack collars strangling water birds). Garbage-polluted wetlands and water-filled containers are probably an ideal breeding habitat for *Culex pipiens* (see e.g. Headlee 1945:284-285), one of the mosquitoes believed to be a vector of West Nile virus. Non-capped landfills and miscellaneous dumps should be remediated or removed. Also, we have noticed a large amount of roadside trash in some areas of the Meadowlands. Local communities might be able to clean up and control roadside littering and dumping by means of stronger ordinances, enforcement, and public education, as has been done for other natural open spaces throughout the state. We think there would be public support for such activities.

Management of Invasive Plants

The interagency management plan for the Meadowlands (USFWS et al. 2000) states, "Invasive species of particular concern in the Meadowlands include common reed, purple loosestrife, mugwort, ailanthus (*Ailanthus altissima*), and Japanese knotweed (*Polygonum cuspidatum*). These plants tend to proliferate in nearly monotypic stands to the detriment of native plant species. This proliferation alters the basic character of the affected plant community and reduces habitat diversity and habitat value for many of the species of management concern. Additionally, proliferation of these invasive species on a large scale can adversely affect ecosystem processes including primary production, nutrient cycling, and hydrology. Meeting the goals and objectives in this management plan must include measures to control and possibly eliminate invasive species." These statements do not consider recent literature regarding the functions and values of common reed stands. Hartman and Smith (1999) state, "The primary methods of controlling *Phragmites* will be to restore tidal flushing by altering topography and/or the creation of impoundments with adequate water depth. This approach is not feasible in some areas because of the high levels of contaminants, which may be mobilized by earth moving activities. This problem is common throughout the Meadowlands District, so it is important for HMDC to identify alternative methods to eliminate or control *Phragmites*. We will evaluate alternative methods of controlling *Phragmites*, such as soil amendments to change salinity or pH, mowing, and combinations of methods, as needed."

We believe that findings of recent reed research require a new approach to management of reed in the Meadowlands, and indeed throughout the northeastern states. It is time for the emphasis to shift from eradication to alteration of reed stands. There is an urgent need for well designed and monitored small and large scale experiments in reed management for specific goals. At some sites in the Meadowlands, these goals would optimize water quality amelioration, habitat for nektonic animals (fishes, crabs, etc.), and habitat for marsh and water birds. Other considerations may include immobilization of contaminants, soil stabilization and accretion, muskrat habitat, and aesthetics. What is best for one site and combination of goals may be unsuitable for the next situation. All management, mitigation, and restoration projects should be accompanied by quantitative documentation and monitoring that meet reasonable scientific standards and that are recorded in written documents; documents and data should be available to the public.

RESEARCH NEEDS

Although many research and biological survey projects have been conducted in the Meadowlands, there is much that needs study to improve the basis for making planning and management decisions. Meadowlands research has been inhibited at times by a perception that there is little worthy of study in urban, degraded, or altered ecosystems, difficulties of access to sites, challenges of working in extensive stands of dense reed (see e.g. Wander and Wander 1995), and focus on limited aspects of Meadowlands ecosystems. The conspectus of research needs, below, grows from our synthesis of available information on the Meadowlands. We do not consider this discussion comprehensive and admit of our possible biases as ecologists who focus on higher organisms.

Invasive Plants

The sheer abundance and poor current knowledge of the ecology of tree-of-heaven, mugwort, Japanese knotweed, common reed, purple loosestrife, princess tree, and other invasive species demand that we learn more about them to allow sensible management decisions (see Kiviat submitted b). The relationship of invasive plants to trust species (i.e. species protected by law including game species, migratory birds, and endangered species), especially birds and fishes, is an important subject. Also, ecological interactions of reed and other invasives with other biota in general should be studied. We need to understand the long-term development of soil, vegetation, and wildlife in reed stands in the absence of active management. Research on alternative methods of managing reed is also important (see above). The considerable European literature on reed ecology and management is useful in this regard.

Rare Plants

Rare plant surveys should be conducted widely in the Meadowlands, focusing first on sites likely to be altered for development, mitigation, or management. Surveys should include species of regional significance as well as species listed statewide by the New Jersey Natural Heritage Program. “Pristine” habitats are not required by many rare plants, some of which occur in abandoned mines, on vacant lots, in recently abandoned farm fields, and on dredge spoil deposits in the New York City region (EK, personal observations).

Birds

Although birds are the best-studied organisms of the Meadowlands, many important questions remain. Larger scale patterns of bird use and movement among Meadowlands sites, and between the Meadowlands and nearby areas, need elucidation. For example, the role of the Meadowlands as a foraging area for the "harbor herons" and the locally breeding peregrine falcons (Endangered) needs further study. Research should be conducted on the relative roles of vegetation, inundation, and other local habitat features vs. patterns of the larger landscape in determining the distribution of birds in the Meadowlands. Many details of how birds use common reed stands and other wetland and upland plant communities remain to be studied, including comparative density and productivity of birds in different wetland habitats at different seasons, and use of other invasive species (such as tree-of-heaven) by birds. Studies of the diets and food base of birds in the Meadowlands would also further our understanding of how the Meadowlands support such abundance and diversity of birds.

Fish Populations

Surveys of fish use of smaller tributaries, creeks, and ditches at all seasons are badly needed. Also, surveys of early life stages (eggs, larvae, and juveniles) are needed to identify important spawning and nursery habitats (some of which may be outside the Meadowlands). More extensive survey work is needed in light of recent improvements in water quality and the continued consideration of altering existing marshes.

Invertebrates

The paucity of information on terrestrial invertebrates (i.e. species that do not have an aquatic life stage, whether they occur in uplands or wetlands) impedes understanding of food webs, habitat functions (of e.g. fill, reed stands), invasive plant ecology, and other important subjects. Basic biological surveys are needed as well as functional studies addressing topics such as the role of terrestrial invertebrates in soil development on fill, and the function of terrestrial invertebrates as food for fishes. Additional work on aquatic invertebrates is needed as well, because studies to date have been limited in taxonomic and ecological scope. In addition to the aquatic invertebrates of low salinity wetlands, studies should be conducted on special habitats and taxa (such as the clam-shrimp in puddles on a dirt road, see Aquatic Invertebrates, above). Non-target impacts of mosquito management on other invertebrates and other elements of biodiversity and ecosystem function should be addressed.

Other Groups of Organisms

An area that is being developed and managed as intensively as the Meadowlands, and that has such high values associated with its habitat and ecological functions, should be thoroughly understood biologically. This will require additional studies of relatively well known groups (e.g. marsh and water birds) as well as many poorly known groups (e.g. fungi, lichens, mosses, algae, and most invertebrates).

Toxic Contaminants and Biota

That water and marsh birds are abundant in the Meadowlands does not necessarily mean the Meadowlands are as “healthy” an environment for wildlife as they could be. Behavior and ecology of potentially sensitive species, such as black-crowned night-heron and tree swallow, should be compared to relatively non-contaminated areas to determine if individuals and populations in the Meadowlands are adversely affected by contaminants. Species that are likely to accumulate high body burdens of contaminants from their prey should also be studied; for example, PCB accumulation in double-crested cormorants which eat (among other prey) American eels and European carp, and snapping turtles which were shown to be highly contaminated in the Hudson River, needs to be examined. Basic study of contaminant fate and transport, and the potential for bioremediation in existing plant communities, should precede further intensive alteration of marsh ecosystems (J. Ehrenfeld, personal communication to EK and KM, 2001). Potential tidal transport up the Hackensack River of contaminants remobilized by dredging in Newark Bay and New York Bay needs study.

Functions and Processes

Most of the information available on the Meadowlands pertains to taxonomy, distribution, and in some cases abundance and behavior (e.g. reproduction or foraging). There is very little information on other functional aspects of populations such as the diet, productivity, mortality, and population dynamics of animals, and the environmental tolerances, biomass production, pathology, and herbivory of plants. Lack of this information for target species makes it difficult to predict the responses of organisms to restoration or other changes in the environment. There is also virtually no information on carbon storage or release, removal and sequestration of nitrogen vs. loss to estuarine waters, sediment accretion and erosion budgets, fire regimes, and other ecosystem-level processes. Knowledge of the transformations of nitrogen, for example, by soils and vegetation in the Meadowlands would allow better understanding and evaluation of the contributions of different habitats to maintenance of water quality in the Hackensack River and its tributaries. Phosphorus should be added to the list of water quality parameters monitored.

Fire

Behavior and ecological influences of fire in the Meadowlands should be studied to enable design of firebreaks for protection of developed areas, and to improve understanding of which habitats need protection from fire and how to manage accidentally burned areas. Prescribed fire could be considered as a component of certain habitat management programs.

Hydrology

There appears to be little organized information on hydrology of the tributaries, tidal creeks, and marshes (tidal and impounded) of the Hackensack River estuary. Effective management and restoration will be nearly impossible without increased study of hydrology. An ongoing modelling study will address this issue (MERI, personal community to EK, 2002).

Small Areas of Habitat

The biological and ecological significance of large habitat units such as the Carlstadt-Moonachie site is appropriately of great interest, but little attention is being paid to smaller areas. Many such areas exist where the landscape has been fragmented by transportation infrastructure and other development. Small habitat units may be important to some mobile animals that can cross barriers such as highways, as well as to small or sedentary organisms such as insects and plants.

The Landscape

Much of what we know about the Meadowlands is at the level of individual species and habitat units. There is virtually no information at the level of the landscape, e.g. how organisms and materials move through space and across habitat boundaries. (An exception is the "Hackensack River Migratory Bird Report" [Kane and Githens 1997] which considered the habitat support of migratory birds region-wide.) Ecological information at a larger scale is required before ecology can be integrated with zoning, land use planning, restoration design, waste site remediation, and other planning and management activities.

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