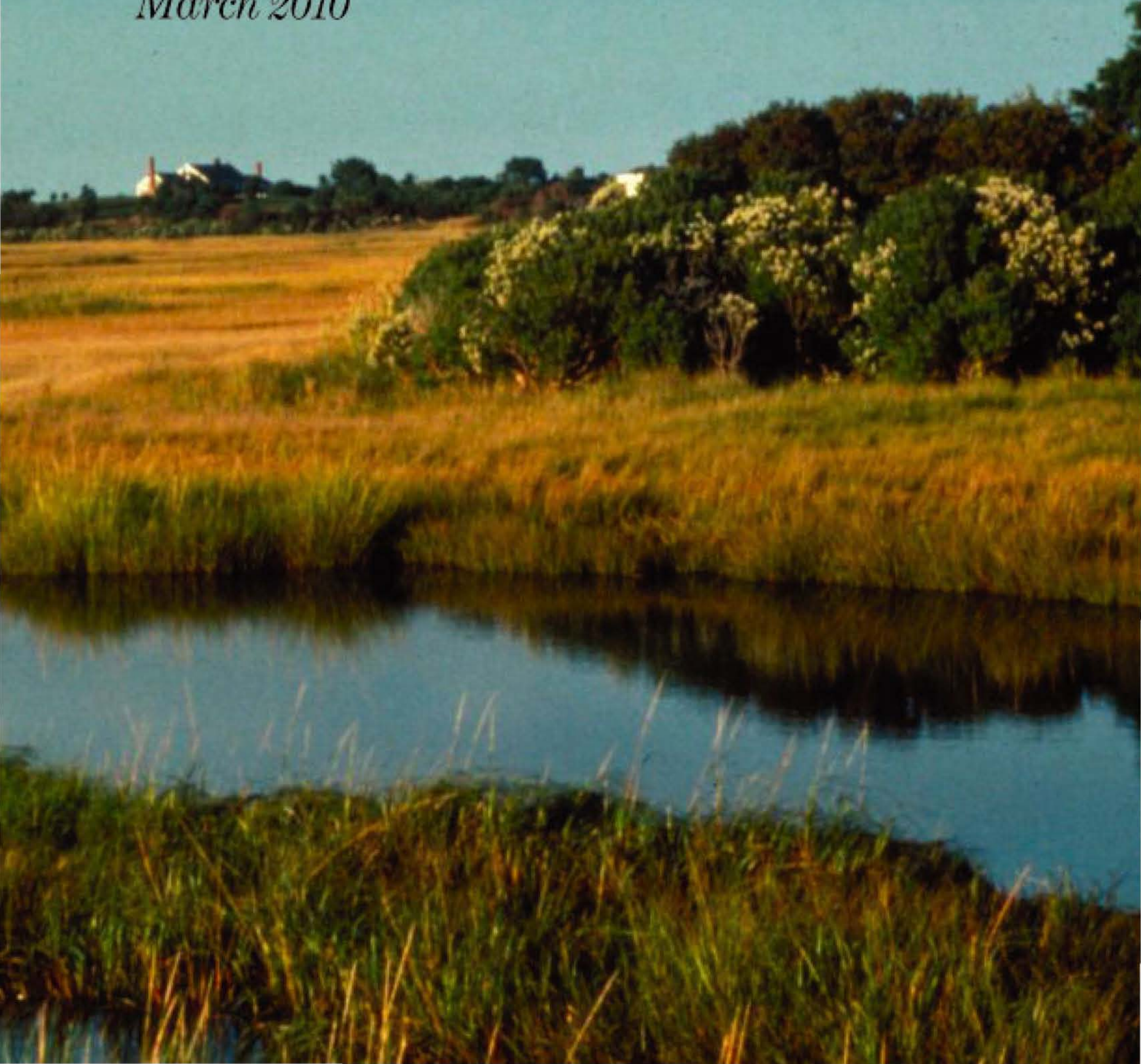
U.S. Fish & Wildlife Service

Wetlands of Cape Cod and the Islands, Massachusetts:

Results of the National Wetlands Inventory and Landscape-level Functional Assessment

March 2010



Cover photo: Nantucket tidal marsh (Ralph Tiner)

Wetlands of Cape Cod and the Islands, Massachusetts: Results of the National Wetlands Inventory and Landscape-level Functional Assessment

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A National Wetlands Inventory Report

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(Note: Thematic maps are included in a separate file.)

Table of Contents

<u>Note</u>: Maps are contained in separate files labeled for each of the four study areas.

List of Figures

List of Tables

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Introduction

The U.S. Fish and Wildlife Service (FWS) initiated its National Wetlands Inventory Program (NWI) in the mid-1970s to identify, classify, and map the variety of wetlands occurring across the country. To do this, the NWI employs remote sensing techniques where aerial photos or digital imagery are interpreted to delineate and classify wetlands according to the FWS' official wetland classification system (Cowardin et al. 1979). For the first 25 years of the program, the NWI produced hardcopy maps mostly at a scale of 1:24,000.

Massachusetts was among the first states to be inventoried. For that work, the NWI interpreted wetlands and deepwater habitats from mid-1970s 1:80,000 black and white (panchromatic) aerial photography, with the results summarized in a 1992 report (Tiner 1992). Much change has occurred since that time and the original mapping is no longer relevant for most areas, especially those where development and/or beaver activity have taken place.

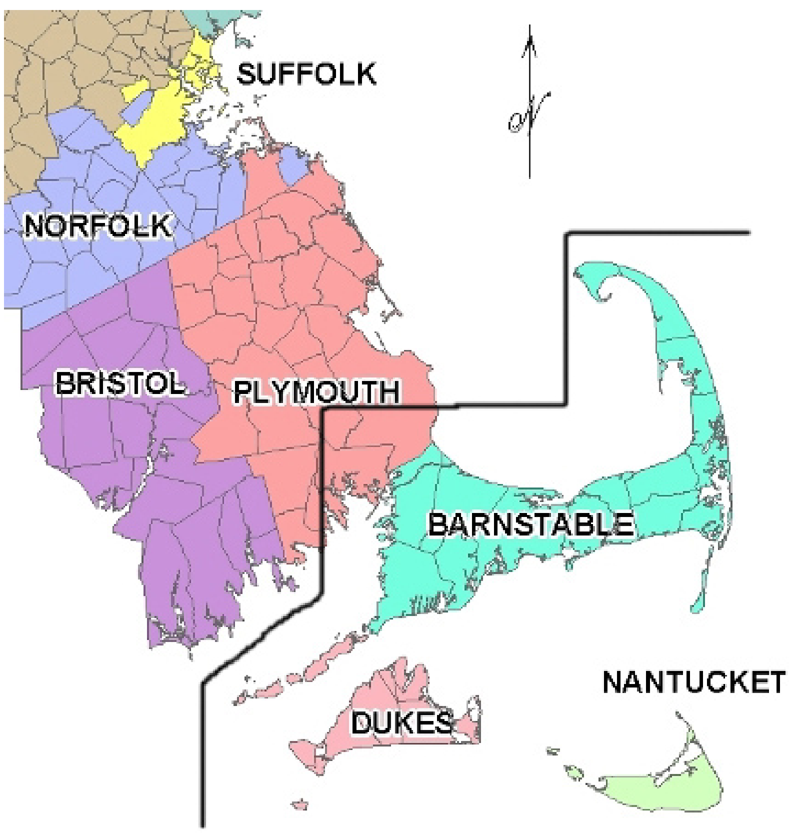
The NWI is updating its wetland mapping on a priority basis across the country. Since Massachusetts wetlands were mapped by the NWI, remote sensing technology has advanced with better quality aerial imagery available plus geospatial technology has evolved to make desktop interpretation of digital imagery possible. These advances allow production of a more comprehensive inventory with both improved detection (i.e., more wetlands identified) and better classification detail. Also, the Massachusetts Department of Environmental Protection produced wetland data from 1990-1993 large-scale (1:12,000) aerial photos. The availability of 1999 aerial imagery made it possible for NWI to generate a more up-to-date wetland inventory for the Cape Cod region than the original NWI. The NWI also created additional descriptors for landscape position, landform, water flow path, and waterbody type (LLWW descriptors) to expand wetland classification that allowed for more detailed classification of types that could be used to perform a preliminary assessment of functions for wetlands in the region.

This publication reports on the methods and the findings of the updated and enhanced wetland inventory. It includes information on wetland status (e.g., acreage of different wetland types) and a preliminary functional assessment of wetlands. The functional assessment highlights wetlands that are predicted to perform eleven functions at significant levels and includes thematic maps showing the location of these wetlands. The report also contains a brief description of the region's wetland types to introduce readers to the diversity of wetland plant communities found on Cape Cod and the islands. Appendices provide NWI classification coding (Appendix A), coding for LLWW types (Appendix B), correlation between wetland characteristics and functions (Appendix C), and an overview of wetland values (Appendix D).

Study Area

The study area includes Barnstable, Dukes, and Nantucket Counties and a portion of Plymouth County (Figure 1). It encompasses approximately 665 square miles of land area and represents about eight percent of the Commonwealth of Massachusetts. For reporting purposes, the study area was subdivided into four areas: 1) Cape Cod and vicinity (Barnstable County and a small portion of Plymouth County), 2) Elizabeth Islands, 3) Martha's Vineyard, and 4) Nantucket. The Elizabeth Islands are comprised of several islands: Cuttyhunk, Nashawena, Naushon, Nonamesset, Pasque, Penikese, Weepecket Islands, and Uncatena. Note: Nomans Land Island was not included in the study area.

Figure 1. Approximate limits of study area in southeastern Massachusetts: Barnstable, Dukes, and Nantucket Counties and a portion of Plymouth County. Lines within counties represent town boundaries. (Base map from Massachusetts Department of Environmental Protection)



Overview of the NWI Wetland Definition and Classification System

Since some readers may be unfamiliar with the Service's wetland definition and classification system and this system serves as the foundation for this report, an introduction to the definition and classification is presented here. Other readers may simply proceed to the next section of this report on page 12.

Wetland Definition

Conceptually, wetlands usually lie between the better drained, rarely flooded uplands and the permanently flooded deep waters of lakes, rivers and coastal embayments. Wetlands include the variety of marshes, bogs, swamps, shallow ponds, and bottomland forests that occur throughout the country. They usually form in upland depressions or along rivers, lakes and coastal waters in areas subject to periodic flooding. Some wetlands, however, occur on slopes where they are associated with ground-water seepage areas or drainageways.

For mapping wetlands, the Service defines wetlands as follows:

> "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year." (Cowardin et al. 1979)

This definition emphasizes three key attributes of wetlands: (1) hydrology - the degree of flooding or soil saturation, (2) wetland vegetation (hydrophytes), and (3) hydric soils. All areas considered wetland must have enough water at some time during the year to stress plants and animals not adapted for life in water or saturated soils. Most wetlands have hydrophytes and hydric soils present, yet many are nonvegetated (e.g., tidal mudflats). Wetlands typically fall within one of the following four categories: (1) areas with both hydrophytes and hydric soils (e.g., marshes, swamps, and bogs), (2) areas without hydrophytes, but with hydric soils (e.g., farmed wetlands), (3) areas without soils but with hydrophytes (e.g., seaweed-covered rocky shores), and (4) periodically flooded areas without soil and without hydrophytes (e.g., gravel bars and tidal mudflats). All wetlands must be periodically saturated or covered by shallow water during the growing season, whether or not hydrophytes or hydric soils are present. Effectively drained hydric soils that are no longer capable of supporting hydrophytes due to a major change in hydrology are not considered wetland. Areas with effectively drained hydric soils are, however, good indicators of historic wetlands, which may be suitable for restoration.

The Service does not generally include permanently flooded deep water areas as wetland, although nontidal shallow waters (ponds) are classified as wetland. Instead, these deeper waterbodies are defined as deepwater habitats, since water and not air is the principal medium in which dominant organisms live. Along the coast in tidal areas, the deepwater habitat begins at the extreme spring low tide level. In nontidal freshwater areas, this habitat starts at a depth of 6.6 feet (2 m) because the shallow water areas are often vegetated with emergent wetland plants.

Wetland Classification

For the NWI, wetlands were classified following the Service's official wetland classification - Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979). This classification system has also been adopted as the federal wetland classification standard by the Federal Geographic Data Committee. The following discussion represents a simplified overview of the Service's wetland classification system. Since some of the more technical points have been omitted from this discussion, readers are advised to refer to the official classification document (Cowardin et al. 1979) when attempting to classify a wetland and should not rely solely on this overview.

The Service's wetland classification system is hierarchial or vertical in nature proceeding from general to specific, as noted in Figure 2. In this approach, wetlands are first defined at a rather broad level - the SYSTEM. The term SYSTEM represents "a complex of wetlands and deepwater habitats that share the influence of similar hydrologic, geomorphologic, chemical, or biological factors." Five systems are defined: Marine, Estuarine, Riverine, Lacustrine, and Palustrine. The Marine System generally consists of the open ocean and its associated high-energy coastline, while the Estuarine System encompasses salt and brackish marshes, nonvegetated tidal shores, and brackish waters of coastal rivers and embayments. Freshwater wetlands and deepwater habitats fall into one of the other three systems: Riverine (rivers and streams), Lacustrine (lakes, reservoirs, and large ponds), or Palustrine (e.g., marshes, bogs, swamps, and small shallow ponds). Thus, at the most general level, wetlands can be defined as either Marine, Estuarine, Riverine, Lacustrine or Palustrine (Figure 3).

Each system, with the exception of the Palustrine, is further subdivided into SUBSYSTEMS. The Marine and Estuarine Systems both have the same two subsystems, which are defined by tidal water levels: (1) Subtidal - continuously submerged areas and (2) Intertidal - areas alternately flooded by tides and exposed to air. Similarly, the Lacustrine System is separated into two systems based on water depth: (1) Littoral - wetlands extending from the lake shore to a depth of 6.6 feet (2 m) below low water or to the extent of nonpersistent emergents (e.g., arrowheads, pickerelweed, or spatterdock) if they grow beyond that depth, and (2) Limnetic - deepwater habitats lying beyond the 6.6 feet (2 m) at low water. By contrast, the Riverine System is further defined by four subsystems that represent different reaches of a flowing freshwater or lotic system: (1) Tidal - water levels subject to tidal fluctuations for at least part of the growing season, (2) Lower Perennial - permanent, flowing waters with a well-developed floodplain, (3) Upper Perennial - permanent, flowing water with very little or no floodplain development, and (4) Intermittent - channel containing nontidal flowing water for only part of the year.

Figure 2. Wetland and deepwater habitat classification hierarchy (Cowardin et al. 1979).

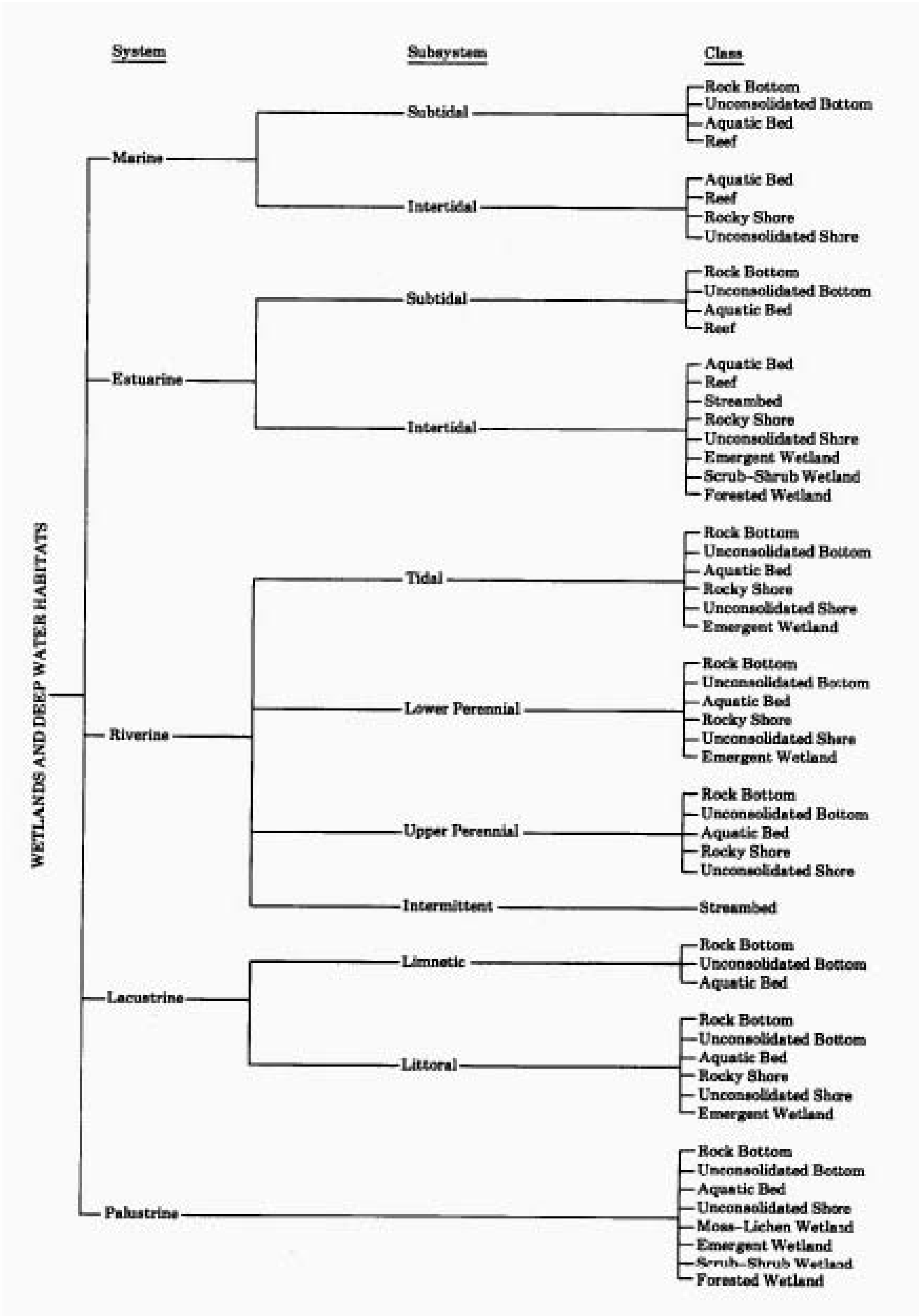
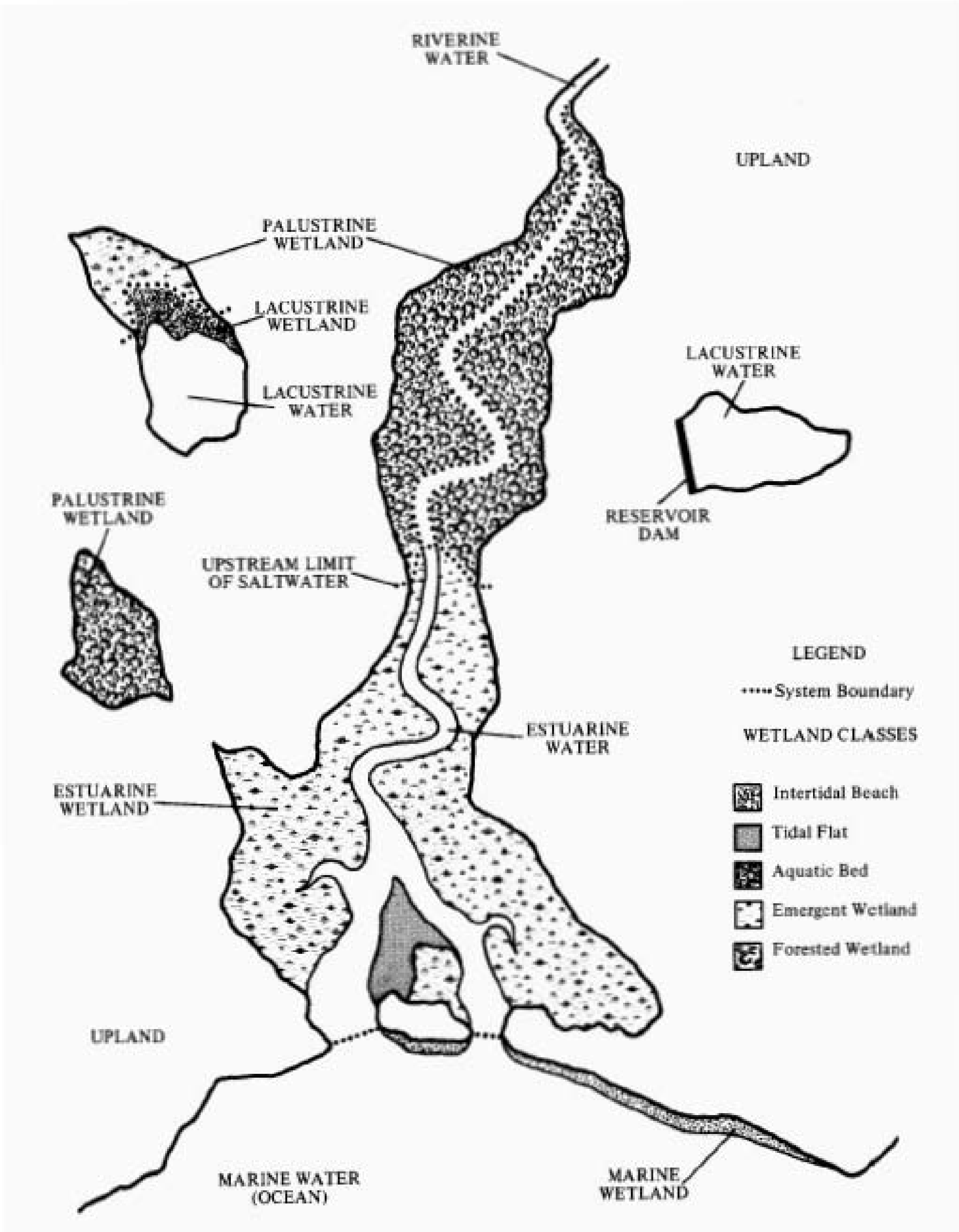


Figure 3. Schematic drawing showing positions and types of wetlands on the landscape.



The next level - CLASS - describes the general appearance of the wetland or deepwater habitat in terms of the dominant vegetative life form or the nature and composition of the substrate, where vegetative cover is less than 30% (Table 1). Of the 11 classes, five refer to areas where vegetation covers 30% or more of the surface: Aquatic Bed, Moss-Lichen Wetland, Emergent Wetland, Scrub-Shrub Wetland and Forested Wetland. The remaining six classes represent areas generally lacking vegetation, where the composition of the substrate and degree of flooding distinguish classes: Rock Bottom, Unconsolidated Bottom, Reef (sedentary invertebrate colony), Streambed, Rocky Shore, and Unconsolidated Shore. Permanently flooded nonvegetated areas are classified as either Rock Bottom or Unconsolidated Bottom, while exposed areas are typed as Streambed, Rocky Shore, or Unconsolidated Shore. Invertebrate reefs are found in both permanently flooded and exposed areas.

Each class is further divided into SUBCLASSES to better define the type of substrate in nonvegetated areas (e.g., bedrock, rubble, cobble-gravel, mud, sand, and organic) or the type of dominant vegetation (e.g., persistent or nonpersistent emergents, moss, lichen, or broad-leaved deciduous, needle-leaved deciduous, broad-leaved evergreen, needle-leaved evergreen, and dead woody plants). Below the subclass level, DOMINANCE TYPE can be applied to specify the predominant plant or animal in the wetland community.

To allow better description of a given wetland or deepwater habitat in regard to hydrologic, chemical, and soil characteristics and to human impacts, the classification system contains four types of specific modifiers: (1) Water Regime, (2) Water Chemistry, (3) Soil, and (4) Special. These modifiers may be applied to class and lower levels of the classification hierarchy.

Water regime modifiers describe flooding or soil saturation conditions and are divided into two main groups: tidal and nontidal. Tidal water regimes are used where water level fluctuations are largely driven by oceanic tides. Tidal regimes can be subdivided into two general categories, one for salt and brackish water tidal areas and another for freshwater tidal areas. This distinction is needed because of the special importance of seasonal river overflow and ground-water inflows in freshwater tidal areas. By contrast, nontidal modifiers define conditions where surface water runoff, ground-water discharge, and/or wind effects (i.e., lake seiches) cause water level changes. Both tidal and nontidal water regime modifiers are presented and briefly defined in Table 2.

Water chemistry modifiers are divided into two categories which describe the water's salinity or hydrogen ion concentration (pH): (1) salinity modifiers and (2) pH modifiers. Like water regimes, salinity modifiers have been further subdivided into two groups: halinity modifiers for tidal areas and salinity modifiers for nontidal areas. Estuarine and marine waters are dominated by sodium chloride, which is gradually diluted by fresh water as one moves upstream in coastal rivers. On the other hand, the salinity of inland waters is dominated by four major cations (i.e., calcium, magnesium, sodium, and potassium) and three major anions (i.e., carbonate, sulfate, and chloride). Interactions between precipitation, surface runoff, ground-water flow, evaporation, and sometimes plant evapotranspiration form inland salts which are most common in arid and semiarid regions of the country. Table 3 shows ranges of halinity and salinity modifiers which are a modification of the Venice System (Remane and Schlieper 1971). The other set of water chemistry modifiers are pH modifiers for identifying acid ($pH<5.5$), circumneutral (5.5-7.4) and alkaline ($pH>7.4$) waters. Some studies have shown a good correlation between plant distribution and pH levels (Sjors 1950; Jeglum 1971). Moreover, pH can be used to distinguish between mineral-rich (e.g., fens) and mineral-poor wetlands (e.g., bogs). For the current study, the acid modifier ("a") was applied to evergreen shrub bogs.

The third group of modifiers - soil modifiers - are presented because the nature of the soil exerts strong influences on plant growth and reproduction as well as on the animals living in it. Two soil modifiers are given: (1) mineral and (2) organic. In general, if a soil has 20% or more organic matter by weight in the upper 16 inches, it is considered an organic soil, whereas if it has less than this amount, it is a mineral soil. For specific definitions, please refer to Appendix D of the Service's classification system (Cowardin et al. 1979) or to Soil Taxonomy (Soil Survey Staff 1975). For the current study, the organic modifier was applied to palustrine evergreen forested wetlands that were dominated by Atlantic white cedar (Chamaecyparis thyoides).

The final set of modifiers - special modifiers - were established to describe the activities of people or beaver affecting wetlands and deepwater habitats. These modifiers include: excavated, impounded (i.e., to obstruct outflow of water), diked (i.e., to obstruct inflow of water), partly drained, farmed, and artificial (i.e., materials deposited to create or modify a wetland or deepwater habitat).

Table 1. Classes and subclasses of wetlands and deepwater habitats (Cowardin et al. 1979).

Class	Brief Description	Subclasses
Rock Bottom	Generally permanently flooded areas with bottom substrates consisting of at least 75% stones and boulders and less than 30% vegetative cover.	Bedrock; Rubble
Unconsolidated Bottom	Generally permanently flooded areas with bottom substrates consisting of at least 25% particles smaller than stones and less than 30% vegetative cover.	Cobble-gravel; Sand; Mud; Organic
Aquatic Bed	Generally permanently flooded areas vegetated by plants growing principally on or below the water surface line.	Algal; Aquatic Moss; Rooted Vascular; Floating Vascular
Reef	Ridge-like or mound-like structures formed by the colonization and growth of sedentary invertebrates.	Coral; Mollusk; Worm
Streambed	Channel whose bottom is completely dewatered at low water periods.	Bedrock; Rubble; Cobble-gravel; Sand; Mud; Organic; Vegetated
Rocky Shore	Wetlands characterized by bedrock, stones or boulders with areal coverage of 75% or more and with less than 30% coverage by vegetation.	Bedrock; Rubble
Unconsolidated Shore	Wetlands having unconsolidated substrates with less than 75% coverage by stone, boulders and bedrock and less than 30% vegetative cover, except by pioneer plants.	Cobble-gravel; Sand; Mud; Organic; Vegetated
Moss-Lichen Wetland	Wetlands dominated by mosses or lichens where other plants have less than 30% coverage.	Moss; Lichen
Emergent Wetland	Wetlands dominated by erect, rooted, herbaceous hydrophytes.	Persistent; Nonpersistent
Scrub-Shrub Wetland	Wetlands dominated by woody vegetation less than 20 feet (6 m) tall.	Broad-leaved Deciduous; Needle-leaved Deciduous; Broad-leaved Evergreen; Needle-leaved Evergreen; Dead
Forested Wetland	Wetlands dominated by woody vegetation 20 feet (6 m) or taller.	Broad-leaved Deciduous; Needle-leaved Deciduous; Broad-leaved Evergreen; Needle-leaved Evergreen; Dead

Table 2. Water regime modifiers, both tidal and nontidal groups (Cowardin *et al*. 1979).

Group	Type of Water	Water Regime	Definition
Tidal	Saltwater and brackish areas	Subtidal	Permanently flooded tidal waters
		Irregularly exposed	Exposed less often than daily by tides
		Regularly flooded	Daily tidal flooding and exposure to air
		Irregularly flooded	Flooded less often than daily and typically exposed to air
	Freshwater	Permanently flooded-tidal	Permanently flooded by tides and river or exposed irregularly by tides
		Semipermanently flooded-tidal	Flooded for most of the growing season by river overflow but with tidal fluctuation in water levels
		Regularly flooded	Daily tidal flooding and exposure to air
		Seasonally flooded-tidal	Flooded irregularly by tides and seasonally by river overflow
		Temporarily flooded-tidal	Flooded irregularly by tides and for brief periods during growing season by river overflow
Nontidal	Inland freshwater and saline areas	Permanently flooded	Flooded throughout the year in all years
		Intermittently exposed	Flooded year-round except during extreme droughts
		Semipermanently flooded	Flooded throughout the growing season in most years
		Seasonally flooded	Flooded for extended periods in growing season, but surface water is usually absent by end of growing season
		Saturated	Surface water is seldom present, but substrate is saturated to the surface for most of the season
		Temporarily flooded	Flooded for only brief periods during growing season, with water table usually well below the soil surface for most of the season

Intermittently flooded	Substrate is usually exposed and only flooded for variable periods without detectable seasonal periodicity (not always wetland; may be upland in some situations)
Artificially flooded	Duration and amount of flooding is controlled by means of pumps or siphons in combination with dikes or dams

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Table 3. Salinity modifiers for coastal and inland areas (Cowardin *et al.* 1979).

Coastal Modifiers[1]	**Inland Modifiers**[2]	**Salinity (‰)**	**Approximate Specific Conductance (Mhos at 25° C)**
Hyperhaline	Hypersaline	> 40	> 60,000
Euhaline	Eusaline	30-40	45,000-60,000
Mixohaline (Brackish)	Mixosaline[3]	0.5-30	800-45,000
Polyhaline	Polysaline	18-30	30,000-45,000
Mesohaline	Mesosaline	5-18	8,000-30,000
Oligohaline	Oligosaline	0.5-5	800-8,000
Fresh	Fresh	< 0.5	< 800

[1]Coastal modifiers are employed in the Marine and Estuarine Systems.

[2]Inland modifiers are employed in the Riverine, Lacustrine and Palustrine Systems.

[3]The term "brackish" should not be used for inland wetlands or deepwater habitats.

Methods

The project involved several steps: 1) updating the basic wetlands data, 2) enhancing the wetland classification, 3) correlating wetland types with wetland functions, 4) analyzing data and compiling summary statistics and preparing thematic maps for the report, and 5) report preparation.

Updating the Wetland Data

For updating purposes, two sets of wetland digital data were available: 1) the original NWI data compiled from 1970s aerial photography (1:80,000 black and white) and 2) Massachusetts Department of Environment Protection's Wetland Conservancy Program data produced from April 1993 color infrared aerial photography (except for a small portion of Wareham derived from April 1990 photography). The latter data utilized a more general wetland classification scheme where wetlands were placed into broad categories (e.g., salt marsh, freshwater marsh, wet meadow, shrub swamp, and wooded swamp), yet the data were more detailed and current than the original NWI data. Consequently, the wetland polygons from the Massachusetts data were selected as the data to use as the foundation for the update.

The wetland polygons were re-examined and classified according to the official U.S. Fish and Wildlife Service wetlands classification system (Cowardin et al. 1979; Appendix A).[4] Polygons were subdivided into smaller units as necessitated by the wetland type. This allowed more detailed classification of wetlands by vegetation, hydrology, water chemistry, and special modifiers. Recent (1991) 1:40,000 color infrared photography was then used to review and revise the wetland boundaries where necessary. After this, 1999 black and white photography (1:40,000) was used to create a more up-to-date database. The intermediate step (i.e., interpreting the 1991 photography) was necessary since the color infrared film offers significant advantages over black and white film for wetland detection (Tiner 1990). If the 1999 photos were color infrared, this intermediate step would not have been needed.

Three collateral digital data sources were used to aid in the photointerpretation: 1) the original NWI data, 2) U.S.D.A. Natural Resources Conservation Service digital soil survey data, and 3) U.S. Geological Survey digital line graphs (DLGs) for 1:24,000 hydrology data. Hydric soil mapping units were culled from the soils data base to identify potential wetland sites. The DLGs were used to represent stream locations.

A fourth source of digital data – Massachusetts eelgrass data – was added to the NWI database (http://www.mass.gov/mgis/eelgrass.htm) to include these valuable aquatic resources in the

[4] This classification was adopted by the Federal Geographic Data Committee as the national standard for classifying wetlands when creating federally supported geospatial data (Federal Geographic Data Committee 1996).

inventory. Most of these beds were subtidal and were therefore classified as estuarine or marine subtidal aquatic bed deepwater habitats.

Enhancing the NWI Data For Functional Assessment

While recognizing the value of the Cowardin et al. system for addressing biotic components of wetlands, Dr. Mark Brinson found it lacking in coverage of certain abiotic features (i.e., geomorphic setting, water sources, and hydrodynamics) that were vital for assessing wetland functions. Consequently, he developed the hydrogeomorphic classification (Brinson 1993), yet in this system, he used some of the Cowardin terms but defined them differently (e.g., Riverine and Lacustrine) making it impossible to simply add the hydrogeomorphic terms to the NWI wetland types to improve wetland classification. Brinson stated that his classification was, however, "a generic approach to classification and not a specific one to be used in practice." Expectations were that the approach would be modified regionally and eventually merged with other classifications that dealt with biotic features.

To use NWI data for landscape-level analysis, one could either expand the classification of individual wetlands or use other geospatial databases and analytical procedures to group wetlands into categories suitable for predicting wetland functions. The latter could be done on a project-by-project basis, while the former would provide a more comprehensive wetland database that could be used for functional assessment as well as for other purposes (e.g., to better characterize wetlands). Given that the NWI will continue to be updated, it made sense to develop more descriptors to expand the NWI database. Recognizing the value of adding hydrogeomorphic properties to the NWI database (i.e., increased functionality), a set of hydrogeomorphic-type descriptors were developed that could be added to NWI types to facilitate predicting wetland functions. The combination of these attributes with traditional NWI types can be called "NWIPlus" resulting in an enhanced NWI database (Tiner 2010).

The new attributes describe landscape position, landform, water flow path, and waterbody type – "LLWW descriptors."[5] Dichotomous keys have been developed to interpret these attributes (Tiner 2003a). Table 4 provides a set of simplified dichotomous keys for applying these descriptors (see Appendix B for coding scheme). LLWW descriptors are added to the project's wetland database by interpreting topography from digital raster graphics (DRGs) or by analyzing more detailed topographic data. Stream courses now come from national hydrographic data (NHD) and waterbody types from interpreting aerial imagery. While the interpretations for this project were done manually by trained wetland image-analysts, automated tools have been develop to facilitate GIS-based classifications which then are reviewed and edited by wetland specialists.

For this project, LLWW descriptors were applied to all wetlands in the NWI digital database. To determine these properties, NWI data were viewed with on-line U.S. Geological Survey topographic maps (digital raster graphics) to identify wetlands along streams and general slope characteristics and aerial imagery was used to determine waterbody types (e.g., ponds).

[5] LLWW stands for the first letter in each descriptor (landscape position, landform, water flow path, and waterbody type).

Landscape position defines the relationship between a wetland and an adjacent waterbody, if present. Six wetland landscape positions were identified: 1) marine – on the shores of the open ocean and its embayments, 2) estuarine - associated with tidal brackish waters (estuaries), 3) lotic - along freshwater rivers and streams and periodically flooded at least during high discharge periods (including freshwater tidal reaches of coastal rivers), 4) lentic - in lakes, reservoirs, and their basins where water levels are significantly affected by the presence of these waterbodies, and 5) terrene - isolated or headwater wetlands, fragments of former isolated or headwater wetlands that are now connected to downslope wetlands via drainage ditches, and wetlands on broad, flat terrain cut through by stream but where overbank flooding does not occur (e.g., hydrologically decoupled from streams). Lotic wetlands are further separated by river and stream sections (based on watercourse width - polygon = river vs. linear = stream at a scale of 1:24,000) and then divided into one of five gradients: 1) high (e.g., shallow mountain streams on steep slopes - not present in the study areas), 2) middle (e.g., streams with moderate slopes - not present in the study areas), 3) low (e.g., mainstem rivers with considerable floodplain development and slow-moving streams), 4) intermittent (i.e., periodic flows), and 5) tidal (i.e., under the influence of the tides). Figure 4 shows the general location of these wetland types across the landscape.

Landform is the physical form of a wetland or the predominant land mass upon which it occurs (e.g., floodplain). Eight types are recognized: basin, flat, floodplain, fringe, island, slope, and interfluve (see Table 5 for definitions).

Additional modifiers were assigned to indicate water flow paths associated with wetlands: bidirectional-tidal, bidirectional-nontidal, throughflow, inflow, outflow, or isolated. Surface water connections are emphasized because they are more readily identified than groundwater linkages. Bidirectional flow is two-way flow either related to tidal influence (bidirectional-tidal) or water level fluctuations in lakes and impoundments (bidirectional-nontidal). Throughflow wetlands have either a watercourse or another type of wetland above and below them, so water flows through these wetlands. Most lotic wetlands are throughflow types. Inflow wetlands are sinks where no surface water outlets exist, yet water is entering via a stream or river (often intermittent) or an upslope wetland. Outflow wetlands have water leaving them and moving downstream via a watercourse or a slope wetland; they are often sources of streams. Isolated wetlands are essentially closed (“geographically isolated”) depressions or flats where water comes from direct precipitation, localized surface water runoff, and/or ground water discharge. From the surface water perspective, these wetlands are “isolated” from other wetlands since they lack an apparent surface water connection, however it must be recognized that they may be hydrologically linked to other wetlands and waterbodies via groundwater, while others may be connected by small streams that were not mapped on the collateral data sources.

Other descriptors applied to mapped wetlands include headwater, drainage-divide, and partly drained. Headwater wetlands are sources of streams or wetlands along first-order (perennial) streams. Drainage-divide wetlands are wetlands that have outflow in two directions to two separate drainage systems. Partly drained wetlands are typically ditched wetlands.

For open water habitats, additional descriptors following Tiner (2003a) were applied including water flow path, and pond, estuary, and lake types. Since ponds were separated from wetlands for the LLWW classification, wetland acreage totals will be different between NWI and LLWW. Also, in a number of cases, large ponds (generally 10 acres or greater in size), particularly kettle ponds on the Cape, were believed to contain water deeper than 6.6 feet (2 m), so they were classified as lakes rather than ponds in LLWW. NWI routinely classifies open water areas 20 acres or smaller as palustrine unconsolidated bottom wetlands. These areas were not reclassified as lacustrine in the NWI database, so deepwater habitat acreage of lacustrine waters and acreage of palustrine unconsolidated bottoms based on NWI will be different than LLWW totals for lakes and ponds. Ponds were separated into three categories: natural, dammed/impounded, and excavated.

Classifications were reviewed for accuracy prior to performing the analysis of wetland functions. Despite this review, it is possible that a few wetlands were misclassified due to the complexity and enormity of the dataset that contained over 14,000 polygons.

Besides providing more features that can be used to predict wetland functions from the original NWI database, NWIPlus (the addition of the LLWW descriptors) makes it possible to better characterize the nation's wetlands. For example, now all the palustrine wetlands which account for 95% of the wetlands in the conterminous U.S. can be linked to rivers, streams, lakes, ponds where appropriate, so the acreage of floodplain wetlands, lakeside wetlands, and geographically isolated wetlands can be reported. The Wetlands Subcommittee of the Federal Geographic Data Committee (FGDC) recognized the "value-added" of the LLWW descriptors and recommended that they be included in wetland mapping to increase the functionality of wetland inventory databases (FGDC Wetlands Subcommittee 2009).

Table 4. Simplified keys for classifying wetlands by landscape position, landform, and water flow path. (Adapted from Tiner 2003a)

Landscape Position

1. Wetland borders a river, stream, lake, reservoir, in-stream pond, estuary, or ocean……..2
1. Wetland does not border one of these waterbodies; it is surrounded by upland or borders a pond that is surrounded by upland……………………………………………Terrene
2. Wetland lies along an ocean shore and is subject to tidal flooding………………………Marine
2. Wetland does not lie along an ocean shore or if oceanside, it is not subject to tidal flooding..3
3. Wetland lies along an estuary (salt-brackish waters) and is subject to tidal flooding……Estuarine
3. Wetland does not lie along an estuary or if along the estuary, it is not subject to tidal flooding……………………………………………………………………………..4
4. Wetland lies along a lake or reservoir or within its basin (i.e., the relatively flat plain contiguous to the lake or reservoir)…………………………. ………………………..Lentic
4. Wetland lies along a river or stream, or in-stream pond, or borders a marine or estuarine wetland or associated waters but is not flooded by tides (except episodically)……….....5
5. Wetland is associated with a river or stream……………………………………………..6
5. Wetland is not associated with a river or stream; it is a freshwater nontidal wetland bordering a marine or estuarine wetland or associated waters.…………………………Terrene

6. Wetland is the source of a river or stream and this watercourse does not flow through the wetland………..………………………………………………………………………Terrene
6. A river or stream flows through or alongside the wetland ……………………………...7
7. Wetland is periodically flooded by river or stream ………..……………………………Lotic[6]
7. Wetland is not periodically flooded by the river or stream ………..……….………...Terrene

Landform

1. Wetland occurs on a slope >2%...Slope
1. Wetland does not occur on a slope >2%...2
2. Wetland forms an island completely surrounded by water…………….……….….…Island
2. Wetland does not form an island…….……………………………………….…….…….3
3. Wetland occurs in the shallow water zone of a permanent nontidal waterbody, the intertidal zone of an estuary with unrestricted tidal flow, or the regularly flooded (daily tidal inundation) zone of freshwater tidal wetlands……………….…..…….Fringe
3. Wetland does not occur in these waters or in estuarine intertidal zones with unrestricted tidal flow…………………………………………………..……..4
4. Wetland occurs in a portion of an estuary with restricted tidal flow due to tide gates, undersized culverts, dikes, or similar obstructions……..…………………………..…Basin
4. Wetland does not occur in such location……...……………………………………5
5. Wetland forms a nonvegetated bank or is within the banks of a river or stream…....Fringe
5. Wetland is a vegetated river or stream bank or not within the banks…….….……..6
6. Wetland occurs on an active alluvial plain of a river (a polygonal feature)[7]………. Floodplain*
6. Wetland does not occur on an active floodplain……………………………………7
7. Wetland occurs on a broad interstream divide (including headwater positions) associated with coastal or glaciolacustrine plains or similar plains…………….......Interfluve*
7. Wetland does not occur on such a landform...………………………………………8
8. Wetland occurs in a distinct depression…………………………………………..Basin
8. Wetland occurs on a nearly level landform…………………………………..……Flat

*Basin and Flat sub-landforms can be identified within these landforms when desirable.

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[6] Lotic wetlands are separated into river and stream sections (based on watercourse width - polygon = Lotic River vs. linear = Lotic Stream at a scale of 1:24,000) and then divided into one of five gradients: 1) high (e.g., shallow mountain streams on steep slopes), 2) middle (e.g., streams with moderate slopes), 3) low (e.g., mainstem rivers with considerable floodplain development and slow-moving streams), 4) intermittent (periodic flows), and 5) tidal (hydrology under the influence of the tides).

[7] For practical purposes, floodplain is restricted to rivers (i.e., polygonal watercourses); similar areas along streams (i.e., linear watercourses) are designated as basins or flats.

Table 4 (cont'd).

Water Flow Path[8]

1. Wetland is typically surrounded by upland (nonhydric soil); receives precipitation and runoff from adjacent areas with no apparent outflow[9]…..……..……………..…Isolated**
1. Wetland is not geographically isolated………………..……………………..……….2
2. Water flow is mainly bidirectional from tides or lake/reservoir fluctuations……..….3
2. Water flow is essential one-directional (downstream)…………………………...….4
3. Wetland is subjected to tidal flooding……………………………………Bidirectional-Tidal
3. Wetland is located along a lake or reservoir and not along a river or stream entering this type of waterbody; water levels are mainly affected by the rise and fall of lake or reservoir water levels ………..………………...Bidirectional-Nontidal***

4. Wetland is a sink, receiving water from a river, stream, or other surface water Source and lacking surface-water outflow………..………………………………Inflow
4. Wetland is not a sink; surface water flows through or out of the wetland…………...5
5. Water flows out of the wetland, but does not flow into this wetland from another source……………………………………………………………….…….Outflow
5. Water flows through the wetland, often coming from upstream or uphill sources (typically wetlands along rivers and streams)….………………..……..Throughflow

**Wetland is geographically isolated; hydrological relationship to other wetlands and watercourses may be more complex than can be determined by simple visual assessment of surface water conditions. If groundwater relationships are known can apply other water flow paths as appropriate, but add "groundwater" to the term (e.g., outflow-groundwater).

***Bidirectional-Nontidal flow could be expanded to reference the water flow path of the associated waterbody: BH – bidirectional-nontidal/throughflow, BN – Bidirectional-nontidal/inflow, BO – Bidirectional-nontidal/outflow, and BS – Bidirectional-nontidal/isolated.

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[8]Surface water connections are emphasized because they are more readily identified than groundwater linkages (see footnote below for paludified landscapes).

[9] Water flow path for some bogs and similar wetlands may be paludified; paludification processes occur in areas of low evapotranspiration and high rainfall, peat moss moves uphill creating wetlands on hillslopes (i.e., wetland develops upslope of primary water source).

Figure 4. Classification of nontidal wetlands by landscape position, landform and water flow path. Coding: TE (Terrene), LE (Lentic), LS (Lotic Stream), LR (Lotic River), BA (Basin), FP (Floodplain), SL (Slope), FR (Fringe), PD or pd (Pond), LK (Lake), TH (Throughflow), IS (Isolated), OU (Outflow), BI (Bidirectional-nontidal), and hw (headwater).

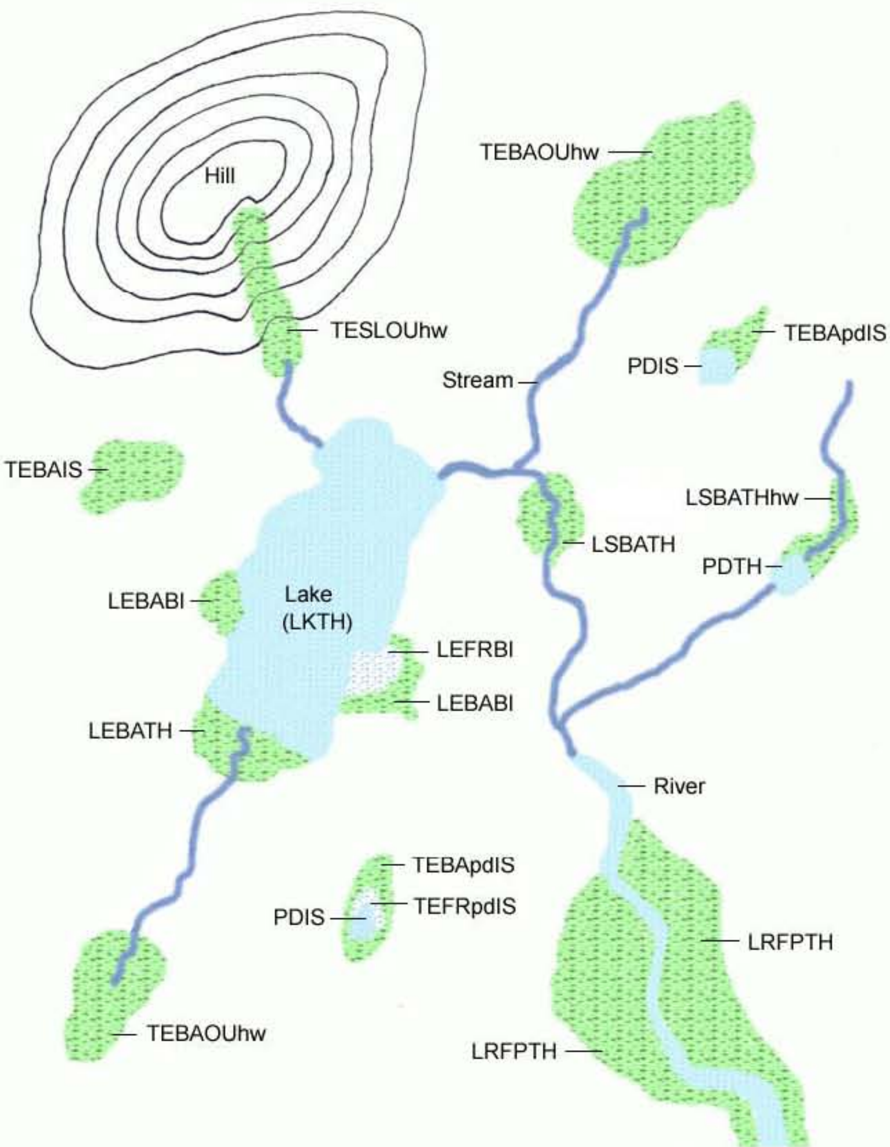


Table 5. Definitions and examples of landform types (Tiner 2003a). Map codes in parentheses.

Landform Type	General Definition	Examples
Basin* (BA)	a depressional (concave) landform	lakefill bogs; wetlands in the saddle between two hills; wetlands in closed or open depressions, including narrow stream valleys
Slope (SL)	a landform extending uphill (on a slope)	seepage wetlands on hillside; wetlands along drainageways or mountain streams on slopes
Flat* (FL)	a relatively level landform, often on broad, level landscapes	wetlands on flat areas with high seasonal ground-water levels; wetlands on terraces along rivers and streams; wetlands on hillside benches; wetlands at toes of slopes
Floodplain (FP)	a broad, generally flat landform occurring on a landscape shaped by fluvial or riverine processes	wetlands on alluvium; bottomland swamps
Interfluve (IF)	a broad, level to imperceptibly depressional poorly drained landform occurring between two drainage systems (on interstream divides)	flatwood wetlands on coastal or glaciolacustrine plains
Fringe (FR)	a landform occurring along a flowing or standing waterbody (lake, river, stream) and typically subject to permanent, semipermanent, or tidal flooding	buttonbush swamps; aquatic beds; semipermanently flooded marshes; wetlands in river channels; salt and brackish marshes with unrestricted tidal flow
Island (IL)	a landform completely surrounded by water (including deltas)	deltaic and insular wetlands; floating bog islands

*May be applied as sub-landforms within the Interfluve (IFba, IFfl) and Floodplain (FPba, FPfl).

Preliminary Assessment of Wetland Functions

After creating the NWIPlus database (the enhanced NWI database), analyses were performed to produce a preliminary assessment of wetland functions for the study area. Both wetlands and ponds were evaluated for performance of eleven functions: 1) surface water detention, 2) streamflow maintenance, 3) nutrient transformation, 4) sediment and other particulate retention, 5) coastal storm surge detention, 6) shoreline stabilization, 7) provision of fish and shellfish habitat, 8) provision of waterfowl and waterbird habitat, 9) provision of other wildlife habitat, 10) conservation of biodiversity, and 11) carbon sequestration.

This study employed a landscape-level functional assessment approach that may be called "Watershed-based Preliminary Assessment of Wetland Functions" (W-PAWF). W-PAWF applies general knowledge about wetlands and their functions to develop a watershed or area-wide overview that highlights possible wetlands of significance in terms of performance of various functions. The rationale for correlating wetland characteristics with wetland functions is described in a separate report (Tiner 2003b, posted online at: http://www.fws.gov/nwi/PubsReports/HGMReportOctober2003.pdf). These correlations are outlined in Appendix C. A few departures from the original correlation document were made for various reasons. The criteria for provision of other wildlife habitat were modified as follows: vegetated wetland polygons 10 acres or larger were designated as having high potential, while smaller vegetated wetland polygons were identified as moderate; semipermanently flooded, semipermanently flooded-tidal, estuarine aquatic beds, and farmed wetlands (commercial cranberry bogs) were excluded. This was done to simplify the selection process as the GIS specialist was having some difficulty identifying large wetland complexes as one unit to evaluate the size criteria. It was easier to use NWI polygons for this function, hence the change in the criteria. For the conservation of biodiversity, the following types were identified as uncommon types in the study area or as wetlands that may possess high plant diversity: 1) tidal freshwater marsh, 2) tidal freshwater shrub swamp, 3) tidal freshwater forested wetland, 4) estuarine oligohaline (slightly brackish) marsh, 5) regularly flooded estuarine marsh (low marsh), 6) Atlantic white cedar swamp, 7) shrub bog, 8) semipermanently flooded wetlands, and 9) intertidal eelgrass. The presence of rare and endangered plants and animals were not used because such data requires field observations or merging with other datasets which was beyond the scope of this study. Carbon sequestration was added to the list of functions due to recent interest in conserving wetlands to reduce carbon dioxide release into the atmosphere. For this function, all seasonally flooded or wetter vegetated wetlands (including irregularly flooded and regularly flooded tidal wetlands) and cranberry bogs were rated as having high potential because they are likely to have high organic matter content due to long-term flooding or soil saturation. In contrast, temporarily flooded and seasonally saturated wetlands were rated as moderate since they experience long-term periods with low water tables that would oxidize organic matter in the upper soil layers. Intertidal aquatic beds were also rated as moderate since underground eelgrass biomass is substantial and contributes to carbon sequestration (Thom et al. 2001).

It is important to emphasize that W-PAWF is designed to reflect the potential of a wetland to provide a function (see next section: "General Scope and Limitations of the Inventory and Assessment" for details). It does not consider the condition of the adjacent upland (e.g., level of outside disturbance) or the actual water quality of the associated waterbody which may be regarded as important metrics for assessing the "health" or condition of individual wetlands.

Data Analysis and Compilation

ArcInfo 9.0 was used to analyze the data and produce wetland statistics (acreage summaries) for the study areas. Tables were prepared to summarize the results of the inventory (i.e., the extent of different wetland types by NWI classifications) and to correlate wetland characteristics with wetland functions to identify wetlands of significance for 11 functions. After running the analyses, a series of maps were generated to display the variety of wetland types and to highlight wetlands that may perform various functions at significant levels. Statistics (acreage summaries) were mostly generated from Microsoft's Access program, whereas topical maps were generated by ArcView software. For carbon sequestration and other wildlife habitat assessments, Excel spreadsheets were used to compile the summary statistics; no maps were prepared due to time and budget limitations. *Special Note: When summarizing data, percentages given usually refer to percent of wetland acreage, while for convenience, the narrative will refer to them as "percent of wetlands." In reference to ponds, the actual number of ponds mapped is known, so both percent of wetlands by number and by acreage are reported*.

Field Work

Most recently, field work was performed from May 20-22, 2009 to collect data for preparing general descriptions of wetland plant communities on Cape Cod for this report. When the NWI data were updated in the early 2000s, limited field checking was performed on Cape Cod to review some LLWW classifications. Previously, when the original NWI data were collected in the late 1970s/early 1980s, wetland delineations and classifications were reviewed in the field with University of Massachusetts interpreters and the state wetland data were field checked by Massachusetts Department of Environmental Protection personnel.

General Scope and Limitations of the Inventory and Assessment

Wetland Inventory and Digital Database

Since the NWI data were derived from 1999 imagery, changes in some wetlands have occurred that are not reflected in the database. These changes may be due to permitted alterations by federal, state, and local governments or to natural process including erosion, accretion, and sea-level rise. Despite this, the 1999 database should reasonably reflect contemporary conditions because wetlands in this area are well regulated.

It is important to recognize the limitations of any wetland mapping effort derived mainly through photointerpretation techniques (see Tiner 1990, 1997, and 1999 for details). NWI data or any other wetland data derived from these techniques do not show all wetlands. Some wetlands are simply too small to map given the imagery used, while others avoid detection due to evergreen tree cover, dry surface conditions, or other factors. The minimum size of wetland targeted mapping unit was one acre, but many wetlands (especially ponds) smaller than this were mapped. Wetland units may contain small areas that are different from the mapped type (inclusions) due to scale and map complexity issues. For example, a 10-acre forested wetland may include a 1-acre stand of emergent wetland and a 1-acre upland island. Also the use of spring (leaf-off) aerial photography for wetland mapping precluded identification of freshwater aquatic beds that are most evident in summer. Because the vegetation was not developed, such areas are included within areas mapped as open water (e.g., lacustrine and palustrine unconsolidated bottom) as they appear as water on the aerial photographs. Drier-end wetlands such as seasonally saturated and temporarily flooded palustrine wetlands are often difficult to separate from nonwetlands through photointerpretation. Finally, despite our best attempts at quality control, some errors of interpretation and classification are likely to occur due to the sheer number of polygons in the wetland database (over 14,000).

Differences between LLWW and NWI Summaries

When comparing the LLWW stats with NWI stats, some differences in what appear to be similar types will occur due to different definitions, mainly for estuarine wetlands and open water of lakes and ponds (or palustrine unconsolidated bottoms in NWI). The acreage of estuarine wetlands according to the LLWW classification will be greater than the NWI totals for estuarine wetlands because the estuarine definition of LLWW included tidally influenced freshwater wetlands contiguous with salt and brackish marshes in the estuarine category (e.g., PFO1R and PEM1R).[10] Tidal freshwater wetlands further

[10] Since this project's completion, to avoid this confusion, LLWW estuarine wetlands are restricted to salt and brackish wetlands so the acreage will be the same as NWI estuarine wetlands; the tidally influenced freshwater wetlands contiguous to salt and brackish marshes will be classified as terrene wetlands with an "ed" modifier to indicated discharge to an estuarine wetland.

upstream along tidal fresh rivers and streams were designated as lotic tidal wetlands. When reporting on extent of estuarine wetlands (saltwater-influenced) wetlands, the NWI data should be referenced. Pond and lake acreage also differ between the two classifications, with lake acreage being greater and pond acreage less according to LLWW summaries. By mapping convention, NWI included all standing freshwater bodies less than 20 acres in size as palustrine unconsolidated bottom, whereas upon closer inspection by this project, water bodies in the 10-20 acre range appeared to have water depths greater than 6.6 feet (2m) at mean low water and were classified as lakes by LLWW. Also NWI mapped the following small lakeside water bodies as palustrine unconsolidated bottom: contiguous open water bodies that appeared to be cut off by a road and an open water area enclosed within a lakeshore marsh. LLWW treated these waters as part of the lake as they are open water hydrologically connected to the lake (i.e., their water levels rise and fall with lake levels). NWI data were not changed to reflect these differences, hence the acreage discrepancies.

Preliminary Assessment of Wetland Functions

The landscape-level functional assessment employed in this study is a preliminary one based on wetland characteristics interpreted through remote sensing and using the best professional judgment of the author and other wetland specialists. Wetlands believed to be providing high and moderate levels of performance for a particular function were highlighted. As the focus of this report is on wetlands, a functional assessment of deepwater habitats (e.g., lakes, rivers, estuaries, and submerged marine aquatic beds) and linear features such as perennial and intermittent streams was not done. The importance of permanently flooded habitats to fish, for example, should be obvious and the beneficial functions of small streams (even intermittent ones) to water quality and sediment retention should also be recognized (Meyer et al. 2003). Also, no attempt was made to produce a more qualitative ranking for each function or for each wetland based on multiple functions as this would require more input from other sources, well beyond the scope of this study. For a technical review of wetland functions, see Mitsch and Gosselink (2008) and for a broad overview, see Tiner (2005).

Functional assessment of wetlands can involve many parameters. Typically such assessments have been done in the field on a case-by-case basis, by considering observed features relative to those required to perform certain functions or by actual measurement of performance. The present study does not seek to replace the need for such evaluations as they are the ultimate assessment of the functions for individual wetlands. Yet, for a landscape-level analysis, area-wide on-the-ground assessments are not practical or cost-effective or even possible given access considerations. For watershed planning and landscape-level evaluation purposes, a more generalized assessment is worthwhile for targeting wetlands that may provide certain functions, especially for those functions dependent on landscape position, landform, vegetation life form, and other photointerpretable features. These preliminary results can be field-verified when evaluating particular wetlands for acquisition, e.g., for conservation of biodiversity or for preserving flood storage capacity. More recent aerial photography may also be examined to aid in further evaluations (e.g., condition of wetland/stream buffers or adjacent land use) that can supplement this preliminary assessment.

This study employed a landscape-level or watershed assessment approach called "Watershed-based Preliminary Assessment of Wetland Functions" (W-PAWF). W-PAWF applies general knowledge about wetlands and their functions to develop a watershed overview that highlights possible wetlands of significance for various functions. To accomplish this objective, the relationships between wetlands and various functions must be simplified into a set of practical criteria or observable characteristics. Such assessments could be further expanded to consider the condition of the associated waterbody and the neighboring upland or to evaluate the opportunity a wetland has to perform a particular function or service to society.

W-PAWF does not account for the opportunity that a wetland has to provide a function resulting from a certain land-use practice upstream or the presence of certain structures or land-uses downstream. For example, two wetlands of equal size and like vegetation may be in the right landscape position to retain sediments. One, however, may be downstream of a land-clearing operation that has generated considerable suspended sediments in the water column, while the other is downstream from an undisturbed forest. The former should be actively performing sediment trapping in a major way, while the latter is not accumulating as much material. Yet if land-clearing takes place upstream of the latter area, the second wetland will likely trap sediments as well as the first wetland. The entire analysis typically tends to ignore opportunity since such opportunity may have occurred in the past or may occur in the future and the wetland is awaiting a call to perform this service at higher levels than presently…the potential is there.

W-PAWF also does not consider the condition of the adjacent upland (e.g., level of disturbance) or the actual water quality of the associated waterbody which may be regarded as important metrics for assessing the health of individual wetlands (not part of this study).

This preliminary assessment does not obviate the need for more detailed assessments of the various functions. It should be viewed as a starting point for more rigorous assessments, as it attempts to cull out wetlands that may likely provide significant functions based on generally accepted principles and the source information used for this analysis. This type of assessment is most useful for regional or watershed planning. The data may also be useful for town-wide assessments and other geographic area-specific evaluations, yet the wetland classifications (both NWI and LLWW) should be field checked for accuracy as this will influence the functional assessment results. The wetland characteristics/function correlations presented in this assessment method could serve as a rapid site-assessment technique to gain a general sense of what functions are likely to be performed by a particular wetland, with more in-depth site evaluation following other assessment methods conducted as necessary depending on project objectives. This is particularly true for assessing fish and wildlife habitats and biodiversity. Other sources of data may exist to help refine some of the findings of this report. Additional modeling could be done, for example, to identify habitats of likely significance to individual species of animals (based on their specific life history requirements). Massachusetts Natural Heritage & Endangered Species Program data could be used to highlight wetlands supporting rare, threatened, and endangered species.

Field checking of seasonally flooded and seasonally flooded/saturated emergent wetlands (PEM1C and PEM1E wetlands) should be done to determine if they are marshes or wet meadows. If the former, they will likely have high potential for both fish/shellfish habitat and waterfowl/waterbird habitat rather than the moderate rating given in this report.

For this report, no maps highlighting carbon sequestration or the provision of other wildlife habitat were prepared due to time and budget constraints. For the provision of other wildlife habitat, this assessment focused on the size of vegetated wetland polygons. Consequently, some smaller polygons associated with large wetland complexes were designated as moderate in the data summaries, whereas the larger polygons in the same complex were identified as high. In practice, the entire complex should be treated as high. It is important to recognize that intertidal beaches are used by seals as resting and breeding areas (haul-out areas). On Monomoy Island, huge congregations of gray seals can be seen on the beaches (Figure 5) where females give birth to pups from late December to mid-February (Provincetown Center for Coastal Studies; http://www.coastalstudies.org/what-we-do/stellwagen-bank/seal-identification.htm).

Figure 5. Gray seals resting on a Monomoy Island beach. (Keith Shannon photo)

Results

Wetland Plant Communities

The following narrative was developed from field notes taken by the author and a review of some publications dealing with wetlands in the study area (e.g., Swain and Kearsley 2001, Tiner 2009). This discussion should provide readers with a sense of the variety of species colonizing and representing different wetland types in the study area. It is intended simply as an introduction and therefore does not include a comprehensive examination of the region's wetland flora. Some examples of the region's wetlands are shown in Figures 6-16. The text includes some discussion of rare plants and animals; further information on this topic can be gained from the Massachusetts Natural Heritage and Endangered Species Program. Summary information on general wetland values can be found in Appendix D which was taken from the state wetland report for Rhode Island (Tiner 1989). Nomenclature used in the following text follows that reported in the U.S.D.A. plants database (http://plants.usda.gov/).

Marine and Estuarine Tidal Flats

These wetlands are largely nonvegetated flats composed of various combinations of sand, silt, and clay (Figure 6). Some flats may be colonized by sea lettuce (*Ulva lactuca*) and filamentous green algae (*Enteromorpha intestinalis*), while others may support beds of eelgrass (*Zostera marina*) and widgeon-grass (*Ruppia maritima*) – species that are more typical of shallow estuarine waters. The common mudsnail (*Ilyanassa obsoleta*), diatoms, and microalgae may be especially abundant on some tidal flats. Tidal flats are important feeding areas for shorebirds at low tide and for fish, macroinvertebrates (e.g., crabs), terns and other water birds at high tide.

Figure 6. Intertidal sand flat along exposed shoreline. (Kate Iaquinto photo)

Estuarine Vegetated Wetlands

Tidal wetlands formed along salt and brackish tidal waters are classified as estuarine wetlands. Their plant composition varies with that of the waterbody. Those closest to the ocean are called "salt marshes" due to their relatively high salinities. Those occurring along tidal rivers and streams where salt water is significantly diluted by fresh water may be called "brackish marshes."

Salt Marshes

Environmental conditions above the tidal flats are suitable for the establishment of vascular plant communities. Salt marshes occur from about mean sea level to an elevation frequently inundated by tides where salt water continues to stress vegetation (Figure 7). The marsh may be divided into two zones based on the frequency of flooding: low marsh (lowest elevations subject to daily flooding – regularly flooded) and high marsh (flooded less often – irregularly flooded – and only completely submerged by the highest tides usually associated with full and new moons and coastal storms). The diversity of habitats within salt marshes (e.g., grasslands, shrublands, creeks, ponds, and saline depressions) and their connection with estuarine and marine waters make them vital resources for many fish and wildlife species. Killifishes (*Fundulus* spp.), juveniles of other species, and grass shrimp (*Palaemonetes* spp.) frequent the marshes at high tide where they feed and seek shelter from predatory fishes. Salt marshes are important for both resident and migratory bird species. Moreover, they are among the nature's most productive natural habitats.

Figure 7. Cape Cod salt marsh.

The low marsh is characterized by the dominance of smooth cordgrass (*Spartina alterniflora*). Here due to frequent tidal flushing and other factors, it grows in a tall form (roughly 4-6 feet tall). In general, the low marsh is limited to creek banks and newly formed marshes on tidal flats. Among the few other species found in this zone are common glasswort (*Salicornia depressa*) and brown algae (knotted seaweed, *Ascophyllum nodosum* or rockweed, *Fucus vesciculosus*).

The high marsh contains a more diverse assemblage of plants. The interior of the high marsh is often pure or mixed stands of one or more species: smooth cordgrass (short form), salt hay cordgrass (*Spartina patens*), salt grass (*Distichlis spicata*), and black grass (*Juncus gerardii*). Other high marsh species include sea lavender (*Limonium* spp.), seaside gerardia (*Agalinis maritima*), seaside arrow-grass (*Triglochin maritima*), seaside plantain (*Plantago maritima*), silverweed (*Argentina anserina*), salt marsh bulrush (*Schoenoplectus robustus*), marsh orach (*Atriplex patula*), salt marsh sand spurrey (*Spergularia salina*), and salt marsh aster (*Symplotrichum tenuifolium*). Depressions in the high marsh that concentrate salts and have salinities well above that of sea water are colonized by the most salt tolerant species including glassworts (*Salicornia* spp.) and the short form of smooth cordgrass. Depressions that are permanently flooded (salt marsh ponds) may be vegetated by widgeon-grass.

The upper border of the high marsh is more diverse, given less salt stress. Plants here may include prairie cordgrass (*Spartina pectinata*), common three-square (*Schoenoplectus pungens*), creeping bent grass (*Agrostis stolonifera*), switchgrass (*Panicum virgatum*), seaside goldenrod (*Solidago sempervirens*), grass-leaved goldenrod (*Euthamia graminifolia*), high-tide bush or marsh elder (*Iva frutescens*), groundsel-bush (*Baccharis halimifolia*), sweet gale (*Myrica gale*), swamp rose (*Rosa palustris*), seaside rose (*Rosa rugosa*), poison ivy (*Toxicodendron radicans*), northern bayberry (*Morella pensylvanica*), and red cedar (*Juniperus virginicus*). Where fresh water seeps into the salt marsh from underground sources, several other species may be found in abundance: narrow-leaved cattail (*Typha angustifolia*), rose mallow (*Hibiscus moscheutos*), common three-square, and Olney's three-square (*Schoenoplectus americanus*).

An introduced form of common reed (*Phragmites australis*) frequently occurs along the upper marsh, especially in developed areas. It is most abundant in tidal marshes that have been cut off from tidal flow or where tidal flow is severely restricted by undersized culverts. The native form of common reed (*P. australis* ssp. *americanus*) occurs in places but its distribution has not been determined. A recent investigation has, however, identified the presence of the native form in Falmouth at four locations of 268 reed stands examined (Payne and Blossey 2007). Three of these stands were found in the Great Sippewisset Marsh. Species growing in mixed stands with the native Phragmites included high-tide bush, prairie cordgrass, seaside goldenrod, poison ivy, switchgrass, and golden dock (*Rumex maritimus*).

A few state rare plants may be found in salt and brackish marshes in the study area: big cordgrass (*Spartina cynosuroides*) - a state-threatened grass, on Cape Cod (especially common in Brewster), the state-endangered sea pink or annual marsh pink (*Sabatia* *stellaris*) on Martha's Vineyard, and another state-threatened grass – bearded sprangletop or saltpond grass (*Leptochloa fusca* ssp. *fascicularis*) on both the Vineyard and Nantucket (Swain and Kearsley 2001). The state-threatened diamond-backed terrapin (*Malaclemys terrapin*) frequents salt marshes, tidal flats, and tidal creeks on the Cape; it lays its eggs in sandy upland areas in June and July and overwinters in the bottom of estuaries and salt marsh creeks (Natural Heritage and Endangered Species Program 2008a). The state-endangered short-eared owl (*Asio flammeus*) overwinters in salt marshes (Tiner 2005), while the state-threatened northern harrier (*Circus cyaneus*) has been observed in coastal and inland marshes on the Cape (Natural Heritage and Endangered Species Program 2008c).

Brackish Marshes

Located further upstream from the salt marshes where there is more mixing of fresh and salt water or along the upper reaches of salt marshes where freshwater influence is significant, brackish marshes become established. These marshes contain many of the same species found in salt marshes but include species with more freshwater affinities. Species that were restricted to the upper salt marsh now become dominant species in the marsh proper including salt marsh bulrush, salt marsh aster, creeping bent grass, big cordgrass, narrow-leaved cattail, rose mallow, common three-square, salt marsh bulrush, switchgrass, prairie cordgrass, and common reed. New species in this community may include lilaeopsis (*Lilaeopsis chinensis*; which commonly grows beneath smooth cordgrass), mock bishop-weed (*Ptilimnium capillaceum*), seaside crowfoot (*Ranunculus cymbalaria*), smartweeds (*Polygonum* spp.), water pimpernel (*Samolus valerandi* ssp. *parviflora*), spike-rushes (*Eleocharis* spp.), and Nuttall's flatsedge (*Cyperus filicinus*) The absence of some salt marsh species like glassworts, seaside arrow-grass, and salt marsh plantain may also be a useful indicator of brackish marshes.

The uppermost brackish marshes (oligohaline marshes) resemble the freshwater marshes upstream (Figure 8). Plants such as arrowheads (*Sagittaria* spp.), arrow arum (*Peltandra virginica*), sweet flag (*Acorus calamus*), pickerelweed (*Pontederia cordata*) and narrow-leaved cattail may be present in the low marsh zone, while other species including smartweeds and beggar-ticks (*Bidens* spp.) may occupy higher elevations with other brackish species. Invasive species such as common reed and purple loosestrife (*Lythrum salicaria*) may dominate some oligohaline wetlands. Poison ivy may be abundant in places.

Rare species in brackish marshes may include state-threatened water pygmyweed (*Crassula aquatica*) on Martha's Vineyard and Nantucket, big cordgrass on the Cape, and bristly foxtail (*Setaria parviflora*), a species-of-concern, on both the Vineyard and the Cape (Swain and Kearsley 2001). A moth species-of-concern, the Spartina borer (*Spartiniphaga inops*), lays its eggs on the stems of prairie cordgrass; it has been reported on Martha's Vineyard and Nantucket (Nelson 2007).


Figure 8. Narrow-leaved cattail tidal marsh.

Palustrine Wetlands

Palustrine wetlands are freshwater wetlands. They include wetlands characterized by persistent vegetation (trees, shrubs, and persistent herbs) - marshes, swamps, and bogs, and also include shallow open waterbodies (ponds). The former types may form along rivers, lakes, and streams, or be completed surrounded by upland (i.e., geographically isolated wetlands such as dune swale wetlands). Palustrine wetlands include tidal freshwater wetlands as well as nontidal wetlands (beyond the reach of tides).

Tidal Freshwater Wetlands

These wetlands are extremely limited in the study area due to the lack of tidal rivers with large contributing watersheds and the prevalence of sandy soils on Cape Cod. Where present, they may be dominated by species that are typical of similar wetlands elsewhere in southern New England. Marshes may include wild rice (*Zizania aquatica*), bluejoint (*Calamagrostis canadensis*), soft-stemmed bulrush (*Schoenoplectus tabernaemontani*), arrowheads, arrow arum (on Cape Cod), common cattail (*Typha latifolia*), narrow-leaved cattail, woolgrass (*Scirpus cyperinus*), jewelweed (*Impatiens capensis*), tearthumbs (*Polygonum arifolium* and *P. sagittatum*), smartweeds, prairie cordgrass, common three-square, tussock sedge (*Carex stricta*), sweet flag, marsh fern (*Thelypteris palustris*), and climbing hempweed (*Mikania scandens*). Shrub swamps may be represented by buttonbush (*Cephalanthus occidentalis*), alders (*Alnus* spp.), silky dogwood (*Cornus amomum*), swamp rose, and common winterberry (*Ilex verticillata*). Forested wetlands may be dominated by red maple (*Acer rubrum*) and green ash (*Fraxinus pennsylvanica*) along with understory and groundcover species typical of nontidal swamp forests.

Dune Swale Wetlands

These wetlands occur in depressions between sand dunes where the land is inundated or where the sandy soils are waterlogged due to seasonal high water tables. These depressions are formed by aeolian (wind-driven) processes. They are most common on the northern end of Cape Cod (part of the Cape Cod National Seashore, CCNS; Figure 9) but are also prominent on Sandy Neck (Barnstable) and Monomoy Island National Wildlife Refuge (Chatham). These wetlands include palustrine emergent wetlands (e.g., marshes and wet meadows), scrub-shrub wetlands (shrub swamps), and shallow ponds (Figure 10).

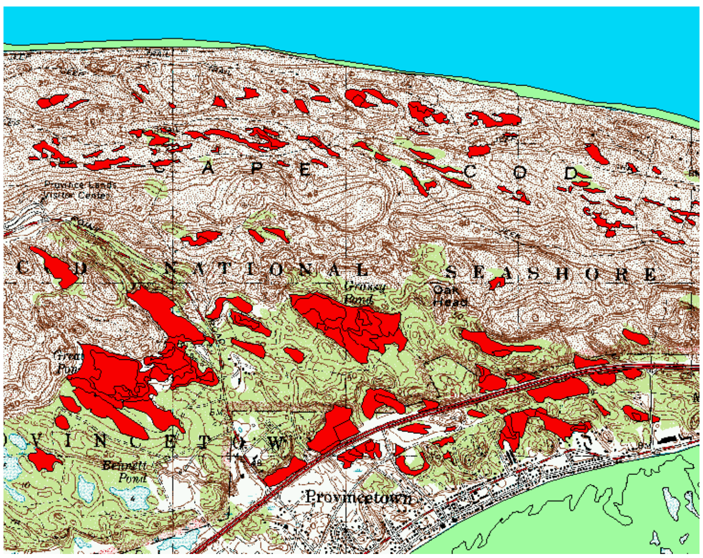


Figure 9. Dune swale wetlands (red areas) are the predominant wetland type throughout much of the Cape Cod National Seashore.

Figure 10. Dune swale wetland at Monomoy Island. (Kate Iaquinto photo)

A recent study of dune wetlands at the CCNS provides information on the formation of these wetlands (Smith et al. 2008). Interestingly, only five of the 356 dune wetlands studied were buried by sand since 1936. This suggests the relative stability of these wetlands in this landscape.

Among the 97 species found in CCNS dune wetlands, several plants were common including big cranberry (*Vaccinium macrocarpon*), highbush blueberry (*Vaccinium corymbosum*), northern bayberry, sheep laurel (*Kalmia angustifolia*), Greene's rush (*Juncus greenei*), Canada rush (*J. canadensis*), poison ivy, common winterberry (*Ilex verticillata*), woolgrass, and intermediate sundew (*Drosera intermedia*). Abundance of woody plants appears to be indicative of well-established, older wetlands, while Greene's rush and other graminoids typify the younger wetlands (Smith et al. 2008). Woolly rosette grass (*Panicum lanuginosum*), winter bent grass (*Agrostis hyemalis*), bog rush (*J. pelocarpus*), beak-rushes (*Rhynchospora* spp.) and twig-rush (*Cladium mariscoides*) are other graminoids that may be well-represented in these wet sandy depressions.

Several species of orchids may be found in interdunal swale wetlands: rose pogonia (*Pogonia ophioglossoides*), grass-pink (*Calopogon tuberosus*), nodding ladies'-tresses (*Spiranthes cernua*), dragon's mouth (*Arethusa bulbosa*, state-threatened), and ragged fringed orchis (*Platanthera lacera*) (Swain and Kearsley 2001). Plymouth gentian (*Sabatia kennedyana*), a state species-of-concern, may be locally abundant in these wetlands.

Nontidal Emergent Wetlands

Emergent wetlands are dominated by herbaceous (nonwoody) plants. Two main types of emergent wetlands are marshes and wet meadows. Marshes are found along freshwater ponds, lakes, streams, and rivers. They are characterized by herbaceous (nonwoody) species. Common cattail, bur-reeds (*Sparganium* spp.), pickerelweed, arrowheads, arrow arum, wild rice, common reed, purple loosestrife, rice cutgrass (*Leersia oryzoides*), soft-stemmed bulrush, hard-stemmed bulrush (*Schoenoplectus acutus*), and water-willow (*Decodon verticillatus*) may be among the more abundant marsh species. Duckweeds (*Lemna* spp.) and bladderworts (*Utricularia* spp.) may be found floating in open water along with floating-leaved species like white water lily (*Nymphaea odorata*), little floating-heart (*Nymphoides cordata*), and water-shield (*Brasenia schreberi*). Yellow flag (*Iris pseudacorus*), an invasive species, may be observed along pond margins. Three rare birds have been observed in the study area's freshwater marshes: 1) state-endangered least bittern (*Ixobrychus exilis*; from Provincetown, Truro, and Harwich), 2) the state-threatened king rail (*Rallus elegans*; from Provincetown), and 3) the state-threatened northern harrier (from several areas on the Cape and the Islands) (Natural Heritage and Endangered Species Program 2007, 2008b).

Wet meadows may be seasonally flooded or not, but all have seasonally high water tables that create waterlogged soil conditions. Some meadows may be dominated by a single species such as reed canary grass (*Phalaris arundinacea*), bluejoint or tussock sedge, while others may be represented by a variety of species including those species plus woolgrass, green bulrush (*Scirpus atrovirens*), sedges (e.g., lurid sedge *Carex lurida*, fox sedge *C. vulpinoidea*, stalkgrain sedge *C. stipata*, and broom sedge *C. scoparia*), Joe-Pye-weeds (*Eupatoriadelphus* spp. and *Eupatorium purpureum*), boneset (*Eupatorium perfoliatum*), asters (e.g., swamp aster, *Symphyotrichium puniceum*), goldenrods (*Euthamia* spp. and *Solidago* spp.), beggar-ticks, square-stemmed monkeyflower (*Mimulus ringens*), swamp candles (*Lysimachia terrestris*), jewelweed, smartweeds, arrow-leaved tearthumb (*Polygonum sagittatum*), and purple loosestrife.

On the Cape and the Islands, the shores of natural ponds called "coastal ponds" are colonized by both marsh and wet meadow species and exhibit a zonation pattern that fluctuates with annual precipitation patterns. Marsh and aquatic bed species dominate the shallow water zone, while emergent species typify the meadow zone which may be bordered above by a shrub zone of highbush blueberry, sweet pepperbush (*Clethra alnifolia*), and common greenbrier (*Smilax rotundifolia*) (Swain and Kearsley 2001). During dry years, the shoreline community is expansive, whereas in wet years, such vegetation is replaced by shallow water species including floating-leaved aquatics such as white water lily, variegated yellow water lily (*Nuphar lutea* ssp. *variegata*), little floating-heart, and water-shield, and aquatic emergents like bayonet rush (*Juncus militaris*), pipeworts (*Eriocaulon* spp.), water lobelia (*Lobelia dortmanna*), and spike-rushes. (Note: The floating and floating-leaved species may also be classified as lacustrine wetlands where associated with a standing waterbody 20 acres or larger in size and would be further classified as aquatic beds.) A study of five kettle ponds on the Cape recorded 49 species of plants (Roman et al. 2001). Some plants characteristic of the exposed shores are pink tickseed (*Coreopsis rosea*), slender-leaved goldenrod (*Euthamia galetorum*), bog rush, golden-pert (*Gratiola aurea*), beak-rushes or beak-sedges (including brownish beak-rush or brown beak-sedge *Rhynchospora capitellata*), lance-leaved violet (*Viola lanceolata*), and dwarf St. John's-wort (*Hypericum muticum*) (Swain and Kearsley 2001). Bluejoint may also occur here along with other species including yellow-eyed grass (*Xyris difformis*), sundews (*Drosera* spp.), twig-rush, Virginia meadow-beauty (*Rhexia virginica*), and zig-zag bladderwort (*Utricularia subulata*) (Edinger 2002). Many rare plants (including some state-threatened and -endangered species) can be found in these pondshore wetlands including Wright's panic-grass or rosette grass (*Dichanthelium wrightianum*), thread-leaved sundew (*Drosera filiformis*), black-fruited spike-rush (*Eleocharis melanocarpa*), three-angled spike-rush (*E. tricostata*), New England boneset (*Eupatorium leucolepis* var. *novae-angliae*), dwarf umbrella-sedge (*Fuirena pumila*), creeping St. John's-wort (*Hypericum adpressum*), two-flowered rush (*Juncus biflorus*), redroot (*Lachnanthes caroliniana*), pondshore knotweed (*Polygonum puritanorum*), Maryland meadow-beauty (*Rhexia mariana*), beak-sedges (*Rhynchospora inundata*, *R. nitens*, *R. scirpoides*, and *R. torreyana*), slender marsh-pink (*Sabatia campanulata*), terete or slender arrowhead (*Sagittaria teres*), reticulate nut-rush (*Scleria reticularis*), and two-flowered bladderwort (*Utricularia gibba*, formerly *U. biflora*) (Swain and Kearsley 2001). Over 43 species of dragonflies and damselflies have been observed in these wetlands including three rare species – two state-species of special concern: the comet darner (*Anax longipes*) and the New England bluet (*Enallagma laterale*), and the state-threatened pine barrens bluet (*E. recurvatum*). The northern red-bellied cooter (*Pseudemys rubriventris bangsi*), a federal-endangered species, is an important resident of some coastal ponds.

Nontidal Shrub Swamps

Shrub swamps are found in wet depressions and along fresh water bodies (Figure 11). Common shrubs include buttonbush (in the wettest shrub swamps), alders, willows, broad-leaved meadowsweet (*Spiraea latifolia*), steeplebush (*Spiraea tomentosa*), winterberry, highbush blueberry, silky dogwood, arrowwoods (*Viburnum dentatum* and *V. recognitum*), swamp azalea (*Rhododendron viscosum*), red chokeberry (*Photinia pyrifolia*, formerly *Aronia arbutifolia*), serviceberry (*Amelanchier arborea*), common elderberry (*Sambucus nigra* ssp. *canadensis*), and swamp rose. Sweet gale may be common in places. Some shrub swamps are dominated by saplings of red maple, while others are remnant cranberry bogs and may have big cranberry as a common groundcover species. Various herbs may also be present in shrub swamps including skunk cabbage (*Symplocarpus foetidus*), sensitive fern (*Onoclea sensibilis*), marsh fern (*Thelypteris palustris*), soft rush, jewelweed, asters, and goldenrods. Water-willow (*Decodon verticillatus*) can be found in some of the wettest shrub swamps along with stunted red maples, or in open water areas within forested swamps. Woody vines including common greenbrier, Virginia creeper, and poison ivy may be present in some shrub swamps. Large gray willow (*Salix cinerea*), an invasive shrub, may be found in wetlands in the study area.

Figure 11. Small depressional shrub swamp on Cape Cod.

Shrub Bogs

Bogs are wetlands characterized by a peat substrate (peatland) formed under near permanent saturation. They may have developed in "kettle ponds" that gradually filled in with vegetation during the past 10,000 years. Leatherleaf (*Chamaedaphne calyculata*) dominates some natural shrub bogs and may be found along the shores of some kettle ponds. Other bog species include sheep laurel (*Kalmia angustifolia*), cranberries (*Vaccinium oxycoccus* and *V. macrocarpon*), rhodora (*Rhododendron canadense*), rose pogonia (*Pogonia ophioglossoides*), and insectivorous plants - northern pitcher plant (*Sarracenia purpurea*) and sundews. Water-willow may also occur. The state-endangered few-seeded sedge (*Carex oligosperma*) may be found in bogs in the Provincelands.

The study area has many "cranberry bogs" created for agricultural purposes (Figure 12). These bogs may have been built from natural wetlands, including Atlantic white cedar swamps, although some bogs have been created by excavating sand down to the water table to establish wet sandy substrates for cranberry production. These bogs are farmed wetlands. Some of these bogs have been taken out of production and once abandoned a variety of plants may become established. An abandoned cranberry bog in Mashpee (Jehu Pond section of Mashpee National Wildlife Refuge) was dominated by poison ivy and big cranberry. Common reed was also abundant, while a few scattered red maple and pitch pine saplings were present. In other cases, where the bog was contiguous with coastal waters, tidal flow may have entered the abandoned bog allowing colonization by estuarine plant species.

Figure 12. Commercial cranberry bog.

Nontidal Forested Wetlands

Forested wetlands in the study area tend to be dominated by one or more of the following species: red maple, black gum (*Nyssa sylvatica*), pitch pine (*Pinus rigida*), and Atlantic white cedar (*Chamaecyparis thyoides*). American holly (*Ilex opaca*), gray birch (*Betula populifolia*), and white oak (*Quercus alba*) may be present in lesser numbers. On occasion, red cedar may be seen, especially in forests that have established on abandoned farmland.

Red maple swamps are the most common type (Figures 13 and 14). The other trees listed above may occur in these stands. Common shrubs include sweet pepperbush, highbush blueberry, fetterbush (*Eubotyrs racemosa*), maleberry (*Lyonia ligustrina*), swamp azalea, and arrowwoods. Inkberry (*Ilex glabra*), sheep laurel, red chokeberry, serviceberry, northern wild raisin (*Viburnum nudum* var. *cassinoides*), spicebush (*Lindera benzoin*), and pussy willow (*Salix discolor*) may also be present. Poison sumac (*Toxicodendron vernix*) may be found in the wettest swamps, probably in association with organic or organic-rich soils, especially in more open canopies. Swamp rose may also occur in openings in wetter swamps. Typical herbs of these swamps include cinnamon fern (*Osmunda cinnamomea*), royal fern (*Osmunda regalis*), sensitive fern, net-veined chain fern (*Woodwardia areolata*), an evergreen wood fern (*Dryopteris* sp.), horsetails (*Equisetum* spp.), sedges (*Carex* spp.including bladder sedge *C. intumescens*), Canada mayflower (*Maianthemum canadense*), starflower (*Trientalis borealis*), skunk cabbage, jewelweed, jack-in-the-pulpit (*Arisaema triphyllum*), false nettle (*Boehmeria cylindrica*), turtlehead (*Chelone glabra*), marsh blue violet (*Viola cucullata*), blue flag (*Iris versicolor*), rough-stemmed goldenrod (*Solidago rugosa*), tall meadow-rue (*Thalictrum pubescens*), asters (*Symphyotrichum* spp.), and cardinal flower (*Lobelia cardenalis*). Soft rush (Juncus effusus) may occupy depressions beneath openings in the forest canopy. Wintergreen (*Gaultheria procumbens*) and partridgeberry (*Mitchella repens*) may be present on the forest floor. The most abundant woody vine is often common greenbrier which may form virtually impenetrable thickets in drier-end swamps or along the upper edges of other swamps. A trailing woody vine – swamp dewberry (*Rubus hispidus*) – may be an abundant groundcover species. Virginia creeper (*Parthenocissus quinquefolia*) and poison ivy are other woody vines that may be frequently observed either trailing on the ground or climbing trees, while grape vines (*Vitis* sp.) may also occur. Sphagnum mosses may be abundant, especially in the wetter swamps. Invasive species present in some swamps include multiflora rose (*Rosa multiflora*), Morrow's honeysuckle (*Lonicera morrowii*), and European or black alder (*Alnus glutinosa*).


Figure 13. Red maple swamp at edge of a marsh.


Figure 14. A dense understory of shrubs and herbs characterize many red maple swamps.

Pitch pine lowlands are also prevalent on Cape Cod (Figure 15). These forested wetlands have lower plant diversity than the red maple swamps. Red maple is often co-dominant with pitch pine. Other species found in these wetlands include black gum, highbush blueberry, swamp azalea, sweet pepperbush, arrowwoods, northern bayberry, poison ivy, Canada mayflower, starflower, ground pine (*Lycopodium obscurum*), common greenbrier, and hair-cap moss (*Polytrichum* sp.).

Figure 15. Pitch pine lowland.

Atlantic white cedar swamps are an uncommon type of forested wetland on the Cape. The most notable and perhaps the largest one is found at the Cape Cod National Seashore – Marconi Station (Figure 16). The cedar often forms a thick overstory that creates dense shade below. The microtopography of this cedar swamp may be characterized as a mosaic of mounds and pits with most of the plants growing on the former and open water (probably seasonal) and peat moss occupying the latter. Associated vegetation includes red maple, pitch pine, fetterbush, sweet pepperbush, inkberry, sheep laurel, swamp azalea, dangleberry or tall huckleberry (*Gaylussacia frondosa*), cinnamon fern, starflower, common greenbrier, and mosses (including peat moss). Round-leaved sundew (*Drosera rotundifolia*) may also occur. A summary report on these swamps in Massachusetts has been published (Motzkin 1991). Heartleaf twayblade (*Listera cordata*), a state-endangered orchid, grows in Atlantic white cedar swamps. Several rare animals may frequent these swamps: Hessel's hairstreak (*Callophrys hesseli*, a green and brown butterfly with white spots is a state species of concern), pale green pinion moth (*Lithophane viridipallens*, special concern), pitcher plant borer (*Papaipema appassionata*, threatened), four-toed salamander (Hemidactylium scutatum), blue-spotted salamander (*Ambystoma laterale*, special concern), spotted turtle (*Clemmys guttata*), and northern parula (*Parula americana*; threatened) (Swain and Kearsley 2001).

Figure 16. Atlantic white cedar swamp at Cape Cod National Seashore.

Lacustrine and Riverine Wetlands

Aquatic beds in shallow water (less than 6.6 feet deep at low water) and nonpersistent herb-dominated wetlands along lakes (e.g., standing waterbodies 20 acres or larger) and rivers are classified as lacustrine or riverine wetlands, respectively.[11] Floating-leaved aquatic species (e.g., white water lily, variegated yellow pond lily, and water-shield) often dominate the shallow water zone, while submergents (e.g., naiads, *Najas* spp., pondweeds, *Potamogeton* spp., and stonewort, *Nitella* sp.) may be present here as well as in deeper waters. Nonpersistent emergents in the shallow water zone such as wild rice (an annual plant), pickerelweed, arrowheads, and arrow arum are classified as lacustrine nonpersistent emergent wetlands. (Note: Persistent vegetation like cattails, water-willow, shrubs, and trees in similar locations or along these waterbodies represent palustrine and not lacustrine wetlands.) For more information on the vegetation of kettle ponds on Cape Cod, see Roman et al. (2001).

[11] Similar wetlands along smaller waterbodies deeper than 6.6 feet at annual low water should also be classified as lacustrine, but have typically been classified as palustrine unconsolidated bottom by NWI mapping convention. NWI mapping typically uses the size of the waterbody to separate lakes from ponds, so some deep waterbodies may have been classified as lacustrine by this convention. When applying the LLWW descriptors, however, waterbodies 10- 20 acres in size were re-evaluated to determine whether they should be lacustrine or palustrine based on likely depth at low water. Consequently, a number of these waterbodies were considered “lakes” so the “pond” acreage is less than the “palustrine unconsolidated bottom” acreage. The NWI data were not adjusted to reflect this difference.

Wetlands of Cape Cod and Vicinity[12]

The following text describes the statistical results of the inventory and assessment and includes a set of tables summarizing the findings.

A set of thirteen maps showing NWI types, LLWW types (landscape position, landform, and water flow path), and potential wetlands of significance for each of nine functions are presented in a separate online companion file labeled "Final Maps_Cape Cod." No maps were prepared for carbon sequestration and provision of other wildlife habitat.

Map No.	Theme
1	Wetlands by NWI Types
2	Wetlands by Landscape Position
3	Wetlands by Landform
4	Wetlands by Water Flow Path
5	Potential Wetlands of Significance for Surface Water Detention
6	Potential Wetlands of Significance for Coastal Storm Surge Detention
7	Potential Wetlands of Significance for Streamflow Maintenance
8	Potential Wetlands of Significance for Nutrient Transformation
9	Potential Wetlands of Significance for Sediment and Other Particulate Retention
10	Potential Wetlands of Significance for Shoreline Stabilization
11	Potential Wetlands of Significance for Provision of Fish and Shellfish Habitat
12	Potential Wetlands of Significance for Provision of Waterfowl and Waterbird Habitat
13	Potential Wetlands of Significance for Conservation of Biodiversity

NWI Types

Wetlands totaled nearly 53,500 acres (Table 6) and covered between 12 to 16 percent of this region's land area.[13] Estuarine wetlands were most abundant, occupying 21,362 acres or 40 percent of the area's wetlands. Emergent wetlands were the most common estuarine type (77%). Alone, they accounted for about 31 percent of the area's wetlands. Palustrine wetlands were second-ranked in abundance, covering 18,453 acres, with scrub-shrub wetlands being most common and representing nearly 50 percent (47%) of the palustrine wetlands. They were twice as abundant as forested wetlands and occupied more than six times the acreage of freshwater emergent wetlands. Ponds (palustrine unconsolidated bottoms and shores) accounted for 3,816 acres which amounted to seven percent of the wetlands (or about 21% of the freshwater wetlands). In all, palustrine wetlands represented about 35 percent of the area's wetlands. Marine wetlands totaled 13,630 acres and accounted for about one-quarter (25%) of the area's wetlands.

[12] Data for the Cape also include a small portion (roughly 115 square miles) of Plymouth County.
[13] Estimates vary depending how marine wetlands are treated vs. land area.

Unconsolidated shore (e.g., intertidal beaches and flats) were the most common marine type. Only 53 acres of lacustrine wetlands were inventoried.[14]

LLWW Types

When ponds are treated as waters rather than wetlands, estuarine wetlands accounted for nearly half of the wetlands (47%), while marine wetlands represented nearly 28 percent (Table 7). By definition, all of these two types had bidirectional-tidal water flow. Over eight percent of the area's wetlands were associated with rivers and streams (lotic) and nearly all of these were associated with streams as few rivers exist on the Cape. Lotic wetlands were typically throughflow types (92%), while the rest were bidirectional-tidal (freshwater tidal). Less than three percent of the wetlands were lentic types (along lakes and deep ponds classified as palustrine unconsolidated bottoms by NWI). The water flow path of 81 percent of the lentic wetlands was classified as bidirectional-nontidal, whereas about ten percent of the lentic wetlands had a stream running through them and eight percent was under tidal influence (i.e., bidirectional-tidal). The remaining wetlands (nearly 15%) were located in the terrene landscape position, mainly in headwater positions or in isolated depressions. About half (52%) of the terrene wetlands were geographically isolated (surrounded by upland), while 36 percent were outflow types (typically the source of a stream).

Nearly all of the marine wetlands and about three-quarters of the estuarine wetlands were identified as fringe types with open access to Cape Cod Bay, Nantucket Sound, Buzzards Bay, or the Atlantic Ocean. Most of the remaining estuarine wetlands were located behind roads or railroad crossings and were classified as basins, while five percent of the estuarine wetlands were marsh islands (completely surrounded by water). Nearly all of the lotic wetlands (88%) were basin types, whereas about ten percent were represented by flats. Ninety-five percent of the terrene wetlands were basins (depressions). Nearly three-quarters (73%) of the lentic wetlands were seasonally flooded basins, with most of the remaining wetlands equally divided among flat and fringe types.

A total of 1,255 ponds were inventoried, with nearly half (45%) classified as natural, 38 percent identified as excavated, and the remainder being dammed/impounded (Table 8). From an acreage standpoint, over half (56%) of the pond acreage was represented by natural ponds, 25% by excavated ponds, and 19 percent by dammed/impounded ponds. The average size of ponds for Cape Cod and vicinity was 1.9 acres. Over half (54%) of the pond acreage was isolated, while one-quarter had perennial or intermittent throughflow and 12 percent had outflow only. The remaining ponds were mostly affected by tides (bidirectional-tidal water flow path) or were sinks (inflow only).

[14] The extent of lacustrine wetlands is underestimated since leaf-off imagery was used for the inventory; floating leaved aquatic beds are not visible on this imagery.

Preliminary Functional Assessment

Over 50 percent of the wetlands (including ponds) were predicted to perform nine of the eleven functions at significant levels (Table 9). More than 90 percent of the wetlands were deemed important for surface water detention and retention of sediments and other particulates, while more than two-thirds of the wetlands were projected to serve as coastal storm surge detention areas, fish and shellfish habitat, and waterfowl and waterbird habitat. Sixty-two percent of the wetlands were recognized as significant for carbon sequestration. About half of wetlands were classified as significant for nutrient transformation, shoreline stabilization, and for providing habitat for other wildlife. Relatively few wetlands (9%) were located in landscape positions where they could contribute to maintaining streamflow. Only six percent of the wetlands were recognized as uncommon types and significant for contributing to the area's biodiversity.

Table 6. Wetlands of Cape Cod and vicinity classified by NWI types (Cowardin et al. 1979).

System	Class	Acreage
Marine	Aquatic Bed	53.3
	Rocky Shore	80.9
	Unconsolidated Shore	13,495.3
	Total Marine Wetlands	**13,629.5**
Estuarine	Emergent	16,414.6
	Scrub-Shrub	846.8
	Unconsolidated Shore	4,070.3
	Aquatic Bed	0.7
	Rocky Shore	29.5
	Total Estuarine Wetlands	**21,361.9**
Lacustrine	Unconsolidated Bottom	52.7
	Total Lacustrine Wetlands	**52.7**
Palustrine	Aquatic Bed	0.9
	(Subtotal Aquatic Bed)	(0.9)
	Emergent	1,041.3
	Emergent/Aquatic Bed	11.0
	Emergent/Forested	20.5
	Emergent/Scrub-Shrub	239.1
	Emergent/Unconsolidated Bottom	3.0
	Emergent/Unconsolidated Shore	11.6
	(Subtotal Emergent)	(1,326.5)
	Forested, Broad-leaved Deciduous	3,480.1
	Forested, Needle-leaved Evergreen	1,132.1
	(Subtotal Forested)	(4,612.2)
	Scrub-Shrub, Broad-leaved Deciduous	3,659.1
	Scrub-Shrub, Broad-leaved Evergreen	324.8
	Scrub-Shrub, Needle-leaved Evergreen	563.5
	Scrub-Shrub, Farmed	4,150.5
	(Subtotal Scrub-Shrub)	(8,697.9)
	Unconsolidated Bottom	3,620.3
	Unconsolidated Bottom/Emergent	88.8
	Unconsolidated Bottom/Forested	10.9
	Unconsolidated Bottom/Scrub-Shrub	59.6
	Unconsolidated Shore	36.1
	(Subtotal Nonvegetated)	(3,815.7)
	Total Palustrine Wetlands	**18,453.2**
GRAND TOTAL (All Wetlands)		**53,497.3**

Table 7. Wetlands classified by landscape position, landform, and water flow path for Cape Cod and vicinity. Note: Ponds were treated as a waterbody type (see separate table) for summary.

Landscape Position	Landform	Water Flow Path	Acreage
Marine	Fringe	Bidirectional-tidal	13,316.2
	Island	Bidirectional-tidal	313.3
Total Marine			**13,629.5**
Estuarine	Fringe	Bidirectional-tidal	17,043.0
	Basin	Bidirectional-tidal	4,730.7
	Island	Bidirectional-tidal	1,176.2
Total Estuarine			**22,949.9**
Lentic	Basin	Bidirectional-nontidal	826.2
		Throughflow	106.5
	(Subtotal Basin)		(932.7)
	Flat	Bidirectional-nontidal	144.6
		Throughflow	21.0
	(Subtotal Flat)		(165.6)
	Fringe	Bidirectional-nontidal	66.3
		Throughflow	5.7
		Bidirectional-tidal	108.1
	(Subtotal Fringe)		(180.1)
	Island	Bidirectional-nontidal	6.6
	(Subtotal Island)		(6.6)
Total Lentic			**1,285.0**
Lotic River	Fringe	Throughflow	1.9
		Bidirectional-tidal	8.7
	(Subtotal Fringe)		(10.6)
	Floodplain-basin	Throughflow	7.7
	(Subtotal Basin)		(7.7)
	Floodplain-flat	Throughflow	9.8
		Bidirectional-tidal	1.1
	(Subtotal Flat)		(10.9)
Total Lotic River			**29.2**

Table 7 (cont'd).

Lotic Stream	Basin	Throughflow	3,388.1
		Bidirectional-tidal	210.0
	(Subtotal Basin)		(3,598.1)
	Flat	Throughflow	394.4
		Bidirectional-tidal	1.6
	(Subtotal Flat)		(396.0)
	Fringe	Throughflow	33.0
		Bidirectional-tidal	91.8
	(Subtotal Fringe)		(124.8)
Total Lotic Stream			**4,118.9**
Terrene	Basin	Isolated	3,621.2
		Inflow	27.3
		Outflow	2,537.9
		Throughflow	694.1
	(Subtotal Basin)		(6,880.5)
	Flat	Isolated	239.6
		Throughflow	9.7
		Outflow	98.3
		Inflow	8.4
	(Subtotal Flat)		(356.0)
	Fringe	Isolated	37.0
		Outflow	19.3
		Throughflow	9.5
	(Subtotal Fringe)		(65.8)
Total Terrene			**7,302.3**
GRAND TOTAL			**49,314.8**

Table 8. Pond acreage for Cape Cod and vicinity.

Type of Pond	Water Flow Path	Number of Ponds	Acreage
Natural	Isolated	382	919.3
	Inflow	41	82.6
	Throughflow	44	112.2
	Throughflow-intermittent	8	18.7
	Outflow	50	123.2
	Bidirectional-nontidal	2	2.3
	Bidirectional-tidal	39	61.2
Total Natural Ponds		**566**	**1,319.5**
Dammed/Impounded	Isolated	110	117.2
	Throughflow	54	180.4
	Throughflow-intermittent	17	67.5
	Outflow	27	92.7
	Bidirectional-nontidal	1	0.7
	Bidirectional-tidal	1	1.3
Total Dammed/Impounded Ponds		**210**	**459.8**
Excavated	Isolated	272	240.8
	Inflow	1	0.2
	Throughflow	81	142.1
	Throughflow-intermittent	34	82.2
	Outflow	62	95.9
	Bidirectional-tidal	27	31.8
	Bidirectional-nontidal	2	3.8
Total Excavated Ponds		**479**	**596.8**
GRAND TOTAL		**1,255**	**2,376.1**

Table 9. Wetlands of potential significance for various functions for Cape Cod and vicinity. Note: Results include ponds.

Function	Significance	Acreage	% of All Wetlands
Surface Water Detention	High	40,250.4	77.9
	Moderate	6,763.6	13.1
	Total	**47,014.0**	**91.0**
Coastal Storm Surge Detention	High	36,522.9	70.7
	Total	**36,522.9**	**70.7**
Streamflow Maintenance	High	1,968.2	3.8
	Moderate	2,712.0	5.2
	Total	**4,680.2**	**9.0**
Nutrient Transformation	High	26,607.5	51.5
	Moderate	1,042.1	2.0
	Total	**27,649.6**	**53.5**
Sediment and Other Particulate Retention	High	22,506.5	43.5
	Moderate	24,400.8	47.2
	Total	**46,907.3**	**90.7**
Shoreline Stabilization	High	20,564.8	39.8
	Moderate	5,856.0	11.3
	Total	**26,420.8**	**51.1**
Fish and Shellfish Habitat	High	29,957.6	58.0
	Moderate	2,916.8	5.6
	(Subtotal)	(32,874.4)	(63.6)
	Shading	1,429.4	2.8
	Total	**34,303.8**	**66.4**
Waterfowl and Waterbird Habitat	High	33,834.9	65.5
	Moderate	3,074.8	5.9
	Wood Duck	1,251.8	2.4
	Total	**38,161.5**	**73.8**
Other Wildlife Habitat	High	15,349.4	29.7
	Moderate	12,050.1	23.3
	Total	**27,399.5**	**53.0**

Table 9 (cont'd).

Function	Significance	Acreage	% of All Wetlands
Conservation of Biodiversity	Tidal Fresh PEM	228.8	0.4
	Tidal Fresh PSS	895.0	1.7
	Tidal Fresh PFO	41.6	0.1
	Oligohaline Marsh	465.6	1.0
	Low Salt Marsh	741.5	1.4
	Atlantic White Cedar	325.2	0.6
	Shrub Bog	229.5	0.4
	Semiperm. Wetland	32.6	0.1
	Submg. Aquatic Bed	1.8	--
	Total	**2,961.6**	**5.7**
Carbon Sequestration	High	30,737.2	59.5
	Moderate	1,098.7	2.1
	Total	**31,835.9**	**61.6**

Wetlands of the Elizabeth Islands

The following text describes the statistical results of the inventory and assessment and includes a set of tables summarizing the findings.

A set of thirteen maps showing NWI types, LLWW types (landscape position, landform, and water flow path), and potential wetlands of significance for each of nine functions are presented in a separate online companion file labeled "Final Maps_Elizabeth Islands." No maps were prepared for carbon sequestration and provision of other wildlife habitat.

Map No.	Theme
1	Wetlands by NWI Types
2	Wetlands by Landscape Position
3	Wetlands by Landform
4	Wetlands by Water Flow Path
5	Potential Wetlands of Significance for Surface Water Detention
6	Potential Wetlands of Significance for Coastal Storm Surge Detention
7	Potential Wetlands of Significance for Streamflow Maintenance
8	Potential Wetlands of Significance for Nutrient Transformation
9	Potential Wetlands of Significance for Sediment and Other Particulate Retention
10	Potential Wetlands of Significance for Shoreline Stabilization
11	Potential Wetlands of Significance for Provision of Fish and Shellfish Habitat
12	Potential Wetlands of Significance for Provision of Waterfowl and Waterbird Habitat
13	Potential Wetlands of Significance for Conservation of Biodiversity

NWI Types

More than 1,300 acres of wetlands were inventoried on these islands (Table 10). Wetlands therefore cover up to 15 percent of the Elizabeth Islands. Nearly half of the wetlands were marine wetlands, mostly unconsolidated shores (beaches and tidal flats) and rocky shores. Nearly 40 percent of the wetlands were freshwater types, with deciduous scrub-shrub and forested wetlands predominating. Ponds (palustrine unconsolidated bottoms) represented almost nine percent of the wetlands. Approximately 14 percent of the wetlands was estuarine, with tidal marshes (emergent wetlands) having slightly more than twice the acreage of tidal flats (unconsolidated shores).

LLWW Types

About 72 percent of the wetlands (excluding ponds) were associated with salt or brackish tidal waters: 53 percent was marine and 19 percent estuarine (Table 11). Fringe wetlands predominated in these two landscapes, whereas basin wetlands predominated in the other landscapes. Wetlands associated with lakes and streams represented slightly more than one percent of the wetlands (1.0% and 0.2%, respectively). Terrene wetlands made up the remaining 26 percent, with isolated basins accounting for roughly 83 percent of this type.

Seventy-six ponds were mapped (Table 12) and more than half (54%) were isolated (surrounded by upland). Natural bidirectional-tidal and isolated ponds each accounted for nearly 20 acres and combined to represent 80 percent of the pond acreage. No dammed/impounded ponds were identified and only four acres of excavated ponds were inventoried. The average pond size was 0.7 acre.

Preliminary Functional Assessment

All of the wetlands were rated as significant for surface water detention (Table 13). More than two-thirds of the wetland acreage was deemed important for sediment and other particulate detention, waterfowl and waterbird habitat, shoreline stabilization, and coastal storm surge detention. About 40 percent of the wetlands were identified as providing significant habitat for other wildlife and for nutrient transformation and carbon sequestration. From the fish and shellfish perspective, about 30 percent of the wetlands were regarded as providing significant habitat for these species. Nearly nine percent of the wetlands were located at positions that would significantly contribute to streamflow maintenance or were uncommon types important for maintaining biodiversity on the islands.

Table 10. Wetlands of the Elizabeth Islands classified by NWI types (Cowardin et al. 1979).

System	Class	Acreage
Marine	Aquatic Bed	9.9
	Rocky Shore	152.9
	Unconsolidated Shore	479.0
	Total Marine Wetlands	**641.8**
Estuarine	Emergent	107.5
	Scrub-Shrub	8.0
	Unconsolidated Shore	52.5
	Aquatic Bed	9.0
	Rocky Shore	2.6
	Total Estuarine Wetlands	**179.6**
Palustrine	Emergent	28.2
	(Subtotal Emergent)	(28.2)
	Forested, Broad-leaved Deciduous	155.0
	Forested, Needle-leaved Evergreen	6.0
	(Subtotal Forested)	(161.0)
	Scrub-Shrub, Broad-leaved Deciduous	196.1
	Scrub-Shrub, Broad-leaved Evergreen	1.6
	(Subtotal Scrub-Shrub)	(197.7)
	Unconsolidated Bottom	113.9
	(Subtotal Nonvegetated)	(113.9)
	Total Palustrine Wetlands	**500.8**
GRAND TOTAL (All Wetlands)		**1,322.2**

Table 11. Wetlands classified by landscape position, landform, and water flow path for the Elizabeth Islands. Note: Ponds were treated as a waterbody type (see separate table) for summary.

Landscape Position	Landform	Water Flow Path	Acreage
Marine	Fringe	Bidirectional-tidal	630.2
	Island	Bidirectional-tidal	11.5
Total Marine			**641.7**
Estuarine	Fringe	Bidirectional-tidal	209.2
	Basin	Bidirectional-tidal	21.7
	Island	Bidirectional-tidal	1.6
Total Estuarine			**232.5**
Lentic	Basin	Bidirectional-nontidal	2.9
Total Lentic			**2.9**
Lotic Stream	Basin	Throughflow	12.5
Total Lotic Stream			**12.5**
Terrene	Basin	Isolated	263.8
		Bidirectional-tidal	22.9
		Outflow	31.7
Total Terrene			**318.5**
GRAND TOTAL			**1,208.0**

Table 12. Pond acreage for the Elizabeth Islands.

Type of Pond	Water Flow Path	Number of Ponds	Acreage
Natural	Isolated	41	19.9
	Outflow	1	6.2
	Bidirectional-tidal	26	19.6
Total Natural Ponds		**68**	**45.7**
Excavated	Bidirectional-tidal	8	4.4
Total Excavated Ponds		**8**	**4.4**
GRAND TOTAL		**76**	**50.1**

Table 13. Wetlands of potential significance for various functions for the Elizabeth Islands. Note: Results include ponds.

Function	**Significance**	**Acreage**	**% of All Wetlands**
Surface Water Detention	High	961.1	76.4
	Moderate	297.0	23.6
	Total	**1,258.1**	**100.0**
Coastal Storm Surge Detention	High	864.0	68.7
	Total	**864.0**	**68.7**
Streamflow Maintenance	High	67.1	5.3
	Moderate	43.2	3.4
	Total	**110.3**	**8.7**
Nutrient Transformation	High	511.2	40.6
	Moderate	1.1	0.1
	Total	**512.3**	**40.7**
Sediment and Other Particulate Retention	High	274.3	21.8
	Moderate	828.4	65.8
	Total	**1,102.7**	**87.6**
Shoreline Stabilization	High	287.4	22.8
	Moderate	567.8	45.1
	Total	**855.2**	**67.9**
Fish and Shellfish Habitat	High	323.2	25.7
	Moderate	50.1	4.0
	(Subtotal)	(373.3)	(29.7)
	Shading	2.9	0.2
	Total	**376.2**	**29.9**
Waterfowl and Waterbird Habitat	High	827.3	65.8
	Moderate	54.2	4.3
	Wood Duck	49.8	4.0
	Total	**931.3**	**74.1**
Other Wildlife Habitat	High	71.7	5.7
	Moderate	428.7	34.1
	Total	**500.4**	**39.8**

Table 13 (cont'd).

Function	**Significance**	**Acreage**	**% of All Wetlands**
Conservation of Biodiversity	Tidal Fresh PEM	13.9	1.1
	Tidal Fresh PSS	66.0	5.2
	Oligohaline Marsh	4.3	0.3
	Submg. Aquatic Bed	18.9	1.5
	Total	**103.1**	**8.2**
Carbon Sequestration	High	502.4	39.9
	Moderate	18.8	1.5
	Total	**521.3**	**41.4**

Wetlands of Martha's Vineyard

The following text describes the statistical results of the inventory and assessment and includes a set of tables summarizing the findings.

A set of thirteen maps showing NWI types, LLWW types (landscape position, landform, and water flow path), and potential wetlands of significance for each of nine functions are presented in a separate online companion file labeled "Final Maps_Martha's Vineyard." No maps were prepared for carbon sequestration and provision of other wildlife habitat.

Map No.	Theme
1	Wetlands by NWI Types
2	Wetlands by Landscape Position
3	Wetlands by Landform
4	Wetlands by Water Flow Path
5	Potential Wetlands of Significance for Surface Water Detention
6	Potential Wetlands of Significance for Coastal Storm Surge Detention
7	Potential Wetlands of Significance for Streamflow Maintenance
8	Potential Wetlands of Significance for Nutrient Transformation
9	Potential Wetlands of Significance for Sediment and Other Particulate Retention
10	Potential Wetlands of Significance for Shoreline Stabilization
11	Potential Wetlands of Significance for Provision of Fish and Shellfish Habitat
12	Potential Wetlands of Significance for Provision of Waterfowl and Waterbird Habitat
13	Potential Wetlands of Significance for Conservation of Biodiversity

NWI Types

Nearly 4,000 acres of wetlands were mapped on Martha's Vineyard (Table 14). Wetlands occupy up to seven percent of the Vineyard. Half of the wetlands were estuarine, with vegetated types representing nearly two-thirds of them. Estuarine emergent wetlands alone accounted for 22 percent of the Vineyard's wetlands. Marine wetlands, mainly unconsolidated shores (beaches and tidal flats), comprised nearly one-quarter of the area's wetlands. Over 1,500 acres of freshwater wetlands (palustrine) were inventoried. Scrub-shrub wetlands were the most common freshwater type (49% of the palustrine wetlands). Less than 400 acres of forested wetlands were detected and 302 acres of ponds (unconsolidated bottoms and shores). These types represented nine and eight percent of the Vineyard's wetlands, respectively.

LLWW Types

Estuarine and marine fringe wetlands account for 64 percent of the Vineyard's wetlands (excluding ponds; Table 15). About 18 percent of the area's wetlands were classified as terrene types, with more than half of this acreage (57%) associated with isolated basins and 30 percent with outflow basins. Ten percent of the wetlands were located along streams where they are likely to be subjected to periodic flooding. Less than one percent (0.3%) of the wetlands was associated with lakes (lentic) and most were identified as being tidally influenced.

Martha's Vineyard possessed 182 ponds covering nearly 190 acres (Table 16). Two-thirds of the ponds were classified as natural, representing about 58 percent of the pond acreage. Thirty-seven percent of the pond acreage was created by diking (i.e., dammed and impounded), while only six percent was excavated. Thirty-four percent of the pond acreage was associated with throughflow ponds, while 31 percent was isolated and 20 percent outflow. Nearly all of the remaining acreage was subject to tidal influence. Only three ponds totaling five acres were classified as inflow ponds. The average pond size was one acre.

Preliminary Assessment of Functions

Nearly all of the Vineyard's wetlands were rated as significant for surface water detention and sediment and other particulate retention (Table 17). Most of the other functions were performed by more than half the wetlands: waterfowl and waterbird habitat, coastal storm surge detention, shoreline stabilization, carbon sequestration, nutrient transformation, and other wildlife habitat. About 40 percent of the wetlands were rated as important habitat for fish and shellfish, 18 percent significant for streamflow maintenance, and 12 percent as particularly valuable for contributing to the island's biodiversity.

Table 14. Wetlands of Martha's Vineyard classified by NWI type (Cowardin et al. 1979).

System	Class	Acreage
Marine	Aquatic Bed	42.2
	Rocky Shore	34.3
	Unconsolidated Shore	826.5
	Total Marine Wetlands	**903.0**
Estuarine	Emergent	851.4
	Scrub-Shrub	43.8
	Unconsolidated Shore	504.9
	Aquatic Bed	15.5
	Rocky Shore	0.3
	Forested	1.6
	Total Estuarine Wetlands	**1,417.5**
Palustrine	Emergent	117.5
	(Subtotal Emergent)	(117.5)
	Forested, Broad-leaved Deciduous	358.4
	Forested, Needle-leaved Evergreen	3.3
	(Subtotal Forested)	(361.7)
	Scrub-Shrub, Broad-leaved Deciduous	737.9
	Scrub-Shrub, Farmed	3.9
	(Subtotal Scrub-Shrub)	(741.8)
	Unconsolidated Bottom	287.4
	Unconsolidated Bottom/Emergent	4.1
	Unconsolidated Bottom/Scrub-Shrub	10.5
	Unconsolidated Shore	0.3
	(Subtotal Nonvegetated)	(302.3)
	Total Palustrine Wetlands	**1,523.3**
GRAND TOTAL (All Wetlands)		**3,843.8**

Table 15. Wetlands classified by landscape position, landform, and water flow path for Martha's Vineyard. Note: Ponds were treated as a waterbody type (see separate table) for summary.

Landscape Position	Landform	Water Flow Path	Acreage
Marine	Fringe	Bidirectional-tidal	902.0
	Island	Bidirectional-tidal	1.1
Total Marine			**903.1**
Estuarine	Fringe	Bidirectional-tidal	1,332.2
	Basin	Bidirectional-tidal	117.8
	Island	Bidirectional-tidal	179.5
Total Estuarine			**1,630.5**
Lentic	Basin	Bidirectional-nontidal	7.6
	Flat	Bidirectional-nontidal	1.3
	Fringe	Bidirectional-tidal	0.9
Total Lentic			**9.8**
Lotic Stream	Basin	Throughflow	349.9
		Bidirectional-tidal	1.4
	(Subtotal Basin)		(351.3)
	Flat	Throughflow	3.0
	Fringe	Throughflow	1.5
		Bidirectional-tidal	8.1
	(Subtotal Fringe)		(9.6)
Total Lotic Stream			**363.9**
Terrene	Basin	Isolated	364.1
		Inflow	55.2
		Outflow	193.4
		Throughflow	20.7
	(Subtotal Basin)		(633.4)
	Flat	Isolated	0.8
Total Terrene			**634.2**
GRAND TOTAL			**3,541.5**

Table 16. Pond acreage for Martha's Vineyard.

Type of Pond	Water Flow Path	Number of Ponds	Acreage
Natural	Isolated	64	45.3
	Inflow	3	5.0
	Throughflow	1	0.5
	Throughflow-intermittent	10	26.3
	Outflow	14	9.6
	Bidirectional-tidal	30	22.2
Total Natural Ponds		**122**	**108.9**
Dammed/Impounded	Isolated	2	3.9
	Throughflow	9	18.2
	Throughflow-intermittent	11	18.9
	Outflow	15	27.3
	Bidirectional-tidal	1	1.0
Total Dammed/Impounded Ponds		**38**	**69.3**
Excavated	Isolated	17	8.9
	Throughflow-intermittent	2	0.4
	Outflow	3	1.9
Total Excavated Ponds		**22**	**11.2**
GRAND TOTAL		**182**	**189.4**

Table 17. Wetlands of significance for various functions for Martha's Vineyard.
Note: Results include ponds.

Function	Significance	Acreage	% of All Wetlands
Surface Water Detention	High	2,969.5	79.6
	Moderate	753.6	20.2
	Total	**3,723.2**	**99.8**
Coastal Storm Surge Detention	High	2,542.9	68.2
	Total	**2,542.9**	**68.2**
Streamflow Maintenance	High	501.6	13.4
	Moderate	173.6	4.7
	Total	**675.2**	**18.1**
Nutrient Transformation	High	2,154.4	57.7
	Moderate	16.4	0.4
	Total	**2,170.8**	**58.1**
Sediment and Other Particulate Retention	High	1,612.9	43.2
	Moderate	2,076.5	55.7
	Total	**3,689.4**	**98.9**
Shoreline Stabilization	High	1,332.8	35.7
	Moderate	1,100.4	29.5
	Total	**2,433.2**	**65.2**
Fish and Shellfish Habitat	High	1,345.9	36.1
	Moderate	191.0	5.1
	(Subtotal)	(1,536.9)	(41.2)
	Shading	77.7	2.1
	Total	**1,614.6**	**43.3**
Waterfowl and Waterbird Habitat	High	2,366.5	63.4
	Moderate	183.9	4.9
	Wood Duck	159.5	4.3
	Total	**2,709.9**	**72.6**
Other Wildlife Habitat	High	636.8	17.1
	Moderate	1,488.9	39.9
	Total	**2,125.7**	**57.0**

Table 17 (cont'd).

Function	Significance	Acreage	% of All Wetlands
Conservation of Biodiversity	Tidal Fresh PEM	46.2	1.2
	Tidal Fresh PSS	140.8	3.8
	Tidal PFO	3.6	0.1
	Oligohaline Marsh	192.5	5.1
	Low Salt Marsh	4.3	0.1
	Semiperm. Wetland	1.5	--
	Submg. Aquatic Bed	57.7	1.5
	Total	**446.6**	**12.0**
Carbon Sequestration	High	2,115.7	56.7
	Moderate	62.7	1.7
	Total	**2,178.4**	**58.4**

Wetlands of Nantucket

The following text describes the statistical results of the inventory and assessment and includes a set of tables summarizing the findings.

A set of thirteen maps showing NWI types, LLWW types (landscape position, landform, and water flow path), and potential wetlands of significance for each of nine functions are presented in a separate online companion file labeled "Final Maps_Nantucket." No maps were prepared for carbon sequestration and provision of other wildlife habitat.

Map No.	Theme
1	Wetlands by NWI Types
2	Wetlands by Landscape Position
3	Wetlands by Landform
4	Wetlands by Water Flow Path
5	Potential Wetlands of Significance for Surface Water Detention
6	Potential Wetlands of Significance for Coastal Storm Surge Detention
7	Potential Wetlands of Significance for Streamflow Maintenance
8	Potential Wetlands of Significance for Nutrient Transformation
9	Potential Wetlands of Significance for Sediment and Other Particulate Retention
10	Potential Wetlands of Significance for Shoreline Stabilization
11	Potential Wetlands of Significance for Provision of Fish and Shellfish Habitat
12	Potential Wetlands of Significance for Provision of Waterfowl and Waterbird Habitat
13	Potential Wetlands of Significance for Conservation of Biodiversity

NWI Types

Nearly 4,450 acres of wetlands were inventoried for Nantucket (Table 18). They comprised up to 15 percent of Nantucket. Freshwater wetlands (palustrine) were most abundant (2,374 acres) representing slightly more than half of the wetlands (52%). Deciduous scrub-shrub wetlands were the most common freshwater type, accounting for nearly two-thirds (64%) of the acreage. Forested wetlands represented only ten percent of the palustrine wetlands, while ponds (palustrine unconsolidated bottoms and shores) and emergent wetlands each made up seven percent. Marine wetlands totaled 1,141 acres which amounted to 25 percent of the island's wetlands. Unconsolidated shores (beaches and tidal flats) predominated. Estuarine wetlands were nearly as abundant as the marine wetlands, representing 23 percent of the wetlands. Emergent wetlands (salt and brackish marshes) comprised 70 percent of these tidal wetlands.

LLWW Types

Marine and estuarine wetlands combined to represent roughly half (52%) of the island's wetlands (excluding ponds), with fringe types (uninterrupted tidal flow) being most common (Table 19). Nearly 120 acres of the estuarine wetlands were located behind roads and railroad embankments (basin type). Over one-third of the wetlands (35%) were classified as terrene wetlands. Sixty percent of these were basins situated in headwater positions where water flowed out of the ground to create streams, while 40 percent were isolated depressions. Wetlands along streams (lotic) and lakes (lentic) accounted for only five percent and eight percent of the wetland acreage, respectively.

A total of 63 ponds were mapped on Nantucket (Table 20). Most (73%) of the ponds and 81 percent of the acreage were classified as natural. Two-thirds of this acreage was geographically isolated (surrounded by upland), while 22 percent experienced outflow. Only 15 acres of created ponds were identified and most were dammed/impounded. The average pond size was 1.2 acres.

Preliminary Functional Assessment

Surface water detention and retention of sediment and other particulates were predicted to be performed at significant levels by more than 90 percent of the island's wetlands (Table 21). Other functions performed by more than 50 percent of the wetlands were carbon sequestration, nutrient transformation, shoreline stabilization, provision of other wildlife habitat, provision of waterfowl and waterbird habitat, and coastal storm surge detention. One third of the wetland acreage was classified as providing important fish and shellfish habitat, while 27 percent of the wetland acreage was rated as significant for streamflow maintenance. Uncommon wetland types contributing to the island's biodiversity accounted for only three percent of the island's wetlands.

Table 18. Wetland of Nantucket classified by NWI type (Cowardin et al. 1979).

System	Class	Acreage
Marine	Aquatic Bed	12.8
	Unconsolidated Shore	1,128.4
	Total Marine Wetlands	**1,141.2**
Estuarine	Emergent	718.1
	Scrub-Shrub	12.8
	Unconsolidated Shore	295.4
	Aquatic Bed	4.6
	Rocky Shore	0.3
	Total Estuarine Wetlands	**1,031.2**
Palustrine	Emergent	161.7
	Emergent/Unconsolidated Bottom	3.4
	(Subtotal Emergent)	(165.1)
	Forested, Broad-leaved Deciduous	224.8
	Forested, Needle-leaved Evergreen	5.9
	(Subtotal Forested)	(230.7)
	Scrub-Shrub, Broad-leaved Deciduous	1,528.3
	Scrub-Shrub, Needle-leaved Evergreen	0.7
	Scrub-Shrub, Farmed	271.1
	(Subtotal Scrub-Shrub)	(1,800.1)
	Unconsolidated Bottom	159.6
	Unconsolidated Bottom/Emergent	8.4
	Unconsolidated Bottom/Forested	9.6
	(Subtotal Nonvegetated)	(177.6)
	Total Palustrine Wetlands	**2,373.5**
GRAND TOTAL (All Wetlands)		**4,545.9**

Table 19. Wetlands classified by landscape position, landform, and water flow path for Nantucket. Note: Ponds were treated as a waterbody type (see separate table) for summary.

Landscape Position	Landform	Water Flow Path	Acreage
Marine	Fringe	Bidirectional-tidal	1,132.1
	Island	Bidirectional-tidal	9.1
Total Marine			**1,141.2**
Estuarine	Fringe	Bidirectional-tidal	999.5
	Basin	Bidirectional-tidal	117.3
Total Estuarine			**1,116.8**
Lentic	Basin	Bidirectional-nontidal	325.3
		Throughflow	10.8
	(Subtotal Basin)		(336.1)
	Fringe	Bidirectional-tidal	2.5
Total Lentic			**338.6**
Lotic Stream	Basin	Throughflow	229.7
Total Lotic Stream			**229.7**
Terrene	Basin	Isolated	612.4
		Inflow	5.8
		Outflow	916.1
Total Terrene			**1,534.3**
GRAND TOTAL			**4,360.6**

Table 20. Pond acreage for Nantucket.

Type of Pond	Water Flow Path	Number of Ponds	Acreage
Natural	Isolated	28	41.5
	Outflow	8	13.9
	Bidirectional-nontidal	1	0.5
	Bidirectional-tidal	9	7.0
Total Natural Ponds		**46**	**62.9**
Dammed/Impounded	Isolated	2	3.7
	Throughflow	2	6.4
	Outflow	1	0.9
Total Dammed/Impounded Ponds		**5**	**11.0**
Excavated	Isolated	12	4.0
Total Excavated Ponds		**12**	**4.0**
GRAND TOTAL		**63**	**77.9**

Table 21. Wetlands of significance for various functions for Nantucket. Note: Results include ponds.

Function	Significance	Acreage	% of All Wetlands
Surface Water Detention	High	2,827.5	63.7
	Moderate	1,347.5	30.7
	Total	**4,175.0**	**94.1**
Coastal Storm Surge Detention	High	2,249.0	50.7
	Total	**2,249.0**	**50.7**
Streamflow Maintenance	High	538.4	12.1
	Moderate	664.7	14.9
	Total	**1,203.1**	**27.0**
Nutrient Transformation	High	2,683.0	60.4
	Moderate	261.2	5.9
	Total	**2,944.2**	**66.3**
Sediment and Other Particulate Retention	High	1,409.7	31.8
	Moderate	2,765.1	62.3
	Total	**4,174.8**	**93.1**
Shoreline Stabilization	High	1,286.9	29.0
	Moderate	1,477.6	33.3
	Total	**2,764.5**	**62.3**
Fish and Shellfish Habitat	High	1,282.8	28.9
	Moderate	72.1	1.6
	(Subtotal)	(1,354.9)	(30.5)
	Shading	115.6	2.6
	Total	**1,470.5**	**33.1**
Waterfowl and Waterbird Habitat	High	2,309.9	52.0
	Moderate	82.2	1.9
	Wood Duck	118.3	2.7
	Total	**2,510.4**	**56.6**
Other Wildlife Habitat	High	1,187.1	26.7
	Moderate	1,458.7	32.9
	Total	**2,645.8**	**59.6**

Table 21 (cont'd).

Function	Significance	Acreage	% of All Wetlands
Conservation of Biodiversity	Tidal Fresh PEM	22.0	0.5
	Tidal Fresh PSS	70.6	1.6
	Oligohaline Marsh	21.9	0.5
	Submg. Aquatic Bed	17.4	0.4
	Total	**131.9**	**3.0**
Carbon Sequestration	High	2,941.2	66.3
	Moderate	20.9	0.5
	Total	**2,962.1**	**66.8**

Discussion

As mentioned previously, the functional assessment presented here is a preliminary one based on correlations between wetland characteristics in the enhanced NWI database (NWIPlus) and eleven wetland functions. The assessment focused on wetlands (including ponds) and not on other aquatic habitats (deepwater habitats). The Natural Heritage & Endangered Species Program of the Massachusetts Division of Fisheries and Wildlife (NHESP) recently produced maps showing areas important for preserving biodiversity across the Commonwealth. Biodiversity can be interpreted in many ways. For the current study, the conservation of biodiversity function was based on identifying particular wetlands that were uncommon in the study area or are reported to have high plant diversity, whereas the NHESP used rare aquatic plant and animal data to identify areas important for freshwater diversity (NHESP 2003a, b). Figure 17 shows the location of these areas for Cape Cod and the islands (see NHESP 2003b for detailed information on the procedures for highlighting these areas). They also developed a biomap showing priority areas (core habitats and supporting watersheds) for biodiversity conservation statewide (Figure 18). A series of National Park Service reports describe several wetland types found on the Cape Cod National Seashore – freshwater ponds, vernal pools, dune slack wetlands, and salt marshes (Smith et al. 2007, Smith et al. 2006, Smith and Hanley 2006, and Smith 2004, respectively). An interagency (state-federal) report on estuarine marsh trends for Cape Cod, the Islands, and Boston Harbor provides a historic perspective on tidal marsh changes in these areas since the late 1800s (Carlisle et al. 2005). The studies listed above coupled with results presented in this report should be valuable to natural resource planners, natural resource agencies, conservation commissions, and others with interest in wetland conservation and management.

Figure 17. Fresh water areas in a portion of eastern Massachusetts designated as important for rare plants and animals by the NHESP. Supporting watersheds are also identified. (Source: NHESP 2003a,b).

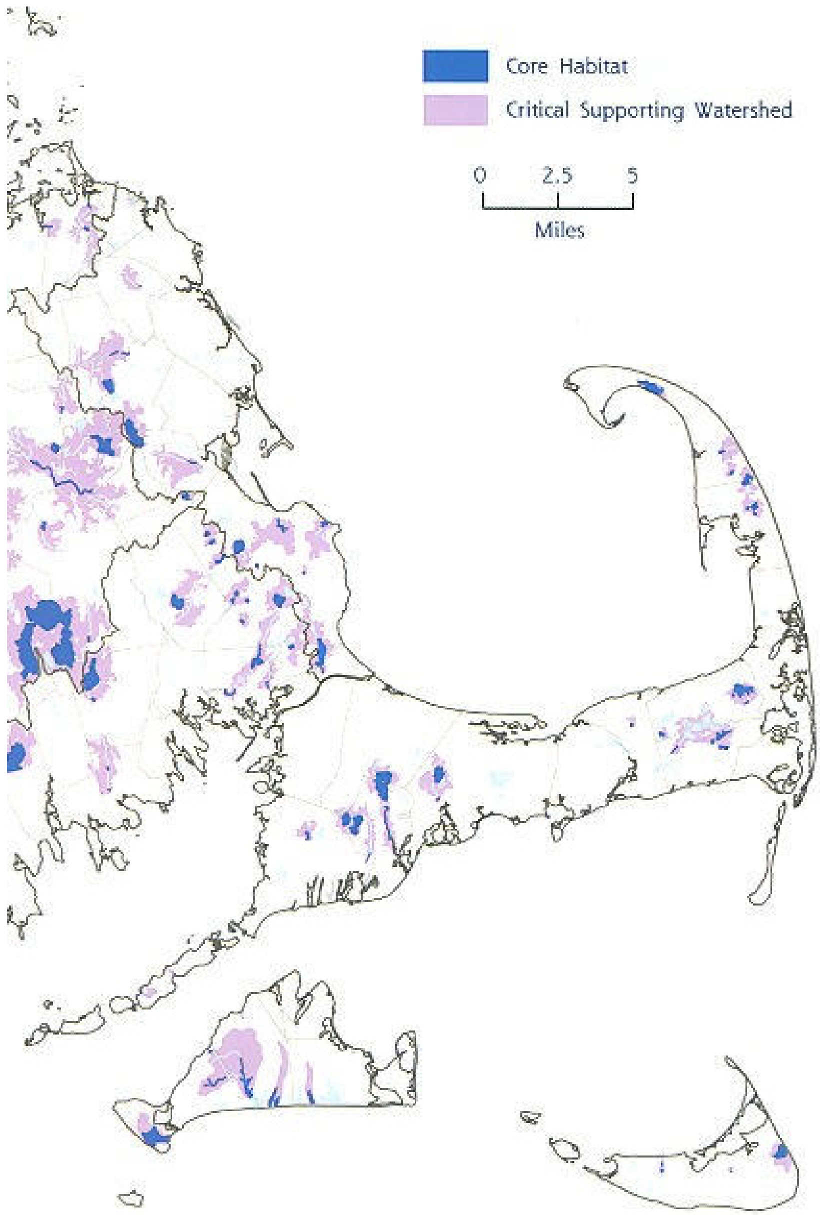
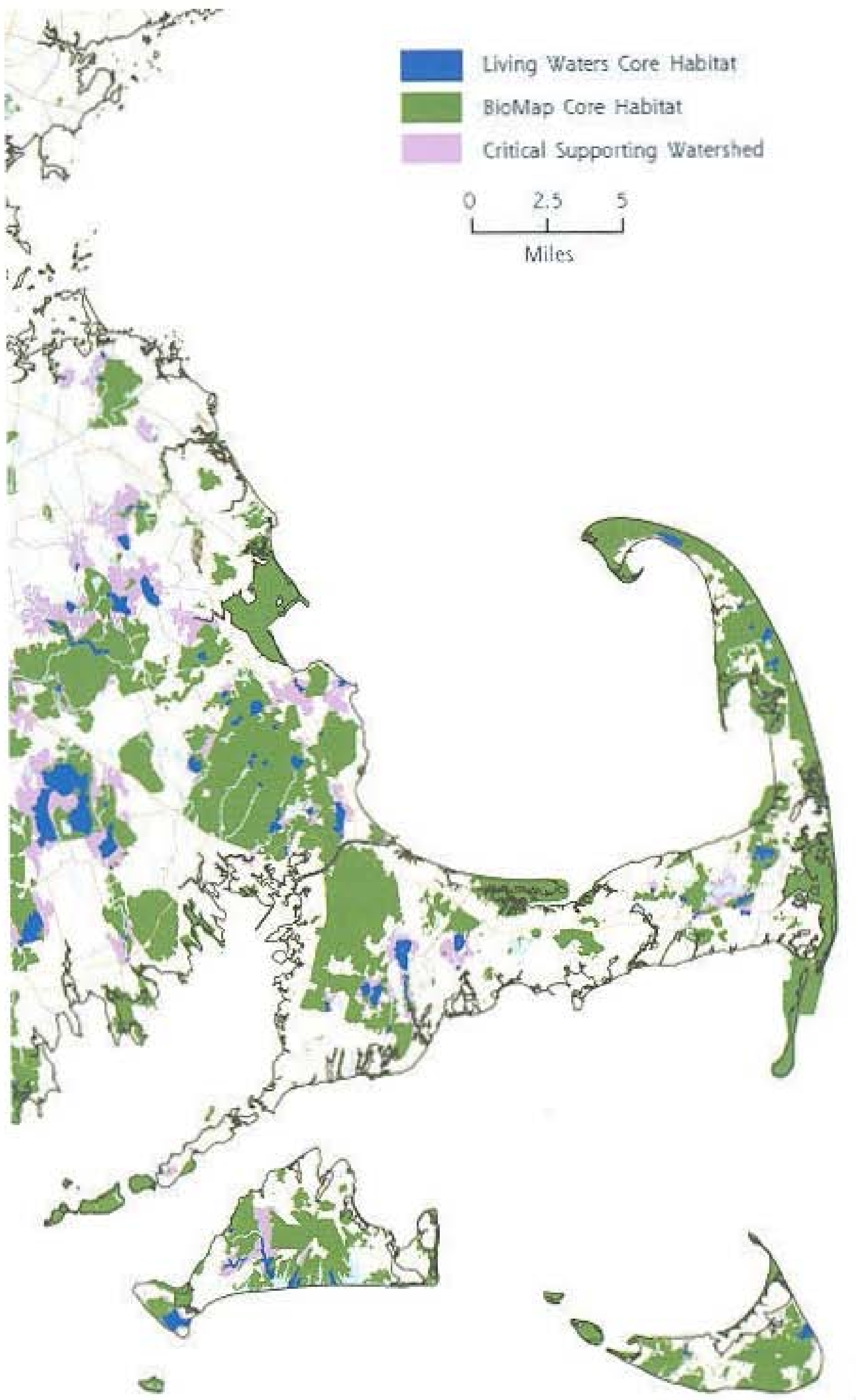


Figure 18. NHESP designated biodiversity core habitats and supporting watersheds for part of eastern Massachusetts. (Source: NHESP 2000a). (Note: These areas include uplands and wetlands.)



Summary

The NWI mapped over 63,000 acres of wetlands in the study area. Wetlands comprised about 15 percent of the area. Marine and estuarine wetlands represented more than half of the wetlands in all areas, except for Nantucket where palustrine wetlands predominated. Unconsolidated shores (beaches and tidal flats) were the chief marine type across the region, while emergent wetlands were the dominant estuarine type. Broad-leaved deciduous scrub-shrub wetlands were most common freshwater (palustrine) wetland type. Most of the freshwater wetlands (61%) were situated at headwater positions at the top of individual watersheds (outflow water flow path and sources of local streams) or in isolated basins - the terrene landscape position. Twenty-nine percent of the area's freshwater wetlands were located along streams (lotic wetlands), while only 10 percent were associated with lakes and deepwater impoundments (lentic wetlands).

From a functional standpoint, nearly all of the wetlands were predicted as having high or moderate significance for surface water detention and sediment and other particulate retention since most were basin (depressional) or fringe wetlands. More than half of the wetland acreage was recognized as important for coastal storm surge detention, nutrient transformation, shoreline stabilization, fish and shellfish habitat, waterfowl and waterbird habitat, other wildlife habitat, and carbon sequestration. Less wetland acreage was designated as significant for streamflow maintenance because fewer wetlands were in headwater positions than along coastal waters. Since wetlands identified as important for the conservation of biodiversity were uncommon wetland types in the region, only six percent of the area's wetlands were so designated, yet they contribute disproportionately to maintaining the area's biodiversity.

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Photointerpretation was performed by Gabriel DeAlessio and John Swords, with the latter responsible for quality control. They received assistance from Lisa Reisner, Meaghan Shaffer, and Lauren McCubbin. Bobbi Jo McClain added LLWW descriptors to the NWI database. Olya Tsvetkova (University of Massachusetts) finalized the database and prepared thematic maps and compiled nearly all of the summary statistics referenced in this report. Ralph Tiner reviewed the database, assisted in final editing, compiled the summary statistics for other wildlife habitat and carbon sequestration, and prepared the report.

The draft report was peer reviewed by Bill Wilen (USFWS), Charles Roman (University of Rhode Island, Graduate School of Oceanography), Andrew Baldwin (University of Maryland-College Park, Department of Environmental Science and Technology), and Charles Costello (Massachusetts Department of Environmental Protection), Jo Ann Mills (USFWS), and David Stout (USFWS). Their thoughtful comments are much appreciated. Thanks to Stephen Smith (National Park Service) for providing information on dune wetlands. Most of the photographs were taken by the author with a few provided by Kate Iaquinto and Keith Shannon (USFWS). Gina Jones (USFWS) prepared the cover.

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APPENDICES

Appendix A. NWI Classification Coding.

(Note: Only for types referenced in this report.)

Systems/Subsystem: M2 = Marine Intertidal, E = Estuarine Intertidal, P = Palustrine, L2 = Lacustrine Littoral, and R = Riverine

Classes: EM = Emergent, SS = Shrub-Shrub, FO = Forested, AB = Aquatic Bed, UB = Unconsolidated Bottom, US = Unconsolidated Shore, and RS = Rocky Shore

Subclasses for Forested and Scrub-Shrub Wetlands: 1 = Broad-leaved Deciduous, 2 = Needle-leaved Deciduous, 3 = Broad-leaved Evergreen, 4 = Needle-leaved Evergreen, and 5 = Dead

Subclasses for Algal Beds (used in this study): 1 = Algal and 2 = Rooted Vascular

Subclasses for Unconsolidated Shores (used in this study): 2 = Sand and 3 = Mud.

Nontidal Water Regime Modifiers: A = Temporarily Flooded, B = Saturated, C = Seasonally Flooded, E = Seasonally Flooded/Saturated, F = Semipermanently Flooded, and H = Permanently Flooded

Tidal Water Regime Modifiers: L = Subtidal, N = Regularly Flooded, P = Irregularly Flooded, R = Seasonally Flooded/Tidal, S = Temporarily Flooded/Tidal, and T = Semipermanently Flooded/Tidal

Other Modifiers: a = acidic (used for highlighting shrub bogs), b = beaver, d = partly drained, f = farmed (used for identifying commercial cranberry bogs in the study area), g = organic soil (used for Atlantic white cedar swamps), h = diked/impounded, x = excavated and 6 = oligohaline (water chemistry modifier to identify slightly brackish marshes).

Appendix B. Coding for LLWW Types.

Coding System for LLWW Descriptors

The following is the coding scheme for expanding classification of wetlands and waterbodies beyond typical NWI classifications. When enhancing NWI maps/digits, codes should be applied to all mapped wetlands and deepwater habitats (including linears). At a minimum, landscape position (including lotic gradient), landform, and water flow path should be applied to wetlands, and waterbody type and water flow path to water. Wetland and deepwater habitat data for specific estuaries, lakes, and river systems could be added to existing digital data through use of geographic information system (GIS) technology.

Codes for Wetlands

Wetlands are typically classified by landscape position, landform, and water flow path. Landforms are grouped according to Inland types and Coastal types with the latter referring to tidal wetlands associated with marine and estuarine waters. Use of other descriptors tends to be optional. They would be used for more detailed investigations and characterizations. (Note: Ponds are treated as waterbodies so refer to Waterbody section for their classification.)

Landscape Position

ES Estuarine
LE Lentic
LR Lotic river
LS Lotic stream
MA Marine
TE Terrene

Lotic Gradient

1 Low
2 Middle
3 High
4 Intermittent
5 Tidal
6 Dammed
- a lock and dammed
- b run-of-river dam
- c beaver
- d other dammed

7 Artificial (ditch)

Lentic Type

1 Natural deep lake (see also Pond codes for possible specific types)
- a main body
- b open embayment
- c semi-enclosed embayment
- d barrier beach lagoon

2 Dammed river valley lake
- a reservoir
- b hydropower
- c other

3 Other dammed lake
- a former natural
- b artificial

4 Excavated lake
- a quarry lake

5 Other artificial lake

Estuary Type

1 Drowned river valley estuary
- a open bay (fully exposed)
- b semi-enclosed bay
- c river channel

2 Bar-built estuary
- a coastal pond-open
- b coastal pond-seasonally closed
- c coastal pond-intermittently open
- d hypersaline lagoon

3 River-dominated estuary

4 Rocky headland bay estuary
- a island protected

5 Island protected estuary

6 Shoreline bay estuary
- a open (fully exposed)
- b semi-enclosed

7 Tectonic
- a fault-formed
- b volcanic-formed

8 Fjord

9 Other

Inland Landform

SL	Slope	
SLpa		Slope, paludified
IL	Island*	
ILde		Island, delta
ILrs		Island, reservoir
ILpd		Island, pond
FR	Fringe*	
FRil		Fringe, island*
FRbl		Fringe, barrier island
FRbb		Fringe, barrier beach
FRpd		Fringe, pond
FRdm		Fringe, drowned river mouth
FP	Floodplain	
FPba		Floodplain, basin
FPox		Floodplain, oxbow
FPfl		Floodplain, flat
FPil		Floodplain, island
IF	Interfluve	
IFba		Interfluve, basin
IFfl		Interfluve, flat
BA	Basin	
BAcb		Basin, Carolina bay
BApo		Basin, pocosin
BAcd		Basin, cypress dome
BApp		Basin, prairie pothole
BApl		Basin, playa
BAwc		Basin, West Coast vernal pool
BAid		Basin, interdunal
BAwv		Basin, woodland vernal
BApg		Basin, polygonal
BAsh		Basin, sinkhole
BApd		Basin, pond
BAgp		Basin, grady pond
BAsa		Basin, salt flat
BAaq		Basin, aquaculture (created)
BAcr		Basin, cranberry bog (created)
BAwm		Basin, wildlife management (created)
BAip		Basin, impoundment (created)
BAfe		Basin, former estuarine wetland

BAff	Basin, former floodplain
BAfi	Basin, former interfluve
BAfo	Basin, former floodplain oxbow
BAdm	Basin, drowned river-mouth

FL	Flat	
FLsa		Flat, salt flat
FLff		Flat, former floodplain
FLfi		Flat, former interfluve

*Note: Inland slope wetlands and island wetlands associated with rivers, streams, and lakes are designated as such by the landscape position classification (e.g., lotic river, lotic stream, or lentic), therefore no additional terms are needed here to convey this association.

Coastal Landform

IL	Island	
ILdt		Island, delta
ILde		Island, ebb-delta
ILdf		Island, flood-delta
ILrv		Island, river
ILst		Island, stream
ILby		Island, bay

DE	Delta	
DEr		Delta, river-dominated
DEt		Delta, tide-dominated
DEw		Delta, wave-dominated

FR	Fringe	
FRal		Fringe, atoll lagoon
FRbl		Fringe, barrier island
FRbb		Fringe, barrier beach
FRby		Fringe, bay
FRbi		Fringe, bay island
FRcp		Fringe, coastal pond
FRci		Fringe, coastal pond island
FRhl		Fringe, headland
FRoi		Fringe, oceanic island
FRlg		Fringe, lagoon
FRrv		Fringe, river
FRri		Fringe, river island
FRst		Fringe, stream
FRsi		Fringe, stream island

BA Basin
BAaq Basin, aquaculture (created)
BAid Basin, interdunal (swale)
BAst Basin, stream
BAsh Basin, salt hay production (created)
BAtd Basin, tidally restricted/road (not a management area)
BAtr Basin, tidally restricted/railroad (not a management area)
BAwm Basin, wildlife management (created)
BAip Basin, impoundment (created)

Water Flow Path

PA Paludified
IS Isolated
IN Inflow
OU Outflow
OA Outflow-artificial*
OP Outflow-perennial
OI Outflow-intermittent
TH Throughflow
TA Throughflow - artificial*
TN Throughflow - entrenched
TI Throughflow - intermittent
BI Bidirectional Flow - nontidal
BT Bidirectional Flow - tidal

*Note: To be used with wetlands connected to streams by ditches.

Other Modifiers (apply at the end of the code as appropriate)

br barren
bv beaver
ch channelized flow
cl coastal island (wetland on an island in an estuary or ocean including barrier islands)
cr cranberry bog
dd drainage divide
dr partly drained
ed freshwater wetland discharging directly into an estuary
fe former estuarine wetland
fg fragmented
fm floating mat
gd groundwater-dominated (apply to Water Flow Path only)
hi severely human-induced
hw headwater
li lake island (wetland associated with a lake island)

md freshwater wetland discharging directly into marine waters
ow overwash
pi pond island border
ri river island (wetland associated with a river island)
sd surface water-dominated (apply to Water Flow Path only)
sf spring-fed
ss subsurface flow
td tidally restricted/road
tr tidally restricted/railroad

(Note: "ho" was formerly used to indicate human-induced outflow brought about by ditch construction; now this is addressed by the water flow path "OA" Outflow-Artificial.)

Codes for Waterbodies (Deepwater Habitats and Ponds)

Besides Waterbody Type, waterbodies can be classified by water flow path (for lakes and ponds), estuary hydrologic type (for estuaries), and tidal range types (for estuaries and oceans).

Waterbody Type

RV River
- 1 low gradient
  - a connecting channel
  - b canal
- 2 middle gradient
  - a connecting channel
- 3 high gradient
  - a waterfall
  - b riffle
  - c pool
- 4 intermittent gradient
- 5 tidal gradient
- 6 dammed gradient
  - a lock and dammed
  - b run-of-river dammed
  - c other dammed

ST Stream
- 1 low gradient
  - a connecting channel
- 2 middle gradient
  - a connecting channel
- 3 high gradient
  - a waterfall
  - b riffle

c pool
4 intermittent gradient
5 tidal gradient
6 dammed
a lock and dammed
b run-of-river dammed
c beaver dammed
d other dammed
7 artificial
a connecting channel
b ditch

LK Lake
1 natural lake (*see also Pond codes for possible specific types*)
a main body
b open empbayment
c semi-enclosed embayment
d barrier beach lagoon
2 dammed river valley lake
a reservoir
b hydropower
c other
3 other dammed lake
a former natural
b artificial
4 other artificial lake

(Consider using a modifier to highlight specific lakes as needed, especially the Great Lakes, e.g., LK1E for Lake Erie or LK2O for Lake Ontario, and Lake Champlain, LK1C)

EY Estuary
1 drowned river valley estuary
a open bay (fully exposed)
b semi-enclosed bay
c river channel

2 bar-built estuary
a coastal pond-open
b coastal pond-seasonally closed
c coastal pond-intermittently open
d hypersaline lagoon
3 river-dominated estuary
4 rocky headland bay estuary
a island protected
5 island protected estuary

6 shoreline bay estuary
a open (fully exposed)
b semi-enclosed
7 tectonic
a fault-formed
b volcanic-formed
8 fjord
9 other

Note: If desired, you can also designate river channel (rc), stream channel (sc),and inlet channel (ic) by modifiers. *Examples*: EY1rc = Drowned River Valley Estuary river channel; EY2ic= Bar-built estuary inlet channel. If not, simply classify all estuarine water as a single type, e.g., EY1 for Drowned River Valley or EY2 for Bar-built Estuary.

OB Ocean or Bay
1 open (fully exposed)
2 semi-protected oceanic bay
3 atoll lagoon
4 other reef-protected waters
5 fjord

PD Pond
1 natural
a bog
b woodland-wetland
c woodland-dryland
d prairie-wetland (pothole)
e prairie-dryland (pothole)
f playa
g polygonal
h sinkhole-woodland
i sinkhole-prairie
j Carolina bay
k pocosin
l cypress dome
m vernal-woodland
n vernal-West Coast
o interdunal
p grady
q floodplain
r other

2 dammed/impounded
a agriculture
a1 cropland

	a2	livestock
	a3	cranberry
	b	aquaculture
	b1	catfish
	b2	crayfish
	c	commercial
	c1	commercial-stormwater
	d	industrial
	d1	industrial-stormwater
	d2	industrial-wastewater
	e	residential
	e1	residential-stormwater
	f	sewage treatment
	g	golf
	h	wildlife management
	i	other recreational
	o	other
3	excavated	
	a	agriculture
	a1	cropland
	a2	livestock
	a3	cranberry
	b	aquaculture
	b1	catfish
	b2	crayfish
	c	commercial
	c1	commercial-stormwater
	d	industrial
	d1	industrial-stormwater
	d2	industrial-wastewater
	e	residential
	e1	residential-stormwater
	f	sewage treatment
	g	golf
	h	wildlife management
	i	other recreational
	j	mining
	j1	sand/gravel
	j2	coal
	o	other
4	beaver	
5	other artificial	

Water Flow Path

IN	Inflow
OU	Outflow
OA	Outflow-artificial*
OP	Outflow-perennial
OI	Outflow-intermittent
TH	Throughflow
TA	Throughflow-artificial*
TI	Throughflow-intermittent*
TN	Throughflow-entrenched
BI	Bidirectional-nontidal
IS	Isolated
MI	Microtidal
ME	Mesotidal
MC	Macrotidal

*Note: OA and TA are human-caused by ditches; TI is to be used with throughflow ponds along intermittent streams.

Estuarine Hydrologic Circulation Type

SW	Salt-wedge/river-dominated type
PM	Partially mixed type
HO	Homogeneous/high energy type

Other Modifiers (apply at end of code)

ch	Channelized or Dredged
dv	Diverted
ed	freshwater stream flowing directly into an estuary
fv	Floating vegetation (on the surface)
lv	Leveed
md	freshwater stream flowing directly into marine waters
sv	Submerged vegetation

Appendix C. Correlation Between Functions and Wetland Types. (Adapted from Tiner 2003a.)

CORRELATION BETWEEN FUNCTIONS AND WETLAND TYPES

For coding, refer to Appendix A (the NWI legend) and Appendix B for LLWW types.

Function (code)	Level of Function	Wetland Types
Surface Water Detention (SWD)	High	ESFR, ESBA, ESIL, LEBA, LEFR, LEFL (in reservoir and dammed areas only: LE2FL and LE3FL), LEIL, LSBA, LRFPba, LSFR, LRFR, LRIL, MAFR, MAIL, PDTH, TEFRpdTH, TEBApdTH, PDBI, PDBT, TEBApdBT, TEBATH, TEBATI (Note: Retained floating mat bogs such as LEFR because their area will store surface water when lake levels rise.)
	Moderate	LRFPfl, LSFL, LE1FL, TEIF, TEBA (other than above), PD (other except PD2f), TE__pd (other, excluding slope wetlands TESLpd__), TEFP__ (Note: Exclude any saturated wetlands "B" water regime from Moderate, e.g., PFO1B that is LSFL)
Coastal Storm Surge Detention (CSS)	High	ESBA, ESFR, ESIL, LR5FR, LR5FP, LR5IL, MAFR, MAIL (should exclude diked wetlands and tidal ponds that are impounded and associated tidal wetlands in these categories since the dike prevents storm flowage except during extremes such as hurricanes)
	Moderate	Other tidal wetlands not include above and any TE wetland (FL or BA) contiguous with an estuarine wetland (usually marked by "ef" – these are bordering nontidal wetlands subject to infrequent or occasional tidal flooding during storms)

Streamflow Maintenance (SM)	High	hw (not dr = not ditched)
	Moderate	hwdr, LR1FP, LS_BA (excluding LS5), PDTH, TE__pdTH, PDOU, TE__pdOU, TEOU (not hw but associated with streams not rivers – will usually be all TE__OU), LE wetlands associated with throughflow lakes (LK__TH)
Nutrient Transformation (NT)	High	P__(AB, EM, SS, FO and mixes)C, P__(AB, EM, SS, FO and mixes)E, P__(AB, EM, SS, FO and mixes including __/UB and UB/__, etc.)F, P__(AB, EM, SS, FO and mixes)R, P__(AB, EM, SS, FO and mixes)T, P__(AB, EM, SS, FO and mixes)N, P__(AB, EM, SS, FO and mixes)H, P__(AB, EM, SS, FO and mixes)L, E2AB3, E2EM (and mixes), E2SS (and mixes), E2FO (and mixes), M2AB3, P__(AB, EM, SS, FO and mixes)B (not on coastal plain or glaciolacustrine plain)
	Moderate	P__(AB, EM, SS, FO and mixes)B (e.g., on coastal plain or glaciolacustrine plain; excluding bogs such as PSS3Ba), P__(AB, EM, SS, FO)A, P__(AB, EM, SS, FO and mixes)S
	(Note: Commercial cranberry bogs – PSSf – are not significant for this function.)	
Sediment and Other Particulate Retention (SR)	High	ES__(vegetated and mixes), LEBA, LEFR (vegetated and mizes, not “fm”-floating mat), LEIL(veg and mixes, not “fm”), M2AB3__, LSBA, LRBA, LSFP, LRFP, LRFR (veg, not “fm”), LSFR(veg),

		LRIL (veg), PDTH, TE__pdTH (including __pq), PDBI, TE__pdBI (including __pq), PDBT, TE__pdBT, TEBATH, TEBATI, TEIFbaTH, TEIFbaTI
	Moderate	E2__(US, SB, excluding RS), LEFR (nonveg), LSFL (not P___B_), LRIL (nonveg), LRFR (nonveg), LSFR (nonveg), M2US, Other TEBA (not P__B_), PD (not c, d, e, f, g, j types), Other TE__pd (not P__B_), TEFP__, TEFL__ (P__A, not P__B_)
	(Note: No "B" wetlands should be identified as significant for this function; only flooded types: A, C, E, F, H, R, S, T, R, N, M, and L should be rated)	
Shoreline Stabilization (SS)	High	E2__(AB, EM, SS, FO and mixes), E2RS (not ESIL), M2RS(not MAIL), M2AB1N (not IL), LR_(AB, EM, SS, FO and mixes; not LRIL), LS_(AB, EM, SS, FO and mixes), LE__(AB, EM, SS, FO and mixes; not LEIL and not "fm")
	Moderate	E2US2P (not IL), M2US2P (not IL), TE__pd (AB, EM, SS, FO and mixes), TE__OUhw (AB, EM, SS, FO and mixes)
Fish and Shellfish Habitat (FISH)		
	High	E2EM (including mixes with other types where EM1 or EM2 predominates; excluding E2EM5P__ and mixes where EM5 predominates and mixed communities dominated by E2FO or E2SS), E2US_M, E2RF, E2AB, E2RS (vegetated with macroalga; may be classified as E2AB1; not E2RSPr – jetty/groin), L2_F, L2AB, L2UB/__(AB, EM, SS, FO), LE__ (vegetated; AB, EM, SS, FO) and NWI water regime = H (permanently flooded), M2AB, M2RS (vegetated with macroalgae; may be classified as M2AB1; not

M2RSPr = jetties or groins), M2US_M, M2RF, P__F and adjacent to PD, LK, RV (all except LR4), ST (all except LS4), or EY waters, PAB, PUB/__(AB, EM, SS, FO), P__(EM, SS, FO)H, PEM__(N,R,T, or L, except EM5), PD associated with P__(AB, EM, SS, FO)F, R1EM, R1US(except S)

(Note: M1AB3L = submerged eelgrass – impt habitat but not wetland so is not included above; reports will note this.)

Moderate

LE__ and PEM1E (and mixes), LR__ and PEM1E (and mixes), LS__ and PEM1E (and mixes), PEM5F and adjacent to LK, RV (except LR4), ST(except LS4) and EY, M2US_N, E2US_N, E2EM5N (and mixes), PEM5N (and mixes), E2EM5/1P, E2EM5P__ and adjacent to the estuary (and mixes, but not "interior" E2EM5P_), E2FO/EM__ (not EM5), E2SS/EM__ (not EM5), LR5__ and PFO/EM_R or T (not EM5), LS5__ and PFO/EM_R or T (not EM5), PD (≥ 1 acre in size and PD1, PD2 a3, b, h, PD3 a3, b, h, or PD4), TEFRpd (along these ponds)

(Note: Ponds one acre or greater and certain types were selected as moderate.)

Stream Shading (Shade)

LS (not LS4 or not LS__pd) and PFO, LS (not LS4) and PSS (not PSS_Ba or not PSSf)

(Note: Shrub bogs should be excluded from all the above, e.g., PSS3Ba and commercial bogs = PSSf .)

Waterfowl and Waterbird Habitat (WBIRD)	High	E2EM1 or E2EM2 (includes mixes where they predominate), E2US__ M, N, P, and T water regimes (not S water regime), E2RF, E2AB, E2RS, L2_F (vegetated, AB, EM, SS, FO and mixes with nonvegetated), L2AB (and mixes with nonvegetated), L2US_(F,E, or C), L2_H (vegetated, AB, EM, SS, FO and mixes with nonvegetated), M2AB, M2RS (excluding jetties and groins – M2RSPr), M2US, M2RF, P__F (excluding EM5-dominated wetlands) and adjacent to PD, LK, RV(not LR4) ST(not LR4), or EY waters; PAB, P__H (vegetated, EM, SS, FO including mixes with UB), P__Eh, P__Eb; LS__ and PEM1E (including mixes), LR__ and PEM1E (including mixes), TE__ hw and PEM1E (including mixes); LE__ and PEM1E (including mixes); PEM__N,R,T, or L (includes mixes, but excludes Phragmites-dominanted EM5), PD associated with P__(AB, EM, SS, FO)F, PEM1R (and mixes), PEM1T (and mixes), PUB__b, R1EM, R1US (except S water regime)
	Moderate	E2EM5N (and mixes), E2EM5P (and mixes) and contiguous with open water (not "interior" marshes), E2SS1/EM1P6, E2EM5/1P, PEM5__E,F, R, or T and adjacent to PD, LK, RV(not LR4), ST(not LS4), or EY, other L2UB (not listed as high), Other PD (≥ 1 acre in size and PD1, PD2 a3, b, h, PD3 a3, b, h, or PD4), PEM1E__ (including mixes) and associated with PD, LK, RV(not LR4), or ST(not LS4)
	Wood Duck	LS(1,2, or 5)BA and P__ (FO or SS and mixes; not PSS3Ba or PSSf – commercial cranberry bog), LS(1,2, or 5)FR and P__ (FO or SS and mixes; not PSS3Ba or PSSf), LR(1,2, or 5)FPba and P__(FO or SS and mixes; not PSS3Ba or PSSf), LR(1,2, or 5)BA and P__(FO or SS and mixes; not PSS3Ba or PSSf), LRFPba and PFO/EM, LRFPba

and PUB/FO; PFO_R, T, or L (and mixes) and contiguous with open water, PSS_R, T, or L (and mixes) and contiguous with open water

(Note: Shrub bogs should be excluded from all the above, e.g., PSS3Ba and commercial bogs = PSSf .)

Other Wildlife Habitat (OWH)*	High	Any vegetated wetland polygon ≥ 10 acres (excluding semipermanently flooded, semipermanently flooded-tidal, and estuarine aquatic bed wetlands)
	Moderate	Other vegetated wetland polygons

*Note: These criteria were modified as shown for the Cape Cod study only.

Conservation of Biodiversity (BIO)	Regional significant (Northeast U.S.)	E2EM1N, E2EM1P6, R1EM, R1US, PEM1N, PEM1R, PEM2N, PEM2R, PSS_R, PSS_T, PFO4__g (Atlantic white cedar; including mixtures), PEM__i (herbaceous fen), PSS__i (shrub fen), PFO__i (treed fen), PFO2__ (bald cypress), E1AB__ (eelgrass and SAV beds), LS__FR, LR__FR, **PD1m (woodland vernal pool), *forested wetlands within >7410-acre forest

**Note: Can't easily do, would need to hand pick or do additional GIS analysis.

	Locally significant (Northeast U.S.)	PFO2__ (larch), urban wetlands, PSS3Ba or PSS1Ba (and mixes; shrub bog), E2RF2 (mussel reef), northern white cedar swamps, hemlock swamps, E2EM1N and P (some areas), LEFR with EM/AB and AB/EM vegetation, Other uncommon types in watershed

Carbon Sequestration (CAR)	High	P__ (AB,EM, SS, FO, and mixes)E, P__ (AB,EM, SS, FO, and mixes)F, P__ (AB,EM, SS, FO, and mixes)C, P___Ba (and mixes), PFO4Bg (and mixes), E2EM (and mixes), E2SS (and mixes), E2F0 (and mixes)
	Moderate	P__ (AB,EM, SS, FO, and mixes)A, P__ (AB,EM, SS, FO, and mixes)B
	(Note: Commercial cranberry bogs – PSSf – are not included.)	

Appendix D. An Overview of Wetland Values (Chapter 7 from "Wetlands of Rhode Island" pp. 52-66; Tiner 1989).

CHAPTER 7.
Wetland Values

Introduction

Rhode Island's wetlands have been traditionally used for hunting, trapping, fishing, berry harvest, timber and salt hay production, and livestock grazing. These uses tend to preserve the wetland integrity, although the qualitative nature of wetlands may be modified, especially by salt hay production and timber harvest. Human uses are not limited to these activities, but also include destructive and often irreversible actions such as drainage for agriculture and filling for industrial or residential development. In the past, many people considered wetlands as wastelands whose best use could only be attained through "reclamation projects" which led to the destruction of many wetlands. To the contrary, wetlands in their natural state provide a wealth of values to society (Table 19). These benefits can be divided into three basic categories: (1) fish and wildlife values, (2) environmental quality values, and (3) socio-economic values. The following discussion emphasizes the more important values of Rhode Island's wetlands, with significant national examples also presented. For an in-depth examination of wetland values, the reader is referred to *Wetland Functions and Values: The State of Our Understanding* (Greeson, *et al.* 1979). In addition, the U.S. Fish and Wildlife Service has created and maintains a wetland values database which records abstracts for over 5000 articles.

Table 19. List of major wetland values.

Fish and Wildlife Values

- Fish and Shellfish Habitat
- Waterfowl and Other Bird Habitat
- Mammal and Other Wildlife Habitat

Environmental Quality Values

- Water Quality Maintenance
  - Pollution Filter
  - Sediment Removal
  - Oxygen Production
  - Nutrient Recycling
  - Chemical and Nutrient Absorption
- Aquatic Productivity
- Microclimate Regulator
- World Climate (Ozone layer)

Socio-economic Values

- Flood Control
- Wave Damage Protection
- Shoreline Erosion Control
- Ground-water Recharge
- Water Supply
- Timber and Other Natural Products
- Energy Source (Peat)
- Livestock Grazing
- Fish and Shellfishing
- Hunting and Trapping
- Recreation
- Aesthetics
- Education and Scientific Research

Fish and Wildlife Values

Fish and wildlife utilize wetlands in a variety of ways. Some animals are entirely wetland-dependent, spending their entire lives in wetlands. Others use wetlands only for specific reasons, such as reproduction and nursery grounds, feeding, and resting areas during migration. Many upland animals visit wetlands to obtain drinking water and food. In urbanizing areas, the remaining wetlands become important habitats—a type of refuge—for "upland" wildlife displaced by development (F. Golet, pers. comm.). Wetlands are also essential habitat for numerous rare and endangered animals and plants.

Fish and Shellfish Habitat

Due to their linkage with adjacent waters, Rhode Island's coastal and inland wetlands are important fish habitats. Estuarine wetlands are also essential habitats for grass shrimp, crabs, oysters, clams, and other invertebrates.

Approximately two-thirds of the major U.S. commercial fishes depend on estuaries and salt marshes for nursery or spawning grounds (McHugh 1966). Among the more familiar wetland-dependent fishes are menhaden, bluefish, flounder, white perch, sea trout, mullet, croaker, striped bass, and drum. Forage fishes, such as anchovies, killifishes, mummichogs, and Atlantic silversides, are among the most abundant estuarine fishes. Narragansett Bay and its associated wetlands are important spawning and nursery grounds for many fish species (T. Lynch, pers. comm.). Winter flounder spawn in the shallow shoals of the Bay on beds of sea lettuce (*Ulva lactuca*), with peak spawning taking place from January to March. These same beds are used in the spring by spawning tautogs. Other nearshore spawners include scup, butterfish, and squid. Coastal ponds serve as spawning areas for tomcod beginning in November. As many as 63 fish species use Narragansett Bay as a nursery ground, with highest use in the fall.

Coastal wetlands are also important for shellfish including bay scallops, grass shrimp, blue crabs, oysters, quahogs and other clams. A critical stage of the bay scallop's life cycle requires that larvae attach to eelgrass leaves for about a month (Davenport 1903). Blue crabs and grass shrimp are abundant in tidal creeks of salt marshes. Estuarine aquatic beds, in general, also provide important cover for juvenile fishes and other estuarine organisms (Good, *et al.* 1978).

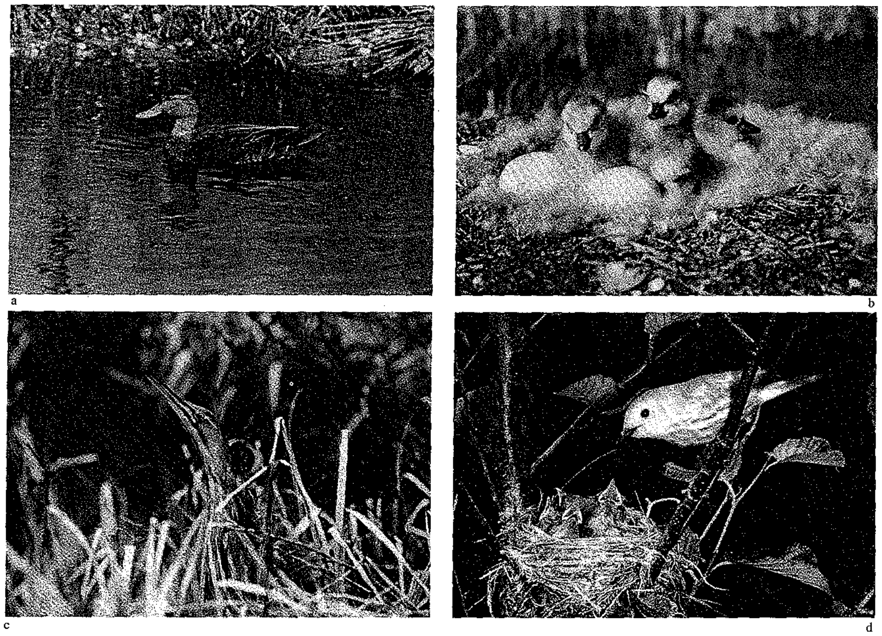

Figure 22. Migratory birds depend on Rhode Island wetlands: (a) black duck, (b) Canada goose goslings, (c) American bittern, and (d) yellow warbler.

Freshwater fishes also find wetlands essential for survival. In fact, nearly all freshwater fishes can be considered wetland-dependent because: (1) many species feed in wetlands or upon wetland-produced food, (2) many fishes use wetlands as nursery grounds, and (3) almost all important recreational fishes spawn in the aquatic portions of wetlands (Peters, *et al.* 1979). Many rivers and streams along Rhode Island's coast are spawning grounds for alewife and a few rivers are also used by sea-run brown trout, rainbow smelt, and American shad. Common fishes in Rhode Island's freshwater rivers, lakes, and ponds include northern pike, chain pickerel, largemouth bass, smallmouth bass, bluegill, common sunfish, yellow perch, brown bullhead, brook trout, rainbow trout, and white perch (Guthrie and Stolgitis 1977; RI DEM, pers. comm.). Northern pike spawn in early spring in flooded marshes and aquatic beds, while chain pickerel prefer aquatic beds. White perch are also early spring spawners, spawning in ponds and brackish coastal waters. Smallmouth bass spawn in about two feet of water from late May to early June. For all fish species, the presence of aquatic vegetation helps juvenile fishes avoid predator attacks, so wetlands are important nursery grounds.

Waterfowl and Other Bird Habitat

In addition to providing year-round habitats for resident birds, wetlands are particularly important as breeding grounds, over-wintering areas and feeding grounds for migratory waterfowl and numerous other birds (Figure 22). Both coastal and inland wetlands are valuable bird habitats.

Rhode Island's salt marshes are used for nesting by birds such as common terns, clapper rails, king rails, mallards, black ducks, blue-winged teals, mute swans, willets, herring gulls, great black-backed gulls, red-winged blackbirds, marsh wrens, sharp-tailed sparrows, and seaside sparrows. Red-winged blackbirds and seaside sparrows prefer stands of the short form of smooth cordgrass (*Spartina alterniflora*) which border permanent salt ponds, while marsh wrens prefer stands of the tall form of smooth cordgrass bordering tidal creeks and ditches (Reinert, *et al.* 1981). Moreover, the availability of open water and/or the short form smooth cordgrass community are directly related to the density of all breeding species. Bird breeding densities are over 2.5 times higher in unditched salt marshes than in ditched marshes (Reinert, *et al.* 1981). Wading birds, such as little blue herons, black-crowned night herons, glossy ibises, cattle egrets, snowy egrets and great egrets, also feed and nest in and adjacent to Rhode Island's coastal wetlands. Great blue herons feed in these wetlands, but nest inland. The U.S. Fish and Wildlife Service (Erwin and Korschgen 1979) has identified nesting colonies of coastal water birds in Rhode Island and other northeastern states. Ospreys also nest in wetlands along the coast.

Southern New England coastal marshes are important feeding and stopover areas for migrating raptors, waterfowl, shorebirds and wading birds. In Rhode Island, intertidal mudflats are principal feeding grounds for migratory shorebirds (e.g., sandpipers, plovers, and yellowlegs), while swallows can often be seen feeding on flying insects over the marshes. The U.S. Fish and Wildlife Service's winter waterfowl survey found an annual average of 9,700 scaup, 3,000 Canada geese, and 2,700 black ducks as well as hundreds of canvasbacks, mallards, mergansers, mute swans, scoters and other waterfowl overwintering in Rhode Island between 1980–1986.

Coastal beaches are used for nesting by piping plover (a Federal threatened species), American oystercatcher, and least tern. Rocky shores are nesting sites for gadwall, double-crested cormorant, roseate tern, and common tern (R. Enser, pers. comm.).

Rhode Island's inland wetlands are used by a variety of birds, including waterfowl, wading birds, rails and songbirds. Among the more typical species are black duck, wood duck, mallard, green-winged teal, Canada goose, mute swan, green-backed heron, great blue heron, least bittern, American bittern, Virginia rail, sora, common moorhen, spotted sandpiper, marsh wren, winter wren, red-winged blackbird, belted kingfisher, tree swallow, northern rough-winged swallow, Acadian flycatcher, willow flycatcher, eastern kingbird, warbling vireo, swamp sparrow, and woodcock. Most of these species are associated with freshwater marshes and open water bodies. Wood duck, Acadian flycatcher, barred owl, northern saw-whet owl, northern waterthrush, Louisiana waterthrush, Canada warbler, and white-throated sparrow nest in forested wetlands. Among the birds breeding in shrub swamps are woodcock and willow flycatcher. Lowry (1984) reported on numerous observations made over a seven-year period in red maple swamps and Atlantic white cedar swamps. Forty-four bird species were seen in the maple swamps, whereas only 25 species were found in cedar swamps. Similar results were reported for southern New Jersey by Wander (1980). Among the birds nesting or assumed to nest in the 30-acre Diamond Bog are mallard, black duck, wood duck, ruffed grouse, Virginia rail, ruby-throated hummingbird, red-winged blackbird, northern oriole, common grackle, common flicker, downy woodpecker, eastern kingbird, great-crested flycatcher, purple finch, American goldfinch, eastern phoebe, tree swallow, blue jay, black-capped chickadee, red-breasted nuthatch, northern waterthrush, common yellowthroat, Canada warbler, American robin, wood thrush, veery, cedar waxwing, black and white warbler, yellow warbler, ovenbird, song sparrow, and swamp sparrow (F. Golet, pers. comm.). (*Note:* Diamond Bog, located in the town of Richmond, is a mosaic of forested, scrub-shrub, and emergent wetlands with some open water.) In a study of eight red maple swamps in western Massachusetts, Swift (1980) found 46 breeding species. The most common breeders included common yellowthroat, veery, Canada warbler, ovenbird, northern waterthrush, and gray catbird. Anderson and Maxfield (1962) studied birdlife in a red maple-Atlantic white cedar swamp in southeastern Massachusetts and found the same species plus ruffed grouse, hairy woodpecker, downy woodpecker, blue jay, black-capped chickadee, American robin, wood thrush, black-and-white warbler, and common grackle.

Wetlands are, therefore, crucial for the existence of many birds, ranging from waterfowl and shorebirds to migratory songbirds. Some spend their entire lives in wetland environments, while others primarily use wetlands for breeding, feeding or resting.

Mammal and Other Wildlife Habitat

Many mammals and other wildlife inhabit Rhode Island wetlands. Muskrats are perhaps the most typical and widespread wetland mammal (Figure 23). Other furbearers inhabiting wetlands include river otter, mink, beaver, raccoon, skunk, red fox, fisher, and weasel. Hardwood swamps are reported to be the favorite habitat of raccoons in Rhode Island (Cronan and Brooks 1968). Beaver populations in the state have been growing since re-introduction in the 1950's. Beaver are most abundant in the Moosup River system in central western Rhode Island (C. Allin, pers. comm.). Smaller mammals also frequent wetlands such as eastern cottontail, New England cottontail, snowshoe hare, meadow vole, boreal red-backed vole, southern bog lemming, water shrew, and meadow jumping mouse, while large mammals may also be observed. White-tailed deer depend on Atlantic white cedar swamps for shelter and food during severe winters, but often use palustrine deciduous forested wetlands and scrub-shrub wetlands for resting and escape cover (Cronan and Brooks 1968; RI DEM, pers. comm.). Another group of mammals—bats—also use wetlands. They can often be seen in considerable numbers feeding over ponds, marshes, and other waterbodies in summer.

Figure 23. The muskrat is the most familiar and widespread wetland mammal in the state.

Besides mammals and birds, other forms of wildlife make their homes in wetlands. Reptiles (i.e., turtles and snakes) and amphibians (i.e., toads, frogs, and salamanders) are important residents. DeGraaf and Rudis (1983) described the non-marine reptiles and amphibians of New England including their habitat and natural history. Turtles are most common in Rhode Island's freshwater marshes and ponds and the more common ones include the eastern painted, spotted, box, stinkpot, wood, and snapping turtles. Common snakes found in and near wetlands include northern water, northern redbelly, eastern garter, eastern ribbon, eastern smooth green, and northern black racer. Among the more common toads and frogs in Rhode Island are Fowler's toad, American toad, northern spring peeper, green frog, bullfrog, wood frog, pickerel frog, and gray tree frog. Less common species include the northern leopard frog (a state special interest species) and the eastern spadefoot (state threatened) (R. Enser, pers. comm.). Adults of the red-spotted newt live in ponds with an abundance of submerged vegetation, while the juveniles are terrestrial. Many salamanders use temporary ponds or wetlands for breeding, although they may spend most of their years in upland or streamside habitats. Nearly all of the approximately 190 species of amphibians in North America are wetland-dependent at least for breeding (Clark 1979). Salamanders common in Rhode Island wetlands include the mudpuppy, spotted, northern dusky, and northern two-lined salamanders, while the four-toed and marbled salamanders are less common and are considered species of concern (R. Enser, pers. comm.).

Rare, Threatened, or Endangered Plants

Currently, the Rhode Island Natural Heritage Program is tracking 261 plant species that are rare, threatened, endangered, or of special interest or concern to the state due to their low numbers (R. Enser, pers. comm.). Of this list, approximately half (132 species) of the plants are considered wetland plants (Table 20). Among the wetland habitats where most of these plants occur are coastal plain pond shores (28 species), salt marshes, estuarine waters, and beaches (15 species), and bogs and fens (15 species).

Environmental Quality Values

Besides providing habitat for fish and wildlife, wetlands play a less conspicuous but essential role in maintaining high environmental quality, especially in aquatic habitats. They do this in a number of ways, including purifying natural waters by removing nutrients, chemical and organic pollutants, and sediment, and producing food which supports aquatic life.

Water Quality Improvement

Wetlands help maintain good water quality or improve degraded waters in several ways: (1) nutrient removal and retention, (2) processing chemical and organic wastes, and (3) reducing sediment load of water. Wetlands are particularly good water filters because of their locations between land and open water (Figure 24). Thus, they can both intercept runoff from land before it reaches the water and help filter nutrients, wastes and sediment from flooding waters. Clean waters are important to humans as well as to aquatic life.

First, wetlands remove nutrients, especially nitrogen and phosphorus, from flooding waters for plant growth and help prevent eutrophication or overenrichment of natural waters. Much of the nutrients are stored in the wetland soil. Freshwater tidal wetlands have proven effective in reducing nutrient and heavy metal loading from surface water runoff from urban areas in the upper Delaware River estuary (Simpson, *et al.* 1983c). Wetlands in and downstream of urban areas in Rhode Island probably also perform this function. It is, however, possible to overload a wetland and thereby reduce its ability to perform this function. Every wetland has a limited capacity to absorb nutrients and individual wetlands differ in their ability to do so.

Wetlands have been shown to be excellent removers of waste products from water. Sloey and others (1978) summarize the value of freshwater wetlands at removing nitrogen and phosphorus from the water and address management issues. They note that some wetland plants are so efficient at this task that some artificial waste treatment systems are using these plants. For example, the Max Planck Institute of Germany has a patent to create such

Table 20. Plant species of special concern to Rhode Island that occur in wetlands (R. Enser, pers. comm.).

Plant Species	Common Name	State Status[1]
Equisetum fluviatile	Water Horsetail	State Special Interest
Equisetum hyemale	Rough Horsetail	Species of Concern
Lycopodium inundatum var. *robustum*	Northern Bog Clubmoss	State Endangered
Isoetes engelmannii	Engelmann's Quillwort	State Special Interest
Isoetes muricata	Pointed Quillwort	State Special Interest
Isoetes riparia var. *canadensis*	River Quillwort	State Special Interest
Matteuccia struthiopteris	Ostrich Fern	Species of Concern
Larix laricina	American Larch	State Threatened
Picea mariana	Black Spruce	Species of Concern
Sparganium minimum	Small Bur-reed	State Extirpated
Najas guadalupensis	Naiad	State Threatened
Scheuchzeria palustris	Pod Grass	State Endangered
Sagitarria graminea	Grassleaf Arrowhead	State Special Interest
Sagittaria subulata var. *gracillima*	River Arrowhead	State Extirpated
Sagittaria teres	Slender Arrowhead	State Endangered
Panicum philadelphicum	Philadelphia Panic Grass	State Special Interest
Spartina cynosuroides	Salt Reed Grass	State Special Interest
Tripsacum dactyloides	Northern Gamagrass	State Threatened
Zizania aquatica	Wild Rice	Species of Concern
Carex collinsii	Collin's Sedge	State Endangered
Carex exilis	Bog Sedge	State Threatened
Cyperus aristatus	Awned Cyperus	State Extirpated
Eleocharis equisetoides	Horse-tail Spike-rush	State Special Interest
Eleocharis melanocarpa	Black-fruited Spike-rush	State Endangered
Eleocharis tricostata	Three-angle Spike-rush	State Endangered
Eriophorum gracile	Slender Cotton-grass	State Threatened
Eriophorum vaginatum	Hare's Tail	State Endangered
Eriophorum viridicarinatum	Bog Cotton-grass	State Special Interest
Fuirena pumila	Umbrella Grass	State Endangered
Psilocarya scirpoides	Long-beaked Bald Rush	State Endangered
Rhynchospora inundata	Drowned Horned Rush	State Endangered
Rhynchospora macrostachya	Beaked Rush	State Threatened
Rhynchospora torreyana	Torrey's Beaked Rush	State Threatened
Scirpus etuberculatus	Untubercled Bulrush	State Endangered
Scirpus hudsonianus	Cotton Club Rush	State Extirpated
Scirpus longii	Long's Bulrush	State Endangered
Scirpus maritimus var. *fernaldii*	Saltmarsh Bulrush	State Special Interest
Scirpus robustus	Leafy Bulrush	State Special Interest
Scirpus smithii	Smith's Bulrush	State Threatened
Scirpus torreyi	Torrey's Bulrush	State Special Interest
Scleria reticularis	Reticulated Nut-rush	State Threatened
Orontium aquaticum	Golden Club	State Endangered
Xyris montana	Northern Yellow-eyed Grass	State Threatened
Xyris smalliana	Small's Yellow-eyed Grass	Species of Concern
Juncus debilis	Weak Rush	State Special Interest
Alectris farinosa	Colicroot	Species of Concern
Smilacina trifolia	Three-leaved False Solomon's Seal	State Extirpated
Streptopus roseus	Rosy Twisted Stalk	State Threatened
Trillium erectum	Purple Trillium	State Threatened
Lachnanthes caroliniana	Carolina Redroot	State Threatened
Arethusa bulbosa	Swamp Pink	Species of Concern
Calopogon tuberosus	Tuberous Grass Pink	Species of Concern
Corallorhiza trifida	Early Coralroot	State Special Interest
Cypripedium calceolus	Yellow Lady's-slipper	State Threatened
Liparis loeselii	Yellow Twayblade	State Threatened
Malaxis unifolia	Green Adder's Mouth	State Endangered
Platanthera blephariglottis	White-fringed Orchis	State Threatened
Platanthera ciliaris	Yellow-fringed Orchis	State Endangered
Platanthera flava var. *herbiola*	Pale Green Orchis	State Endangered
Platanthera hyperborea	Northern Green Orchis	State Threatened
Platanthera psycodes	Small Puple-fringed Orchid	State Special Interest
Spiranthes lucida	Shining Ladies'-tresses	State Extirpated
Saururus cernuus	Lizard's Tail	State Endangered
Salix pedicellaris	Bog Willow	State Extirpated
Ulmus rubra	Slippery Elm	State Special Interest
Arceuthobium pusillum	Dwarf Mistletoe	State Endangered
Polygonum glaucum	Seabeach Knotweed	State Threatened
Polygonum puritanorum	Pondshore Knotweed	State Endangered
Polygonum setaceum var. *interjectum*	Strigose Knotweed	State Extirpated
Atriplex glabriuscula	Smooth Orache	State Special Interest
Chenopodium leptophyllum	Goosefoot	State Special Interest
Suaeda maritima	Sea-blite	Species of Concern
Amaranthus pumilus	Seabeach Amaranth	State Extirpated
Honkenya peploides	Sea-beach Sandwort	Species of Concern
Anemone riparia	Large Anemone	State Extirpated
Ranunculus aquatilis	White Water Crowfoot	State Extirpated
Ranunculus cymbalaria	Seaside Buttercup	State Extirpated
Ranunculus flabellaris	Yellow Water Crowfoot	Species of Concern

Table 20. *(Continued)*

Plant Species	Common Name	State Status[1]
Draba reptans	Carolina Whitlow-Grass	State Extirpated
Drosera filiformis	Thread-leaved Sundew	State Endangered
Podostemum ceratophyllum	Riverweed	State Extirpated
Parnassia glauca	Grass-of-Parnassus	State Extirpated
Saxifraga pensylvanica	Swamp Saxifrage	State Threatened
Dalibarda repens	Dewdrop	State Endangered
Crotalaria sagittalis	Rattlebox	State Threatened
Polygala cruciata	Cross-leaved Milkwort	State Threatened
Hypericum adpressum	Creeping St. John's-wort	State Threatened
Hypericum ellipticum	Pale St. John's-wort	State Special Interest
Viola incognita	Large-leaf White Violet	State Special Interest
Elatine americana	American Waterwort	State Special Interest
Rotala ramosior	Toothcup	State Endangered
Circaea alpina	Small Enchanter's Nightshade	Species of Concern
Epilobium palustre	Marsh Willow-herb	State Special Interest
Ludwigia sphaerocarpa	Round-fruited False Loosestrife	State Endangered
Myriophyllum alterniflorum	Alternate-flowered Water-milfoil	State Extirpated
Myriophyllum pinnatum	Pinnate Water-milfoil	State Extirpated
Angelica atropurpurea	Large Angelica	State Extirpated
Hydrocotyle verticillata	Saltpond Pennywort	State Endangered
Ligusticum scothicum	Scotch Lovage	State Threatened
Ptilimnium capillaceum	Mock Bishop's Weed	State Special Interest
Andromeda polifolia	Bog Rosemary	State Endangered
Gaultheria hispidula	Creeping Snowberry	State Special Interest
Gaylussacia dumosa var. *bigeloviana*	Dwarf Huckleberry	Species of Concern
Kalmia polifolia	Pale Laurel	State Endangered
Leucothoe racemosa var. *projecta*	Projecting Fetter-bush	Species of Concern
Rhododendron periclymenoides	Pinxter-flower	State Extirpated
Glaux maritima	Sea Milkwort	State Extirpated
Hottonia inflata	Featherfoil	State Special Interest
Fraxinus nigra	Black Ash	Species of Concern
Gentiana andrewsii	Closed Gentian	State Extirpated
Gentiana clausa	Bottle Gentian	State Special Interest
Gentianopsis crinita	Fringed Gentian	State Threatened
Sabatia kennedyana	Plymouth Gentian	State Endangered
Sabatia stellaris	Sea Pink	State Threatened
Physostegia virginiana	False Dragon-head	State Special Interest
Stachys hyssopifolia	Hyssop-leaf Hedge-nettle	State Endangered
Agalinis maritima	Seaside Gerardia	Species of Concern
Limosella australis	Mudwort	Species of Concern
Utricularia biflora	Two-flower Bladderwort	State Threatened
Utricularia geminiscapa	Paired Bladderwort	State Special Interest
Utricularia gibba	Humped Bladderwort	State Special Interest
Utricularia intermedia	Flatleaf Bladderwort	State Special Interest
Utricularia minor	Small Bladderwort	State Extirpated
Utricularia resupinata	Reversed Bladderwort	State Threatened
Utricularia subulata	Zigzag Bladderwort	State Threatened
Viburnum nudum	Swamp-haw	State Threatened
Lobelia dortmanna	Water Lobelia	Species of Concern
Bidens connata	Swamp Beggar-ticks	State Special Interest
Bidens coronata	Tickseed Sunflower	State Special Interest
Coreopsis rosea	Pink Tickseed	State Threatened
Eupatorium leucolepis var. *novae-angliae*	New England Boneset	State Endangered
Sclerolepis uniflora	Sclerolepis	State Endangered

[1]Definitions of State Status:

"State Endangered" are native species in imminent danger of extirpation from Rhode Island; these species meet one or more of the following criteria:

1. A species currently listed, or proposed by the U.S. Fish and Wildlife Service as Federally endangered or threatened.
2. A species with 1 or 2 known or estimated total occurrences in the state.
3. A species apparently globally rare or threatened, and estimated to occur at approximately 100 or fewer occurrences range-wide.

"State Threatened" are native species which are likely to become state endangered in the future if current trends in habitat loss or other detrimental factors remain unchanged; these species meet one or more of the following criteria:

1. A species with 3 to 5 known or estimated occurrences in the state.
2. A species with more than 5 known or estimated occurrences in the state, but especially vulnerable to habitat loss.

"State Special Interest" are native species not considered to be State Endangered or State Threatened at the present time, but occur in 6 to 10 sites in the state.

"Species of Concern" are native species which do not apply under the above categories but are additionally listed by the Natural Heritage Program due to various factors of rarity and/or vulnerability.

"State Extirpated" are native species which have been documented as occurring in the state but for which current occurrences are unknown. When known, the last documentation of occurrence is included. If an occurrence is located for a State Extirpated species, that species would automatically be listed in the State Endangered category.

Figure 24. Wetlands are important for water quality improvement as well as flood water storage. Their location between the upland and the water facilitates these functions.

systems, where a bulrush (*Scirpus lacustris*) is the primary waste removal agent. Numerous scientists have proposed that certain types of wetlands be used to process domestic wastes and some wetlands are already used for this purpose (Sloey, *et al.* 1978; Carter, *et al.* 1979; Kadlec 1979). It must, however, be recognized that individual wetlands have a finite capacity for natural assimilation of excess nutrients and research is needed to determine this threshold (Good 1982). In the meantime, it may be prudent to use artificial wetlands for treatment of secondary wastes and then run the tertiary products into a natural wetland, rather than having natural wetlands process the entire wasteload. Godfrey and others (1985) discuss ecological considerations of using wetlands to treat municipal wastewaters.

Perhaps the best known example of the importance of wetlands for water quality improvement is Tinicum Marsh (Grant and Patrick 1970). Tinicum Marsh is a 512-acre freshwater tidal marsh lying just south of Philadelphia, Pennsylvania. Three sewage treatment plants discharge treated sewage into marsh waters. On a daily basis, it was shown that this marsh removes from flooding waters: 7.7 tons of biological oxygen demand, 4.9 tons of phosphorus, 4.3 tons of ammonia, and 138 pounds of nitrate. In addition, Tinicum Marsh adds 20 tons of oxygen to the water each day.

Swamps also have the capacity for removing water pollutants. Bottomland forested wetlands along the Alcovy River in Georgia have been shown to filter impurities from flooding waters. Human and chicken wastes grossly pollute the river upstream, but after passing through less than 3 miles of swamp, the river's water quality is significantly improved. The value of the 2,300-acre Alcovy River Swamp for water pollution control was estimated at $1 million per year (Wharton 1970). In New Jersey, Durand and Zimmer (1982) have demonstrated the capacity of Pine Barrens wetlands to assimilate excess nutrients from adjacent agricultural land and upland development. Rhode Island's wetlands undoubtedly function similarly to these wetlands.

Wetlands also play a valuable role in reducing turbidity of flooding waters. This is especially important for aquatic life and for reducing siltation of ports, harbors, rivers and reservoirs. Removal of sediment load is also valuable because sediments often transport adsorbed nutrients,

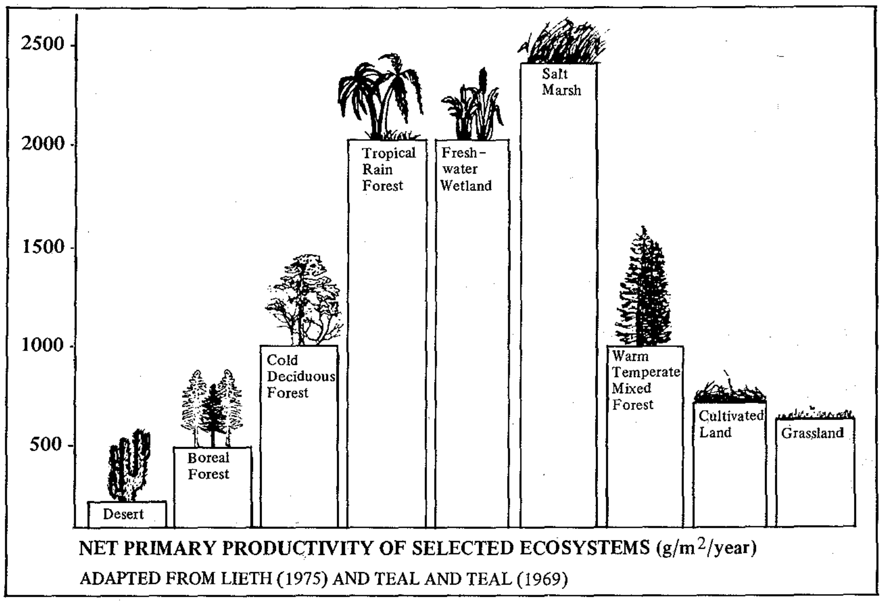

Figure 25. Relative productivity of wetland ecosystems in relation to other ecosystems (redrawn from Newton 1981). Salt marshes and freshwater marshes are among the world's most productive systems.

pesticides, heavy metals and other toxins which pollute our Nation's waters (Boto and Patrick 1979). Depressional wetlands should retain all of the sediment entering them (Novitzki 1978). In Wisconsin, watersheds with 40 percent coverage by lakes and wetlands had 90 percent less sediments in water than watersheds with no lakes or wetlands (Hindall 1975). Creekbanks of salt marshes typically support more productive vegetation than the marsh interior. Deposition of silt is accentuated at the water-marsh interface, where vegetation slows the velocity of water, causing sediment to drop out of solution. In addition to improving water quality, this process adds nutrients to the creekside marsh which leads to higher plant density and plant productivity (DeLaune, *et al.* 1978).

The U.S. Army Corps of Engineers has investigated the use of marsh vegetation to lower turbidity of dredged disposal runoff and to remove contaminants. In a 50-acre dredged material disposal impoundment near Georgetown, South Carolina, after passing through about 2,000 feet of marsh vegetation, the effluent turbidity was similar to that of the adjacent river (Lee, *et al.* 1976). Wetlands have also been proven to be good filters of nutrients and heavy metal loads in dredged disposal effluents (Windom 1977).

Recently, the ability of wetlands to retain heavy metals has been reported (Banus, *et al.* 1974; Mudroch and Capobianca 1978; Simpson, *et al.* 1983c). Wetland soils have been regarded as primary sinks for heavy metals, while wetland plants may play a more limited role. Waters flowing through urban areas often have heavy concentrations of heavy metals (e.g., cadmium, chromium, copper, nickel, lead, and zinc). The ability of freshwater tidal wetlands along the Delaware River in New Jersey to sequester and hold heavy metals has been documented (Good, *et al.* 1975; Whigham and Simpson 1976; Simpson *et al.* 1983a, 1983b, 1983c). Wetlands along heavily industrialized rivers in Rhode Island probably are retaining various heavy metals also. Additional study is needed to better understand retention mechanisms and capacities in wetlands.

Aquatic Productivity

Wetlands are among the most productive ecosystems in the world and they may be the highest, rivaling our best cornfields (Figure 25). Wetland plants are particularly efficient converters of solar energy. Through photosynthesis, plants convert sunlight into plant material or biomass and produce oxygen as a by-product. Other mate-

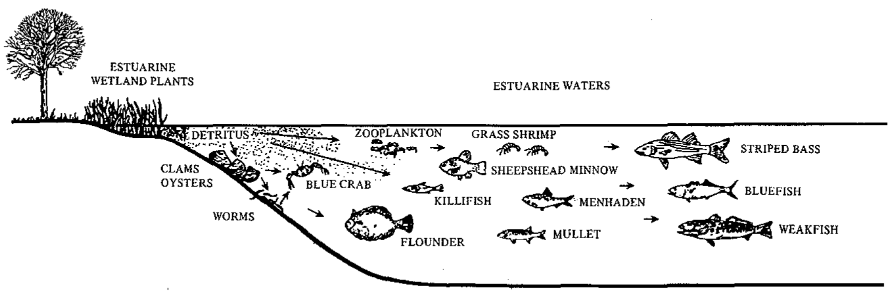

Figure 26. Simplified food pathways from estuarine wetland vegetation to commercially and recreationally important fishes and shellfishes.

rials, such as organic matter, nutrients, heavy metals, and sediment, also are captured by wetlands and either stored in the sediment or converted to biomass (Simpson, *et al.* 1983a). This biomass serves as food for a multitude of animals, both aquatic and terrestrial. For example, many waterfowl depend heavily on seeds of marsh plants, while muskrats eat cattail tubers and young shoots. Surprisingly, one of the favorite winter foods of the eastern cottontail is the tender new growth of red maples (Cronan and Brooks 1968).

Although direct grazing of wetland plants may be considerable in freshwater marshes, their major food value to most aquatic organisms is reached upon death when plants break down to form "detritus." This detritus forms the base of an aquatic food web that supports higher consumers, e.g., commercial fishes. This relationship is especially well-documented for coastal areas. Animals like zooplankton, shrimp, snails, clams, worms, killifish, and mullet eat detritus or graze upon the bacteria, fungi, diatoms and protozoa growing on its surfaces (Crow and Macdonald 1979; de la Cruz 1979). Forage fishes (e.g., anchovies, sticklebacks, killifishes, and silversides) and grass shrimp are the primary food for commercial and recreational fishes, including bluefish, flounder, weakfish, and white perch (Sugihara, *et al.* 1979). A simplified food web for estuaries in the Northeast is presented as Figure 26. Thus, wetlands can be regarded as the farmlands of the aquatic environment where great volumes of food are produced annually. The majority of non-marine aquatic animals also depend, either directly or indirectly, on this food source.

Socio-economic Values

The more tangible benefits of wetlands to society may be considered socio-economic values and they include flood and storm damage protection, erosion control, water supply and ground-water recharge, harvest of natural products, livestock grazing and recreation. Since these values provide either dollar savings or financial profit, they are more easily understood by most people.

Flood and Storm Damage Protection

In their natural condition, wetlands serve to temporarily store flood waters, thereby protecting downstream property owners from flood damage. After all, such flooding has been the driving force in creating these wetlands to begin with. This flood storage function also helps to slow the velocity of water and lower wave heights, reducing the water's erosive potential. Rather than having all flood waters flowing rapidly downstream and destroying private property and crops, wetlands slow the flow of water, store it temporarily and slowly release stored waters downstream (Figure 27). Wetlands, thereby, help reduce the peak flood heights as well as delay the flood crest. This becomes increasingly important in urban areas, where development has increased the rate and volume of surface water runoff and the potential for flood damage (Figure 28).

In 1975, 107 people were killed by flood waters in the U.S. and potential property damage for the year was estimated to be \$3.4 billion (U.S. Water Resources Council 1978). Almost half of all flood damage was suffered by farmers as crops and livestock were destroyed and productive land was covered by water or lost to erosion. Approximately 134 million acres of the conterminous U.S. have severe flooding problems (Figure 29). Of this, 2.8 million acres are urban land and 92.8 million acres are agricultural land (U.S. Water Resources Council 1977). Many of these flooded farmlands are wetlands. Although regulations and ordinances required by the Federal Insurance Administration reduce flood losses from urban land, agricultural losses are expected to remain at present levels

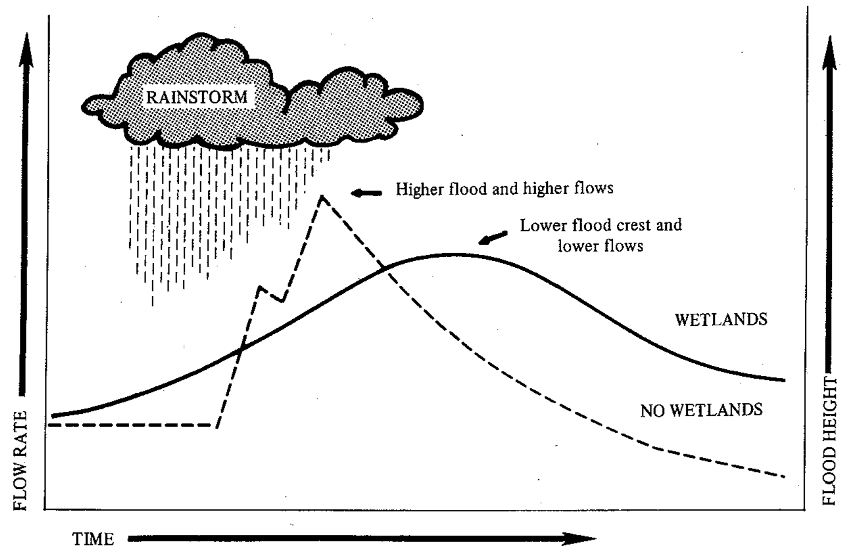

Figure 27. Wetlands help reduce flood crests and slow flow rates after rainstorms (adapted from Kusler 1983).

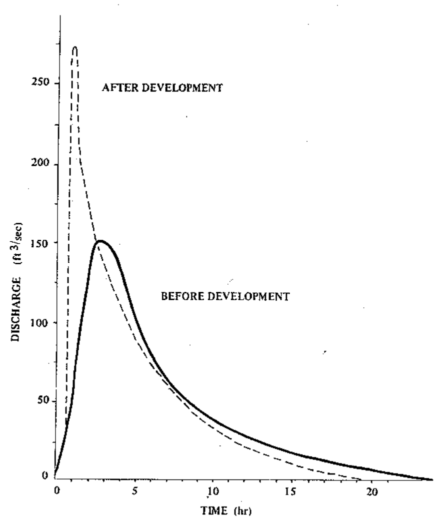

Figure 28. Urban development increases peak discharge in rivers. Comparisons of hydrographs for a watershed before and after development (redrawn from Fusillo 1981).

or increase as more wetland is put into crop production. Protection of wetlands is, therefore, an important means to minimizing flood damages in the future.

The U.S. Army Corps of Engineers have recognized the value of wetlands for flood storage in Massachusetts. In the early 1970's, they considered various alternatives to providing flood protection in the lower Charles River watershed near Boston, including: (1) a 55,000 acre-foot reservoir, (2) extensive walls and dikes, and (3) perpetual protection of 8,500 acres of wetland (U.S. Army Corps of Engineers 1976). If 40 percent of the Charles River wetlands were destroyed, flood damages would have increased by at least $3 million annually. Loss of all basin wetlands would cause an average annual flood damage cost of $17 million (Thibodeau and Ostro 1981). The Corps concluded that wetlands protection—"Natural Valley Storage"—was the least-cost solution to future flooding problems. In 1983, they completed acquisition of approximately 8,500 acres of Charles River wetlands for flood protection.

This protective value of wetlands has also been reported for other areas. Undeveloped floodplain wetlands in New Jersey protect against flood damages (Robichaud and Buell 1973). In the Passaic River watershed, annual property losses to flooding approached $50 million in

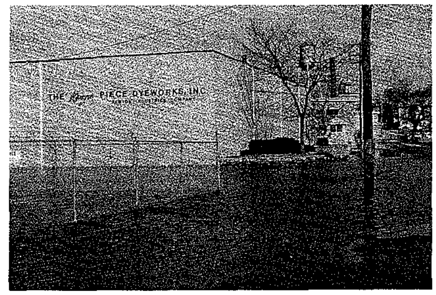

Figure 29. Wetland destruction accelerates flood damages.

1978 and the Corps of Engineers is considering wetland acquisition as an option to prevent flood damages from escalating in the future (U.S. Army Corps of Engineers 1979). A Wisconsin study projected that floods may be lowered as much as 80 percent in watersheds with many wetlands compared with similar basins with few or no wetlands (Novitzki 1978). Pothole wetlands in the Devils Lake basin of North Dakota store nearly 75 percent of the total runoff (Ludden, *et al.* 1983).

Rhode Island's wetlands also serve as temporary storage basins for retaining flood waters, thereby reducing potential flood damages. The 3,000-acre Great Swamp, Chapman Swamp and numerous other wetlands provide great flood storage for the Pawcatuck River in Washington County and without these wetlands flooding of downstream uplands would be enormous. The Pawtuxet River system, in marked contrast, has fewer wetlands (many wetlands were filled) and less flood storage area. Consequently, Warwick and Cranston experience serious flooding problems. Annual flood losses in 1978 for the Pawtuxet River basin were about $1.5 million. Corps of Engineers projections for 1990 suggest that increased urbanization in the basin would raise flood losses to $3.6 million for a 20-year flood and $5.5 million for a 50-year flood (F. Golet, pers. comm.).

Shoreline Erosion Control

Located between watercourses and uplands, wetlands help protect uplands from erosion. Wetland vegetation can reduce shoreline erosion in several ways, including: (1) increasing durability of the sediment through binding with its roots, (2) dampening waves through friction, and (3) reducing current velocity through friction (Dean 1979). This process also helps reduce turbidity and thereby helps improve water quality.

Obviously, trees are good stabilizers of river banks. Their roots bind the soil, making it more resistant to erosion, while their trunks and branches slow the flow of flooding waters and dampen wave heights. The banks of some rivers have not been eroded for 100 to 200 years due to the presence of trees (Leopold and Wolman 1957; Wolman and Leopold 1957; Sigafoos 1964). Among the freshwater grass and grass-like plants, common reed (*Phragmites australis*) and bulrushes (*Scirpus* spp.) have been regarded as the best at withstanding wave and current action (Kadlec and Wentz 1974; Seibert 1968). Common three-square (*Scirpus pungens*) often forms fringing marshes along the margins of many Rhode Island lakes and ponds. Along the coast, salt marshes of smooth cordgrass (*Spartina alterniflora*) are considered important shoreline stabilizers because of their wave dampening effect (Knudson, *et al.* 1982). While most wetland plants need calm or sheltered water for establishment, they will effectively control erosion once established (Kadlec and Wentz 1974; Garbisch 1977). Wetland vegetation has been successfully planted to reduce erosion along U.S. waters. Willows (*Salix* spp.), alders (*Alnus* spp.), ashes (*Fraxinus* spp.), cottonwoods and poplars (*Populus* spp.), maples (*Acer* spp.), and elms (*Ulmus* spp.) are particularly good stabilizers (Allen 1979). Successful emergent plants include reed canary grass (*Phalaris arundinacea*), common reed, cattails (*Typha* spp.), and bulrushes in freshwater areas (Hoffman 1977) and smooth cordgrass along the coast (Woodhouse, *et al.* 1976).

Water Supply

Most wetlands are areas of ground-water discharge and their underlying aquifers may provide sufficient quantities of water for public use. In neighboring Massachusetts, 40 percent to 50 percent of the wetlands may indicate the location of productive underground aquifers—potential sources of drinking water. At least 60 municipalities in the state have public wells in or very near wetlands (Motts and Heeley 1973). Prairie pothole wetlands store water which is important for wildlife and may be used for irrigation and livestock watering by farmers during droughts (Leitch

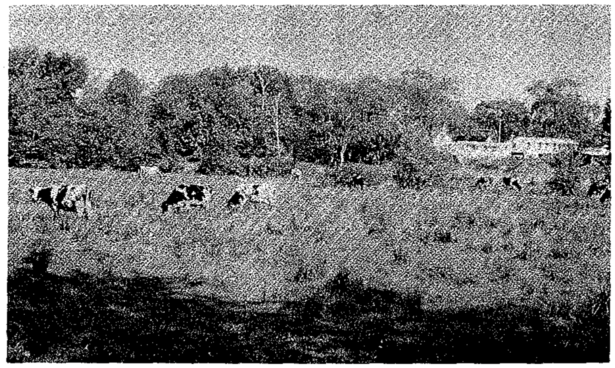

Figure 30. Cows often graze in wet meadows.

1981). These situations may hold true for Rhode Island and other states. Wetland protection and ground-water pollution control could be instrumental in helping to solve current and future water supply problems.

Ground-water Recharge

Ground-water recharge potential of wetlands varies according to numerous factors, including wetland type, geographic location, season, soil type, water table location and precipitation. In general, most researchers believe that most wetlands do not serve as significant ground-water recharge sites (Carter, *et al.* 1979). A few studies, however, have shown that certain wetland types may help recharge ground-water supplies by adding water to the underlying aquifer or water table. Shrub wetlands in the Pine Barrens may contribute to ground-water recharge (Ballard 1979). Depressional wetlands, like cypress domes in Florida and prairie potholes in the Dakotas, may also contribute to ground-water recharge (Odum, *et al.* 1975; Stewart and Kantrud 1972).

Floodplain wetlands also may do this through bank water storage (Mundorff 1950; Klopatek 1978). In urban areas where municipal wells pump water from streams and adjacent wetlands, "induced infiltration" may draw in surface water from wetlands into public wells. This type of human-induced recharge has been observed in Burlington, Massachusetts (Mulica 1977). These studies and others suggest that certain wetlands do help recharge ground-water and that additional research is needed to better assess the role of different types of wetlands in performing this function.

Harvest of Natural Products

A variety of natural products are produced by wetlands including timber, fish and shellfish, wildlife, peat moss, cranberries, blueberries, and wild rice. Wetland grasses are hayed in many places for winter livestock feed. During other seasons, livestock graze directly in numerous New England wetlands (Figure 30).

In the 49 continental states, an estimated 82 million acres of commercial forested wetlands exist (Johnson 1979). These forests provide timber for such uses as home construction, furniture, newspapers and firewood. Most of these forests lie east of the Rockies, where oak, gum, cypress, elm, ash and cottonwood are most important. The standing value of southern wetland forests is $8 billion. These southern forests have been harvested for over 200 years without noticeable degradation, thus they can be expected to produce timber for many years to come, unless converted to other uses. Rhode Island's forested wetlands provide timber for fuelwood and building construction. Braiewa (1983) reported on the biomass and fuelwood production of red maple stands in the state.

Many wetland-dependent fishes and wildlife are also utilized by society. Commercial fishermen and trappers make a living from these resources. From 1956 to 1975, about 60 percent of the U.S. commercial landings were fishes and shellfishes that depend on wetlands (Peters, *et al.* 1979). Nationally, major commercial species associated with wetlands are menhaden, salmon, shrimp, blue crab and alewife from coastal waters and catfish, carp and buffalo from inland areas. In Rhode Island, the 1985 commercial harvest of wetland-dependent coastal fishes (i.e., flounders, bluefish, weakfish, striped bass, shad, and white perch) had a value of $3.25 million, while the hard-shell clam or quahog harvest alone was valued at more than $14 million according to National Marine Fisheries Service commercial catch and value data. The fisheries value of Rhode Island's coastal ponds is discussed by Lee (1980). Recreational fishing and shellfishing are important activities for many Rhode Island residents.

Nationally, furs from beaver, muskrat, mink, nutria, and otter yielded roughly $35.5 million in 1976 (Demms and Pursley 1978). Louisiana is the largest fur-producing state and nearly all furs come from wetland animals. In Rhode Island, muskrat harvest was valued at near $60,000 in 1980 and only about $6,500 in 1988 due to declining pelt prices (L. Suprock and M. Lapisky, pers. comm.). Currently, muskrats are an under-harvested resource.

Recreation and Aesthetics

Many recreational activities take place in and around wetlands. Hunting and fishing are popular sports. Waterfowl hunting is a major activity in wetlands, but big game hunting is also important locally. In 1980, 5.3 million people spent $638 million on hunting waterfowl and other migratory birds (U.S. Department of the Interior and Department of Commerce 1982). Moreover, nearly all freshwater fishing is dependent on wetlands. In 1975 alone, sportfishermen spent $13.1 billion to catch wetland-dependent fishes in the U.S. (Peters, *et al.* 1979). Fishing was reported to be the second most popular leisure sport in America in a 1985 Gallup Poll (Sport Fishing Institute 1986). Fishing was the top activity for adult men with 44 percent participating. Since 1977, there has been a steady increase in the percent of Americans fishing.

Other recreation in wetlands is largely non-consumptive and involves activities like hiking, nature observation and photography, and canoeing and other boating. Many people simply enjoy the beauty and sounds of nature and spend their leisure time walking or boating in or near wetlands and observing plant and animal life. This aesthetic value is extremely difficult to place a dollar value upon, although people spend a great deal of money traveling to places to enjoy the scenery and to take pictures of these scenes and plant and animal life. In 1980, 28.8 million people (17 percent of the U.S. population) took special trips to observe, photograph or feed wildlife. Moreover, about 47 percent of all Americans showed an active interest in wildlife around their home (U.S. Department of the Interior and Department of Commerce 1982).

Summary

Marshes, swamps and other wetlands are assets to society in their natural state. They provide numerous products for human use and consumption, protect private property and provide recreational and aesthetic appreciation opportunities. Wetlands may also have other values yet unknown to society. For example, a microorganism from Pine Barrens swamps of southern New Jersey has been recently discovered to have great value to the drug industry. In searching for a new source of antibiotics, the Squibb Institute examined soils from around the world and found that only one contained microbes suitable for producing a new family of antibiotics. From a Pine Barrens swamp microorganism, scientists at the Squibb Institute have developed a new line of antibiotics which will be used to cure diseases not affected by present antibiotics (Moore 1981). This represents a significant medical discovery. If these wetlands were destroyed or grossly polluted, this discovery might not have been possible.

Destruction or alteration of wetlands eliminates or minimizes their values. Drainage of wetlands, for example, eliminates all the beneficial effects of the wetlands on water quality and directly contributes to flooding problems (Lee, *et al.* 1975). While the wetland landowner can derive financial profit from some of the values mentioned, the general public receives the vast majority of wetland benefits through flood and storm damage control, erosion control, water quality improvement and fish and wildlife resources. It is, therefore, in the public's best interest to protect wetlands to preserve these values for themselves and future generations. Since over half of the Nation's original wetlands have already been destroyed, the remaining wetlands are even more valuable as public resources.

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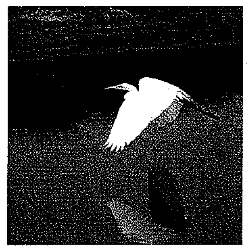
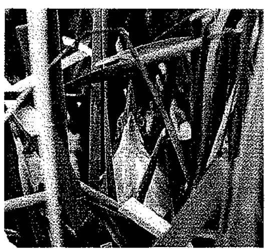
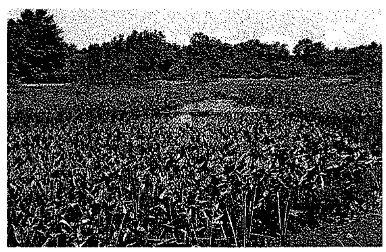
WETLANDS OF RHODE ISLAND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