National Park Service
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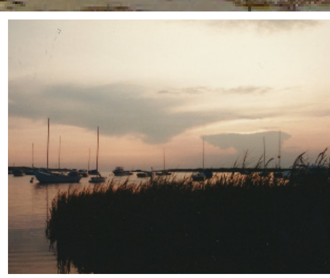
Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Cape Cod National Seashore, Massachusetts

Natural Resource Report NPS/NER/NRR—2012/605



ON THE COVER

Cape Cod National Seashore

Photographs by: Sarah J. Nelson and Peter Vaux, Senator George J. Mitchell Center for Environmental and Watershed Research, University of Maine.

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Executive Summary

This report is an assessment of the condition of the natural resources of Cape Cod National Seashore (CACO) and a review of the threats that act on these resources. The assessment focuses on the four landscape types present in the Park: uplands; barrier islands/spits/dunes; freshwaters (ponds, streams, wetlands and groundwater); and estuaries/salt marshes.

Scoping for this assessment included meetings with CACO staff and other scientists, and a review of past and ongoing research at the Park. The assessment relies primarily on published information, although some new data analyses of existing data are presented in this report. The natural resources of CACO are reviewed herein as 37 topics; each topic addresses one or more ecosystem attributes. Some topics (e.g. rare species, critical habitats, forest health and pond fish assemblages) address natural resources, per se. In contrast, other topics (e.g. land cover, atmospheric deposition, tidal restrictions) focus on issues that, while being integral to natural resource condition, may be considered more as threats or stressors. Both topic groups contribute to the fuller description of natural resource conditions at CACO. The long-term monitoring program at CACO, initiated in 1988, is focusing on a series of 'vital signs' and measures to document status and trends for key ecosystem attributes in the Park. Some of this research has been published and is incorporated into this assessment. However, additional information from this program is currently (2010) unpublished and could not be included here.

The Park includes 12,472 hectares (30,819 acres), representing approximately 40% of the combined area of the towns of Provincetown, Truro, Wellfleet, Eastham, Orleans and Chatham. The Park was established by legislation of 1961 and funds to complete acquisition of its lands were secured in 1967. Land use patterns across Cape Cod were highly dynamic following initial European settlement. During the 1800s, approximately one third of the Cape was used for agriculture, but farming declined since that time. Currently, about one half of CACO is forested. Salt water beaches and open water constitute 24% and 13%, respectively, of the Park, while wetlands represent <10%. An increase in the human population of Cape Cod through the mid-1800s was followed by a period of emigration. During the second half of the twentieth century, there was a renewed population influx; the rate of increase has slowed over the past several years.

Studies over the past half century or more have documented the plant and animal species inhabiting CACO and adjacent areas. Current totals for the number of vertebrates and plant species documented at CACO are: mammals (34 terrestrial, 20 marine); birds (376); reptiles (18); amphibians (12); fish (74); vascular plants (1088). Although less is known about many invertebrate groups, Lepidoptera (butterflies and moths; 488 documented species) and Odonata (dragonflies and damselflies; 105 documented species) have been intensively surveyed at CACO and in surrounding areas.

The remainder of this summary presents a brief overview of each of the topics selected for this assessment. It is important to underscore that the assessment is based on a highly heterogeneous suite of information. For some topics, resource conditions were evaluated using published numerical criteria or benchmarks. For other topics, while quantitative data describing the CACO resource may exist, accepted (published) benchmarks against which to compare (and thereby 'rank') these data are not available. This report therefore is not restricted to those resource components for which a fully quantitative condition assessment is possible. Rather, it attempts to provide as broad and complete a picture as possible of resource conditions at CACO.

Land cover / land use: status & change. Within CACO, the area of anthropogenic (essentially, urbanized) land-use ranges from 0% (Chatham) to about 4% (Eastham). Including non-park lands, anthropogenic land-use in the six eastern Cape towns ranges from 11% (Provincetown) to 25% (Eastham). In other areas of the Northeast, a value of <10% anthropogenic land-use has been used as a benchmark to characterize 'reference' (relatively unimpacted) watersheds. The area under anthropogenic land-use on the eastern Cape increased by 44% during the period 1971-1999. Increasing development of lands outside of the Park is of significant concern because, in many cases, these lands are ecologically connected to the natural resources within CACO. Impacts of residential and other forms of development include habitat fragmentation and changes in groundwater quality and quantity.

Atmosphere: ozone & visibility. High ozone levels can have adverse human health impacts and may cause damage to some plant species. CACO is a Class II area (under the Clean Air Act), meaning that some air pollution may be permitted as long as air quality does not increase beyond baseline levels and national air quality standards are not exceeded. Air quality is monitored at a site in Wellfleet. Although trends suggest improvement in meeting ozone standards, ozone concentrations remain a significant concern at CACO. Visibility at CACO has been assessed by the National Park Service (NPS) as being of moderate concern.

Nitrogen & sulfur in atmospheric deposition. The deposition of nitrogen and sulfur can influence the chemistry – and thereby the biota – of terrestrial and aquatic ecosystems. Sulfate deposition (wet-only) at CACO has declined by approximately one half since 1982. Nitrogen deposition has not exhibited a significant decline during this period. Both trends are consistent with patterns observed across the Northeast. Dry deposition of these elements is not measured at CACO; however data from elsewhere suggest that dry deposition can equal or exceed wet-only deposition.

Mercury in atmospheric deposition. Mercury is atmospherically deposited in regions remote to its origin. In the Northeast, approximately 75% of mercury deposition from the atmosphere is from anthropogenic sources. Mercury deposition in the CACO area is of significant concern for its potential impacts on wildlife and human health. Mercury deposition (wet-only) has been measured at CACO since 2003 (this site is the only Massachusetts site in the national Mercury Deposition Network). Data from elsewhere suggest that dry deposition of mercury could be 1.5-3 times wet-only values. Currently available data are insufficient to determine trends in total mercury deposition at CACO.

Mercury in freshwater and estuaries. In a regional study, lakes on Cape Cod and in southeastern New England typically had low concentrations of total mercury. Estuarine and marine systems have been studied less frequently than freshwaters. Current research on Cape Cod is investigating mercury transport between groundwater and estuarine/marine systems.

Mercury in biota. There is significant concern regarding levels of mercury in fish at CACO. Concentrations of mercury in fish fillets from the Park typically exceed human health consumption thresholds. Accordingly, fish consumption advisories were issued for eight freshwater ponds at CACO in 2007. Whole-body fish concentrations of mercury sampled in the 1990s at CACO were usually greater than levels proposed to be protective of piscivorous wildlife. Insufficient information on mercury levels in reptiles, birds and mammals in the Cape Cod area prevents an adequate evaluation of the status of this contaminant in these groups. Assessment of mercury levels across different faunal groups is complicated by differences in sampling and analytical methodologies.

Rare species: flora. 29 state-listed plant species have been recorded from CACO, representing 11% of all MA-listed flora. Published information does not appear to be available on the current status or trends for Park populations of these listed species. It is possible that additional rare species occur at CACO but have not yet been documented from park lands.

Rare species: fauna. Almost two thirds (44/68) MA-listed vertebrate species are known to occur in CACO. These include 6 marine mammals, 28 birds, 2 fish, 7 reptiles and 1 amphibian. A total of 13 federally-listed animal species are present in CACO and adjacent waters. Seventeen of the 46 MA-listed rare Lepidoptera species, and eight of the 30 listed Odonata species, are known to occur on the Cape Cod. None of these is federally-listed. Rare species are threatened by a variety of stressors, including pollution, decreasing habitat quantity/quality, and competition with other species. However, in general there is little information available documenting how environmental stressors may be impacting individual populations of these state-listed species.

Critical terrestrial & aquatic habitats. All of CACO upland areas are contained within two state-designated critical habitats. The Pamet River and many of CACO's kettle ponds have been identified by the MA Living Waters Program as being critical habitats within the state. Large areas of critical marine habitat, including intertidal zone, marsh and tidal flats, are found within the Park. Large portions of Pleasant Bay and Wellfleet Bay are contained within designated Areas of Critical Environmental Concern. The Park includes several state-designated high-value natural communities, including Atlantic White Cedar Bog (imperiled), Coastal Plain Pondshore (imperiled), Estuarine Intertidal – Saline/Brackish Flats (vulnerable), Maritime Dune Community (imperiled), and Sandplain Heathland (critically imperiled).

Flora & fauna: non-native & invasive species. Invasive species are non-native taxa whose introduction is likely to cause economic or environmental harm, or harm to human health. Only some non-native species are considered to be invasive. Nineteen percent of vascular plants species recorded from CACO are considered to be non-natives. Two percent of plant species are considered to be invasive. Only 2% of CACO's animal species are considered to be exotics or native transplants – most of these are fish. There are an additional 19 invasive species known to be present in Barnstable County and in the Atlantic Ocean bordering CACO – these may pose emerging threats to CACO. Sixteen of the 30 insect pests present in Barnstable County and tracked by USDA pose either an extreme or medium risk of infestation. Phragmites is a commonly observed invasive plant in CACO's dune slack wetlands and in freshwater ponds. The Park's forested vernal wetlands have relatively few invasive species. Black locust is an aggressive invader and is one terrestrial species for which there are quantitative data on population size – most (81%) stands of this species decreased in area between the 1970s and 2002. Although benchmarks for assessing the future status of invasive species at CACO do not appear to have been published, convenient benchmarks might include (i) no increase or a reduction in the number of invasive taxa present in the Park, and/or (ii) a stable or decreasing area infested by invasive plant species.

Terrestrial vegetation assemblages. Forest cover on the Cape has been increasing since the 1800s, following abandonment of agriculture. Increases in the basal area of several forest tree species at monitoring sites over the past quarter century reflect this trend. Fire suppression has contributed to the successional process. The fires that have occurred occasionally over the past century or more have primarily influenced overstory composition and structure in continuously wooded areas – these fires have not eradicated the major patterns of vegetation land use. Gypsy moth infestation has influenced forest structure at CACO (see next topic). Heathland and grassland communities are currently uncommon at CACO. Their restoration will require management strategies that mimic the effects of past agricultural activity. Baseline data on dune vegetation in the Park have recently been collected. Environmental variables related to salt and wind influence are the best predictors of dune plant assemblage composition. Metric value classes that could be used to define condition 'ranks' have not yet been published for terrestrial vegetation assemblages at CACO.

Forest health: disease incidence. Non-indigenous forest pests can pose threats to CACO forests. Barnstable County has been rated as having a high risk of infestation by the pine shoot beetle and the white pine blister rust. Recent forest pest alerts for Massachusetts include the Asian longhorned beetle and the virburnum leaf beetle. Forest susceptibility in Barnstable County to the longhorned beetle has been rated as moderate. Gypsy moth can exert a significant influence on forest dynamics. The last major infestation by this insect at CACO occurred in the early 1980s. The infestation influenced stand dynamics and successional patterns over the decade following that event. However, the effect of defoliation became diluted over the following decade. In general, published detailed information on the spatial and temporal patterns of disease incidence in CACO trees and shrubs appears to be scarce.

Terrestrial mammals: population dynamics. Mammals interact in multiple ways with CACO's animal and plant communities. Large mammals exert significant predation pressure on shorebird species. Baseline data on small mammal abundance and habitat preferences in the Park are available from 2000 and 2001. Published data are not available to document temporal trends in population size. No terrestrial mammals are state- or federal-listed.

Birds: assemblage structure & population dynamics. CACO was nominated in 2001 as an Important Bird Area. A total of 376 bird species have been recorded from the Park. Twenty eight of these are state-listed. CACO provides important habitat for several shorebird species and thousands of migrating shorebirds and terns annually congregate at Nauset Marsh and Coast Guard Beach and other locations in the Park. Numbers of Piping plover have been relatively stable over the past decade. However, the numbers of other shorebird species, including Least tern and Common tern, have declined markedly. The American oystercatcher was first recorded nesting at CACO in 2002. Overwash and changes in beach morphology, while natural processes, can have substantial impacts on shorebird species. Predation and habitat loss influence both shorebirds and other species. In waterfowl surveys conducted annually since 1984, six species have been most abundant. Over this period, there were apparent declines in the numbers of some species, including Canvasback, Northern pintail and Scaup. Grassland species have declined regionally and at CACO as open areas revert to forest. Grasshopper and Vesper sparrows were both historically present at CACO. However, the former appears to be now extirpated from the outer Cape, while the population of the latter has declined by over half in recent years. The CACO population of Northern harrier, a threatened species that typically nests in wetlands, was (in 2004) probably the largest breeding population of this species on the Massachusetts mainland. Nevertheless, the population density at CACO was about 50% of the rangewide average, perhaps reflecting modest habitat quality for this species at CACO.

Amphibians & reptiles: population status & trends. The CACO fauna list includes a total of 25 amphibian and reptile species, with an additional five species of marine turtles. One amphibian and seven reptiles in the Park are state-listed. The Diamondback terrapin (threatened) lives in the salt marshes of Wellfleet Harbor and to the south. The CACO population of the Eastern spadefoot toad (threatened) is one of the most important regionally – this species is found throughout the Park but is rare elsewhere in Massachusetts. Two species (Four-toed salamander and Spotted turtle) were delisted in recent years. Two other species, although unlisted, are of special interest at CACO – the Eastern hognose snake (possibly a declining population at CACO) and the Northern water snake (appears to be uncommon at CACO, although suitable habitat is abundant). Most amphibians are dependent on temporary or permanent freshwater habitat – just one species is terrestrial. The distribution and abundance of amphibians and non-marine turtles in the Park have been well documented since about 2003. Based on published data, a few trends in population parameters (e.g. egg mass counts) are apparent. However, the period of methodologically consistent monitoring data is relatively short.

Parabolic dunes & associated wetlands. Over the past seven decades, parabolic dunes in the Province Lands have migrated at average rates of between 1 and 4 m/yr. Dune migration is more rapid in drier years. Imagery from six times during the 1947-2001 period provides a base from which to identify the age (post-1947) of individual wetlands. There are approximately 350 dune slack wetlands within this system – these provide critically important habitat for many species. Future trends in dune vegetation assemblages will be able to be documented using 2003-2004 survey data as a baseline. Dune slack wetlands appear to be in good and relatively unimpacted condition at the present time. However, their hydrologic regimes and, in turn, their biological communities may be highly susceptible to future reductions in groundwater levels.

Wetlands: distribution, hydrology & biology. There are two groups of freshwater wetlands at CACO – dune slack wetlands (see above) and forested vernal pools. Wetlands provide critical habitat for many plant and animal species. Vernal pools typically reach their largest areal extent in June, and smallest in January. Pool water levels are sensitive to water table draw-down, but the responses of multiple pools to changing groundwater levels have not yet been modeled. Vegetation assemblages of the forested wetlands are relatively pristine, with low incidence of exotic species. Inter-annual variations in plant assemblages appear to be quite large and are likely related to hydrologic factors. Both within and, especially, outside the Park, wetland loss has occurred at a few sites, typically associated with residential development or road building. Areas of wetland change have been small – all < 0.25 ha.

Ponds: acid-base chemisty. CACO kettle ponds are naturally acidic and pH has changed little through time. The ionic composition of these ponds is dominated by sodium and chloride, which appear to be from marine aerosol deposition and not from road salt or other anthropogenic sources.

Ponds: nutrients & trophic condition. In a 1999 survey of 20 CACO kettle ponds, 3 were eutrophic (high productivity), 9 were mesotrophic (moderate productivity) and 8 were oligotrophic (low productivity). Overall, trophic indicators suggest more desirable conditions in the CACO ponds than the statewide average. Although available data restrict the ability to document trends in the trophic condition of these ponds, it appears that two ponds (Duck and Ryder) have exhibited large declines in water transparency in recent years. Data availability has improved since 1996 and ongoing monitoring should provide a record that can be used for future trend analyses. Most sources of phosphorus to the ponds are likely to be human-associated.

Ponds: aquatic vegetation assemblages. Coastal plain pond plant species represent one of the most critical rare species assemblages in New England. Plant assemblage data are available from the two groups of permanently flooded ponds at CACO: kettle ponds and Province Lands ponds. Species richness (number of species) in the kettle ponds ranged from 12-30, while in the Province Lands ponds richness was in the range 14-37. Plant assemblage structure (species composition and growth form) appears to be a useful indicator of trophic condition and other responses to environmental change, including climate variables and hydrology.

Ponds: fish assemblages. Of the 74 fish species recorded for CACO, 22 are freshwater taxa. CACO ponds are characterized by warm-water fish assemblages. Environmental variables thought to play a role in structuring these assemblages include pH, pond depth and macrophyte (plant) density. Multi-metric biological integrity indices for pond fish assemblages at CACO would provide a valuable tool for evaluating this resource – however there appear to be no published efforts to tailor the biological integrity index concept to CACO ponds.

Diadromous fish: connectivity issues. In eight catchments of the outer Cape, there are in-stream structures that might interfere with fish migration. In approximately one half of these watersheds, one or more barriers have been judged to significantly reduce fish passage. In view of declining populations throughout the Northeast, Alewife harvests have been prohibited throughout Massachusetts. Historical data on the run sizes for migratory fish are largely absent for outer Cape watersheds.

Groundwater: quantity. The aquifer of Lower Cape Cod is a critically important resource. Four groundwater lenses in this area supply all drinking water, provide numerous ecosystem services and receive septic effluent. Municipal withdrawals from the Pamet lens represent 7% of the entire hydrologic budget for that section of the aquifer. Changes in water extraction regimes will likely affect kettle-hole ponds, some streams and wetlands. Sea-level rise is affecting groundwater levels and is predicted to result in a thinning of the Pamet and other lenses.

Groundwater: quality. Wastewater and landfills are the primary contaminant sources for groundwater in the outer Cape. Although all landfills are now closed, they continue to leach contaminants. Nitrate concentrations in wells have increased over the past two decades. Nevertheless, fewer than 5% of groundwater samples from Eastham exceeded the 10 ppm federal and state maximum contaminant level for nitrogen in all years during a 2003-2006 survey. Increasing development has the potential to further increase groundwater nitrogen levels, which in turn may contribute to nutrient enrichment of surface waters.

Tidal restrictions: occurrence, impacts & restoration. Since the 1800s, dikes and other structures have resulted in tidal restrictions at over 30 sites on the outer Cape. Ecological impacts from these restrictions vary but can be substantial, including loss of large areas of salt marsh, and conversion of estuarine plant and animal assemblages to more freshwater or upland types. At CACO, large-scale restoration of tide-restricted systems has begun at two sites: Hatches Harbor and East Harbor Lagoon. There are also plans for the restoration of tidal flow to the entire Herring River system – several hydrologic modeling studies have been implemented to predict the impacts of this restoration. A more natural tidal regime in the Herring River is predicted to reduce fecal coliform densities to levels which will be acceptable for shellfish growing.

Salt marsh: flora & fauna. Nekton and vegetation data are collected as part of the CACO long-term monitoring program. While initial data are available for Hatches Harbor and Nauset Marsh, most of the data have not yet been published. (See also next topic for more information on landscape-level vegetation changes in CACO salt marshes.)

Salt marsh: landscape changes. The NPS is currently monitoring salt marsh elevation and accretion at several sites within the Park. Data from this study have not yet been published. However, other data suggest that Nauset marsh appears to be keeping pace with sea-level rise (2.4 mm/yr over the period 1921-1993). There is evidence of wetland submergence at Nauset marsh. Changes in plant species in the past indicate the marsh is getting wetter (but see below for conclusion from another study). Half of the marshes on the outer Cape have experienced vegetation losses of over 30% during the past half century. Vegetation at Nauset Marsh appears to have been stable over the last century.

Eelgrass distribution & population status. Eelgrass beds on the Cape decreased by about 30% between 1995 and 2001. The most recent data (2006-2007) suggest that this reduction in eelgrass extent has continued in Pleasant Bay. Since the 1950s, eelgrass beds in this systems have decreased by about one quarter. Nutrient enrichment is thought to be one of the primary factors causing declines in eelgrass populations at both regional and global levels. Storm-mediated disturbance is thought to influence spatial patterns of eelgrass cover in Pleasant Bay and Cape Cod Bay. Eelgrass wasting disease was recorded on Cape Cod in the 1980s but its contribution to current plant declines is uncertain.

Horseshoe crabs: population status & dynamics. Horeshoe crabs are an important component of the estuarine benthic system on the Cape. They are harvested for bait and for use in the biomedical industry. State managers have become increasingly concerned about horseshoe crab spawning densities throughout Massachusetts and have instituted more regulations regarding the harvest of crabs. Sex ratios for spawning horseshoe crabs were strongly skewed towards males within Pleasant Bay and there is evidence that spawning dynamics have changed in this embayment since the 1950s. Spawning 'hot-spots' in Pleasant Bay may be responsible for a significant percent of all spawning Cape-wide. Overfishing and spawning habitat loss (e.g. from construction of hardened shorelines) are two key threats to horseshoe crab populations.

Shellfish resources. Cape Cod waters provide habitat for several commercially important shellfish species. Shellfish aquaculture is practiced in waters adjacent to CACO. Some species (e.g. Quahog and Bay scallop) have experienced local harvest declines, while others (e.g. Razor clam and Soft shell clam) have experienced local increases. In a recent stock assessment, NOAA fisheries managers concluded that overfishing was not occurring for populations of the three Atlantic Coast commercial shellfish species studied (Atlantic surf clam, Ocean quahog and Sea scallop).

Beach closures. The NPS has sampled bathing beach waters at CACO since 2006. Additional data are available from a Massachusetts Department of Public Health monitoring program. In general, bathing beach water quality in CACO is good. From June 2002 to June 2009, CACO beaches have only been closed because of high coliform levels on 6 dates – all of these closures occurred in 2004. The majority of closures outside of CACO since 2002 have occurred in Provincetown Harbor (46 closures) and Cape Cod Bay (56 closures).

Beach fouling: marine macroalgal accumulations. Accumulations of nuisance drift macroalgae along the open-coast Atlantic beaches of Cape Cod have been observed on an anecdotal basis for over 50 years. Historically, they have caused beach closures. Detailed data on macroalgal abundance at CACO are available only from a 2006 study. Peak macroalgal biomass occurred in early August and highest densities were observed at Head of the Meadow beach, in both intertidal and subtidal habitats. Macoalgae probably originate in northern New England and are transported south by ocean currents. It is unlikely that accumulations are associated with nutrient availability.

Harmful algal blooms & shellfish closures. The state of Massachusetts monitors for paralytic shellfish poisoning (PSP) to determine the safety of shellfish harvested in state waters. Elevated biotoxin levels are usually detected every year, forcing harvest closures. In 2009, elevated biotoxin levels were detected in Nauset estuary. Currently there are no published trend analyses for PSP data (although the Division of Marine Fisheries is in the process of analyzing the data).

Water and sediment quality: coastal & surface freshwaters. Reporting for the Clean Water Act includes a list of 19 waterbodies (or sections thereof) on the outer Cape that are impaired. A study of Pleasant Bay has quantified nitrogen loading sources and identified load reductions needed to bring this system back into attainment. The National Coastal Assessment evaluates water and sediment quality at coastal sites around the U.S. A total of 23 sites have been surveyed in Cape Cod Bay, Nauset Harbor and Chatham Harbor. All Cape Cod Bay sites are ranked as being in 'good' condition for all metrics. Nauset and Chatham Harbor sites are ranked 'poor' for some metrics and 'fair' or 'good' for others.

Coastal geomorphology: Nauset Beach & Pleasant Bay sediment dynamics. Nauset Beach undergoes multi-decadal cycles of elongation and subsequent breaching. The most recent breach occurred during the Patriot's Day storm of 2007. Changes in the geomorphology of this barrier beach system influence sediment dynamics and tidal amplitude within Pleasant Bay. Sediment dynamics in this bay may also be influenced by erosion control structures, which in turn affect critical habitats within the system. In 1998, it was estimated that 8% of Pleasant Bay was armored with 133 erosion control structures; this number increased by 24% by 2008.

Coastal geomorphology: bluff erosion. Erosion of coastal bluffs north of Nauset Beach is a natural process that is being influenced by changes in sea level. A series of 229 coastal profiles were originally surveyed in the late 1880s and re-surveyed in a recent study. These data provide an excellent document of bluff erosion and accretion on the Cape. The century-scale erosion rate is 0.8 m/yr. Erosion rates are highest in the areas just north of Nauset Beach and decrease in a northward direction. The coast of the outer Cape is rotating clockwise as sea level rise changes the wave climate, in turn influencing the pattern of longshore sediment transport.

Coastal vulnerability to sea-level rise. Coastal vulnerability to sea-level rise reflects largely natural patterns of geomorphology. The vulnerability of CACO coastal areas to sea-level rise has been evaluated using a series of six metrics, including geomorphology, erosion/accretion rates, topography and wave height. The most vulnerable area to sea-level rise is Nauset Beach and spit. Least vulnerable areas extend from Head of the Meadow Beach to Marconi Beach.

Disclaimer

This Natural Resource Condition Assessment report is based on existing data and information that were available through 2009.

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Introduction

This report is an assessment of the condition (status and trends) of the natural resources of Cape Cod National Seashore and a review of the threats and stressors that act on these resources. The assessment focuses on the four landscape types present in the Park (Roman and Barrett 1999): Uplands, Barrier Islands/Spits/Dunes, Freshwaters (lakes, streams, wetlands – groundwater systems are also included), and Estuaries/Salt Marshes. As development continues to expand adjacent to the park boundaries, and with annual visitation exceeding five million (Roman and Barrett 1999), park managers are continually challenged to address a spectrum of issues such as water quality degradation, introduction of exotic species, air pollution, habitat fragmentation, recreational use, and others. These may all have dramatic impacts on aquatic and terrestrial ecosystem function and integrity, and habitat quantity and quality.

Cape Cod National Seashore (CACO – we also use the terms 'Park' and 'Seashore' interchangeably in this report) includes 12,472 hectares within the towns of Provincetown, Truro, Wellfleet, Eastham, Orleans and Chatham - or about 40% of the total area of these municipalities (Figure I.1). The Park's establishment was authorized in August of 1961; funds to complete acquisition of its lands were secured through legislation in 1967.

Table I.1 and Figure I.2 summarize a series of ecoregional, climatic and geologic characteristics of Cape Cod within the broader context of the Commonwealth of Massachusetts. Precipitation recorded by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) typically ranges between 100-150 cm on the Cape (Figure I.3). Numerous publications describe the geologic history of the outer Cape (see overviews in Masterson 2004 and Portnoy et al. 1999).

Currently, about one half of the Park's total area is forested (Figure I.4). Salt water beaches and open water represent the next two most common land cover types (24% and 13%, respectively). Freshwater and saltwater wetlands collectively comprise less than 10% of Park area. The amount of urban-classified land within the Park is < 3%. Across the six towns of the outer Cape (i.e. both within and outside CACO), forests/woodlands cover approximately 35% of the total area, while urban lands represent just under 20%.

Land-use patterns across Cape Cod have been highly dynamic during the period following initial European settlement. During the 1800s, approximately one third of the Cape was used for some form of agriculture (Hall et al. 2002).

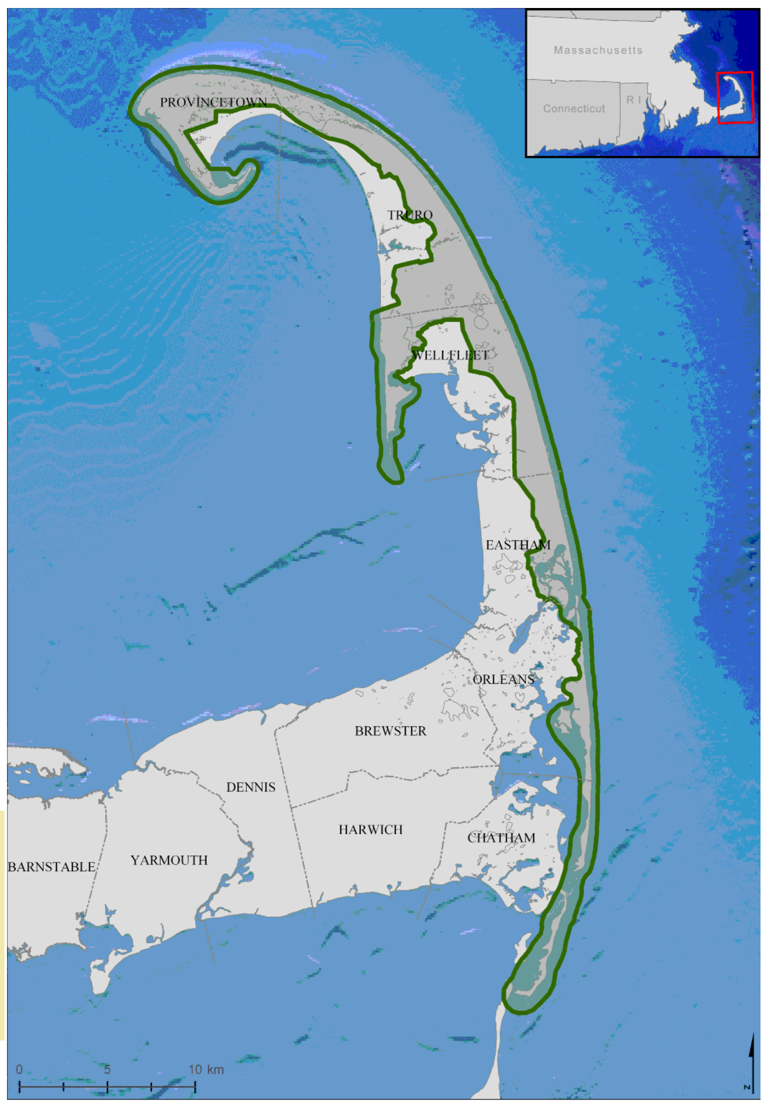


Figure I.1. Map showing the location of Cape Cod National Seashore. The following terms are used used to indicate various sections of the Cape:
- **Upper - section closest to the mainland.**
- **Mid - Barnstable to Dennis.**
- **Lower - Harwich & Brewster to Provincetown.**
- **Outer - Eastham to Provincetown.**

Table I.1. Environmental characteristics for four sub-regions within the North-eastern Coastal Zone ecological region and for the state of Massachusetts. See Figure B for map of sub-regions. Data are means (standard deviations) (Data source: Hall et al. 2002)

Variable	**Cape Cod & Islands**	Coastal Plains & Hills	Boston Basin	Bristol Lowlands	MA State-wide
Mean elevation (m)	**19 (16)**	8.5 (60)	32 (20)	27 (15)	163 (158)
Modelled growing degree days	**3839 (63)**	3588 (93)	3674 (41)	3804 (45)	3497 (284)
Modelled precipitation (cm)	**121 (2)**	114 (4)	112 (1)	117 (2)	119 (8)
Mean percent slope	**1.3 (1.4)**	2.3 (2.2)	1.6 (1.6)	1.0 (1.0)	3.7 (4.9)
Mean January temperature (C)	**-2.5 (0.4)**	-4.2 (0.5)	-3.8 (0.2)	-2.8 (0.3)	-4.5 (1.4)
Mean July temperature (C)	**22.6 (0.2)**	21,8 (0.4)	22.1 (0.2)	22.5 (0.1)	21.4 (1.1.)
Surficial geology type (%)					
Till / bedrock	**2**	57	47	43	59
Sand / gravel	**73**	37	44	40	32
Fine grain	**8**	6	8	13	6
Floodplain	**1.5**	0	0	0	1
End moraine	**1**	1	2	4	1
Bedrock type (%)					
Acidic sedimentary (sed.)	**0**	20	38	62	38
Acidic granitic	**26**	50	32	37	29
Mafic / intermediate granitic	**0**	16	30	1	14
Coarse sediments	**74**	0	0	0	7
Calcareous sediments / metased.	**0**	4	0	0	7
Mod. Calcareous sediments / metased.	**0**	10	0	0	6

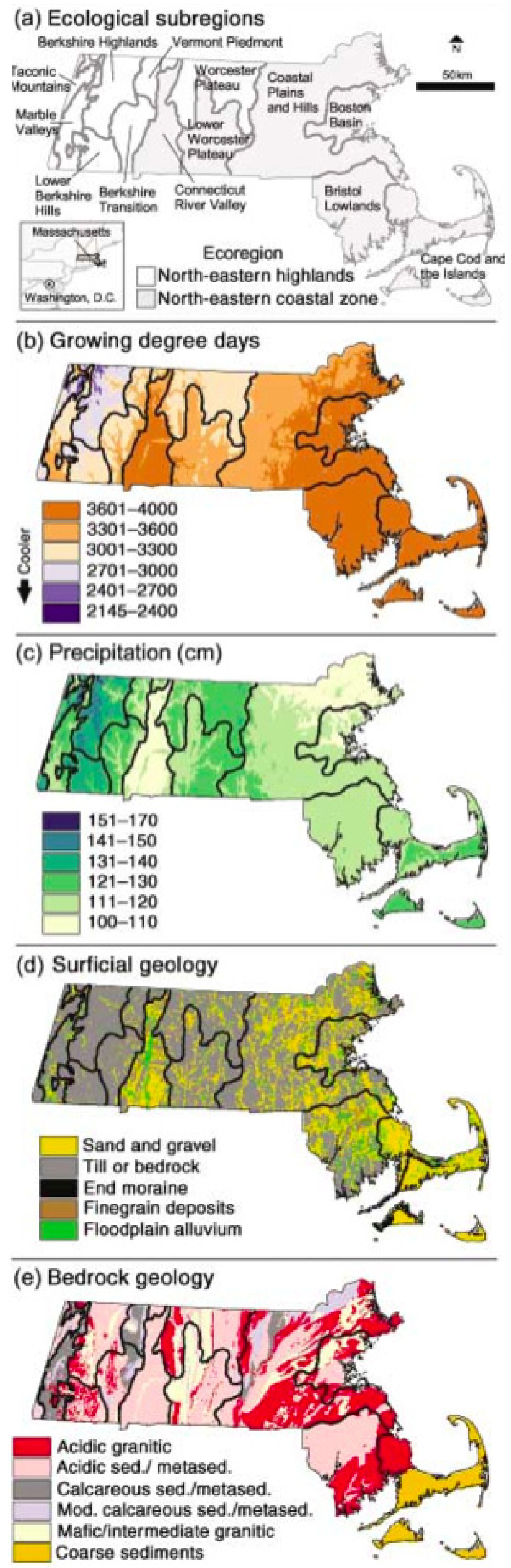


Figure I.2. Ecological sub-regions, selected climate parameters, and geology for Massachusetts. (Figure from Hall et al. 2002, used with permission)

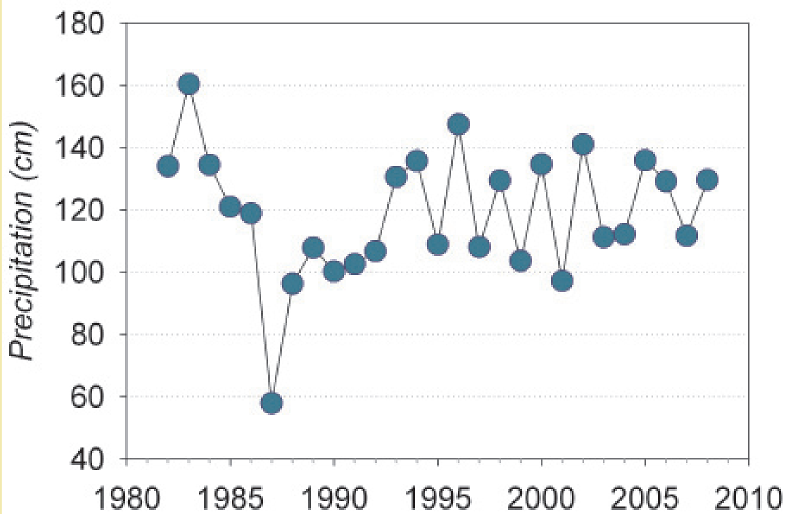


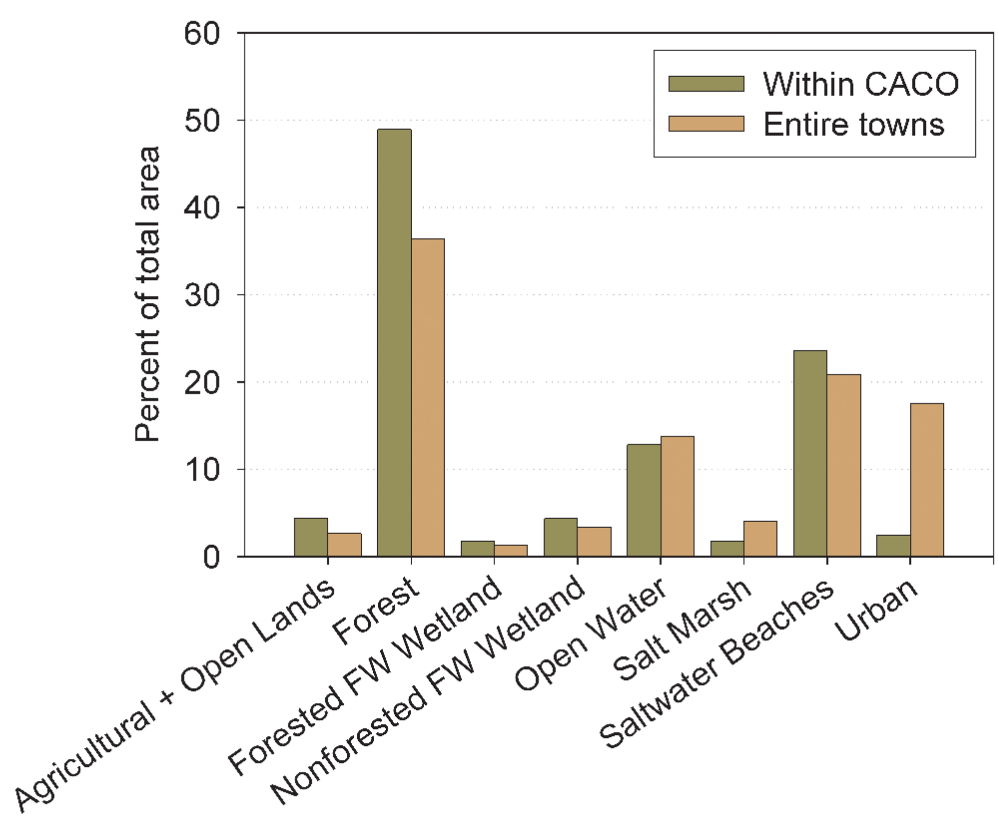
Figure I.3. Annual precipitation at NADP site MA01, Wellfleet, MA. Data courtesy NADP/NTN, 2010.

Currently agriculture represents < 3% by area in the six towns of the outer Cape (Figure I.4). Across Cape Cod as a whole, forest cover did not change substantially between 1800 and the mid-1900s. However, it decreased in the second part of the twentieth century with the expansion of urban centers (Hall et al. 2002). On the outer Cape, however, the pattern was different. By the mid-1800s, this part of the Cape had been extensively settled, with the result that only about 20% of Truro, Wellfleet and Eastham remained wooded (Eberhardt et al. 2003). Gradual abandonment of agriculture since that time has resulted in an increase in forest cover at CACO and in surrounding areas. Less than one half (44%) of current woodlands in these three towns were wooded during the mid-1800s (Eberhardt et al. 2003). As will be further described in this assessment, historical land-use patterns exert a legacy effect that continues to influence the structure and composition of contemporary upland vegetation (see section on Terrestrial Vegetation Assemblages).

Population trends for towns of the outer Cape during the past two centuries illustrate the pattern of increasing settlement through the mid-1800s, followed by a period of emigration (Figure I.5). During the second half of the twentieth century, there was a renewed population influx, although the rate of increase in most towns has slowed over the past few years (Figure I.6).

Figure I.4. Current land use / cover in CACO and in the towns of the outer Cape and in the six towns of the eastern Cape.

See Table 1.1. for more detailed data. Data source: MassGIS.



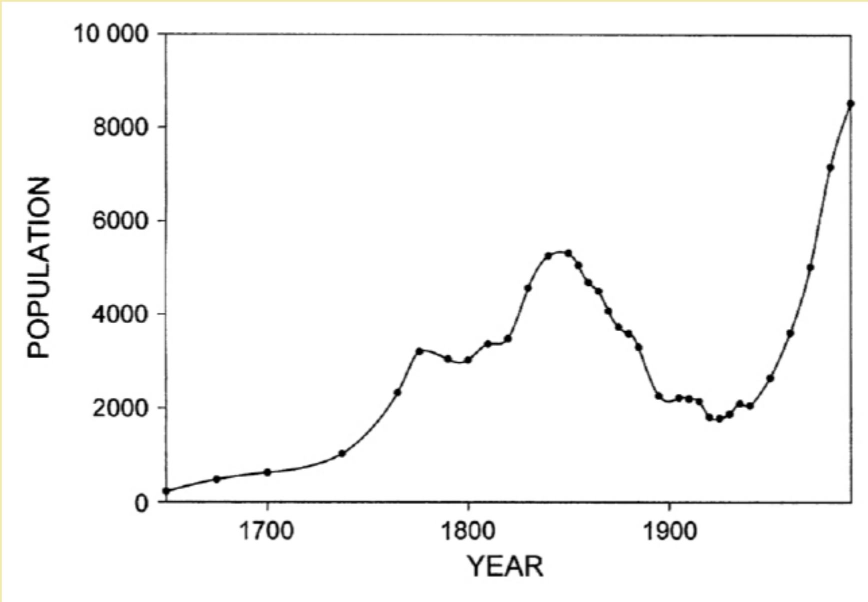


Figure I.5. European population trends in Eastham, Wellfleet and Truro, 1650-1990. (Figure from Eberhardt et al. 2003).

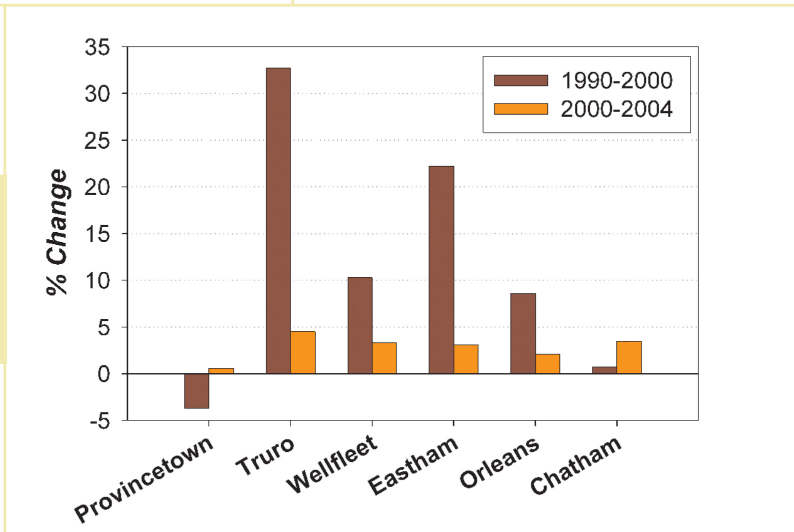


Figure I.6. Population change on the outer Cape, by town: 1990 – 2004. (Data source: Cape Cod Commission 2008)

Studies over the past half century or more have documented the plant and animal species inhabiting CACO and adjacent areas. The numbers of species of various plant and animal groups are shown in Figure I.7.

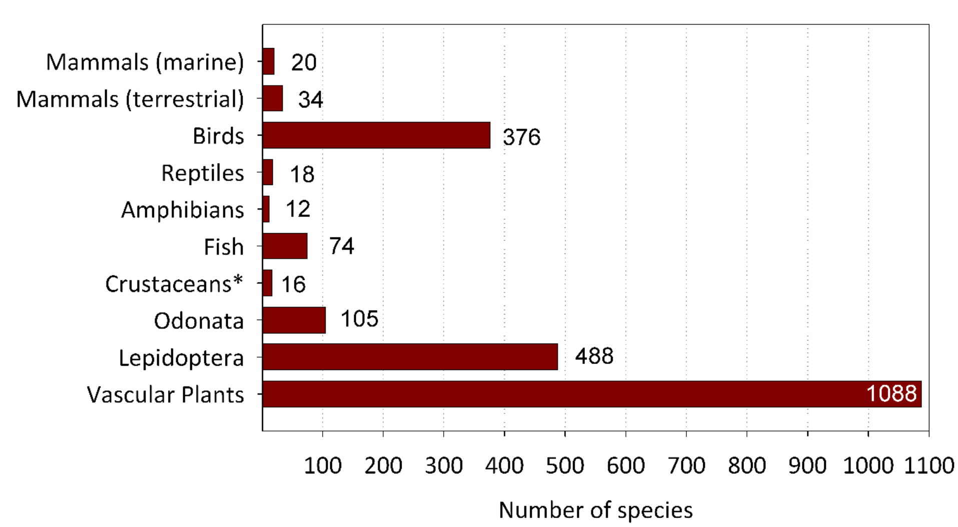


Figure I.7. Species richness for selected plant and animal groups on Cape Cod. The vertebrate and plant data are from the NPSpecies database and refer to taxa recorded from (or suspected as being present in) the Park. Marine fish are probably under-represented in the NPSpecies database. The Lepidoptera (butterflies and moths) and Odonata (dragonflies and damselflies) data are from multiple sources and refer to the broader Cape Cod area. The Crustacea data are from the NPSpecies database.

*** Decapods and horseshoe crabs.**

Assessment Approach

Scoping for this assessment included meetings with CACO staff and other scientists, and a review of past and ongoing research at the Park. The scoping process identified, for each of the Park's four landscape types, as well as the atmospheric system, a series of ecosystem attributes considered to be pertinent to the evaluation of natural resource conditions. These attributes were eventually structured into a series of 37 topics within which we present a review of current knowledge about the status, trends and overall condition for natural resources at CACO. Each topic addresses one or more ecosystem attributes or metrics. Some topics (e.g. rare species, critical habitats, forest health and pond fish assemblages) address natural resources, per se. In contrast, other topics (e.g. land cover, atmospheric deposition, tidal restrictions and harmful algal blooms), focus on issues that, while being integral to natural resource condition, may be considered more as stressors or threats. While the distinction between these two groups can be indistinct, both contribute to the fuller description of natural resource condition at CACO.

Ecologically, many of the natural resources at CACO are integrally linked to surrounding watersheds and coastal areas that lie outside of the Park boundary. Thus, although the primary focus of the assessment is on lands and waters within the Seashore, we also include information from areas outside of the Park where this is relevant to the interpretation of conditions within CACO.

For this report, we have designed the presentation of each topic to be essentially a stand-alone piece. Each presentation follows a consistent structure consisting of the following six sections:

1. key points – the main conclusions derived from the topic review;
2. assessment statement - in the case of resource-focused topics, this statement characterizes resource condition: Good, Fair, Significant Concern, Unknown. In the case of threat-focused topics, the assessment statement ranges from No Concern to Significant Concern to Unknown. In both cases, the justification for the ranking is provided;
3. benchmarks – numerical criteria or more qualitative measures which can be used as a base from which to assess condition or threat status;
4. rationale – an overview of the relevance of, and background for, the topic;
5. status & trends – description of what is known about the current status and trends for the attribute(s); and
6. factors influencing the attribute(s) discussed within the topic.

The suite of topics selected for inclusion in this assessment is quite heterogeneous in terms of breadth of material covered. Some topics have a relatively narrow focus, often addressing one or two individual parameters (e.g. nitrogen and sulfur in atmospheric deposition; mercury in deposition; mercury in biological media). Other topics are much broader – for example terrestrial vegetation assemblages and groundwater quality/quantity. This heterogeneity reflects, in part, the judgment of assessment team members but is also influenced by the availability and 'cohesiveness' of the data.

Some topics are specific to individual ecosystems (landscape types) while others address multiple systems. This cross-system approach is intended to foster a broader perspective of those topics that are relevant to more than a single ecosystem. Table I.2 presents the series of assessed topics and indicates which ecosystem(s) they address.

This assessment is based entirely on published scientific research – no new field data were collected for the assessment. In many instances we have used published graphics and other information products[1]. In some cases we have generated new displays of data that were published in another format. The long-term monitoring program that was initiated at CACO in 1998 is focusing on a series of Vital Signs and measures to document status and trends for key ecosystem attributes in the Park (Table I.3). Some of this research has been published and is incorporated into this assessment. However, much of the data are currently unpublished and thus could not be included here.

1 Original units have been retained for graphics extracted from published materials; consequently, there is a mix of metric and English units.

Table I.2. List of topics addressed in this assessment, by ecosystem.

Topic	System					
	Atmo-sphere	Uplands	Ground-water	Freshwater-surface	Marine - coastal & estuary	Marine - off-shore
Land cover / land use: status & change		x		x	x	
Atmosphere: ozone & visibility	x					
Nitrogen & sulfur: atmospheric deposition	x					
Mercury: atmospheric deposition	x					
Mercury: freshwater & estuaries				x	x	
Mercuy: biota		x		x		
Rare species: flora		x		x	x	
Rare species: fauna		x		x	x	x
Critica terrestrial & aquatic habitats				x	x	
Flora & fauna: non-native & invasive species		x		x	x	
Terrestrial plant assemblages		x				
Forest health: disease incidence		x				
Terrestrial mammals: population dynamics		x				
Birds: assemblage structure & population dynamics		x		x	x	x
Amphibians & reptiles: population status & trends		x		x		
Wetlands: distribution, hydrology and biology			x	x		
Parabolic dunes & associated wetlands		x	x	x		
Ponds: acid-base chemistry				x		
Ponds: nutrients & trophic condition				x		
Ponds: plant assemblages				x		
Ponds: fish assemblages				x		
Diadromous fish runs				x	x	x
Groundwater: quantity			x			
Groundwater: quality			x			
Tidal restrictions: occurrence, impacts & restoration				x	x	
Salt marsh vegetation & nekton					x	
Salt marsh landscape changes					x	
Eelgrass distribution & population status					x	
Horseshoe crabs: population status & dynamics					x	
Shellfish resources					x	x
Beach Closures					x	
Beach fouling: marine macroalgae accumulations					x	
Harmful algal blooms & shellfish closures					x	x
Coastal water & sediment quality					x	x
Coastal geomorphology: Nauset Beach & Pleasant Bay sediment dynamics		x			x	
Coastal geomorphology: bluff erosion		x			x	
Coastal vulnerability to sea-level rise					x	

Table I.3. Vital signs and measures that are included in the long-term ecological monitoring program at CACO. (Data source: National Park Service 2010)

Vital Sign	Measure
Air Quality	Wet deposition: ammonium, nitrate, sulfate, mercury
	Ozone
	Visibility
Forest Vegetation	Age (tree cores to be extracted in 2012)
	Growth of every individual tree per decade (trees were tagged in 2002-2003)
	Structural composition (% trees, shrubs, herbaceous, etc.)
	Taxonomic composition, % early succession sp.
	Species richness
	% exotics vs. natives
	Tree Condition (health of selected indicator sp.)
	Canopy cover
	Recruitment - number of new trees (untagged) per plot per decade; counts of understory seedlings/saplings at time of each survey
	Litter depth
	Relative abundance of coarse woody debris
Kettle Pond Vegetation	Species composition, % indicator sp.
	Species richness in ponds
	System-wide species richness (i.e., all taxa in ponds, including all area outside transects)
	Total vegetation cover
	Proportion of floating leaved taxa vs. rosette forming taxa
	Distance that vegetation extends into pond from shoreline
	Distance that woody species extend into pond from shoreline
	% exotics vs. natives
	Soil organic matter content
Kettle Ponds: Hydrology, Water & Sediment Quality	Dissolved oxygen, salinity, maximum temperature, turbidity, chlorophyll a, light transmissivity, nutrients (TP, TN, DIN, DIP), Secchi transparency, pH, ANC, sediment C:N ratio, pond stage height
Groundwater level	Average water levels: Nauset, Chequessett, Pamet & Pilgrim lenses
Amphibian Monitoring:	
Fowler's Toad	Calling Survey Estimated Site Occupancy Rate
Grey Treefrog	Calling Survey Estimated Site Occupancy Rate
Spring Peeper	Calling Survey Estimated Site Occupancy Rate
American Bullfrog	Calling Survey Estimated Site Occupancy Rate
Green Frog	Calling Survey Estimated Site Occupancy Rate
Pickeral Frog	Calling Survey Estimated Site Occupancy Rate
Anuran Community	# species detected by calling surveys
Wood frogs	total # egg masses
Spotted Salamander	total # egg masses
Vernal Pool hydrology	avg water level/duration of flooded period

Table I.3, continued.

Vital Sign	Measure
Threatened species (Box Turtles)	Number of captures (incidential encounters)
Salt Marsh Vegetation (Hatches Harbor & East Harbor)	Change in *Phragmites* infested area (HH & EH)
	Change in *Phragmites* frequency (HH & EH-Moon Pond)
	Change in area with native salt marsh vegetation (HH & EH)
	Change in *Spartina alterniflora* frequency (HH)
	Change in *Spartina patens* frequency (HH)
	Max distance (m) of *S. alterniflora* expansion upslope (HH)
	Max distance (m) of *S. patens* expansion upslope (HH)
	Max distance (m) of *Salicornia/Suaeda* spp. expansion upslope (HH)
	Max distance (m) of *Phragmites* retreat upslope (HH)
	Change in *Typha* infested area (EH)
	Change in freqency of *Typha* (EH-Moon Pond)
Salt Marsh Nekton (Hatches Harbor, East Harbor, Moon Pond, Nauset Marsh)	Species richness for site, pools and creeks, traps only (HH - unrestricted)
	Average density (all nekton in streams) /m^2 (HH-unrestricted)
	Average density (all nekton in pools) /m^2 (HH-unrestricted)
	Species richness for site, pools and creeks, traps only (HH-restricted)
	Average density (all nekton in streams) /m^2 (HH-restricted)
	Average density (all nekton in pools) /m^2 (HH-restricted)
	Species richness for lagoon, traps and seine (EH)
	Average density (all nekton) in lagoon /m^2 (EH)
	Species richness for creeks, traps only (Moon Pond)
	Average density (all nekton in streams) /m^2 (Moon Pond)
	Average density (all nekton in pools) /m^2 (Moon Pond)
	Species richness for site, pools and creeks, traps only (NM)
	Average density (all nekton in streams) /m^2 (NM)
	Average density (all nekton in pools) /m^2 (NM)
Salt Marsh Elevation (Hatches Harbor, Herring River, Nauset Marsh)	Sediment accretion+elevation, unrestricted side (HH)
	Sediment accretion+elevation, formerly restricted side (HH)
	Sediment accretion+elevation, unrestricted side (HR)
	Sediment accretion+elevation, restricted side (HR)
	Sediment accretion+elevation (NM)
Estuarine Nutrient Enrichment (Pleasant Bay & Nauset Marsh)	Dissolved oxygen (PB & NM)
	Salinity (PB & NM)
	Maximum Temperature (PB & NM)
	Turbidity (PB & NM)
	Chlorophyll a concentration (PB & NM)
	Attenuation of Photosynthetically Available Radiation (PB & NM)
Seagrass condition & distribution	Total biomass all transects, shoot density all transects, within-bed % cover, bed size
Ocean shoreline position	# acres eroded/accreted compared to baseline
Coastal Geomorphology	position of bluff toe vegetation

1. Land cover/land use: status & change

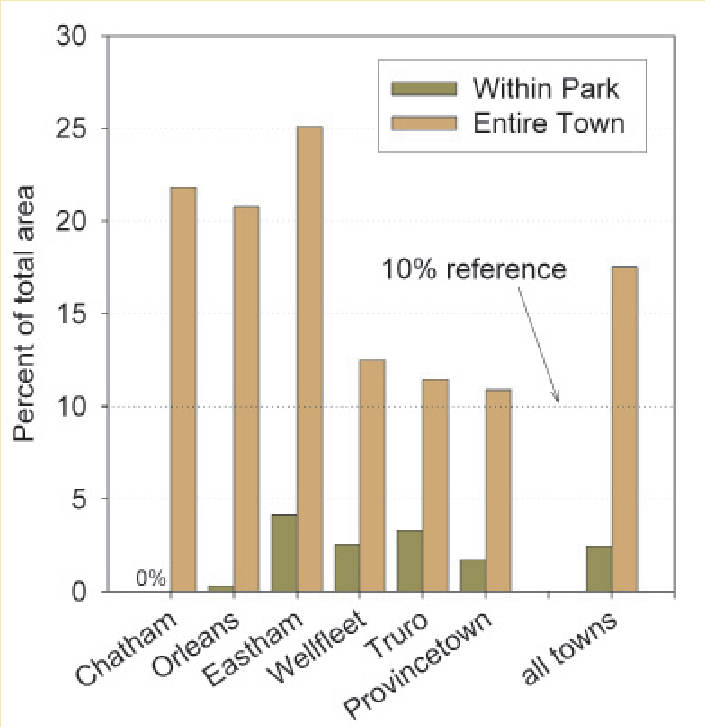


Figure 1.1. Percent anthropogenic land use ('urban', as defined in Table 1.1) by town, both within the Park and in each entire town. Data source: MassGIS Land cover data (2005) analyzed by NPS FTSC at the University of Rhode Island.

Key points:

- Approximately one half of Park lands are forested. The next two most common land-cover types are saltwater beaches and open water.
- Within the Park, anthropogenic land use ranged from 0% (Chatham) to 4.2% (Eastham).
- Including non-park lands, anthropogenic land use in the six eastern Cape towns ranged from 10.9% (Provincetown) to 25.1% (Eastham).
- Anthropogenic land use on the eastern Cape increased by 44% in the period 1971-1999.

Assessment Statement

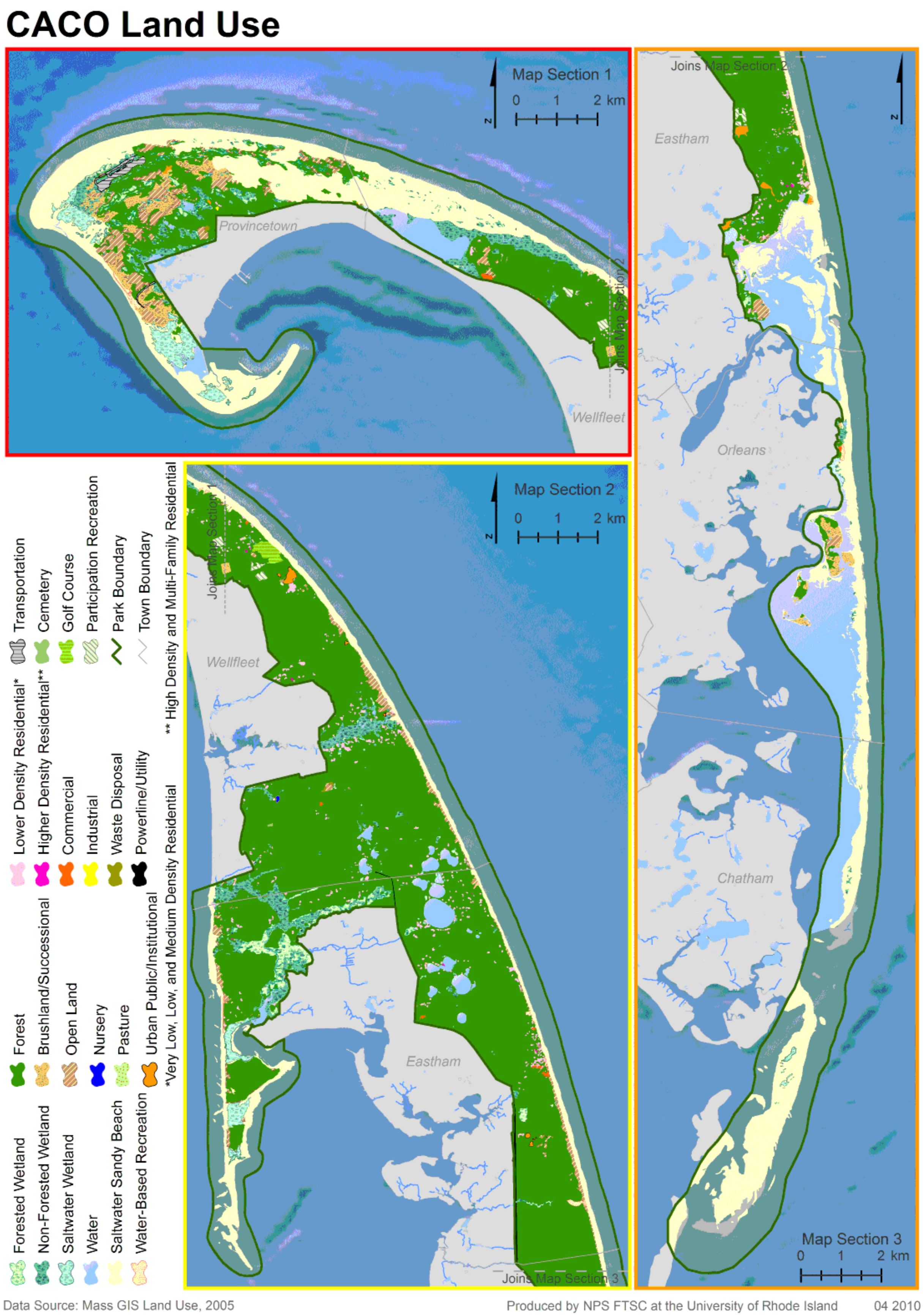
In general, land-use change within the Park is of No Concern since the lands are protected. Outside of the Park, land-use change is of Significant Concern because of residential development, habitat fragmentation and other factors. Changes in land use outside the Park are likely influencing some natural resources within the Park.

Rationale

Increases in the amount of developed land can influence terrestrial and aquatic ecosystems in multiple ways. For example, residential and commercial construction, along with its associated infrastructure, may contribute to habitat fragmentation which, in turn, can have a range of impacts on wildlife resources (Fahrig 2003, Way et al. 2004).

Impervious surfaces affect both hydrologic and chemical fluxes in runoff. Parking lot and road runoff contributes metals to ecosystems and may contribute phosphorus, which can lead to eutrophication. In winter, road de-icing practices may lead to increased sodium and choride in streams adjacent to roads. In New York, road salt was implicated as a potential cause of decline of some amphibians inhabiting wetlands near major roads (Karraker et al. 2008). How-

Figure 1.2. Land cover/land use within CACO, based on 2005 data.



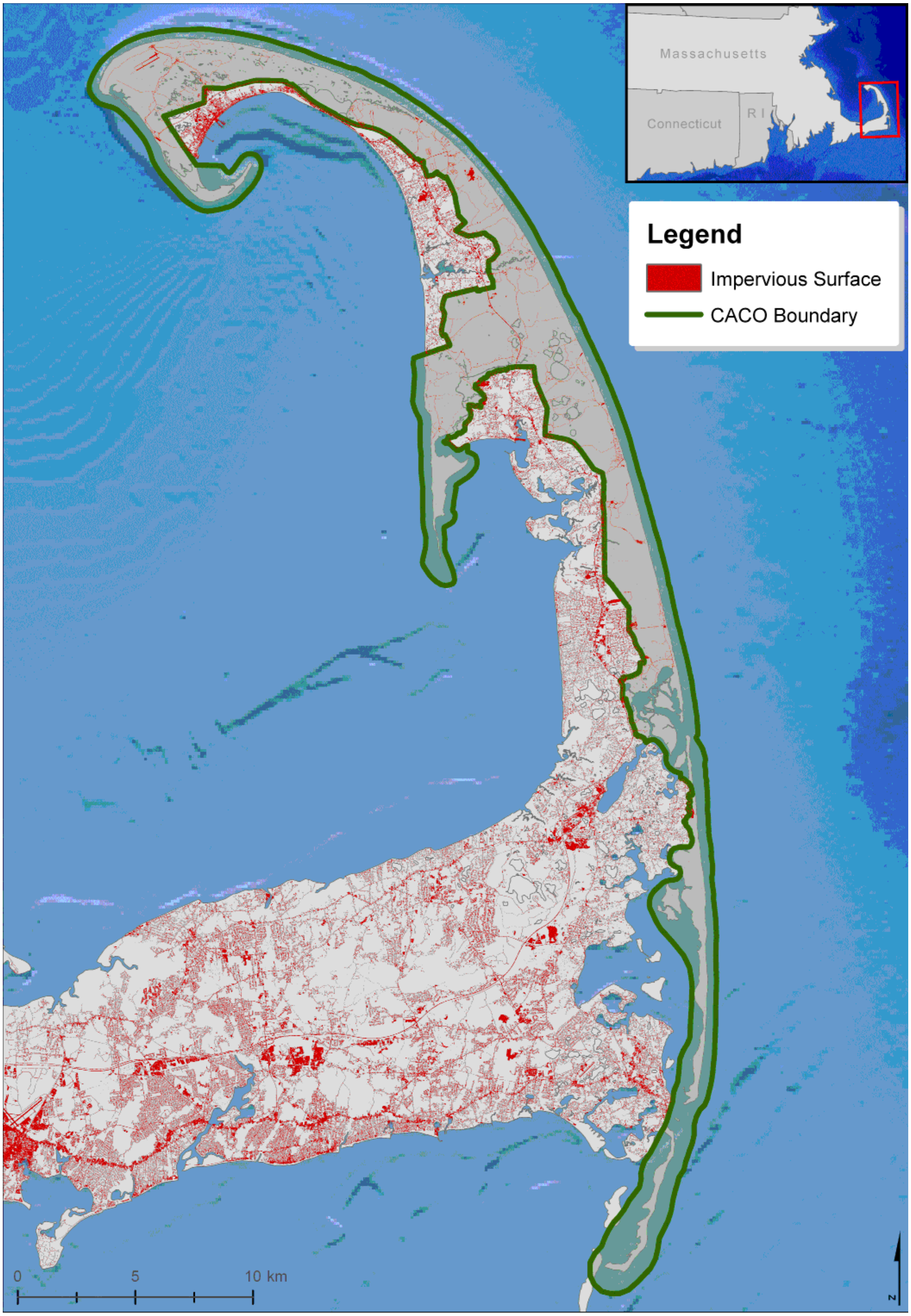
Land cover/land use: status & change, continued

Table 1.1. MassGIS land use data for Chatham, Eastham, Wellfleet, Truro, Provincetown, and Orleans. Data are presented as percent of total town areas and of lands within the park boundary. Data source: MassGIS Land cover data (2005) analyzed by NPS Field Technical Support Center for GIS (FTSC) at the University of Rhode Island. Descriptions of codes (in parentheses) below. See Figure 1.2 for map of these land use data.

Town		Chatham	Eastham	Wellfleet	Truro	Provinc-etown	Orleans	**all towns**
Total Area (hectares)	*Whole Town*	*6825.5*	*4741.1*	*5943.9*	*5718.1*	*2859.1*	*5542.2*	***31629.9***
	Within Park	*855.2*	*1436.1*	*3222.6*	*3847.5*	*2273.1*	*1108.0*	***12742.5***
Urban (7,8,10,11,12, 13,15,16,17,18,19,24, 26,29,31,34,38,39)	% Whole	21.8	25.1	12.5	11.5	10.9	20.8	**17.5**
	% Park	0.0	4.2	2.5	3.3	1.7	0.3	**2.4**
Saltwater Beaches (9, 25)	% Whole	37.1	21.9	13.7	12.0	34.4	10.0	**20.9**
	% Park	72.2	20.6	10.5	13.4	40.7	28.2	**23.6**
Agricultural, Open Land (1,2,6,23,35,36,40)	% Whole	1.3	1.1	1.5	2.3	12.7	1.9	**2.6**
	% Park	0.0	1.8	2.0	2.0	15.2	4.7	**4.4**
Mining (5)	% Whole	0.0	0.2	0.1	0.2	0.0	0.0	**0.1**
	% Park	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Forest (3)	% Whole	13.6	33.2	55.0	62.3	24.5	26.8	**36.4**
	% Park	0.0	47.3	70.9	69.4	24.8	3.0	**48.9**
Nonforested Fresh-water Wetland (4)	% Whole	2.0	1.4	3.8	6.1	6.4	1.6	**3.3**
	% Park	0.5	0.7	4.0	6.9	5.7	1.1	**4.3**
Forested Freshwater Wetland (37)	% Whole	0.6	0.6	3.1	0.3	3.3	1.0	**1.3**
	% Park	0.0	0.3	4.2	0.4	3.2	<0.1	**1.8**
Salt Marsh (14)	% Whole	3.3	5.5	7.8	1.8	5.4	1.6	**4.1**
	% Park	0.8	<0.1	1.9	0.0	6.6	0.2	**1.7**
Open Water (20)	% Whole	20.3	11.1	2.6	3.6	2.5	36.3	**13.8**
	% Park	26.5	25.1	4.0	4.5	2.1	62.5	**12.8**

Numbers in parentheses are the MassGIS land use codes included in each category, defined as follows:

1-Cropland - intensive agriculture
2-Pasture - extensive agriculture
3-Forest
4-Nonforested fresh wetland
5-Mining - sand; gravel and rock
6-Open land - abandoned agriculture, power lines, areas of no vegetation
7-Participation recreation - golf, tennis, playgrounds, skiing, etc.
8-Spectator recreation - stadiums, fairgrounds, racetracks, drive-ins
9-Water-based recreation - becahes, marinas, swimming pools
10-Residential - multifamily
11-Residential - high density (< 1/4 acre lots)
12-Residential - medium density (1/ to 1/2 acre lots)
13-Residential - low density (1/2 to 1 acre lots)
14-Saltwater Wetland
15-Commercial - general urban, shopping center
16-Industrial
17-Transitional - open areas in development from one use to an other (previously Urban Open)
18-Transportation - airports, docks, divided highway, freight, storage, rail
19-Waste Disposal - landfills, sewage lagoons
20-Water - fresh water, coastal embayment
23-Cranberry Bog
24-Powerline/Utility
25-Saltwater Sandy Beach - also includes tidal flats, rocky intertidal areas, dunes, banks, and cliffs along the shore
26-Golf Course
29-Marina - includes parking lots and facilities but not docks
31-Urban Public/Institutional - schools, churches, hospitals, town halls, etc; may include public open green spaces
34-Cemetery
35-Orchard
36-Nursery
37-Forested Wetland
38-Residential - Very Low Density (>1 acre lots and very remote, rural housing)
39-Junkyard
40-Brushland/Successional - predominantly (>25%) shrub cover



Produced by NPS FTSC at the University of Rhode Island and the University of Maine 06 2008

Figure 1.3. Impervious surfaces (red areas) within the park boundary and in towns that include Park lands. Data source: MassGIS; data dated February 2007. Map produced by NPS FTSC at the University of Rhode Island and the University of Maine.

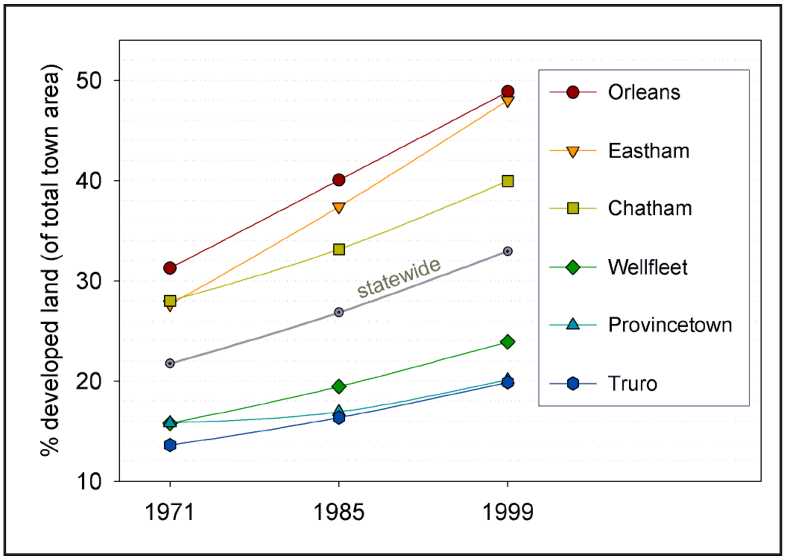


Figure 1.4. Changes in area of developed land in the towns of the outer Cape, 1971-1999. Data are area of developed land expressed as a percentage of total town area. Data source: MassGIS, Land Use Summary Statistics - September 2003, August 2007.

Note that this figure uses a different data source (MassGIS statistics) compared to Figure 1.1 (recent land cover map).

ever, due to its coastal location, CACO is expected to have elevated concentrations of sea salt. Rosfjord et al. (2007) developed an equation to estimate 'background' sea salt concentrations for lakes in the Northeast that were within 100 km of the coast, where signficant sea salt influence was expected in freshwaters.

Residential and commercial development may also influence surface water and ground water hydrology, with potential ramifications for plant and animal communities.

Natural changes in land cover occur on Park lands as succession converts abandoned fields to shrub and/or forest vegetation.

Benchmarks

The 2005 land use/cover (Table 1.1, Figure 1.2) and 2007 impervious surface (Figure 1.3) map data provide baselines for documenting future changes on the eastern Cape.

Percent of total impervious surface area in a watershed is frequently used as an indicator of environmental condition. For example, impervious surface values > 6% were associated with a marked decrease in the species richness of pollution-intolerant invertebrate taxa in Maine streams (Morse and Huryn 2003). The New England Wadeable Streams Project adopted a value of 10% urban land-use as the benchmark to characterize reference watersheds (Snook et al. 2007). To our knowledge, CACO-specific benchmarks to assess urbanization and habitat fragmentation have not been developed.

Condition

Status

Forested and open/agricultural lands represent 53% of the Park's area, while aquatic systems and saltwater beaches represent 44% (Table 1.1, Figure 1.1). The condition of individual natural resources within these ecosystems is discussed under other topics in this assessment.

Anthropogenic land use represents < 10% of Park lands in each of the six towns of the eastern Cape (Table 1.1, Figure 1.1). When entire town areas are considered, anthropogenic land use ranges from 11% (Provincetown) to 25% (Eastham).

Within these six towns, there were 1185 km of roads as of 2005 (calculated by NPS FTSC at the University of Rhode Island, 2010). However, park lands contained only 216 km of roads (NPS FTSC, 2010). Figure 1.3 displays impervious surfaces on the Cape.

Trends

Although lands within the Park are below the 10% urban threshold used by Snook et al. (2007), urban land-cover in non-Park lands was above this threshold 40 years ago and has been increasing since that time. Between 1971 and 1999 in the six eastern Cape towns, the increase in urban land-cover ranged from about 27% (Provincetown) to 74% (Eastham) (MassGIS, 2003,2007). Across Massachusetts, urban lands increased by an average of 52% during the same period (MassGIS, 2003,2007) (Figure 1.4).

Data for impervious surfaces in 2007 are available from MassGIS (Figure 1.3) and will serve as a baseline for future trend analyses.

Natural succession, especially in abandoned fields, is continuing to modify vegetation assemblages in some areas of the Park.

Factors influencing land cover/land use

- Commercial and, especially, residential development will likely result in future increases in the amount of anthropogenic land use in the eastern Cape towns. The impact of these changes on within-Park lands and their natural resources will depend on several factors, including the location, type and design of the developments, and their interactions with ground- and surface-water resources.
- Land cover is also being influenced by natural succession, resulting in a trend towards greater shrub and forest cover in areas that were formerly used for agriculture.

In this assessment, "anthropogenic land use" is defined as the classes considered "urban" in the most recent land cover data (MassGIS, 2005 data) (Table 1.1, Figure 1.2). Those classes include:

- Participation recreation (golf, tennis, playgrounds, skiing, etc.) and golf courses
- Spectator recreation (stadiums, fairgrounds, racetracks, drive-ins)
- Residential - multifamily
- Residential - multi-family, high, medium, low, and very low density
- Commercial - general urban, shopping center
- Industrial
- Transitional - open areas in development from one use to another
- Transportation - airports, docks, divided highway, freight, storage, rail
- Waste Disposal - landfills, sewage lagoons
- Powerline/Utility
- Marina - includes parking lots and facilities but not docks
- Urban Public/Institutional - schools, churches, hospitals, town halls, etc; may include public open green spaces
- Cemeteries, Junkyards

2. Atmosphere: ozone and visibility

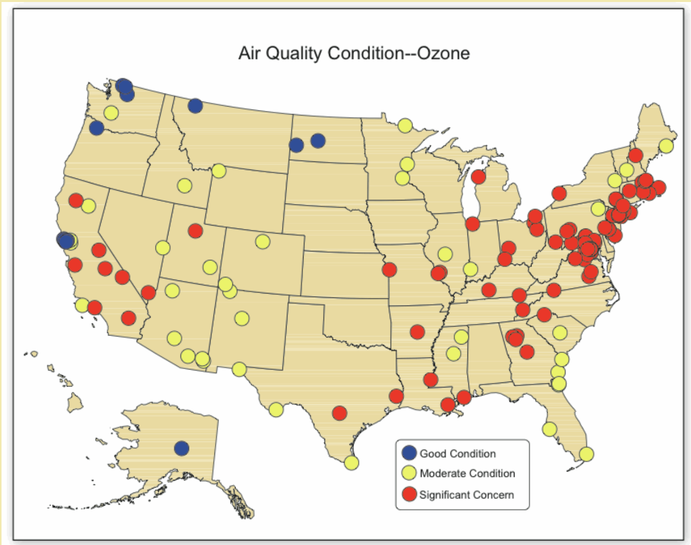


Figure 2.1. Air quality condition assessments for ozone concentration in the US. Assessments were derived from interpolated values of the annual 4th-highest 8-hour ozone concentrations, 2003-2007. CACO is shown in the "Significant Concern" category. Figure from NPS-ARD 2009.

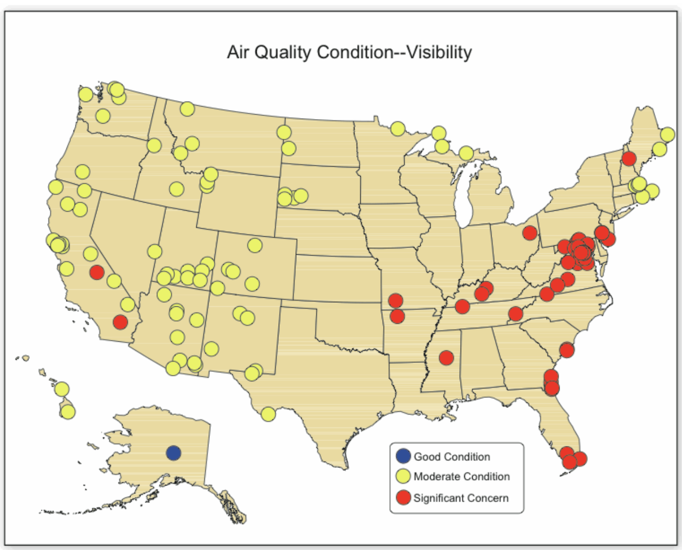


Figure 2.2. Air quality condition assessments for visibility in the US. Condition assessments were derived from interpolations of average visibility conditions, 2003-2007. CACO is shown in the "Moderate Condition" category. Figure from NPS-ARD 2009.

Key Points

- Although trends suggest improvement in meeting ozone standards, ozone concentrations are still a significant concern, with respect to both national standards and in terms of risk to ozone-sensitive plants.

- Visibility at CACO is considered "Moderate", as it is at other New England coastal parks.

Assessment statement

Significant concern (ozone)

Fair (visibility)

Rationale

The NPS measures progress toward improving park air quality by examining trends for key air quality indicators, including:

- visibility–which affects how well and how far visitors can see;
- atmospheric deposition–which affects ecological health through acidification and fertilization of soil and surface waters; and
- ozone–which affects human health and native vegetation (NPS-ARD 2009).

Benchmarks

(adapted from NPS-ARD, 2009)

The NPS had the following system-wide goals for 2008 in accordance with the Government Performance and Results Act, and quantified using statistical trend analyses:

- Stable or improving visibility in 95% of NPS reporting parks (using data for the clearest and haziest 20% of days).

- Stable or improving ozone in 85% of NPS reporting parks

For 2012, NPS establishes air quality goals as follows:

- Stable or improving visibility in 95% of NPS reporting parks

- Stable or improving ozone in 89% of NPS reporting parks

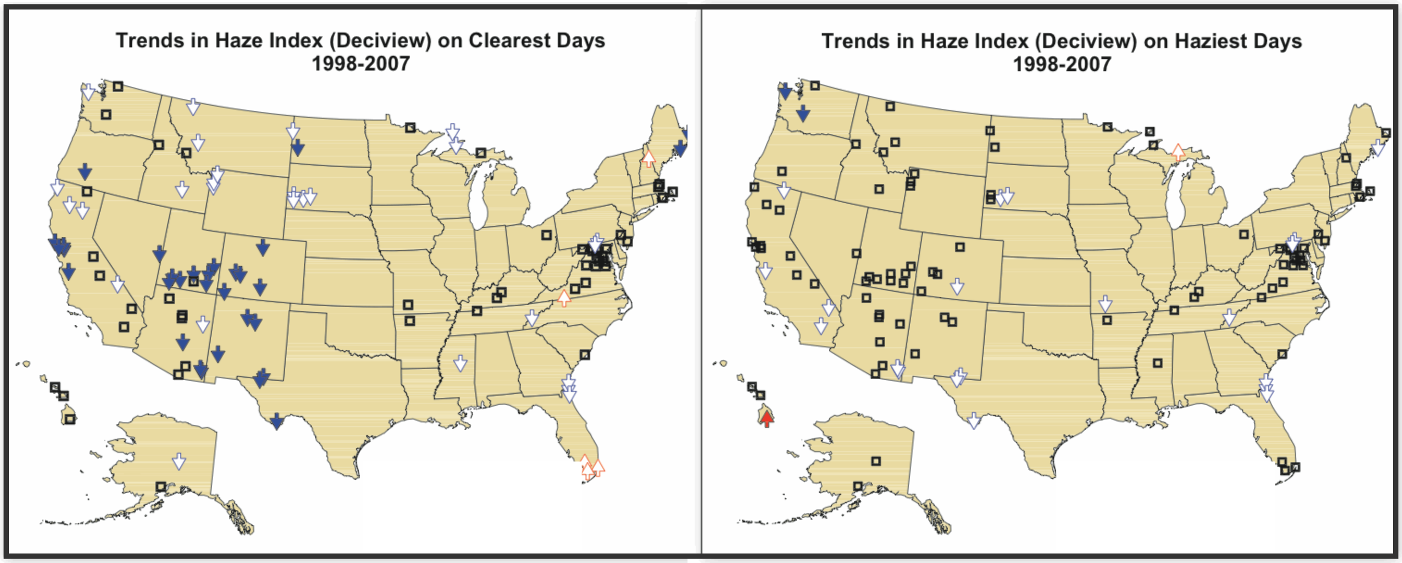


Figure 2.3. Trends in haze index on the clearest 20% of days (left), and haziest 20% of days (right), 1998-2007. CACO had no significant trend in this analysis. Figures from NPS-ARD 2009.

The NPS ARD notes that a stable trend in an area that already has poor air quality may not be sufficient. The ARD assigns current condition to each park as follows:

Ozone (4th highest daily maximum 8-hour average ozone concentration averaged over 5 years):

- Significant concern ≥ 76 ppb
- Moderate 61-75 ppb
- Good ≤ 60 ppb

Visibility (haze index, in deciviews (dv)):

- Significant concern >8
- Moderate 2-8
- Good <2

A proposed, but not adopted, US EPA standard for ozone exposure to prevent harmful impacts to vegetation was between 7-21 ppm-hours (a cumulative sum of weighted hourly ozone concentrations, called the W126 statistic). The W126 statistic provides an index of the total amount of ozone that plants are exposed to during the daytime. Though not a legislated standard, NPS ARD is calculating this statistic as an "important indicator of the potential for damage to ozone-sensitive plant species".

Condition

Status

CACO is a Class II area (under the Clean Air Act), meaning that some air pollution may be permitted as long as air quality does not increase over baseline levels, and national ambient air quality standards are not exceeded. The park's air quality is affected by the Boston Metropolitan area and the urban/industrial corridor to the south and west of the park.

One or more of the air quality indicators is monitored in 57 park units and in cooperation with nearby state and local monitoring programs. NPS has summarized the most recent trend assessment in a 2009 report that used 181 monitoring locations, representing 228 park units, including CACO (NPS-ARD 2009). Ozone is monitored on-site at CACO (site name: North Atlantic Coastal Lab (MA01), inWellfleet), so data represent actual measurements, not kriged (interpolated) values (as with all other NCBN parks).

In the 2008 air quality assessment, CACO's 4th-highest 8-hour ozone was 89.8 ppb (NPS-ARD Air Atlas 2010) and its condition was listed as "Significant concern" (≥76 ppb) with respect to ozone, as were all other NCBN parks (Figure 2.1). CACO's

Atmosphere: ozone and visibility, continued

W126 statistic was listed as 13 ppm, above the minimum of the range of the proposed threshold (7-21 ppm)(NPS-ARD 2009). In a risk assessment that used three indices – including the W126 statistic - to evaluate the risk of foliar injury from ozone at parks, CACO and all other NCBN parks were characterized as having “high” risk of foliar injury (Kohut 2007). This assessment listed 15 ozone-sensitive plant species present at CACO, and found that the W126 and Sum06 (90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥60 ppb (0.60 ppm)) thresholds were exceeded and the N-value (the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb) was sufficiently high to warrant high risk to plants (Kohut 2007).

In the 2008 NPS ARD Air Quality assessment, CACO was listed as “Moderate” condition – representing the range of 2-8 deciviews above natural condition - with respect to visibility, as were all other coastal New England parks (Figure 2.2). CACO’s average value for 2003-2007 was 7.12 dv, near the top of the “moderate” range (NPS-ARD Air Atlas 2010).

Trends

Ninety-nine percent of Parks, including CACO, had stable or increasing trends for visibility during 1998-2007 (NPS-ARD 2009). CACO had no trend on both the haziest and clearest 20% of days (Figure 2.3), as did the other NCBN parks.

CACO was one of two parks within the NCBN that had a strongly ($p<0.05$) significant trend for decreasing ozone during 1998-2007 (Figure 2.4)(NPS-ARD 2009). Ninety-four percent of all assessed parks had stable or increasing ozone trends over that time period (NPS-ARD 2009). NPS also assessed 27 parks, including CACO, that had longer-term ozone data available. Of those parks, only CACO (1989-2007 data) and Pinnacles had statistically significant improving trends (Table 2.1, Figure 2.5)(NPS-ARD 2009).

Factors influencing ozone & visibility

- Regional air quality and emissions and automobile traffic (local and regional) are the major influences on air quality indices.
- Weather conditions can influence ozone concentrations (in the lower troposphere). High ozone levels in the northeast U.S. have been associated with light winds, high temperatures, few clouds and low rainfall (Seaman and Michelson 2000).
- For ozone, dry soil conditions may reduce the likelihood of injury developing in the highest exposure years (Kohut 2007).

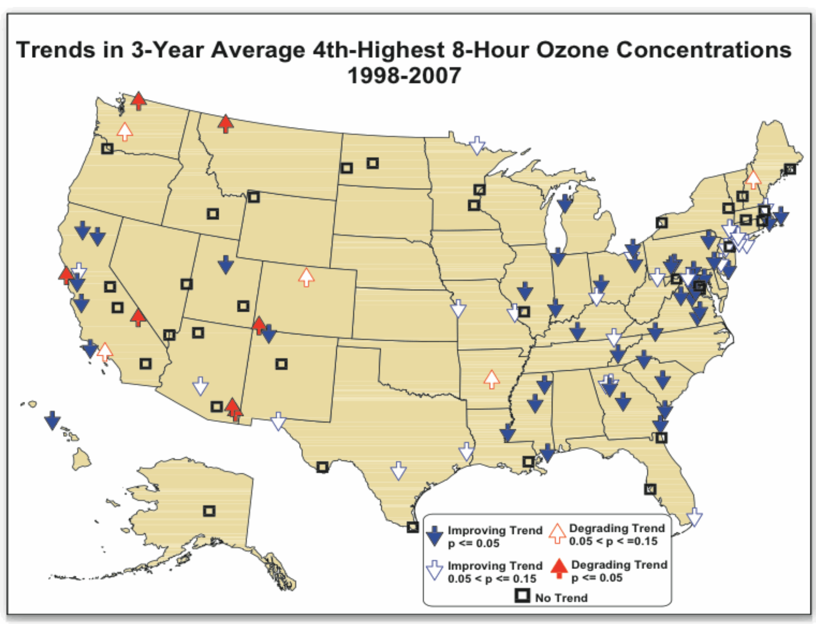


Figure 2.4. Trends in the 3-year average of the annual 4th-highest 8-hour ozone concentration, 1998-2007. CACO is shown with a significantly improving trend. Figure from NPS-ARD 2009.

Table 2.1. Long-term ozone trends from park monitors that have been collecting data since 1997 or earlier. CACO shows a significantly improving trend in this longer-term analysis. Table from NPS-ARD 2009.

Trends in Annual 4th-Highest 8-Hour Daily Maximum Ozone Concentration

Park	Slope (ppb/year)	P-value	Number of Valid Years	First Year of Data	Last Year of Data
Acadia	-0.38	0.32	12	1996	2007
Big Bend	0.00	0.46	15	1992	2007
Canyonlands	0.33	0.14	15	1993	2007
Cape Cod	-1.00	< 0.01	18	1989	2007
Chamizal	0.13	0.41	16	1992	2007
Chiricahua	0.14	0.15	17	1990	2007
Cowpens	-0.33	0.18	19	1989	2007
Craters Of The Moon	0.76	< 0.01	12	1993	2007
Death Valley	0.33	0.06	13	1994	2007
Denali	0.27	0.02	18	1990	2007
Glacier	0.24	0.13	19	1989	2007
Grand Canyon	0.00	0.42	15	1993	2007
Great Basin	0.25	0.14	14	1994	2007
Great Smoky Mountains	0.00	0.53	18	1989	2007
Joshua Tree	-0.60	0.17	14	1994	2007
Lassen Volcanic	0.06	0.37	19	1989	2007
Mesa Verde	0.61	0.02	13	1994	2007
Mount Rainier	-0.18	0.34	13	1994	2007
North Cascades	0.67	0.11	11	1996	2007
Pinnacles	-0.43	0.01	19	1989	2007
Rocky Mountain	0.50	0.02	18	1989	2007
Saguaro	0.00	0.42	19	1989	2007
Sequoia/Kings Canyon	-0.07	0.34	19	1989	2007
Shenandoah	-0.14	0.34	19	1989	2007
Voyageurs	-0.50	0.08	11	1997	2007
Yellowstone	-0.11	0.32	11	1997	2007
Yosemite	-0.40	0.10	14	1994	2007

Degrading air quality trend, statistically significant (p <= 0.05)

Degrading air quality trend, not statistically significant (0.05 < p <= 0.15)

Improving air quality trend, statistically significant (p <= 0.05)

Improving air quality trend, not statistically significant (0.05 < p <= 0.15)

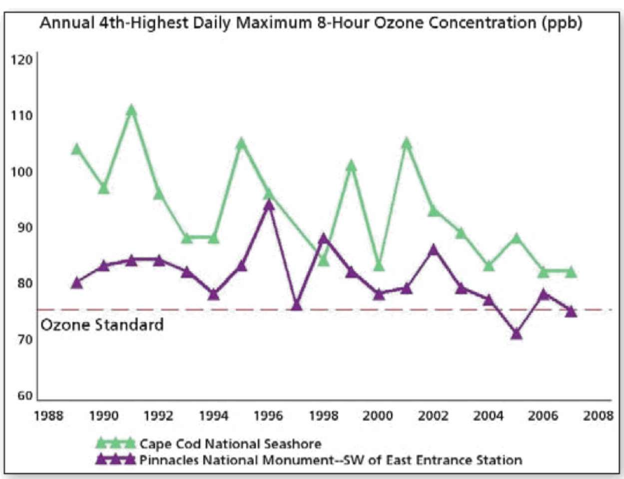


Figure 2.5. Trends in the annual 4th-highest 8-hour ozone concentration show a decrease at Cape Cod and Pinnacles, the only two parks with significantly improving trends in the NPS-ARD analysis. Figure from NPS-ARD 2009.

3. Nitrogen & sulfur: atmospheric deposition

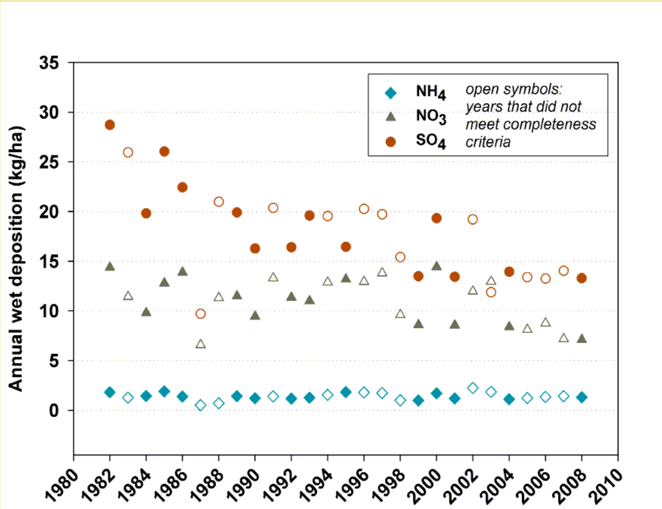


Figure 3.1. Wet-only atmospheric deposition of sulfate (SO_4), nitrate (NO_3), and ammonium (NH_4) from Station MA01, North Atlantic Coastal Lab, in Wellfleet. Completeness criteria are as defined by NADP/NTN. Data source: NADP/NTN 2009.

Sulfur (S) and nitrogen (N) compounds both contribute to acidity, although the former have been the major acidifying substances in acid rain in Maine (Kahl et al. 1991). Primary anthropogenic sources of atmospheric S and N include power plants, other industrial sites and vehicle emissions. Natural sources of atmospheric S are volcanoes (SO_2) and emissions from organisms and decaying matter (dimethyl sulfide), which are subsequently oxidized in the atmosphere to sulfuric acid (H_2SO_4) (Turco 2002). Deposition of atmospheric S and N occurs through precipitation (wet deposition), dry deposition and ground-level cloud/fog. Coastal sites like CACO may receive more SO_4 than inland sites because of marine inputs of S.

Because S has a short residence time (days) in the atmosphere and is readily scavenged by wet deposition (Turco 2002), emissions reductions following implementation of the 1990 Clean Air Act Amendments had immediate effects on S deposition (Kahl et al. 2004). Across the Northeast, a region strongly affected by acidic deposition, SO_4 in wet atmospheric deposition declined ~39% between 1993 and 2003 (Kahl et al. 2004). At CACO, annual average SO_4 concentrations in wet-only deposition measured at the NADP site suggest a similar decline (Figure 3.1). In contrast, N deposition through the early 2000s did not decline to the same extent (Figure 3.1). Recent data, however, suggest that nitrate (NO_3) concentrations may be trending lower than levels observed during the most of the 1980s and 1990s while ammonium (NH_4) deposition appears to remain more constant (Figure 3.1). Kahl et al. (2004) observed that continued N deposition may contribute to the lack of recovery in acid neutralizing capacity (ANC) of surface waters.

Key points

- Sulfate deposition has declined since 1982.
- The decline in sulfate and lack of pattern in nitrogen are consistent with patterns observed across the northeast region.

Assessment statement

Fair (sulfate); significant concern (nitrogen). Due to documented sulfate declines, nitrogen is potentially a greater threat.

Rationale

Wet-only deposition is a measurement of atmospheric inputs of solutes in rain and snow. Though it does not include dry deposition, which can equal or exceed wet-only deposition, it is the best measure available for long-term trend analysis and cross-site comparison.

Benchmarks

For sulfate deposition, an improving trend would mean decreasing sulfate deposition, consistent with the goals of the Clean Air Act Amendments of 1990, which sought to reduce acidification of surface waters by reducing emissions of sulfur. For nitrogen, critical loads (based on a variety of ecosystem indicators) could be developed as benchmarks but are not currently available.

Condition

Status

Wet-only deposition of sulfate (SO_4) was 13.28 kg/ha in 2008, the most recent year reported (Figure 3.1, 3.2). This value is similar to that estimated for eastern Massachusetts and coastal New Hampshire and Maine, and less than that estimated for western Massachusetts, despite potential inputs of sulfur from sea spray at coastal site MA01. However, dry deposition of sulfate is not included in NADP estimates and may equal or exceed wet-only inputs, particularly at forested sites (Weathers et al. 2006). This site is located in Wellfleet and represents a single point; atmospheric deposition is known to be spatially variable and site MA01 may not be represen-

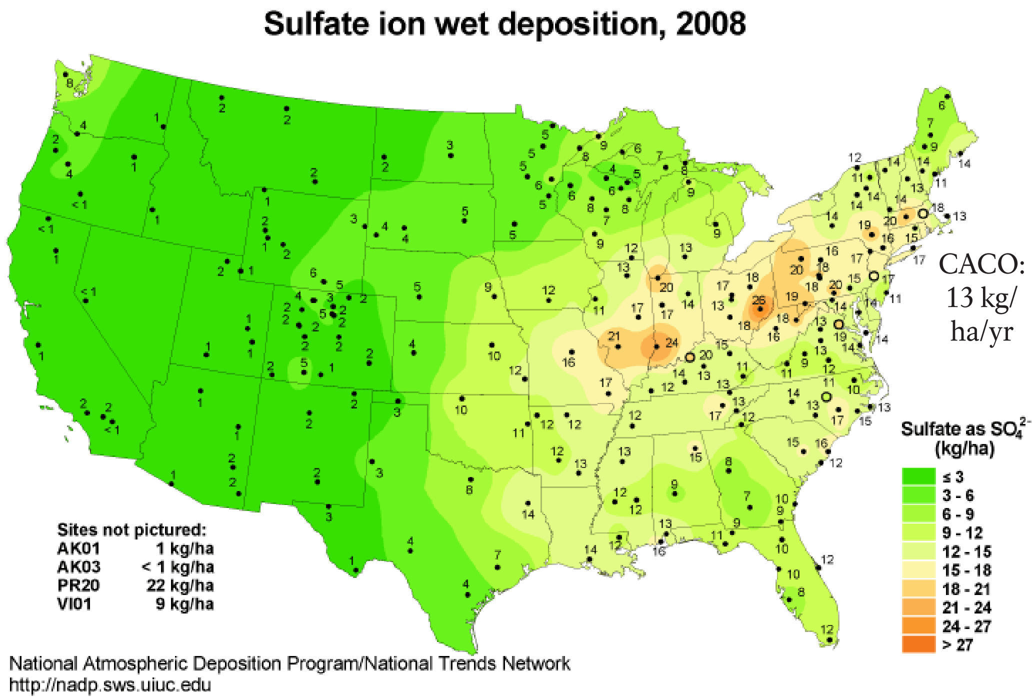


Figure 3.2. Isopleth map showing National Atmospheric Deposition Program estimates of wet deposition of sulfate, in kg/ha/yr, for the US, including one Cape Cod site, for 2008. Maps courtesy of National Atmospheric Deposition Program (NRSP-3). 2009.

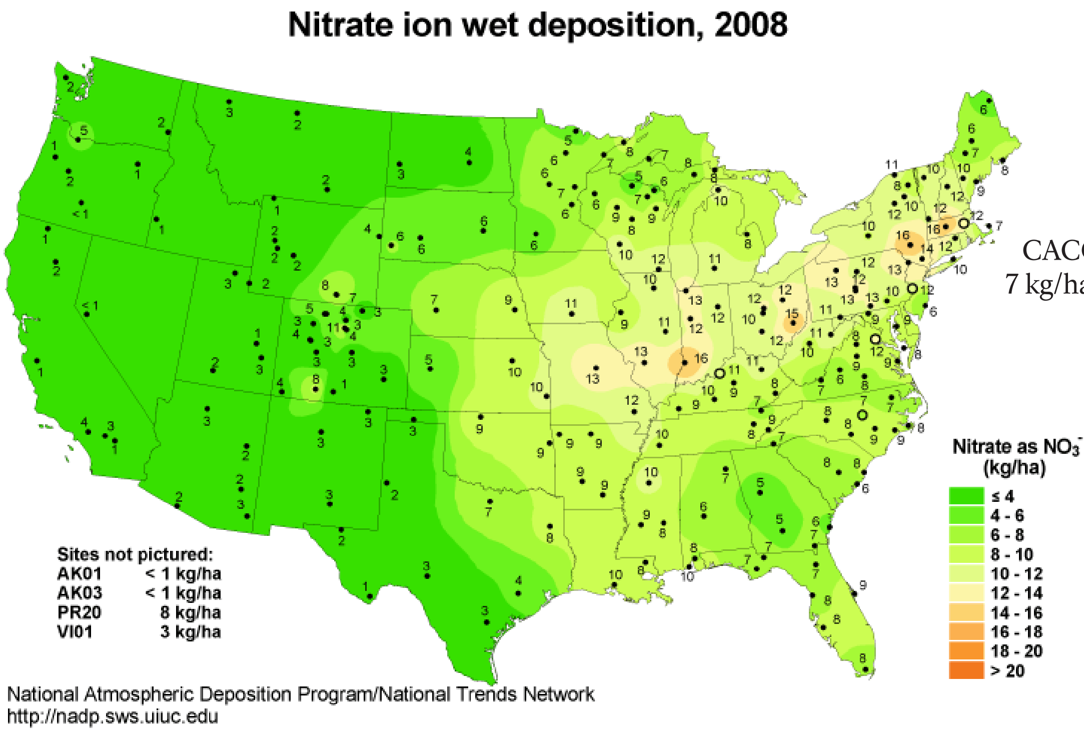
tative of other parts of the Park.

Wet-only deposition of nitrate (NO_3) was 7.11 kg/ha in 2008, the most recent year of data (Figure 3.3). This value is also similar to that estimated for Eastern Massachusetts and coastal New Hampshire and Maine, and less than that estimated for Western Massachusetts. Lajtha et al. (1995) measured nitrogen (DIN + DON) in throughfall at Waquoit Bay, a site on Cape Cod but not within CACO. Using these measurements during 1991-1992, they estimated the input flux of N to be 11.3 kg N/ha/yr, significantly greater than what would be estimated using published regression models at the time (8.4 kg N/ha/yr, or twice the wet deposition at that time)(Lajtha et al. 1995).

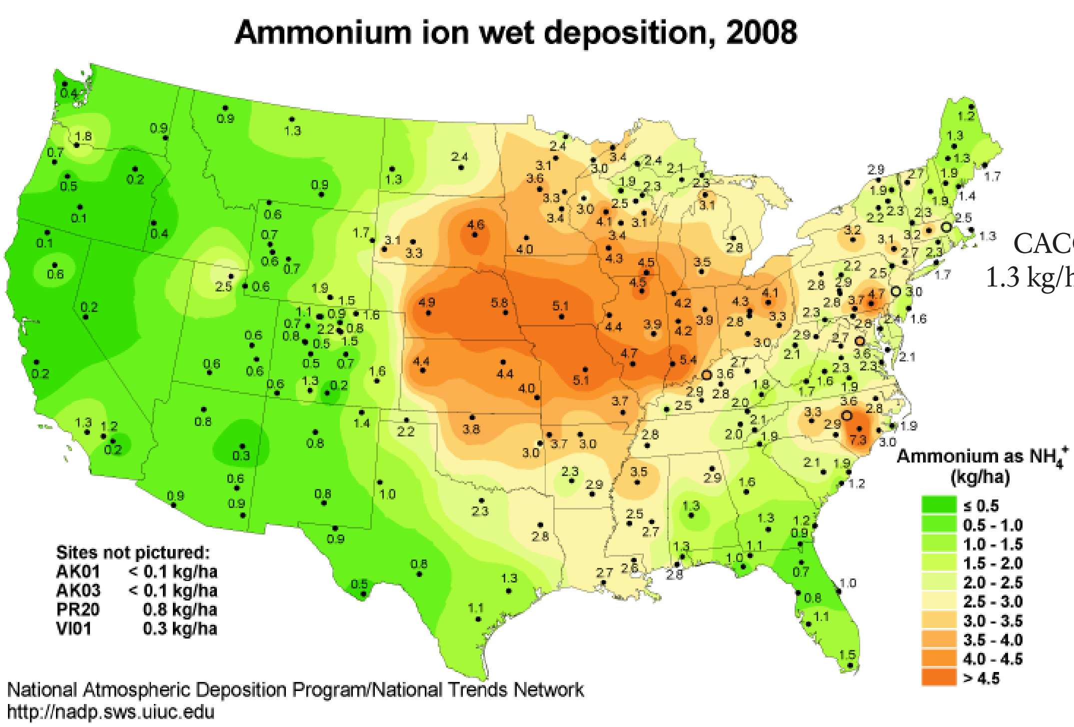
Currently, Howarth et al. (Chesapeake Bay Program, 2007) are evaluating the role of vehicle traffic as an additional source of dry N deposition along Cape Cod roadways. Using passive samplers, bulk, and throughfall collectors, their preliminary results suggest patterns of decreasing throughfall N and gaseous N with increasing distance from roads (Chesapeake Bay Program, 2007)

Trends

Wet-only deposition of SO_4 at CACO's NADP site has declined from 25 kg/ha (average, 1982-1984) to 13.5 kg/ha (average, 2005-2007) during the period of record (Figure 3.1). This ~45% decline is somewhat steeper than that reported for other northeast sites (Kahl et al, 2004), typically 25-35%. Trend analysis was not performed on these data because of several years of incomplete records, but the consistent pattern suggests that the decreasing trend is occurring at this site as elsewhere. Wet-only deposition of NO_3 and NH_4 have neither increased nor declined. There are insufficient data at this time to evaluate patterns in total deposition measured as throughfall, although baseline data for the inner Cape are available from the early 1990s (Lajtha et al. 1995). Dry deposition is not measured in CACO or on Cape Cod, but measure-



CACO:
7 kg/ha/yr



CACO:
1.3 kg/ha/yr

Figure 3.3. Isopleth maps showing National Atmospheric Deposition Program estimates of wet deposition nitrate and ammonium, in kg/ha/yr, for the US, including one Cape Cod site, for 2008. Maps courtesy of National Atmospheric Deposition Program (NRSP-3). 2009.

Nitrogen & sulfur: atmospheric deposition, continued

ments are available from a CASTNET site at Abington, CT, the nearest site to CACO. Dry deposition measurements made by CASTNET appear to suggest a slight decline in both dry SO_2 and dry SO_4 (Figure 3.4). The CASTNET data from Abington appear to indicate lower dry HNO_3 (nitric acid) recently (2006-2007), but longer-term data would be necessary to assess trends (Figure 3.5). Current nitrate and ammonium wet-only deposition at CACO were moderate compared to the network of national sites.

Factors influencing atmospheric deposition

- Increased development in the airshed west of CACO.
- Vehicle traffic on roadways contributing to dry N deposition.
- Potential effects of climate change on atmospheric deposition are not known at this time.

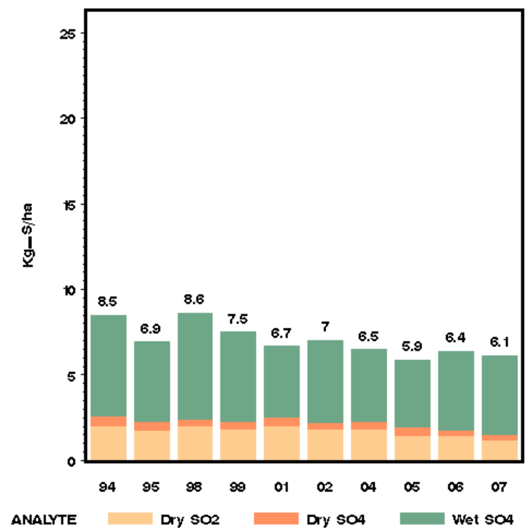


Figure 3.4. Total S deposition at Abington, CT (Site ABT147), measured by CASTNET and the NADP-NTN. Only years with complete data are included.

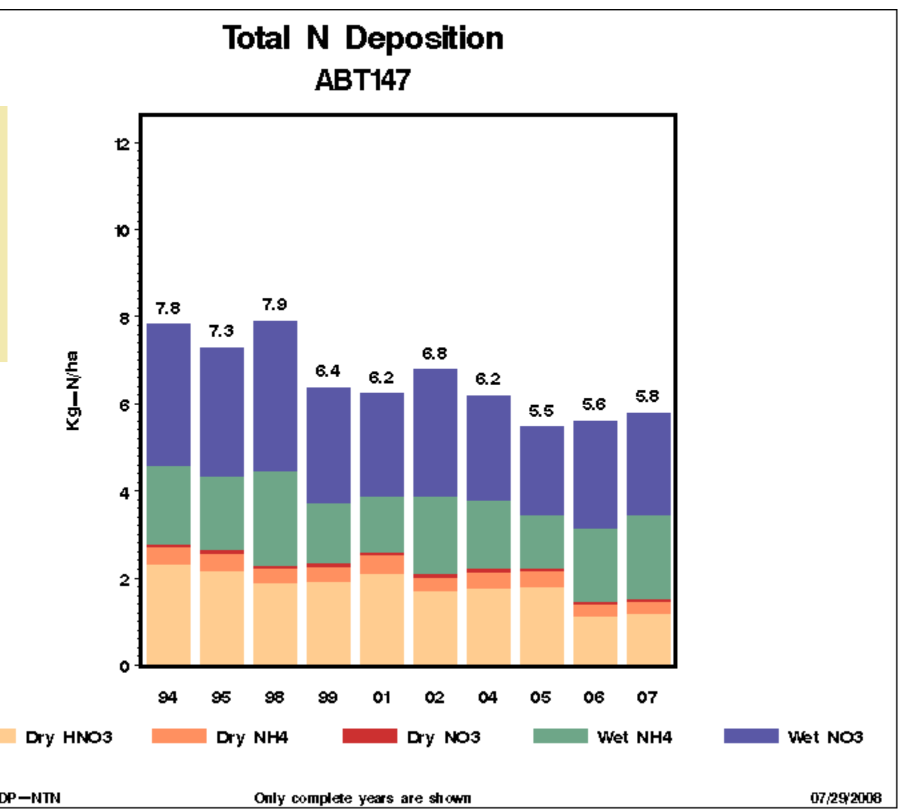


Figure 3.5. Total N deposition at Abington, CT (Site ABT147), measured by CASTNET and the NADP-NTN. Only years with complete data are included.

4. Mercury: atmospheric deposition

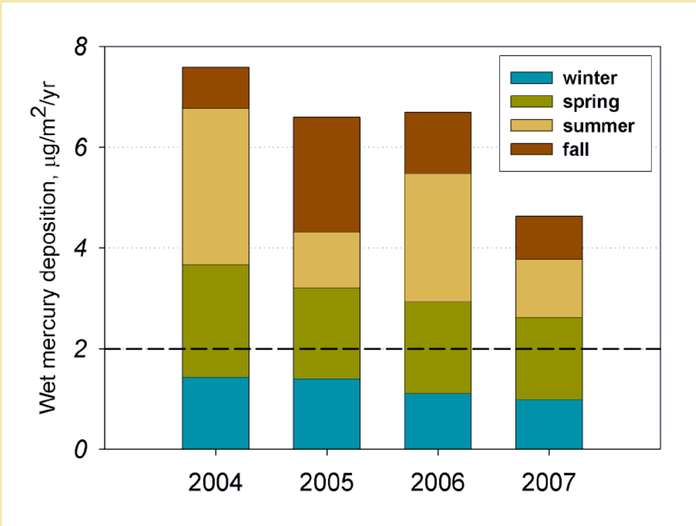


Figure 4.1. Annual mercury wet deposition, in mg/m^2/yr, measured by the Mercury Deposition Network/National Atmospheric Deposition Program at site MA01 (North Atlantic Coastal Lab) in Wellfleet. Stacked bars show inputs during each season of each of the four years for which data were complete. Monitoring began in July 2003. Data source: http://nadp.sws.uiuc.edu/mdn/

Photo of NADP wet-only collector at CACO courtesy of NADP/NTN 2009.

Key points

- Since July 2003, wet-only deposition of mercury has been monitored at Cape Cod as part of the Mercury Deposition Network (MDN). Continued long-term monitoring will ensure that the Park can assess changes in mercury deposition with proposed emissions reductions.
- Currently, wet-only deposition of mercury is 2.5-4 times greater than probable pre-industrial mercury deposition.
- Wet-only deposition does not take into account dry or fog deposition, which can be the largest fluxes of Hg to terrestrial ecosystems. Model results suggest that dry deposition to the Cape Cod region could be 1.5-3 times the reported value for wet-only deposition.

Assessment statement

Significant concern

Rationale

Mercury (Hg) is atmospherically deposited in regions remote to its origin (Haines and Webber 1999). Atmospheric Hg is delivered to ecosystems by rain, snow, and dry and occult (cloud and fog) deposition. In the Northeast, approximately 75% of mercury deposition from the atmosphere is from anthropogenic sources (Northeast States & NEIWPCC 2007, Roos-Barraclough et al. 2006, Perry et al. 2005). Lake sediment data for the Northeast indicate that atmospheric deposition of Hg has increased since around 1875, with a peak after 1970 (Perry et al. 2005). Lake sediment data from CACO underscore the global nature of mercury pollution; cores from a west coast (Washington state) site had statistically similar Hg accumulation rates as a core from Gull Pond at CACO (Colman, in review). In 2004, it was estimated that 53% of global Hg emissions were from Asia (US EPA citing Pacyna & Munthe presentation); researchers at west coast observatories have documented Hg from these Asian sources (Jaffe et al. 2005).

Benchmarks

Using ombrotrophic peat cores from Caribou Bog in Maine, background Hg accumulation rates averaged 1.7±1.3 mg/m^2/yr during pre-industrial periods; values were slightly higher (3.1±2.3 mg/m^2/yr) for minerotrophic peat (Roos-Barraclough et al. 2006). In this report, 2 mg/m^2/yr is taken to represent probable pre-industrial Hg deposition (S.A. Norton, pers. comm.). A decline in Hg deposition toward pre-industrial levels could be used as a benchmark.

Condition

Status

The MDN, part of the National Atmospheric Deposition Program (NADP), measures wet-only deposition of mercury at a network of sites in North America, using standardized methods and coordinated timing (NADP 2009). At CACO, MDN site MA01 (North Atlantic Coastal Lab, in Wellfleet) has measured Hg wet deposition since July 2003. For the three years with complete data, Hg wet deposition inputs have ranged 5.2-8.0 mg/m^2/yr, similar to that measured at other Northeast sites (Figure 4.1, 4.2). These values are 2.5-4 times the probable pre-industrial Hg accumulation rates of 2 mg/m^2/yr.

Average Hg concentration in wet-only precipitation was greater in summer (22.5 ng/L) than in other seasons (spring, 8.67 ng/L; fall 6.29 ng/L; winter, 6.11 ng/L)(Figure 4.1), as has been reported elsewhere (Mason 2000). Though the concentration pattern is fairly robust, seasonal patterns in deposition depend on hydrologic inputs as well as concentrations and can vary with interannual differences in weather (e.g., snow cover, drought). These interannual weather patterns can confound interpretation of trend data, so any future evaluation of Hg in wet deposition trends should include analysis of weather patterns such as droughts or unusually rainy/snowy years.

Where total deposition of Hg has been measured, dry deposition (particles and gases) equals or exceeds wet deposition (Hg in rain and snow) and is likely the largest vector of

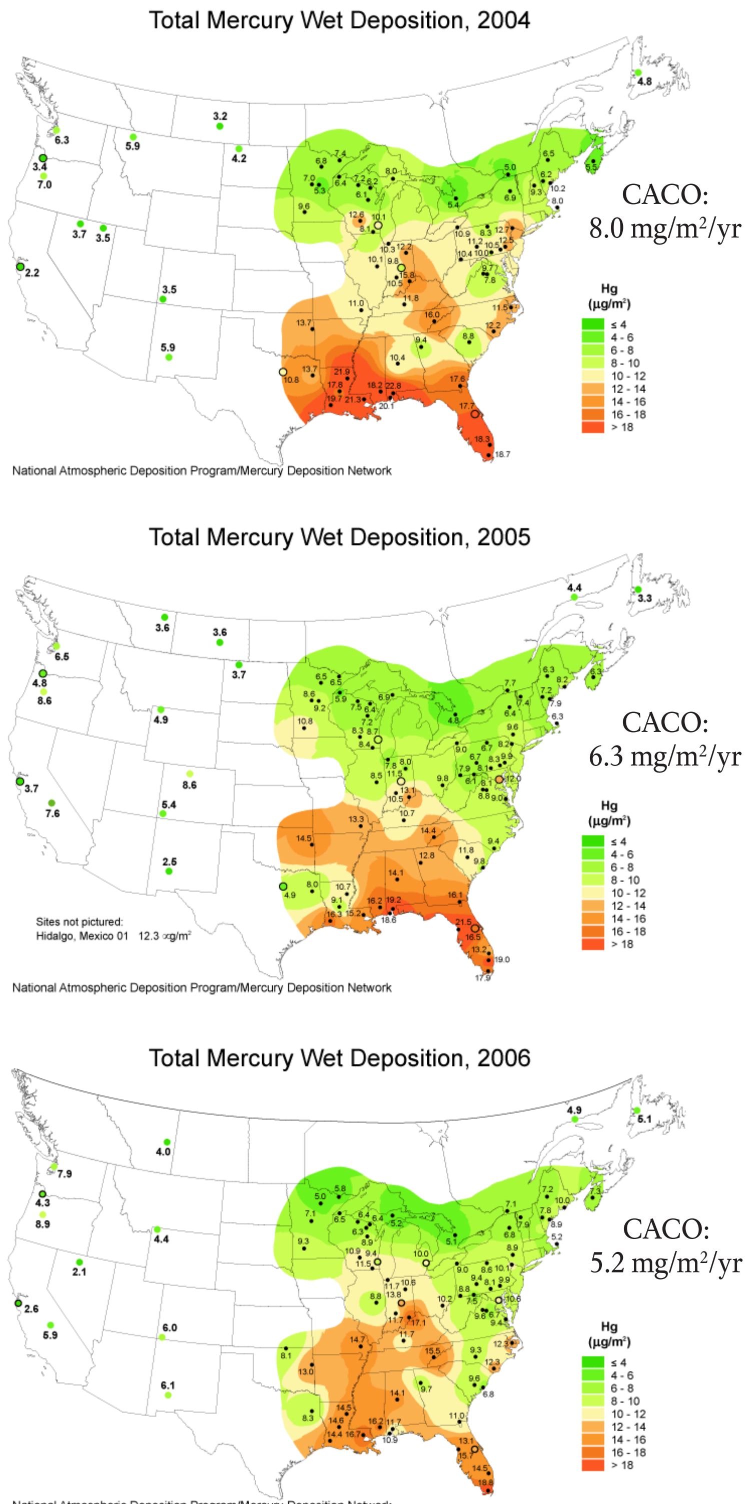


Figure 4.2. Isopleth maps showing Mercury Deposition Network/ National Atmospheric Deposition Program estimates of mercury wet deposition, in ug/m2/yr, for the US, including one Cape Cod site, for 2004-2006. Maps courtesy of National Atmospheric Deposition Program (NRSP-3) 2009.

Mercury: atmospheric deposition, continued

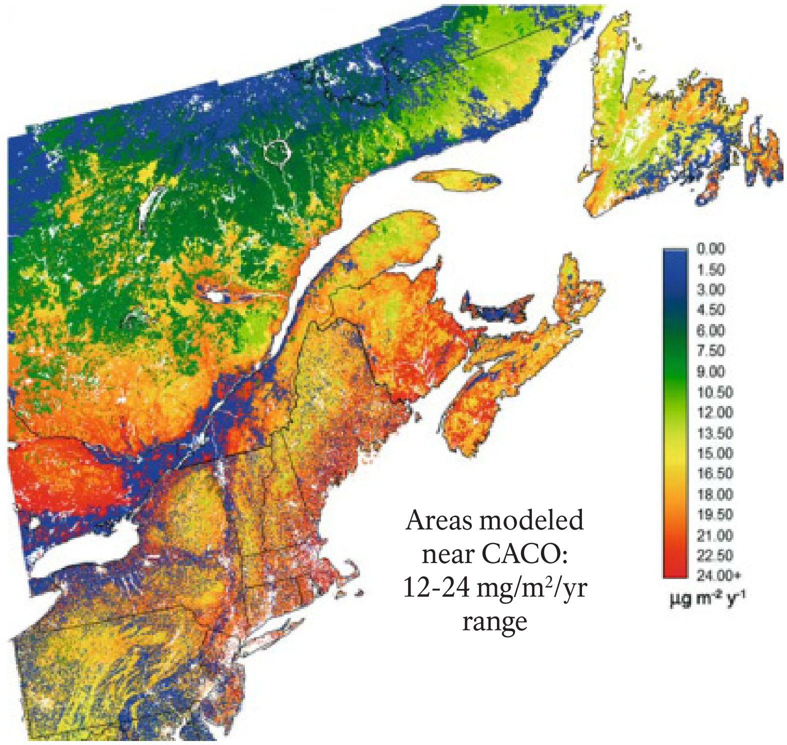


Figure 4.3. Estimated dry mercury deposition in mg/m^2/yr to rural areas. Deposition was not estimated for areas with urban or residential land cover. Mercury deposition is likely to be much greater than depicted here in the immediate vicinity of urban areas and emissions sources. The effects of urban and point emissions sources are not well captured by the sparse, rural mercury observation network. Source: Miller et al. 2005.

Hg input from the atmosphere to terrestrial ecosystems (Lindberg et al. 2007, Miller et al. 2005, Grigal 2002). Forest cover enhances Hg deposition because forests act as filters that scavenge dry particles and gases from air masses (Rea et al. 2000, Lindberg et al. 1994). Forest canopies also take up Hg and can re-emit Hg previously deposited on the canopy (Graydon et al. 2007). Wet deposition and the net remaining Hg deposited on forest canopies via dry deposition subsequently are washed by precipitation as throughfall to the forest floor or deposited later as litterfall (Rea et al. 2000, Lindberg et al. 1994).

At Acadia NP, throughfall deposition was, on average, 1.6 (deciduous), 2.3 (coniferous), and 2.6 (mixed) times higher at forested than open sites during 1999-2000 (Johnson 2002).

Direct measurements of throughfall or dry deposition of Hg at CACO were not available the time of this report.

A regional model for dry deposition of Hg that incorporates enhancement of Hg deposition by vegetation type suggests that, like much of the coastal region in the Gulf of Maine, dry Hg deposition in the Cape Cod region ranges between 12-24 mg/m^2/yr, about 1.5-3 times the reported value for wet-only deposition (Miller et al. 2005) (Figure 4.3). Although the Miller model has a broad scale, it is useful for context because it is one of the only estimates of total (wet plus dry) deposition in the CACO area. Dry deposition is shown in Figure 4.3; Miller et al. (2005) also depicts wet and total deposition across the region.

The apparent coastal enhancement in Hg deposition could also be, in part, due to fog deposition. Though not studied on Cape Cod, Ritchie et al. (2006) observed Hg concentrations in fog ranging from 2 – 435 ng/L along a geospatial gradient from an ocean island (Grand Manan, high concentration) to an inland site (Fredericton NB, low concentration). At these sites in Canada, Hg concentrations were greatest on days with stationary fog banks. Because of its coastal location and frequent fog immersion, these data suggest that future research regarding fog contributions to both Hg and acid loading to the Park's ecosystems could be warranted.

Trends

There are insufficient MDN data to determine long-term patterns in Hg deposition; continued monitoring at site MA01, the only Massachusetts site, will provide information to eventually determine whether reduction goals, such as those developed as part of the Northeast Regional Mercury TMDL (75% reduction by 2010 and future Phase III reductions), are being met (See Box at right).

Factors influencing Hg deposition

- The Northeast Regional Mercury TMDL suggests strategies for reducing inputs of mercury to the region.
- However, sources of mercury – including global emissions - are largely from outside Park boundaries and require state, federal, or international efforts and collaboration.

The Northeast Regional Mercury TMDL

Representatives from northeast states (CT, ME, MA, NH, NY, RI, and VT) and other agencies have developed a TMDL – Total Maximum Daily Load – for mercury for the Northeast. Recognizing that most of the mercury that affects northeast ecosystems is from atmospheric deposition, the TMDL describes a strategy for reducing concentrations of mercury in fish to below 0.3 ppm (for MA and most other states; stricter targets are set for ME and CT). The plan seeks to reduce in- and out of region sources of Hg by 50% during Phase I (1998-2003), by 75% during Phase II (2003-2010), and provides for monitoring and re-assessment before Phase III (2010-) goals are set.

According to the TMDL document, "The Northeast states have already reduced deposition by approximately 74 percent between 1998 and 2002 and have reasonable assurances (including product legislation and emissions controls) in place to assure attainment of Phase II goals on an adaptive basis. To meet out-of region goals, Northeast states recommend EPA implement plant-specific MACT limits for mercury under Section 112(d) of the Clean Air Act to control power plant emissions by 90 percent by cost-effective and available technologies."

For more information, see:

www.neiwpcc.org/mercury/MercuryTMDL.asp

5. Mercury: freshwater & estuaries

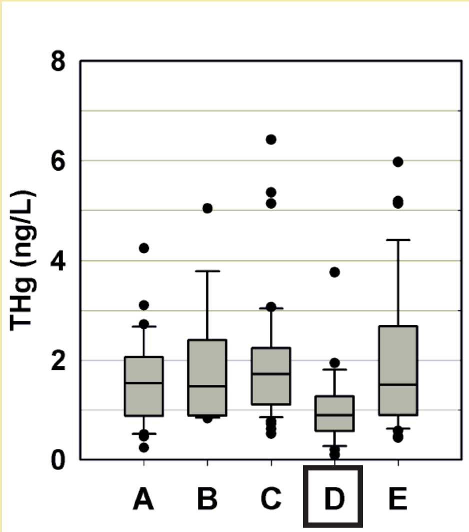


Figure 5.1. Box plot depicting total mercury concentration in lake water (ng/L) in five sub-regions of the northeastern US; the line across the middle of each box is the median value. Sub-region D contains CACO and eastern Massachusetts, CT, and RI. The entire study region was US EPA's Region 1 and study lakes were those from the Eastern Lakes Survey-II. See Figure 5.2 for mapped data. Data source: Nelson, unpubl.

Fitzgerald et al. (2007) summarize general findings regarding **mercury in coastal systems:**

"(1) Total Hg loadings to all marine systems are generally dominated by direct and/or indirect (i.e., riverine) atmospheric inputs (e.g., LIS [Long Island Sound] and CB [Chesapeake Bay]).

(2) With a few notable exceptions (e.g., Minamata Bay), internal production is an important source of MMHg [methylmercury].

(3) Mass balances for total Hg generally result in good closure, indicating that the major features of Hg cycling have been identified and appropriately described.

(4) The number of these mass balance studies is relatively small, and they do not currently include coastal or estuarine systems that are relatively pristine."

Key points

- In a regional study, lakes on Cape Cod and in southeastern New England typically had low total mercury concentrations.
- Estuarine and marine systems have been studied less frequently than freshwaters, but new mercury research on Cape Cod is linking the two systems and providing mass balance estimates.
- In Waquoit Bay, researchers identified groundwater as a potential source of mercury. Typically mercury content is very low in groundwater in the Northeast.

Assessment statement

Signficant concern. There are no mercury (Hg) concentration data for waterbodies within the park, but there are consumption advisories for fish in many waterbodies.

Rationale

In 2007, waterbody-specific fish consumption advisories (in addition to the statewide advisory) were issued for eight freshwater ponds at CACO due to mercury levels above the US FDA's action level for mercury (1 ppb). Scientists recognize that mercury uptake by organisms depends not only on the concentration of mercury in lake, stream, or estuary water, but also on the bioavailability of the Hg species in water. Recent lake studies outside the Park are relating water chemistry and landscape factors to fish Hg (Simonin et al. 2008, Kamman et al. 2004).

Benchmarks

There are no clear benchmarks or thresholds for Hg in water. See Table 6.2 in Topic 6-Mercury: biota, for a listing of some proposed benchmarks and effects levels.

Condition

Status

Freshwaters

Throughout the Northeast, total mercury ranged 0.1-6.42 ng/L in lakewater. Lakes in southeastern Massachusetts, including Cape Cod but not within CACO, had total Hg concentrations <2 ng/L (Figure 5.1, 5.2). Cur-

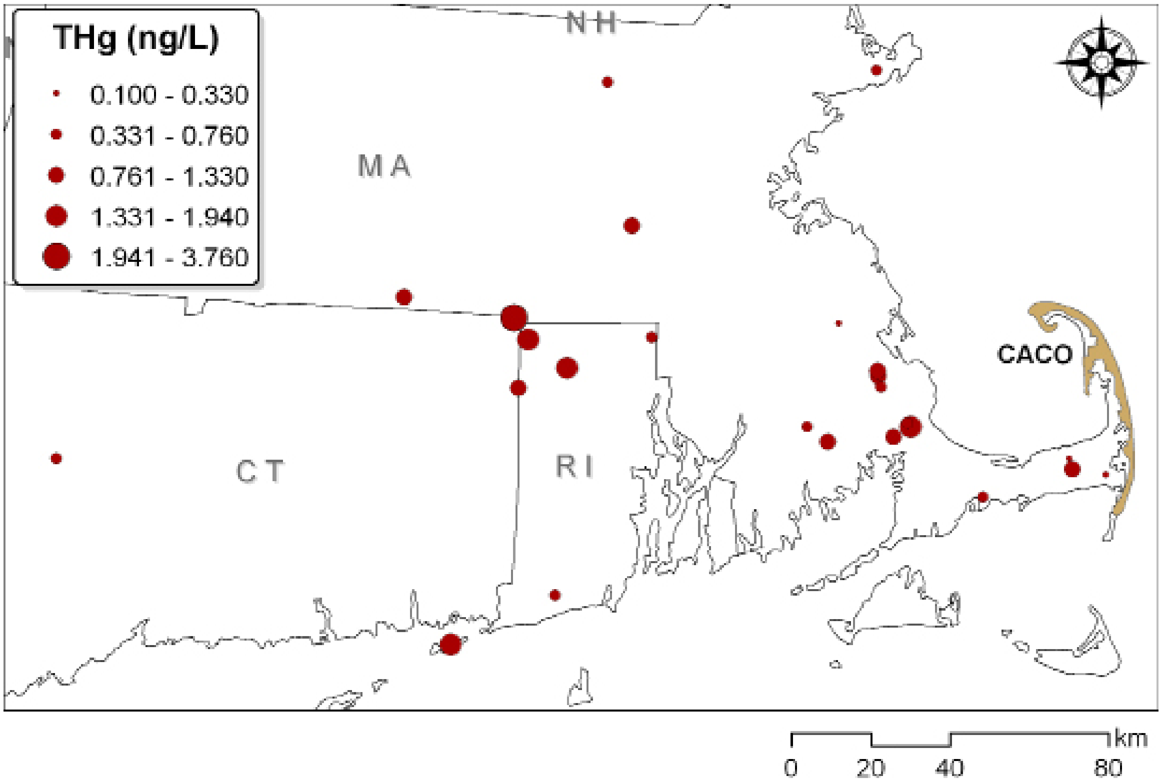


Figure 5.2. Map of US EPA's Eastern Lakes Survey lakes sampled by the University of Maine in 2004 in US EPA's sub-region D and total mercury (THg) concentrations, in ng/L. Size of the dot marking the location of each lake indicates relative total mercury concentration. Data source: S. Nelson, unpubl.

rent research (Lamborg & Drevnik 2008) is evaluating mercury in several CACO ponds and groundwater; this study will provide baseline mass balance information for the Park's freshwater and coastal systems.

Estuarine waters

Estuarine and marine systems have been studied less frequently than freshwaters, but new mercury research on Cape Cod is linking the two systems and providing mass balance estimates. Recent research at Waquoit Bay on Cape Cod (Bone et al. 2007) has identified a potential source of mercury that is atypical compared to the systems mentioned above. The researchers hypothesize that because Cape Cod soils are sandy and have low organic carbon content, they do not effectively store mercury and therefore allow it to move into groundwater and subsequently offshore. Research is being conducted to investigate this hypothesis and characterize mercury in bays and ponds, including several within CACO (Lamborg & Drevnik 2008). No data were available to directly assess the condition of estuarine waters with respect to one possible threshold (25 ng/L) (Table 6.2).

Trends

Insufficient data to evaluate.

Factors influencing Hg: freshwater & estuaries

- Atmospheric deposition of mercury continues to be greater than probable background levels (see also topic 4- Mercury: atmospheric deposition). If the hypothesis regarding lack of retention of mercury by CACO's sandy soils is supported by further evidence, then coastal systems could be receiving greater loads of mercury than might be expected.
- Freshwater pond and stream chemistry – for example, acidity, dissolved organic carbon, and sulfur concentrations - and landscape setting might also affect mercury loads and bioavailability.
- See also topic 33- Coastal Water & Sediment Quality.

6. Mercury: biota

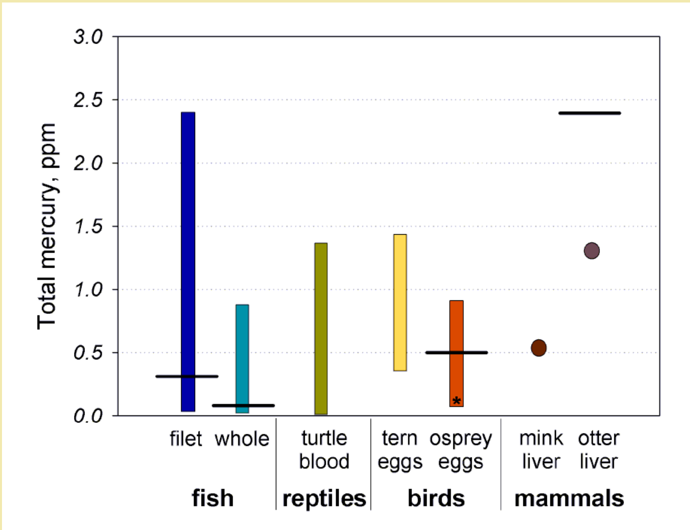


Figure 6.1. Summary of ranges in mercury concentrations in biota at CACO or in the Cape Cod region, in ppm. These and other data are presented in Table 6.1. Where appropriate, criteria or threshold values are shown as horizontal lines for each type of biota. See Table 6.2 for a listing of these criteria.

Key points

- Concentrations of mercury in fish filets (sampled at CACO in both the 1990s and 2000s) typically exceed human health consumption thresholds; accordingly, eight freshwater ponds at CACO have water-body-specific fish consumption advisories.
- Whole-body fish concentrations of mercury sampled in the 1990s at CACO were usually greater than levels proposed to be protective of piscivorous wildlife.
- Although some data are available for other biota, the tissues sampled or reporting method do not allow for comparison to published thresholds or effects levels for mercury. Many of the species sampled are considered good indicators of mercury status for estuarine ecosystems, so future sampling would benefit from ensuring the sampling approach will be comparable to such thresholds.

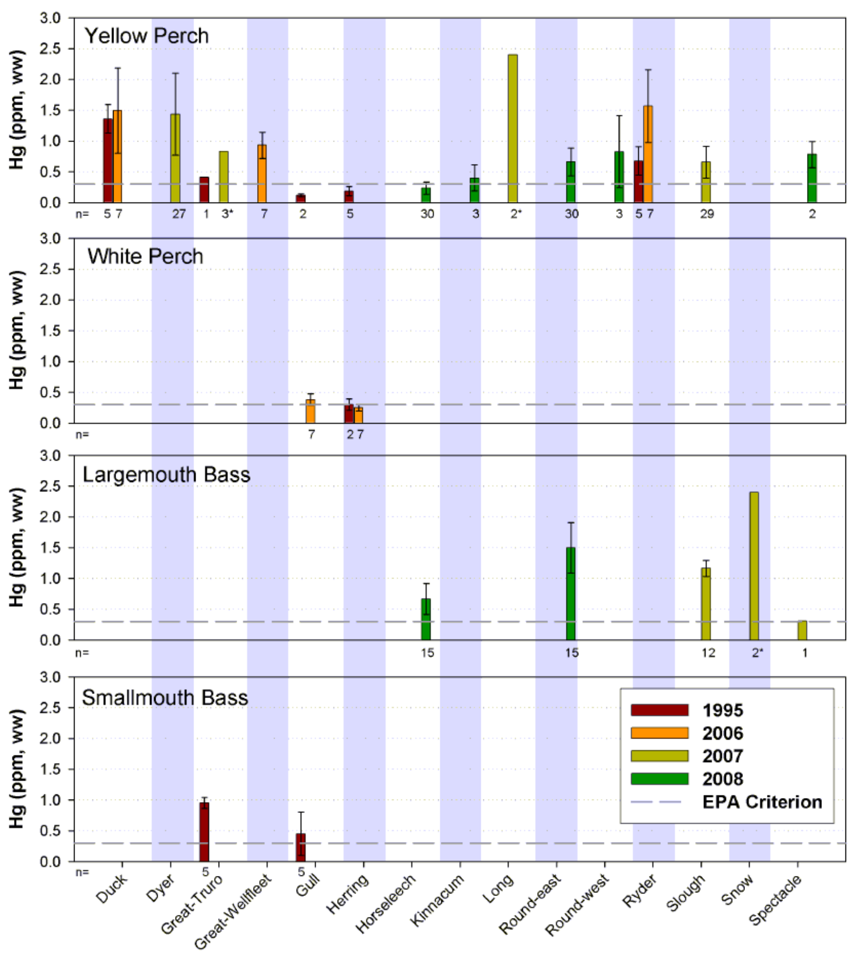


Figure 6.2. Mercury concentration (mean ± standard deviation, in ppm) in skin-off filets of four fish species collected in ponds at CACO during 1995-2008. The US EPA's fish consumption advisory level (0.3 ppm) is shown as a dotted line across each graph. Data sources: Haines 1996, Mass DEP, and Colman et al. 2009.

Mercury: biota, continued

Table 6.1. Summary of mercury in biota at CACO or in the vicinity of Cape Cod and estuaries. All values are in ppm, wet weight (ww) unless noted. Dry weight is abbreviated dw. If not specified, ww/dd noted as "ns". *Comparison data from broader geographic ranges are included for each major biotic group.

Matrix	Site(s)	Total Hg mean (SD) and/or Range	**Comment**	Source
Predator Fishes (Largemouth bass (LMB), Smallmouth bass (SMB))				
Filet (skin off)	3 CACO ponds	0.567 (0.365)		11
	3 CACO ponds	1.058 (0.548)	LMB only	12
	2 CACO ponds	0.98-2.4	LMB only	13
Comparison data:*	*US Sites*	*0.157 and 0.38*		*6*
Whole-body	3 CACO ponds	0.313 (0.253)		11
Comparison data:	*5 ponds*	*0.259 (0.141)*		*14*
Forage Fishes (White perch (WP), Yellow perch (YP))				
Filet (skin off)	5 CACO ponds	0.617 (0.509)		11
	5 CACO ponds	0.473 (0.297)	YP only	12
	9 CACO ponds	0.18-2.4		13
Comparison data:	*US Sites*	*0.11*		*6*
Whole-body	5 CACO ponds	0.388 (0.344)		11
Comparison data:	*10 ponds*	*0.124 (104)*		*14*
Snapping Turtles				
Carapace	23 ponds across Cape Cod	2.90** (3.16); range <0.1-15.7	ww/dw ns	15
Blood	23 ponds across Cape Cod	0.33 (0.34); range <0.2-1.35		15
Comparison data:	*CT sites*	*0.5-3.3*	*ww/dw ns*	*16*
Common Tern				
Initial feathers	Bird Island, Buzzard's Bay	1.8	dw	17
Regrown feathers	Bird Island, Buzzard's Bay	11.8	dw	17
Feathers	Bird Island, Buzzard's Bay	3	dw; bird age varied	18
Egg content	Bird Island, Buzzard's Bay	1.46	dw	19
	Nauset, Cape Cod Estuary	1.01	dw	19
	Ram Island, Buzzard's Bay	0.4-0.6	dw	20
Compar. data - juvenile blood:	*NE US and E. Canada*	*0.1-1*	*ww/dw ns*	*10*
Osprey				
Egg content	Narragansett/Buzzard's Bay	0.06	Median	21
	New Bedford Hbr/Buzzard's Bay	0.91	ww/dw ns	22
Mink				
Liver	Buzzard's Bay	0.54		23
Comparison data - liver:	*NE US and E. Canada*	*1.76 (1.01-3.01)*		*24, 10*
Compar. data - 'carcasses':	*9 in MA*	*0.008-1.92*	*ww/dw ns*	*21*
N. American River Otter				
Liver	Buzzard's Bay	1.31		25
Comparison data - liver:	*NE US and E. Canada*	*0.85-2.10*	*range of means; ww/dw ns*	*10*
Harbor Seal				
Liver	Off MA coast	38.5		26

Table 6.2. Mercury criteria, thresholds, and effects levels from published reports and literature for various media, biota and tissues.

Medium	Hg value	Description	Notes	Source
Atmospheric deposition	THg≈2 μg/m²/yr	estimate of likely 'pre-industrial' Hg deposition	developed from sediment and peat cores from Maine	1,2
Water, streams	THg<7.5 ppt	suggested value for 'reference' streams in the northeastern U.S.		3
Water, streams	MeHg=0.25 ppt (general fish) MeHg=0.11 ppt (predator fish)	MeHg level presumed to lead to body burdens >0.3 ppm	"tenuous" translation of EPA fish criterion (0.3 ppm ww) to water	4
Water, freshwaters	THg>12 ppt MeHg>10 ppt	adverse effects expected with chronic exposure.	from US EPA 1992 Standard; see other thresholds in ref. 5	5
Water, freshwaters - wildlife criteria	THg<0.641 ppt MeHg<0.05 ppt	calculated values	based on avian and mammalian species using RfD and NOAELs	6
Water, Drinking	THg<2000 ppt	Maximum Contaminant Level (MCL)		7
Water, saltwater	THg<25 ppt		1 to 4 day average	5
Sediments	THg<0.14 ppm dw	Canada, marine & freshwater, 'safe'	CA value for "low toxic effects" was >0.15 ppm dw	5
Soils, organic matter	THg>0.5 ppm dw	"levels of concern"		8
Wildlife, terrestrial/freshwater	THg<0.077 ppm	most likely affords protection to predators of these species		6
Fish, fillets	THg<0.3 ppm ww	Human health criterion		6
Fish, fillets	THg>0.5 ppm ww	"levels of concern"		8
Fish, muscle	THg>5-8 ppm ww	toxic	THg>10-20 ppm ww is lethal	5
Fish, whole-body	THg<0.1 ppm ww MeHg<0.02 ppm ww (birds) MeHg<0.1 ppm (mammals)	as diet for piscivorous wildlife		5
Fish, whole-body	THg>1 ppm ww	adverse effects	>0.959 ppm in diet altered schooling; see ref. 10	5
Birds, feathers	THg<5 ppm ww	'safe'		5
Birds, common tern eggs	THg<1 ppm ww	normal reproduction	2.0-4.7 ppm ww characterized reduced hatching and fledging success	5
Birds, various spp. eggs	THg<0.5 to <2.0 ppm ww	safe	THg<0.5 ppm ww listed in ref. 10	5
Birds, tree swallow eggs	THg<0.8 ppm ww	known effect concentration		5,9
Birds, blood	THg<1 ppm ww (eagles) THg<3 ppm (other birds)			10
Otters, hair	THg<1.0 to <5.0 ppm dw	acceptable		5
Otters, liver	THg<4.0 ppm dw	acceptable		5
Mammals, liver, kidney	THg<30 ppm ww	acceptable, most spp.	alternatively, kidney <1.1 ppm listed separately in ref. 5	5
Mammals, blood	THg<1.2 ppm ww	acceptable, most spp.		5
Mammals, brain	THg<1.5 ppm ww	acceptable, most spp.		5
Mammals, hair	THg<2.0 ppm ww	acceptable, most spp.		5

Assessment statement

Significant concern (fish); insufficient data (other biota)

Rationale

Mercury, in its toxic form, methylmercury, is a widespread contaminant in the Northeast. It biomagnifies with increasing trophic level. Fish in eight ponds within CACO have been found to exceed safe eating guidelines for mercury. Further, fish and other biota may have mercury levels greater than that proposed to be detrimental to other wildlife.

Benchmarks

Thresholds, adverse effects levels, and reference values for mercury in various tissues have been proposed for several species. Some refer to levels that put at risk species that consume biota, such as fish consumption advisories for humans, whereas others refer to levels of concern to the organism itself. These values are summarized in Table 6.1, and specific values are referenced throughout this section. For CACO data, the values that are most applicable are the US EPA's fish consumption advisory level for humans, 0.3 ppm, and the wildlife criteria, 0.077 ppm, which is thought to be protective of species that consume other biota.

Condition

Status

Mercury in fish

In 2007, waterbody-specific fish consumption advisories (in addition to statewide advisories) were issued for eight ponds at CACO due to mercury levels above the US FDA's action level for mercury (1 ppb; an "action level" is a concentration above which the FDA may legally remove a product from market). These ponds are: Dyer Pond, Great Pond, Duck Pond, and Great Pond in Wellfleet, plus Great Pond, Snow Pond, Slough Pond, and Ryder Pond in Truro. Some fish in each species sampled exceed the 0.3 ppm EPA fish consumption threshold (Figure 6.1). Mean mercury concentrations in whole fish and in filets exceed the wildlife criterion (0.077 ppm; Table 6.2) for all species sampled in all time periods (Table 6.1), suggesting that current mercury burdens in fish are not protective of piscivorous wildlife. Further, mean concentrations found in CACO ponds that have been sampled are slightly greater than values reported for the US (Mercury Study Report to Congress 1997) and in EMAP lakes sampled in the 1990s in Massachusetts (US EPA)(Table 6.1).

Data sources, tables 6.1 and 6.2.

1 Roos-Barraclough et al. 2006
2 S.A. Norton, pers. comm.
3 Snook et al. 2007
4 Grigal
5 Eisler 2006
6 Mercury Study Report to Congress 1997
7 US EPA
8 Meili et al. 2003
9 Longcore et al. 2007
10 Evers et al. 2005
11 Haines 1996
12 Mass. DEP
13 Colman et al. 2009
14 EMAP 1992-1994, MA Lakes
15 Tuxbury 2003
16 Golet & Haines 2001
17 Burger et al. 1992b†
18 Burger et al. 1994 †
19 Hart, 1998†
20 French et al. 2001†
21 Audet et al. 1992†
22 Welch, unpubl.†
23 Major & Carr 1991a†
24 Yates et al. 2005
25 Organ 1989†
26 Lake et al. 1995†

** means recalculated using 1/2 of the reported detection limit

† Data were extracted from: Rattner et al. 2008. Contaminant Exposure and Effects--Terrestrial Vertebrates (CEE-TV) Database. Version 8.0. [Updated March 2008; cited 04/10/2009]. U.S. Geological Survey, Patuxent Wildlife Research Center , Laurel , Maryland. Available from: http://www.pwrc.usgs.gov/contaminants-online/.

Mercury: biota, continued

Recent research and ongoing monitoring suggest that differences among ponds appear to more strongly influence mercury in fish than differences between years (Colman et al. 2009), though limited data are available for each pond and species (Figure 6.2). Research in New York, Vermont, and elsewhere demonstrated links between pond chemistry, such as dissolved organic carbon, and fish mercury concentrations. Further efforts to investigate pond chemistry and landscape setting could help identify some factors that contribute to elevated mercury in some of CACO's ponds.

Mercury in Reptiles

Snapping turtles have been proposed to be a good indicator of vulnerability to mercury in Atlantic coast estuaries; they were ranked third (in order of decreasing vulnerability) in a recent analysis based on the USGS CEE-TV dataset (Golden et al. 2008). At CACO, snapping turtles were sampled to determine mercury in blood and carapace tissue (Table 6.1). Snapping turtle carapace mercury was greater than blood, consistent with findings from other locations (Golet & Haines, 2001). At CACO, as in Connecticut (Golet & Haines, 2001), there was little relationship between turtle size and mercury; mercury in fish is often positively correlated with fish size. Generally, there are few data for reptiles or amphibians in the literature, making comparisons across sites difficult. We were not aware of threshold or benchmark values for mercury in these tissues of snapping turtles and the wildlife criterion may be inappropriate because it is usually applied to the tissues that are eaten by other biota, so we could not assess turtle mercury with respect to such criteria.

Mercury in birds

Birds are often considered useful indicators of mercury in an ecosystem. Golden et al. (2008) ranked estuarine bird species as follows, with respect to utility as indicators:

1. Double crested cormorant
2. Black-crowned night heron
3. Great blue heron & osprey (tie)
4. Common tern

Million, billion, trillion-
Common mercury unit conversions

1 mg/g (microgram per gram)
= 1 ppm (part per million)

1 mg/kg (milligram per kilogram)
= 1 ppm

1 mg/kg (microgram per kilogram)
=1 ppb (part per billion)

1 ng/g (nanogram per gram)
=1 ppb (part per billion)

1 ppm = 1000 ppb

1 ng/L (nanogram per liter)
=1 ppt (part per trillion)

At or near CACO, several studies have investigated mercury in common tern egg content and feathers (Table 6.1). For eggs, no significant difference was observed among first, second, or third-laid eggs around Buzzard's Bay (French et al. 2001). Results from studies of egg mercury content – one of which was conducted at Nauset – were reported on a dry weight basis, and cannot be compared to thresholds listed in Table 6.2.

Osprey egg contents at Buzzard's Bay were also reported in two studies (Table 6.1). A mean of 0.91 ppm, if it is indeed reported on a wet weight basis, would just exceed the known effect concentration of 0.80 ppm ww (Heinz 1979; Newton & Haas 1988); but since the dry or wet weight basis was not specified, no conclusion can be drawn. Citing longer-term, broad-ranging data from the Atlantic coast, Rattner et al. (2008) noted that mercury concentrations in osprey and bald eagle eggs have not declined during the last forty years.

Mercury in Mammals

In New York state, concentrations of mercury in mink and otter have declined since the 1980s (Evers et al. 2005, Yates et al. 2005). In a data compilation for New York, New England, and Nova Scotia, the greatest concentrations of mercury in mink liver were found in Massachusetts and Connecticut (Evers et al. 2005, Yates et al. 2005). For the one study reported in Buzzard's Bay area, mink liver mercury was slightly lower than the regional range (Table 6.1). For the one study of otter liver reported around Buzzard's Bay, mean mercury concentration was within the range of values reported elsewhere. Threshold or reference values for these tissues vary widely and the limited data available for the Cape Cod area do not facilitate comparison. Future sampling could be based on mink and otter fur, which can be sampled non-lethally and has been associated with adverse effects at about 20 ppm.

One study in 1980 evaluated mercury in the livers of harbor seals off the Massachusetts coast (Lake et al. 1995). Although the reported value (Table 6.1) is slightly greater than a potentially comparable threshold for mammal liver (30 ppm, Table 6.2), older mercury data always need to be quality assured due to major improvements in instrumentation and sample collection and handling that have since been implemented.

Trends

Although data are limited, fish Hg concentrations were available for 1995 and 2005-2009. Some fish exceeded safe eating guidelines in both time periods. There are insufficient data for trend analysis at this time.

Factors influencing Hg in biota

- For lakes, ponds, and streams, the chemical environment – such as the acidity of a water body – can affect mercury methylation rates.
- Mercury bioavailability is tightly linked with many ecosystem processes and a broader understanding of ecosystem and watershed processes is necessary.

7. Rare species: flora

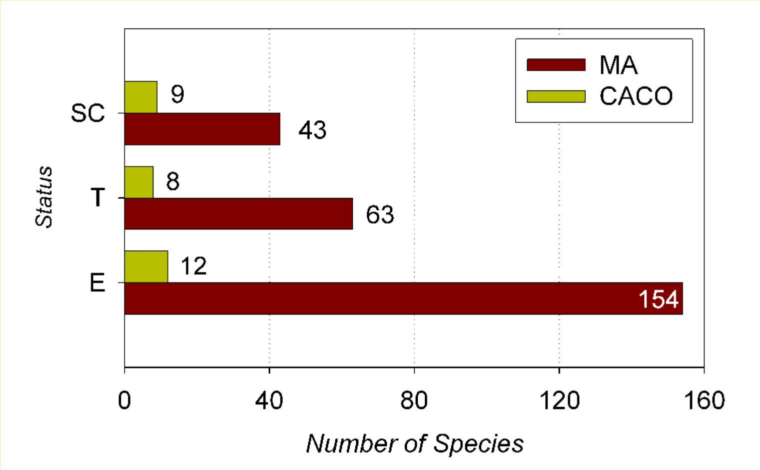


Figure 7.1. Number of rare plant species in Massachusetts and at CACO, by conservation status. (Data source: Massachusetts Natural Heritage and Endangered Species Program and NPSpecies database, accessed 2010).

Definitions of species conservation status:

“Endangered" (E) species are native species which are in danger of extinction throughout all or part of their range, or which are in danger of extirpation from Massachusetts, as documented by biological research and inventory.

“Threatened” (T) species are native species which are likely to become endangered in the forseeable future, or which are declining or rare as determined by biological research and inventory.

“Special concern" (SC) species are native species which have been documented by biological research or inventory to have suffered a decline that could threaten the species if allowed to continue unchecked, or which occur in such small numbers or with such restricted distribution or specialized habitat requirements that they could easily become threatened within Massachusetts.

(Source: Massachusetts Natural Heritage and Endangered Species Program)

Key Points

- 29 state-listed plant species are present in CACO, representing 11% of all MA-listed flora.
- Only three federally-listed plant species are present in Massachusetts. None of these has been recorded from CACO.

Assessment statement

Unknown. Although 29 state-listed species are known to occur in the Park, we are unaware of data that address the current status and trends in the populations of these species in the Park.

Rationale

Rare species are an important biodiversity conservation target.

Benchmarks

No benchmark is available to quantify an ‘appropriate’ or expected number of rare plant species for CACO. No data on population sizes are available that would serve as a baseline from which to measure change.

Condition

Status

According to the Massachusetts Natural Heritage Program, a total of 29 state-listed plant species have been observed in CACO – 12 of these are Endangered, 8 Threatened, and 9 are of Special Concern (Figure 7.1 , Table 7.1). While CACO represents just 0.64% of the area of Massachusetts, the Park is home to 11% of the total number of listed plants in the State.

It is possible that additional state-listed plant species occur in CACO. For example, the MA Natural Heritage Program lists a total of 29 rare plant species for the six towns of the eastern Cape (Provincetown - 11; Truro - 9; Wellfleet - 13; Eastham - 10; Orleans - 9; Chatham - 11). Of these species, 8 were not included within the NPSpecies database for CACO as of 2010. The NPSpecies list, however, includes 8 state-listed species at CACO that do not appear on the town lists of the

MA Natural Heritage Program. Thus, based on both NPSpecies and Natural Heritage data, a total of 37 state-listed species have been recorded from the eastern Cape.

Trends

To our knowledge, no published data are available on trends in the size or distribution of listed plant populations in CACO.

Factors influencing rare flora

- Rare and endangered species are threatened by a variety of stressors such as habitat loss and competition with other species.

Table 7.1. Massachusetts state listed species that have been documented at CACO. Town designations: C: Chatham, E:Eastham, O:Orleans, P:Provincetown, T:Truro, W:Wellfleet. n/a indicates species has been observed in CACO but none of the towns adjacent to CACO list the species, indicating a possible new record for one or more of these towns. Data sources: Massachusetts Natural Heritage and Endangered Species Program (2010); NPSpecies database (accessed 2010).

Vascular Plants: Common Name	Scientific Name	MA status	Town where listed
American dune grass/ Sea lyme-grass	*Leymus mollis*	E	P
Arrowfeather treeawn/Purple needlegrass	*Aristida purpurascens*	T	T
Big cordgrass/ Salt reedgrass	*Spartina cynosuroides*	T	O,W
Broom crowberry	*Corema conradii*	SC	E,P,T,W
Bushy frostweed	*Helianthemum dumosum*	SC	C,E,O,P,T,W
Coastal plain blue-eyed grass/Sandplain blue-eyed grass	*Sisyrinchium fuscatum*	SC	P
Devil's tongue/ Prickly pear	*Opuntia humifusa*	E	E,P,T,W
Dragon's mouth	*Arethusa bulbosa*	T	n/a
Fewseed sedge/Few-fruited sedge	*Carex oligosperma*	E	P
Golden club	*Orontium aquaticum*	E	n/a
Lake quillwort	*Isoetes lacustris*	E	n/a
Large-Leaved Goldenrod	*Solidago macrophylla*	T	n/a
Lavender bladderwort	*Utricularia resupinata*	T	T,W
Long-beaked bald-sedge	*Rhynchospora scirpoides*	SC	W
Maryland Meadow Beauty	*Rhexia mariana*	E	C,E
Mitchell's Sedge	*Carex mitchelliana*	T	E
Northern adder's-tongue/Adder's-tongue Fern	*Ophioglossum pusillum*	T	C,P,T
Ovate spike-sedge	*Eleocharis ovata*	E	W
Oysterleaf	*Mertensia maritima*	E	C,P,T,W
Plymouth gentian	*Sabatia kennedyana*	SC	C,E,O,T
Prickly Currant/ Bristly Black Currant	*Ribes lacustre*	SC	n/a
Seaside knotweed/Sea-beach knotweed	*Polygonum glaucum*	SC	C
Slender Arrowhead/ Terete Arrowhead	*Sagittaria teres*	SC	C,O,W
Swamp wedgescale/Swamp oats	*Sphenopholis pensylvanica*	T	W
Taperleaf water horehound	*Lycopus rubellus*	E	n/a
Walter's sedge	*Carex striata var. brevis*	E	W
Weak rush	*Juncus debilis*	E	P
Whorl-leaf watermilfoil	*Myriophyllum verticillatum*	E	n/a
Zigzag bladderwort	*Utricularia subulata*	SC	W

8. Rare species: fauna

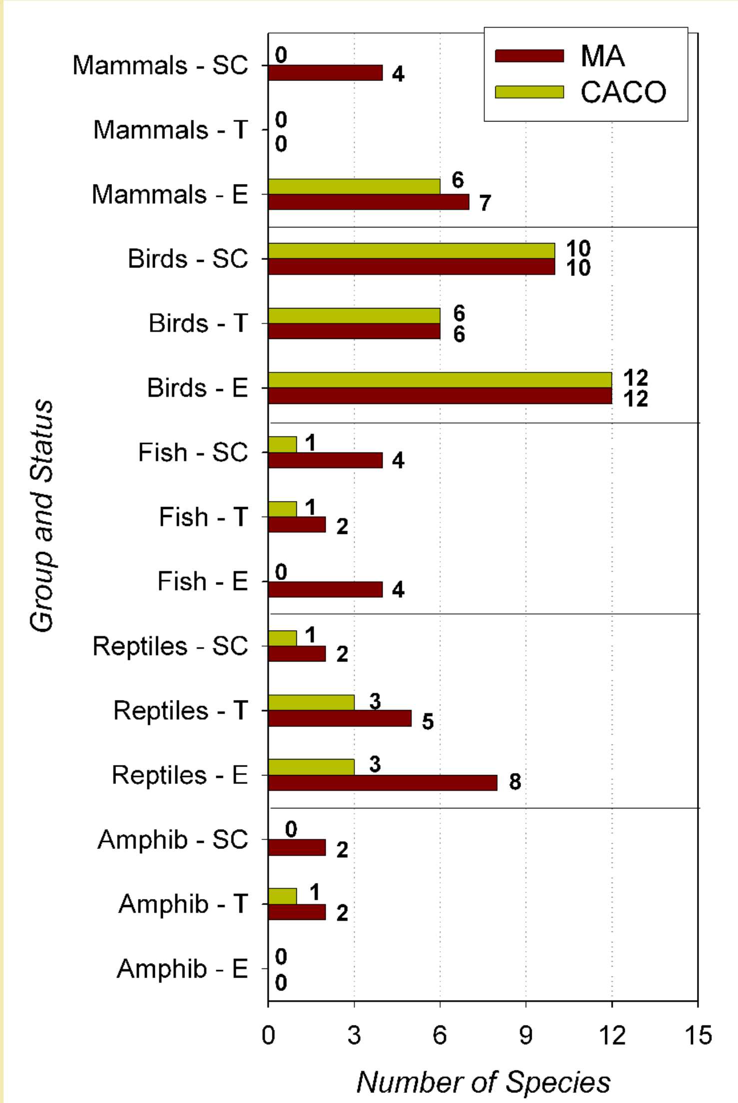


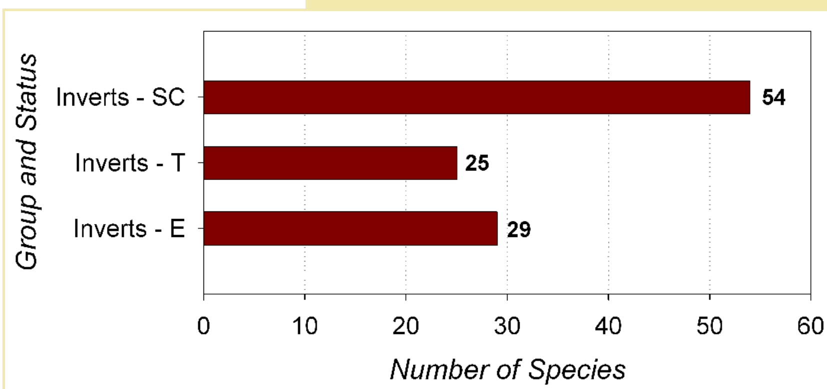
Figure 8.1 (a). Number of rare vertebrate species in Massachusetts and at CACO, by conservation status. E = endangered; T = threatened; SC = special concern. Definitions of these categories are provided in the topic: Rare Species – Flora. (Data sources: Massachusetts Natural Heritage and Endangered Species Program (2009); NPSpecies database [accessed 2009]).

Key Points

- 65% (44/68) of the Massachusetts-listed vertebrate species are known to occur in CACO.
- Of these 44 state-listed species, 6 are marine mammals; there are 28 listed birds, 2 fish, 7 reptiles and 1 amphibian.
- A total of 13 federally-listed species occur at CACO (and off-shore waters).
- Extensive Lepidoptera and Odonata surveys have been conducted in the CACO area. Although the NPSpecies database for the Park does not currently (2010) include many of these taxa, data have been compiled for this assessment from multiple sources.
- This topic presents an overview of rare fauna at CACO. More detailed information appears under other topics that focus on specific faunal groups.

Figure 8.1 (b). Number of rare invertebrate species in Massachusetts, by conservation status. (Data source: Massachusetts Natural Heritage and Endangered Species Program, accessed 2010). Because invertebrates are inadequately represented in the NPSpecies database, no values are provided for CACO-recorded taxa. However, 16 listed Lepidoptera species and 7 listed Odonata species have been recorded from the six towns of the eastern Cape. The composition of the MA-listed invertebrates is as follows:

Sponges (1); Flatworms (1); Segmented worms (1); Snails (6); Freshwater mussels (7); Crustaceans (7); Dragonflies/damselflies (30); Beetles (9); Butterflies/moths (46).



Assessment statement

Species lists: Good - Fair. Species lists for rare vertebrate species are probably largely complete. The completeness of species lists for rare invertebrates varies by taxonomic group. Odonates and Lepidoptera have been well surveyed.

Population status: Fair - significant concern - unknown. For some rare vertebrates, data exist on current population status and trends. These data are reviewed under the respective group-specific topics, below. For most invertebrates, there are few quantitative data on population status and trends.

Rationale

Rare species are an important biodiversity conservation target. Furthermore, some rare species, particularly vertebrates, have high 'public perception' values.

Benchmarks

None given

Condition

Status and Trends

A total of 44 state listed vertebrate species have been observed at CACO (this total includes 5 marine turtles and 6 whales, and is based on records in the NPSpecies database). Of this total, 64% are birds, 18% are amphibians or reptiles, and 14% are marine mammals (Figure 8.1, Table 8.1). The number of listed faunal species at CACO represents 65% (44/68) of all Massachusetts-listed vertebrates (Figure 8.1a). Of the state-listed vertebrates known to occur at CACO, 13 are also federally listed (5 marine tutles, 2 birds, 6 whales).

Although many of the listed vertebrates of Massachusetts occur in or around CACO, available information permits the population status to be characterized for only a few of these taxa. The checklist of Cape Cod birds (Appendix 2; Nikula 2008) indicates that populations of two state-listed bird species have been increasing in recent years, while eight species have exhibited declining populations (Table 8.1). Note, however, that trend statistics are not provided by Nikula (2008) and information in the checklist addresses the entire Cape Cod region.

Twenty-two of the 28 state state listed bird species have been identified as priority species by Partners in Flight (PIF, Dettmers and Rosenberg 2000). Three species (piping plover, golden-winged warbler, and Henslow's sparrow) are listed as Tier I, high continental priority species, with piping plover as IA, indicating that the SE New England area has a high regional responsibility for this species. Three other species are Tier III species (high regional priority) and the remaining 15 are Tier V species (state listed species).

For more information on selected rare animal species see these topics:

- Parabolic Dunes & Associated Wetlands
- Birds: Assemblage Compositions & Population Dynamics
- Amphibians & Reptiles: Assemblage Composition & Population Dynamics

In terms of invertebrates, the NPSpecies database is very incomplete. We have compiled from multiple sources a list of 488 butterflies and moths recorded from Cape Cod (collections were not necessarily restricted to Park area) (Appendix A). Within Massachusetts, there are 46 state-listed Lepidoptera species - 17 of these are included in the Cape Cod list. None of these species is federally listed.

We also compiled from multiple sources a list of 104 dragonfly and damselfly species recorded from Cape Cod (Appendix A). Within Massachusetts, there are 30 state-listed Odonata species (25 dragonflies, 5 damselflies) - 8 of these are included in the Cape Cod list. None of these species is federally listed.

Factors influencing rare species: fauna

- Rare and endangered species are threatened by a variety of stressors including pollution, decreasing quantity and/or quality of habitat, and competition with other species.

- In general, little quantitative information is available documenting how environmental stressors may be impacting populations of state-listed species.

Rare species: fauna, continued

Table 8.1. Massachusetts state listed species that have been documented at CACO. Invertebrate records are derived from MANHESP database, not from NPSpecies database. Town designations: C: Chatham, E:Eastham, O:Orleans, P:Provincetown, T:Truro, W:Wellfleet. n/a indicates species has been observed in CACO but none of the towns adjacent to CACO list the species, indicating a possible new record for one or more of these towns. For the bird list, arrows by common names indicate whether the overall Cape Cod has been characterized as increasing or decreasing by Nikula (2008). ↑ = population has been "increasing locally in recent years". ↓ = population has been "decreasing locally in recent years". Note that (i) trend statistics are not provided by Nikula (2008), and that (ii) trend observations apply to the Cape Cod region, not CACO specifically. For more information, see text.
(Data sources: Massachusetts Natural Heritage and Endangered Species Program (2010); NPSpecies database [accessed 2010]; Nikula [2008]).

Common Name	Scientific Name	MA status	Town where listed
Birds			
American bittern	*Botaurus lentiginosus*	E	C,T
Arctic Tern ↓	*Sterna paradisaea*	SC	C,E,O,P,W
Bald Eagle ↓	*Haliaeetus leucocephalus*	E	n/a
Barn Owl	*Tyto alba*	SC	C
Blackpoll Warbler	*Dendroica striata*	SC	n/a
Common Loon	*Gavia immer*	SC	n/a
Common Moorhen ↓	*Gallinula chloropus*	SC	C
Common Tern	*Sterna hirundo*	SC	C,E,O,P,T,W
Golden-winged Warbler	*Vermivora chrysoptera*	E	n/a
Grasshopper Sparrow ↓	*Ammodramus savannarum*	T	n/a
Henslow's sparrow	*Ammodramus henslowii*	E	n/a
King Rail	*Rallus elegans*	T	P
Leach's storm-petrel	*Oceanodroma leucorhoa*	E	n/a
Least Bittern	*Ixobrychus exilis*	E	P,T
Least Tern	*Sterna antillarum*	SC	C,E,O,P,T,W
Long-eared Owl	*Asio otus*	SC	n/a
Mourning Warbler	*Oporornis philadelphia*	SC	n/a
Northern Harrier ↓	*Circus cyaneus*	T	C,P,T,W
Northern Parula	*Parula americana*	T	n/a
Peregrine Falcon ↓	*Falco peregrinus*	E	n/a
Pied-billed Grebe ↓	*Podilymbus podiceps*	E	C
Piping Plover	*Charadrius melodus*	T	C,E,O,P,T,W
Roseate Tern	*Sterna dougallii*	E	C,E,O,P,T,W
Sedge Wren	*Cistothorus platensis*	E	n/a
Sharp-shinned Hawk	*Accipiter striatus*	SC	W
Short-eared Owl ↓	*Asio flammeus*	E	C,O
Upland Sandpiper ↓	*Bartramia longicauda*	E	E,T
Vesper Sparrow ↓	*Pooecetes gramineus*	T	P.T,W
Fish			
Bridle Shiner	*Notropis bifrenatus*	SC	C,T
Three-spine stickleback (FW population)	*Gasterosteus aculeatus*	T	n/a
Amphibians & Reptiles			
Spadefoot toad	*Scaphiopus holbrookii holbrookii*	T	E, P, T, W
Diamondback terrapin	*Macaclemys terrapin*	T	E, P, T, W

Table 8.1, continued.

Eastern box turtle	*Terrapene carolina carolina*	SC	C,E,O,P,T,W
Atlantic hawksbill sea turtle	*Eretmochelys imbricata imbricata*	E	n/a
Green sea turtle	*Chelonia mydas*	T	n/a
Kemp's Ridley Seaturtle	*Lepidochelys kempii*	E	n/a
Leatherback Seaturtle	*Dermochelys coriacea coriacea*	E	n/a
Loggerhead Seaturtle	*Caretta caretta*	T	n/a
Mammals			
Blue whale	*Balaenoptera musculus*	E	n/a
Northern right whale	*Eubalaena glacialis*	E	n/a
Sperm whale	*Physeter macrocephalus*	E	n/a
Finback Whale	*Balaenoptera physalus*	E	n/a
Humpback whale	*Megaptera novaeangliae*	E	n/a
Sei whale	*Balaenoptera borealis*	E	n/a
Butterfly/moth*			
Drunk Apamea Moth	***Apamea inebriata***	SC	T
Waxed Sallow Moth	***Chaetaglaea cerata***	SC	W
Melsheimer's Sack Bearer	***Cicinnus melsheimeri***	T	W,E
Barrens Buckmoth	***Hemileuca maia***	SC	W,C
Pale Green Pinion Moth	***Lithophane viridipallens***	SC	P,W
Coastal Swamp Metarranthis Moth	***Metarranthis pilosaria***	SC	P,T
Northern Brocade Moth	***Neoligia semicana***	SC	W,E
Dune Noctuid Moth	***Oncocnemis riparia***	SC	T,W,E
Chain Fern Borer Moth	***Papaipema stenocelis***	T	P,E
Water-willow Stem Borer	***Papaipema sulphurata***	T	P,T,W,E,O
Pink Sallow	***Psectraglaea carnosa***	SC	P,W,E
Oak Hairstreak	***Satyrium favonius***	SC	W
Pine Barrens Zale	***Zale sp. 1 nr. lunifera***	SC	P
Coastal Heathland Cutworm	***Abagrotis nefascia***	SC	C,E,P,T,W
Gerhard's Underwing moth	*Catocala herodias gerhardi*	SC	C,E,P,T,W
Chain Dot Geometer	*Cingilia catenaria*	SC	P,T
Dragonfly/Damselfly			
New England Bluet	*Enallagma laterale*	SC	C,E,O,W
Pine Barrens Bluet	*Enallagma recurvatum*	T	C,O,T,W
Comet Darner	*Anax longipes*	SC	P,E,O,C
Attenuated Bluet	*Enallagma daeckii*	SC	T,W
Scarlet Bluet	*Enallagma pictum*	T	T,E,C
Spine-crowned Clubtail	*Gomphus abbreviatus*	E	P
Spatterdock Darner	*Rhionaeschna mutata*	SC	T,E
Marine Gastropod			
Walker's Limpet	*Ferrissia walkeri*	SC	W

* Two other state-listed Lepidoptera species are included in our Cape Cod composite list (Appendix A) but are not present in the MANHESP lists for the eastern Cape towns: *Callophrys irus* and *Euchlaena madusaria*.

9. Critical terrestrial & aquatic habitats

Figure 9.1. Natural communities designated as core habitats by the MA Natural Heritage and Endangered Species Program (MA-NHESP 2008a). Note that the freshwater systems designated by the Living Waters Program (MA-NHESP 2008b) are not included in this figure.

Key Points

- All of CACO upland areas are contained within two state-designated critical habitats (BioMap Core Habitats).
- The Pamet River and many of CACO's kettle ponds have been identified by the Living Waters Program as critical habitats within the state.
- Large areas of critical marine habitat (intertidal zone, marsh and tidal flats) are found within CACO along the back barrier of the Nauset beach spit on Pleasant Bay.
- Large portions of Pleasant Bay and Wellfleet Bays are contained within designated Areas of Critical Environmental Concern.
- Several state-designated high-value natural communities are found in CACO.

Assessment statement

Good - for marine natural communities, based on assessment by MA Natural Habitat & Endangered Species Program (MANHESP). High value of other core habitats is recognized by designation within this program.

Rationale

The BioMap and Living Waters Programs of MANHESP identify areas most in need of protection in order to conserve the native biodiversity of the State (MANHESP 2008a). These areas have particularly high habitat value and thus are of critical environmental concern. The Seashore includes a number of these core habitats (Table 9.1). In addition, MANHESP has also designated Areas of Critical Marine Habitat (ACMH), two of which are in the vicinity of the Park.

This topic presents an overview narrative of MANHESP-designated critical habitats in the CACO region. For more in-depth discussion of flora and fauna assemblages of the Park's terrestrial and aquatic ecosystems, and what is known about the condition of individual groups, see the following topics:

- Terrestrial plant assemblages
- Terrestrial mammals: population dynamics
- Birds: assemblage structure & population dynamics
- Amphibians & reptiles: population status & trends
- Ponds: plant assemblages
- Ponds: fish assemblages
- Eelgrass distribution & population status

Benchmarks

Conservation and preservation of state-designated critical habitats is necessary to protect the native biodiversity of the Commonwealth. However, the MANHESP does not identify specific benchmark metrics with which to evaluate current condition of these habitats and their biotic communities.

Condition

Status & Trends

The entire Seashore is contained within two BioMap core habitats (habitats BM1109 and C1241). Natural communities that are found in the Park in these habitats include maritime dune communities, level bog, Atlantic White Cedar bog, coastal Atlantic White Cedar swamp, and sandplain heathland (Figure 9.1). The natural communities within these BioMap core habitats have been designated as being vulnerable, imperiled or critically imperiled (Table 9.1). The following overview of these habitats is taken from MANHESP (2008a, b).

The BM1109 core habitat covers over 1300 hectares and includes the largest dune system in the state and in the northeast. It includes excellent examples of a maritime dune natural community, the best example of classic bog vegetation on Cape Cod, Atlan-

Table 9.1. BioMap Core Habitats as designated by MANHESP. *

The Natural Community "coastal plain pondshore" could not be located on the MANHESP Natural Communities GIS data for Provincetown. BM: BioMap Core Habitat; LW: Living Waters Core Habitat.

Natural Community	Core Habitat ID	Habitat Status (designated by MA-NHESP)
Atlantic White Cedar Bog	BM1109	Imperiled
Coastal Atlantic White Cedar Swamp	BM1109	Imperiled
Coastal Plain Pondshore*	BM1109	Imperiled
Estuarine Intertidal: Saline/ Brackish Flats	BM1109/1241	Vulnerable
Level Bog	BM1109	Vulnerable
Maritime Dune Community	BM1109	Imperiled
Sandplain Heathland	BM1109	Critically Imperiled
Atlantic Coastal Plain Pond, Great Pond (Truro)	LW049	n/a
Atlantic Coastal Plain Pond, Slough Pond	LW050	n/a
Atlantic Coastal Plain Pond, Dyer Pond	LW052	n/a
Pamet River	LW123	n/a
Atlantic Coastal Plain Pond	LW191	n/a
Fish Habitat, Pilgrim Lake	LW319	n/a
Atlantic Coastal Plain Pond, Herring Pond	LW333	n/a
Atlantic Coastal Plain Pond, Round Pond	LW341	n/a
Atlantic Coastal Plain Pond, Great Pond (Wellfleet)	LW342	n/a
Atlantic Coastal Plain Pond, Duck Pond	LW343	n/a

Critical terrestrial & aquatic habitats, continued

tic White Cedar bogs and swamps, and the state's best mainland sandplain heathlands. A diversity of rare plant species are found within this core habitat, including most of the state's populations of the endangered Few-fruited Sedge and some of the state's best populations of Broom Crowberry.

The sandy upland habitats dominated by pine-oak forests and barrens support the largest populations of Eastern Spadefoot Toad in New England. There are also significant and widespread populations of Eastern Box Turtle as well as Spotted Turtle. These woodlands and shrublands provide some of the most important habitat in New England

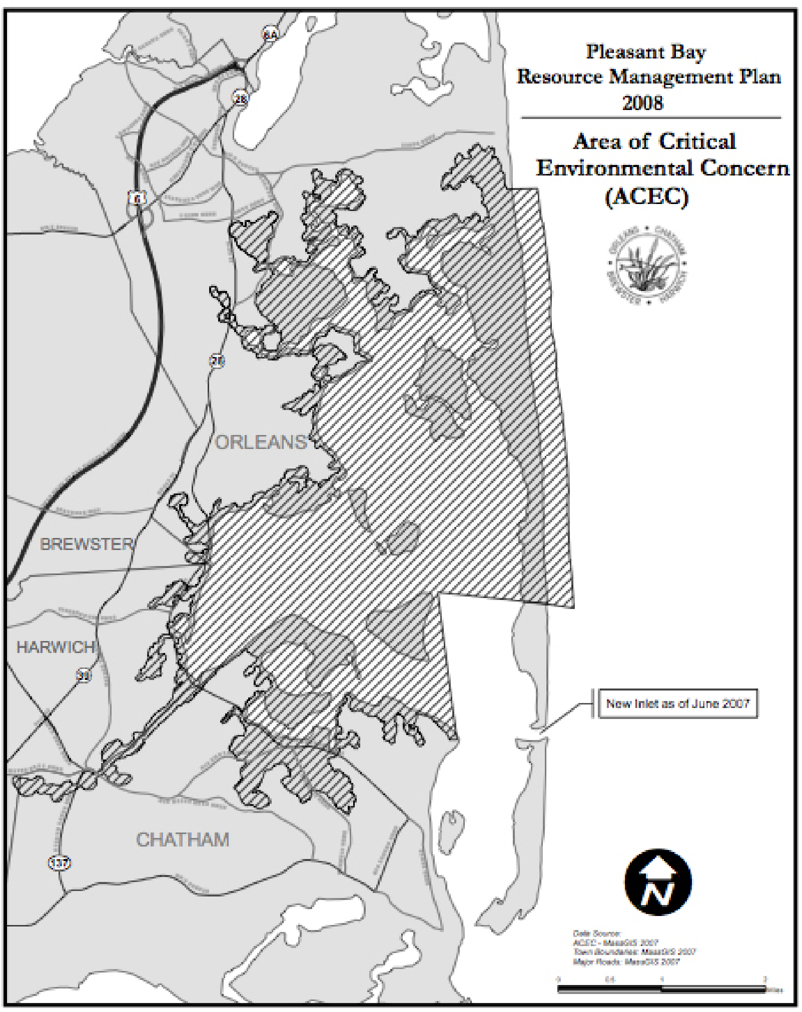


Figure 9.2.Pleasant Bay Area of Critical Environmental Concern. Source: Pleasant Bay Resounce Management Plan 2008. Also see: http://www.mass.gov/dcr/stewardship/acec/acecs/l-plebay.htm.

for landbirds characteristic of Pitch Pine - Scrub Oak barrens, including the Eastern Towhee and the Prairie Warbler. This area also encompasses breeding habitat for Vesper Sparrow. Northern Harriers have been recorded near Pilgrim Lake and Hatches Harbor.

The numerous coastal plain ponds of the outer Cape are home to rare species of dragonflies and damselflies, including the Red and Green Comet Darner and the Blue Pine Barrens Bluet. The acidic shrub swamps and bogs associated with the ponds are habitat for rare species of moths such as the Pale Green Pinion Moth. The open-canopy pitch pine - scrub oak barrens provide habitat for other rare moths (Melsheimer's Sack Bearer and the Barrens Buckmoth). These ponds, with their acidic waters and sandy, cobble, or mucky pond bottoms, provide uncommon freshwater habitats for aquatic plants and insects. Great Pond (Truro) and Great Pond (Wellfleet), Dyer Pond, Round Pond, Slough Pond, Duck Pond and Herring Pond are excellent examples of Atlantic Coastal Plain ponds that have little or no development in their riparian area and are removed from cranberry agriculture. Great Pond supports an excellent diversity of dragonflies and damselflies, while Dyer Pond, Round Pond, and Great Pond (Wellfleet) are low in nutrients, reflecting the low amount of development in the area. Slough and Duck Ponds are deep with moderate levels of nutrients. Herring Pond is sandy-bottomed, nutrient-rich, surrounded by emergent vegetation, and contains spawning habitat for Alewife. One of only nine known populations of the rare Resupinate Bladderwort in Massachusetts inhabits the peaty margin of Horseleech Pond. Sections of Pamet River support one of only two known populations of Bridle Shiner on Cape Cod.

The C1241 core habitat contains a number of coastal beaches on both the eastern and western shores of outer Cape Cod that collectively comprise some of the most important breeding habitat for Piping Plovers along the Atlantic Coast. Significant areas of nesting habitat for Least Terns are also present. New Island in Nauset Marsh has traditionally supported one of the largest breeding colonies of Common Terns and Laughing Gulls in Massachusetts. The beaches and extensive sandflats and mudflats at North and South Monomoy Islands and South Beach Island represent one of the most important shorebird migration stopover areas in New England. In addition, this core habitat encompasses large, high-quality natural communities, including Estuarine Intertidal Flats, Maritime Beach Strands, and Maritime Dune systems. The exemplary barrier beach system of this core habitat includes five miles of good-quality maritime beach strand, located on the oceanside of a high quality maritime dune system with natural vegetation, limited access, and no vehicle damage. Also included in the C1241 core habitat are the estuarine intertidal saline/brackish flats along the shores of Monomoy Island. This core habitat also contains salt marsh, tidal creeks, beaches, dune areas, shallow waters, and sandy uplands that support Diamondback Terrapins.

Pleasant Bay and Wellfleet Bay have been designated as Areas of Critical Environmental Concern (ACEC) by the state of Massachusetts (Figures 9.2 and 9.3). The Pleasant Bay ACEC, designated in 1987, encompasses 3,739 ha, and includes over 1,500 ha of salt marsh and several hundred hectares of tidal flats. Other important habitats include islands, salt and freshwater ponds, rivers, bays, and barrier beaches. Pleasant Bay has also been designated as containing Areas of Critical Marine Habitat (ACMH) by the Pleasant Bay Resource Management Alliance (Pleasant Bay Resource Alliance 2008). The Wellfleet Bay ACEC, designated in 1989, encompasses 5050 ha of Cape Cod and Wellfleet Bay. Portions of the area have been designated by the MA Department of Conservation and Recreation as containing visual landscapes and cultural resources that place it in the top 5% of all landscapes in the Commonwealth. Important habitats within the ACEC boundary include largely unaltered barrier beaches, islands, marsh systems, salt and fresh water ponds, rivers, bays, and tidal flats. The marine subtidal flats and associated eelgrass beds along the eastern side of Cape Cod Bay are one of the MANHESP-designated exemplary marine communities on the outer Cape. These subtidal flats are the largest and most pristine in Massachusetts.

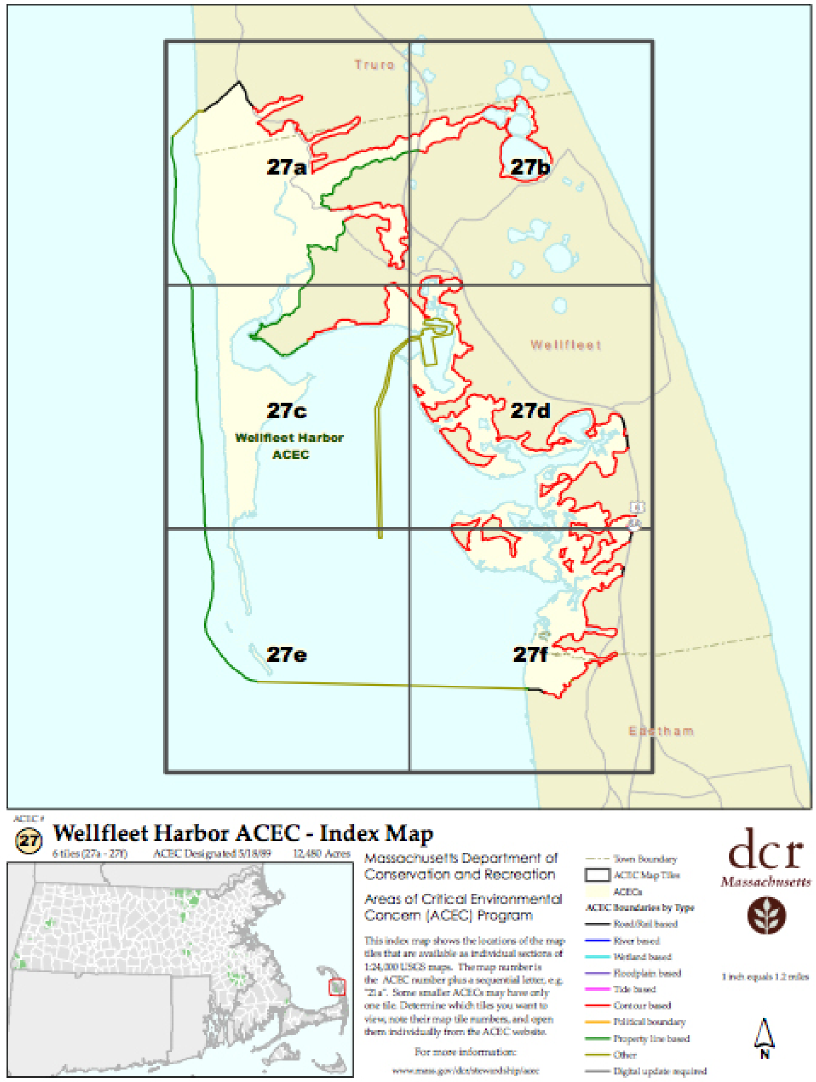


Figure 9.3. Wellfleet Bay Area of Critical Environmental Concern. Source: http://www.mass.gov/dcr/stewardship/acec/acecs/l-welhar.htm. Detailed maps for each of the tiles shown in this figure may be accessed from this website.

Factors influencing critical habitats

- Threats to these critical habitats include human disturbance, predation, habitat degradation, and nutrient enrichment.
- For specific threats to individual biological groups, see the relevant sections of this report, listed above.

10. Flora & fauna: non-native & invasive species

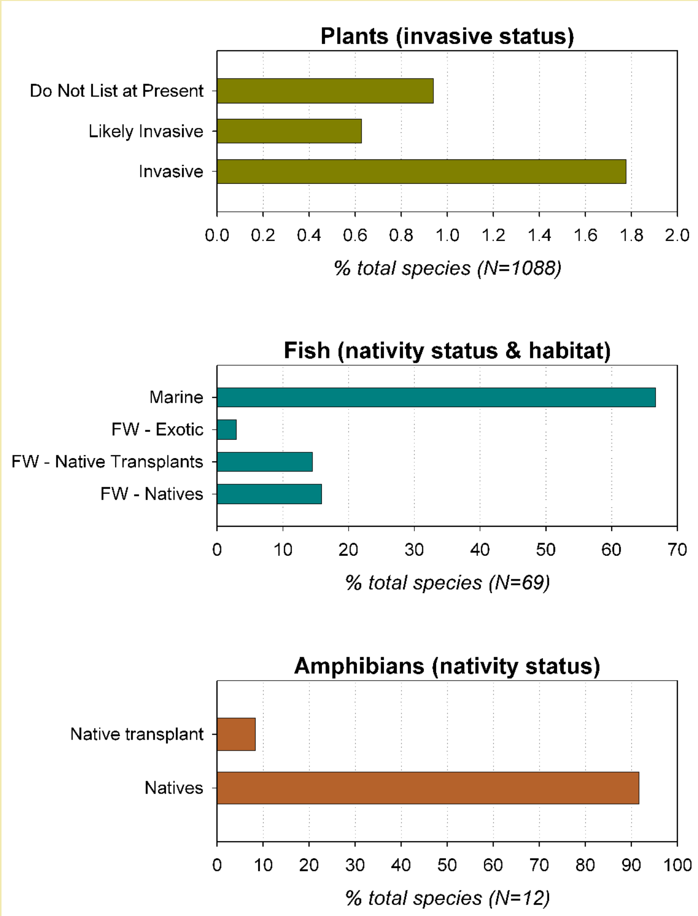


Figure 10.1. Invasive status or nativity for plants, fish and amphibians at CACO.

"N" = species totals as reflected in NPSpecies database (for plants, total includes both species, sub-species and varieties). Plant invasive status as defined by MIPAG (2009). Faunal nativity as defined by USGS (2009). Fish habitat: FW (freshwater) designation applies if species is assumed to spend some or all of its life cycle in freshwater in the Cape area. All 18 reptile species at CACO are considered natives.

Key Points

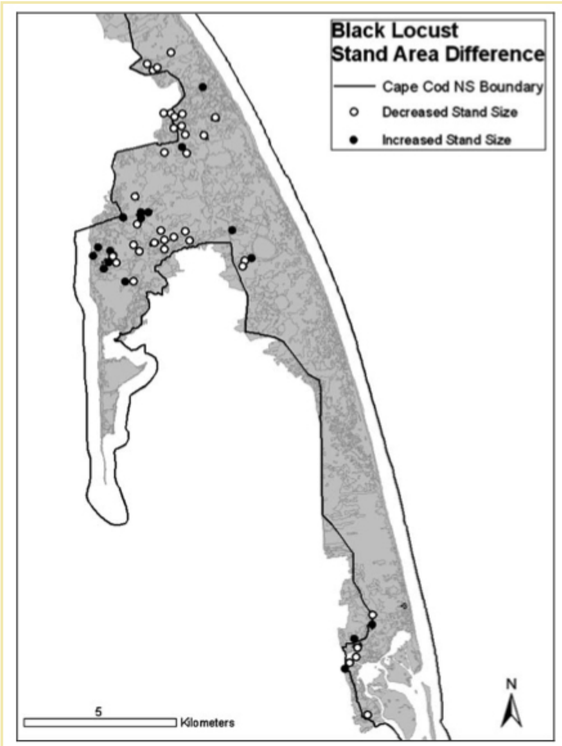
- Nineteen percent of vascular plant species listed in the NPSpecies are considered to be non-native to CACO. (The nativity status of another 16% is unspecified.)
- Two percent (21 species) of the plant species listed in the NPSpecies database for CACO are considered to be invasive or likely invasive (Figure 10.1, Table 10.1). This total represents 34% of the plant species considered to be invasive or likely so in Massachusetts (MIPAG 2009).
- Only two percent (11 species) of the animal species at CACO are considered to be native transplants or exotic; however, the majority of these species (10) are fish and they comprise 15% of the fish species in CACO (Figure 10.1, Table 10.2).
- There are another 19 invasive species that have been recorded in the area (Atlantic Ocean, Barnstable County) in the vicinity of CACO and these may pose emerging threats to CACO (Table 10.3)
- Sixteen of 30 the insect pests tracked by the USDA that are present in Barnstable County pose either an extreme or medium risk of infestation based on the basal area of host plant species.
- Invertebrates are poorly represented in the NPSpecies database. Consequently, it is not possible to assess levels of nativity for these groups.

Assessment statement

Signficant concern. Non-native (especially invasive) species will continue to represent a potential threat to CACO plant and animal communities in the future.

Rationale

An invasive species is a "non-native species (including seeds, eggs, spores, or other propagules) whose introduction causes or is likely to cause economic harm, environmental harm, or harm to human health. The term 'invasive' is used for the most aggressive species. These species grow and reproduce rapidly, causing major disturbance to the areas in which they are present" (Center for Invasive Species and Ecosystem Health, 2010). Only some non-native species are considered



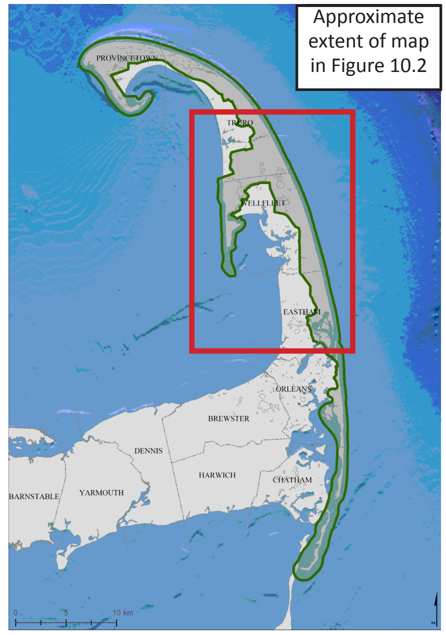


Figure 10.2 Black locust stands within CACO that increased or decreased in area from the 1970s to 2002. Note that these stands are those that were assessed for cover change – they do not represent the full set of *Robinia* stands at CACO (these numbered 129 in 1991). (Figure from Von Holle et al. 2006, used with permission)

to be invasive. A species is considered to be a native transplant to an area when it has been introduced to that area from elsewhere within its range (within North America). While the term "exotic" is sometimes used as a synonym for non-native, exotic species more correctly refer to taxa that are not native to (in the current context) North America.

Many studies have concluded that non-native and, especially, invasive species represent a threat to native flora and fauna communities (e.g. Levine and D'Antonio 2003, Stohlgren et al. 2006, Gavier-Pizarro et al. in press). Exotic species can cause habitat modifications that promote the establishment of other non-native species (e.g. Von Holle et al. 2006). Among vascular plants, New England exhibits one of the globally highest levels of non-native species (30.5% of the species total is non-native; Vitousek et al. 1996). The proportion of non-native species is frequently used as one metric contributing to composite measures of biological integrity (e.g. U.S. EPA 2002; Miller et al. 2006). However, biological integrity indices have not yet been developed for CACO ecosystems.

Benchmarks

An appropriate benchmark for a NPS unit – albeit one that is today unattainable – might be an absence of invasive (or even non-native) species. More pragmatic benchmarks for assessing the future status of invasive species at CACO will likely either address (a) the number of invasive present in the Park (e.g. no increases, or even reductions, in the number of species present), and/or (b) the areas infested by these taxa (e.g. stable or decreasing area colonized by invasive plant species). With the exceptions of (i) black locust (*Robinia pseudoacacia*), for which the 1970s distribution is known (Von Holle et al. 2006), and restoration-mediated changes in the distribution of invasive salt marsh plant species (Smith et al. 2009), there appear to be no published historical data that could serve as baselines for comparing the current abundance and/or distribution of non-native or invasive species in the CACO area.

Condition

Status

Flora. In Massachusetts, 66 plant species are listed as being invasive, likely invasive or potentially invasive (MIPAG 2009, USDA 2009). Of these, 30 species have been recorded at CACO – 21 of these are invasive

Flora & fauna: non-native & invasive species, continued

or likely invasive, while the others have another designation (Table 10.1). This total represents 2% of CACO plant species listed in NPSpecies database. Fifteen of the 30 CACO species are invasive, six are likely invasive, and an additional nine were evaluated for invasiveness but they did not meet the necessary criteria to list them as invasive; these species were therefore labeled as likely invasive or potentially invasive at the time of evaluation (MIPAG 2009). According to the Center for Invasive Species and Ecosystem Health (2010) Barnstable County has a recorded 73% of the total number of 'invasive' plant species in Massachusetts. However, these figures clearly use a different definition for 'invasive' since the state total is 488.

Wetland invasive species recorded in CACO include *Phragmites australis* (common reed) and *Lythrum salicaria* (purple loosestrife). These species were found in 26% and 4%, respectively, of 336 dune slack wetlands surveyed in 2003-2004 (Smith and Hanley 2005). At least seven freshwater ponds (Long, Round, Snow, Ryder, Great Ponds, Bennett and Herring Ponds) have been invaded by *Phragmites*. Control of populations of this species has been partially successful in some of these ponds – a criterion for success being pond water levels that are high enough to ensure continued inundation of broken *Phragmites* stems (Smith 2003).

Invasive species are sparsely represented in CACO's forested vernal wetlands (Smith et al. 2006). Out of 109 surveyed wetlands, common reed and purple loosestrife were found at only three and one sites, respectively. Another non-native species, large grey willow (*Salix cinerea*), was present in five wetlands. The invasive status of this species is unclear – it is not recognized as an invasive taxon by MIPAG (2009; Table 10.1).

Early stages of tidal restoration to the Hatches Harbor salt marsh have resulted in a change in the spatial distribution, but not the overall abundance, of *Phragmites* populations (Smith et al. 2009). Similarly, partial restoration of tidal flow in the East Harbor system has resulted in a decrease in the *Phragmites* population of the Moon Pond wetlands (Portnoy et al. 2007). Implementation of restoration projects at other tidally restricted sites will likely result in changes in abundance and/or distribution of *Phragmites* populations (see also Topic 24- Tidal Restrictions).

Black locust is one of the terrestrial invasive plant species listed for CACO (Table 10.1). This nitrogen-fixing species is regarded as one of the 100 most aggressive woody plant invaders globally (Cronk and Fuller 2001). Martin (2001, cited by Von Holle et al. 2006) ranked *R. pseudoacacia* as one of the ten most significant non-native species at CACO in terms of its potential impact on indigenous plant communities. It is shade intolerant and tends to be associated with disturbed areas, including former homesteads (Von Holle et al. 2006). There were 129 stands of black locust (covering 305 acres) within

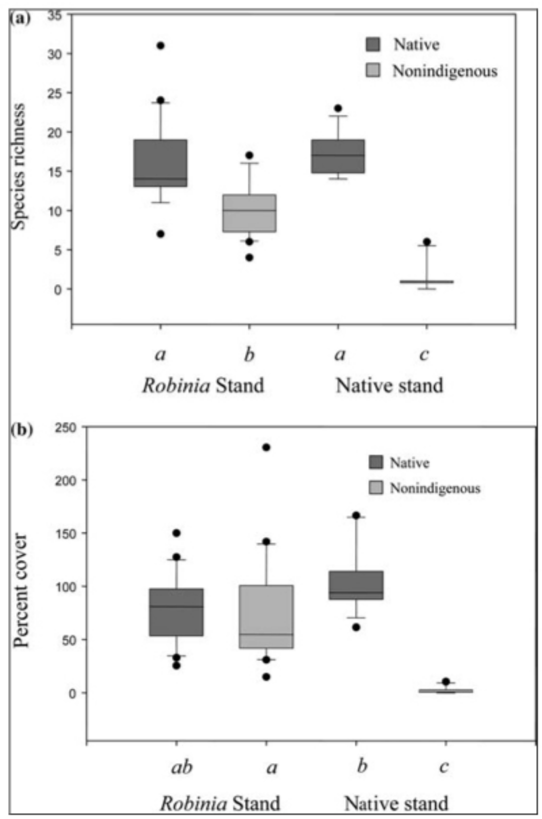


Figure 10.3. Species richness (a) and cover (b) for non-native and native plant species in black locust and native stands. Data with different subscripts are significantly different (based on Tukey-Kramer test, p<0.05). (Figure from Von Holle et al. 2006, used with permission).

Table 10.1. Invasive status of plant species that have been documented as being present at CACO. (Data source: MIPAG 2009).

Common Name	Scientific Name	MIPAG status
Autumn-olive	*Elaeagnus umbellata*	Invasive
Black locust	*Robinia pseudoacacia*	Invasive
Common buckthorn	*Rhamnus cathartica*	Invasive
Common mullein	*Verbascum thapsus*	Do not list at this time
Common privet	*Ligustrum vulgare*	Do not list at this time
Common reed	*Phragmites australis*	Invasive
Creeping buttercup	*Ranunculus repens*	Likely Invasive
Cypress-spurge	*Euphorbia cyparissias*	Likely Invasive
Dwarf honeysuckle	*Lonicera xylosteum*	Do not list at this time
European barberry	*Berberis vulgaris*	Likely Invasive
Garlic mustard	*Alliaria petiolata*	Invasive
Hair fescue	*Festuca filiformis*	Likely Invasive
Japanese barberry	*Berberis thunbergii*	Invasive
Japanese honeysuckle	*Lonicera japonica*	Invasive
Japanese knotweed	*Polygonum cuspidatum*	Invasive
Morrow's honeysuckle	*Lonicera morrowii*	Invasive
Multiflora rose	*Rosa multiflora*	Invasive
Paleyellow iris	*Iris pseudacorus*	Invasive
Pickerel weed	*Pontederia cordata*	Invasive
Purple loosestrife	*Lythrum salicaria*	Invasive
Reed canarygrass	*Phalaris arundinacea*	Invasive
Rugosa rose	*Rosa rugosa*	Do not list at this time
Scotch broom	*Cytisus scoparius*	Do not list at this time
Sheep-fescue	*Festuca ovina*	Do not list at this time
Spotted knapweed	*Centaurea biebersteinii*	Likely Invasive
Tartarian honeysuckle	*Lonicera tatarica*	Likely invasive
Tree of heavan	*Ailanthus altissima*	Invasive
Water cress	*Rorippa nasturtium-aquaticum*	Do not list at this time
White mullberry	*Morus alba*	Do not list at this time
White poplar	*Populus alba*	Do not list at this time

CACO in 1991. Between the 1970s and 2002, 81% of 53 surveyed stands decreased in area (Figure 10.2). This is thought be a result of the increase in forest cover on the outer Cape since abandonment of agriculture, as well as the impact of extreme storms (Van Holle et al. 2006). Black locust stands act as focal areas for the establishment of non-native species (Figure 10.3). Species richness of exotic taxa in black locust stands was approximately 10 times that of native stands, while exotics cover was over 50 times greater. Richness and cover of native species, however, did not differ significantly between *Robinia*-dominated and native-dominated patches.

Fauna. Ten of the 71 fish species (13%) observed in CACO are native transplants and one species (1%), the brown trout, is considered an exotic (Table 10.2).

An additional 20 species (1 bird, 2 fish, 4 reptiles, 10 invertebrates [aquatic and marine], and 3 plants) that are considered either native transplants or exotics have been

Flora & fauna: non-native & invasive species, continued

recorded in the vicinity of the park (Table 10.3). These species could represent new and emerging threats to the park's native flora and fauna communities.

Forest Pests: The USDA tracks 71 forest pests in the United States (USDA 2008). Thirty of these pests are present in Barnstable County and two of these (the Columbian timber beetle and Chestnut Blight) are considered to have an extreme risk of infestation based on the basal volume of host plant species. Another 12 species have a moderate risk of infestation. There are an additional 10 species that are not found in Barnstable County, but the risk of infestation is either extreme or moderate, indicating that if the range of these pests expands into Barnstable County the forests of CACO could be at risk of infestation from these species. For more information, see Topic 13- Forest Health.

Trends

Black locust stands have been decreasing in area since at least the 1970s. For other invasive species, data limitations prevent assessment of trends in the distribution and abundance of these taxa at CACO.

Factors influencing non-native & invasive species

- Natural spread and human-mediated introductions of non-native and, especially, invasive species represent a persistent threat to the native flora and fauna of the area.

Table 10.2. Nativity status of aquatic faunal species that have been documented as being present at CACO. Nativity status is as identified the USGS Nonindigenous Aquatic Species Database (USGS 2009). Native transplants are species that are native to North America but have been introduced to areas outside of their original range.

Common Name	Scientific Name	Nativity Status
Fish		
Alewife	*Alosa pseudoharengus*	Native Transplant
Banded killifish	*Fundulus diaphanus*	Native Transplant
Brook trout	*Salvelinus fontinalis*	Native Transplant
Brown Trout	*Salmo trutta*	Exotic
Chain pickerel	*Esox niger*	Native Transplant
Largemouth Bass	*Micropterus salmoides*	Native Transplant
Rainbow Trout	*Salmo gairdnerii*	Native Transplant (stocked)
Smallmouth bass	*Micropterus dolomieui*	Native Transplant
Threespine stickleback	*Gasterosteus aculeatus*	Native Transplant
White perch	*Morone americana*	Native Transplant
Yellow perch	*Perca flavescens*	Native Transplant
Invertebrate		
Green Crab	*Carcinus maenas*	Exotic
Asian shore crab	*Hemigrapsus sanguineus*	Exotic

Table 10.3. Invasive aquatic species that have been documented in Barnstable County, MA and may be present in CACO. Invasive status: E: Exotic; NT: Native transplant. Native habitat: F: Freshwater; M: Marine; F/M: Freshwater & Marine. (Data sources: USGS 2009, 2010).

Common Name	Scientific Name	Invasive Status and native habitat	Location observed
Birds			
European starling	*Sturnus vulgaris*	E	Entire USA
Fish			
Western mosquitofish	*Gambusia affinis*	NT (F)	Quashnet River on Cape Cod
Atlantic salmon	*Salmo salar*	NT (F/M)	Stocked in several ponds (Cliff, Peters, and Sheep Ponds)
Reptiles			
Coastal Plain Cooter	*Pseudemys concinna floridana*	NT (F)	Mashpee
Red-eared Slider	*Trachemys scripta elegans*	NT (F)	Orleans
Aquatic Invertebrates			
Colonial tunicate	*Didemnum vexillum*	E (M)	Pleasant Bay, Chatham
Freshwater jellyfish	*Craspedacusta sowerbyi*	E (F)	Long Pond and others
Clinging jellyfish	*Gonionemus vertens*	E (M)	Atlantic Ocean, Woods Hole
Calanoid copepod	*Eurytemora affinis*	NT (F/M)	Waquoit Bay
Dungeness crab	*Cancer magister*	NT (F/M)	Atlantic Ocean off Gloucester
Entoproct	*Barentsia benedeni*	E (M)	Atlantic Ocean off MA
Orange sheath tunicate	*Botrylloides violaceus*	E (M)	Pleasant Bay
Golden star tunicate	*Botryllus schlosseri*	E (M)	Atlantic Ocean at Woods Hole
Asian tunicate	*Styela clava*	E (M)	Cape Cod Bay, Buzzards Bay, Woods Hole
Plants			
Pond water-starwort	*Callitriche stagnalis*	E (F)	Barnstable County
Hydrilla	*Hydrilla verticillata*	E (F)	Long Pond, South Yarmouth
European water-clover	*Marsilea quadrifolia*	E (F)	Woods Hole

11. Terrestrial vegetation assemblages

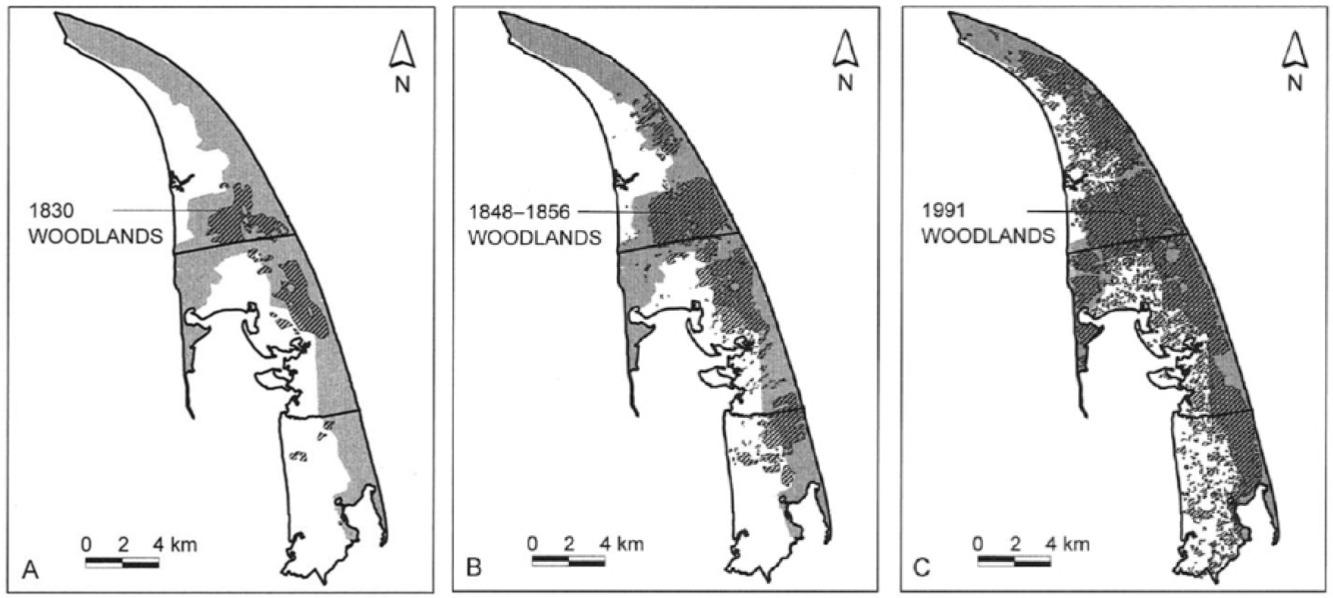
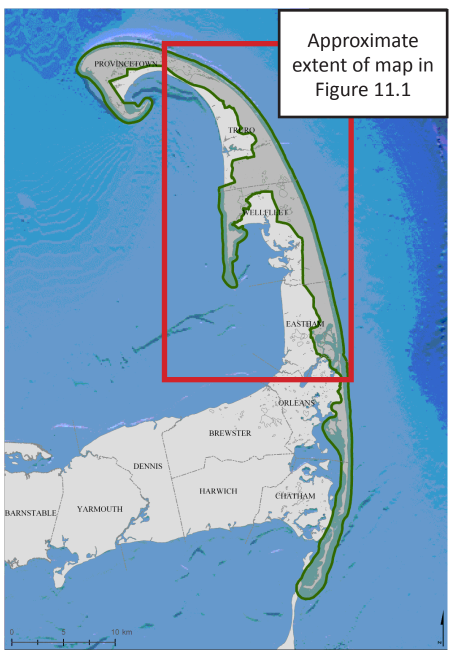


Figure 11.1. Distribution of woodlands on outer Cape Cod, from 1830 to 1991. (Figures from Eberhardt et al. 2003).



Key Points

- Contemporary vegetation assemblages on Cape Cod reflect historic patterns of land-use, as well as geomorphology and surficial geology.
- Forest cover on the Cape has been increasing since the 1800s following abandonment of agriculture. Increases in the basal area of several forest tree species at monitoring sites over the past quarter century reflect this trend of forest expansion.
- Heathland and grassland communities are currently uncommon at CACO. Their restoration will require management strategies that mimic the effects of past agricultural activity.
- Baseline data on dune vegetation have recently been collected. Environmental variables related to salt and wind influence are the best predictors of dune assemblage composition.
- Metric value classes that could be used to define condition 'ranks' or 'grades' have not yet been published for terrestrial vegetation assemblages at CACO.

Assessment statement

Unknown. Metric value classes to quantify condition have not yet been published; see Benchmarks, below.

Rationale

Forests are currently the most common vegetation assemblage within CACO, in terms of area occupied and biovolume (Smith et al. 2004). Dunes represent approximately one third of CACO's area (Smith and Hanley 2005). Both ecosystems reflect the legacy of past land use practices. CACO was predominantly wooded prior to clearance for agriculture and logging in the mid-1800s. By mid century, approximately 44% of the area of sand-plain woodlands was being used for agriculture and pasture, while 42% was repeatedly logged but not cleared (Eberhardt et al. 2003). Although agriculture has been largely abandoned for over a century, historical patterns of land use continue to be a factor influencing the distribution and abundance of many forest species (Motzkin et al. 2002). Forests are an important indicator of overall ecological health at CACO since they occupy a broad range of landscape conditions (Smith et al. 2004).

Most of the dune habitat at CACO is located in the Province lands. Here, dunes are largely the product of deforestation by European settlers (Smith 2006). Dunes are a valuable aesthetic resource for Park visitors, as well as providing habitat for many plant and animal species. The Maritime Dune community is also recognized as a critical habitat in the state (MA NHESP). Changes in plants assemblage structure and extent of cover influence the magnitude of dune migration.

Benchmarks

Research has documented the pattern of increasing forest cover on Cape Cod from the 1800s until the present time (Figure 11.1). Vegetation assemblage data from forested sites are available from the 1980s. These data have been used to estimate trends in species composition and area. More recently, development of a proposed forest monitoring protocol has yielded data that include species composition, relative abundance and tree size (Smith et al. 2004). Other metrics being used in forest monitoring at CACO include: tree growth, canopy cover, recruitment, litter depth and abundance of coarse woody debris. Spatial and temporal comparisons of individual metrics will contribute to future characterizations of forest condition at CACO. While some data analyses have been published (see below), forest condition assessment will clearly involve further investigation and definition of appropriate benchmarks and reference conditions. We make no attempt here to propose additional benchmarks beyond those already published by Smith et al. 2004. Data are also available documenting patterns of gypsy moth infestations of oaks and other species since the 1980s.

Dune vegetation data collected in 2005 provide a baseline from which to evaluate future trends in this assemblage. Historical dune vegetation data, while quite rich, are generally of limited value in evaluating trends because these older data were typically not geo-referenced with sufficient precision to permit comparisons with contemporary data (Smith 2006).

Condition

Status & Trends

Forest Vegetation Assemblages: As noted above, past land-use continues to exert a strong influence on current vegetation patterns. For example, the following assemblage types, all having open understories, tend to be found today in areas previously used for agriculture: Pine-Bearberry, Pine-Hairgrass, and Pine-Oak-Sedge. Other vegetation assemblages (e.g. Pine-Oak-Huckleberry) have dense shrub understories and typically occur in former woodlots (Eberhardt et al. 2003). Geomorphology and surficial geology also influence plant assemblage structure on Cape Cod. For example, "Oak–Pine–Maple and Oak–Pine–Huckleberry associations occur disproportionately on moraines, Pitch Pine–Scrub Oak and Pine–Oak–Hairgrass types are characteristic of outwash areas, whereas Pitch Pine–Hairgrass, Bearberry–Scrub Oak and Poverty Grass–Hairgrass . . . types are characteristic of beach/dune deposits. The Cedar–Bayberry–Honeysuckle association typically occurs on lake-bottom

Terrestrial vegetation assemblages, continued

deposits with relatively fine textured soils and high cation concentrations" (Motzkin et al. 2002).

Forest assemblages continue to change at CACO as a result of succession. For example, Pitch Pine (*Pinus rigida*) is gradually being replaced by more shade-tolerant species such as Black Oak (*Q. velutina*) and White Oak (*Q. alba*). Fire suppression has contributed to this successional process (Smith et al. 2004).

Although fire appears to have been a major disturbance process pre-European settlement, the fires that have occurred occasionally since that time have primarily "influenced overstory composition and structure in continuously wooded areas and have not eradicated the major patterns of vegetation land use" (Eberhardt et al. 2003).

One additional factor influencing some forest species, in particular the oaks, is infestation by gypsy moth which can result in defoliation. The last major infestation at CACO was in the early 1980s. The infestation influenced stand dynamics and successional patterns over the decade following that event. However, the effect of defoliation became diluted over the following decade (Barron and Patterson 2008). (For more information on forest health see Topic 12- Forest Health: Disease Incidence.)

As of 2004, there were 39 forest monitoring sites at CACO representing 8 assemblage types (Smith et al. 2004). Sampling in 2002-2003 documented a total of 11 over-story species (trees), 65 taxa in the near-ground layer and 79 taxa in the ground layer (Smith et al. 2004). The four most common tree species were: Pitch Pine, Black Cherry (*Prunus serotina*), Black Oak and Red Maple (*Acer rubrum*) (Figure 11.2).

Changes in forest species composition and abundance (basal area) have been compared over the period from the early 1980s to the early 2000s (Barron and Patterson 2008).

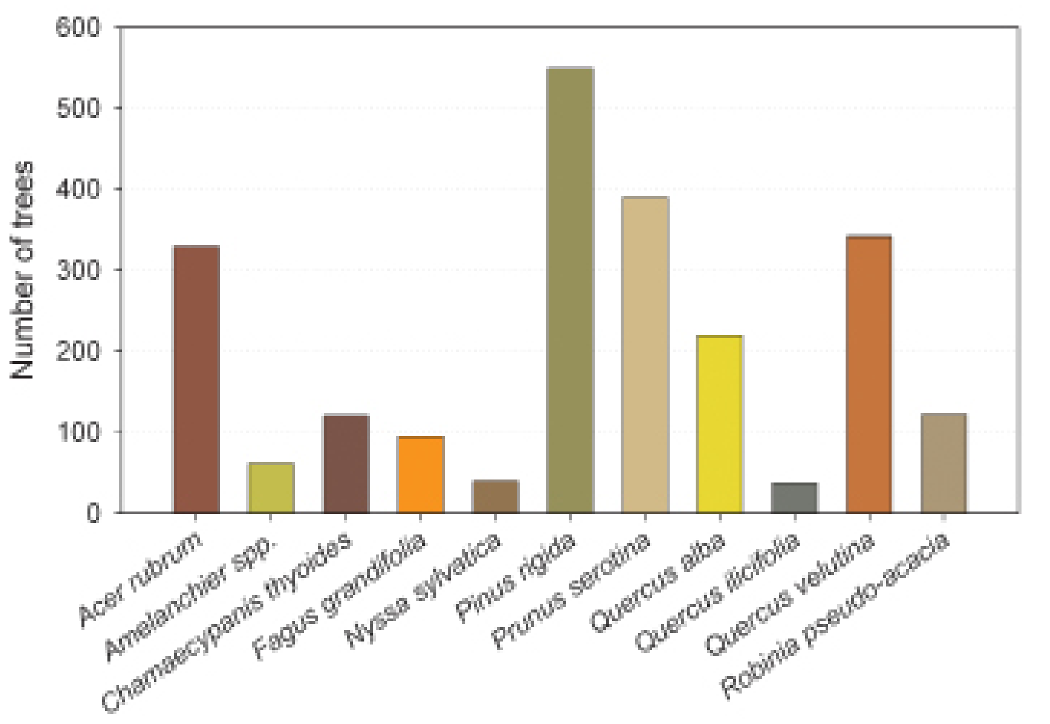


Figure 11.2. Number of trees by species across all sites sampled in 2003. (Figure adapted from Smith et al. 2004).

Pitch Pine exhibited a significant increase in basal area at 75% of study sites (N=16), while Black Oak increased significantly at only 12% of sites. White Oak basal area did not increase at any site. There were no significant decreases in basal area at any site for any of these three species.

Metric class values which could be used to define or grade forest condition at CACO do not appear to have been published.

Heathland and grassland communities: These assemblages are currently uncommon at CACO. Their restoration will require management that mimics former agricultural practices, for example removal of woody vegetation and exposure of mineral soil by mechanical disturbance, grazing and /or fire (Eberhardt et al. 2003).

Dune Vegetation Assemblages: As noted above, historical data on dune vegetation were generally not well geo-referenced and consequently contribute little to an understanding of vegetation dynamics over the past several decades. (Smith 2006). Nevertheless, historical data have contributed to an analysis of dune slack wetlands (Smith et al. 2008; see Topic 16). More recent data provide a baseline from which to evaluate future trends in this assemblage (Smith 2006). Key findings of this study include:

- 44 vascular plant species were recorded.
- Environmental variables related to salt and wind influence best explained plant assemblage composition.
- Species richness per site was inversely related to soil pH.
- Younger sites were less speciose that older sites.
- The amount of salt spray was inversely related to elevation and distance to the ocean.
- Large changes in ground surface elevation were observed primarily at bluff sites, whereas inland sites exhibited little change.
- Because of the slow rate of change in dune plant communities, future monitoring at approximately decadal intervals will probably be sufficient to document trends in this system, although new sites will need to be established to compensate for sites that are lost through erosion.

Metric class values which could be used to define or grade the condition dune vegetation at CACO have not yet been published.

Factors influencing terrestrial vegetation assemblages

- Exotic and invasive flora and fauna.
- Plant pests and pathogens.
- Natural succession.
- Climate change and hydrologic shifts.

Hog Island, Pleasant Bay. Photo courtesy M.J. James-Pirri, URI.

12. Forest health: disease incidence

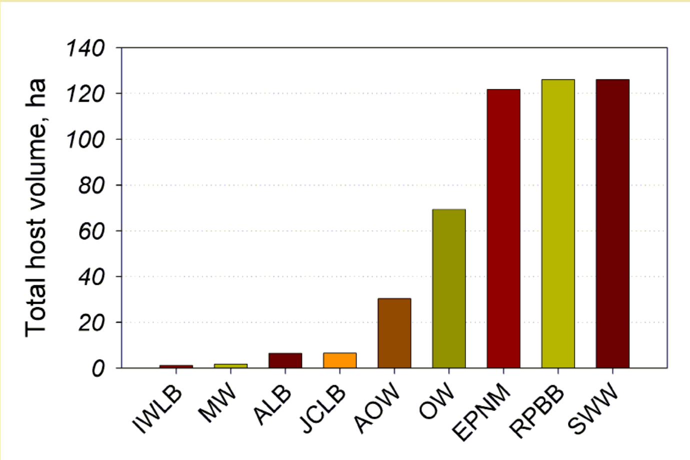


Figure 12.1. Forest susecptibility to various pests for Barnstable county, displayed as total potential host volume, in hectares. IWLB=Imported willow leaf beetle; MW=Mimosa webworm; ALB=Asian longhorned beetle; JCLB=Japanese cedar longhorn bettle; AOW=Asiatic oak weevil; OW=Oak wilt; EPNM=European pine needle midge; RPBB=Red-haired pine bark beetle; SWW=Sirex wood wasp. Data courtesy of the USDA Forest Service, Alien Forest Pest Explorer, available: www.fs.fed.us/ne/morgantown/4557/AFPE/

More information from the U.S. Forest Service:

An animated display of the spread of gypsy moth

www.fs.fed.us/ne/morgantown/4557/AFPE/animations/gm_animation.gif

Browntail Moth fact sheet

USDA Forest Service. 2004. Pest Alert- Browntail Moth factsheet. Northeast Area. NA-PR-04-02. www.fs.fed.us/na/durham/foresthealth/pdf/browntail_moth2.pdf

Key points

- Non-indigenous forest pests could pose threats to CACOs forest.
- Published information on the spatial and temporal patterns of disease incidence in CACO trees and shrubs is unavailable.

Assessment statement

Signficant concern.

Rationale

Published information on the incidence of disease agents and their impacts on CACO trees and shrubs is sparse, although it is known that *Quercus* spp. have sporadically been defoliated by gypsy moths during the last several decades . The forest health monitoring protocol prepared for CACO does not address forest pests (Smith et al. 2004).

The US Forest Service maps the distribution and susceptibility of forests to infestation by a variety of non-indigenous forest pest species. Susceptibility of forests is based on the basal area of preferred host species (tree and shrubs). Several of these insect pests have distribution ranges that include Barnstable County, MA (Table 12.1). Additionally, there are several other pests where Barnstable County forests have a high or medium susceptibility to infestation. If the distribution of the pests expands to Barnstable County, these insects could become potential threats to the forests of CACO (Table 12.2).

Benchmarks

Undefined.

Condition

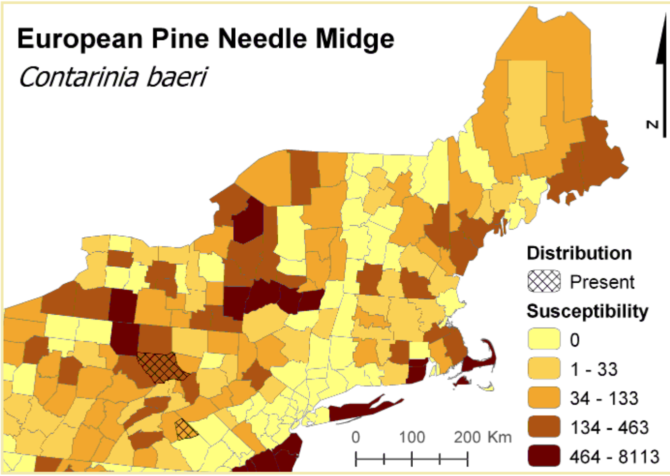
Status

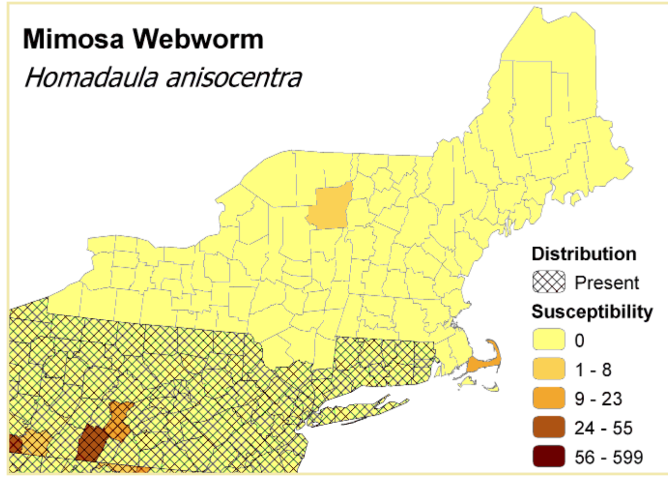
As mentioned above, quantitative data on the incidence of tree and shrub pests at CACO are not available. The following discussion therefore describes the broader (county-level) distributions of insect and other pests, and the potential susceptibility of CACO forests and woodlands to these disease agents.

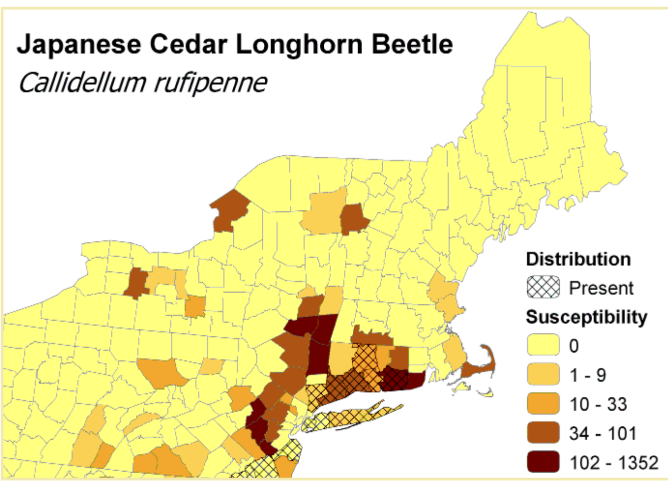
Table 12.1. Current threats to CACO forests by non-indigenous insect pests and diseases that are tracked by the US Forest Service Alien Forest Pest Explorer. Distribution information as of July 2009. Forest susceptibility based on host species (tree) volume.

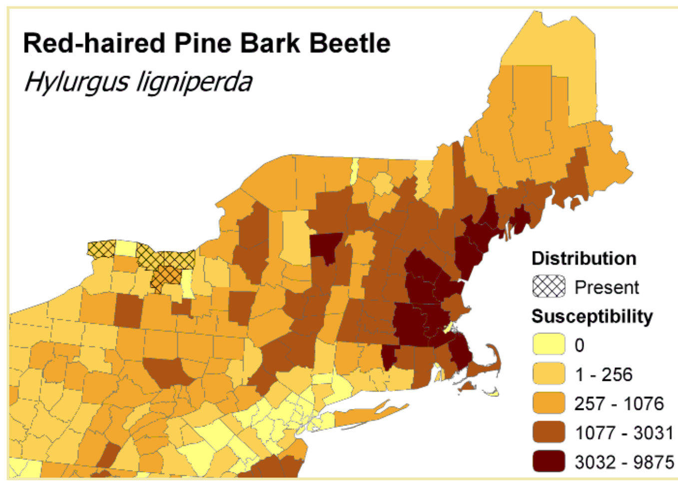
Common Name	Latin Name	Presence in Barnstable County	Forest susceptibility in Barnstable County
Pine Shoot Beetle	*Tomicus piniperda*	Yes	high
White Pine Blister Rust	*Cronartium ribicola*	Yes	high
Browntail Moth	*Euproctis chrysorrhoea*	Yes	medium
Gypsy Moth	*Lymantria dispar*	Yes	medium
Phytophthora Root Rot	*Phytophthora cinnamomi*	Yes	medium
Poplar and Willow Borer	*Cryptorhynchus lapathi*	Yes	medium
Willow Scab	*Venturia saliciperda*	Yes	medium
Winter Moth	*Operophtera brumata*	Yes	medium
Calico Scale	*Eulecanium cerasorum*	Yes	low
European Pine Sawfly	*Neodiprion sertifer*	Yes	low
Introduced Pine Sawfly	*Diprion similis*	Yes	low
Japanese Beetle	*Popillia japonica*	Yes	low
Oystershell Scale	*Lepidosaphes ulmi*	Yes	low
Pine False Webworm	*Acantholyda erythrocephala*	Yes	low
Satin Moth	*Leucoma salicis*	Yes	low
Beech Bark Disease	*Cryptoccocus fagisuga Lind.*	Yes	none
Birch Leafminer	*Fenusa pumila*	Yes	none
Black Vine Weevil	*Otiorhynchus sulcatus*	Yes	none
Chestnut Blight	*Cryphonectria parasitica*	Yes	none
Cryptodiaporthe Canker	*Cryptodiaporthe populea*	Yes	none
Dogwood Anthracnose	*Discula destructiva*	Yes	none
Dutch Elm Disease	*Ophiostoma novo-ulmi*	Yes	none
Eastern Spruce Gall Adelgid	*Adelges abietis*	Yes	none
Elm Leafbeetle	*Xanthogaleruca luteola*	Yes	none
Elm Leafminer	*Fenusa ulmi*	Yes	none
Elongate Hemlock Scale	*Fiorinia externa*	Yes	none
European Pine Shoot Moth	*Rhyacionia buoliana*	Yes	none
Green Spruce Aphid	*Elatobium abietinum*	Yes	none
Hemlock Woolly Adelgid	*Adelges tsugae*	Yes	none
Juniper Scale	*Carulaspis juniperi*	Yes	none
Pear Thrips	*Taeniothrips inconsequens*	Yes	none
Poplar sawfly	*Trichiocampus viminalis*	Yes	none
Smaller European Elm Bark Beetle	*Scolytus multistriatus*	Yes	none

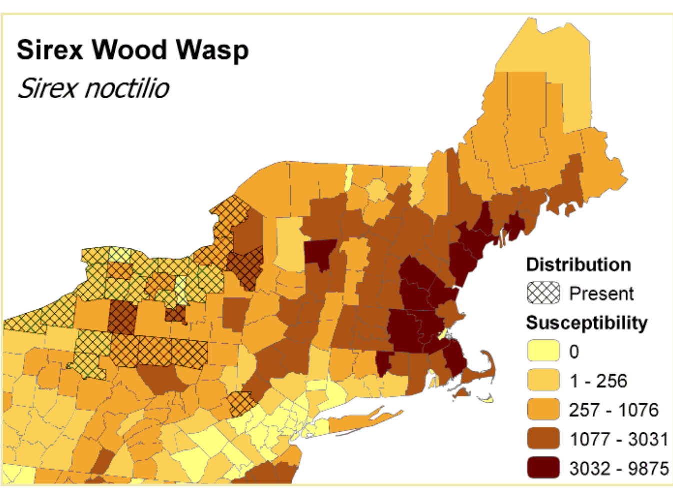
Forest health: disease incidence, continued

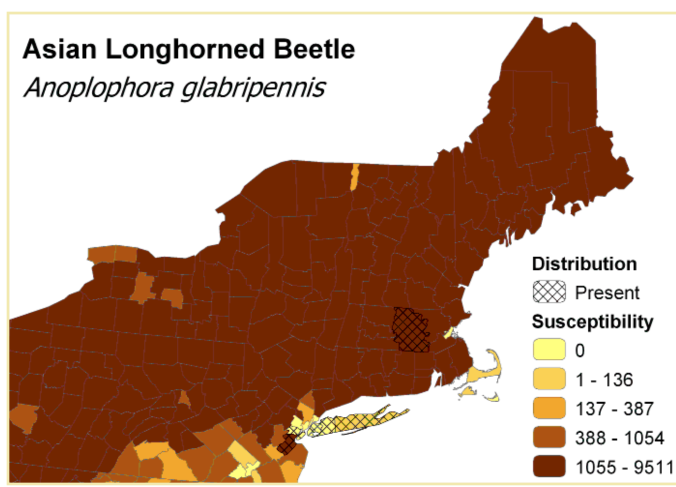


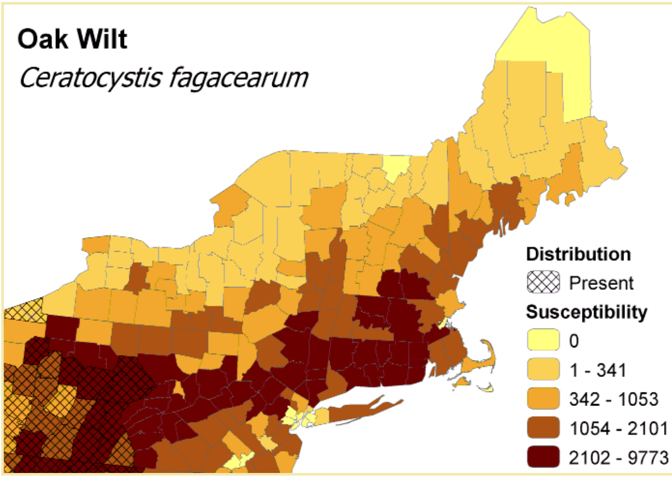


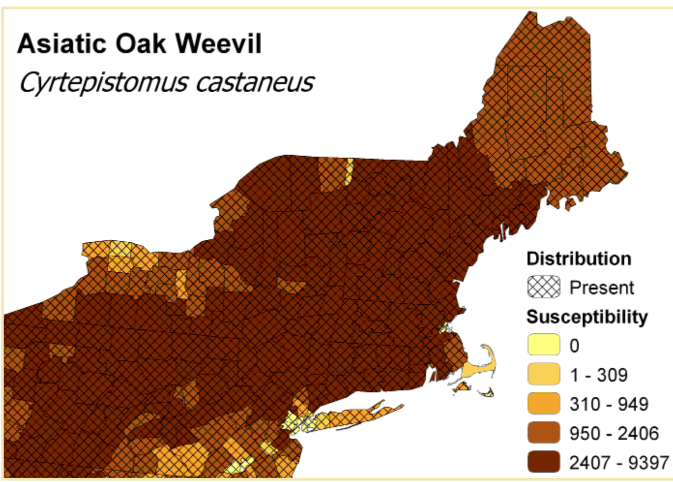












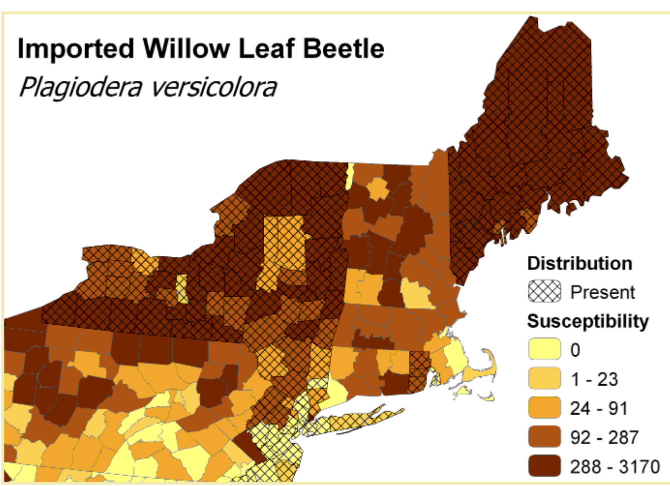


Figure 12.2. Current estimates of distribution of forest pests considered to be potential emerging threats for CACO (crosshatched areas), and area-normalized forest susceptibility, displayed as a pest's host volume/area of each county, in m^3/ha (color coding). Cross-hatched areas display counties where each pest has already been documented. The distribution data are derived from a variety of sources and represent a best estimate of the geographical distribution of established populations.

Data courtesy of the USDA Forest Service, Alien Forest Pest Explorer, available:

www.fs.fed.us/ne/morgantown/4557/AFPE/

For more information on several of these pests, visit:

www.umassgreeninfo.org/fact_sheets/index.html

Forest health: disease incidence, continued

Table 12.2. Potential emerging threats to CACO forests by non-indigenous insect pests and diseases that are tracked by the US Forest Service Alien Forest Pest Explorer. Distribution information as of July 2009. Forest susceptibility based on host species (tree) volume.

Common Name	Latin Name	Presence in Barnstable County	Closest State where found	Forest susceptibility in Barnstable County
European Pine Needle Midge	*Contarinia baeri*	No	PA	extreme
Mimosa Webworm	*Homadaula aniso-centra*	No	RI	high
Japanese Cedar Long-horn Beetle	*Callidiellum ru-fipenne*	No	CT	high
Mediterranean Pine Engraver Beetle	*Orthotomicus erosus*	No	CA	high
Red-haired Pine Bark Beetle	*Hylurgus ligniperda*	No	NY	high
Sirex Woodwasp	*Sirex noctilio*	No	NY	high
Asian Longhorned Beetle	*Anoplophora gla-bripennis*	No	MA	medium
Cherry Bark Tortrix	*Enarmonia formo-sana*	no	OR	medium
European Mistletoe	*Viscum album*	no	CA	medium
Oak Wilt	*Ceratocystis fagacearum*	No	PA	medium
Asiatic Oak Weevil	*Cyrtepistomus cas-taneus*	No	MA	low
Imported Willow Leaf Beetle	*Plagiodera versi-colora*	No	NY, ME	low
Laurel Wilt Disease	*Raffaelea lauricola*	No	SC	low
Sudden Oak Death	*Phytophthora ramo-rum*	No	CA	low

Forest health at CACO may be affected by the future spread of insect pests and other disease agents to eastern Barnstable County. Multiple factors could influence this process – a full discussion of these factors is beyond the scope of this report.

Figure 12.1 summarizes estimated susceptibility to pest threats, and Figure 12.2 presents a series of maps displaying recent distributions of pest species considered to be potential emerging threats (Table 12.2).

Barnstable County has been rated as having a high risk of infestation by two non-indigenous pests that are present in the county, the pine shoot beetle and white pine blister rust (Table 12.1). An additional six species are present in Barnstable County and the susceptibility of the forests to infestation is rated as medium, indicating that these pests could be threats to the forests of CACO. There is one species (European Pine Needle Midge, *Contarinia baeri*) whose range does not include Barnstable County, but the risk of infestation was rated extreme; and there were an additional five species whose risk of infestation was rated as high (Table 12.2). If these species ranges expand into the County, then these could be potential emerging threats to the forests of the Park.

The browntail moth (*Euproctis chrysorrhoea*), a native of Europe, was first found in Massachusetts in 1897. The moth quickly spread throughout the Northeast, but had begun to decline by the 1920s. Browntail moth caterpillars feed on leaves of many hardwood trees and shrubs, such as apple, oak, cherry, hawthorn, serviceberry, rugosa rose, and bayberry . In Massachusetts, they may completely defoliate beachplum (*Prunus maritima*) and black cherry (*Prunus serotina*) when population levels are high. Moreover, the urticating hairs that present on the caterpillars can cause a severe skin rash making this insect a public health issue.

Currently, the distribution of the moth is limited to a few islands in Casco Bay, ME, and the coastal dunes of CACO, where they are considered relict populations.

There have been two recent forest pest alerts for Massachusetts, the Asian longhorned beetle (*Anoplophora glabripennis*) and the viburnum leaf beetle (*Pyrrhalta viburni*). The Asian longhorned beetle was first detected in Massachusetts in 2008 in Worcester County and there is a state eradication program for this insect. The Asian longhorned beetle is a pest of hardwood trees including maple, birch, horse chestnut, plane-tree, poplar, willow, and elm trees. Other susceptible trees include ash (especially green ash), silk tree, hackberry, and mountain-ash. The beetle causes damage by tunneling into the trunk and branches of trees, disrupting sap flow that weakens and eventually kills infected trees. Forest susceptibility in Barnstable County was rated as medium (Table 12.2); however, this could be an emerging threat to hardwood trees in CACO if the range of the beetle expands from Worcester County.

The viburnum leaf beetle was first discovered in Massachusetts in 2004, in Berkshire County. In July 2008, new sightings of this introduced pest were reported in Bristol, Franklin, and Middlesex Counties. This insect is a pest of viburnum plants and heavy infestations can defoliate shrubs, cause dieback, and eventually kill plants. The distribution of the beetle appears to be spreading throughout Massachusetts and native viburnums, as well as ornamental plantings and nursery stock, could be at risk for infestation. Several species of *Viburnum* are present on the CACO NPSpecies list.

Trends

Browntail Moth: This invasive insect expanded through the Northeast in the late 19th century and then declined by the 1920s. Currently it exists in isolated populations in the coastal dunes of the park and is considered a relict population.

Gypsy Moth: This species first became established in the US in Massachusetts (USDA Forest Service 2009) and is known to have caused defoliation of oaks in the Park over the past several decades (Smith et al. 2004). Although the spread of this insect pest across the northeastern US has been well documented (USDA Forest Service 2009), detailed information on defoliation trends at CACO is not available.

Factors influencing forest health: disease incidence

- Forest health at CACO may be affected by the future spread of insect pests and other disease agents to eastern Barnstable County.
- Multiple factors could influence this process – a full discussion of these factors is beyond the scope of this report.

Hemispherical photo of a CACO forest site. Photo courtesy Steve Smith, CACO.

13. Terrestrial mammals: population dynamics

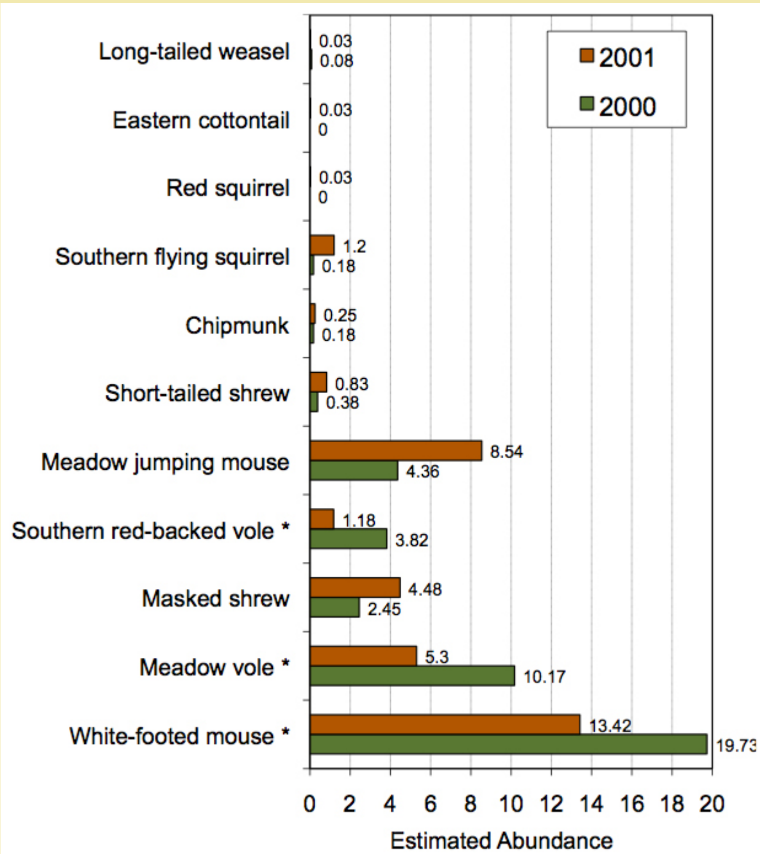


Figure 13.1. Mean estimated abundance for small mammal species, by year. Data are based on trapping survey. (Data source: Cook et al. 2006c).

Key Points

- Mammals interact in multiple ways with CACO's animal and plant communities. Large mammals exert significant predation pressure on shorebird species.
- Baseline data on small mammal abundance and habitat preferences are available from 2000 and 2001.
- Published data are not available to document temporal trends in population size.
- No terrestrial mammals are state- or federal- listed.

Assessment statement

Condition cannot be evaluated at this time.

Rationale

Mammals are an important component of CACO ecosystems. Through food-web interactions, mammals may impact populations of many species groups, including plants, insect pests, disease vectors, and some birds, including hawks, owls and piping plovers. Roman and Barret (1999) identified small mammals for possible inclusion in the long-term monitoring program at CACO.

Table 13.1. Mean estimated abundance for 11 small mammal species at CACO, by habitat. Bold entries indicate species for which there is a significant among-habitat difference (p≤0.05). Means with the same subscript are statistically insignificant from each other. (Table from Cook et al. 2006).

	Heath	Wet	Oak	Pine	Grass	Mean
All Species-summed	22.25_{1}	60.71_{2}	$51.11_{1,2}$	22.46_{1}	34.96_{1}	38.30
Rodents-summed	20.75_{1}	48.52_{3}	$47.79_{2,3}$	21.09_{1}	$33.02_{1,2}$	34.23
Shrews-summed	1.50_{1}	12.00_{2}	3.31_{1}	1.38_{1}	1.88_{1}	4.01
Peromyscus leucopus	$15.83_{2,3}$	$12.22_{1,2}$	28.09_{3}	$19.46_{2,3}$	7.30_{1}	16.58
Microtus pennsylvanicus	$4.60_{1,2}$	18.35_{3}	$4.06_{1,2}$	0.50_{1}	11.16_{2}	7.74
Sorex cinereus	1.13_{1}	11.00_{2}	2.56_{1}	0.69_{1}	1.69_{1}	3.41
Clethrionomys gapperi	0.00_{1}	0.00_{1}	12.33_{2}	0.06_{1}	0.13_{1}	2.50
Zapus hudsonius	0.06_{1}	17.75_{2}	0.00_{1}	0.00_{1}	14.43_{2}	6.45
Blarina brevicauda	0.38	1.00	0.75	0.69	0.19	0.60
Tamias striatus	0.25	0.00	0.00	0.81	0.00	0.21
Glaucomys volans	0.00_{1}	0.00_{1}	3.31_{2}	$0.13_{1,2}$	0.00_{1}	0.69
Tamiasciurus hudsonicus	0.00	0.06	0.00	0.00	0.00	0.01
Sylvilagus floridanus	0.00	0.00	0.00	0.00	0.06	0.01
Mustela frenata	0.00	0.13	0.00	0.00	0.06	0.04

P. leucopus - White-footed Mouse. *M. pennsylvanicus* - Meadow Vole. *S. cinereus* - Masked Shrew. *C. gapperi* - Southern Red-backed Vole. *Z. hudsonius* - Meadow Jumping Mouse. *B. brevicauda* - Short-tailed Shrew. *T. striatus* - Chipmunk. *G. volans* - Southern Flying Squirrel. *T. hudsonicus* - Red Squirrel. *S. floridanus* - Eastern Cottontail. *M. frenata* – Long-tailed Weasel.

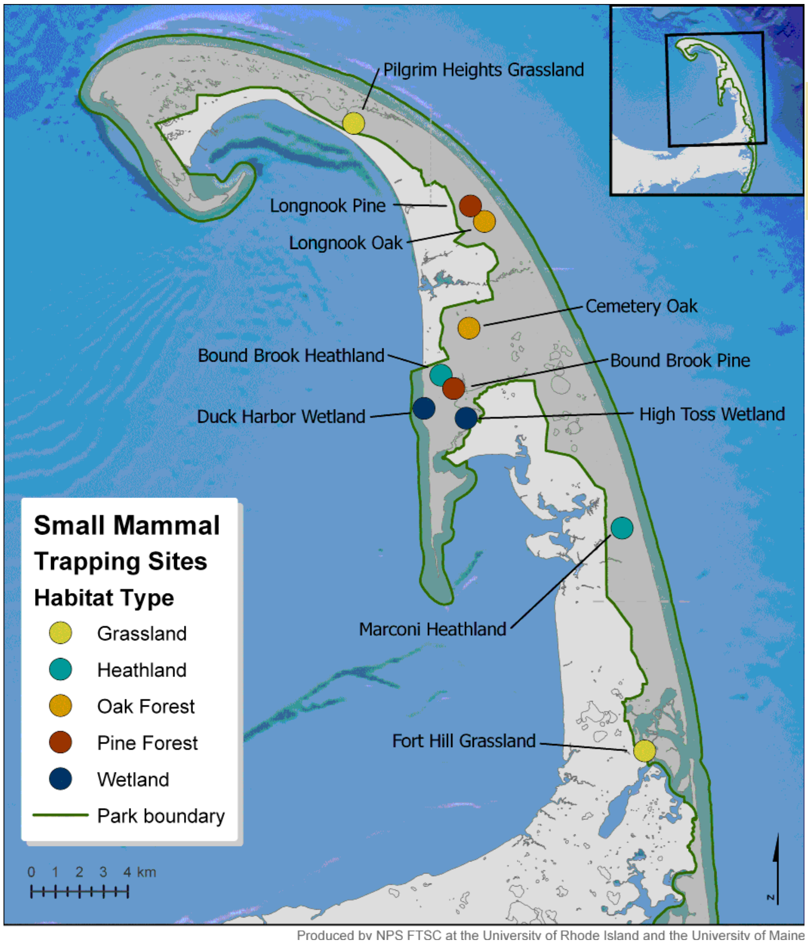


Figure 13.2. Small mammal trapping sites in 2000 and 2001. Map based on Cook et al. 2006c.

Benchmarks

Surveys in 2000 and 2001 provide some baseline data for assessing future trends in population size and relative abundance. There are no published benchmarks for expected population sizes at CACO.

Condition

Status & Trends

The study of Cook et al. (2006c) provides most of the currently published information on small mammal populations at CACO (Figure 13.1). A trapping survey was conducted in 2000 and 2001 at 10 sites (Figure 13.2). Eleven species were collected. For three species there were significant between-year differences in estimated abundance (Figure 13.1). Other findings from this study include::

- White-footed Mouse (*Peromyscus leucopus*), Meadow Vole (*Microtus pennsylvanicus*) and Southern Red-backed Vole (Clethrionomys gapperi). However, with just two years of data, population trends cannot be determined.
- Abundance of small mammal species varied by habitat, with numbers being highest in wetlands and oak forest (Table 13.1).
- Large terrestrial mammals, including Red Fox (*Vulpes vulpes*) and Coyote (*Canis latrans*) are significant predators of shorebirds at CACO. No published data appear to exist on population size or trends for these species.

Factors influencing terrestrial mammal populations

- Less frequent fires, resulting in reductions in herbaceous vegetation.
- Human-caused increases in populations of predators such as skunks and red foxes.
- Declines in native forage species as these are replaced by exotic plants.

14. Birds: assemblage structure & population dynamics

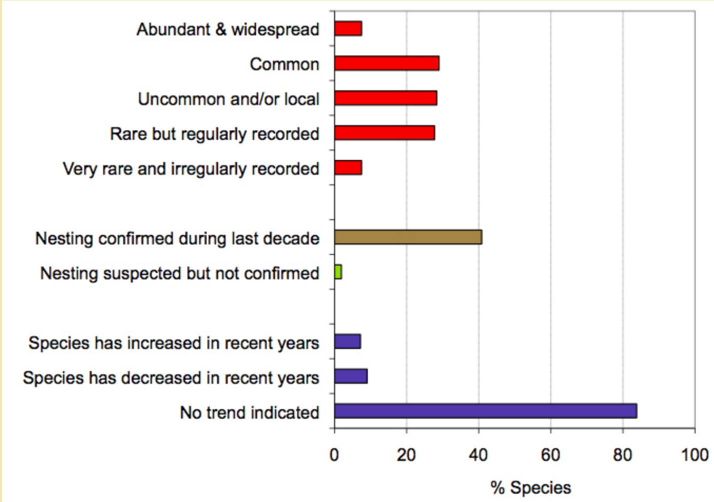


Figure 14.1. Selected population characteristics of Cape Cod bird species, as defined in the Checklist of Cape Cod Birds (Nikula 2008). According to this checklist, the total number of species recorded from the Cape is 322.

However, the NPSpecies database currently (2010) includes 376 bird species for CACO. Of these, 28% (107) are considered breeders at CACO, 47% (176) are migratory, 6% (22) are residents, and 19% (70) are considered vagrants.

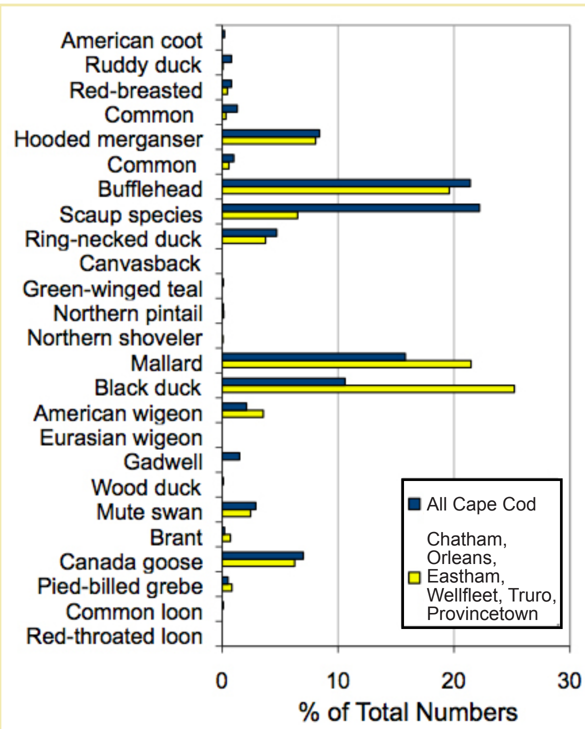


Figure 14.2. Relative abundance of 25 bird species recorded during surveys of Cape Cod lakes and ponds. Data are shown for the entire Cape and for Chatham, Orleans, Eastham, Wellfleet, Truro and Provincetown. (Data source: Nikula 2009)

Key Points

- CACO was nominated in 2001 as an Important Bird Area.
- 376 bird species have been recorded at CACO, including 28 state-listed taxa.
- In waterfowl surveys from 1984 through the present, six species (Black duck, Mallard, Bufflehead, Scaup, Hooded merganser and Canada goose) have been most abundant. Over this period, there were apparent declines in the abundance of some taxa, including Canvasback, Northern pintail and Scaup.
- CACO provides important habitat for several shorebird species. Numbers of nesting pairs of Piping plover have been relatively stable over the past decade. However, the number of other species has declined markedly.
- Grassland species have declined regionally and at CACO as open areas revert to forest. Grasshopper and Vesper sparrows were both historically present at CACO. However, the former appears to be now extirpated from the outer Cape, while the population of the latter has declined by over half in recent years.
- Overwash and changes in beach morphology, while natural processes, can have substantial impacts on shorebird species. Predation and habitat loss influence both shorebirds and other species.

Assessment statement

Significant concern – some species, only. See below for more information

Rationale

Birds are an important component of the Cape's biodiversity, with high 'public interest' value. CACO was nominated as an Important Bird Area in 2001. All of the state-listed rare species (endangered, threatened, special concern) have been recorded in the Park. The populations of several species have declined markedly at CACO and/or on the Cape in recent years. Many assemblages (or individual species within these assemblages) may serve as indicators of environmental condition (e.g. Erwin et al. 2002).

Benchmarks

The quantity and detail of population data varies among species. For the Cape, Christmas Bird Count data are available from 1951, for some species. We have found no published trend analyses from these data[1]. Surveys of lake and pond species extend from 1984 through the present. Shorebird surveys started in the 1990s. Data for other bird assemblages are less frequent. Spring census surveys of birds in Provinceton (Beech Forest) provide abundance data from 1982 through at least 2007 (Nikula 2010). For the Piping plover, the Federal goal for recovery of this species is a five-year average productivity of 1.5 fledged chicks per pair (Hake 2007). Survey data on raptors at Pilgrim Heights (Provincetown) are available since the late 1990s at www.hawkcount.org.

Condition

Status & Trends

The nomination of CACO as an Important Bird Area in 2001 was based, in part, on the following attributes (Massachusetts Audubon 2010). The Seashore:

- supports significant breeding populations of certain threatened and endangered species (e.g. terns, Piping plover, Vesper sparrow);
- supports important migratory and wintering habitat for large numbers of shorebirds, waterfowl, wading birds, and seabirds;
- provides significant breeding populations of many high conservation priority species;
- regularly supports 1,000 or more shorebirds (e.g. plovers, sandpipers, snipe, woodcocks, and phalaropes) at one time at a coastal site, during some part of the year, or a significant concentration of shorebirds at one time at a non-tidal site;
- regularly supports 500 or more waterfowl (e.g. loons, grebes, cormorants, geese, ducks, coots, and moorhens) at any one time;
- regularly supports 25 or more breeding pairs of wading birds (e.g. bitterns, herons, egrets, and ibises) or 100 or more foraging individuals (at one time) during migration;
- regularly supports 300 or more pelagic seabirds (e.g. shearwaters, storm-petrels, fulmars, gannets, jaegers, and alcids) and/or terns or 3,000 or more gulls at one time.

The Cape Cod checklist of birds includes 322 species that have been recorded at least 10 times over the period 1988-2008 (Nikula 2008). This checklist covers the entire Cape region. The NPSpecies database indicates that 376 species have been recorded from CACO. Of these, 28 are state-listed taxa (see Topic 8- Rare species: fauna). Six species are listed as non-natives - the rest are considered native to the Cape. The NPSpecies database ranks the abundance of CACO birds as follows: Abundant - 23 species; Common - 75 species; Uncommon - 97 species; Occasional - 84 species; Rare - 96 species; Historic - 1 species.

Just over 40% of the checklist species have been confirmed as breeding on the Cape, although the NPSpecies database considers 28% of species as breeders at the Seashore. (Figure 14.1). Approximately 10% of species exhibit an increasing or a decreasing trend ‘in recent years’ (Nikula 2008; see Appendix 2 for trend information on individual species).

Waterfowl & Marsh Assemblages: An average of 326 ponds are surveyed annually by volunteers in 15 towns as part of the Cape Cod Lake and Pond Waterfowl Survey (Nikula 2009). Data are available from 1984 through 2009. Between 1984 and 2009, the waterfowl surveys recorded 28 species in one or more towns across the Cape, while 20 species were observed in the six towns from Chatham through Provincetown.

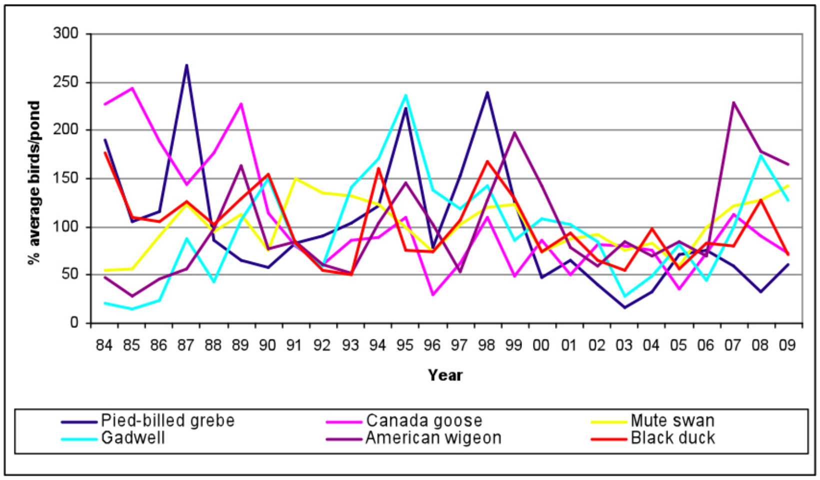
Six bird taxa were most abundant (each representing > 5% of total numbers) in ponds and lakes across the entire Cape region as well as in the six towns of the outer Cape: Black duck (*Anas rubripes*), Mallard (*A. platyrynchos*), Bufflehead (*Bucephala albeola*), Scaups (*Aythya sp.*), Hooded merganser (*Lophodytes cucullatus*) and Canada goose (*Branta Canadensis*) (Figure 14.2).

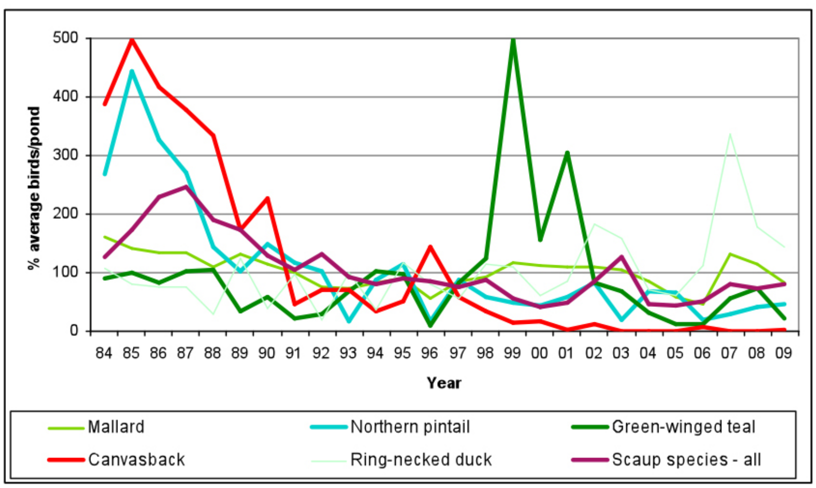
Figure 14.3 shows temporal patterns in the abundance of the more common species (those with an average total of ≥ 10 indivduals for all surveyed ponds). The Canvasback (*Aythya valisneria*) and Northern Pintail

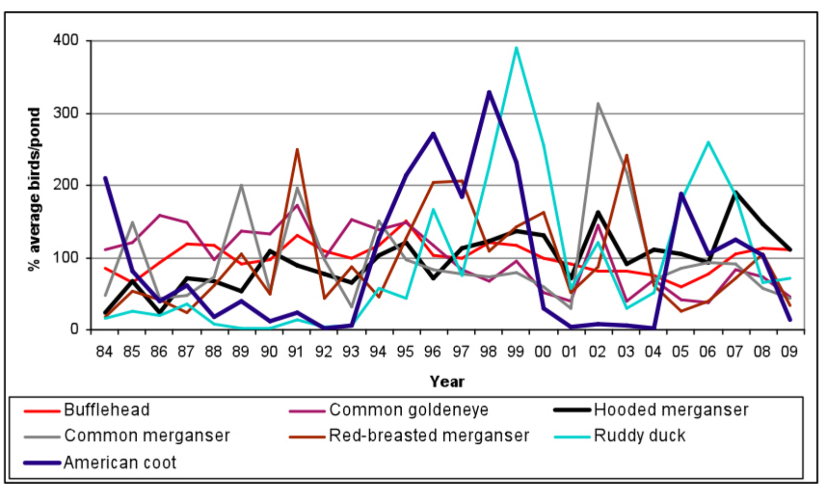
[1] We have not performed trend analyses of the CBC data for this Assessment since there appear to be a number of data quality issues that would need to be addressed before proceeding with trend analysis – especially with reference to species names.

Birds: assemblage structure & pop. dynamics, continued

Figure 14.3. Abundance of 19 selected bird species from 1984 through 2009. All species were recorded during surveys of lakes and ponds on the Cape. Data are the mean number of individuals per pond that were observed each year across all 15 towns of Cape Cod, expressed as a percentage of the mean number of individuals per pond over the period 1984-2008. Thus year-specific abundance data for each species have been normalized to the average abundance of that species over the 28-year period. An average of 326 ponds were surveyed annually (range: 213-383). For scientific names of species, see Appendix 1. (Data source: Nikula 2009)







(*Anas acuta*) both exhibited a trend of decreasing abundance over the survey period, particularly through the early 1990s. Scaup species (presumably Greater Scaup – *Aythya marila* – and Lesser Scaup – *A. affinis*, although many individuals are not identified to species level in the Nikula [2009] database) also became less common over this time period. Most other species did not exhibit clear trends.

There are few data available on distribution and abundance of marsh birds on Cape Cod pre-1999. Erwin et al. (2004) conducted a survey of birds in Nauset Marsh, Pamet River, Pleasant Bay, Wood End, Great Island-Jeremy Point, Hatches Harbor and Herring River. They also surveyed a number of fresh or brackish ponds.

These researchers confirmed the presence of 7 of the 11 marsh bird species most likely to occur at CACO. The most frequently detected species were: Sora (*Porzana carolina*), Pied-billed Grebe (*Podilymbus podiceps*), and Virginia Rail (*Rallus limicola*). Other species detected were: American Bittern (*Botaurus lentiginosus*), Least Bittern (*Ixobrychus exilis*), American Coot (*Fulica americana*), and King Rail (*Rallus elegans*). No trend data are available from this survey, although Erwin et al. (2004) noted that in Nauset Marsh and Pleasant Bay there was a 26% decrease in Black Duck numbers since the 1970s. The cause(s) of this decrease are not known and are not necessarily associated with the decline in marsh area. Note, however, that waterfowl survey data do not show a clear trend for Black Duck across Cape Cod (Figure 14.3). The checklist of Cape Cod birds (Nikula 2008) indicates that the Pied-billed Grebe population has been decreasing in recent years.

Bowen (2006) studied the CACO population of Northern Harrier (*Circus cyaneus*), a Threatened species that typically nests in wetlands. In 2004, there were 10 breeding pairs at CACO (Figure 14.4), likely representing the largest breeding population on the Massachusetts mainland. The following year, five nesting pairs were observed; another four formed territories but did not nest. The population density at CACO was about 50%

of the rangewide average, likely due to the fact that habitat quality in the Park is only average to poor. However, the productivity of nests at CACO appeared to be similar to the rangewide average, although the proportion of successful nests was lower.

Shorebird Assemblage: CACO provides important habitat for beach-nesting birds, including Piping Plover (*Charadrius melodus*), Least Tern (*Stern antillarum*), Common tern (*Sterna hirundo*), Roseate tern (*Sterna dougallii*), and the American oystercatcher (*Haematopus palliates*). Thousands of migrating shorebirds and terns annually congregate at Nauset Marsh and Coast Guard Beach, Jeremy Point and Hatches Harbor/Herring Cove. Shorebirds monitoring occurred on 18 beaches in 2007 (see Hake, 2007, for information on survey methods).

Piping Plover: In 2007, 85 pairs nested at CACO (with a total of 113 nests). The number of Piping plover pairs in 2008-2010 remained about the same as in 2007 (unpublished data provided by R. Cook, CACO). In 2007, 59% of nests hatched at least one chick. On average, 63% of eggs hatched. However, hatching success depended on location. For example, no eggs hatched at Marconi Beach and New Island, while all hatched at LeCount Hollow and Duck Harbor. Highest fledging rates in 2007 were at Bound Brook and Duck Harbor – areas where there were no documented nesting plovers from the late 1990s through 2002. Over the past decade, the number of Piping Plover nesting pairs has been relatively stable (Figure 14.5, 14.6). The Federal goal for recovery of piping plover populations is a five-year average productivity of 1.5 fledged chicks per pair (Hake 2007). The productivity at CACO is approximately at this level (Figure 14.5). Figure 14.7 summarizes selected nesting statistics for this species. Monitoring and management of Piping plover is a very significant component of natural resources management at CACO (R. Cook, pers. comm.).

Least Terns: 83 nesting pairs were recorded in 2007. The number of nesting pairs has declined markedly since 2003 and productivity has been low (Figure 14.6).

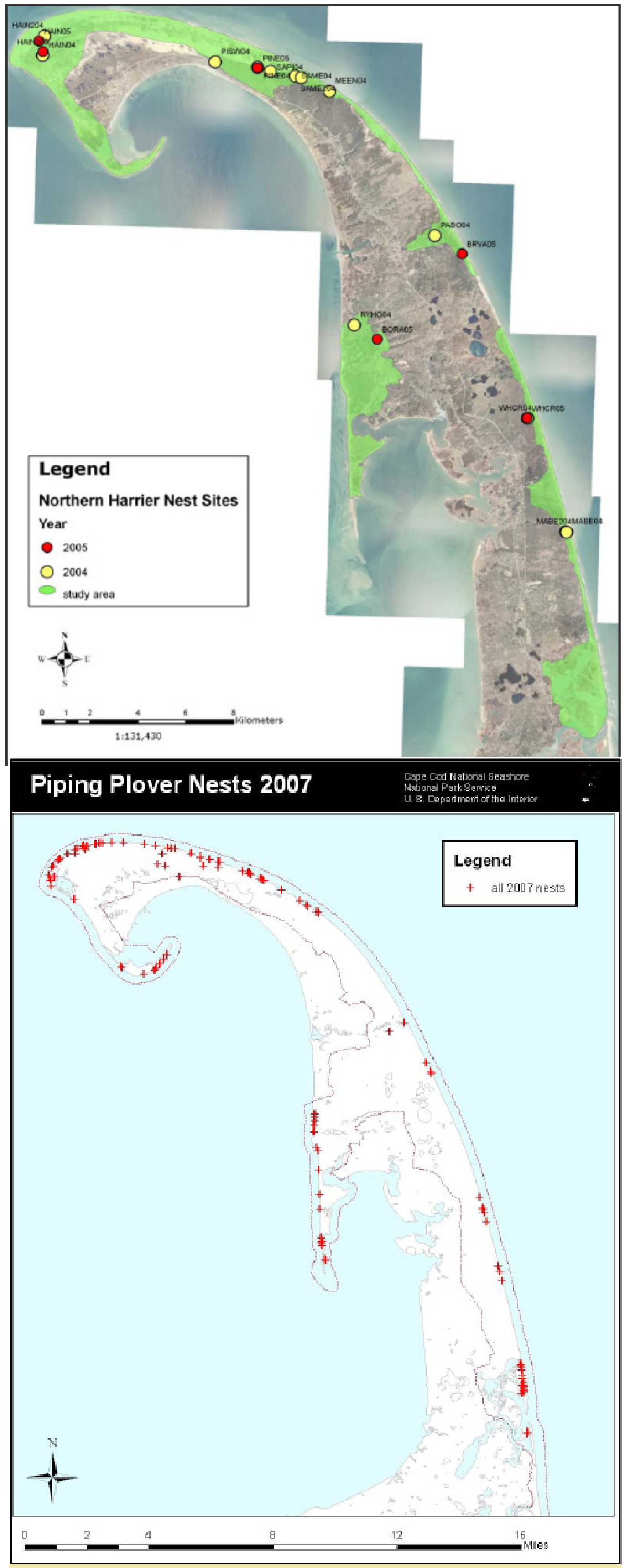


Figure 14.4. Nest sites of Northern Harrier in 2004 and 2005 (upper panel); and Piping Plover in 2007. (Maps from Bowen 2006 and Hake 2007, respectively). Note difference in distance units between two maps.

Birds: assemblage structure & pop. dynamics, continued

Common Terns: Most nesting has historically occurred on New Island, Orleans. A total of 2176 nesting pairs were recorded in 1999. The number decreased to 1078 and 495 pairs in 2000 and 2001, respectively (Figure 14.6). Productivity in those years was low. In 2002, there were no nesting terns on New Island. About 8 pairs nested here in 2007 – all disappeared with predation being implicated. However, while the nesting population on New Island has decreased over the past decade, the breeding population at the Monomoy National Wildlife Refuge (Chatham) has increased substantially. It appears as though the terns have changed their preferred nesting area.

Aside from nesting, CACO is an important staging area for migrating terns – many hundreds of immature and post-breeding individuals use Nauset Marsh, Jeremy Point and Hatches Harbor from July-September.

Roseate Terns: No nesting pairs were recorded at CACO in 2007 (Figure 14.6). Immature and post-breeding adults were observed in Nauset Marsh and Jeremy Point in mid- to late-summer. In 2008, large numbers of Roseate terns were observed at CACO, including 15,000-20,000 on Nauset Marsh/Coast Guard Beach, 8,000 at Hatches Harbor/ Herring Cove and 2,600 on Jeremy Point (R. Harris, cited by Hake (2008). The CACO population represents over half of the entire Northwest Atlantic Coast breeding population of Roseate tern.

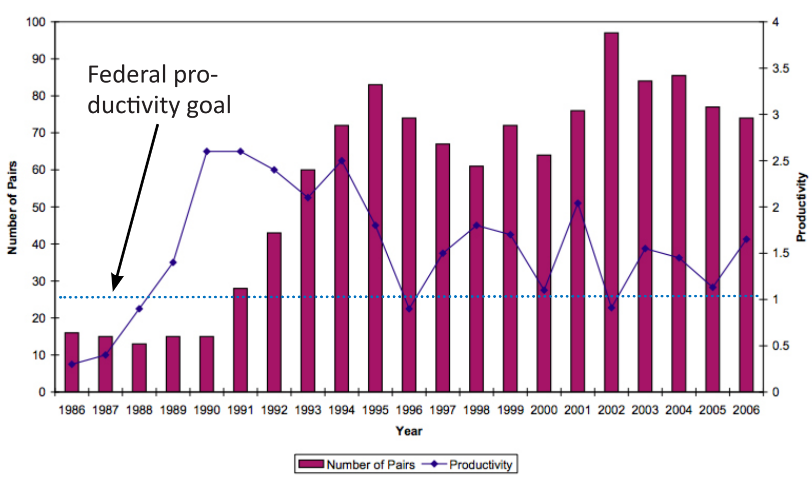


Figure 14.5. Number of piping plover breeding nests and nest productivity at CACO, 1986-2006. In 2007, the number of breeding nests was 85 and the productivity was 1.68. (Figure from Kughen and Hake, 2006). The federal goal is five-year productivity of 1.5 fledged chicks per pair (Hake 2007).

American Oystercatcher: This species was first recorded nesting at CACO in 2002. Four pairs were observed in 2006 and five in 2007 (Figure 14.6). The entire North American population is estimated at only 7,500 birds.

Grassland & Heathland Assemblage: During the past century, populations of grassland-dependent species have decreased as grasslands have reverted to forest. The coastal sandplains of Cape Cod represent one of two remaining areas of significant grassland habitat in Massachusetts (the other is in the Connecticut River valley). However, even here, the area of heathland declined by 62% between 1962 and 1985 (Kearney and Cook 2001). Grasshopper sparrow and Vesper sparrow (both listed in Massachusetts as Threatened species) occur in fields with short grasses and some bare ground (Kearney and Cook 2001). Vesper sparrow are more tolerant of grassland habitat fragmentation than Grasshopper sparrows.

In a 1965 survey, both sparrow species were recorded in suitable habitat across the Cape, although it was noted at that time that numbers had decreased since the 1930s. A mid-1990s survey in Massachusetts revealed that populations of Grasshopper sparrows were declining statewide. Vesper sparrows, although uncommon, were widely distributed (Jones et al. 2001). At that time, the CACO area supported one quarter of all Vesper sparrows recorded statewide – with important areas including the dunes between Provincetown and Truro, and Marconi Barrens and Griffin's Island in Wellfleet. Grasshopper sparrows, however, were not recorded at CACO in the 1990s.

A survey of grassland birds in 2000 recorded one half the number of singing male Vesper sparrows than were found in 1995 (17 vs. 34) – even though sampling effort in 2000 was almost double that in 1995 (Kearney and Cook 2001). Vesper sparrows had disappeared from some areas (e.g. Griffin Island and Pilgrim Heights) where they had been found in the 1990s. This change appears to be related to habitat change - grasslands reverting to woodland. Numbers did not decline in the Marconi Barrens, but are likely to do so in the future as open areas become increasingly vegetated.

Grasshopper sparrows and Eastern meadowlarks were not observed anywhere during the 2000 survey. Other grassland species were recorded more frequently, including the Northern harrier, Horned lark, American kestrel, and Savannah sparrow.

Factors influencing bird assemblages

- Overwash, although a natural process, is one of the most frequent causes of nest loss for shorebird species. The extent and severity of overwash may be influenced by changes in beach morphology, for example narrowing of beaches. Storm timing and intensity are related factors that influence the impact of overwash events. Birds that re-nest following nest destruction may be breeding at times of when there is more human use of the beaches.
- Other factors influencing shorebird populations include abandonment, predation (especially by crows and coyotes), and adult mortality. Predation is one of the most important factors influencing populations of Northern harrier. Disturbance by humans is a further threat to these species. For example, Tuxbury (2001) concluded that there was a strong negative correlation between the level of human disturbance and mean shorebird density, abundance and species richness in Wellfleet Harbor.
- For grassland species, the conversion of open areas to woodland and forest is reducing the amount of habitat available.

Figure 14.7. Nesting statistics for Piping Plover at CACO. (Data source: Hake 2007)

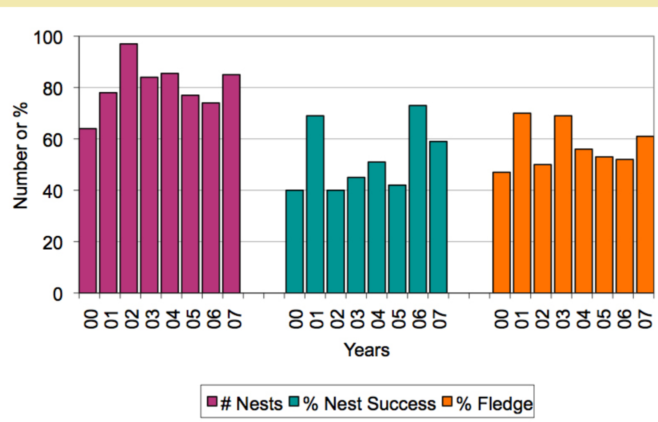
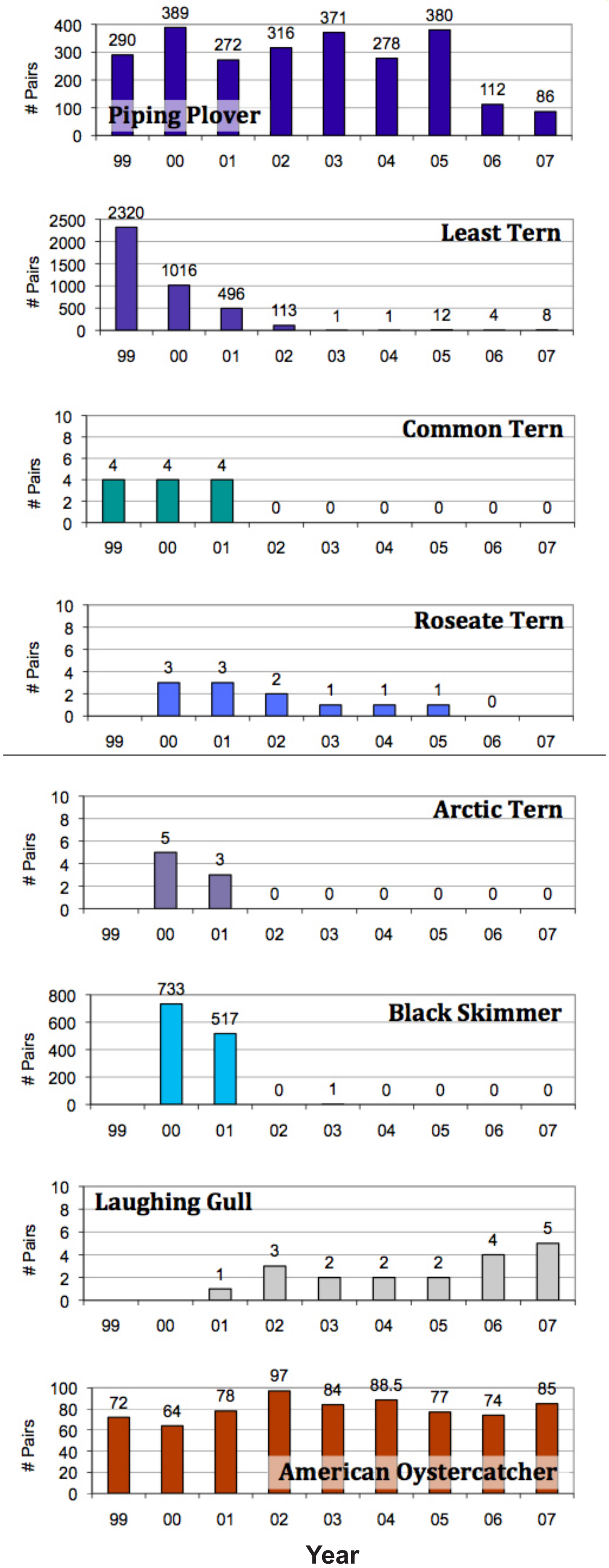


Figure 14.6. Number of nesting pairs of eight shorebird species at CACO. (Data from Hake 2007, Kughen and Hake 2006 and other plover annual reports at http://www.nps.gov/caco/naturescience/piping-plover-annual-reports.htm)



15. Amphibians & reptiles: population status & trends

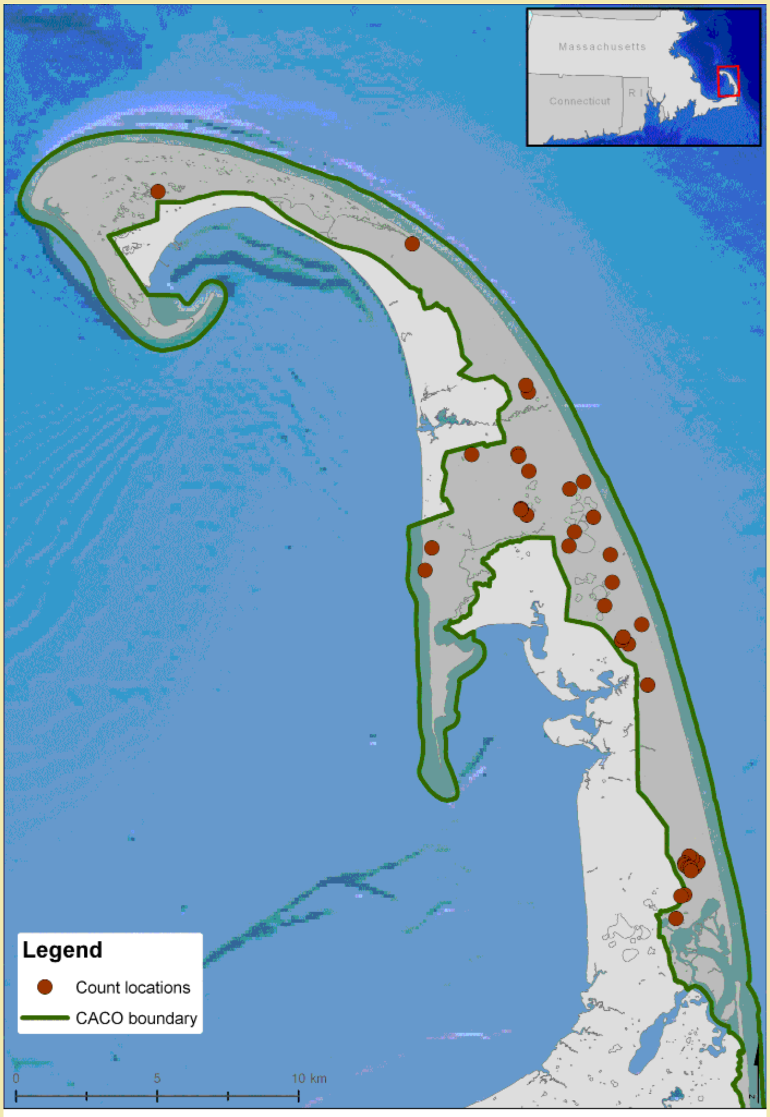


Figure 15.1. Amphibian egg mass count locations. (see also Cook et al. 2006b).

Key Points

- One amphibian and seven (five of which are marine) reptile species at CACO are state-listed. All five marine turtles are also federally listed.
- Most (11/12) amphibians at CACO are dependent on temporary or permanent freshwater habitat. One species is terrestrial.
- The distribution and abundance of amphibians and non-marine turtles have been well documented since about 2003. Based on published data, a few trends in population parameters (egg mass counts) are apparent. However, the period of methodologically consistent monitoring data is relatively short.
- There appear to be few published data on the snakes of CACO.
- Future monitoring will provide a good foundation from which to examine amphibian and reptile population trends and to further study the role of these taxa as indicators of environmental condition.

Assessment statement

Signficant concern. Most amphibian and reptile species are threatened by a range of factors at CACO, including changes in hydrology, development and road traffic.

Rationale

Amphibian and reptile populations are, in general, highly susceptible to a broad range physical, chemical and biological stressors. Amphibians, in particular, are good indicators of environmental condition because of their physiology and habitat requirements.

Benchmarks

Quantitative data on the distribution and abundance of reptiles and amphibians at CACO are only available from the past 6-8 years. These data provide a baseline from future population trends can be assessed.

Condition

Status

There are 25 species of amphibians and reptiles at CACO, and an additional five species of migratory marine turtles that forage offshore (Appendix 1). This Assessment does not address marine turtles. Diversity is lower at CACO than on mainland, in part because of reduced diversity of habitats on the Cape.

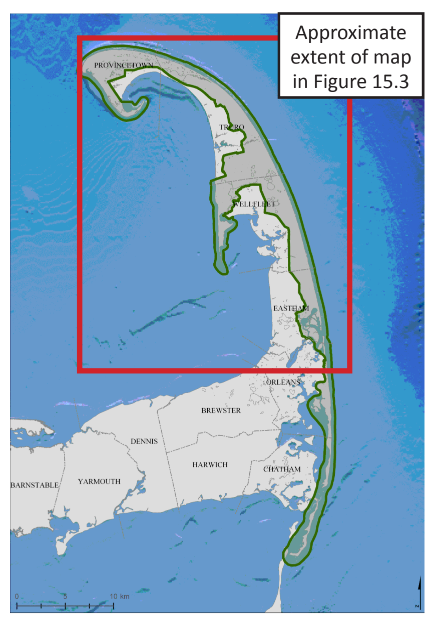
An overview of the rare species is provided by Cook (2008). Four species are state-listed in Massachusetts (see Appendix 1 for scientific names):

- Diamondback terrapin (Threatened) lives in salt marshes of Wellfleet Harbor and to the south.
- Eastern spadefoot toad (Threatened) is found throughout the Park. This species is rare elsewhere in Massachusetts, so the CACO population is one of the most important regionally.
- The Four-toed salamander (now de-listed) breeds in wetlands.
- The Eastern box turtle (Special Concern) is a terrestrial species. It is in decline throughout most of its range in the eastern US – as a result of several factors, including habitat loss, road kill and pet collections.
- Spotted turtles (removed from Special Concern list in 2006) appears to be widespread at CACO but not very numerous. Little known of habitat use in the Park.
- Two other species are unlisted but are of special interest. Eastern hognose snake is still common but appears to have declined at CACO. However, it true status is uncertain because this snake is difficult to find. The Northern water snake is rarely observed at CACO (and primarily in the Wellfleet kettle ponds), even though suitable habitat and food appear to be abundant.

Figure 15.2. Results of anuran call count survey of 2005. Mean maximum index value represent the mean of maximum values only for sites where the species was recorded. Index values in this figure have been multiplied by 10 to enhance clarity. Total number of sites visited was 30. (Data source: Cook et al. 2006b).

Amphibians & reptiles: population status & trends, continued

Figure 15.3. Map of four-toed salamander survey locations in 2006a, with presence/absence status. (Map from Cook et al. 2006a).



Amphibians: Eight of CACO's 12 amphibian species breed primarily in ephemeral, seasonally-flooded, or semi-permanent ponds. Three species (Green frog, Pickerel frog, and American bullfrog) require more permanent water for breeding. One species (Red-backed salamander) is a terrestrial breeder. Three species (Wood frog, Eastern spadefoot toad, and Spotted salamander) only breed successfully in fish-free waterbodies.

The freshwater/kettlepond monitoring protocol at CACO includes monitoring of pond-breeding amphibians (Roman and Barrett 1999). There are two components that focus on distribution and abundance: (i) egg mass counts for two vernal pool breeding species (Spotted salamander and Wood frog); and (ii) anuran call counts of the breeding anuran community across the Park. Egg mass counts were made at 40 vernal pools in 2005 (Figure 15.1; Cook et al. 2006b). Results from this study were supplemented with data from Paton et al. (2003) to evaluate trends. The primary conclusions from these studies are:

- Spotted salamanders were recorded from 74% of surveyed vernal pools – an occupancy rate similar to rates observed elsewhere by other researchers. Egg mass counts ranged from 0 to 1277.
- At seven vernal pools with Spotted salamander data from 2001-2005, there were no significant trends in egg mass counts.
- Wood frog egg masses were observed in 38% of 40 surveyed ponds. Wood frog egg mass counts ranged from 0 to 56.
- At 12 vernal ponds surveyed between 2002 and 2005, a significant trend ($p<0.10$) in number of egg masses was observed in three ponds (all positive trends).
- Pond hydroperiod appeared to be the primary factor influencing egg mass numbers.
- Wood frogs appear to have expanded their range since 2002, but are still found only in Eastham and Wellfleet. However, it appears unlikely that the Wood frog distribution is habitat-related. Spotted salamanders are widespread.
- Anuran call counts were made from 30 sites. Figure 15.2 summarizes results from the call count survey. The most commonly recorded species was the Spring peeper; the least common was the Pickerel frog.

Four-toed salamander (Cook et al. 2006a): This species was first documented on the outer Cape and at CACO in the mid-1980s. Through 2005, most observations on the outer Cape occurred in wetlands associated with the Herring River. Sampling in 2006 revealed that this salamander is widespread across the outer Cape and occurs in riparian habitats and isolated wetlands with a longer hydroperiod (Figure 15.3). Its frequency of occurrence was similar at sites within and outside the Herring River drainage.

The Spadefoot Toad is most abundant in the Province Lands where its preferred habitat of sand dunes and temporary pools is common. This is a long-lived species (5-12 years).

Turtles: Four of the six non-marine turtles at CACO use freshwater habitats. This compares to 8 freshwater species in Massachusetts and 12 freshwater species in the northeastern US.

Prior to 1999, the occurrence and abundance of aquatic turtles on outer Cape Cod were not well known. Surveys conducted from 1999-2003 by Cook et al. (2007) trapped turtles at 76 sites in 10 habitat types. Conclusions from this study include:

- Painted turtle was the most abundant of the freshwater turtle species. This species and Snapping turtles were widespread, being found in all habitat types except for red maple swamps.
- Spotted turtles occurred in all four of the surveyed towns and occupied a range of shallow-water habitats. Populations were small and concentrated in four areas, one in each town.
- The Musk turtle was uncommon on the outer Cape. It was generally found associated with kettle ponds, especially those within the Herring River drainage. The population appeared to be highly male-biased.

Amphibians & reptiles: population status & trends, continued

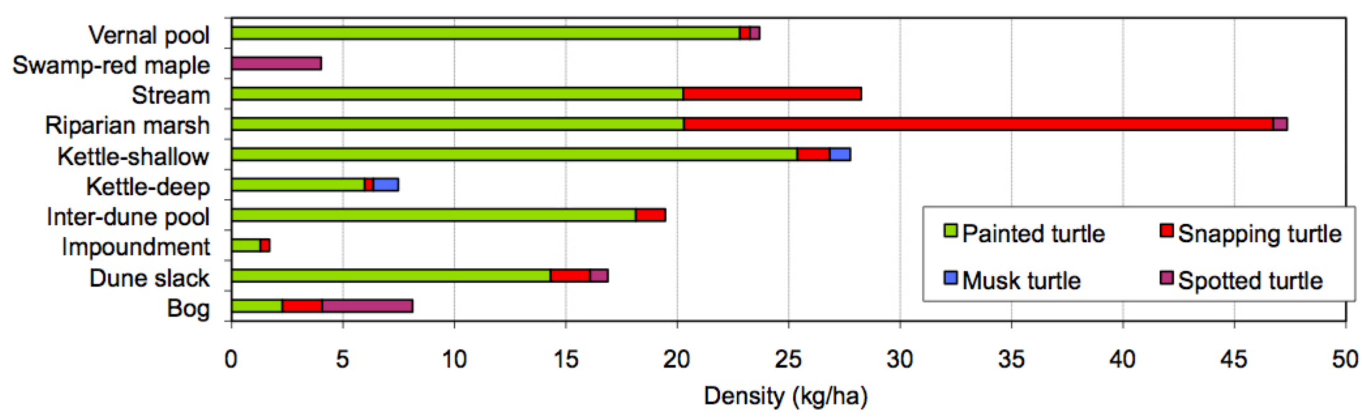


Figure 15.4. Density of four aquatic turtle on the outer Cape, by habitat. (Data source: Cook et al. 2007)

Abundance and habitat of these four turtle species are shown in Figure 15.4.

Trends
Insufficient data to assess CACO trends.

Factors influencing amphibians and reptiles

- Factors influencing amphibian populations at CACO include the following (adapted from Paton et al. 2003):
- Timing of hydroperiod is critical for pond-breeding amphibians, influencing site-specific richness and productivity.
- Acid rain. Although many Cape ponds have pH values above the threshold for many amphibian species and sulfate is declining (see Topic: Nitrogen & Sulfur: Atmospheric Deposition), increasing acidity could impact regional populations because of the low buffering capacity of Cape freshwater systems.
- Contaminants. The impacts of pesticides and other contaminants on Cape amphibian populations is unclear, although some contaminants have been demonstrated elsewhere to be harmful.
- Nutrient enrichment (eutrophication). Increased rates of nitrogen loading from lawn runoff and septic systems may negatively impact Cape amphibians. However, this has not yet been demonstrated.
- Road mortality. This may be an important mortality factor for Cape amphibians. (e.g. Spadefoot Toad).
- Vegetation conversion. Fires have decreased on the Cape over the past few decades, resulting in changes in vegetation assemblages, particularly conversion of pine forests to dominance by oaks. Impacts from these changes on amphibian populations are not known at this time.
- Fish stocking. The introduction of fish into previously fish-free systems is known to negatively affect amphibian populations.

- Little is known of long-term population dynamics of pond-breeding amphibians in North America, including the Cape.

- Tidal restoration projects may influence the amount of habitat available for the Four-toed salamander. Cook et al. (2006a) suggest that habitat needs within the Herring River system could be protected by excluding approximately 18-21% of wetlands from restoration (by using structures to block the flow of salt water at some existing culverts).

- Land development and road traffic are threats to all amphibians, but especially to the Spadefoot toad (Paton et al. 2003). In 2001, approximately one half of toads that were found during a survey were killed on roads. Lowering groundwater levels may also pose a threat by reducing the hydroperiod of vernal pools.

- As for some amphibian species, tidal restoration projects will likely influence the composition of the outer Cape's aquatic turtle assemblage (Cook et al. 2007). Spotted and Snapping turtles are more tolerant of brackish water conditions, whereas Painted turtles are restricted to freshwater systems. Increasing salinity in restored sites may increase the amount of habitat available for Northern diamondback terrapin (a threatened species). Areas where turtle populations may be especially impacted by existing or proposed tidal restorations include: Duck Harbor, Bound Brook, Pilgrim Lake – Salt Meadow, Fresh Brook, Pamet River and Herring River.

- Other threats to freshwater turtles in most parts of the U.S. include: habitat loss, degradation and fragmentation; road kill; invasive species; pollution; disease; unsustainable harvest; and global climate change (Cook et al. 2007). Most of these factors are also relevant at CACO.

16. Parabolic dunes & associated wetlands

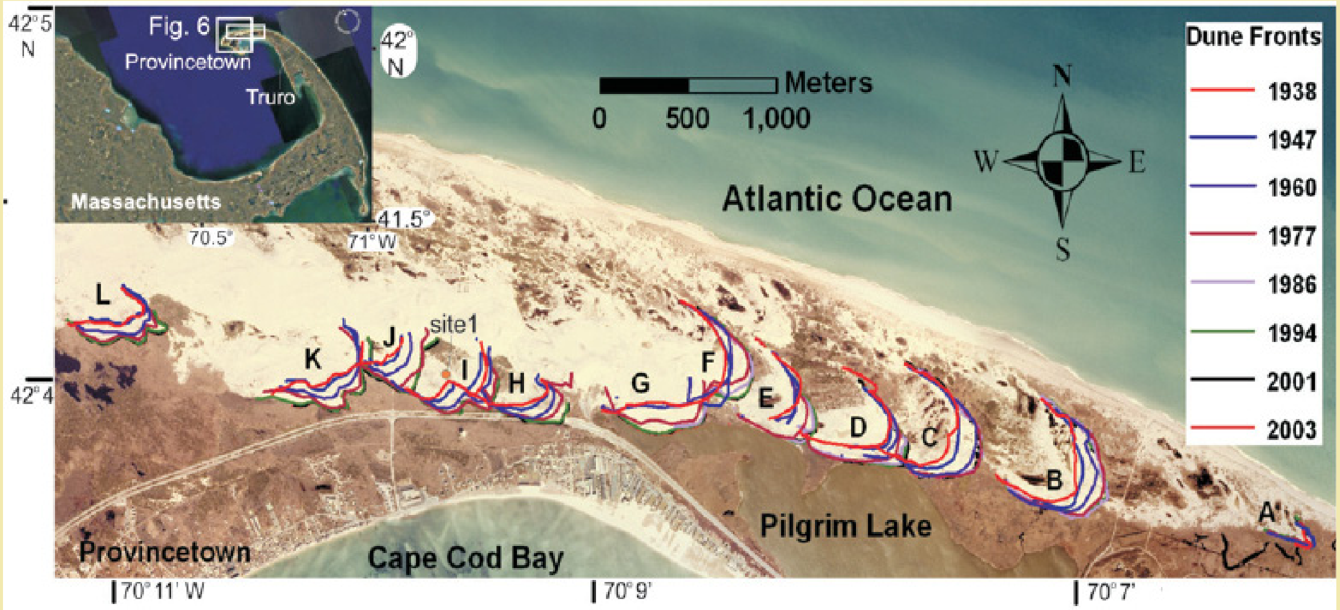


Figure 16.1. Position of parabolic dune fronts at various times during the period 1938-2003. (Image from Forman et al. 2008, used with permission.)

Key Points

- Over the past seven decades, parabolic dunes in the Province Lands have migrated at average rates ranging from 1-4 m/yr.
- Dune migration is more rapid in drier periods and less so in wetter periods.
- There are approximately 350 wetlands within this system of parabolic dunes. These dune slack wetlands provide critically important habitat for many species.
- The wetlands are threatened by several stressors, the most important of which is reductions in groundwater levels.

Assessment statement

Fair. Dune slack wetlands appear to be in good and relatively unimpacted condition at the present time. However, their hydrologic regimes and, in turn, their biological communities may be highly susceptible to future reductions in groundwater levels.

Photo courtesy S. Nelson, UMaine.

Rationale

Human-mediated disturbance in the seventeenth century resulted in a variety of responses in the Cape Cod landscape that persist to the present time. The series of parabolic dunes that occupy approximately 1,800 ha within CACO (Smith and Hanley 2005) are one example of how historic land use practices influence contemporary landscapes on the outer Cape (Forman et al. 2008). Legacy land use patterns combine with climate (e.g. wind, moisture) and the supply of sand to influence the dynamics of the Province Lands dune system.

Benchmarks

Using historical imagery, rates of dune migration over the past seven decades have been documented, a baseline from which to measure future change. The entire population of dune slack wetlands in the Province Lands has been recorded using 2001 imagery. Imagery from six times during the period 1947-2001 provides a base from which to identify the age (post-1947) of individual wetlands. Survey data from 2003-2004 provide a baseline from which future monitoring will be able to document trends in vegetation assemblages, soil composition and hydrology.

Although specific benchmarks for evaluating wetland condition have not been published by CACO researchers, candidate metrics would probably include: plant assemblage composition and structure (e.g. proportion of gramminoid vs. shrub and tree species), areal coverage of dune surfaces by vegetation, amphibian densities, number and abundance of invasive species, groundwater levels and groundwater chemistry (including pH and nitrogen concentration), organic content of wetland soils, and wetland age.

Condition

Status

A "threshold in landscape stability on Cape Cod was exceeded sometime in the late seventeenth to early eighteenth centuries….

Figure 16.2. Dune slack wetlands in the Province Lands. (Figure from Smith et al. 2008, used with permission)

Parabolic dunes & associated wetlands, continued

The juxtaposition of extreme climate variability with rapid and pervasive landscape denudation probably resulted in an irrevocable shift from forested terrain to actively moving dunes…. Climate variability on outer Cape Cod [indicated by the Palmer Drought Severity Index]…. has been insufficient in the past 300 years to fully stabilize this dune system…..It is unclear if wetter conditions in the past 30 years … may result in stabilization of dune forms and succession to forest, similar to the landscape encountered by the Pilgrims" (Forman et al. 2008).

Documentation of dune movement over the past 65 years has revealed that the dune migration rate averaged 4 m/yr between 1938 and 1977, but only 1 m/yr over the 16 year period from 1987 (Figure 16.1; Forman et al. 2008). Higher rates of dune migration between 1940 and 1965 are associated with particularly dry conditions during this period. Wetter conditions prevailed after 1970 and dune migration slowed.

Wetlands form among dunes where depressions intersect the water table. These dune slack wetlands host distinctive assemblages of hydrophytic plant species and provide critical habitat for invertebrates, some amphibians, notably the Spadefoot toad (*Scaphiopus holbrookii*) and Fowler's toad (*Bufo fowleri*), birds and mammals (Smith and Hanley 2005). The wetlands also provide important habitat for hog-nosed snake (*Heterodon platirhinos*), a species that has declined in most of the region and that feeds near-exclusively on these two species of toads (R. Cook, CACO, pers. comm.).

A total of 346 wetlands, with a cumulative area of 45.4 ha, were identified using 2001 imagery and field reconnaisance (Smith et al. 2008). Wetlands occur throughout the dune system, from southwest Provincetown to Truro, but are concentrated in the mid section of this region (Figure 16.2). Forty five percent of these wetlands have been classified as "young" (not present in 1947 imagery), while the remaining 55% are considered "old" (already existed in 1947). Few wetlands (6%) formed after 1986 and only five wetlands were buried by dune movement between 1938 and 2001 – and in each case, the wetland re-emerged in subsequent years (Smith et al. 2008).

Trends

In 15 wetland sites studied intensively, there were no changes in vegetation composition during 2003 and 2004. Although two years of data are insufficient to document trends, among-year variation in the plant communities of these wetlands may be quite low unless there are extreme weather events (Smith and Hanley 2005). Over the longer term, however, changes in groundwater hydrology, as well as natural succession processes, may influence wetland structure and biology.

Factors influencing parabolic dunes and associated wetlands

- Major hydrologic disturbances, including extreme high water, drought and flooding by salt water during storms impact these wetlands. Changes in groundwater levels, as a result of water withdrawals, for example, could influence wetland extent and hydrology.
- Decreasing groundwater influence may promote wetland acidification as rainwater becomes less diluted by relatively alkaline groundwater.
- Nitrogen enrichment via atmospheric deposition may influence wetland chemistry.
- Dune stabilization by upland vegetation will reduce opportunities for new wetland formation.
- Invasive species – two of which are already present in the dune slack wetlands – may impact plant assemblage structure in the future (Smith and Hanley 2005; Smith et al. 2008).

In their study of the vegetation of the dune slack wetlands, researchers recorded a total of 99 wetland taxa (Smith et al. 2008, Smith and Hanley 2005). Key conclusions from their study include:

- The most common species were: Cranberry (*Vaccinium macrocarpon*), Northern bayberry (*Morella pensylvanica*), Sheep laurel (*Kalmia angustifolia*), Highbush blueberry (*V. corymbosum*), and Greene's rush (*Juncus greenei*).
- The rarest species included: Marsh bedstraw (*Galium palustre*), Smooth winterberry (*Ilex laevigata*), Sensitive fern (*Onoclea sensibilis*), Eastern cottonwood (*Populus deltoides*), and Wrinkle-leaved goldenrod (*Solidago rugosa*).
- The most abundant non-wetland species was Pitch-pine (*Pinus rigida*).
- Two invasive species were found: Common reed (*Phragmites australis* – 26 sites) and Purple loosestrife (*Lythrum salicaria* – 4 sites).
- Average species richness per wetland was 11 (range = 2-35). Mean species richness increased from 5.3 in the youngest wetlands to 12.8 in the oldest sites (however richness in the "pre86" wetland group was higher than both younger and older sites).
- 15 wetland species were significantly more abundant in older than in younger wetlands. 11 taxa were significantly less abundant in older wetlands.
- Species richness was not correlated with wetland size.
- Younger wetlands had more graminoid cover, and less cover of trees, shrubs, sub-shrubs, vines and ferns.
- Woody plant cover increased with wetland age.
- Forbs and mosses were most abundant in mid-aged wetlands.
- Obligate wetland species' cover increased with wetland age.
- Although hydroperiod determines whether or not wetland communities develop, it does not appear to be a primary factor structuring assemblage composition.
- Accumulation of organic matter in these wetlands appears to be more influenced by plant succession than hydroperiod.

17. Wetlands: distribution, hydrology & biology

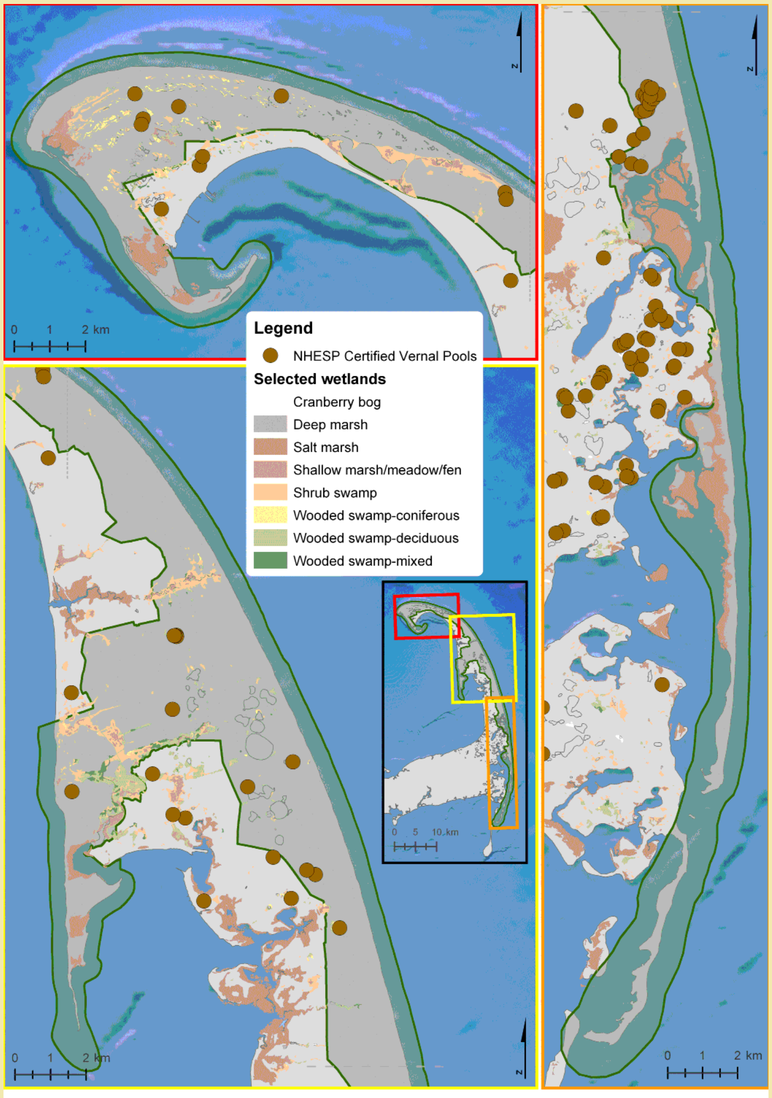


Figure 17.1. Distribution of Massachusetts NHESP certified (by the Natural Heritage & Endangered Species Program (NHESP) according to the Guidelines for Certification of Vernal Pool Habitat (MA Division of Fisheries & Wildlife, 2009)). vernal pools (Jan. 2010 data) and wetlands (MA DEP), excluding beaches, tidal flats, and bluffs/cliffs.

For more information:

Aerial photography: http://www.neiwpcc.org/wetlands/wetlands_pdf/MassDEP%20Using%20Aerial%20Photography%20for%20Enforcement.pdf

Vernal pools: http://www.mass.gov/dfwele/dfw/nhesp/vernal_pools/vernal_pool_cert.htm

List of certified vernal pools: http://www.mass.gov/dfwele/dfw/nhesp/vernal_pools/vernal_pool_data.htm

Key points:

- Forested vernal pools of the glacial outwash plain, dune slack wetlands of the Province Lands, red maple swamps, and the White Cedar Swamp in Wellfleet occur on the outer Cape. These wetlands provide critical habitat to many plant and animal species.
- Vernal pools typically reach their largest areal extent in June and smallest in January.
- Pool water levels are sensitive to water table draw-down, but the responses of multiple pools to changing groundwater levels have not yet been modeled.
- Vegetation assemblages of the forested wetlands are relatively pristine with low incidence of exotic species.
- Inter-annual variations in plant assemblage appear to be quite large and are likely related to hydrologic factors.
- Both within and outside the park, wetland change[1] has occurred at a few sites, typically associated with commercial or residential development, or road building. Areas of wetland change have been small, all < 0.25 ha.

Assessment statement

Fair – Significant Concern, in view of documented wetland losses and the influence of possible future changes in hydrologic regimes.

Rationale

Wetlands are a valuable resource at CACO, providing habitat for many plant and animal species. These systems are vulnerable to changes in hydrology resulting from increased water use in the surrounding towns and from climate change. For example, the town of Eastham is studying the possibility of locating a municipal groundwater well

[1] Change was determined using superimposed aerial imagery, and does not exclusively mean a loss of wetland area. According to the Mass DEP metadata, "Differences detected in areas previously mapped as wetlands on these maps, such as clearing, building, or filling, indicated that some wetlands alteration had occurred."

near vernal pools and Wellfleet recently installed a municipal well inside the Park (R. Cook, CACO, pers. comm.).

Benchmarks

Within the park, an appropriate reference condition is of no change in wetland area (except as a result of natural agents). In terms of biological assemblages, there are recent survey data for plants which will serve as a baseline for evaluating future trends.

Metrics for assessing biological condition might include: plant species richness, cover and frequency of occurrence, assemblage structure (e.g. herbaceous vs. woody species), number of non-native species. The latter metric is likely to be of particular value since these wetlands are known to be relatively pristine in terms of their floral composition.

Benchmarks for wetland hydrology include water levels (e.g. comparison with average historic data, temporal fluctuations), surface area of ponds, and water chemistry.

Another metric might be no decrease in the number of certified vernal pools.

Condition

Status

Spatial Distribution: In the six towns of the outer Cape, non-forested wetlands represent 1.3% of the total area and 1.8% of CACO area. Forested wetlands represent 3.3% and 4.3% of total and Park lands, respectively (for more detailed information, see Table 1.1 in Land cover / Land use: Status & Change). Table 17.1 summarizes the extent of non-forested wetlands by town and Figure 17.1 shows wetland distribution.

There are two main groups of vernal (ephemeral) wetlands on the outer Cape:

- Dune slack wetlands in the Province Lands. These wetlands do not have a glacial origin but rather form as a result of wind-caused sand scour and deposition. Information about these systems is in included in Parabolic Dunes & Associated Wetlands.

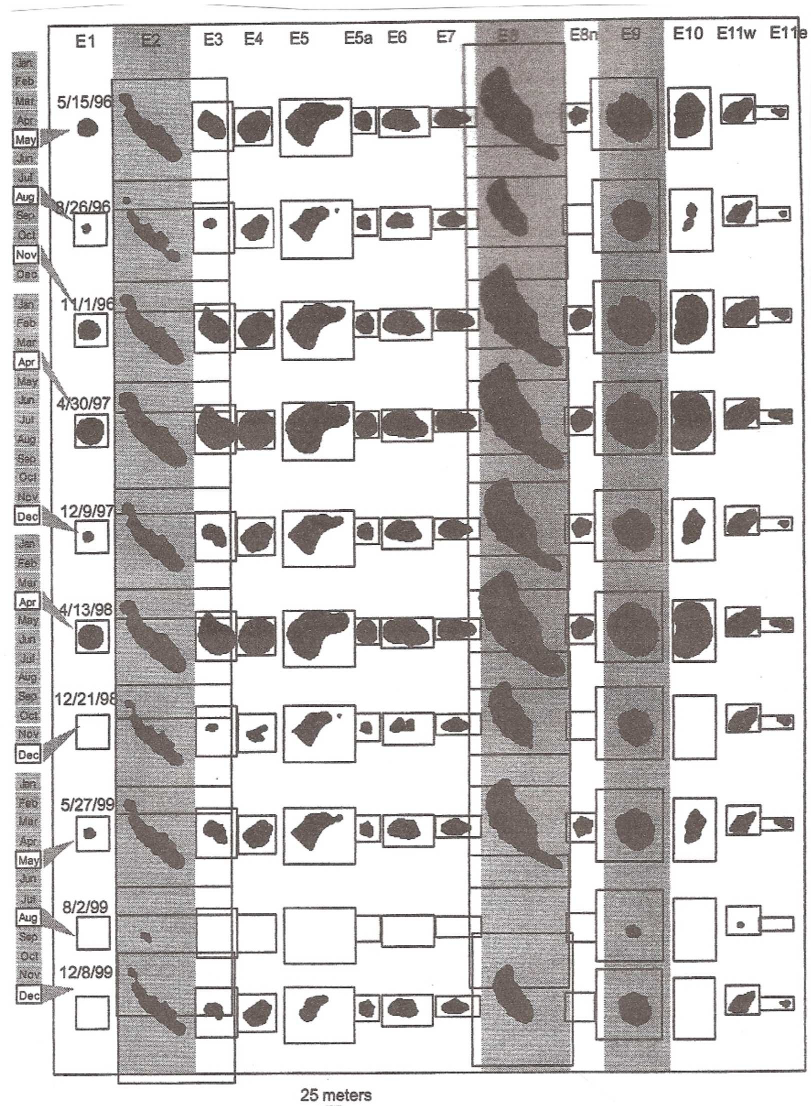


Figure 17.2. Illustration of changes in surface area of 14 vernal pools during the period 1996-1999. (Figure from Sobczak et al. 2003)

- Wetlands on the glacial outwash plain. These vernal pools are surrounded by pine woodland or mixed pine-oak forest (Smith et al. 2006). They form in the "deepest swales in an undulating topographic depression that extends from Nauset Light (on the Atlantic coast) to Herring Marsh (on the Cape Cod Bay coast). Over time, these seasonally-saturated pools have filled in with organic material from the water column and surrounding upland… to form a peat mat which has a relatively flat upper surface and is impermeable to flow towards its center where it is thickest." (Sobczak et al. 2003).

Wetlands: distribution, hydrology & biology, continued

Vernal pools are protected under Title 5 of the Massachusetts Environmental Code, Section 401 of the Federal Clean Water Act, the Massachusetts Surface Water Quality Standards which relate to Section 401, and the Massachusetts Forest Cutting Practices Act. Vernal pools must be certified by the Natural Heritage & Endangered Species Program; certification is based on the presence of certain vernal pool obligate and facultative species.

In Cape Cod towns that include a portion of park lands, the following numbers of vernal pools have been certified as of January, 2009: Chatham –6; Eastham – 20; Orleans – 41; Provincetown– 8; Truro – 5; Wellfleet – 9 (Figure 17.1).

Hydrology: The hydrology of the Eastham group of (glacially-formed) vernal pools (Figure 17.1) was studied by Sobczak et al. (2003). Detailed data were collected over a four-year period (1996-2000) and modeled data were generated for the period 1978-1998. Key findings from this study include:

- Surface-water levels in the vernal pools fluctuate in synchrony with one another.
- Pond surface-water levels are similar to those of the surrounding aquifer during high-water periods, but are higher than aquifer levels during low-water conditions.
- This suggests that water exchange between the vernal pools and the aquifer is restricted during periods of low water. Peat layers in the substrate of vernal pools provide a permeability barrier.
- The disparity between pool and groundwater levels during summer and fall (period of lower levels in the aquifer) results from direct precipitation to the pools.
- Within-year variation in the stage of three pools was approximately one half meter over the period 1996-2000. Between 1978 and 2000, the difference between the minimum and maximum water levels in one pool (for which historical data are available) was approximately 1.2 meters.
- Over the period 1996-2000, 10 of the 14 pools dried up at least once (most in August 1999) (Figure 17.2).
- On average, the aggregated pool area is greatest in the month of June and smallest in January (Figure 17.3). The average January aggregated pool area is approximately one half that of June. However, inter-annual differences in water budgets mean that total pool area is more variable than suggested by these monthly means. The maximum aggregated area during the 1978-1998 period was 24,500 m^2, whereas the minimum was 350 m^2.

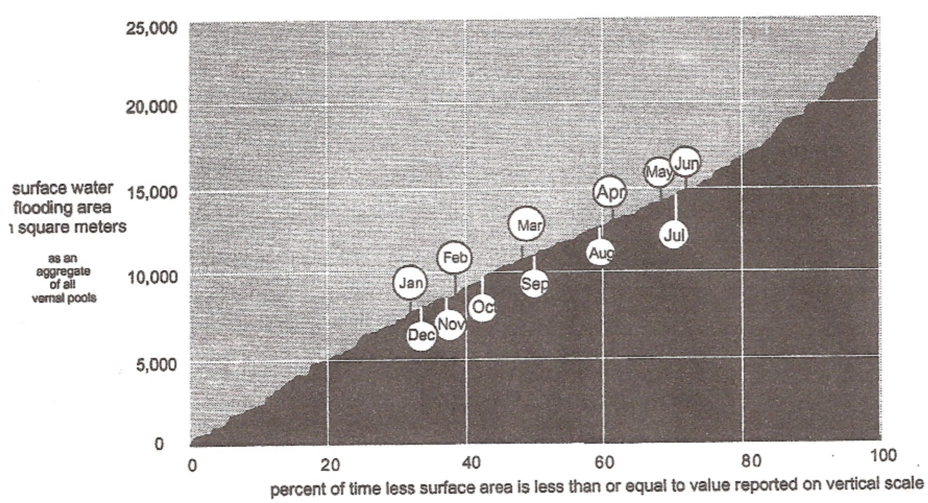


Figure 17.3. Annual-average flooding duration curve for the Eastham vernal pools, displayed as the aggregation of all pools. Data are the percent of time that the total surface of all pools is equal to or less than specific areas. This figure represents all data from the period 1978-1998. Monthly averages across the entire period are shown separately. (Figure from Sobczak et al. 2003)

- Vernal pools are sensitive to water table drawdown during both high and low water periods. Modeled groundwater pumping at a rate of 2,213 m^3/day at one location was estimated to result in drawdowns ranging from 0.01 to 0.75 m in the six surrounding pools, equivalent to a temporary loss of 1,445 m^2 of standing water. However, this loss would likely be recovered almost completely within several hours following cessation of pumping.
- More detailed information is required to be able to predict the effects of groundwater pumping on all of these vernal pools.

Biological Resources: Smith et al. (2006) provide the following introduction to the flora and fauna of these vernal pools.

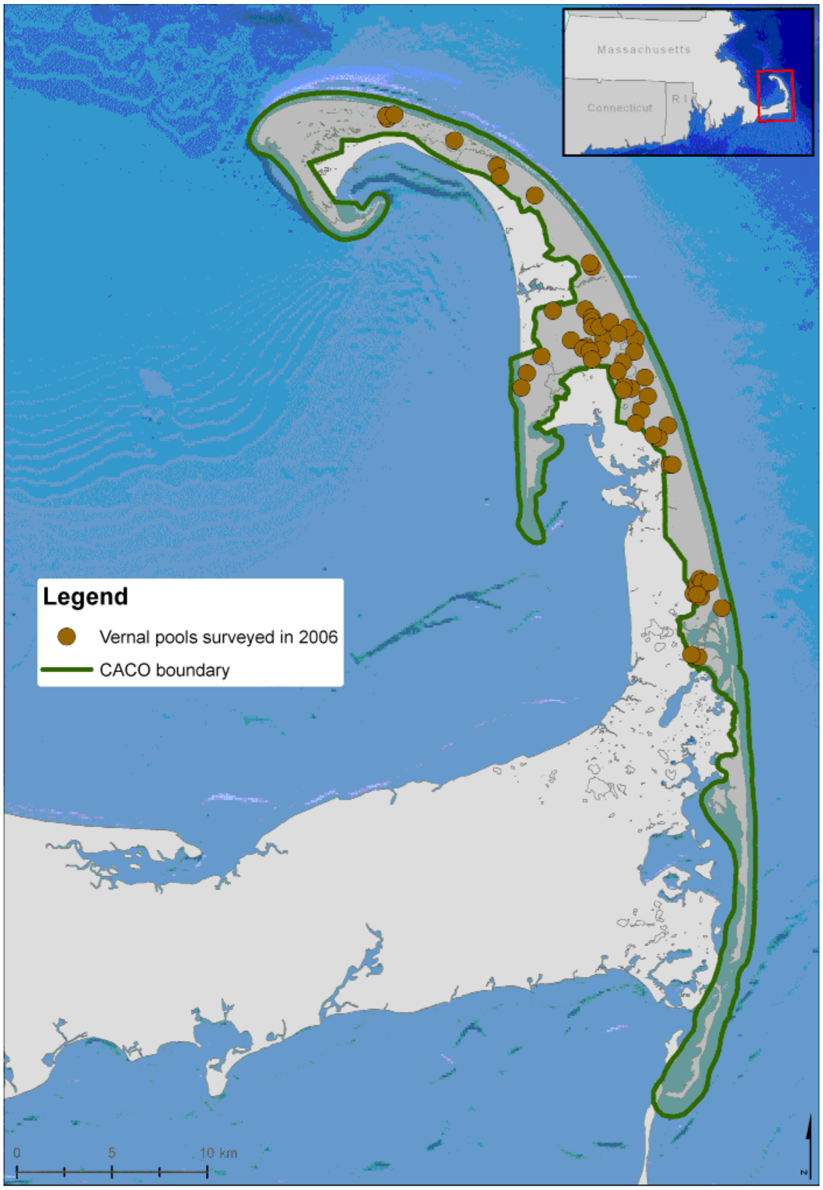
"The seasonal flooding and drying cycle of vernal wetlands fosters the development of distinctive assemblages of plants … and animals. Herbaceous plants, particularly annuals, respond rapidly to water level. As such, vastly different plant communities can develop from year to year depending upon precipitation and the rate of drawdown….. Aside from the floodplains of major river systems such as the Herring River (Wellfleet) and the Pamet River (Truro), vernal wetlands constitute the principal habitat for many freshwater wetland taxa. From a wildlife perspective, vernal wetlands are critical habitat in a number of ways. The State Endangered Water-willow stem borer depends upon *Decodon verticillatus* (Waterwillow), which is a common species in many vernal wetlands. For a wide variety of insects and amphibians such as Wood frogs (*Rana sylvatica*) and Spotted salamanders (*Ambystoma maculatum*) vernal wetlands provide critical breeding habitat. Along with a lesser number of permanent ponds, they are also an important source of fresh drinking water."

More information on the vernal pool amphibians can be found in Amphibians & Reptiles: Population Status &Trends. The flora of dune slack wetlands is discussed in Parabolic Dunes & Associated Wetlands. The remainder of the present section focuses on the vegetation of the forested vernal pools of the glacial outwash plain.

Table 17.1. Wetland change within CACO and in the six towns that contain a portion of the park. Data sources: wetland change- Massachusetts DEP; wetland areas- sum of "Non-forested freshwater wetlands" from MassGIS Land cover data. See also Table 1.1.

Town	Summarized:	Change (ha)	Wetlands (ha)	% of total
Provincetown	Town-wide	0.15	181.8	0.08
	Within-park	-	130.42	-
Truro	Town-wide	0.24	350.3	0.07
	Within-park	0.15	266.5	0.06
Wellfleet	Town-wide	0.04	227.4	0.02
	Within-park	-	128.2	-
Eastham	Town-wide	0.06	66.4	0.09
	Within-park	0.03	10	0.30
Orleans	Town-wide	0.06	90.5	0.07
	Within-park	0.06	11.9	0.50
Chatham	Town-wide	-	137.1	-
	Within-park	-	4.1	-

Wetlands: distribution, hydrology & biology, continued



Produced by NPS FTSC at the University of Rhode Island and the University of Maine

Figure 17.4. Map of vernal pools surveyed in 2006. Other sites were surveyed during an earlier study by R. Cook and J. Portnoy (Cape Cod National Seashore) (also see Smith et al. 2006).

Smith et al. (2006) surveyed 109 wetlands in 2006 – 40 of these had not been previously mapped. More in-depth transect-based surveys were carried out on a sub-set of nine pools. Wetland size ranged from 16 m2 to approximately 30,898 m^2, with an average of 2,752 m^2. Overall, a total of 81 wetland taxa were recorded in this survey – the number per pool ranged from 3 to 22, with an average of 9. Richness in these vernal pools was therefore similar to values observed in dune slack wetlands (range: 2-35; Smith et al. 2008). Species richness was unrelated to pool size. The most common species (by cover and frequency of occurrence) were *Vaccinium corymbosum* (Highbush blueberry), *Sphagnum* sp., *Smilax rotundifolia* (Bullbriar), *Acer rubrum* (Red maple), and *Clethra alnifolia* (Pepperbush).

A key finding of this study was that plant communities were relatively pristine. Two exotic species, *Lythrum salicaria* (Purple loosestrife) and *Phragmites australis* (Common reed), were found at only 1 and 3 sites, respectively – a somewhat lower percentage of sites than was colonized by these same two species in the dune slack wetlands (Smith et al. 2008).

Vernal pool vegetation was dominated by shrub species and obligate wetland taxa. When sites were compared by their similarity in vegetation structure, the group of pools in Eastham were quite similar to each other and to a small group of pools on the Cape Cod Bay side of Wellfleet. They differed from other sites in Wellfleet and in Truro.

Three pools among the group intensively sampled in 2006 had also been sampled in 1997 (Smith et al. 2006). Although with two data points it is not possible to infer temporal trends, plant communities did differ significantly between the two periods, with most species exhibiting lower cover in the later sampling period. This may be related to the fact that pool water levels were higher in 2006 than in 1997 – an observation that parallels the documented increase in groundwater levels in Eastham wells during this same period. Roman and Barrett (2004) had earlier found that water depth was the only significant environmental variable influencing plant distribution in CACO vernal pools.

Trends

Unknown. As noted above, vernal pool plant assemblages are highly responsive to hydrologic regime and would thus be expected to show significant inter-annual variation in assemblage structure. This was supported by data from three pools sampled in 1997 and 2006. The recent survey of Smith et al. (2006) provides an excellent baseline from which to document future trends in the plant communities of these vernal pools, especially in relation to changes in hydrology and climate.

On a broader scale, the loss of wetland area is of greatest interest. Starting in the early 1990s, the Massachusetts Department of Environmental Protection (DEP) began collecting and analyzing aerial photographs to determine areas of wetland change throughout the state for wetlands >1/4 acre. (Note that this approach does not include many smaller vernal pools.) By this method, they can rapidly and broadly identify areas where wetlands have decreased in size between two or more photo dates. By 2003, DEP had identified 3,000 areas of wetland loss throughout the state, including 760 acres in the eastern third of the state. Wetlands within CACO that have changed include: two locations near the Pamet River, related to residential development; and one location on the Park boundary in north Eastham, related to road building (Figure 17.5). Other areas of wetland change in the Park towns are located outside the Park boundary (Figure 17.5, Table 17.1). Massachusetts requires that landowners contact the local conservation commission for approval before starting any work within a 100-foot buffer of a wetland. Certain wetlands have stricter regulations.

Factors influencing wetlands

- Climate change and other drivers of hydrologic change will afffect wetland distribution, extent, and communities of flora and fauna inhabiting these ecosystems.

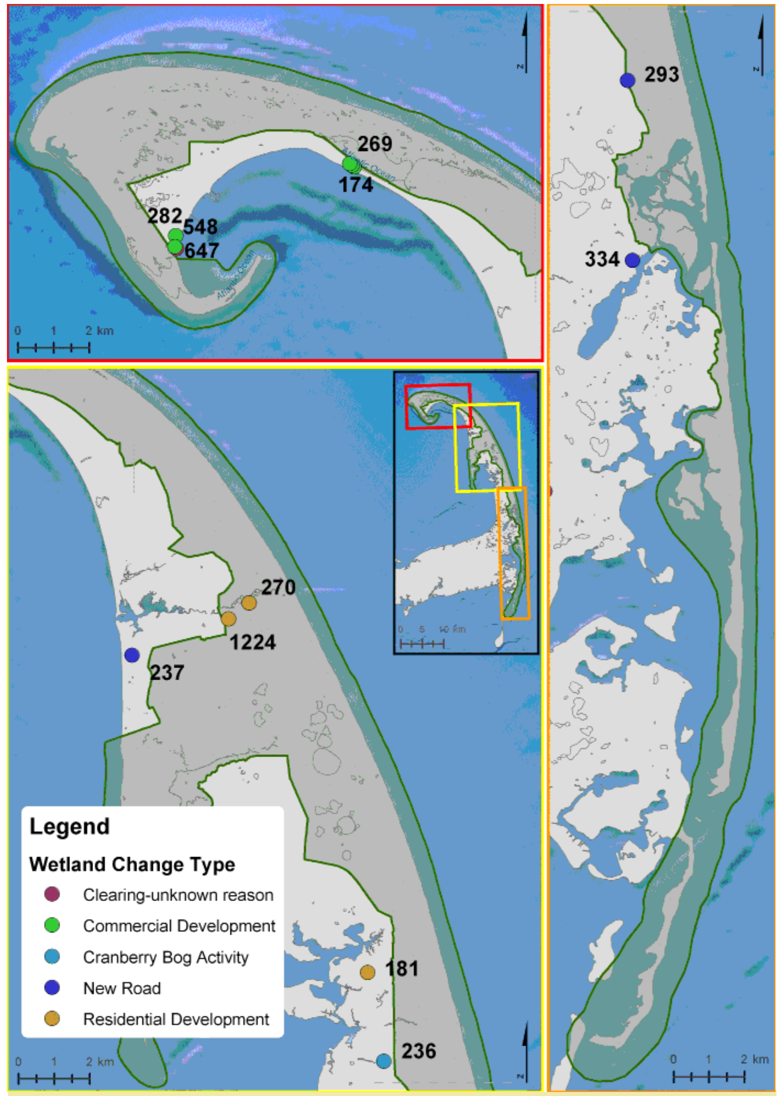


Figure 17.5. Wetland change, by category, within the park boundary and in towns that include Park lands. Numbers labeling each point denote number of square meters changed. Data source: MassGIS. Map produced by NPS FTSC at the University of Rhode Island and the University of Maine.

Photo courtesy C. Roman, NPS.

18. Ponds: acid-base chemistry

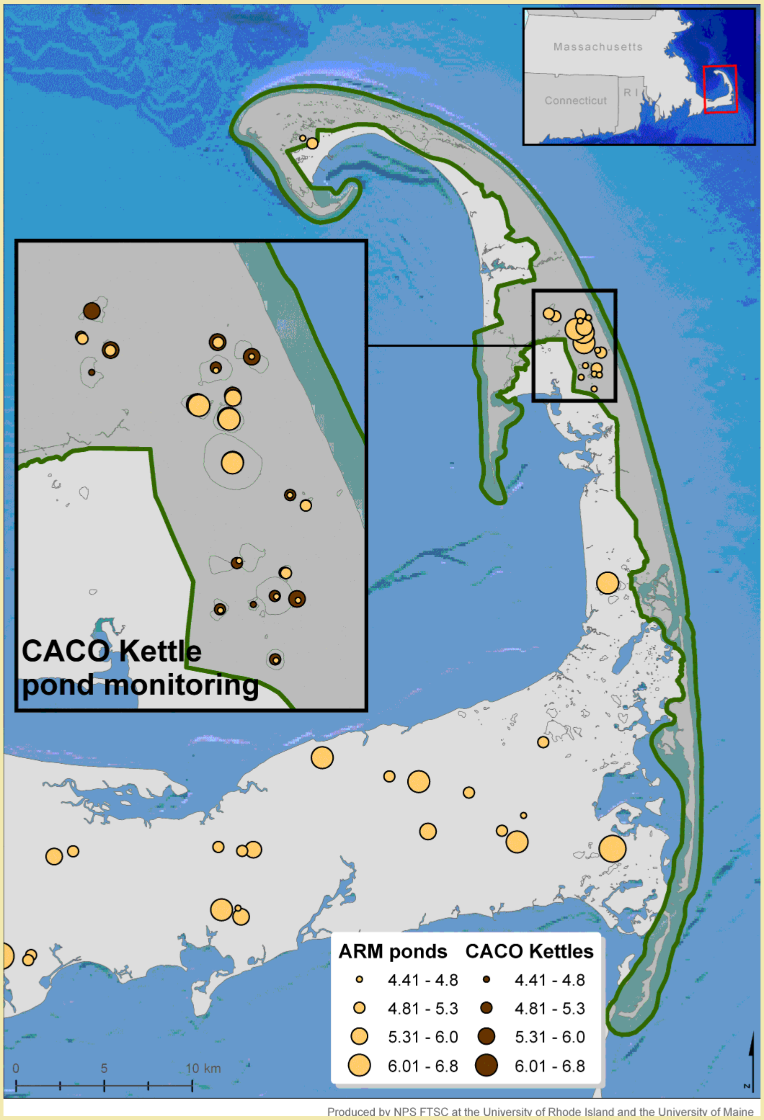


Figure 18.1. Mean pH in ponds in the Cape Cod region, sampled as part of the Acid Rain Monitoring (ARM) program during spring of1990-1993, and (inset) in CACO kettle ponds sampled in April 1999. Data sources: ARM- Godfrey et al. 1996; CACO- Portnoy et al. 2001. For further details, refer to Table 18.1.

Key Points

- CACO Kettle ponds are naturally acidic (pH ~4-6), and pH has changed little through time.
- Trend analyses suggest little change in alkalinity for ponds at CACO, probably due to their dilute chemistry and naturally-acidic status.
- CACO ponds' ionic composition is dominated by sodium and chloride, which appear to be from marine aerosol deposition and not road salt or other anthropogenic sources.

Assessment statement

Good.

Rationale

In freshwaters, acidity (measured and reported as pH) and acid neutralizing capacity (ANC, measured and reported as alkalinity or as Gran ANC, see box, below) can be affected by acidic inputs from precipitation (especially sulfate, nitrate, and ammonium), natural organic acidity (often measured as dissolved organic carbon, or DOC), seasalt exchange in soils (typically affecting streams, not lakes), and weathering rates of bedrock and soils. In turn, pH affects the mobility and toxicity of many metals, such as aluminum (Munson and Gherini 1991a, 1991b), which caused fish kills in Europe and the US and led to policies that reduced emissions of sulfur from anthropogenic sources. Many biota have tolerance ranges for pH and ANC, and the community composition of zooplankton

ANC versus Alkalinity: what's the difference?

Alkalinity (Alk) is the sum of bases in a solution, usually represented by this equation:

$$[Alk] = [HCO_3^-] + 2\,[CO_3^{2-}] + [OH^-] - [H^+]$$

ANC (called Gran ANC, after the scientist who developed the titration method in the laboratory), is the sum of all bases in the solution - which includes organic acids as well as the bicarbonate system. Neal et al. (1999) suggest an equation approximating ANC from Alk, but comparing the two should be done with caution.

Surface water pH, which is affected by carbon dioxide in the air around us, can be analyzed with varying methods: equilibrated with air with a constant amount of carbon dioxide, kept from contact with any air during and after collection, or analyzed with no preparation to limit or standardize exposure to the atmosphere. Depending on this methodological detail, pH can vary over about a unit (10 times, due to the log scale), and data should be interpreted with caution when methods are inconsistent or not specified.

Table 18.1. Adapted from From Portnoy et al. 2001 and Ahrens and Siver 2000. Median or mean (italicized) values of chemical variables for Cape Cod National Seashore ponds compared to samples of lakes from the Northeast US in the early 1980s (Lindthurst et al. 1986) in 2004 (US EPA's ELS-II lakes plus 11 VT lakes; n=154 except for Secchi, where n=106; Rosfjord 2007 and Nelson, unpubl.), and from Massachusetts and Cape Cod during 1983-1993 (Godfrey et al. 1996), from eastern MA, CT, and RI in 2004 (US EPA Eastern lakes Survey sub-region 1D; n=25 except for Secchi, where n=19; Rosfjord 2005 and Nelson, unpubl.), and from four regions of Cape Cod identified by Ahrens and Siver 2000 (see Figure 18.2). Portnoy et al. (2001) CACO data are from April 1999 except for Mn, Fe, Al and Si from April 1993. Smith and Lee (2006) CACO data were from 2005. For Ahrens and Siver data, all lakes were sampled in June 1997 (except Forearm lakes, sampled October 1996), July 1997, and July 1998, and water samples were taken from 1 m depth.

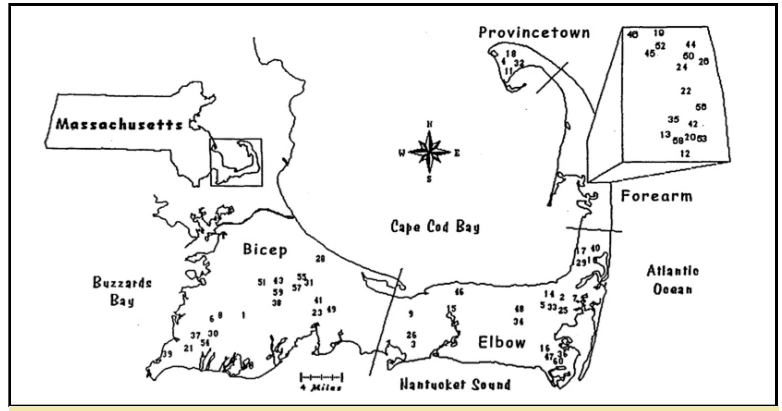


Figure 18.2. Study regions presented in Table 18.1. For list of the 60 lakes studied, see Ahrens & Siver 2000.

Study area	Northeast US	Northeast US	Massachusetts	Eastern MA, RI, CT	Cape Cod	*Cape Cod: Bicep*	*Cape Cod: Elbow*	*Cape Cod: P-town*	*Cape Cod: Forearm (incl. CACO)*	CACO	*CACO*
Data source	(Lindthurst et al. 1986; data 1980s)	(Rosfjord, 2005; data 2004)	(Godfrey et al. 1996; data 1983-1993)	(Rosfjord, 2005; data 2004)	(Godfrey et al. 1996; data 1983-1993)	*Ahrens & Siver, 2000 (data 1996-1998)*	*Ahrens & Siver, 2000 (data 1996-1998)*	*Ahrens & Siver, 2000 (data 1996-1998)*	*Ahrens & Siver, 2000 (data 1996-1998)*	(Portnoy et al. 2001; data 1999)	*(Smith & Lee 2006; data 2005)*
Statistic	Median	Median	Median	Median	Median	*Mean*	*Mean*	*Mean*	*Mean*	Median	*Mean*
Alkalinity (meq/L)	137	64.2 (ANC)	201	36.2 (ANC)	36	*71*	*41*	*60*	*-7.5*	4.4	*14*
pH	6.8	7	6.62	6.88	6	*6.8*	*6.3*	*5.4*	*5.3*	5.1	*5.9*
SO4 (meq/L)	115	78.9	167	108	123	*112*	*110*	*39*	*126*	64	
Ca (meq/L)	177	101	273	94.2	73	*90*	*88*	*79*	*52*	44	
Mg (meq/L)	70	46.1	136	89.3	119	*133*	*148*	*172*	*182*	162	
K (meq/L)	12	8.65	36	20	23	*16*	*16*	*27*	*21*	21	
Na (meq/L)	83	79.6	430	418	446	*347*	*581*	*592*	*625*	583	
Cl (meq/L)	60	66.3	423	493	423	*350*	*615*	*787*	*822*	791	
Na:Cl	1.38	1.20	1.02	0.85	1.05	*1.0*	*0.92*	*0.75*	*0.76*	0.74	
Conductivity (mS/cm)	43	30.4		82		*76*	*106*	*128*	*137*	114	*142*
Mn (meq/L)	12		30		10					50	
Fe (meq/L)	50		230		100					30	
Al (mg/L)	50	22.9	20	7.9	20					45	
Si (mg/L)	1.9	0.81	2.5	0.41	0.6					0.06	

Ponds: acid-base chemistry, continued

Paleolimnology at CACO

Paleolimnology, the study of sediments and diagenetic processes to gain insight into past conditions in lakes and watersheds, is a valuable tool for determining the history and potential future trajectories for lake and pond chemistry and development.

Nine of the Wellfleet-Truro kettle ponds at CACO were sampled in the 1980s and 1990s:

> *"1) to document evolutionary changes in the ponds and in the uplands around the ponds;*
>
> *2) to provide evidence for local and regional changes within the ponds in the years since European settlement (about 360 years ago on the lower Cape); and,*
>
> *3) to determine the direction and rate of recent chemical and biological changes in the ponds in the context of local and regional environmental change throughout their development." (Portnoy et al. 2001).*

Sediment cores extracted from the ponds were radiocarbon dated and analyzed for chemical composition, pollen, charcoal, diatoms, zooplankton (specifically, cladoceran) assemblages. The results of these analyses are summarized in Portnoy et al. 2001 and references therein, and suggest that the CACO ponds are naturally acidic, but that diatom assemblages have changed through time despite relatively consistent pH.

or diatoms are tightly linked to acid-base status. Fish are typically intolerant of very acidic conditions (see Benchmarks).

Chloride and sodium, the largest components of sea salt and most road salt, have recently emerged as ions that may affect our interpretation of recovery from acidification, because increased road salting may mask subtle changes in ionic composition of lake water (Rosfjord et al. 2007). Road salt in developed watersheds may deserve further study because in some lake watersheds in the Northeast, it appears to be increasing through time (Rosfjord et al. 2007).

Benchmarks

Dupont et al. 2005 synthesize various criteria for ANC from the literature and use ANC < 40 meq/L as a tolerance criterion for aquatic organisms (especially fish). The Northeast Temperate Network of the NPS uses a more protective threshold of 100 meq/L. With respect to monitoring the response to the Clean Air Act Amendments of 1990, scientists and policymakers expected increasing ANC, increasing pH, and decreasing SO_4 in surface waters (after about 1994) as a result of declines in SO_4 deposition (Kahl et al, 2004). However, some lakes are naturally acidic (pH<6) and should not be expected to respond in the same way as SO_4-affected lakes; this is the case for many CACO ponds.

Condition

Status

Median or mean pH in ponds within CACO and in the outer Cape (pH ~5.1-5.4) are lower (about 1 pH unit, or 10 times lower) than median or mean pH measured in lakes in the mid-and upper Cape, the whole of Massachusetts, or the Northeastern US (pH ~6.0-7.0)(Table 18.1 and references therein, Figure 18.2). Of the 20 Wellfleet/Truro ponds sampled in 1999, 16 had pH<6.0, and four had pH<5.0 (Figure 18.1)(Portnoy et al. 2001).

Correspondingly, alkalinity was <40 (tolerance criterion) for all but three ponds (Gull, Herring, Higgins), and alkalinity was <100 for all 20 ponds (Portnoy et al. 2001). DOC data were not available, but (1) color, which

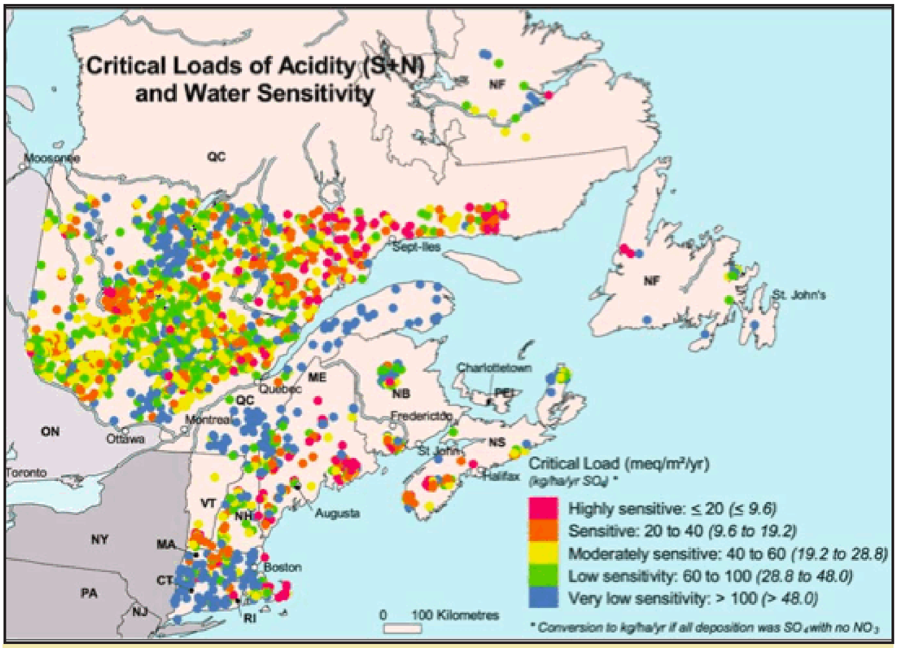


Figure 18.3. From Dupont et al. 2005. Critical loads of acidity (S+N) and the relative sensitivity of surface waters to acidification. CACO area lakes are in the "Highly sensitive" category, in contrast to lakes in inland Massachusetts.

may be used as a rough, screening-level proxy for DOC, tends to be low in these lakes and (2) ionic charge balance differences were low (~4%, Ahrens and Siver, 2000), suggesting that organic acidity may not be the source of the natural acidity in the low-pH, low-alkalinity ponds. Rather, low pH and low alkalinity in CACO ponds may be caused by acidic litter inputs from largely conifer and ericaceous vegetation; crystalline, non-calcareous sandy soils (Winkler 1988); slow weathering of glacial deposits; little alkalinity generation contributed by sulfate reduction, which could occur in these lakes (Ahrens and Siver 2000); and generally dilute (excluding Na and Cl concentrations) water chemistry. Dupont et al.'s (2005) analysis of lakes in the Northeast indicates that the acid/base status of lakes on Cape Cod is extremely vulnerable to loading of N and S (Figure 18.3). The pH and ratios between major ions in the ponds closely mirror those of precipitation measured by the NADP at the nearby North Atlantic Coastal lab site (NADP/NTN 2009); thus, these ponds may be more reflective of precipitation chemistry than chemistry influenced by watershed or soil processing. Further study would be necessary to determine the mechanisms causing relative acidity in these ponds.

Sodium and chloride were the dominant ions in the CACO and outer Cape lakes (Table 18.1, Figure 18.4), with Cl representing approximately 80% of the anionic charge (Ahrens and Siver 2000). Ahrens and Siver (2000) argue that the source of Na and Cl in CACO lakes is probably marine rather than originating from road-salt, based on three findings: (1) a geographic gradient of increasing Cl and Na was documented with distance from the Cape Cod Canal; (2) lakes with the greatest Na and Cl were those in CACO, which had lower road density and human population; and (3) mean Na:Cl in their study (and in CACO lakes, see Table 18.1) was 0.89, similar to that of seawater (0.86).

Trends

Paleoecological coring and the limited trend analyses using data from the early 1980s through 1999 (Table 18.2a, b; Winkler 1988, Portnoy et al. 2001, Godfrey et al 1999; see also Box at left) provide evidence that pH has changed little in the CACO kettle ponds through time. Specifically, of the 18 ponds analyzed for trends, only three had significant increasing trends: one for alkalinity (Table 18.2a) and two for pH, though one of these pH increases was certainly an artifact of liming in the pond (Table 18.2b). For SO_4,

Ponds: acid-base chemistry, continued

Photo courtesy Steve Smith, NPS.

precipitation data suggest that there have been declines in SO_4 atmospheric deposition, consistent with results found elsewhere in the region (Table 18.2c.). However, trend analyses for SO_4 in CACO ponds were not available in the literature at the time of this writing. With ongoing monitoring of CACO ponds, updated trend analyses will continue to document changes in acid-base status of these lakes.

Factors influencing ponds: acid-base chemistry

- Policy changes that result in changes to atmospheric deposition are likely the greatest influence on this topic.
- Increasing human development and road building can result in increases in road salt inputs to surface waters.
- Ponds with the greatest amount of data are located in a small district; lakes outside this zone may have different characteristics and chemistry.

Figure 18.4. Chloride (Cl) versus pH in Massachusetts Acid Rain Monitoring (ARM) lakes vs ARM lakes on Cape Cod in towns that contain portions of CACO. Data shown are means for fall samples taken during 1983-1993. Data source: Godfrey et al. 1996.

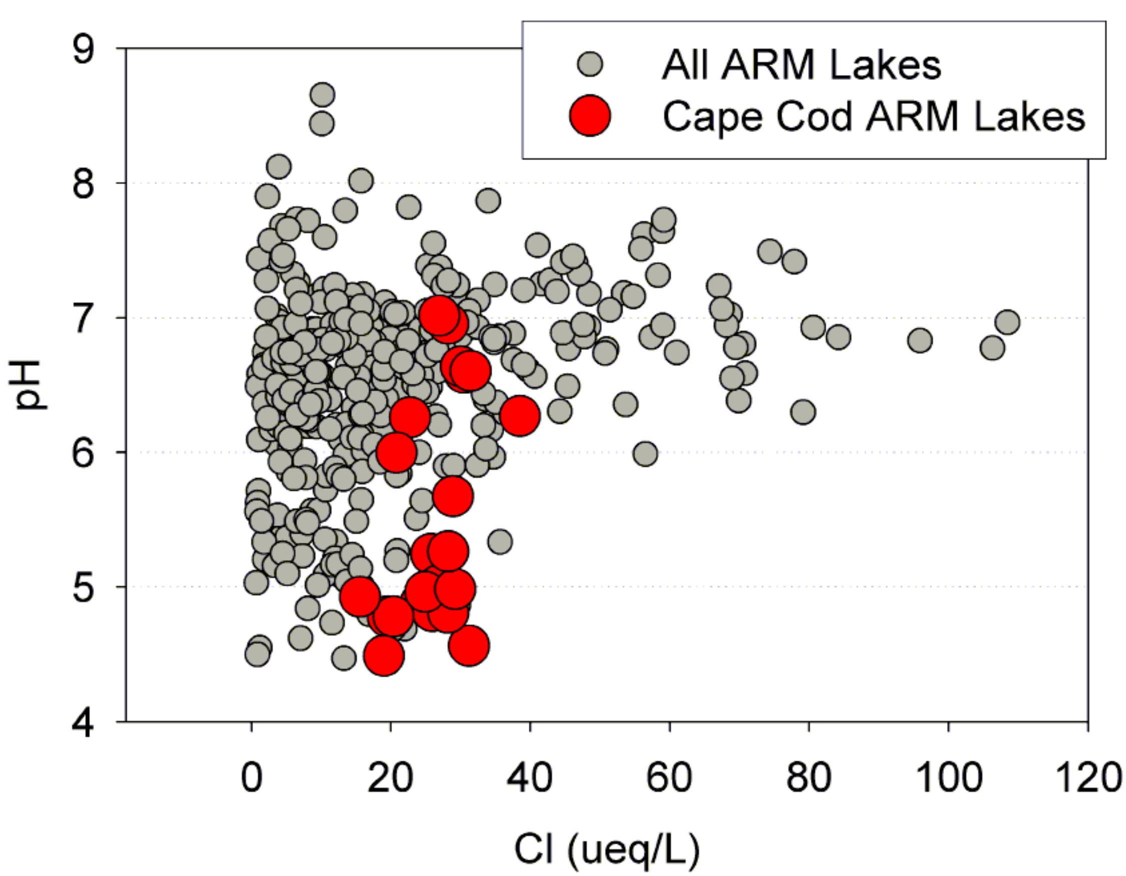


Table 18.2a. Surface water acid/base trends, 1983-1994, on Lower Cape Cod. Average pH, average alkalinity, trend in alkalinity (adjusted to remove the effect of yearly variation in precipitation and runoff), and significance level of trend from Godfrey et al. 1997. Alkalinity and trends of calcium carbonate mg/L and mg/L/yr, respectively. NS=not significant at the 0.05 level. Table from Godfrey et al. 1999.

Pond Name	Town	Average pH	Average Alkalinity	Trend	Significance level
Northeast	Wellfleet	4.86	-0.44	+0.13	<0.05
Kinnacum	Wellfleet	4.47	-1.83	-0.14	<0.05
Dyer	Wellfleet	4.81	-0.64	-0.06	NS
Great	Wellfleet	4.7	-0.83	+0.04	NS
Gull	Wellfleet	6.63	+3.18	+0.06	NS
Higgins	Wellfleet	6.51	+3.30	+0.13	NS
Horseleech	Truro	5.79	+0.67	-0.04	NS
Round	Truro	4.81	-0.56	+0.02	NS
Slough	Truro	4.78	-0.66	+0.02	NS
Spectacle	Wellfleet	5.01	-0.11	+0.01	NS
Williams	Wellfleet	5.92	+1.69	+0.02	NS

Table 18.2b. Significant pH trends (1983-1999) by year derived from corrected seasonal Kendall rank correlation. From Portnoy et al., 2001. * Great Pond was limed in 1975 and 1985, probably overwhelming any signal from changes in atmospheric deposition.

Pond Name	Season	Trend increase	t	p-level
Long	Spring	Increase	0.616	0.0008
Great (Truro)	Winter	Increase*	0.707	0.0004
Dyer, Duck, Great (Wellfleet), Gull, Southeast, Northeast, Ryder, Herring		NS		

Table 18.2c. LTM sites: Regional trend results for acid-sensitive Long-Term Monitoring lakes in ME and VT (n=24), the Adirondacks (n=48), and the Upper Midwest (n=22) for 1990-2000. TIME sites: probability sites (New England n=30; Adirondacks n=43) that can be extrapolated to regional target populations, 1991-2001. TIME lakes include some in Eastern MA. Trend analysis was seasonal Kendall-Tau. Values are weighted mean slopes for all lakes in each region. Units for SO_4, NO_3, base cations (Ca+Mg), Gran ANC, and H^+ are meq/L/yr. Units for DOC are mg/L/yr. Units for aluminum (inorganic monomeric) are mg/L/yr. Adapted from Table 5 and Table 7 from Kahl et al. 2003.

	SO_4	NO_3	Base cations	Gran ANC	H^+	DOC	Al
LTM Sites							
New England Lakes	-1.77**	+0.01^{ns}	-1.48**	+0.11^{ns}	-0.01^{ns}	+0.03*	+0.09^{ns}
Adirondack Lakes	-2.26**	-0.47**	-2.29**	+1.03**	-0.19**	+0.06**	-1.12**
Upper Midwest Lakes	-3.36**	+0.02^{ns}	-1.42**	+1.07**	-0.01*	+0.06**	-0.06^{ns}
TIME sites							
New England Lakes	-1.88**	+0.02^{ns}	-1.57**	+0.40*	+0.01^{ns}	+0.08*	-1.94^{ns}
Adirondack Lakes	-2.10**	+0.01^{ns}	-1.22*	+0.56*	-0.09^{ns}	+0.09*	+0.66^{ns}

ns: regional trend not significant
* p<0.05
** p<0.01

19. Ponds: nutrients & trophic condition

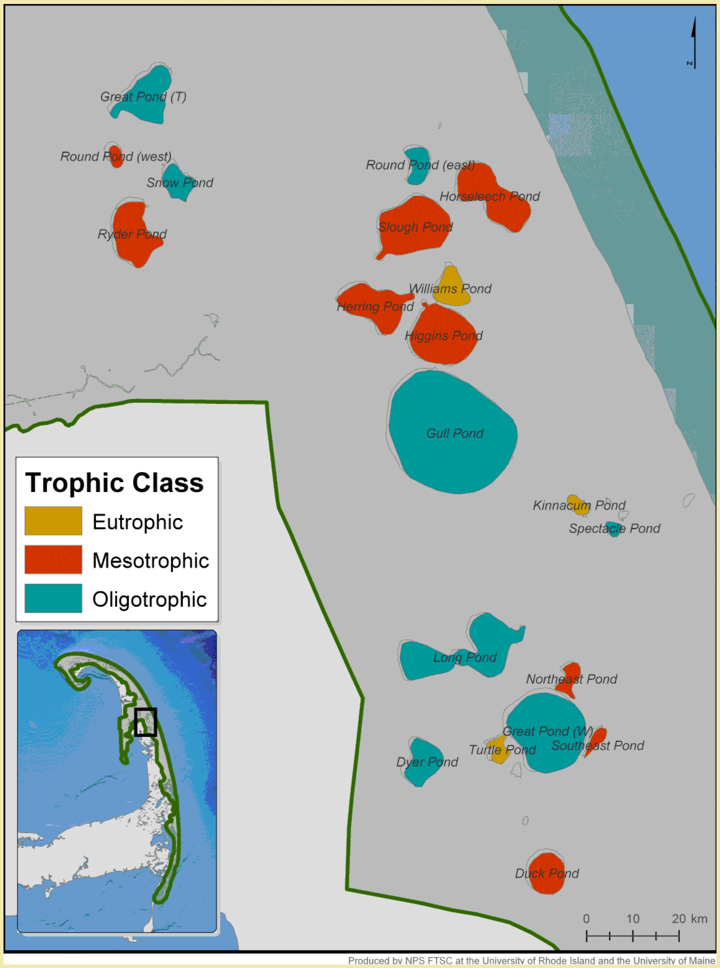


Figure 19.1. Trophic class as determined by Portnoy et al. 2001, for 20 CACO ponds.

Molar or mass basis?

The Redfield ratio of 16:1 is based on the ratio of nitrogen to phosphorus on a molar basis. Often, N and P data are reported on a mass basis; the Redfield ratio becomes ~7:1 when calculated on a mass basis.

With nitrogen, care must also be taken to ensure that it is being reported as N. Some forms of nitrogen, such as nitrate (NO_3), are often reported as nitrate, and one must convert to account for only the N (discounting the oxygen) before using the conversions above.

See: http://lakewatch.ifas.ufl.edu/circpdffolder/Circular105Pts5thru8.pdf for helpful information about the reporting of these and other chemicals.

Key Points

- In a 1999 assessment of 20 CACO kettle ponds, 3 were eutrophic, 9 were mesotrophic, and 8 were oligotrophic (Figure 19.1). Overall, trophic indicators suggest more desirable conditions in these ponds than in statewide surveys, based on limited available data.
- Though lakes were thought to be phosphorus-limited, newer data suggest that they may be susceptible to nitrogen loading as well.
- Most sources of phosphorus to the ponds are probably human-associated (swimmers, septic systems). Though not a major source of phosphorus, nitrogen loading from the atmosphere, in addition to point sources, could be affecting these ponds.
- Many of CACO's kettle ponds have been identified by the states Living Waters Program as critical habitats within the state.

Assessment statement

Fair - signficant concern. Nitrogen loading is a potential issue.

Rationale

Freshwater and estuarine systems in the northeastern U.S. are increasingly at risk of eutrophication as a result of elevated nutrient loading rates (Roman et al. 2000, Jawoski et al. 1997). Excessive nutrient enrichment may lead to dense algal growth, decreased dissolved oxygen concentrations, reduction in submerged vascular plant beds, and other decreases in habitat quality. Atmospheric nitrogen loading has typically not been thought to cause eutrophication of lakes and ponds because phosphorus is the nutrient that most commonly limits primary production in north temperate systems (Bergstrom et al. 2005). However, there is a growing body of evidence to suggest that (a) phosphorus limitation in relatively unproductive lakes is a derived characteristic that has resulted from increased atmospheric nitrogen loading over the past several decades (Goldman 1988, Bergstrom et al. 2005), and

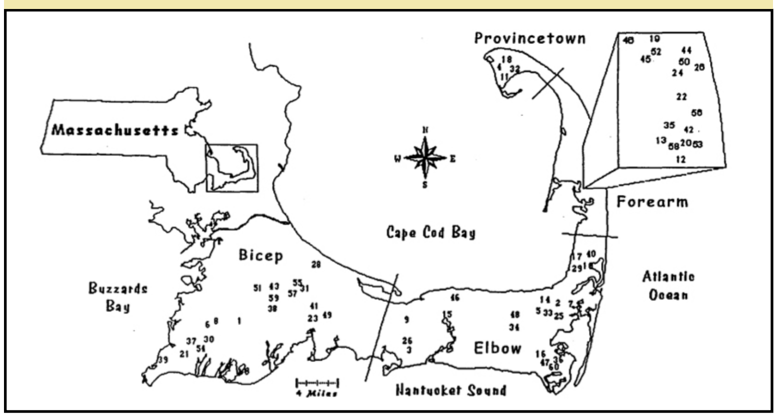
Table 19.1. Adapted from From Portnoy et al. 2001 and Ahrens and Siver, 2000. Median or mean (italicized) values of physical and trophic variables for Cape Cod National Seashore ponds compared to samples of lakes from the Northeast US in the early 1980s (Lindthurst et al. 1986) in 2004 (US EPA's ELS-II lakes plus 11 VT lakes; n=154 except for secchi, where n=106; Rosfjord 2007 and Nelson, unpubl.), and from Massachusetts and Cape Cod during 1983-1993 (Godfrey et al. 1996), from eastern MA, CT, and RI in 2004 (US EPA Eastern lakes Survey sub-region 1D; n=25 except for Secchi, where n=19; Rosfjord 2005 and Nelson, unpubl.), and from four regions of Cape Cod identified by Ahrens and Siver, 2000 (see Figure B). Portnoy et al. (2001) CACO data are from April 1999 except for Mn, Fe, Al and Si from April 1993. Smith and Lee (2006) CACO data were from 2005. For Ahrens and Siver data, all lakes were sampled in June 1997 (except Forearm lakes, sampled October 1996), July 1997, and July 1998, and water samples were taken from 1 m depth.

	Northeast US	North-east US	Massa-chusetts	Eastern MA, RI, CT	Cape Cod	*Cape Cod: Bicep*	*Cape Cod: Elbow*	*Cape Cod: P-town*	*Cape Cod: Forearm (incl. CACO)*	CACO	*CACO*
Data source	Lindthurst et al. 1986 (data 1980s)	Ros-fjord, 2005 (data 2004)	Godfrey et al. 1996) (data 1983-1993)	Ros-fjord, 2005 (data 2004)	Godfrey et al. 1996 (data 1983-1993)	*Ahrens & Siver, 2000 (data 1996-1998)*	*Ahrens & Siver, 2000 (data 1996-1998)*	*Ahrens & Siver, 2000 (data 1996-1998)*	*Ahrens & Siver, 2000 (data 1996-1998)*	Portnoy et al. 2001 (data 1999)	*Smith & Lee 2006 (data 2005)*
Statistic	Median	Median	Median	Median	Median	*Mean*	*Mean*	*Mean*	*Mean*	Median	*Mean*
Lake Area (ha)	16.7	24	4.1	14	3.2					5	*11.2*
Depth (m)	4.2	6.5		6.7						8	*12.5*
Temp (C)						*22.8*	*24.6*	*22.6*	*20.2*		
Secchi depth (m)	2.3	2.85		3		*4.5*	*4.5*	*0.5*	*5.0*	5.4	*6.1*
Chl-a (mg/L)						*2.58*	*3.16*	*9.07*	*2.05*	1.45	*6.2*
Total P (mg/L)	9		8			*11.6*	*12.2*	*52.1*	*10.4*	8.7	
Total N						*250*	*246*	*567*	*173*		*168*
N:P						*23.5*	*21.9*	*14.7*	*16.6*		

(b) nitrogen limitation is more common than originally thought (Smith and Lee 2006, and references therein). Cultural eutrophication – increases in-lake productivity as a result of human-mediated processes – is a concern in many areas where watersheds are subject to development pressures, such as housing development, greater use of fertilizers on lawns, and deterioration of septic systems. Cultural eutrophication is especially important when lakes are situated in nutrient-poor watersheds, as is the case on Cape Cod.

Trophic status of lakes and ponds can be assessed via several metrics, including phosphorus and chlorophyll concentrations, and Secchi depth. The latter is a measure of water transparency. Although influenced by color and dissolved organic carbon (Webster et al.

Figure 19.2. Study regions presented in Table 19.1. For list of the 60 lakes studied, see Ahrens & Siver, 2000.



Ponds: nutrients & trophic condition, continued

2008), this metric is a low-cost and effective approach to tracking changes in lake productivity over time.

Benchmarks

A range of approaches have been used to characterize the trophic state of lakes and to assign 'class values' based, for example, of phosphorus or chlorophyll concentrations, and Secchi depth (Carlson and Simpson 1996). Even though the terms 'eutrophic' (high productivity), mesotrophic (moderate productivity), and 'oligotrophic' (low productivity) have been used to describe the trophic status of Cape Cod lakes and ponds (e.g. Godfrey et al. 1999, Ahrens and Siver 2000, Roman et al. 2001, Portnoy et al 2001), we are aware of no published trophic state classification system that is accepted for Cape Cod lakes. Nevertheless, nutrient concentrations and water transparency can be used to rank waterbodies along a trophic gradient (e.g. Roman et al. 2001). More importantly, when sufficient data are available, these parameters can be used to document temporal trends in trophic state.

To predict which nutrient is likely to be limiting primary production in a lake, N:P ratios are frequently used (See Box). On a molar basis, N:P ratios <10 or <14 (there is variability in literature values; Ahrens and Siver, 2000) indicate N limitation, while N:P ratios >16 suggest phosphorus limitation. Though widely used, recent research is indicating that the ratio may not be applicable to all situations or all forms of N and P. Some researchers calculate ratios based on inorganic N and P, or a combination of some inorganic and some total forms of N and P (Kniffen et al. 2009, Smith and Lee 2006, others).

Condition

Status

Overall, median Secchi depth (5.4 m) in 1999 in CACO ponds was greater (i.e., water was clearer) than across the northeast region in the 1980s (2.3 m) and in 2004 (2.8 m), and in eastern Massachusetts in 2004 (3 m) (Table 19.1, Figure 19.2). 'Forearm' lakes, which were largely CACO kettle ponds – had lower mean Chl-a, total P, and total N and greater Secchi depth than lakes in other parts of Cape Cod, most notably, those in Provincetown, in the late 1990s (Ahrens and Siver, 2000).

Although thought to be P-limited, more recent work suggests that CACO kettles may also be sensitive to additions of nitrogen. First, the N:P ratios published in Ahrens & Siver for 'Forearm' lakes (2000) and converted to molar averaged 7.5, suggesting that N limitation may be dominant. Second, new data from Smith and Lee (2006) indicate that these ratios are below 16 when the inorganic forms of nitrogen are the only ones included. Further, Smith and Lee (2006) provide experimental evidence from the CACO lakes from an N and P addition study. The authors found increased periphyton growth on artificial substrates when either N or N+P were added, but no stimulation of growth when P alone was added (Smith & Lee, 2006).

Kniffen et al. (2009) assayed periphyton and phytoplankton to determine N, P, or N+P stimulation, and found further evidence for co-limitation of N and P. In most of the ponds studied (outside CACO but on Cape Cod in Brewster, Chatham, Falmouth, Barnstable), Kniffen et al. (2009) reported N+P, N, and P stimulation of periphyton growth, and N+P stimulation of phytoplankton growth. N limitation may be more important in some lakes and seasons than in others (Figure 19.3). Smith and Lee (2006) suggest further research and long-term monitoring to assess the relative importance of both N and P in the dilute CACO kettles. A nutrient loading budget has been developed for Gull Pond, a naturally oligotrophic system that is currently showing signs of cultural eutrophication (Portnoy 1990, Winkler 1988). Septic leachage and gull feces contribute most of the phosphorus to this system, 54% and 42%, respectively.

Aquatic macrophyte assemblages – species composition and growth form – have been shown to be useful indicators of the trophic status of Cape Cod kettle ponds (Roman et al. 2001). For example, floating-leaved plants are common in eutrophic ponds such as Herring Pond, while being infrequent in

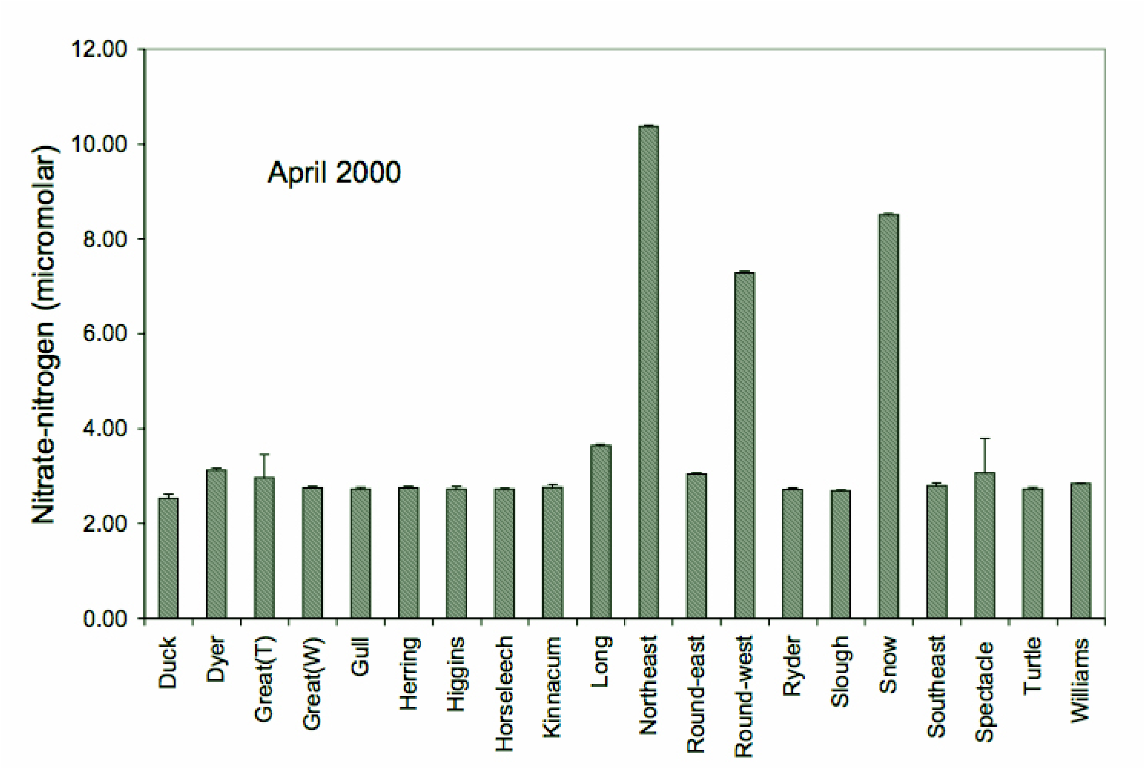


Figure 19.3. Nitrate-nitrogen in pond surface water in April 2000. Mean +/- SE, N=3. Figure from Portnoy et al. 2001.

oligotrophic systems, such as Duck Pond. In lower productivity systems, plant assemblages tend to be characterized by emergent species and those with narrow-leaved rosettes.

Trends

Data are limited for any trends analysis of trophic parameters, with the exception of Secchi transparency. Two ponds have shown large declines in Secchi transparency since the 1970s (Duck Pond), and since 1993 (Ryder Pond)(Portnoy et al. 2001). Data availability has improved since 1996 and ongoing monitoring should provide a record that can be used for future trend analyses.

Factors influencing ponds: nutrients & trophic status

(adapted from Portnoy et al. 2001 except as noted):

- Atmospheric deposition, for N (likely not a large source of P).
- Regional groundwater, for N (Kniffin et al. 2009).
- Soil erosion.
- Recreational swimming (particularly urine inputs).
- Wildlife, especially gull usage – though inputs are probably small except on larger ponds.
- Shoreline septic systems.
- Water level fluctuations may release P from sediments; N responds to the supply of P (Kniffin et al. 2009).

20. Ponds: aquatic vegetation assemblages

Table 20.1. Contribution of environmental variables to explaining macrophyte vegetation patterns in CACO kettle ponds. Data are percent cumulative variance explained as variables are added to the model using a forward-selection procedure. Bold variables are those for which inclusion resulted in a significant 'additional fit' within the model. (Data from Roman et al. 2001).

Variable	% Cumulative Variance
Depth	**31**
Sediment organic matter	**50**
Sediment % sand	**61**
Porewater PO_4-P	**69**
Bottom slope	**77**
Porewater NO_3-N	**84**
Sediment bulk density	**90**
Sediment % cobble and gravel	95
Porewater NH_4-N	98
Sediment % silt and clay	99

Key Points

- Plant assemblage data are available from the two groups of permanently flooded ponds at CACO: kettle ponds and Province Lands ponds.
- Species richness in surveyed kettle ponds ranged from 12-30; in the Province Lands ponds richness was in the range 14-37.
- Plant assemblages of kettle ponds are a good indicator of trophic condition.
- Plant assemblage structure in these ponds will be a valuable indicator of responses to future changes in key environmental attributes, such as nutrient loading, climatic variables and hydrologic regimes.

Assessment statement

Fair. Pond plant assemblages may be influenced by future eutrophication and hydrologic changes.

Rationale

Coastal plain pond plant species represent one of the most critical rare species assemblages in New England (Sorrie 1994). Many ponds have been degraded by development and agriculture, both of which can lead to increased nutrient loading. Eutrophication may result in a transition from pondshore specialists to highly competitive species (Sorrie 1994) and increasing domination by floating-leaved taxa (Roman et al. 2001). Changes in hydrology, precipitation, and temperature, and addition of exotic species may also drive future changes in the plant assemblages of CACO ponds.

Benchmarks

Surveys conducted in the 1990s (kettle ponds) and 2007 (Province Lands ponds) provide a baseline from which future changes in assemblage structure can be documented. Priority metrics for kettle ponds are likely to include plant species composition and growth form, specifically the relative abundance of submerged and floating-leaved taxa vs. emergent and rosette-forming species. For both kettle ponds and Province Lands ponds, the number and relative abundance of non-native taxa (for example, no increase in the number of non-native taxa) is another important metric. With additional research and evaluation, individual metrics may be combined within an index of biotic integrity for CACO pond plant communities.

Condition

Status

Aquatic vegetation has been studied in the two primary groups of permanently-flooded ponds at CACO – kettle-hole ponds and the Province Lands ponds. Because of their different origins, Province Lands ponds are shallower than the kettle ponds and tend to support rooted vegetation across their entire extent (Smith et al. 2007).

A total of 49 species were identified in a study of five kettle ponds (the total number of taxa recorded from each pond is shown in parentheses): Duck (20), Ryder (12), Great (30), Gull (22) and Herring (23) (Roman et al. 2001). Seven environmental variables explained 90% of the documented variation in plant assemblage composition (Table 20.1). Overall, species composition and growth form were shown to be useful indicators of the trophic status of these ponds. In the more productive Herring Pond, submerged-leaved species (e.g. *Utricularia* sp. and *Najas flexilis*) and floating-leaved species (e.g. *Nymphoides cordata*, *Nymphaea odorata* and *Brasenia schreberi*) were common. In the least productive systems emergent and rosette-forming species dominated the assemblage, including *Juncus pelocarpus, J. canadensis*. Only two species were common to all five ponds.

A recent study of Province Lands ponds (Smith et al. 2007) yielded a provisional list of 88 vascular plant species, including four state-listed taxa: *Orontium aquaticum* (Golden club), *Utricularia subulata* (Zigzag bladderwort), *Eleocharis rostellata* (Spike rush), and *Carex oligosperma* (Few-fruited sedge). Six non-native species were recorded during this survey: *Lythrum salicaria* (Purple loosestrife; 2 ponds), *Phragmites australis* (Common reed; 8 ponds), *Typha angustifolia* (Narrowleaf cattail; 2 ponds), *Iris pseudacorus* (Yellow flag; 1 pond), *Rosa multiflora* (Multiflora rose; 1 pond), and *Potomogeton crispus* (Curlyleaf pondweed; 1 pond).

Species richness per pond ranged from 14 to 37 and was similar to richness in the ephemeral dune slack wetlands (range: 2-35; see Parabolic Dunes & Associated Wetlands). Ponds with higher pH and lower amounts of organic matter contained more species (Figure 20.1). Differences in the relative abundance of three species contributed most to overall among-pond variation in assemblage composition: *Nymphaea odorata* (White water lily), *Juncus militaris* (Military rush) and *Decodon verticillatus* (Water willow).

Trends

No data (collected with consistent methodologies) are available to document trends in species composition or relative abundance for these ponds.

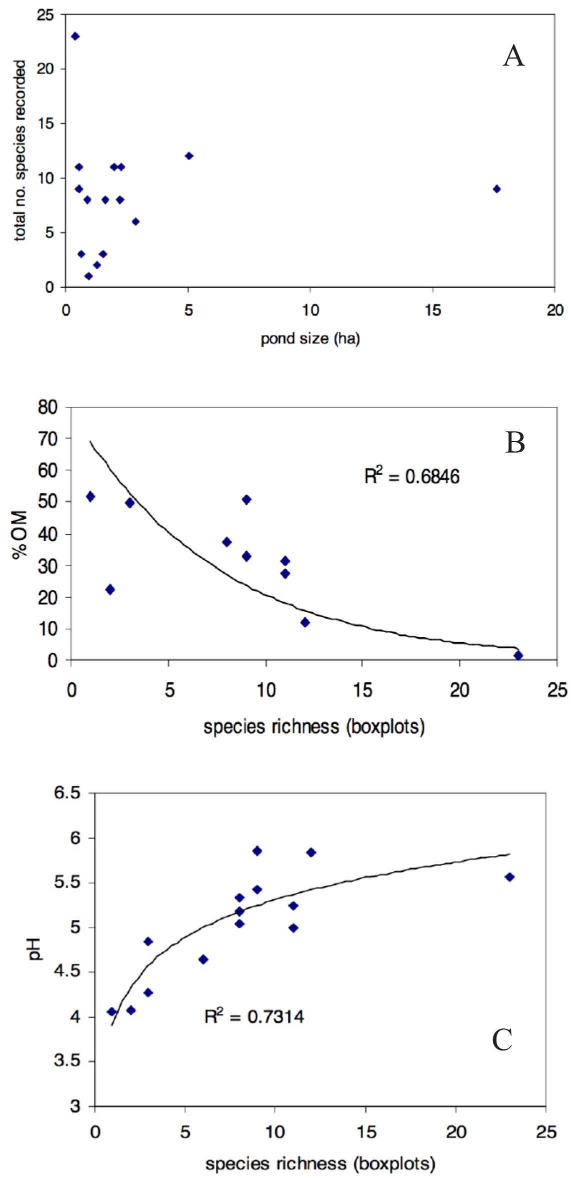


Figure 20.1. Relationships between plant species richness and environmental attributes of Province Lands ponds: (A) pond area, (B) % organic matter in sediments, and (C) pH. (Figures from Smith et al. 2007)

Factors influencing ponds: aquatic vegetation

- Increases in nutrient loading.
- Changes in hydrology.
- Climate change.
- Introduction of exotic species.

21. Ponds: fish assemblages

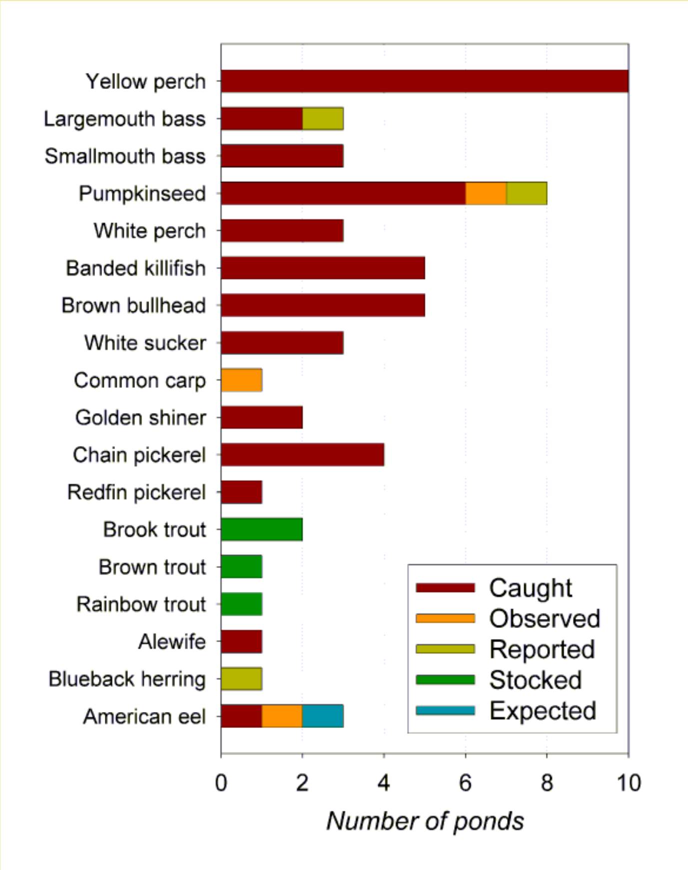


Figure 21.1. Fish species occurrence in CACO ponds. Data show the number of ponds in which each species occurs, by type of record. (Data source: Godfrey et al. 1999)

Key Points

- At least 65% of fish species recorded at CACO occur in ponds.
- These ponds are characterized by warm-water fish assemblages. Pumpkinseed, yellow perch and banded killifish are among the most abundant species.
- Environmental variables thought to play a role in structuring these fish assemblages include pH, pond depth and macrophyte (plant) density.
- There are currently no published multimetric indices that evaluate the overall biological integrity of pond fish assemblages at CACO.

Assessment statement

Good (?). There appears to be no published information suggesting concern about the condition of fish assemblages in CACO ponds.

Rationale

A number of anthropogenic stressors can influence fish community structure, including acidification, eutrophication and habitat alteration. For this reason, fish assemblages are frequently used in the U.S. and elsewhere as one tool to assess the biological integrity of freshwater ecosystems. However, management practices (especially stocking) can complicate the interpretation of fish assemblage data. Although a fish monitoring protocol – along with associated metric development – has not yet been prepared for CACO, this section presents a synopsis of current knowledge about the fish fauna of ponds in the Park.

Benchmarks

The contemporary species composition of CACO ponds is relatively well documented (Godfrey et al. 1999). Relative abundance data for individual species are available from surveys conducted in 1999 and 2000 (Carey and Mather 2008). Historical data on assemblage composition and relative abundance are not available. There is no published re-

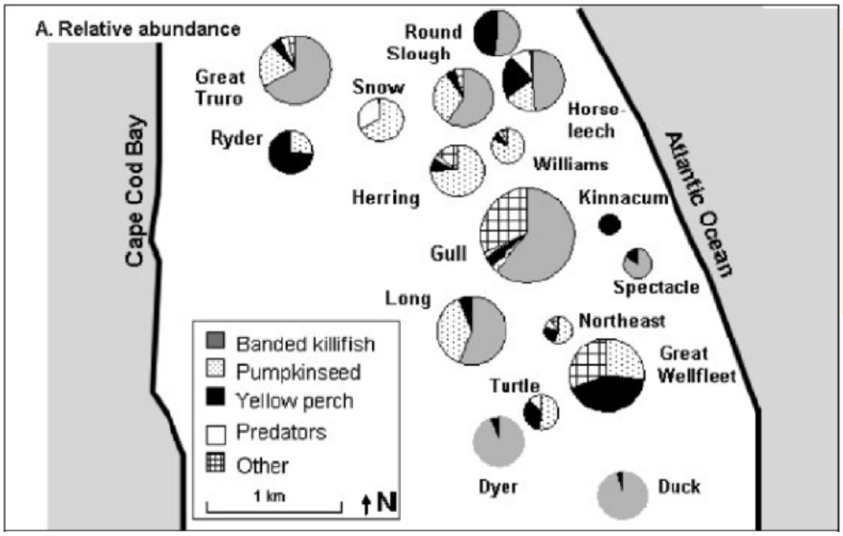


Figure 21.2. Relative abundance (% individuals) of fish taxa in CACO ponds. Top predators include largemouth bass, smallmouth bass and chain pickerel. (Figure from Carey and Mather 2008)

search that evaluates the condition of CACO pond fish assemblages using multi-metric indices of biological integrity. While multi-metric indices of biotic condition exist for fish assemblages in other regions, including the Northeast, these indices have not been evaluated for Cape Cod. It is critical that multimetric indices be tailored to specific geographic areas and not simply be transferred from elsewhere.

Condition

Status

Of the 74 fish species recorded for CACO in the NPSpecies database, 22 are freshwater taxa, while three are diadromous (spend part of their life cycle in salt water). The remaining 49 species are marine. Three freshwater species appear to be stocked under contemporary management practices. However, a total of 14 fish species have been stocked in CACO ponds at some time over the past 100 years. Of these, two (Walleye and Chinook salmon) were early stocking attempts and are not currently found in the Park.

There are two state-listed fish species at CACO (see Topic 7 Rare Species: Fauna). The bridle shiner is found in the Pamet River, while the Three-spined stickleback is classified as threatened only for its freshwater populations.

Ponds at CACO support warmwater fish assemblages; Yellow perch, Pumpkinseed, Banded killifish, Brown bullhead and Chain pickerel are the most commonly observed species (Figure 21.1). Numerically, the former three species appear to be the most abundant (Figure 21.2; Carey and Mather 2008). Cool-water species, such as Brook trout, only occur when stocked.

According to Carey and Mather (2008), four factors most strongly influence the abundance of the three most common species and the top predator group (Bass and Chain pickerel): pH, pond depth, plant density and overall fish species richness.

Diadromous species are further discussed in Topic 22. Estuarine fish assesmblages are covered under Topic 26: Salt marsh - flora and fauna. We do not address the condition of marine fish species in this assessment.

Trends

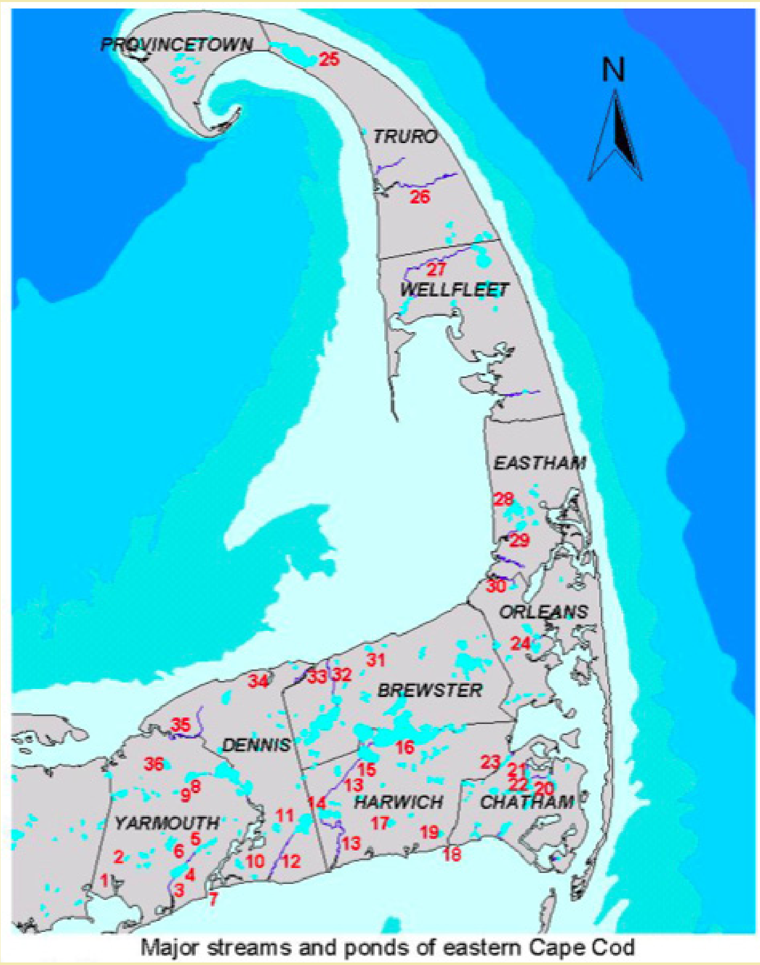
There are no published data on temporal trends in the fish assemblage composition of CACO ponds.

Factors influencing ponds: fish assemblages

- Fish assemblages are potentially influenced by a series of natural and anthropogenic factors, including pH, nutrient enrichment (with consequent impacts on dissolved oxygen levels), stocking, obstructions to fish passage, recreational harvest, and introductions of non-native species.

- However, not all of these factors have been researched at CACO.

22. Diadromous fish: connectivity issues



1	Mill Creek	10	Kelleys Pond	19	Skinequit P.	28	Great Pond
2	Little Sandy P.	11	Fresh Pond	20	Frost Fish Crk.	29	Herring River
3	Parkers River	12	Swan Pond R.	21	Stillwater P.	30	Rock Harbor Crk.
4	Seine Pond	13	Herring River	22	Lovers Lake	31	Cobbs Pond
5	Long Pond	14	West Reservoir	23	Muddy Creek	32	Stony Brook
6	Plashes Pond	15	Hinckley's Pond	24	Pilgrim Lake	33	Quivett Creek
7	Bass River	16	Long Pond	25	Pilgrim Lake	34	Sesuit Creek
8	Mill Pond	17	Grass Pond	26	Pamet River	35	Chase Gardens Crk.
9	Miss Thatchers P.	18	Red River	27	Herring River	36	Matthews Pond

Figure 22.1. Streams and ponds where fish passage has been evaluated in eastern Cape Cod. (Figure from Reback et al. 2004).

Key Points

- In eight catchments of the outer Cape, there are in-stream structures that might interfere with fish migration.
- In approximately one half of these watersheds, one or more barriers have been judged to significantly reduce fish passage.
- In view of declining populations throughout the Northeast, Alewife harvests have been prohibited throughout Massachusetts.
- Historical data on the run sizes for migratory fish are largely absent for outer Cape watersheds.

Assessment statement

Fair. In some watersheds of the outer Cape, there are barriers to fish passage. However, because of the size of these watersheds, the amount of habitat that is currently unavailable to migratory fish is relatively modest.

Rationale

Dams without functional fishways and poorly designed or maintained culverts significantly reduce stream connectivity in many watersheds of the Northeast and elsewhere. Reduced connectivity decreases the amount of habitat available to migratory fish species – anadromous and catadromous taxa (collectively known as 'diadromous' species), as well as others that move between different stream segments and/or ponds while living their entire life cycle within freshwaters (potamodromous taxa).

Improving stream connectivity has become an important focus of watershed restoration in many parts of the country. A key requirement for prioritizing restoration efforts is to survey stream barriers and evaluate the extent to which they impede fish passage.

Benchmarks

Historical data on the size of migratory fish runs in watersheds of the outer Cape are not available. Alewife counts in the Herring River were made (apparently for the first time) in 2009. A suitable benchmark for diadromous fish habitat would be a decreasing number of barriers to fish passage.

Condition

Status & Trends

Three anadromous species have been recorded from CACO – Alewife or River herring (*Alosa pseudoharengus*), Blueback herring (*A. aestivalis*) and White perch (*Morone americana*). (Note that White perch is listed in the NPSpecies database as being a freshwater taxon - see Appendix A.) The catadromous American eel (*Anguilla rostrata*) also occurs on the outer Cape. Alewife appears to be the most common of the diadromous species. In recent years, Alewife populations throughout the Northeast have declined dramatically. As a result, in 2005 the Massachusetts Division of Marine Fisheries (MA-DMF) enacted a 3-year ban on the harvest, possession or sale of this species. Since the moratorium, River herring populations have not rebounded significantly. In November 2008, DMF extended the moratorium to 2011, to further protect the fishery (APCC 2009).

The Association to Preserve Cape Cod conducts volunteer-based Alewife surveys in certain towns of the Cape (APCC 2009). In the first year of counts in the Herring River, the Alewife run was estimated at 31,590 fish.

The MA-DMF has conducted a survey of fish passages throughout the state (Reback et al. 2004). In the six outer Cape towns, eight streams have been identified with potential fish passage barriers (Figure 22.1, Table 22.1). In four of these systems, passage is currently considered to be acceptable, assuming the structures are properly maintained. In three streams, barriers are an obstacle to fish passage. In the case of Pilgrim Lake (Truro / Provincetown), diadromous fish currently have access to this system. However, any future tidal restoration project would presumably reduce the amount of freshwater habitat available to Alewife and White perch.

The connectivity of some kettle ponds (e.g. Higgins, Gull and Williams) has be anthropogenically enhanced by ditching - probably this occurred during colonial or pre-colonial times. In addition, the Herring River below Herring Pond has been converted into a ditch to make it better suited for herring runs (R. Cook, CACO, pers. comm.).

Factors influencing diadromous fish

- Stream barriers – dams without effective fishways and improperly designed and/or maintained culverts and other stream crossings.

Table 22.1. Summary of fish passage conditions in eight catchments of the outer Cape.

Stream Name	Stream Length (miles)	Anadromous Species Present	Number of Obstructions	Fishway Present?	Comments
Frost Fish Creek	0.8	Alewife	1	No	Little potential for additional restoration. Upstream obstructions (into 3 small impoundments) have been removed.
Lovers Lake	0.4	Alewife	4	Yes (all four)	Upstream habitat should support productive fishery assuming fish passage structures are well maintained.
Pilgrim Lake (Orleans)	0.6	Alewife	2	Yes / Yes	Passable with proper flow maintenance. Downstream structure will need replacement in the near future.
Pilgrim Lake (P-town)	0.4	Alewife, white perch	1	No	Tidal restoration will reduce habitat for these species.
Pamet River	4	Alewife, blueback, trout	1	No	Tide gate reduces access by fish. However, little upstream habitat so restoration priority (for fish) is low.
Herring River (Wellfleet)	4.7	Alewife, blueback, white perch	1	No	4 kettle ponds which are source of Herring River provide 157 acres of habitat for alewife. Only obstruction impacting this species is dike and tide gate. Gate is passable at some times, but impact on fish populations is not clearly understood - but losses of juveniles occurs when dissolved oxygen levels are reduced. Little can be done to improve habitat for fish without removal of dike.
Herring River (Eastham)	1.3	Alewife	1	Yes	Stream baffles and weir-pool fishway allow alewife to ascend to Herring Pond.
Rock Harbor Creek	1.5	Alewife, white perch	2	No / No	Small runs supported in past. Some fish pass, but barriers limit the populations. Fishery also impacted by high salinities and seasonally low dissolved oxygen because of eutrophication.

23. Groundwater: quantity

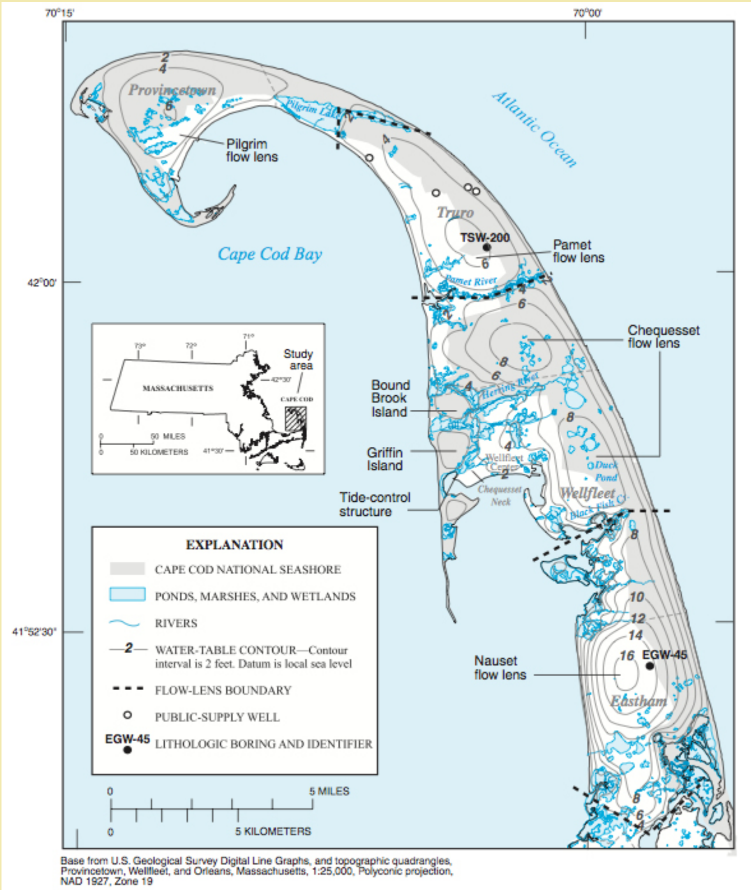


Figure 23.1. The four flow lenses of the Lower Cape Cod aquifer system. (Figure from Masterson 2004)

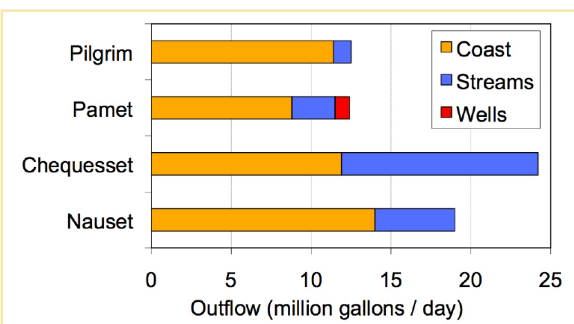


Figure 23.2. Modeled outflows from the four aquifer lenses on Lower Cape Cod. Inflow to each lens equals outflow. All inflow is via precipitation. (Data source: Masterson 2004)

Key Points

- Four groundwater lenses on Lower Cape Cod supply all drinking water, provide numerous ecosystem services and receive septic effluent.
- Municipal water withdrawals from the Pamet lens represent 7% of the entire hydrologic budget for that section of the aquifer.
- Changes in water extraction regimes will likely affect kettle-hole ponds, some streams and some wetlands.
- Sea-level rise is affecting groundwater levels and is predicted to result in a thinning of the Pamet lens as well as other lenses.

Assessment statement

Significant concern. Development pressures and climate change threaten a series of adverse impacts on a critically important resource for the Lower Cape.

Rationale

The aquifer of Lower Cape Cod is a critically important resource. It provides multiple ecosystem services and is used for domestic water supply, as well as being a recipient for wastewater from on-site disposal systems. Increasing development of this part of the Cape brings concerns that there will be negative impacts on groundwater quality and quantity and that these impacts may in turn influence surface water resources (ponds, wetlands) and coastal areas. In addition to increasing use of groundwater resources by residential wells, there is also a concern that large-capacity municipal supplies may contribute to reductions in groundwater discharge to surface waters and to an increase in saltwater intrusion. Future sea-level rise is projected to have a number of impacts on the quantity (depth) of fresh groundwater levels, as a result of both increasing water table elevations and changing patterns of precipitation run-off (Nuttle and Portnoy 1992).

Benchmarks

A network of over 30 wells is providing groundwater level data for the Lower Cape. Some wells have been monitored since the 1950s, while others came on line in the 1970s. These data, together with hydrologic modeling, provide a wealth of information to predict future trends in groundwater quantity and further understand how regional development patterns, increasing water use, global climate change and sea-level rise may influence the ecosystems of Cape Cod.

Key metrics for assessing change in groundwater resources will likely include water table surface area, temporal and spatial patterns in water table altitude, and direction of water flow (McCobb and Weiskel 2002). To our knowledge, numerical criteria for characterizing resource condition based on these metrics have not been published.

Condition

Status & Trends

A detailed review of the Lower Cape Cod aquifer (Masterson, 2004; also Masterson and Portnoy 2005) includes results from a series of simulations designed to predict future scenarios resulting from changing groundwater-use patterns, sea-level rise and removal of tidal restrictions. The following overview is based on this study. (Note: we retain English units used by Masterson.)

- The Lower Cape Cod aquifer systems consists of four groundwater lenses (Figure 23.1). Lenses are separated from each other by surface-water discharge areas, which form wetlands and streams. Currently the lenses are hydraulically separate from each other (although there is anthropogenic water transfer – see below).
- These lenses supply all drinking water for the towns of Provincetown, Truro, Wellfleet and Eastham. Municipal supplies provide drinking water to Provincetown and portions of Truro and Wellfleet – elsewhere on the Lower Cape, residents obtain drinking water from shallow, small-capacity domestic wells.
- There is some inter-lens transport of water. For example, the Pamet lens supplies drinking water to Provincetown. Most water transferred to Provincetown is subsequently discharged to the Pilgrim lens and therefore is 'lost' to the Pamet lens. However, since part of Truro also obtains drinking water from the Provincetown water-supply system, a limited amount of return flow to the Pamet lens does occur via discharge from properties that are connected to this system (Cape Cod Commission 2008).
- Across all four lenses, 68% of outflow goes to the coast, while 31% goes to streams (Figure 23.2). Municipal withdrawals represent just 1% of the total aquifer budget. However all of this pumping withdraws water from the Pamet lens, and is equivalent to 7% of the total budget for that lens.

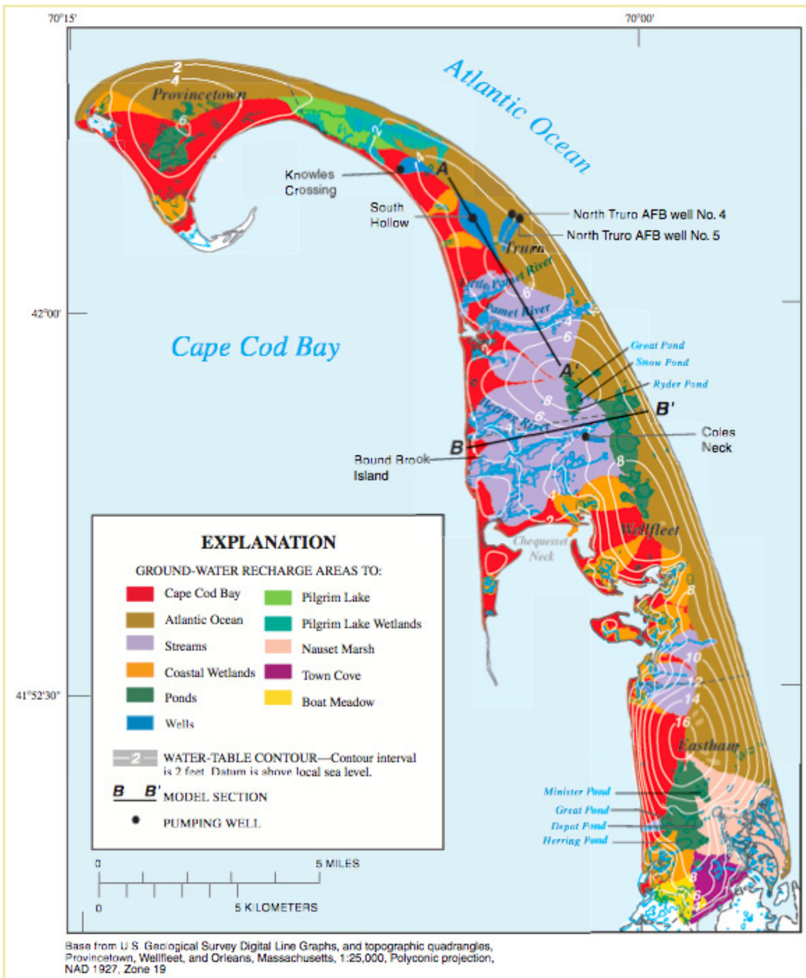


Figure 23.3. Groundwater recharge areas to public-supply wells, ponds, streams and coastal areas, based on 2002 average pumping and recharge conditions. (Figure from Masterson 2004)

Groundwater: quantity, continued

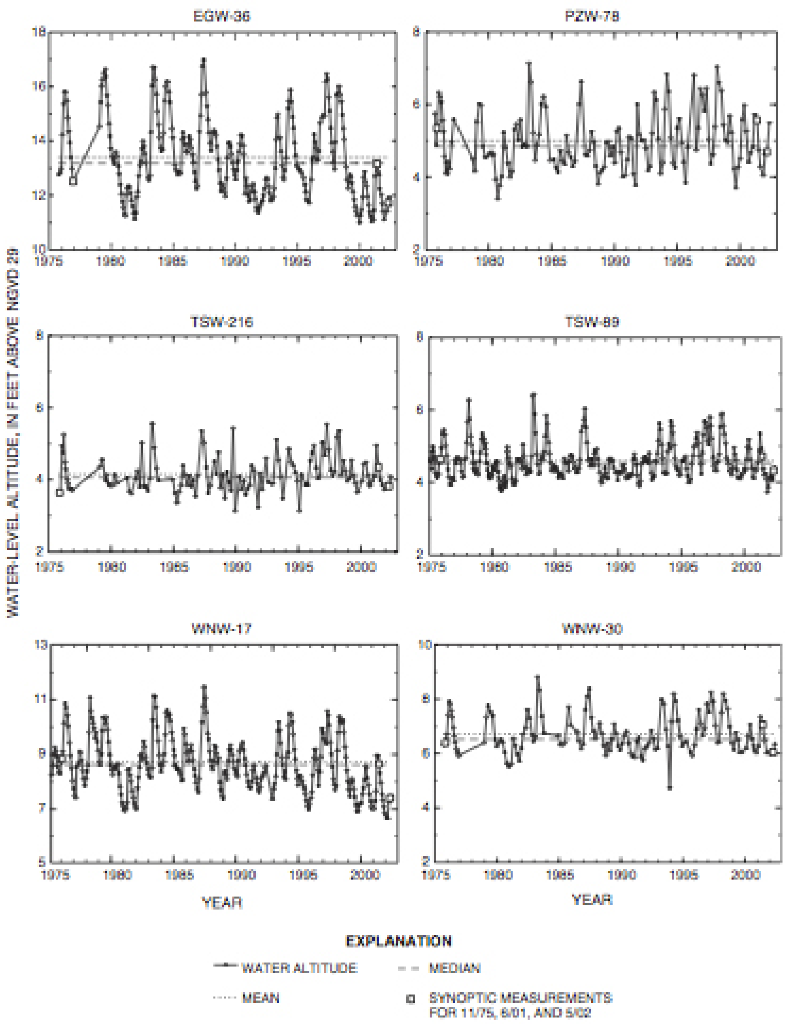


Figure 23.4. Water levels in long-term observation wells, Lower Cape Cod. Well locations are shown in Figure 23.5. (Figure from Masterson 2004)

- Groundwater recharge areas are shown in Figure 23.3. There is more groundwater flow to streams in the Chequesset lens than in the other lenses, largely because of the area occupied by the Herring River and its tributaries.

- Kettle-hole ponds influence, and are influenced by, groundwater levels. Ponds represent areas of net recharge to the aquifer since annual precipitation to the pond surface exceeds evaporation. Ponds in the Chequesset lens are near the top of the water table mound, while those in the Nauset lens are lower. Consequently the Nauset lens ponds have larger recharge areas and higher flow (Figure 23.3). This difference in hydrologic position may influence how ponds are influenced by changes in pumping and recharge regimes.

- Ponds in the Pilgrim lens are not kettles but were formed from more recent flooding of wetlands. Consequently, the responses of these ponds to groundwater hydrology may not mirror that of the kettle ponds.

- Depth to the freshwater-saltwater interface varies among lenses and is directly proportional to the height of the groundwater mound. In the Nauset lens, the depth to the freshwater-saltwater interface is approximately 350 ft, while it is about 250 ft in the Pamet lens.

- Saltwater intrusion is of greatest concern in the Pamet lens because this part of the aquifer supplies nearly all of the municipal water systems of the Lower Cape. There are three active well fields withdrawing water from the Pamet lens – the well field with the greatest threat of saltwater intrusion is at Knowles Crossing, located about 300 m inland of Cape Cod Bay. Simulations of different recharge and pumping scenarios suggest that, while groundwater levels are affected, the position of the freshwater/saltwater interface does not vary appreciably, even under prolonged drought conditions.

- Groundwater levels are being affected by rising sea-level. For example, the level in an observation well near Knowles Crossing rose an average of 2.1 mm/yr over the 51-year period from 1950. The magnitude of the water level increase appears to be influenced by proximity to non-tidal surface-water bodies, such as ponds. These surface-water systems appear to dampen changes in groundwater levels – reducing declines in response to pumping and reducing increases in response to sea-level rise. Figure 23.4 illustrates variation in groundwater levels in six wells in four towns of the Lower Cape.

- Simulations suggest that sea-level rise will result in a thinning of the Pamet lens, since the rate of sea-level rise exceeds the rate at which the water table elevation increases.

- Potential new municipal wells in Eastham are predicted to cause reductions in stream flow in this area, with the greatest impact likely to occur at Hatches Creek. Depending on the pumping scenario, the streamflow reduction in Hatches Creek could be as much as 56% of pre-pumping conditions.

- Proposed expansion of public water supply in Wellfleet may influence water levels in kettle-hole ponds, particularly Duck Pond because it is located high up on the Chequesset lens. Average pumping conditions are predicted to reduce water levels in Duck Pond by about 0.4 ft. The annual fluctuation in pond water levels is predicted to change from 1.2 feet at the present time, to 1.4 ft. under the new pumping regime. Changes in pond water levels will have most effect on littoral areas.

For more on groundwater hydrology, see these topics: 16- Parabolic Dunes & Wetlands; 17- Wetlands: distribution, hydrology & biology; 24- Groundwater: Quality; and 25- Tidal Restrictions and Restorations.

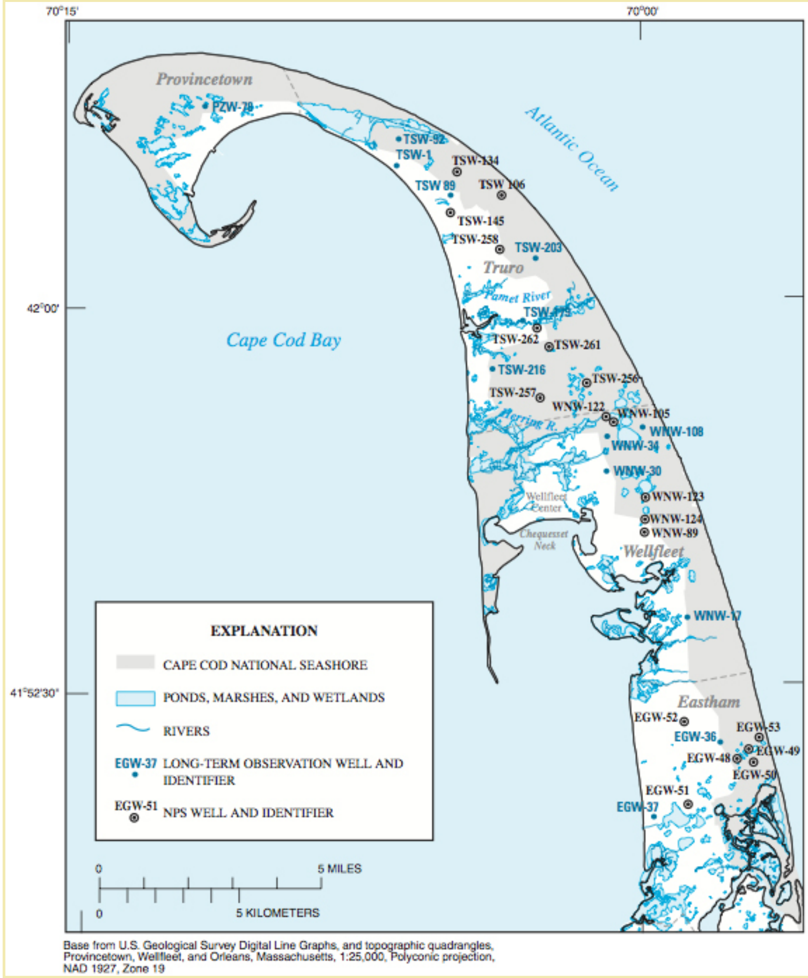


Figure 23.5. Long-term observation wells and CACO coastal ecosystem wells. (Figure from Masterson 2004)

Factors influencing groundwater quantity

- Changing patterns of groundwater extraction and use.

- Climate change and rising sea-level.

24. Groundwater: quality

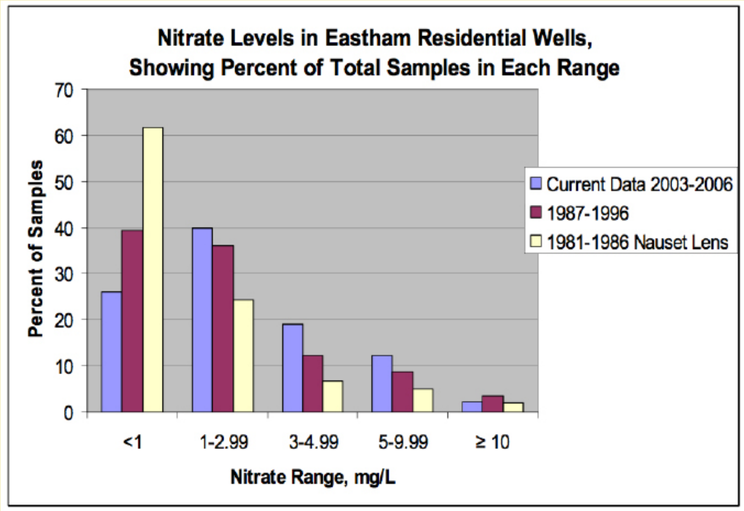


Figure 24.1. Trend in groundwater nitrate concentrations in Eastham wells. (Figure from Barnstable County Department of Health and the Environment 2007)

Key Points

- Wastewater and landfills are the primary contaminant sources for groundwater in the outer Cape. Although all landfills are now closed, they continue to leach contaminants.
- Nitrate concentrations in wells have increased over the past two decades (Figure 24.1)
- Increasing development has the potential to further increase groundwater nitrogen levels, which in turn may contribute to nutrient enrichment of surface waters.
- Leaking underground storage tanks almost certainly exist. However, these tanks are external to CACO. Furthermore, their contribution to groundwater contamination in the CACO region has not been quantified.

Assessment statement

Significant concern. There is evidence that nitrate concentrations are increasing in groundwater.

Rationale

Pollutant sources to the outer Cape Cod aquifer include septic system discharge, landfill leachate and surface runoff. Pollutants include toxics, pathogens and nutrients. All have potential human health impacts. Increased nutrient loading rates promote eutrophication of surface freshwaters and estuaries (Portnoy et al. 2007). Residential and commercial development on Cape Cod has been steadily increasing on the Outer Cape since the 1960s (Godfrey et al. 1999). This development increases the potential for elevated pollutant loading to the area's critically important aquifer system. Faulty septic systems are the largest contributor of pollutants to inland and coastal water bodies (Godfrey et al. 1999).

Benchmarks

Data on nitrate concentrations in well water are available from the 1980 through the present time. This information has been used to document increasing trends in nitrate contamination of groundwater. The state and federal maximum contaminant level for nitrate is 10 ppm (mg/L). A concentration of < 1 ppm is considered to represent a natural background level for nitrate in groundwater.

Groundwater salinity (and/or conductivity) is likely to become an important metric for evaluating seawater intrusion.

Condition

Status & Trends

Nitrogen

Residents of the towns of Truro, Wellfleet, Eastham and Orleans rely entirely on on-site wastewater disposal (septic systems). Provincetown and Chatham have municipal wastewater systems (Table 24.1). All of the on-site systems discharge wastewater to the aquifer – the level of treatment presumably depends in part on the age, type and condition of the system. Water and contaminants flow from the aquifer to streams or directly to the coast (Figure 24.2). A survey of wells within the Pamet lens revealed an average nitrate concentration of 0.92 ppm (mg/L) (Cape Cod Commission 2008). Thus, while the Pamet River watershed contains some of the densest residential development within the town of Truro, average groundwater nitrogen concentrations currently remain well below the federal maximum contaminant level. The river drains to Pamet Harbor which is listed for development of a nitrogen TMDL (Total Maximum Daily Load).

The town of Eastham extracts water from the Nauset lens (a map showing the Lower Cape Cod aquifer lenses is included in Topic 23- Groundwater: quantity). Nitrate levels in Eastham wells have been increasing in recent years and many wells now have nitrate concentrations above the natural background level of < 1 ppm. A 2003-2006 survey of well water revealed a higher proportion

Table 24.1. Wastewater treatment facilities on the outer Cape. Data are current as of 2008.

(Source: Cape Cod Water Protection Collaborative)

Town	Centralized system?	# Indivdual on-site systems (est.) (1)	# Cluster systems (2)	# Satellite plants (3)
Chatham	Yes	5,900	6	1
Eastham	No	5,400	3	1
Orleans	No	4,500	7	3
Provincetown	Yes	1,400	n/a	0
Truro	No	1,900	2	0
Wellfleet	No	3,300	2	1

(1) Generally, septic tank and leaching field systems serving a single home or business, and located on the same parcel as the home or business.

(2) Systems for wastewater collection, treatment and disposal that involve multiple parcels and/or multiple wastewater generators, served by a single system.

(3) Facilities for wastewater collection, treatment and disposal that require a DEP groundwater discharge permit and are intended to serve a closely defined area. They serve e.g. condominium projects, nursing homes, and shopping centers.

Groundwater: quality, continued

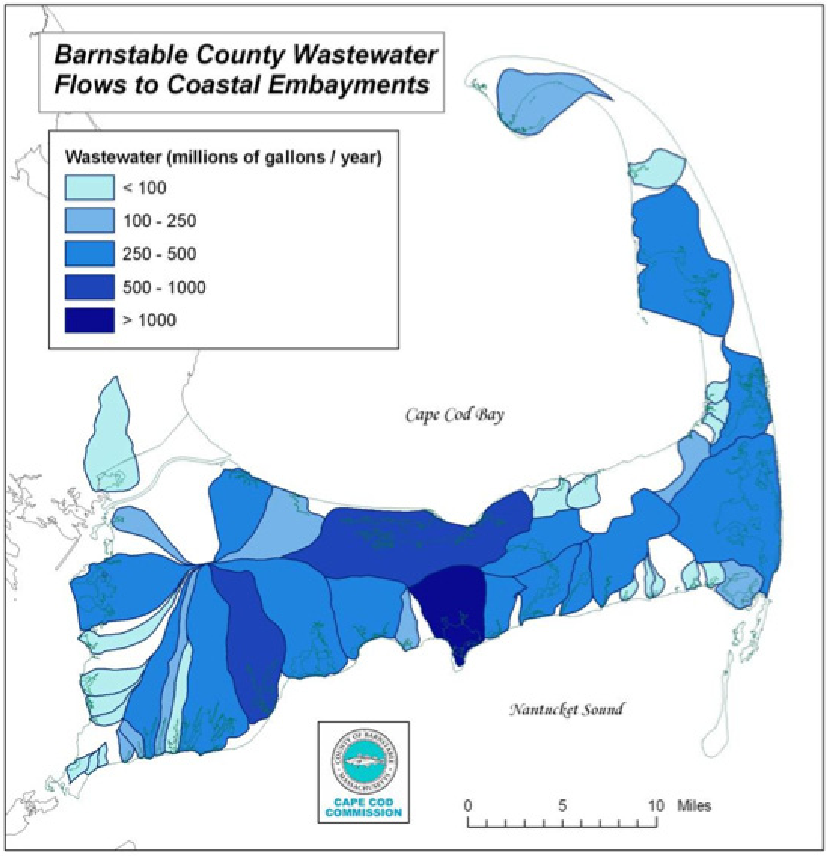


Figure 24.2. Map showing volumes of wastewater flowing to coastal embayment. (Source: Cape Cod Water Protection Collaborative)

of samples with nitrate concentrations > 1 ppm than was the case for samples collected approximately 20 years earlier (Figure 24.1; Rask 2007). The Federal and State maximum contaminant level (MCL) for nitrogen in drinking water is 10 ppm (MA DEP 2009). Less than 5% of Eastham samples exceeded this limit in all survey years.

Among the three towns of Provincetown, Wellfleet and Eastham, average nitrate concentrations in residential wells are positively associated with the winter population density – lowest values are observed in Truro, highest in Eastham (Figure 24.3).

Other Contaminants.
Other sources of contaminants to the aquifer include landfills and leaking underground storage tanks. Godfrey et al. (1999) provides an overview of these contaminant sources, which is summarized below.

There are five landfills – now closed - located on the outer Cape. The Provincetown and Truro landfills are within CACO, while the Wellfleet landfill is adjacent to the Park boundary. The Provincetown landfill is capped but not lined. Until 1991, a lagoon stored septic waste which was allowed to infiltrate the groundwater. Well samples have documented groundwater contamination (organic and inorganic constituents) from the Provincetown landfill – contaminants flow via groundwater from the landfill to Provincetown Harbor.

The Truro landfill is on the Chequesset lens and was in operation for 35 years until its closure in 1990. A landfill leachate plume travels to the Pamet River. Estimates suggest that it takes about 9 years for landfill leachate to travel to the river (Godfrey et al. 1999). The Wellfleet landfill is not lined or capped. The contaminant plume from this landfill flows to the Herring River. The Eastham landfill was unlined as of 1999. Wells down-gradient from this landfill have been shown to contain contaminants.

Data on the extent to which leaking underground storage tanks may be contaminating groundwater on the outer Cape are unavailable.

Factors influencing groundwater quality

- Threats to groundwater quality include: wastewater from residential and commercial sources; leaking fuel-storage tanks; hazardous waste-disposal sites; agriculture; stormwater runoff; road salt; landfills (Cape Cod Commission 2008).

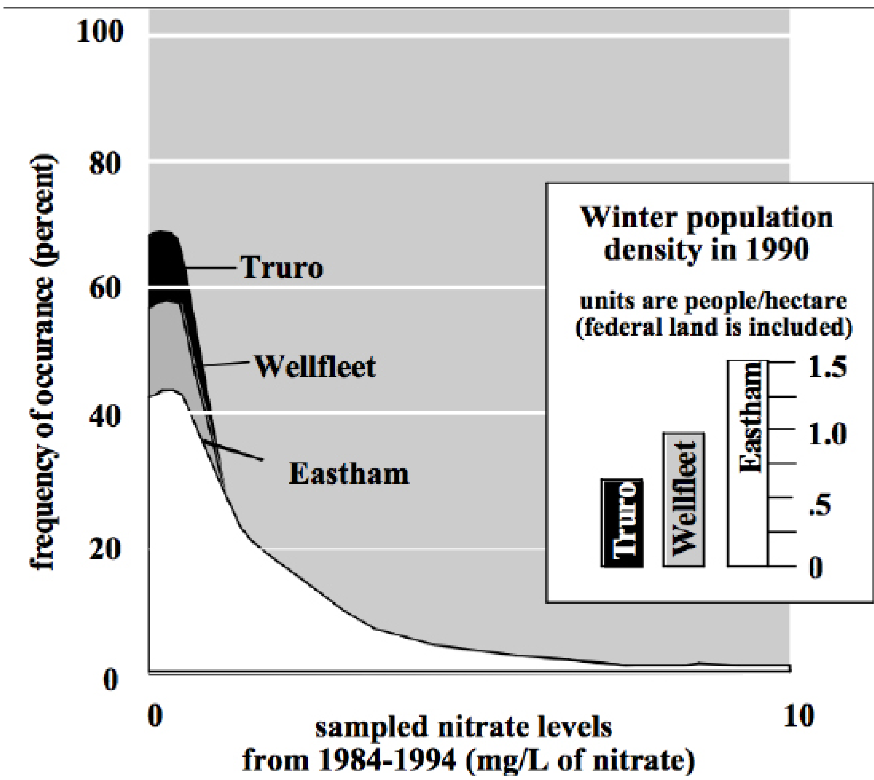


Figure 24.3. Nitrate concentrations in groundwater in three towns with different settlement densities. (Figure from Rask 2007)

25. Tidal restrictions: occurrence, impacts & restoration

Figure 25.1. Priority tidal restriction sites on Cape Cod. These sites have been targeted for restoration under the Cape Cod Water Resources Restoration Project, signed December 23, 2009.

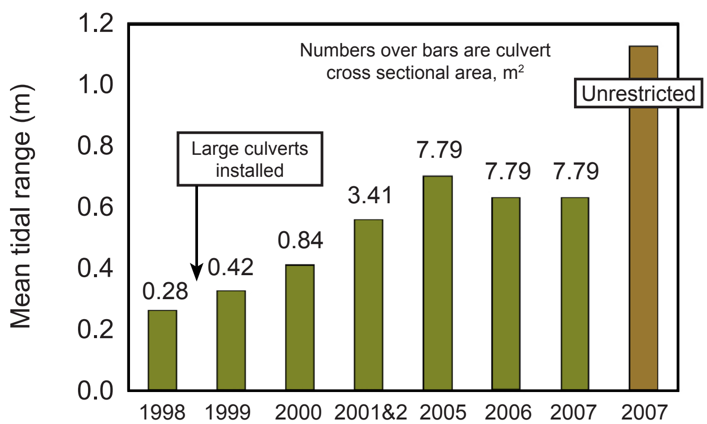


Figure 25.2. Changes in mean tidal range in Hatches Harbor marsh following partial tidal restoration. The first seven bars (from the left) show data from a site 500 m on the landward (restricted) side of the dike. The tidal range for the seaward (unrestricted) side of the dike is shown for 2007. (Figure adapted from Smith et al. 2007)

East Harbor Lagoon. (Photo: Barbara Dougan. Source: Portnoy et al. 2007)

Key Points

- Since the 1800s, dikes and other structures have resulted in tidal restrictions at over 30 sites on the outer Cape.
- Ecological impacts from these restrictions vary but can be substantial, involving loss of large areas of salt marsh, conversion of estuarine plant and animal assemblages to more freshwater or upland types.
- At CACO, large-scale restoration of tidally-restricted systems has begun at two sites (Hatches Harbor and East Harbor Lagoon) and is planned for another (Herring River).

Assessment statement

Significant Concern – for systems that are still tide restricted. Improving / Good – for systems that are being restored.

Rationale

Numerous structures exist throughout Cape Cod that restrict tidal flow into and out of estuaries and bays. In some cases, structures were intentionally designed to reduce flow (tide gates); in others, the hydrologic changes are unintended consequences of inadequately sized culverts. By damping upstream tidal amplitude, these restrictions can result in a broad range of ecosystem impacts, including alteration of the structure and function of salt marshes (Dionne et al. 1997, Roman et al. 2002, Wozniak et al. 2006), changes in surface- and ground-water quality (Portnoy 1999, Portnoy and Allen 2006, Martin 2008), and reduction in migratory fish runs (Roman et al. 1995).

Benchmarks

An appropriate goal is the absence of anthropogenically-caused restrictions to tidal flow in catchments that extend onto Park land. Benchmarks for evaluating the impacts of individual restoration projects include physical, chemical and biological attributes of tidally restricted ecosystems – as determined by both field data and modeling output. Published data are summarized below. Other benchmarks include (a) a trend of decreasing invasive plants, and (b) hydrology that is similar to reference (unrestricted) marshes.

Condition

Status & Trends

Over 30 tidal restriction sites occur on the outer Cape (Table 25.1). Eight sites are located within CACO or near its boundary. Thirteen sites influence streams and wetlands that extend into the Park. Approximately 1,400 ha of salt marsh have been diked on Cape Cod over the past 350 years (Portnoy et al. 2003). Over half of this area is within CACO (Smith et al. 2009). The first major restoration project is at Hatches Harbor which began in 1999. Restoration has also begun for East Harbor Lagoon. Other tidal restrictions are either being studied for potential mitigation or are further along in the planning stage.

In 2009, a major federal funding initiative was authorized that will implement 76 watershed restoration projects across Cape Cod. Included in the project list is the restoration of 1,500 acres of degraded salt marshes and 4,200 acres of migratory fish runs. Priority tidal restriction sites are shown in Figure 25.1.

This section presents a synopsis of available information on the impacts or potential (modeled) impacts of tidal restoration projects on the outer Cape.

Hatches Harbor: Hatches Harbor has been diked since 1930, with the result that about half of the marsh became non-tidal (Smith et al. 2009). Restoration of this sytem began in 1999 with the installation of larger openings through Hatches Harbor Dike. These gates were opened incrementally at that time and in later years, with the final 20-cm increase in culvert opening occurring in 2005 (Smith et al. 2007). Full restoration of tidal flow to this system is not planned because that would impact infrastructure at the Provincetown airport. Increased tidal exchange has resulted in an approximate doubling of the tidal range on the landward side of the dike (Figure 25.2). In 2007, the restricted tidal range was about 57% of tidal range on the seaward side of the dike, as compared to only 26% prior to new culvert installation in 1999.

Restoration impacts on vegetation and porewater chemistry have been studied along a series of transects on both sides of the dike (Smith et al. 2007, Smith et al. 2009). Key findings from this research include the following:

- After restoration, porewater salinity increased behind the dike. By 2006, all sampling sites along a landward transect exhibited a salinity greater than 25 ppt (Figure 25.3).
- Approximately two-thirds of the taxa recorded in 1997 (pre-restoration) declined in cover and frequency of occurrence by 2006. Declining taxa included freshwater, euryhaline and upland species (Figure 25.4). Only salt marsh plants increased in abundance.
- Overall, the area of salt-marsh vegetation (primarily composed of *Spartina alterniflora*) expanded substantially beyond the original 5 ha present in 1995. The restricted side of Hatches Harbor now contains all species of plants (with one exception) that occur on the unrestricted side.
- Phragmites was more abundant in 2006 than in the pre-restoration marsh. However, its distribution has changed – it has shifted upslope toward the wetland periphery.
- Salt-killed vegetation (especially Phragmites) produces a barrier which appears to impede the dispersal of seeds and propagules of salt-marsh species, thus slowing marsh development (Smith 2007).

East Harbor Lagoon: This 291-ha lagoon and salt marsh was isolated from Cape Cod Bay following construction of a dike in 1868, after which salinity declined to near freshwater levels. Water quality declined, producing oxygen depletions and fish kills in 2001. Partial tidal flow was restored in 2002 by opening valves in the culvert that connects the lagoon to the Bay (Portnoy et al. 2007). This has resulted in salinity increases throughout much of the lagoon and the return of estuarine biota.

Tidal restrictions: occurrence, impacts, restoration, continued

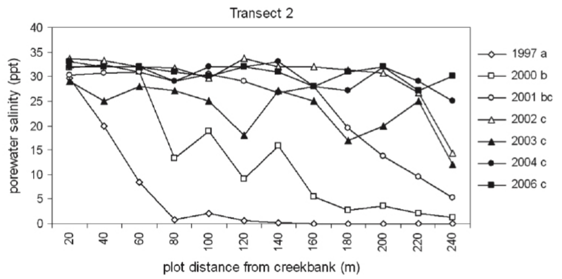


Figure 25.3. Porewater salinities along a transect on the landward (restricted) side of the Hatches Harbor dike. Statistically significant mean values are indicated by different letters in the legend. See Figure C for transect location. (Figure from Smith et al. 2009)

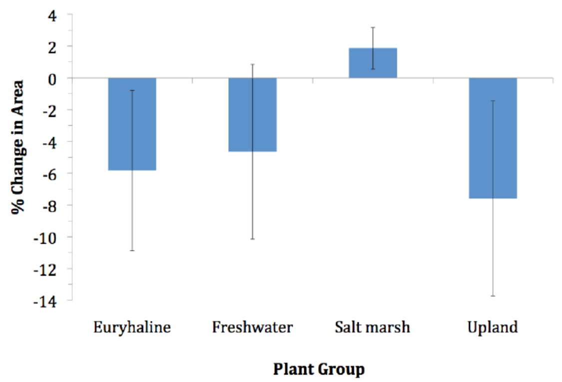


Figure 25.4. Change in mean % cover of plants in Hatches Harbor, 1997-2006, by functional group. Restoration of the system started in 1999. Data are means, across all taxa within each functional group, of percent change in % cover. Vertical bars are standard deviations of means. (Data calculated from data in Smith et al. 2009)

Table 25.1. Number of tidally restricted sites on the outer Cape, as of 2001. (Source: Cape Cod Commission 2001)

Town	Total number of sites	# sites within or on the boundary of CACO	# sites impacting wetlands extending into CACO
Provincetown	2	2	2
Truro	7	3	5
Wellfleet	6	1	4
Eastham	9 (1 shared)	2	2
Orleans			
Chatham	7 (2 shared)	0	0

Key results from research on the East Harbor restoration effort (Portnoy et al. 2007) include:

- Tidal fluctuations in the main lagoon are very low (0.1 ft, at the most) because the opened culvert still restricts tidal flow from Cape Cod Bay.
- Salinity increased from about 4 ppt prior to valve opening to 25-27 ppt (summer) and 20 ppt (winter). Increased tidal forcing following the 2002 culvert opening has been insufficient to restore salinity to the Salt Meadow portion of the system. (The name of this area refers to the fact that it was salt marsh prior to dike construction in the 1800s.)
- Average surface dissolved oxygen concentrations remained close to saturation throughout most of the lagoon in 2007, although severe localized depletions continued to occur at Salt Meadow.
- Phytoplankton densities are low and water transparency is generally high. Higher transparency may be a result, in part, of the elimination of the carp population as salinity has increased. Carp promote turbidity by disturbing sediments and also graze on aquatic vegetation. Reduced grazing has likely promoted greater macrophyte biomass, in turn allowing these plants to compete more effectively for available nutrients, thereby reducing phytoplankton growth. The establishment of filter-feeding bivalve populations has probably also contributed to increased water clarity.
- Dense beds of macroalgae (*Cladophora* and *Ulva intestinalis*), as well as filamentous cyanobacteria, occur in early- to mid-summer, but die back in late summer. Die-offs have contributed to oxygen depletion which, in 2006, led to a die-off of clams and suppression of aquatic macrophytes. However, macroalgae abundance was lower in 2007 than in previous years.
- Widgeon grass proliferated throughout the lagoon in 2004 but, by 2007, was much less abundant.
- Macroalgal growth appears to be nitrogen limited. Nitrogen sources may include:

lagoon sediments and wetlands, fixation by cyanobacteria, atmospheric deposition and tidal inflow. The relative contribution of each of these sources is currently unknown.

- Dissolved inorganic nitrogen concentrations in the lagoon are low. However, initial data suggest that inflowing water from the Bay dilutes lagoon inorganic nitrogen concentrations. Consequently any future project designed to increase tidal flushing should further reduce nitrogen levels in the lagoon.
- Phragmites in the Moon Pond portion of the system has declined in vigor, particularly at low elevations.
- Re-establishment of salt marsh vegetation is being promoted by seeding and other propagation measures.
- Fecal coliform levels are very low in the main lagoon except after heavy precipitation. They remain high in northwest cove and in freshwater discharging from Salt Meadow.
- Estuarine fauna (finfish, shellfish and other groups) continue to reestablish throughout the lagoon. A salt-marsh fish assemblage is replacing the former fresh/brackish fish assemblage. Salt Meadow retains its largely freshwater character since the enhanced tidal flow is still insufficient to substantially influence this section of the system.
- The former Alewife run into East Harbor has been virtually eliminated following the salinity increase.
- In the winter of 2006-2007, large numbers of bay and sea ducks used the lagoon – the first time that this had occurred in several decades.
- Following opening of the culvert, molluscan communities began to rapidly recover. Currently species richness throughout East Harbor is positively correlated with salinity and negatively with distance from the culvert (Thelen and Thiet 2009). The salinity of northwest cove remains too low to support a diverse molluscan assemblage

Because the current culvert is insufficient to permit full tidal flushing of the East Harbor lagoon, there is interest in increasing the size of the connection to Cape Cod Bay. Hydrodynamic modeling demonstrates that increasing channel width would increase the flushing rate and the intertidal area within the lagoon (Figure 25.5).

Modeling groundwater hydrology under future scenarios of additional connectivity to Cape Cod Bay is an important component in understanding how future development of Beach Point (where residential wastewater disposal is on-site) will influence nutrient loading to the lagoon and its aquifer. Martin (2008) studied groundwater hydrology underlying the Beach Point barrier beach. The primary objective was to compare water flow toward, and discharge to, the East Harbor lagoon under existing conditions and with greater tidal flow to the lagoon.

The water table under the beach fluctuates, rising as saline water infiltrates the beach at high tides, and falling as this water drains back at low tides. The vertical zone of groundwater fluctuation is wedge-shaped, with greater amplitude toward the Bay. The surface elevation of the lagoon currently fluctuates by only about 0.25 feet in response to tidal oscillations of about 11.5 feet in Cape Cod Bay. Under the scenario of a 50-m inlet (the maximum possible without encroaching

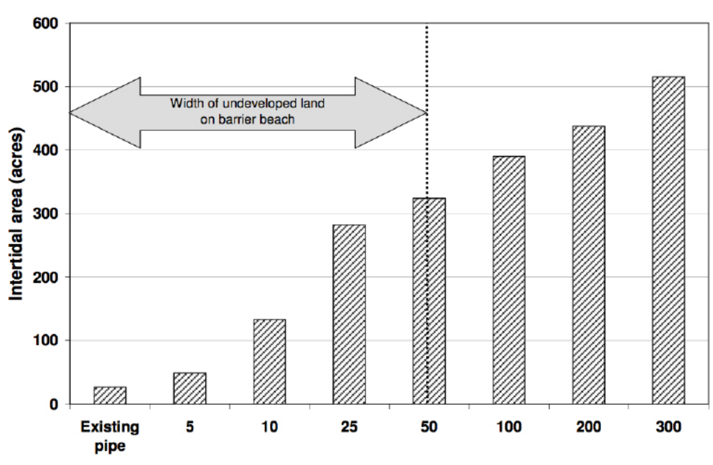


Figure 25.5. Model-predicted increase in intertidal area with increasing inlet width through the Beach Point barrier beach. Inlet depth was held constant at -1 m-NAVD. (Figure from Portnoy et al. 2007, based on work of Spaulding and Grilli)

Tidal restrictions: occurrence, impacts, restoration, continued

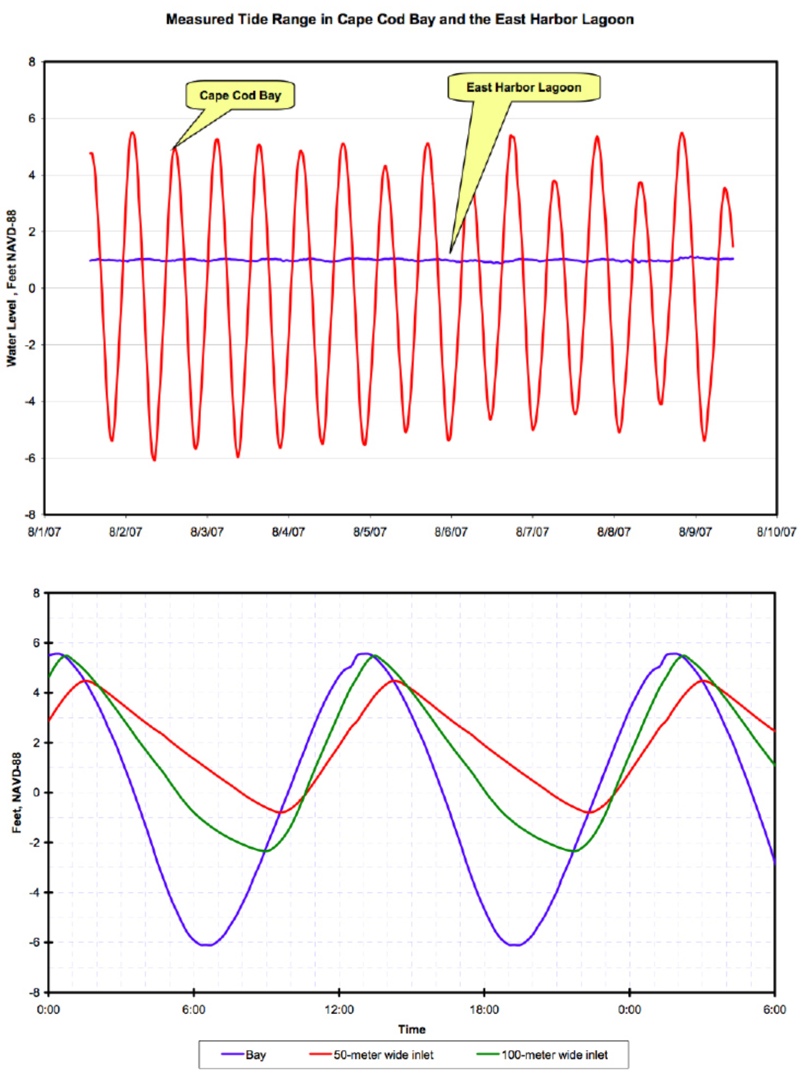


Figure 25.6. Tidal fluctuations in Cape Cod Bay and East Harbor lagoon under current conditions (A) and simulated for two re-designed tidal inlet structures (B). (Figures from Martin 2008)

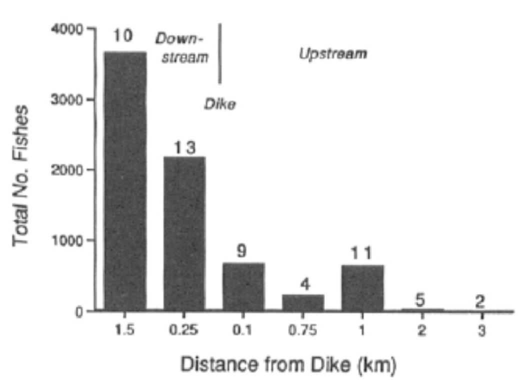


Figure 25.7. Number of fish collected at seining sites upstream and downstream of the Herring River dike in 1984. Number of species at each site is shown above the bars. (Figure from Roman et al. 1995)

on developed land [Figure 25.5]), tidal range within the lagoon would be similar to that in the Bay (Figure 25.6).

Under current conditions of restricted tidal exchange, the net flow of groundwater is toward Cape Cod Bay. For all scenarios of modeled tidal flow restoration, the net flow of groundwater remained from the lagoon to the Bay. Contaminants that might enter the groundwater system from septic effluent and other sources were shown to always enter the Bay, not the lagoon.

Herring River: A dike was built across the mouth of the Herring River in 1908 (Roman et al. 1995). Two of the three culverts in this dike have flapper valves which allow fresh water to exit the system but restrict the entry of salt water (Martin 2007). The third culvert has an adjustable sluice gate. Tidal restriction caused the conversion of hundreds of acres of salt marsh to freshwater wetlands and, primarily, uplands. Currently water quality problems include summer anoxia (Portnoy 1991) which causes die-offs of migratory fish species such as Blueback herring and Alewife (Roman et al. 1995). Other water quality problems include acidification and leaching of metals from sediments (Soukup and Portnoy 1986, Roman et al. 1995). The impact of the dike on fish populations is illustrated by data collected at a series of stations on either side of the dike in 1984 (Figure 25.7).

Current plans are for the restoration of tidal flow to the entire Herring River system. Modeling studies have developed predictions for the impact of various sluice gate opening scenarios on tidal fluctuations in the Herring River system. For mean tidal forcing (a range of 2.37 m), the tidal range behind the barrier would vary from 79% of tidal forcing, for a vertical opening of 0.1 m, to 98% for a gate opening of 3.0 m (Spaulding and Grilli 2005). Figure 25.8 illustrates the model-predicted impact on salinity distribution within the estuary. Roman et al. (1995) modeled water levels upstream of the dike under various scenarios that increase tidal flow through the culverts. With no sluice or tidal gates in the culverts (i.e., least amount of restriction consistent with the culverts remaining in place), high water level upstream increased by 0.4 m. Even under this scenario, the dike would still restrict tidal exchange – the modeled upstream tidal range was predicted to be almost 1 m lower than the downstream range.

Adjacent landowners are concerned that saltwater intrusion from restored tidal flow could infiltrate into the aquifer and affect the availability of freshwater for private domestic use (Martin 2004, 2007). Modeling studies predict that:

- The thickness of the freshwater aquifer might be reduced, but that "this effect would be restricted to an area underlying and immediately adjacent to the new created tidal estuaries. The thickness of the freshwater aquifer increases quickly inland from the ocean shorelines." (Martin 2004).
- The freshwater aquifer will likely continue to be a viable domestic water source in most areas. However, wells constructed less than approximately 200 feet from the ocean (or with intakes near the bottom of the aquifer) are susceptible to saltwater intrusion. Martin (2007) provides a detailed evaluation of areas at risk.

Portnoy and Giblin (1997) suggest that restoration of tidal flow to the Herring River system will increase porewater pH, alkalinity, phosphate (PO_4) and ferrous iron (Fe(II). Elevated nutrient and Fe(II) levels could increase primary production, with potential impacts on dissolved oxygen regimes.

Shellfish, primarily wild oysters (*Crassostrea virginica*) and cultured hard clams (*Mercenaria mercenaria*), are an important resource in the 600-ha diked Herring River. Historically, shellfishing closures have occurred frequently in this system, even though there are no significant sources of human fecal contamination. Portnoy and Allen (2006) investigated potential impacts on fecal coliform levels of the planned restoration of this system. Models suggest that restoration of a more natural tidal regime in the Herring River will result in a 13-fold increase in the river intertidal volume, in turn diluting fecal coliforms to levels that will be acceptable for shellfish-growing waters. By increasing salinity, dissolved oxygen and pH, restoration will also likely contribute to coliform declines. An additional hydrodynamic model is currently (2010) under development (C. Roman, NPS, pers. comm.).

Factors influencing tidal restrictions

- Presence and design of road crossings, dikes and other structures that change the natural hydrology and connectivity of stream channels.

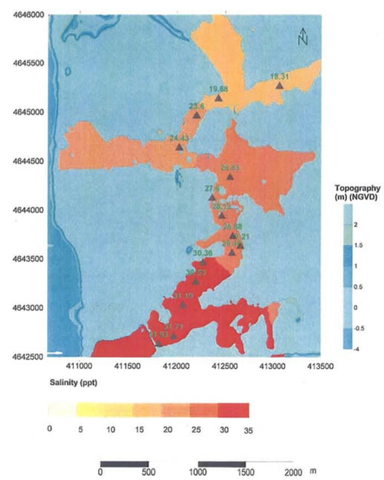


Figure 25.8. Modeled salinity distribution in the Herring River system at high tide, with a gate 30-m wide and 3-m high. (Figure from Martin 2007, based on work of Spaulding and Grilli)

Herring River system. Photo credit: Barbara Dougan. Source Martin 2007.

26. Salt marsh: flora & fauna

Figure 26.1. The distribution of CACO salt marshes, as defined in the Massachusetts DEP wetlands GIS data. (Source: MassGIS)

Salt marshes in Nauset Estuary. Photo courtesy M.J. James-Pirri, URI.

Key Points

- Nekton and vegetation data are collected as part of the CACO long-term monitoring program. While initial data are available for Hatches Harbor and Nauset Marsh, most of the data have not yet been published.
- Half the marshes on the outer Cape have experienced vegetation losses of over 30% during the past half century.
- Vegetation at Nauset marsh appears to have been stable over the last century.

Assessment statement

Fauna: Good, except for in marshes that remain tidally restricted.
Flora: Good in some marshes (e.g. Nauset). Fair in other marshes where vegetation loss has been occurring over the last several decade.

Rationale

Nekton, defined as an assemblage of fishes and crustaceans (such as shrimp and crabs), are an abundant estuarine fauna with unique responses to environmental change. Estuarine nekton are an integral link among primary producers, consumers, and top predators and are likely to respond to either top-down or bottom-up estuarine perturbations. CACO salt marshes are shown in Figure 26.1. The National Park Service monitors nekton at several salt marsh sites throughout CACO as part of the Inventory and Monitoring Program. Monitoring data will be especially useful in documenting change in several tidally-restricted marsh systems as they are restored (see Topic 25: Tidal Restrictions: Occurrence, Impacts & Restoration).

The vegetation of salt marshes is a result of the combined factors of primarily salt marsh surface elevation and hydrologic regime. Changes in salt marsh vegetation communities can signify a change in one or both of these parameters and is an indicator of ecosystem health. The National Park Service monitors vegetation at several salt marsh sites throughout CACO as part of the Inventory and Monitoring Program. Additionally, CACO is restoring some salt marshes by re-establishing tidal flow that had previously been altered by dikes and undersized culverts.

Benchmarks

Long-term monitoring at CACO includes protocols for documenting both nekton and vegetation in salt marshes. These data will provide an excellent base from which to examine future trends. Data to evaluate biological changes associated with restoration of tide-restricted marshes are being collected. Medium-term changes in salt marsh vegetation loss and geomorphology have recently been published – both quantifying changes over the past 5-6 decades and also serving as a baseline for evaluating future change.

Condition

Status

Fauna: Limited data from long-term monitoring are available from two CACO marshes: Hatches Harbor and Nauset Marsh. Most recent data available from Hatches Harbor document three fish and three crustacean species (Portnoy et al. 2007), although more taxa have been recorded over a period of several years (Table 26.1) - for additional information see the discussion of Hatches Harbor in the topic: Tidal Restrictions: Occurrence, Impacts & Restoration. Additional nekton data were collected during sampling at Nauset Marsh in 2004, conducted as part of the Inventory and Monitoring Program (James-Pirri 2004). Overall, a synthesis of data from these various monitoring efforts has not yet been published.

In addition to data being collected by the ongoing Inventory and Monitoring Program, other researchers have studied nekton of CACO salt marshes. Able et al. (2002) sampled several habitats in Nauset Marsh in the 1980s, recording 35 fish and 10 decapod crustacean species. Species richness appeared to be greatest in vegetated habitats. Raposa and Roman (2001) investigated the nekton of the Hatches Harbor salt marsh, comparing assemblage attributes upstream and downstream of the tidal restriction. These researchers concluded that the restricted marsh did represent a degraded habitat for most species. For some taxa, the restricted marsh provided significant breeding, nursery and overwintering habitat.

Flora: The National Park Service initiated long term monitoring of salt marsh vegetation at several sites throughout the park in 2003 (Nauset, Pleasant Bay, Great Island, and West End) and will repeat monitoring at approximate every 3 years. Vegetation at Hatches Harbor marsh has been surveyed periodically since 1997 to monitor the effects of tidal restoration in this system. For more information, see the discussion of Hatches Harbor in the topic: Tidal Restrictions.

At Nauset Marsh peat rhizome analyses from salt marsh peat cores indicated relatively stable vegetation patterns over the past century; however, there was one site where a relatively recent vegetation change from *Spartina patens* to *Distichlis spicata* was noted. This change may indicate that this area of Nauset marsh was getting wetter, possibly a response to an accelerated rate of sea level rise (Roman et al. 1997) – see also topic: Salt Marsh landscape change.

Trends

At Hatches Harbor marsh the recovery of native salt marsh vegetation is progressing towards a more natural state. At Nauset marsh it appears that the majority of the vegetation community has remained stable over the past century. In many other marshes on the outer Cape, there have been substantial losses in vegetated area over the past half century.

Factors influencing salt marsh flora & fauna

- Sea-level rise.
- Tidal restrictions.

Table 26.1. Nekton species recorded from two CACO salt marshes. (Source: Portnoy et al. 2007) (Note that other studies have documented additional taxa in CACO salt marshes; see text for more information.)

Scientific Name	Common Name	Marsh
Anguilla rostrata	American Eel	Hatches Harbor
Apeltes quadracus	Fourspine Stickleback	Hatches Harbor, Nauset
Carcinus maenas	Green Crab	Hatches Harbor, Nauset
Crangon septemspinosa	Sevenspine Bay Shrimp	Hatches Harbor, Nauset
Fundulus heteroclitus	Mummichog	Hatches Harbor, Nauset
Fundulus majalis	Striped Killifish	Hatches Harbor, Nauset
Gasterosteus aculeatus	Three-spine stickleback	Hatches Harbor, Nauset
Menidia menidia	Atlantic Silverside	Hatches Harbor, Nauset
Mugil curema	White mullet	Hatches Harbor
Myoxocephalus aenaeus	Grubby	Hatches Harbor
Pagurus longicarpus	Long-clawed hermit crab	Hatches Harbor
Palaemonetes pugio	Grass shrimp	Nauset
Pseudopleuronectes americanus	Winter flounder	Hatches Harbor

27. Salt marsh landscape changes

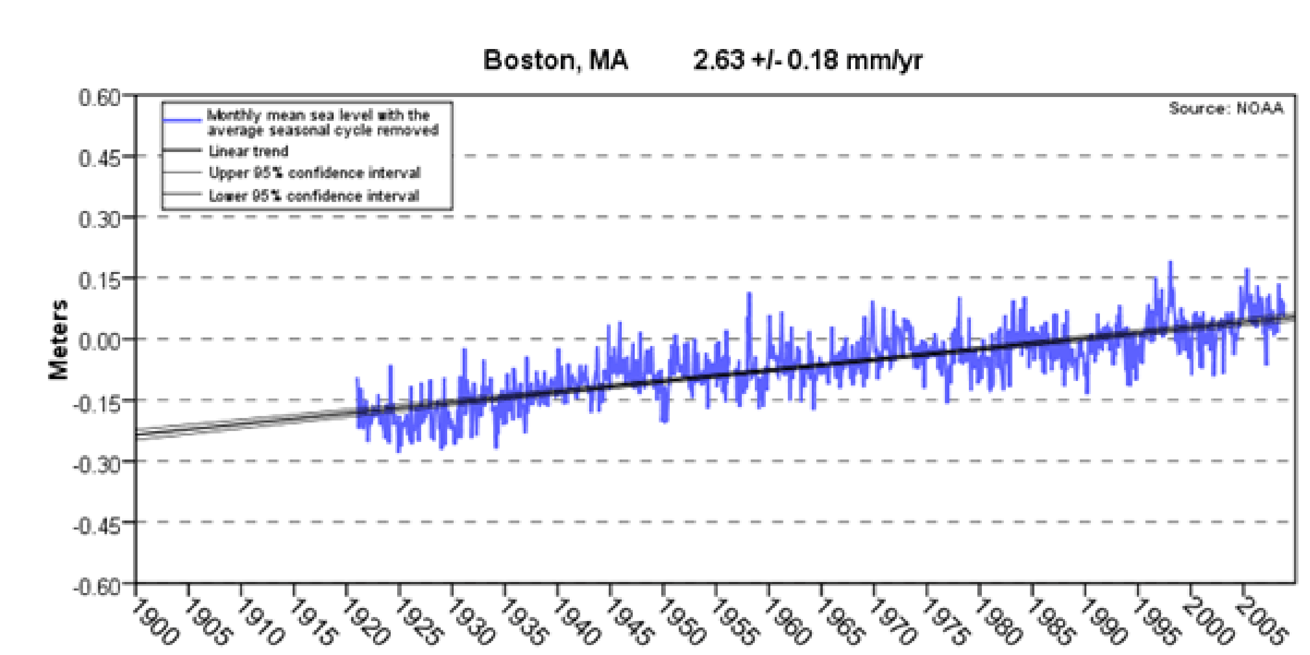


Figure 27.1. Monthly mean sea level and linear trend from 1921 to 2008 at Boston, MA (station #8443970). Sediment accretion rates measured in Nauset Marsh indicate that marsh elevations are keeping pace with sea level rise. Sea level rise data source: http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ma (retrieved February 2009)

- Marsh accretion and herbivory by crabs (see Topic 27).

Key points

- Nauset marsh appears to be keeping pace with the relative rate of sea level rise from 1921 to 1993 of 2.4 mm/yr (Roman et al. 1997).
- There is also evidence of wetland submergence at Nauset marsh. Changes in plant species in the past indicate the marsh is getting wetter.
- The NPS is currently monitoring salt marsh elevation and accretion at several sites within the Seashore. Data from this study have not yet been published.
- One half of the marshes of the outer Cape experienced high-marsh losses of >30% over the past half century.
- High-marsh retreat has become more rapid since the mid-1980s.

Table 27.1. Change in salt marshes of the outer Cape. Data were derived from field surveys in 2006-2007 and analyses of aerial photography. Marsh names with an asterisk (*) indicate sites that were thought to have experienced sudden wetland dieback. (Adapted from Smith 2009)

Marsh / Town	Low-marsh edge vegetation losses	Creek widening or change in structure	Tidal inlet widening	High-marsh dieback with mudflat formation	High-marsh loss (since 1947 or 1952)	High-marsh retreat more rapid after 1984
West End Provincetown					<10%	
Hatches Harbor Provincetown					<10%	
Pamet Harbor* Truro	Extensive	Extensive			<10%	
The Gut* Wellfleet	Limited	Limited		Broad	>30%	Yes
Middle Meadow* Wellfleet	Limited	Limited		Broad	>30%	Yes
Jeremy Marsh Wellfleet	Limited	Limited		Broad	>30%	Yes
Indian Neck* Wellfleet	Extensive	Extensive		Broad	<10%	
Lt. Island* Wellfleet	Extensive	Extensive		Broad	10-30%	Yes
Audubon Sanctuary* Wellfleet	Extensive	Extensive		Broad	10-30%	Yes
Herring River* Eastham	Limited	Limited		Narrow	>30%	Yes
Boat Meadow* Eastham	Limited	Limited		Narrow	>30%	Yes
Nauset Marsh Eastham					>30%	Yes
Pleasant Bay Orleans/Chatham		Limited	Yes		>30%	Yes
Morris Island Chatham			Yes		10-30%	

Notes -
Extensive: observed along most marsh edges, creek segments
Limited: occurs only in few creeks/edges
Broad: distance between S. alterniflora and S. patens extends > 5m
Narrow: distance between S. alterniflora and S. patens is < 5 m

Assessment statement

Fair: based on elevation/accretion data from Nauset marsh and multi-decadal patterns of salt marsh changes across the outer Cape. Data analyses to evaluate more recent accretion rates in Nauset marsh and at other sites are not yet published. Current condition at Nauset Marsh and other sites in CACO is unknown since data analyses are ongoing.

Rationale

Salt marshes keep pace with sea-level rise by several processes that influence elevation of the marsh surface. If the surface elevation of the marsh lags behind sea level rise, the marsh will become wetter and possibly submerged or converted to mudflats (Titus 1991). Changes in the area and characteristics of salt marshes can have a range of ecological impacts, including reduction in habitat quality and quantity for migratory and resident bird species (Erwin et al. 2004). Surface elevation can decrease through erosion as well as subsurface processes of decomposition, compaction and subsidence, while the processes of sedimentation (or accretion) and organic accumulation build up surface elevation (Cahoon et al. 1999). Measuring salt marsh elevation and accretion rate, through the use of radiometric techniques, sediment elevation tables (SETs) and feldspar accretion horizons, provides insight to how well marshes are keeping pace with sea level rise.

Benchmarks

Temporal trend in accretion level vs. sea level rise (Figure 27.1).

Salt marsh landscape changes, continued

Condition

Status & Trends

Accretion rates in CACO salt marshes are being studied using sediment elevation transects (SETs) for Nauset marsh, the Herring River system on both the restricted upstream portion of the dike and the unrestricted downstream portion of the dike, and at Hatches Harbor marsh both upstream and downstream of the dike. The NPS is currently in the process of analyzing the time series of data from these SETs which have been monitored since the late 1990s. Results from these analyses have not yet been unpublished.

Published information on sediment accretion rates in Nauset Marsh is available from a late 1990s study (Roman et al. 1997). This study investigated both short-term sedimentation rates (using feldspar marker horizons) and longer-term accretion (using ^{137}Cs and ^{210}Pb radiometric dating). Short-term accretion rates during 1991-1992 ranged from 5-24 mm/yr (Roman et al. 1997) and exhibited considerable spatial and temporal heterogeneity. Spatial heterogeneity is influenced by factors such as proximity to channels and inlets, and the character of the peat substrate, whereas storm frequency and magnitude influence temporal sedimentation patterns.

Although longer-term accretion rates for the 72-year period from 1921 to 1993 were lower than short-term rates, data suggest that, depending on location, longer-term sediment accumulation in this system is either exceeding or nearly similar to the rate of sea level rise (approximately 2.4 mm /yr)(Roman et al. 1997). Peat-rhizome analysis of plant species replacement suggested that a portion of the Nauset Marsh may be getting wetter, possibly reflecting compaction of freshwater / brackish-water peat deposits (Roman et al. 1997). Information on recent trends in accretion rates is currently unavailable – data are being analyzed by NPS.

View from Portanimicut landing on Pleasant Bay. Photo courtesy M.J. James-Pirri, URI.

Smith (2009) has recently used field surveys and historical aerial imagery to analyze multi-decadal patterns of change in Cape Cod salt marshes. He documented five main patterns of change in these marshes:

- tidal creek widening, creek structural changes, and marsh area reductions associated with edge vegetation losses;
- tidal creek widening and creek structural changes associated with increases in the width of tidal inlets;
- marsh edge/area stability;
- high-marsh losses (landward retreat) with replacement by un-vegetated mudflats;
- high-marsh losses balanced by low-marsh encroachment.

Data from marshes of the outer Cape are summarized in Table 27.1. One half of these marshes experienced high-marsh losses of > 30% over the past half century. In all of these cases, high-marsh retreat has become more rapid since 1984. In many of the marshes, dieback has been accompanied by formation of relatively extensive mudflats. Losses along the edges of low-marsh vegetation was documented in four marshes.

In the Truro and Wellfleet marshes that face Cape Cod Bay, large portions of formerly contiguous marsh have separated to form arrays of tidal channels, mudflats and shrinking islands. In Nauset Marsh, the system has appeared much more stable. Marsh edges did not lose vegetation and tidal inlets have remained essentially unchanged. As noted above, peat cores indicate stable vegetation patterns over the past century.

A key factor in the loss of edge vegetation is herbivory by the crab *Sesarma reticulatum (Holdredge et al. 2008)*. This native species is currently present at high densities in Cape marshes. By removing plant cover, crabs denude the creek banks, making them more susceptible to slumping and erosion. Other factors, for example flooding stress, likely also contribute to marsh die-back (Smith 2009).

Factors influencing salt marsh landscape changes

- Sea-level rise.
- Inlet migration and changes in hydrology (human-made or natural).
- Crab herbivory.

28. Eelgrass distribution & population status

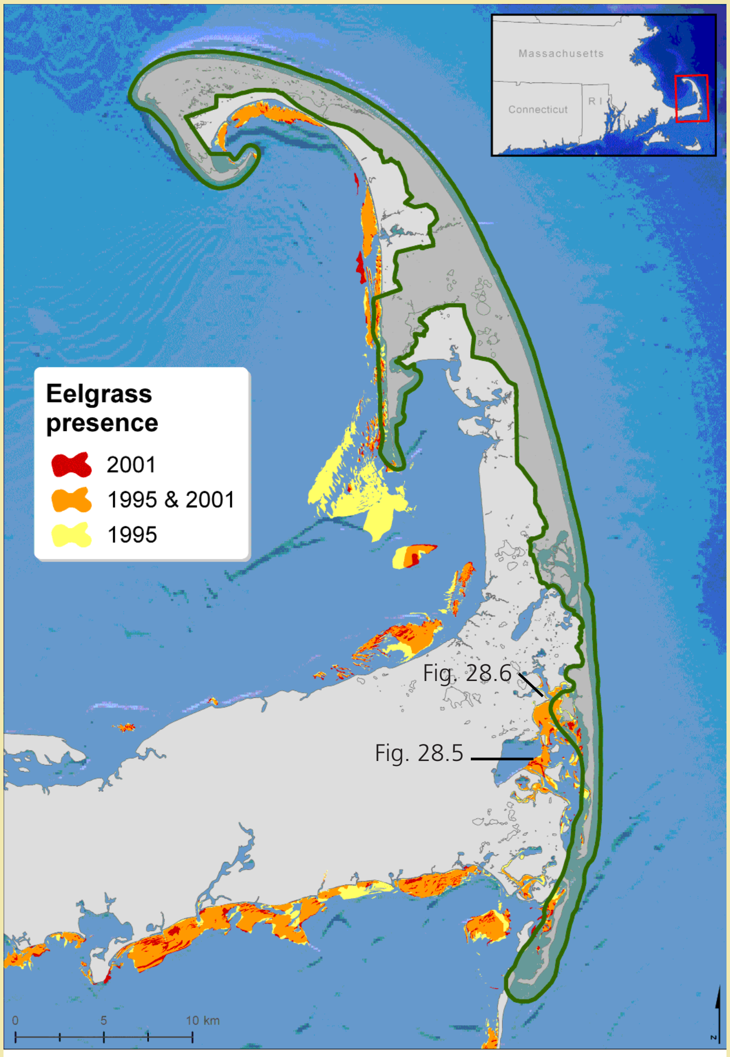


Figure 28.1. Map of eelgrass beds at Cape Cod. 1995 and 2001 and were produced by MA DEP (accessed from MA GIS 2009). Data from 2006 (unpublished as of January 2010) indicate that, in 2006, eelgrass beds on the Cape were restricted to Pleasant Bay.

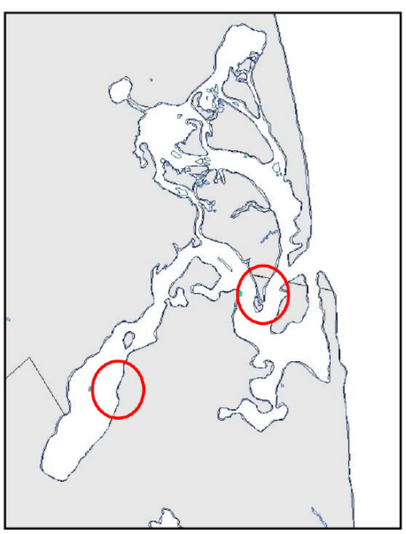


Figure 28.2. In 2001, eelgrass was restricted to just two small areas (indicated by red circles) of the Town Cove / Nauset Harbor system (based on mapping data provided by MA DEP 2009). In 2006, no eelgrass beds were detected here.

Key Points

- Eelgrass beds on the Cape decreased by about 30% between 1995 and 2001.
- The most recent data (from 2006-2007) suggest that this reduction in eelgrass extent has continued in Pleasant Bay. Since the 1950s, eelgrass beds in this system have decreased by about one quarter.
- Nutrient enrichment is thought to be one of the primary factors causing declines in eelgrass populations at both regional and global levels. Storm-mediated disturbance is thought to influence spatial patterns of eelgrass cover in Pleasant Bay and Cape Cod Bay.
- Wasting disease was recorded on Cape Cod in the 1980s but its contribution to current eelgrass declines is uncertain.

Assessment statement

Significant concern. Eelgrass beds have decreased in extent over the past 50 years.

Rationale

Seagrass beds provide a series of high-value ecosystem services, including nursery areas for fish and habitat for other faunal groups, nutrient cycling, sediment stabilization and sequestration of carbon. Coastal development and nutrient enrichment are associated with degradation of seagrass beds, and in turn, likely lead to a cascade of ecosystem impacts. For example, even though eelgrass beds of Nauset marsh are characterized by low diversity of some faunal groups relative to eelgrass beds further south along the mid-Atlantic coast, both decapods and, especially, fishes were more abundant in vegetated than in unvegetated areas of Nauset (Heck et al. 1989). Similarly, a study of other Cape Cod estuaries (Buzzards Bay and Waquoit Bay) revealed that the abundance, biomass, species richness and life history diversity of fish assemblages all decreased significantly along a gradient of decreasing eelgrass habitat complexity (Hughes et al. 2002). In contrast to estuaries, the vegetation effect appears to be less important in open-water environ-

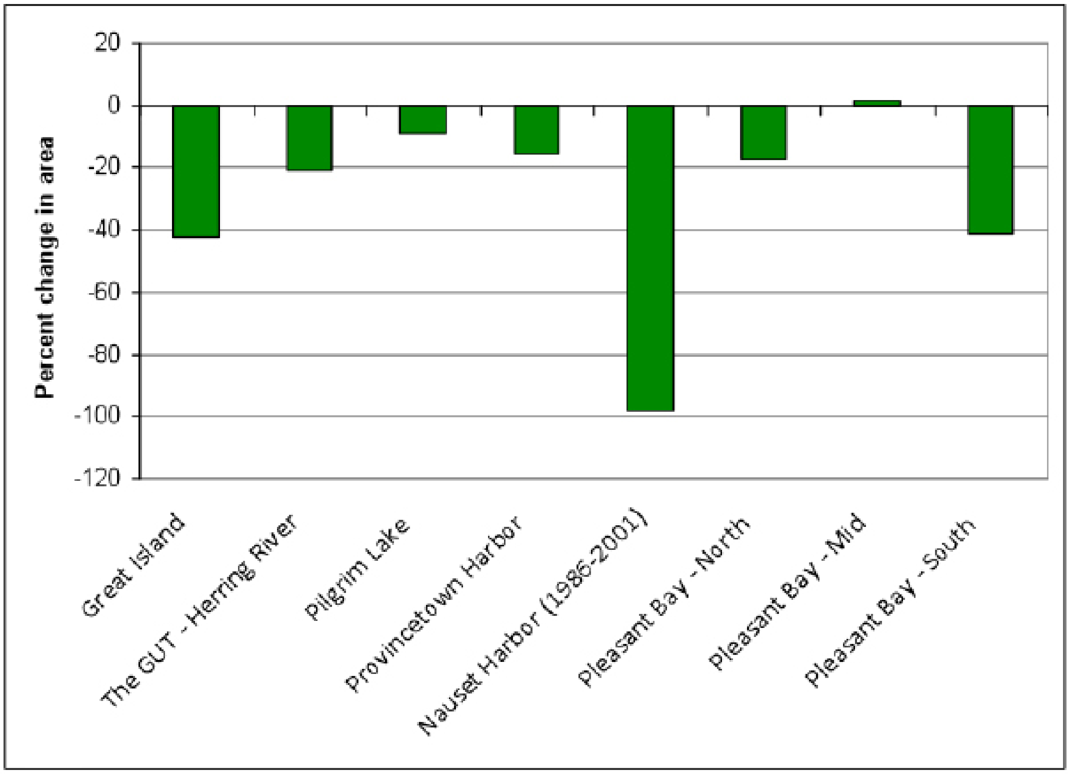


Figure 28.3. Change in areal extent of eelgrass in CACO, 1995-2001. Data from MA DEP (2009). For Nauset marsh, 1995 data are unavailable so change was calculated using 1986 baseline data from Roman et al. (1990).

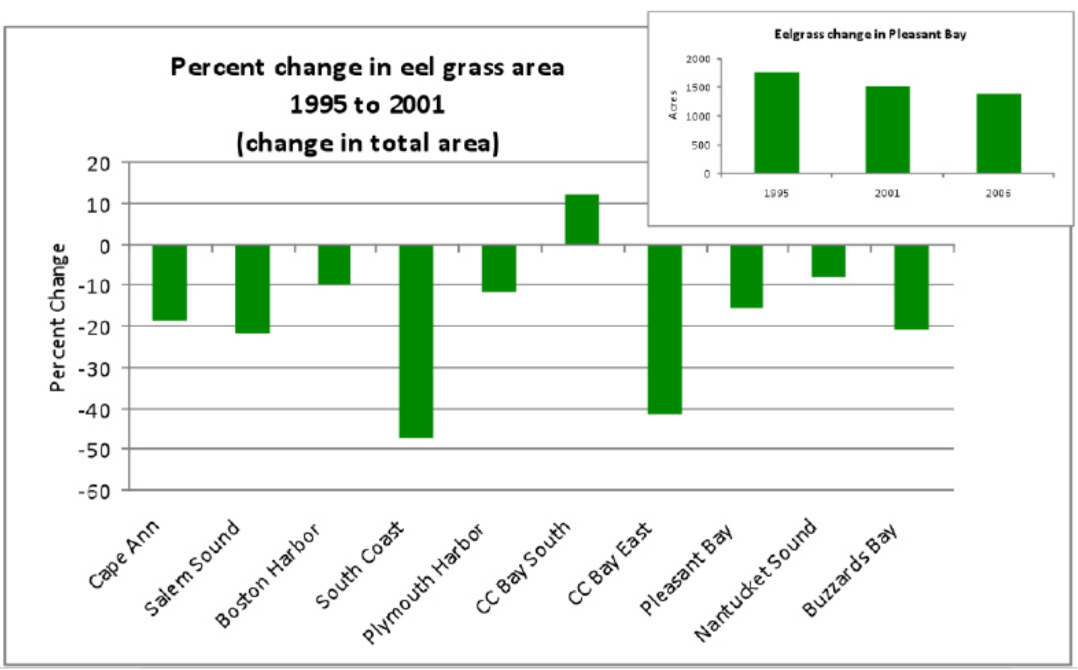


Figure 28.4. Percent change in eelgrass area from 1995 to 2001 in Massachusetts. In 2006, eelgrass was present only in Pleasant Bay. The 1995-2001 data come from MA DEP (2009). Within each region, eelgrass areas for each map were summed to derive regional totals for 1995 and 2001. Changes in areal extents were calculated from these regional totals. Pleasant Bay 2006 data are courtesy of Charles Costello (MA DEP).

Eelgrass distribution & population status Continued

ments. Here areas with and without seagrass appear to be characterized by similar fish species richness, abundance and biomass (Hunter-Thompson et al. 2002).

Globally, it is estimated that 29% of known seagrass areas has been lost since the 1870s and rates of seagrass decline have been accelerating in recent decades (Waycott et al. 2009). Eelgrass (*Zostera marina*) is the most common species of seagrass found in Massachusetts. In most coastal areas of Massachusetts, eelgrass areas decreased between 1995 and 2001, a pattern that is mirrored in most parts of Cape Cod.

A recurrence of the wasting disease that almost eliminated eelgrass in the North Atlantic during the 1930s was recorded at several locations in the northeast U.S., including Cape Cod, during the early 1980s (Short et al. 1987). While wasting disease

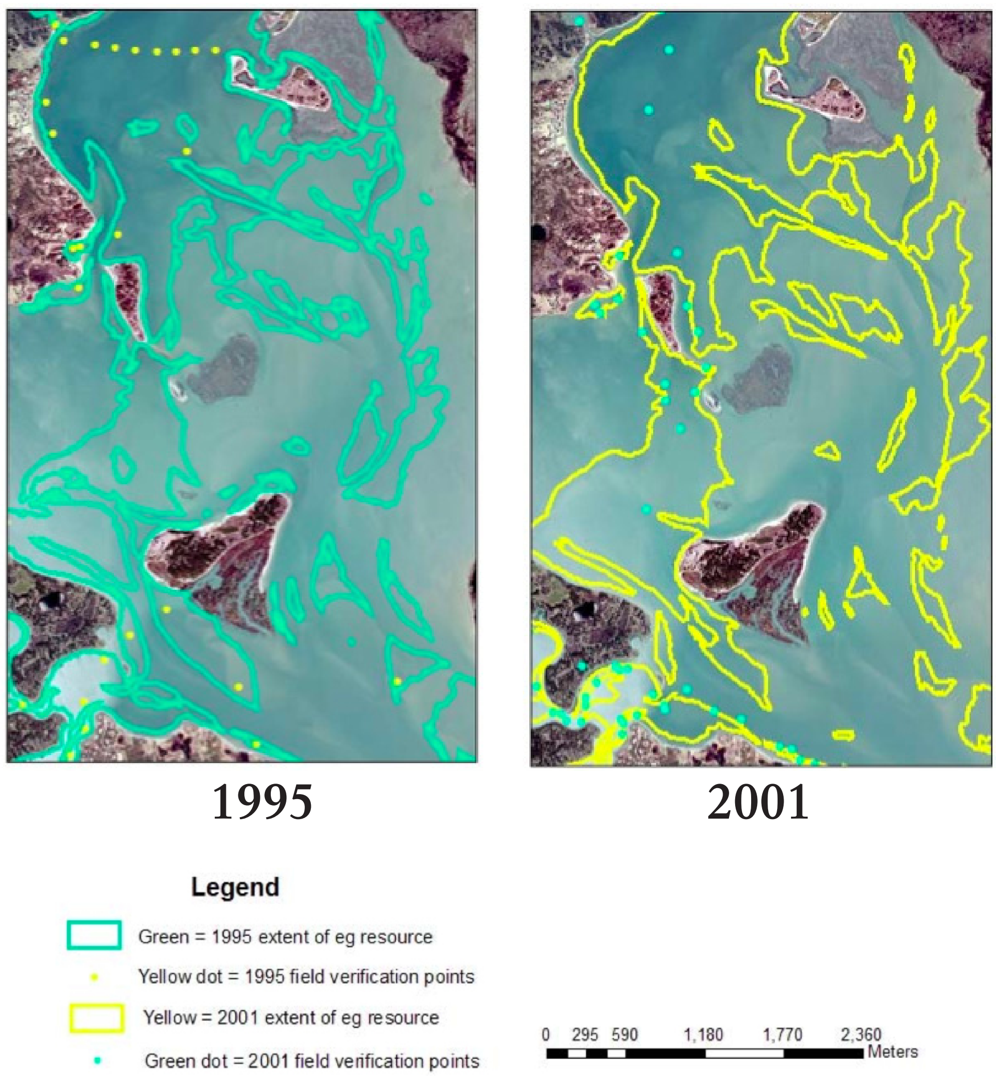


Figure 28.5. Eelgrass bed distribution within the lower portion of the Pleasant Bay System during the period 1955 - 2001. See Figure 28.1 for approximate location of this map area. (Figure from Howes et al. 2006)

may combine with pollution to cause eelgrass declines, the role of the disease in current eelgrass population dynamics is not well understood.

Benchmarks

There are data from the 1950s on the areal extent of eelgrass beds in Pleasant Bay and 1980s data for Town Cove / Nauset Harbor. However, the earliest systematically collected (remote sensing) data for the entire Cape are from 1995. These data serve as a useful baseline from which to measure recent and future trends. It is important to recognize, however, that the 1995 cover likely represents a significant decline from pre-development conditions.

Condition

Status and Trends

In 2001, eelgrass beds on the outer Cape occurred predominantly in the area extending from Great Island to Provincetown, and in Pleasant Bay (Figure 28.1). Eelgrass beds were mapped remotely in 1995, 2001 and 2006-2007 (Pleasant Bay, only). For some areas, data are available from other periods,

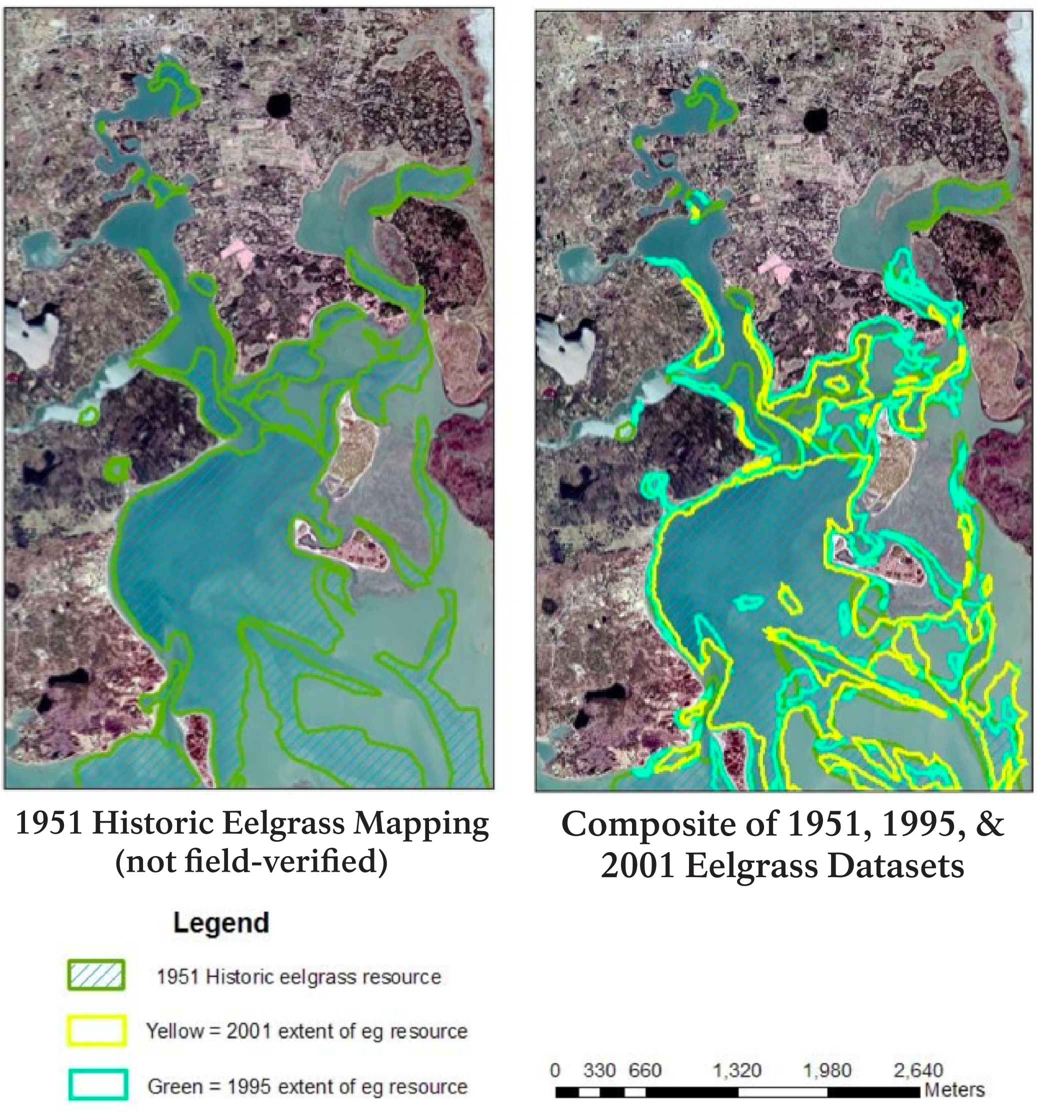


Figure 28.6. Eelgrass bed distribution within the upper portion of the Pleasant Bay System during the period 1955 - 2001. See Figure 28.1 for approximate location of this map area. (Figure from Howes et al. 2006)

Eelgrass distribution & population status Continued

but these data were not derived using remote sensing. Between 1995 and 2001, eelgrass areas decreased by an average of 30% in areas within and adjacent to the Seashore (Figure 28.2, 28.3). The most recent data from Pleasant Bay indicate that the areal extent of eelgrass beds decreased by approximately 17% over the 12-year period from 1995 (Figure 28.4; unpublished data provided by C. Costello, MA DEP).

Changes in eelgrass populations on the Cape mirror those observed in other parts of Massachusetts (Figure 28.4). The eastern section of Cape Cod Bay (Eastham to Provincetown) exhibited some of the most marked declines in eelgrass extent during the 1995-2001 period (but see section below on Nauset Harbor). Declines were greatest in the lower part of this region, from Skaket Beach to Billingsgate. Only in the southern part of Cape Cod Bay was there an increase in eelgrass area.

Great Island to Provincetown: Between 1995 and 2001, the mapped eelgrass area declined from 1137 ha to 1053 ha, a reduction of 8%. As noted above, the overall decline over the broader region from Skaket Beach to Provincetown was greater, about 40% (Cape Cod Bay East in Figure 28.4). The magnitude of this decline reflects the apparent loss of a large area of eelgrass that was present in 1995 just to the south and west of Great Island (Figure 28.1).

Nauset Harbor: In the Town Cove / Nauset Harbor system, Roman et al. (1990) reported that eelgrass covered an area of 55 ha when surveyed in 1986. By the time of the 2001 remotely sensed mapping, the area was just 0.82 ha (Figure 28.2; 1995 data are not available for this map tile).

A 1980s study documented that annual eelgrass production peaked in July in the Nauset Harbor and in August in Town Cove (Roman and Able 1988; Roman et al. 1990).

Pleasant Bay: In Pleasant Bay, eelgrass was recorded at many locations during the 2001 mapping, indicative of a system possessing areas of high habitat quality. At that time, the total area of eelgrass in the Pleasant Bay system was estimated at 730 ha, a decrease of 59 ha since 1995 (MA DEP 2009). These eelgrass beds were generally restricted to the larger lagoonal basins, Little Pleasant Bay, Pleasant Bay and Chatham Harbor. There were also smaller eelgrass areas in Pochet and fringing shallow areas in The River and Meetinghouse Pond. The only tributary embayment to Pleasant Bay with significant eelgrass habitat was Bassing Harbor (Howes et al. 2006). The remaining eelgrass within Pleasant Bay represents a valuable resource with strong potential for restoration (Pleasant Bay Resource Management Alliance 2008).

Pleasant Bay data are also available from the 1950s, a period prior to substantial development of the watershed (Figure 28.6). There was a 24% decline (a loss of 236 ha [583 acres]) in the area of Pleasant Bay eelgrass beds over the 50-year period from the 1950's to the 1990's. During that period there was a several-fold increase in nitrogen loading rates as a result of development (Howes et al. 2006). The overall pattern of eelgrass distribution and temporal decline in coverage is consistent with the spatial pattern of nitrogen enrichment and oxygen and chlorophyll levels in the various basins. If watershed management is able to reduce future nitrogen loading rates to this system, it is possible that eelgrass cover will increase (Howes et al. 2006).

Eelgrass population characteristics (including percent cover, density and biomass) are monitored as part of the NCBN Estuarine Nutrient Protocol (Kopp and Neckles 2009) at two index sites: Duck Harbor in Wellfleet Harbor and adjacent to Hog Island in Little Pleasant Bay. Under this protocol, the eelgrass data are intended as an indicator of water quality, not eelgrass condition per se (Hilary Neckles, USGS, personal communication, January 2010). In contrast to the longer-term data on eelgrass cover and water quality in Pleasant Bay (see discussion above), NCBN data from the period 2003-2009 do not suggest declines in water quality in Cape Cod Bay or Pleasant Bay. Rather, eelgrass dynamics in these areas appear to be associated principally with storm-mediated disturbance (Neckles 2009). In-depth analyses of the NCBN-protocol eelgrass data have not yet been published.

Factors influencing eelgrass distribution & status

- Nutrient enrichment (primarily nitrogen) is thought to represent the primary threat to eelgrass beds on the Cape and elsewhere (Howes et al. 2006). Nutrients promote phytoplankton blooms and epiphytic algal growth. Both reduce the amount of light reaching the eelgrass plants (Short and Burdick 1996, Waycott et al. 2009).

- Storms cause physical disturbance to eelgrass beds (Neckles 2009).

- Eelgrass declines in Pleasant Bay do not appear to be directly related to mooring density, since there are relatively few boat moorings in the main basin where eelgrass loss has been greatest.

- Pier construction is also considered to play a minor role (if any) in eelgrass declines in Pleasant Bay.

- The impact of shellfish harvests on these plants is unknown (Howes et al. 2006).

View of Great Island and Wellfleet Harbor. Photo courtesy M.J. James-Pirri, URI.

29. Horseshoe crabs: population status & dynamics

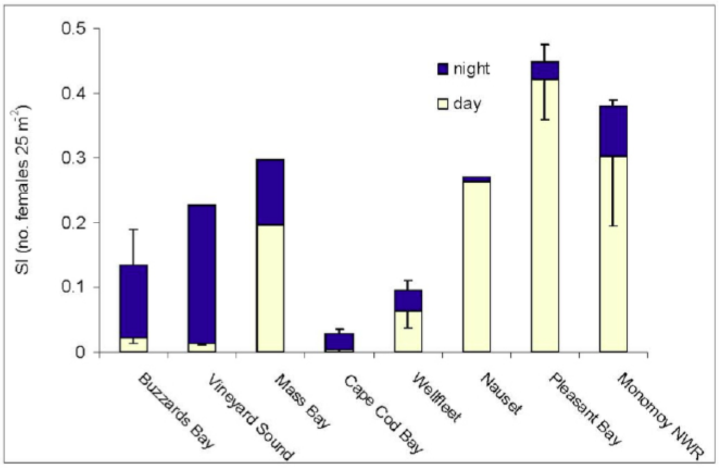


Figure 29.1. Spawning indices (number female horseshoe crabs 25m^{-2}) from horseshoe crab spawning in Massachusetts in 2000 to 2002 and for 2008. Upward facing error bars are standard errors for night surveys; downward facing bars are standard errors for day surveys. Standard errors cannot be calculated where only one beach in an area was surveyed in any given year. (Data source: MA DMF 2008)

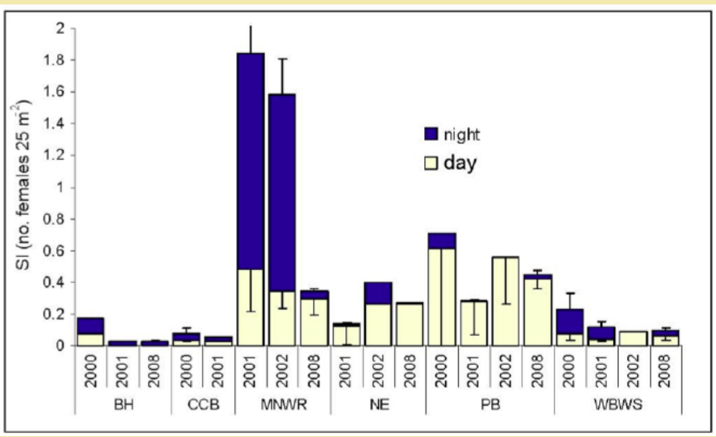


Figure 29.2. Spawning indices (number female horseshoe crabs 25m^{-2}) from horseshoe crab spawning on Cape Cod from 2000 to 2002 and for 2008. Abbreviations: BH: Barnstable Harbor; CCB: Cape Cod Bay; MNWR: Monomoy National Wildlife Refuge; NE: Nauset Estuary; PB: Pleasant Bay; WBWS: Wellfleet Harbor. (Data source: MA DMF 2008)

Key Points

- State managers have become increasingly concerned about horseshoe crab spawning densities throughout the state and have instituted more regulations regarding the harvest of crabs.
- Sex ratios for spawning horseshoe crabs were strongly skewed towards males within Pleasant Bay, and were much higher than those in the 1950's, possibly suggesting that spawning dynamics have changed in this embayment.
- Evidence from tagging studies done in 2000 to 2002 suggests that horseshoe crab populations may be localized within embayments on Cape Cod.
- Spawning "hot spots" within the Seashore in Pleasant Bay may be responsible for a significant percent of all spawning Cape-wide.

Assessment statement

Overall Condition: Fair - Significant concern (latter based on increasingly male-biased spawning sex ratios).

Rationale

Horseshoe crabs are an important component of the estuarine benthic system, are an important resource for migrating shorebirds, and are valuable to a variety of user groups, such as commercial fishermen and the biomedical industry. Prior to 1998, the horseshoe crab fishery was an unregulated fishery in Massachusetts and harvesting both for bait and biomedical use occurred within the boundaries of CACO, particularly within Pleasant Bay. In 2001, the harvesting of horseshoe crabs was prohibited within Seashore boundaries; however, biomedical harvesting still occurs in Pleasant Bay outside of CACO's boundaries (the Bay was closed to bait harvest effective May 1, 2007). Recently, the Massachusetts Division of Marine Fisheries has instituted more regulations regarding the harvest of horseshoe crabs from state waters in an attempt to prevent over-harvest of this resource. The Seashore has monitored spawning horseshoe crabs in 2000 to 2002 and again in 2008 to 2009, as well as participated in tagging studies under a research agreement with the University of Rhode Island.

Benchmarks

Benchmark for spawning sex ratios: the percent of spawning crabs that are female at Pleasant Bay should be similar to other Cape Cod Bays (31-48% percent female) (Figure 29.3).

Condition

Status

The state of Massachusetts initiated annual state-wide monitoring for spawning horseshoe crabs in 2008 (data were collected in 2009 but are not currently available). Spawning indices (number of female crabs per 25m^2) were variable across the state, with the lowest indices in Cape Cod Bay (Wellfleet Harbor and Cape Cod Bay). High indices were observed in the areas on the eastern side of the Cape (Pleasant Bay and Monomoy National Wildlife Refuge) (Figure 29.1). One concern of state managers is the high proportion of surveys with few or no spawning females. Forty-eight percent of all surveys in 2008 recorded no female crabs and only 12% of 2008 surveys had more than 10 females (MA DMF 2008). Historical spawning survey data indicate a possible decrease in spawning indices from 2000 to 2008. All areas except Nauset Estuary and Pleasant Bay show downward trends (Figure 29.2), although the differences were not statistically significant (MA DMF 2008). The large drop at Monomoy may be due to significant physical restructuring of the area due to currents and sand movement, so that former spawning areas are no longer suitable. Earlier work has also suggested decrease in spawning horseshoe crabs on Cape Cod (Bourne, MA) with a reported decline in spawning activity by more than 84% from 1984 to 1999 and a decrease in the length of the spawning period from 56 to 11 days over this same time period (Widner and Barlow 1999).

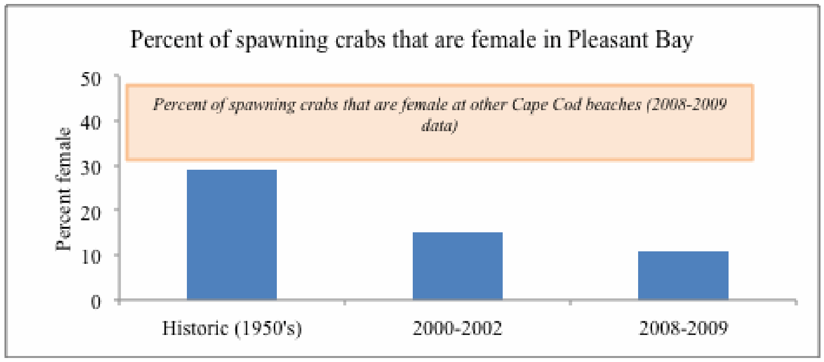


Figure 29.3. Spawning sex ratios for horseshoe crabs within various embayments on Cape Cod. Data from Shuster 1979 (1950's), James-Pirri et al. 2005 (2000 to 2002), and James-Pirri unpublished data (2008 to 2009).

Horseshoe crab spawning survey, Nauset Estuary. Photo courtesy M.J. James-Pirri, URI.

Horseshoe crabs: population status & dynamics, continued

Spawning sex ratios in Pleasant Bay, where there are high densities of spawning crabs in certain locations, are highly skewed towards males (Figure 29.3). The male-biased spawning sex ratios were not observed at other locations on Cape Cod, indicating that the spawning dynamics in Pleasant Bay may be experiencing stressors specific to the Bay. Additionally, historic sex ratios (1950's) for Pleasant Bay were not male-biased, indicating a possible shift in spawning dynamics over recent decades. Sex ratios of non-spawning adults in Pleasant Bay have been reported as 1:2.3 (female to male) (Carmichael et al. 2003) and it has been suggested that a deviation from 1:1 in non-spawning sex ratios towards a male biased ratio may be indicative of overfishing of females (Shuster 1996). Both the bait and biomedical fishery in Pleasant Bay preferentially select females Rutecki et al. 2004; MA DMF 2008). Preliminary field data from recent (2008) studies indicates that spawning sex ratios are even more highly males-biased (1:9.5, female to male) and may be more skewed towards males than those observed from 2000 to 2002. Pleasant Bay has been harvest for biomedical purposes for 30 years (MA DMF 2008) and supports 20% of the Atlantic Coast-wide lysate harvest (Rutecki et al. 2004). The male biased sex ratios have raised concerns among fisheries managers about whether bleeding may have sub-lethal effect on spawning behavior of females (MA DMF 2008).

Spawning horseshoe crabs on Hog Island, Pleasant Bay. Photo courtesy M.J. James-Pirri, URI.

Past studies have indicated, based on tag-recapture data, that horseshoe crab populations on Cape Cod may be localized within specific embayments (e.g., Pleasant Bay, Nauset Estuary, Cape Cod Bay) (James-Pirri et al. 2005). There are localized spawning hot spots in Pleasant Bay within the Seashore's boundaries where high spawning densities (for the Cape Cod area) have been observed. These areas together with two other "hot-spots" within Monomoy National Wildlife Refuge account for about 57% of the total horseshoe crab spawning on Cape Cod (James-Pirri et al. 2005).

The Massachusetts Division of Marine Fisheries has become increasingly concerned about horseshoe crab spawning densities throughout the state and has instituted more regulations regarding the harvest of crabs (MA DMF 2008). These regulations include a moratorium on new permits (as of 2008), daily harvest limits of 400 crabs per day for bait harvest and 1000 crabs per day for biomedical harvest, an annual state quota of 165,000 crabs, weekend closures, bait fishery closure on June 30, and closure of Pleasant Bay to bait harvest (in addition to the Federal closure of Monomoy National Wildlife Refuge and Cape Cod National Seashore). Future regulations may include minimum and maximum size limits for horseshoe crabs (A. Leschen, MA DMF, personal communication to M.J. James-Pirri).

Trends

Spawning indices may be declining in some areas of Cape Cod (Cape Cod Bay).

Spawning sex ratios in Pleasant Bay have shifted from a ratio of 1:2.5 (female to male) in the 1950's to 1:5.8 in the early 2000's and recent evidence indicates that they may be even more male-biased in 2008 (Figure 29.3).

Factors influencing horseshoe crab population and abundance

- Overfishing (see above).
- Spawning habitat loss. The amount of hardened shorelines in Pleasant Bay has increased from 8% (133 structures) of the shoreline in 1998 to 24% (165 structures) in 2008 (see Topic: Coastal Geomorphology – Nauset Beach & Pleasant Bay Sediment Dynamics). The hardened shoreline structures are used for erosion control. Since at high tide there is no beach left in front of these structures, the crabs are unable to spawn. This is compounded by the fact that the new inlet in Pleasant Bay (as of April 2007) has resulted in an approximately 0.3 meter magnification of the tidal amplitude in the bay (see Topic 34- Coastal geomorphology: Pleasant Bay & Nauset Beach sediment dynamics). The higher high tides have also increased the amount of erosion, especially on the beaches with upland bluffs. Additionally, sediment transport patterns have changed in the Bay, resulting in a loss of sand from the beaches in the northern section of the bay (where most the spawning occurs) - what used to be a sand beach that was good for spawning is now a cobblestone beach, an unsuitable habitat for spawning. Global sea level rise is a further factor that is likely influencing horseshoe crab habitat.

Tagging horseshoe crabs and tagged crabs in Pleasant Bay. Photos this page courtesy M.J. James-Pirri, URI.

30. Shellfish resources

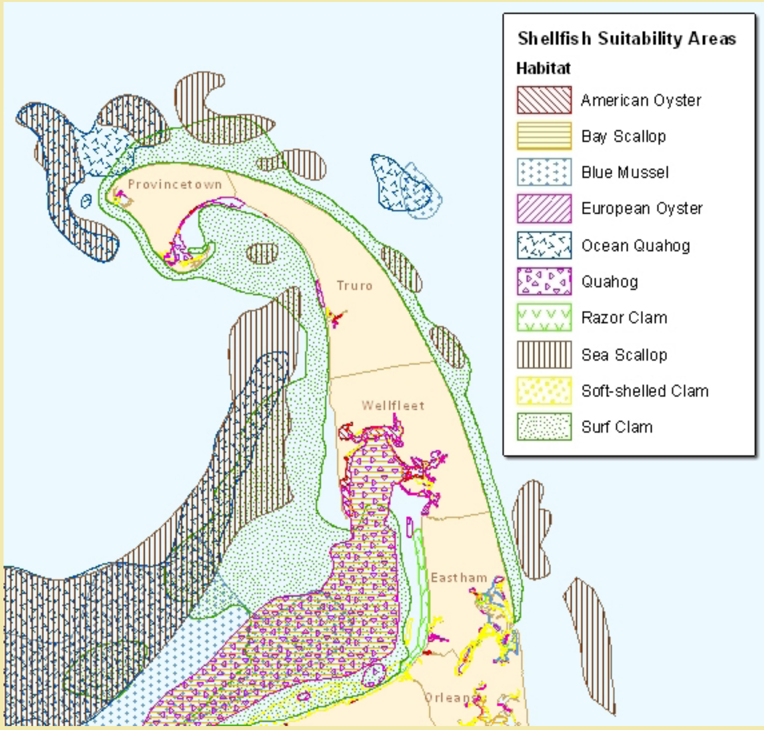


Figure 30.1. Shellfish suitability areas based on habitat type for Cape Cod. Map source: Massachusetts Geographic Information Systems.

Table 30.1. Estimated areal extent of designated shellfish growing areas adjacent or within CACO. Note: this is not an estimate of areas actually leased for aquaculture but rather an estimate of area available for aquaculture. (Data source: Massachusetts Division of Marine Fisheries. Department of Fish and Game, Designated Shellfish Growing Areas. Note: acres converted to hectares in this table. Website accessed September 2009; http://www.mass.gov/dfwele/dmf/programsandprojects/dsga.htm#ccb)

Location	Hectares
Hatches Harbor	33
Herring Cove	7606
Wellfleet (Great Island)	5843
Wellfleet Harbor	2092
Herring River	85
Nauset Beach South Coastal	21719
Nauset Harbor	144
Nauset Marsh	274
Salt Pond	9
Nauset Beach North Coastal	3955
Wellfleet East Coastal	5686
Truro East Coastal	12856
Provincetown North Coastal	7651
Total area	**67952**

Key Points

- Cape Cod waters provide habitat for several commercially important shellfish species.
- Some species have experienced local declines in harvest (e.g., Quahog and Bay scallop); while others have experienced local increases in harvest (e.g., Razor clam and Soft shell clam).
- NOAA fisheries managers have concluded that for the three Atlantic Coast commercial shellfish species assessed by NOAA (Atlantic surf clam, Ocean quahog, and Sea scallop) overfishing was not occurring in the most recent stock assessment in 2006.
- Shellfish aquaculture is practiced in waters adjacent to CACO (e.g., Pleasant Bay).

Assessment statement

Note: we are only able to characterize the condition of shellfish resources based on their landings. We are unaware of other data that might address the health or other attributes of the population status of these species.

Good (increased or sustainable landings) for Razor clam, Soft shell clam, Atlantic surf clam, Ocean quahog, and Sea scallop

Potential Significant Concern (decreased landings) for Quahog and Bay scallop

Unknown (for Cape Cod) for American oyster and Blue mussel

Rationale

The waters of Cape Cod contain habitat for a variety of commercially important shellfish species (Figure 30.1) and numerous shellfish species are harvested in the waters of Cape Cod, among them Quahogs, Scallops, Soft shell clams, and Razor clams.

Marine aquaculture in Massachusetts is limited to the cultivation of shellfish for commercial, research, and propagation purposes. There are no coastal fish farms or ocean ranches in the state and only very limited work, primarily for research purposes, is dedicated to seaweed culture (MA Office of Coastal Zone Management 1995).

Marine aquaculture industry in Massachusetts mainly produces Quahogs (hard clams) and oysters, with small quantities of Scallops, Soft shell clams, and Mussels. Shellfish aquaculture is practiced in waters adjacent to CACO.

The National Seashore cooperates with state agencies and local towns on shellfish aquaculture activities within the boundaries of the park. Shellfish aquaculture on the tidal flats within CACO's boundaries is currently allowed as long as the shellfishing grants continue to be small, dispersed, the cultural pattern of use and enjoyment are sustained, and as long as marine biodiversity is maintained. Other shellfishing activities are management by the state and local communities (National Park Service 1998).

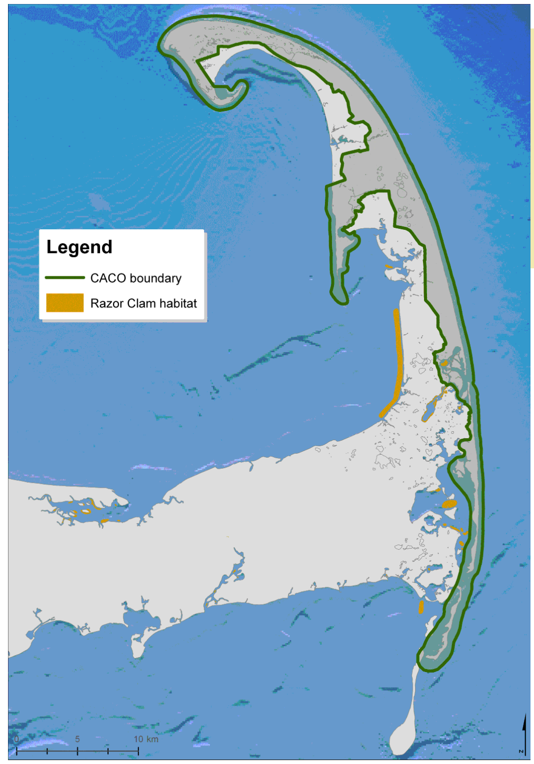


Figure 30.2. Location of razor clam habitat in Cape Cod waters Massachusetts Geographic. Data source: MassGIS.

Benchmarks

Although shellfish landings data data are available, we are unaware of specific benchmarks designed to rate changes in landings or to evaluate other aspects of the condition of shellfish resources.

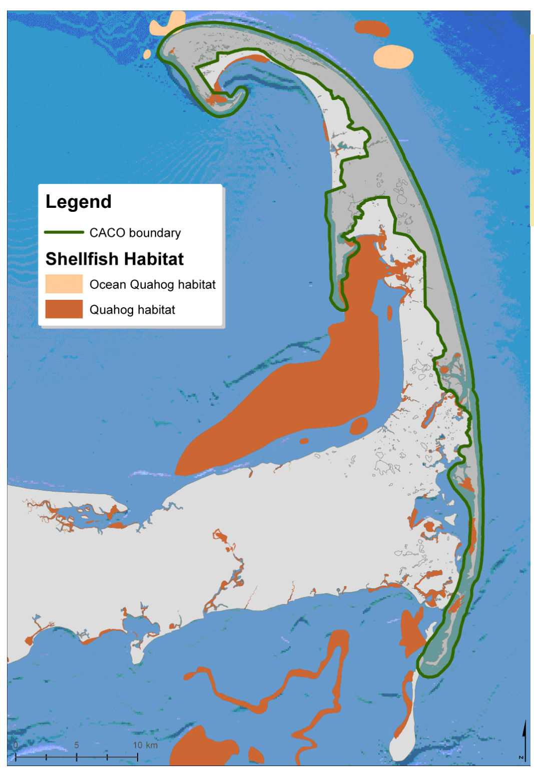


Figure 30.3. Location of quahog and Ocean quahog habitat in Cape Cod waters. Data source: MassGIS.

Condition

Status

Commercial shellfish fisheries:
Suitable benthic habitat for several commercially important shellfish species (American oyster, Bay scallop, Blue mussel, Ocean quahog, Quahog, Razor clam, Sea scallop, Soft shell clam, and Surf clam) occurs in the waters of Cape Cod (Figures 30.2 - 30.9).

Razor Clam (*Siliqua patula*) in Pleasant Bay:
In the past decade, Razor clams have recently emerged as a significant commercial fishery in Pleasant Bay (Pleasant Bay Resource Management Alliance 2008). The rapid increase in harvest has led to concerns about overfishing. Salting, which involves injecting or spraying a saline solution into or onto the substrate to draw out the clams, has made harvesting in subtidal areas of Pleasant Bay more accessible, and also has allowed harvesting to occur year-round. Salting has been found to have no significant environmental effects on the sediment or benthic community, as the salt dissipates within a few hours with the flood tide (Constantino et al.

Shellfish resources, continued

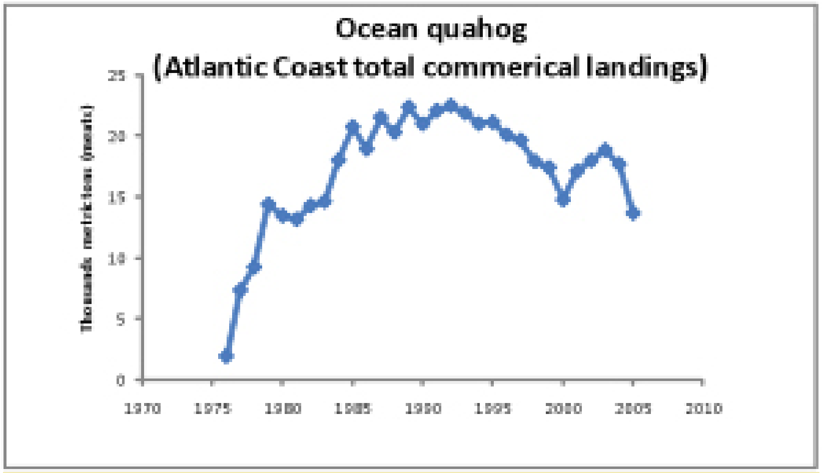
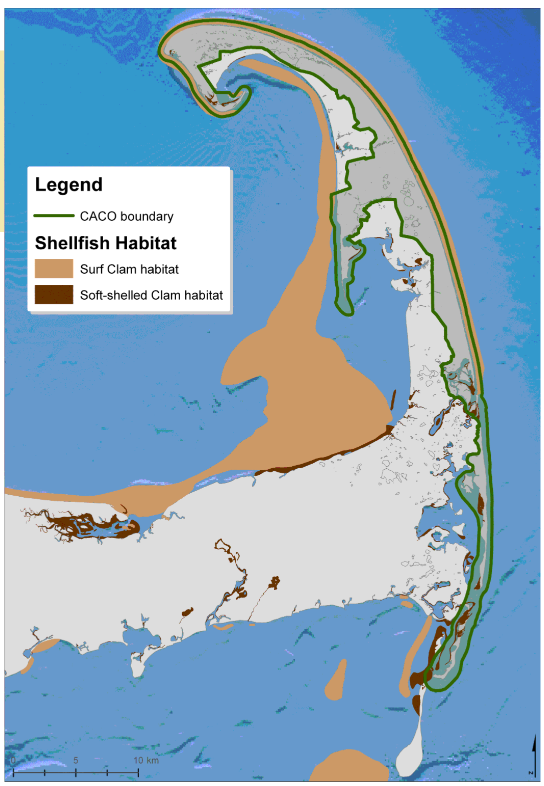


Figure 30.4. Total commercial catch of Ocean quahog for the Atlantic Coast, selected years from 1995 to 2005. Source: NOAA, Status of Fishery Resources off the Northeastern US.

Figure 30.5. Soft shell and Surf clam habitat in Cape Cod waters Data source: MassGIS.



2009). Currently, there are no size or catch limits for razor clam harvesting, although a permit is required.

Quahog (*Mercenaria mercenaria*) in Pleasant Bay:
Quahog harvest dramatically decreased in the mid-1980s and have remained low (Pleasant Bay Resource Management Alliance 2008). Prior to the 1980s decline, Pleasant Bay (particularly in the center of Big Pleasant Bay) was one of the most productive quahog fisheries on the East Coast. Two possible theories for the decline are increases in salinity due to the Chatham inlet break coupled with a change in state regulation of gauge size that resulted in animals being harvested at a smaller size before they reached prime reproductive age (Pleasant Bay Resource Management Alliance 2008). Most quahog productivity in Pleasant Bay is generated by the standing natural population, although private aquaculture grants may be a source of larvae, they are generally harvested at an early age which limits larval production to the natural population. Threats to quahogs in Pleasant Bay and presumably elsewhere include predators and pest/invasive species populations such as green crabs, Asian shore crab, codium algae, sulfur sponge, spider crabs and the disease Quahog Parasite Unknown or QPX. QPX has not yet been identified in any public shellfishing areas in Pleasant Bay, although it has been observed in selected private grants in the northern section of the Bay (Pleasant Bay Resource Management Alliance 2008).

Ocean quahog (*Arctica islandica*):
Ocean quahog harvest data were only available for the entire Atlantic Coast. These fisheries data indicate that in the early to mid- 1990s ocean quahogs were present in Cape Cod Bay and off of Provincetown, but the most recent survey data (2001 to 2005) indicate that they were not present in trawl surveys in this area. Although Atlantic coastwide landings data indicate that commercial harvests have declined somewhat in recent years (Figure 30.4), NOAA fishery managers concluded that ocean quahogs were not overfished in the most recent stock assessment (Jacobson and Weinberg 2006b).

Figure 30.6. Location of scallop habitat in Cape Cod waters Data source: MassGIS.

Soft shell clam (*Mya arenaria*) in Pleasant Bay:
The harvest of soft shell clams has been increasing in Pleasant Bay since 2002 (Pleasant Bay Resource Management Alliance 2008).

Atlantic surf clam (*Spisula solidissima*)
Atlantic surf clam data were only available for the entire Atlantic Coast. These fisheries data indicate that in the early to mid-1980s surf clams were present in Cape Cod Bay but have not been recorded in trawl surveys in the nearshore Cape Cod waters since. Landings during 1984-2005 averaged 22,000 metric tons per year and have been somewhat stable and NOAA fishery managers concluded that surf clams quahogs were not overfished in the most recent stock assessment (Figure 30.8) (Jacobson and Weinberg 2006a). The Georges Bank region has been closed to the harvesting of surf clams since 1990, due to the risk of paralytic shellfish poison (PSP). Southern areas have experienced declines in biomass during recent years due primarily to poor recruitment and slow growth rates associated with warm water conditions (Jacobson and Weinberg. 2006b).

Bay scallop (*Argopecten irradians*) in Pleasant Bay:
Scallop harvests in Pleasant Bay declined dramatically in the mid-1980's and are now virtually non-existent in the bay (Pleasant Bay Resource Management Alliance 2008). Causes of decline are unclear, but loss of eelgrass habitat (24% loss from 1995-2001) has been cited as a possible cause.

Sea scallop (*Placopecten magellanicus*):
Sea scallop quahog harvest data were only available for the entire Atlantic Coast. These fisheries data indicate that sea scallop have been present in a fairly high abundance off the Atlantic Coast of Cape Cod since the earliest fishery trawl data (Figure 30.9). Since 1998, sea scallop biomass has more than doubled due to a combination of strong recruitment and reduced fishing mortality with the highest recorded U.S. landings occurred in 2004 (Figure 30.9, graph). The recent high landings can be attributed to the increase in landed meat weight together with favorable environmental conditions in the Mid-Atlantic. The U.S. Atlantic sea scallop fishery is one of the most valuable fisheries in the United States and the most valuable wild scallop fishery in the world; its ex-vessel value exceeded $430 million in 2005 (Hart 2006). NOAA fishery managers concluded that sea scallops clams quahogs were not overfished in the most recent stock assessment (Hart 2006).

Other commercially important shellfish species that are present in Cape Cod waters American or Eastern oyster (*Crassostrea virginica*), and blue mussel (*Mytilus edulis*) (Figure 30.9). Fishery statistics data were not readily available for these species.

Status – Aquaculture:
The marine aquaculture industry is concentrated on Cape Cod and the Islands with some producers on the South and Southeastern Coasts (MA Office of Coastal Zone Management, Aquaculture in Massachusetts). There are almost 68,000 ha of submerged lands adjacent or within the boundaries of CACO that are designated as shellfish growing areas (Figure 30.1 and Table 30.1). As of 1995 there were approximately 646.5 acres of tidelands licensed for shellfish cultivation (commercial and research) in twenty-two

Shellfish resources, continued

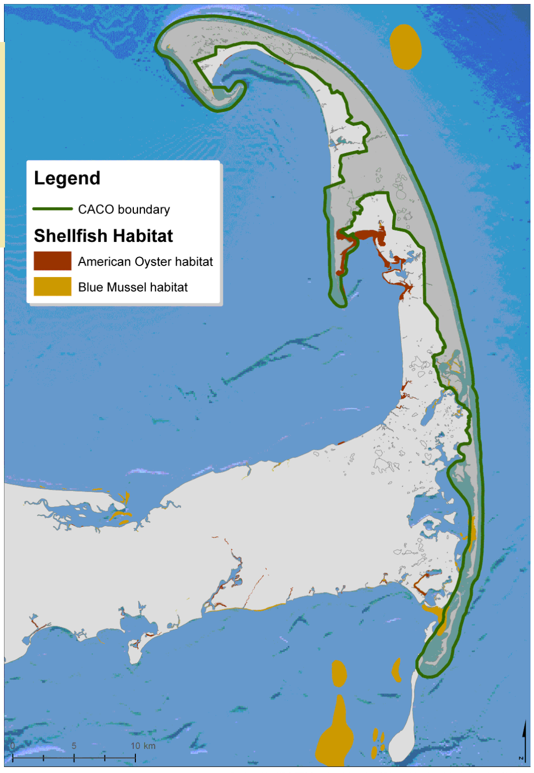
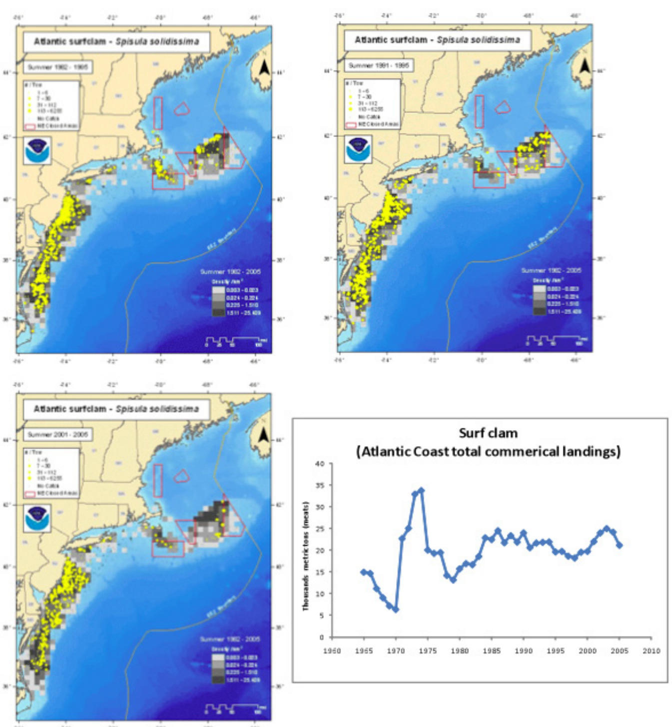


Figure 30.7 American oyster and blue mussel habitat in Cape Cod waters. Data source: MassGIS.

Massachusetts cities and towns (Barnstable, Brewster, Chatham, Dennis, Duxbury, Eastham, Edgartown, Essex, Fairhaven, Falmouth, Gosnold, Mashpee, Mattapoisett, Nantucket, Oak Bluffs, Orleans, Plymouth, Provincetown, Truro, Wareham, Wellfleet, and Yarmouth)(Massachusetts Office of Coastal Zone Management 1995). Cultivated species include, in order of economic importance, (1) quahogs, (2) American oysters, (3) bay scallops, (4) soft shell clams, (5) European oysters, (6) surf clams, and (7) blue mussels.

In 1998, large portions of Pleasant Bay were designated as Areas of Critical Marine Habitat (ACMH) (see Topic 9- Critical estuarine & marine habitats). Aquaculture was one of prohibited activities under this designation, although existing aquaculture grants were not affected (Pleasant Bay Resource Management Alliance 2008). Private Aquaculture remains only within areas specified by the Pleasant Bay Resource Management Plan and no new grants have been permitted, but several existing grants have been expanded contiguous to existing licensed areas. As

Figure 30.8. Relative Distribution and Abundance of Atlantic surf clam in the Northwestern Atlantic (selected years from 1982 to 2005) and total commercial catch for the Atlantic Coast. Distribution information derived from the NOAA, Northeast Fisheries Science Center summer bottom trawl surveys. Yellow circles indicate where Surf clams were present. Source: NOAA, Status of Fishery Resources off the Northeastern US, Atlantic surf clam summer distribution maps.



of 2008, there were a total of 28 acres of private grant area with the potential for an additional 12 acres (all located in the Town of Orleans, MA)(Pleasant Bay Resource Management Alliance 2008). The majority of aquaculture leases are adjacent to CACO near Pochet Island and Hog Island (Figure 30.10).

Aquaculture also occurs in Wellfleet Harbor. In 2002, the Wellfleet Harbor Area of Critical Environmental Concern (ACEC) (Topic 9: Critical terrestrial & aquatic habitats) supported 180 acres of aquaculture lease sites used by 58 license holders (Commonwealth of Massachusetts. Areas of Critical Environmental Concern 2003). Wellfleet is the state's most successful aquaculture site with a combined harvest in 2002 close to $3 million from aquaculture and shellfishing.

Trends

- Commercial harvest of quahog and scallop has declined over the past decade in Pleasant Bay.
- Commercial harvest of razor and soft shell clam has increased in recent years in Pleasant Bay.

Factors influencing shellfish resources

- Potential overfishing.
- Degraded water quality.
- Environmental stress resulting from the Chatham inlet break.
- Loss of habitat, primarily eelgrass.
- Pathogens and disease (e.g., QPX, redtide).
- Increases in predator or pest/invasive species populations (e.g., green grab, Asian shore crab, codium algae).

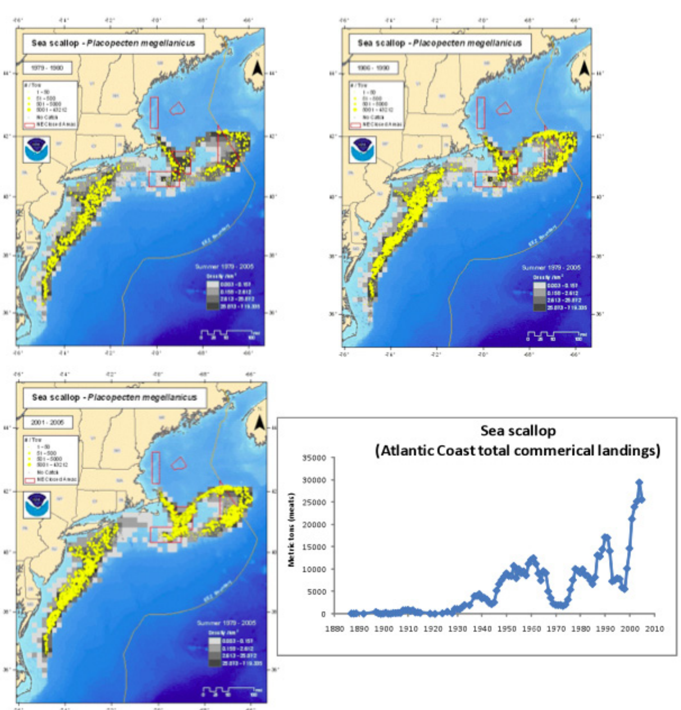


Figure 30.9. Relative distribution and abundance of Sea scallop in the Northwestern Atlantic (selected years from 1979 to 2005) and total commercial catch for the Atlantic Coast. Distribution information derived from the NOAA, Northeast Fisheries Science Center summer bottom trawl surveys. Yellow circles indicate where Sea scallops were present. Source: NOAA, Status of Fishery Resources off the Northeastern US, Sea scallop summer distribution maps.

31. Beach closures

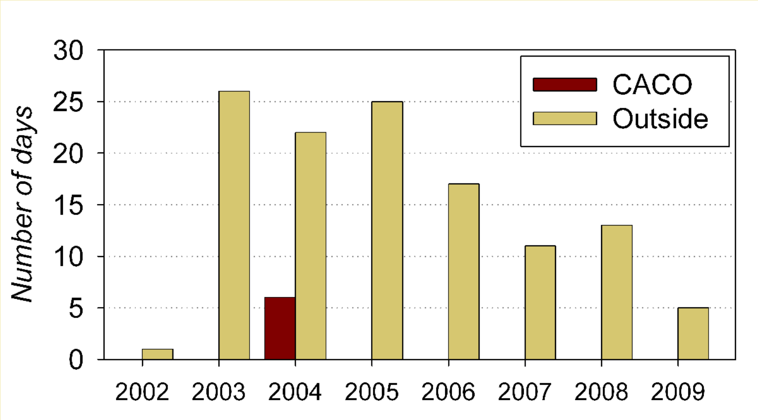
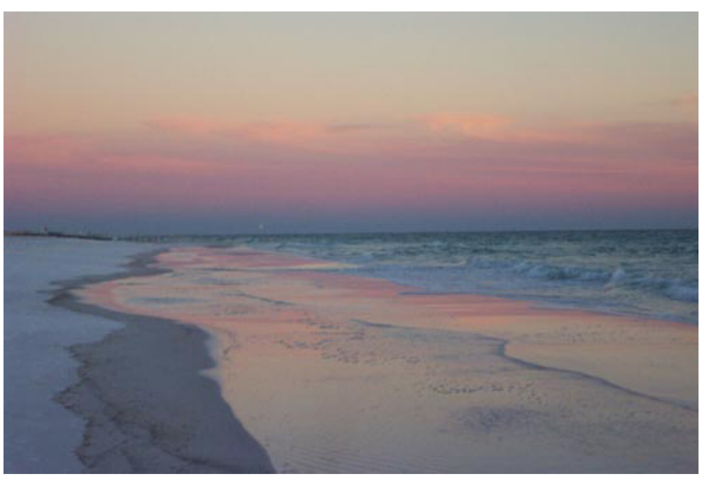


Figure 31.1. Number of days on which bacterial levels exceeded 104 CFU*/100ml (threshold for beach closure) for mid and upper Cape Cod beaches in side CACO and outside the park (Towns of Orleans, Eastham, Wellfleet, Truro, and Provincetown). See Figures 2 – 6 for beach-specific data. (* CFU = colony-forming units)

Massachusetts Department of Public Health, Beach Closure interactive website:

http://mass.digitalhealthdepartment.com/public_21/beaches.cfm?showsearch=1)



CACO beach at sunset. Photo courtesy M.J. James-Pirri, URI.

Key points

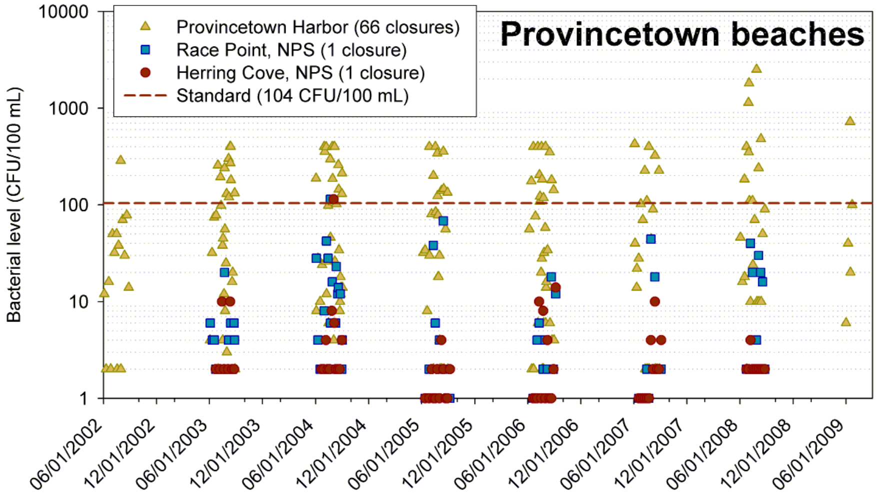
- The NPS has sampled bathing beach waters for NPS ocean beaches since 2006. Additional data are available from a Massachusetts Department of Public Health monitoring program.
- From June 2002 to June 2009, CACO beaches have only been closed (exceedances of 104 CFU/100ml) on 6 dates. All of these closures occurred in 2004. In August 2009, Race Point Beach was closed on two occasions in response to elevated bacterial levels.
- Beaches in towns adjacent to the Park have been closed on a total of 120 days over this same time period.
- The majority of the closures outside of CACO have occurred in Provincetown Harbor (46 closures) and Cape Cod Bay (56 closures) since 2002.

Assessment statement

Good (for CACO beach water quality)

Rationale

The beaches in Massachusetts are monitored by a variety of county and state agencies, with the Massachusetts Department of Conservation and Recreation conducting the vast majority of beach water sampling in Massachusetts. Most marine beach samples collected at public beaches are analyzed at Massachusetts Department of Public Health (MDPH) contracted laboratories. Water quality at beaches is tested at variable intervals, ranging from every day to once per month. The testing frequency depends on how likely the beach is to have water quality issues. Infrequently used beaches or beaches that historically have had very few, if any, water quality issues are tested less often, while high-use or historically problematic beaches are tested more often. The water at marine beaches is tested for the presence of Enterococci. Enterococci are a group of bacterial species within the Streptococcus genus, some of which (e.g. *Streptococcus faecalis*) are typically found in animal digestive



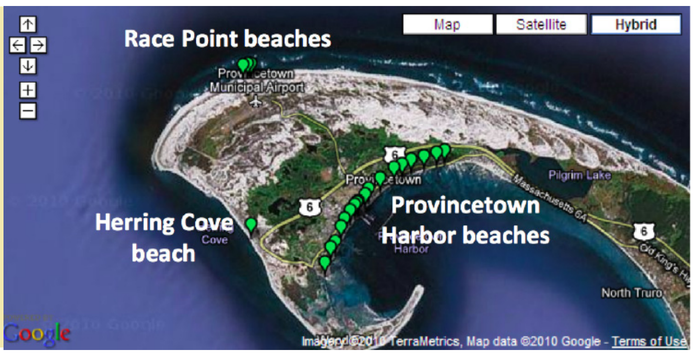
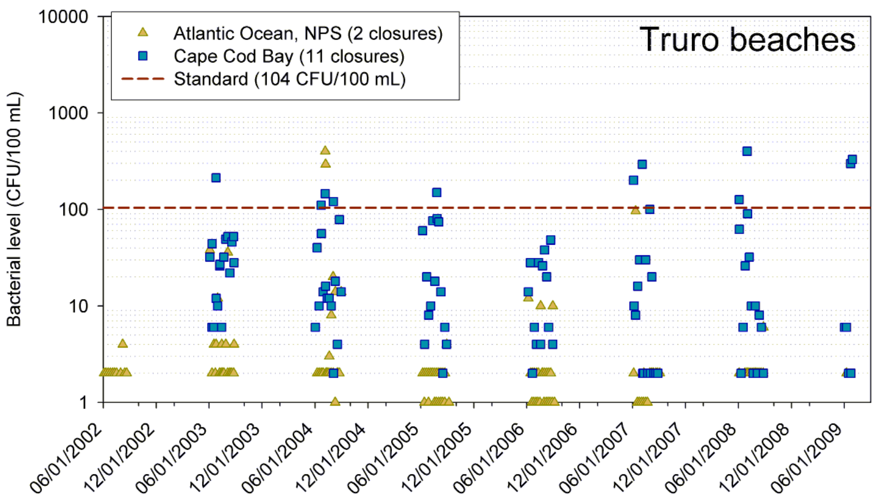


Figure 31.2. Bacterial counts since 2002 at Provincetown beaches. Beaches are closed at counts above 104 CFU/100ml (indicated by red line). Beaches inside CACO are indicated by "NPS".



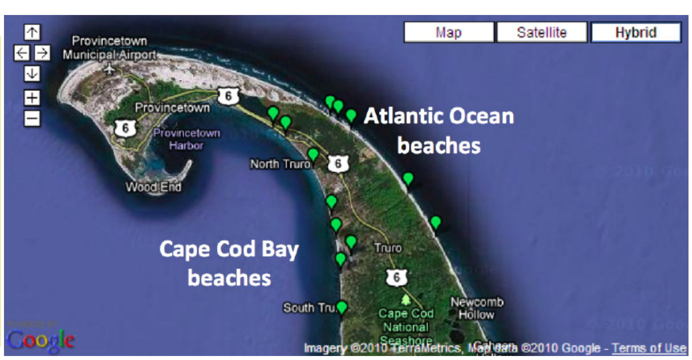
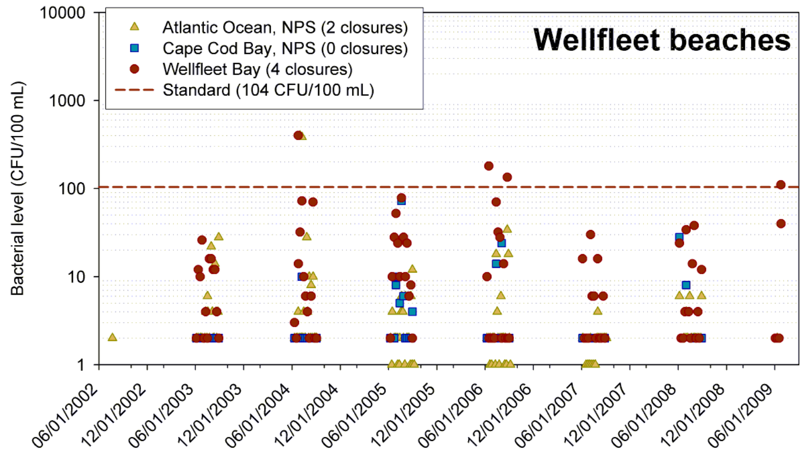


Figure 31.3. Bacterial counts since 2002 at Truro beaches. Beaches are closed at counts above 104 CFU/100ml (indicated by red line). Beaches inside CACO are indicated by "NPS".

Beach closures, continued



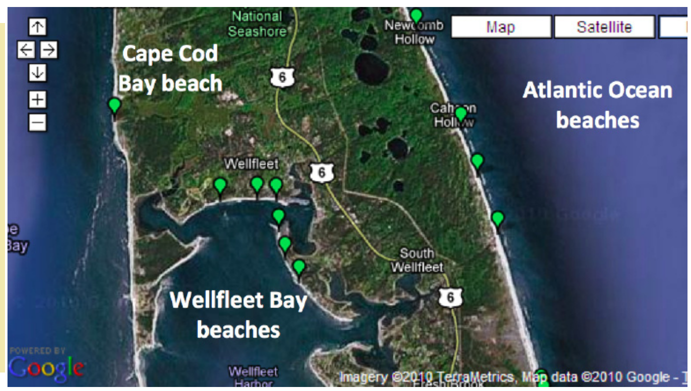
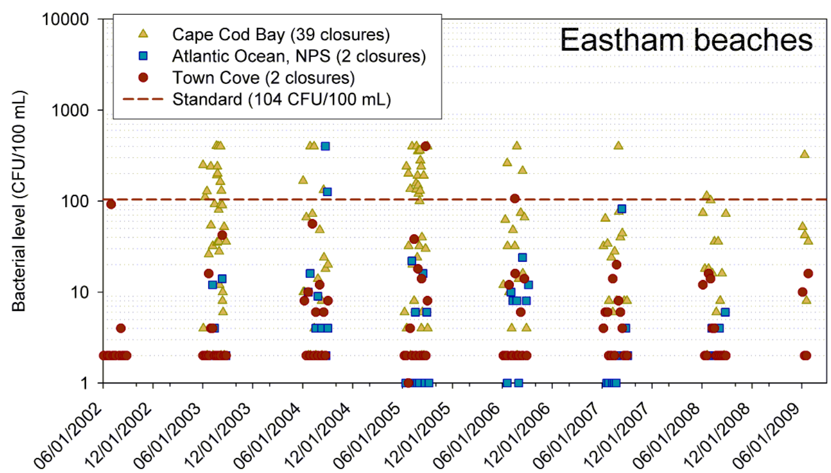


Figure 31.4. Bacterial counts since 2002 at Wellfleet beaches. Beaches are closed at counts above 104 CFU/100ml (indicated by red line). Beaches inside CACO are indicated by "NPS".



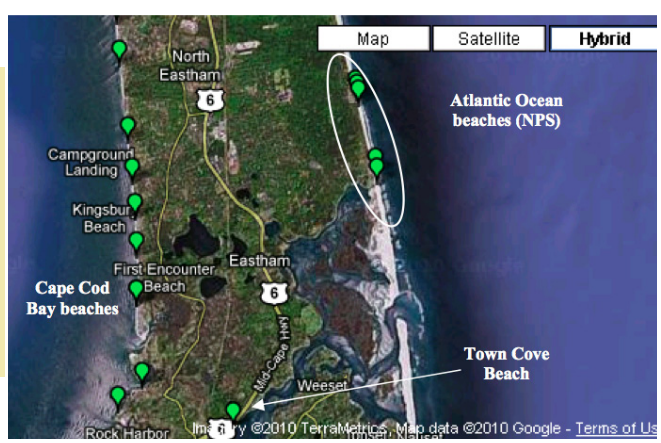
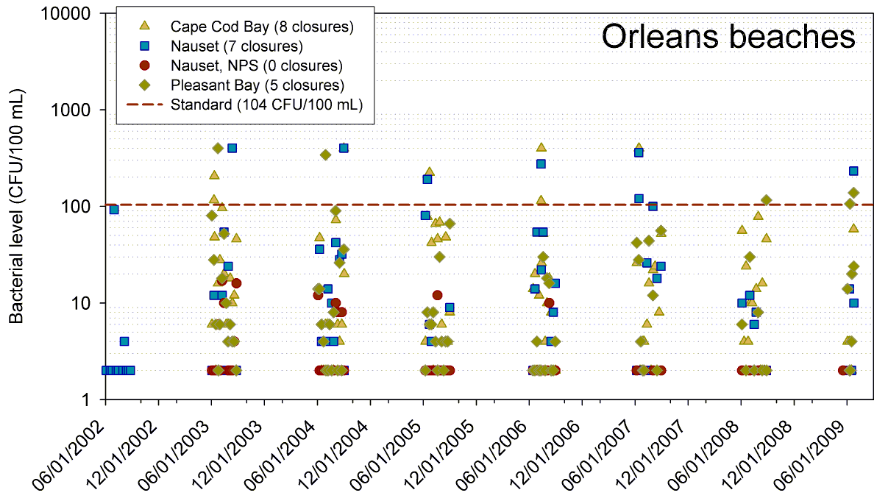


Figure 31.5. Bacterial counts since 2002 at Eastham beaches. Beaches are closed at counts above 104 CFU/100ml (indicated by red line). Beaches inside CACO are indicated by "NPS".



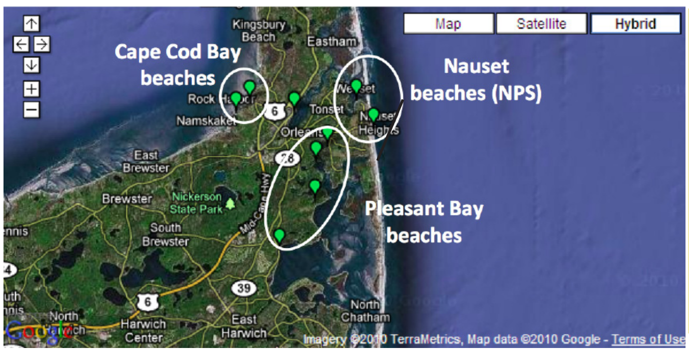


Figure 31.6. Bacterial counts since 2002 at Orleans beaches. Beaches are closed at counts above 104 CFU/100ml (indicated by red line). Beaches inside CACO are indicated by "NPS".

Figures 31.2 - 31.6 Data source: Commonwealth of Massachusetts, Department of Public Health, Bureau of Environmental Health. Website accessed July 2009. http://mass.digitalhealthdepartment.com/public_21/beaches.cfm?showsearch=1

tracts and are therefore present in sewage. In marine waters, the accepted level of Enterococci for a single sample is 104 colony forming units per 100 milliliters (CFU/100 ml) of bathing water or below. A sample above 104 CFU/100ml causes a beach closure, and recreational use of the water is prohibited.

Benchmarks

In marine waters, the accepted level of Enterococci for a single sample is 104 colony-forming units per 100 milliliters (CFU/100 ml) of bathing water or below. A sample above 104 CFU/100ml causes a beach closure, and recreational use of the water is prohibited.

Condition

Status
The beaches in Cape Cod National Seashore have been closed for health reasons (exceedances of 104 CFU/100ml) for only 6 days since 2002 (Figures 31.1-31.6). All of these closures occurred in 2004. The cause of the higher bacteria levels in that year is unclear - higher precipitation does not appear to be a factor. Since this time, none of the Seashore's beaches have been closed for health reasons.

Trends
Since no closures have been posted in the past 6 years, the trend may be characterized as stable / improving..

Factors influencing beach closures

- Sewage from failing septic systems.
- Storm events that cause sewer overflow. However, this is not a factor on the outer Cape.

32. Beach fouling: marine macroalgae accumulations

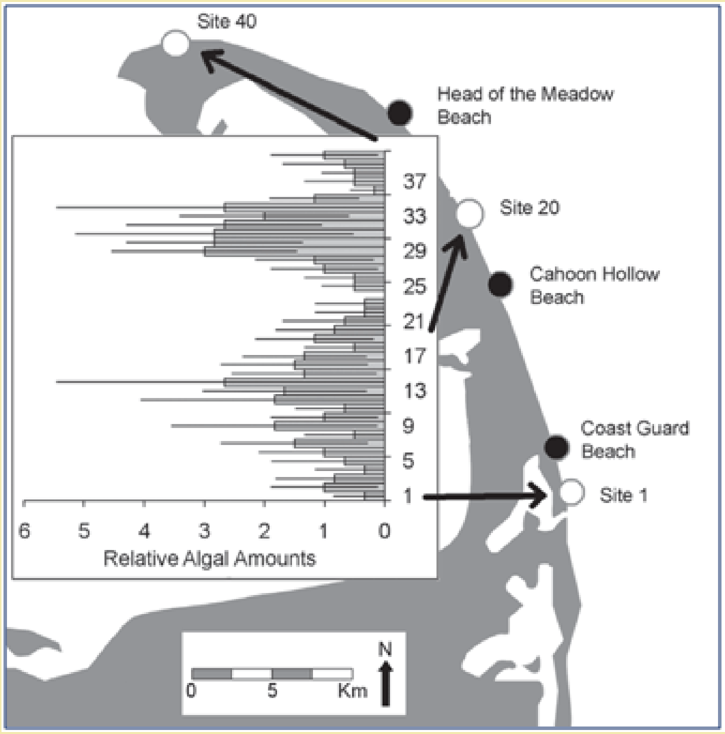


Figure 32.1. Sites surveyed during a 2006 survey of macroalgal accumulations (Lyons et al. 2008, 2009). Black dots depict the three sites where quantitative surveys were conducted. Sites surveyed qualitatively were spaced equally at 1 km apart; three of these 40 sites are indicated on the map by white dots. Data from the qualitative surveys (Relative Algal Amounts) are shown as the sum of intertidal and subtidal scores. For each habitat, algal densities were scored on a scale from 0 (algae absent) to 5 (dense accumulations of algae). Bars represent site means from six survey dates,± 1 standard error. (Figure from Lyons et al. 2008).

Key points

- Accumulations of nuisance drift macroalgae along the open-coast Atlantic beaches of the Cape Cod have been observed on an anecdotal basis for over 50 years and have historically caused beach closures (Gross 1994, cited by Lyons et al. 2008).
- Detailed data on macroalgal abundance at CACO are available only from a study conducted in 2006 (Lyons et al. 2008, 2009)
- In 2006, peak macroalgal biomass occurred in early August. Highest algal densities were found at Head of the Meadow beach, in both intertidal and subtidal habitats.
- Macroalgae probably originate in northern New England and are transported south by Gulf of Maine currents. It is unlikely that accumulations are associated with nutrient availability (Lyons et al.2008, 2009).

Assessment Statement

Unknown. Data are unavailable to permit an assessment of trends in beach fouling from macroalgae accumulations in the CACO area. Consequently, it is difficult to evaluate 'normal' conditions.

Rationale

High macroalgal densities in coastal areas may result from enhanced production in situ (e.g., as a result of nutrient enrichment) or from the accumulation of plants that have been transported from elsewhere. This topic addresses the latter phenomenon. When dense aggregations of marine macroalgae decay, they can produce localized conditions of reduced dissolved oxygen. When the plants accumulate on beaches, they can interfere with recreational quality and may lead to beach closures.

Benchmarks

Transport and beach accumulation of macroalgae are natural processes, although both may presumably be influenced by anthropogenic factors such as nutrient enrichment and shoreline modifications. There is no recognized reference condition for macroalgal accumulations, although temporal trends in plant biomass / cover would be a useful measure. As further discussed below, quantitative data on trends in macroalgal accumulations on Cape Cod beaches are unavailable.

Condition

Status

Accumulations of macroalgae on CACO beaches have been observed at least since the 1980s have resulted in repeated beach closures at Head of the Meadow Beach in some years (Gross 1994, cited by Lyons et al. 2008). Although anecdotal observations indicate that macroalgal accumulations have increased in recent years, there is no quantitative documentation of this (G. Giese, PCCS, personal communication).

The most detailed information on spatial and temporal patterns of macroalgal accumulations along Cape Cod come from a 2006 survey, carried out along a 40 km coastal transect from just south of Coast Guard beach to Race Point (Lyons et al. 2008, 2009). This study employed qualitative and quantitative surveys of both intertidal and subtidal areas. Data from the qualitative survey revealed highest macroalgal densities (composite measures from inter-tidal and sub-tidal areas) in the region just north of Head of the Meadows beach; high densities also occurred in the area around Cahoon Hollow beach (Figure 32.1). Macroalgae were sparse in the southern part of the surveyed region (around Coast Guard Beach), except during the first week of August, 2006, following a period of strong northwest winds. Quantitative measurements at three sites documented that highest densities occurred during the second week of August (Figures 32.2, 32.3).

The most commonly observed species observed in the 2006 survey were filamentous red algae (*Neosiphonia harveyi*, *Polysiphonia flexicaulis*, *P. fucoides*, *P. nigra*, *and P. stricta*) and the green alga *Ulva lactuca*.

It appears that high macroalgal densities are not the result of enhanced nutrient supply in the Cape Cod region. No significant relationship was observed between algal density and upwelling events; the latter are typically associated with nutrient-rich conditions. The most likely source of macroalgae that accumulate on Cape Cod beaches is transport from the Gulf of Maine via the Western Coastal Maine Current. Sandbars along the Atlantic coast of CACO, particularly in the northern section, appear to catch the drifting algae, resulting in beach accumulations (Lyons et al. 2008).

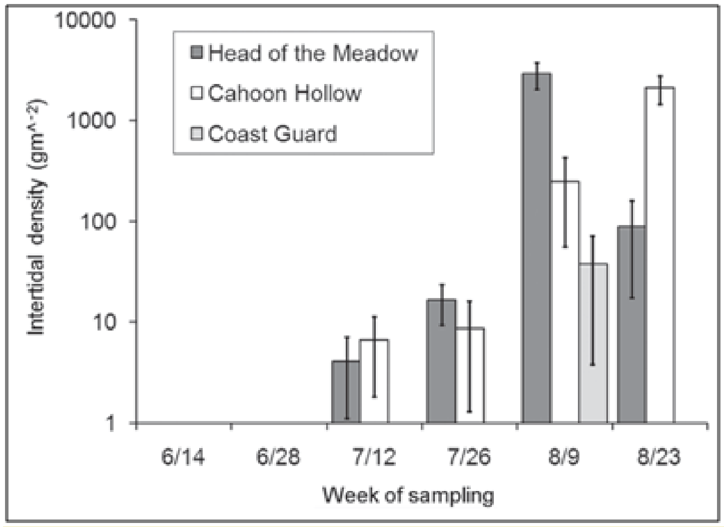


Figure 32.2. Intertidal algal densities (wet mass) at three sites surveyed quantitatively in summer 2006. Data are means + 1 standard error (from Lyons et al. 2008).

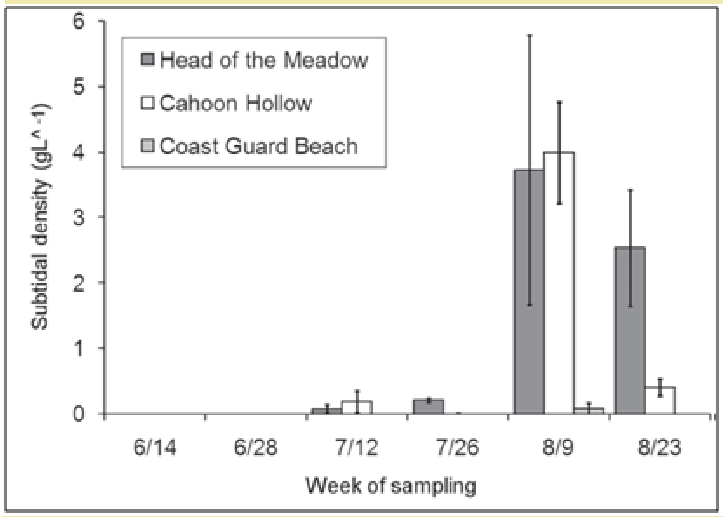


Figure 32.3. Subtidal algal densities (wet mass) at three sites surveyed quantitatively in summer 2006. Data are means + 1 standard error (from Lyons et al. 2008).

Trends

No data are available to quantify trends in macroalgal accumulations.

Factors influencing beach fouling

- Factors influencing densities of macroalgal accumulations on Cape Cod beaches remain undefined. They may include climate (especially wind patterns), ocean currents, coastal geomorphology (especially the structure of the "J bars" along CACO's Atlantic coast), and factors influencing algal production, both locally and, especially, further north in the Gulf of Maine.

33. Harmful algal blooms & shellfish closures

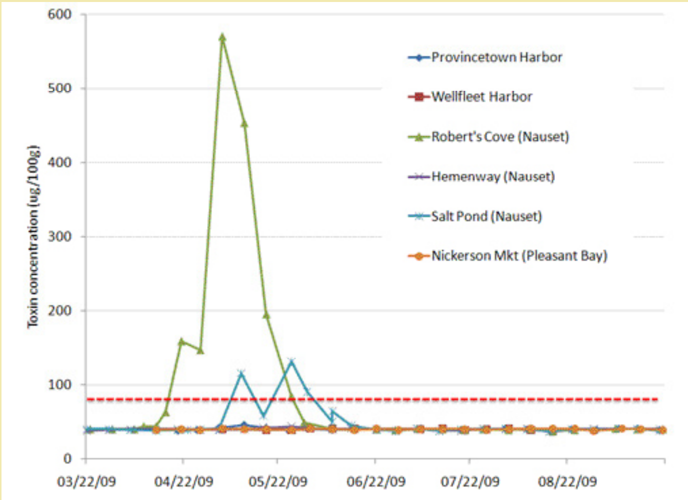


Figure 33.1. Biotoxin levels (mg/100g) from PSP monitoring in waters in and adjacent to CACO in 2009. Biotoxin levels greater than 80 mg/100g (indicated by red line) are considered a health hazard and shellfishing is prohibited in waters until levels are acceptable.

Key Web sites from the Commonwealth of Massachusetts:

PSP closure notices:

↓ http://www.mass.gov/dfwele/dmf/programsandprojects/psp_notice.htm

Massachusetts Division of Marine Fisheries website:

↓ http://www.mass.gov/dfwele/dmf/programsandprojects/psp_notice.htm

Massachusetts Health and Human Services website. Red tide fact sheet

↓ http://www.mass.gov/?pageID=eohhs2modulechunk&L=4&L0=Home&L1=Provider&L2=Guidance+for+Businesses&L3=Food+Safety&sid=Eeohhs2&b=terminalcontent&f=dph_environmental_foodsafety_p_red_tide&csid=Eeohhs2

Key Points

- The state of Massachusetts monitors for paralytic shellfish poisoning (PSP) to determine the safety of shellfish harvested from state waters.
- Elevated biotoxin levels are usually detected every year, forcing the closure of waters to shellfish harvesting.
- In 2009, elevated biotoxin levels were detected in Nauset Estuary.
- Currently there are no published trend analyses for PSP data (the Division of Marine Fisheries is in the process of analyzing data).

Assessment statement

Fair.

Rationale

Harmful algal blooms (HAB) are caused by blooms of highly toxic algae cells that can negatively impact co-occurring organisms, alter food-web dynamics, and cause human illness and mortality following consumption of or indirect exposure to HAB toxins. HAB can also cause substantial economic losses to coastal communities and commercial fisheries, and HAB-associated fish, bird and mammal mortalities. In Massachusetts waters the dinoflagellate, *Alexandrium* is the red-tide causing organism. This dinoflagellate is found along the Northeast Atlantic coast, ranging from the Canadian Maritimes to Southern New England. Factors that are especially favorable to red-tide events include warm surface temperatures, high nutrient content, low salinity, and calm seas. Rain followed by sunny weather in the summer months is often associated with red tide blooms. Shellfish, including hard-shell clams, soft-shell clams, oysters, mussels and scallops, are particularly prone to contamination as they feed by filtering microscopic food out of the water. If toxic planktonic organisms are present, they are filtered from the water along with other nontoxic foods. Whelks and moon snails can also accumulate dangerous levels of the toxin during red tide as they feed on contaminated shellfish.

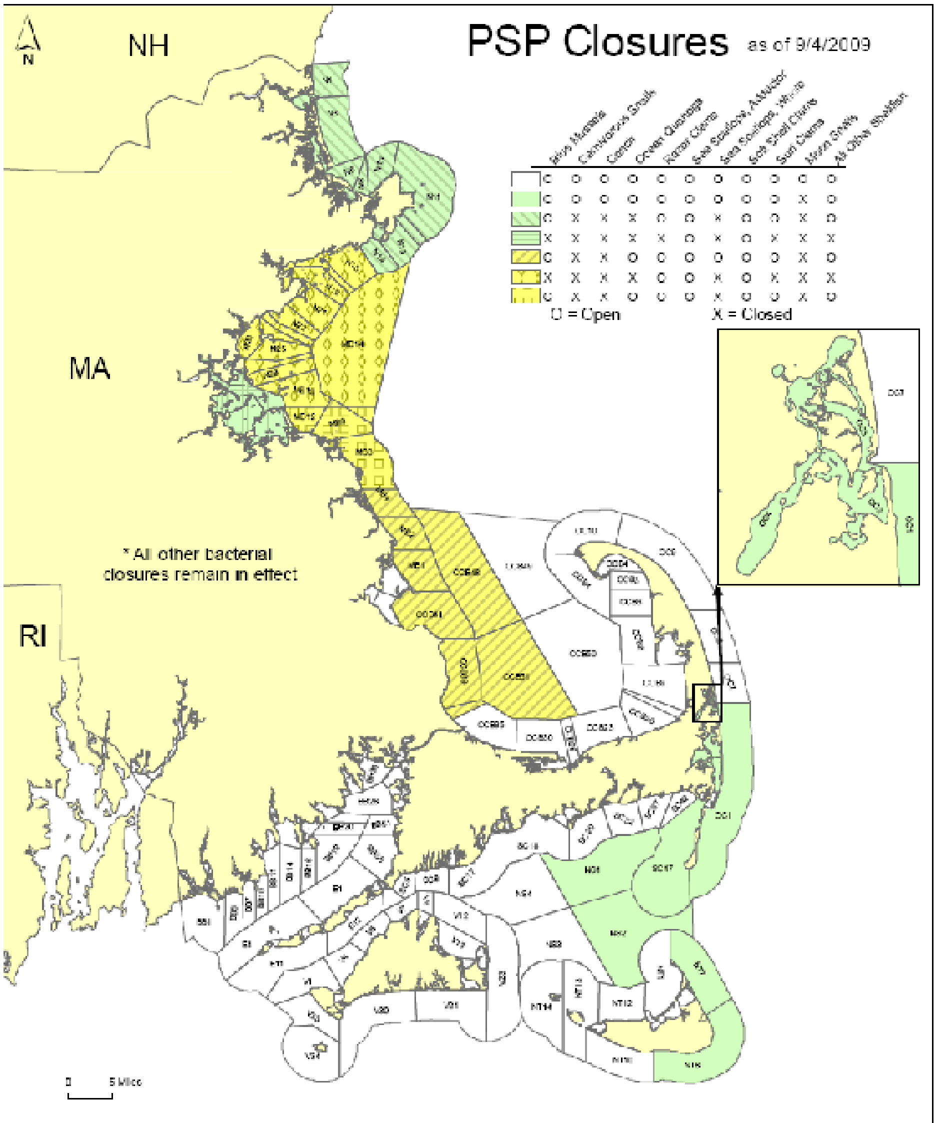


Figure 33.2. Paralytic Shellfish Poisoning (PSP) closures: an example of the shellfish closure information released by the Massachusetts Division of Marine Fisheries (http://www.mass.gov/dfwele/dmf/programsandprojects/psp_notice.htm#shelsani, accessed 10/15/09).

Benchmarks

The Massachusetts Division of Marine Fisheries (MADMF) monitors HAB annually from early April and continues on a weekly basis until November (FIgure 33.1). One such HAB is paralytic shellfish poisoning or PSP, caused by the *Alexandrium tamarense*, a single-celled dinoflagellate 30 to 40 microns in size. When levels of this biotoxin equal or exceed 80 mg/100g, waters are closed to shellfish harvesting and sampling continues until three consecutive samples result in levels of less than 80 mg.

Researchers are currently in the process of analyzing PSP data to determine trends in PSP closure events. Results of this analysis may contribute to identifying appropriate baseline conditions for this topic.

Condition

Status

Data on the occurrence and closures of shellfishing areas have been collected since 1972. The waters of the state are divided into shellfish management areas (Figure 33.2) and these areas may be closed at anytime depending on the level of harmful biotoxins present from April through November (the state's monitoring period for biotoxin levels). The state is currently in the process of reviewing the data to establish a historical perspective of toxin occurrences over the past 22 years . In June 2005, an extremely extensive red-tide occurred prompting the emergency closure of all federal waters in

Harmful algal blooms & shellfish closures, continued

New England to shellfishing (except for scallops). At the time, this was the largest red-tide bloom recorded in New England history and warranted a public health emergency. Many waters of the state remained closed to shellfishing through the summer of 2007 due to this event. In 2008, federal waters were also closed to shellfishing due to red tide.

All embayments and oceanic waters adjacent to CACO (Atlantic Ocean, Pleasant Bay, Nauset Estuary, and Cape Cod Bay) have been closed for a period of time to the harvest of at least one shellfish species in every year since 2005 (the earliest year for which PSP closure notices are available). Species that have been closed to harvesting include blue mussel (*Mytilus edulis*), surf clams (*Spisula solidissima*), moon snails (*Lunatia heros* and *Polinices duplicates*), conch (*Busycon carica* and *Busycotypus canaliculatus*), ocean quahog (*Arctica islandica*), razor clam (*Ensis directus*), sea scallop (*Placopecten magillanicus*), soft shell clam (*Mya arenaria*), as well as other shellfish and carnivorous snails.

Biotoxin data from 2009 indicate (Figure 33.1) that only the Nauset Estuary system experienced elevated levels of biotoxin in this year forcing the closure of the area to shellfishing for approximately 60 days for bivalves (the harvest of carnivorous snails [e.g., *Lunatia heros* and *Polinices duplicates*] was prohibited for approximately 120 days).

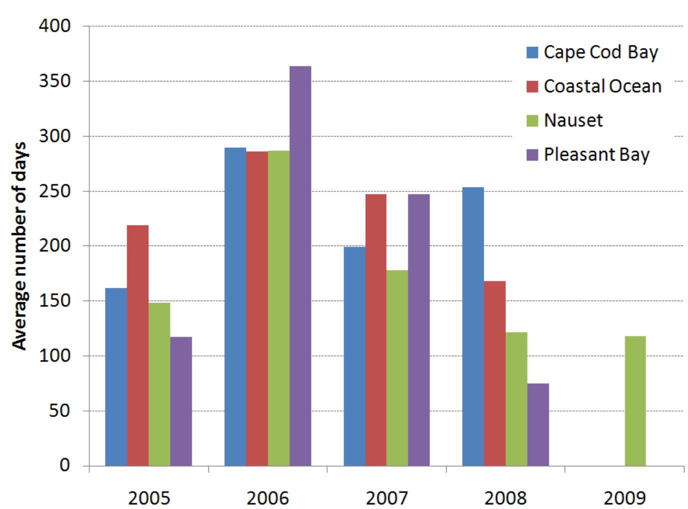


Figure 33.3. Average number of days when shellfishing (all species included) was restricted (based on MADMF closure notices) in embayments in the vicinity of CACO. Note: This is an approximate estimate; MADMF is currently (2010) in the process of summarizing closure data.

Based on historical PSP closure notices a general estimate of the average number of days areas were closed to shellfishing (all species included) can be made (Figure 33.3). Areas in the vicinity of the park have experienced lengthy closures (150 days or more) in the past, particularly in 2006 (this was due to the red-tide event in 2005 that closed many areas for more than a year). In 2009, only the Nauset Estuary system experienced closures due to elevated PSP biotoxin levels.

Trends

More extensive data on trends in PSP incidence and shellfish closures are unavailable, although trend analyses are currently being undertaken. The fact that PSP is known to occur in the CACO region and to cause adverse economic and biological impacts, suggests that the appropriate condition level for this topic is Caution. Results of the on-going trend analyses may suggest a modification in this condition level.

Factors influencing harmful algal blooms

Factors promoting the occurrence of red-tide blooms include:

- Warm surface temperatures.
- High nutrient content, low salinity, and calm seas.
- Rain followed by sunny weather in the summer months.

Other closures and advisories:

In addition to harmful algal blooms, there are several other causes of fish and shellfish consumption advisories in the Northeast. The US EPA lists fish consumption advice in the National Listing of Fish Advsories (available: http://www.epa.gov/waterscience/fish/advisories/), and summarizes information in Coastal Condition Reports. Figures 33.4-33.7 show key graphics for the Northeast from the 2008 Coastal Condition Report (US EPA 2008).

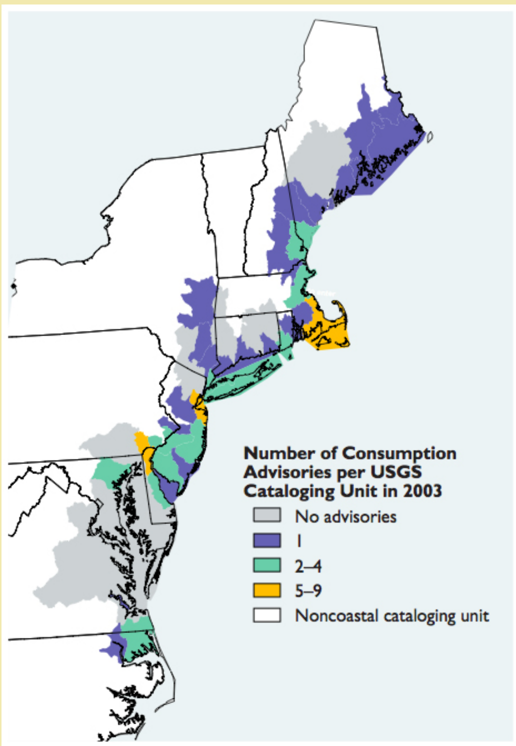


Figure 33.4. The number of fish consumption advisories active in 2003 for the Northeast Coast coastal waters (US EPA, 2004). Source: US EPA 2008.

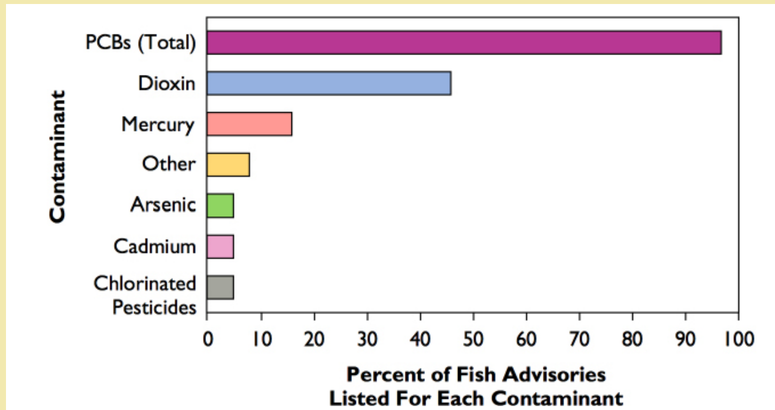


Figure 33.5. Pollutants responsible for fish consumption advisories in Northeast Coast coastal waters. An advisory can be issued for more than one contaminant, so percentages may add up to more than 100 (US EPA, 2004). Source: US EPA 2008.

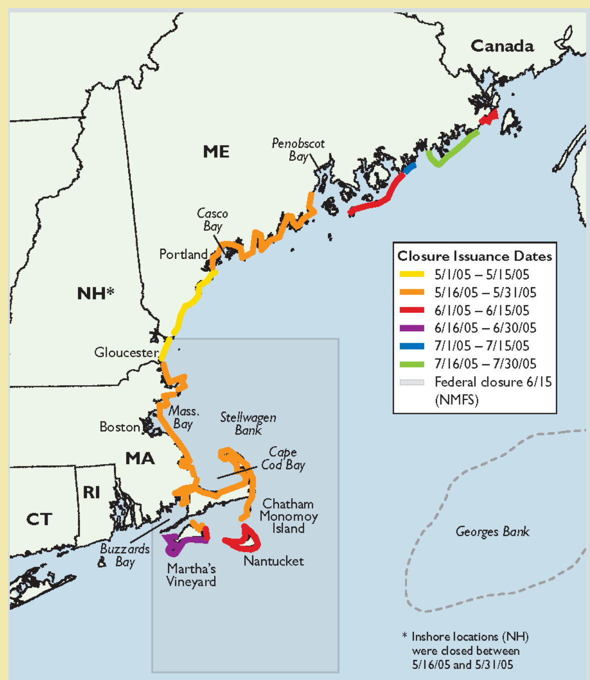


Figure 33.7. Map of shellfish closure areas and area of temporary federal closure of offshore waters with closure issuance dates during the 2005 *Alexandrium fundyense* bloom in Maine, New Hampshire, and Massachusetts (Anderson et al., 2005). Source: US EPA 2008.

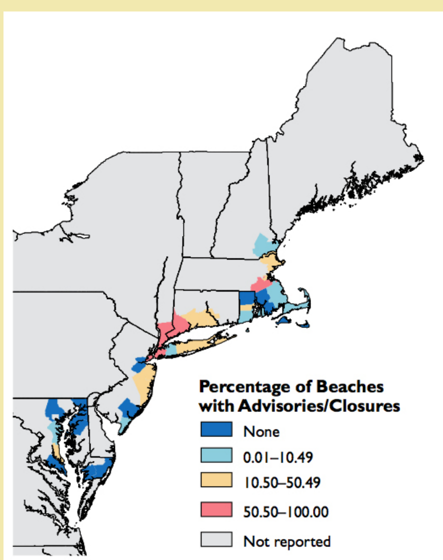


Figure 33.6. Percentage of monitored beaches with advisories or closures, by county, for the Northeast Coast region; The value for Barnstable County is <10%. (US EPA, 2006). Source: US EPA 2008.

34. Water and sediment quality: coastal & surface freshwaters

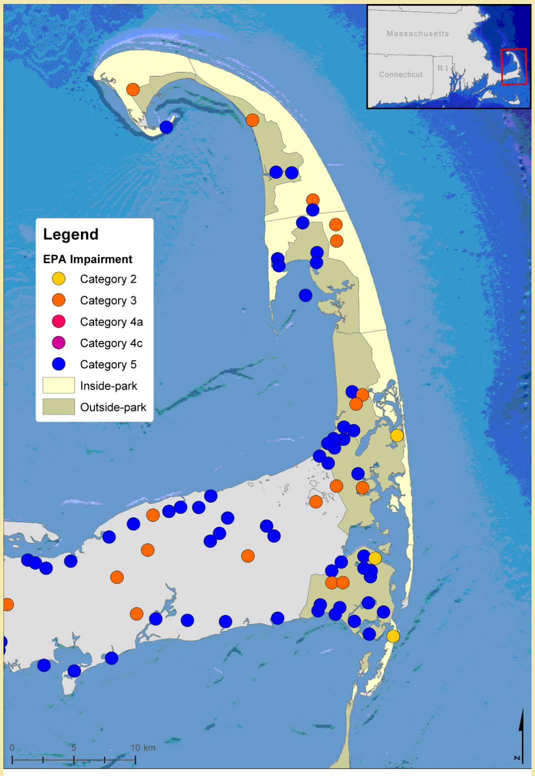


Figure 34.1. Water quality categories for surface waterbodies on Cape Cod. Category definitions are provided in Table 34.2.

Key Points

- Reporting for the Clean Water Act includes a list of 19 waterbodies (or sections thereof) on the outer Cape that are impaired.
- A study of Pleasant Bay has quantified nitrogen loading sources and identified load reductions needed to bring this system back into attainment.
- The National Coastal Assessment evaluates water and sediment quality at coastal sites around the U.S. A total of 23 sites have been surveyed in Cape Cod Bay, Nauset Harbor and Chatham Harbor.
- All Cape Cod Bay sites are ranked as being in 'good' condition for all metrics.
- Nauset and Chatham Harbor sites are ranked 'poor' for some metrics and 'fair' or 'good' for others.

Assessment statement

Good – Significant Concern depending on location and metric.

Rationale

Water and sediment quality in coastal areas of outer Cape Cod are threatened by a range of contaminants, particularly nutrients and pathogens. Increasing levels of development, coupled with existing under-performing septic systems, result in elevated nutrient loading rates. Nitrogen is the nutrient of greatest concern for coastal waters. Atmospheric deposition is a further source of nitrogen. Nutrient enrichment leads to elevated levels of production within aquatic ecosystems, potentially resulting in a series of problems that may include: loss of eelgrass beds, increases in macroalgae, phytoplankton blooms, decreases in dissolved oxygen, and reductions in the diversity of benthic invertebrates (MA DEP 2007). Elevated pathogen levels may adversely affect recreational uses and shellfish harvests (see topics 31- Beach Closures, and 33- Harmful Algal Blooms & Shellfish Closures).

Two large-scale assessment and reporting programs provide background data that have

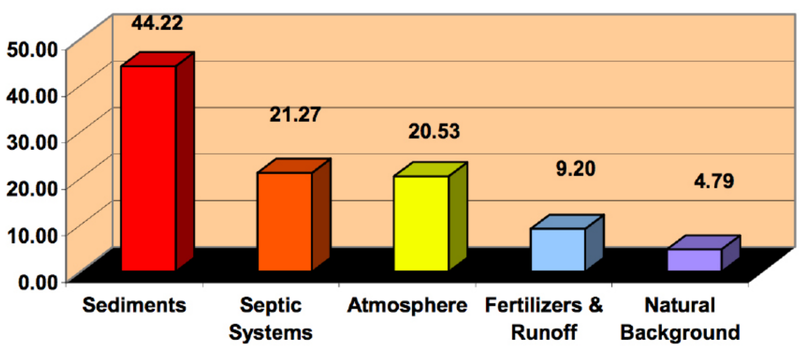


Figure 34.2. Sources of nitrogen loading to the Pleasant Bay system, in percent. (Figure from MA DEP 2007)

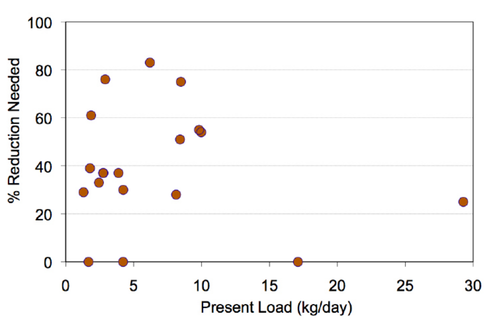


Figure 34.3. Current 'controllable' nitrogen loads from sub-embayments of the Pleasant Bay system and % load reductions needed to attain threshold loads. Controllable loads are combined controllable land use and septic system loadings. Target loads are those needed to meet the embayment threshold concentration for the respective sub-embayment. (Data source: MA DEP 2007)

been used to assess the condition of coastal waters of the outer Cape – the "TMDL" list of impaired waters and the National Coastal Assessment. These data sources are supplemented by a few other studies that have a more limited geographic focus.

Benchmarks

Reporting for the Clean Water Act by the Commonwealth of Massachusetts includes preparation of a list of impaired waters - freshwater and estuarine systems with unacceptable water quality (MA DEP 2008). A recently completed study of Pleasant Bay (MA DEP 2007) identifies target thresholds for nitrogen concentrations in this system– benchmarks which will assist in the design and evaluation of future management actions designed to restore water quality in the Bay. These are described below.

The National Coastal Assessment (NCA) is a program that evaluates the condition of coastal waters across the U.S. By defining series of numeric criteria, the NCA assigns rankings to a series of metrics characterizing water quality and sediment condition. Criteria for these rankings are provided in Table 34.1.

Condition

Status

Impaired Waters & TMDLs. Sections 303(d) and 305(b) of the Clean Water Act require states to list the condition of waters within their jurisdictions. Waters are listed according to several categories, ranging from "attaining all designated uses" to "not in attainment and thus requiring development of a TMDL" (total maximum daily load). TMDL studies are designed to identify mitigation actions that will bring water quality into attainment. TMDLs focus on one or more contaminants.

The 2008 listing (MA DEP 2008) identifies a total of 19 waterbodies, or sections of waterbodies, in the six towns of the upper Cape where the level of impairments is high enough to warrant development of TMDLs (Figure 34.1, Table 34.2). Estuarine areas requiring TMDLs include Provincetown Harbor, Ryder Cove, Stage Harbor, and Wellfleet Harbor.

Pleasant Bay System: Prior listings had identified Pleasant Bay as impaired and requiring a TMDL. A TMDL report has recently been completed for this system (MA DEP 2007); it is based primarily on data collected from 2000 to 2005 by partners in the Massachusetts Estuaries Project (MEP). The MEP identified impairments for 16 sub-embayments within the Pleasant Bay system. In most cases, impairments include nutrients and dissolved oxygen levels (Table 34.3).

Sediments are the largest source of nitrogen to the Pleasant Bay system (Figure 34.2). Septic systems and atmospheric deposition each supply approximately one half the amount of nitrogen that is derived from sediments. Septic systems and land-use (fertilizers and run-off) are the two nitrogen sources that are, in principal, locally controllable via improved management. Septic systems represent 70% of controllable nitrogen loading.

Target threshold concentrations for bioactive nitrogen are below currently observed concentrations in 13 of the sub-embayments. Loading reductions needed to achieve target nitrogen concentrations in sub-embayments range from 0%, i.e. already at threshold, (Crows Pond, Bassing Harbor and Chatham Harbor) to 83% (Meetinghouse Pond) (Figure 34.3). The sub-embayments with the highest current loads are Chatham Harbor (currently at the threshold level) and Pleasant Bay (25% reduction required).

Nitrogen reduction strategies for the Pleasant Bay system are discussed in the TMDL report (MA DEP 2007) and include more effective wastewater treatment, tidal flushing, improved stormwater management, attenuation via wetland and ponds, and water conservation and re-use.

Nauset Marsh: There is concern that on-site wastewater disposal in the Nauset watershed may be increasing nutrient loading and thence eutrophication of this system, currently one of the least disturbed salt marshes within CACO (Nowicki et al. 1999, Portnoy et al. 1998). Groundwater nutrient concentrations in shoreline seeps and springs in three sectors of Nauset Marsh are associated with levels of development (Table 33.4) and appear to have increased from the early 1980s to 1991 (Portnoy et al. 1998).

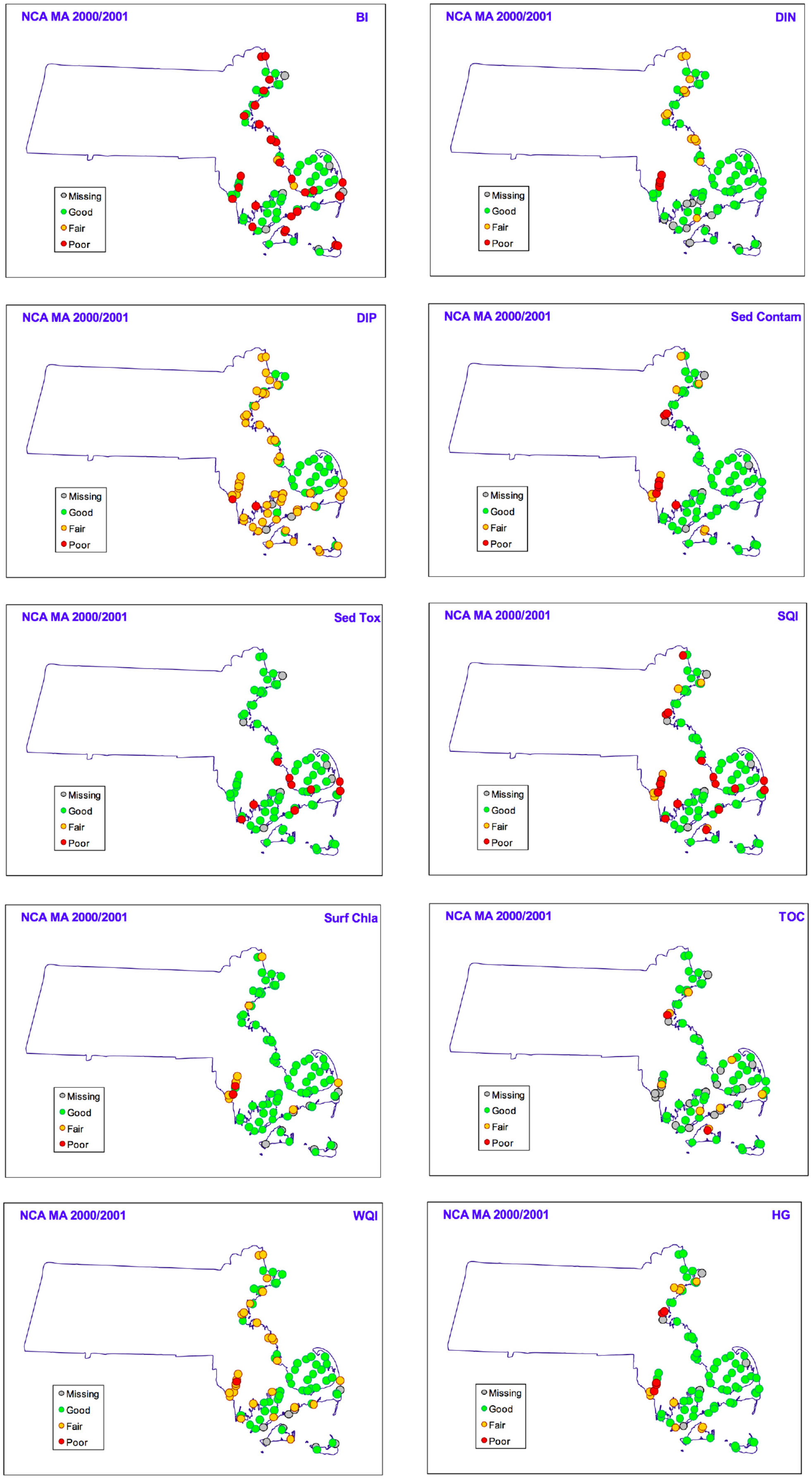


Figure 34.4. Maps showing rankings for water and sediment quality metrics at coastal sites in Massachusetts, from the National Coastal Assessment for years 2000-2001 (NCA MA 2000/2001). Parameter abbreviations are: BI – benthic index; DIN – dissolved inorganic nitrogen; DIP – dissolved inorganic phosphorus; Sed Contam – sediment contaminants; Sed Tox – sediment toxicity; SQI – sediment quality index; Surf Chla – chlorophyll-a concentration of surface water; TOC – sediment total organic carbon; WQI – water quality index. HG – mercury. See Table 34.1 for additional information on metrics. (Figures provided by J. Kiddon, U.S. EPA, personal communication)

Water & sediment quality, continued

Table 34.1. Metrics and rankings used in the Northeast Region of the National Coastal Assessment. (Source: U.S. EPA 2008). Metric data are shown in Figure 33.4.

[1] ERM (Effects Range Median)—Determined values for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.ERL (Effects Range Low)—Determined values for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

[2] see U.S. EPA 2008 for list of analyzed contaminants

[3] measures diversity and abundance of pollution-tolerant and pollution-sensitive species

Dissolved Inorganic Nitrogen	
Good:	< 0.1 mg/L
Fair:	0.1 – 0.5 mg/L
Poor:	> 0.5 mg/L
Dissolved Inorganic Phosphorus	
Good:	< 0.01 mg/L
Fair:	0.01 – 0.05 mg/L
Poor:	> 0.05 mg/L
Chlorophyll-a	
Good:	< 5 µg/L
Fair:	5-20 µg/L
Poor:	> 20 µg/L
Water Quality Index	
Good:	A maximum of one indicator ranked as fine and no indicator ranked as poor.
Fair:	One or more indicators ranked as poor; or two or more indicators ranked as fair.
Poor:	Two or more indicators ranked as poor.
Sediment Toxicity	
Good:	Amphipod survival rate ≥ 80%
Poor:	Amphipod survival rate < 80%
Sediment Contaminants	
Good:	No ERM[1] concentrations are exceeded and < ERL concentrations are exceeded.
Fair:	No ERM concentrations are exceeded and ≥ 5 ERL concentrations are exceeded.
Poor:	An ERM concentration is exceeded for ≥ one contaminant.
Sediment Total Organic Carbon (TOC)	
Good:	TOC concentration < 2%
Fair:	TOC concentration 2-5%
Poor:	TOC concentration > 5%
Sediment Quality Index[2]	
Good:	None of individual component indices (ICI – sediment toxicity, sediment contaminants, sediment TOC) is rated poor, and the sediment contaminants indicator is rated good.
Fair:	None of the ICI is rated poor and the sediment contaminant indicator is rated fair.
Poor:	One or more of the ICI is rated poor.
Benthic Index[3]	
Good:	BI score ≥ 5.0
Fair:	BI score ≥ 4 and < 5.0
Poor:	BI score < 4

Water & sediment quality, continued

Table 34.2. Listing of the condition of waters within the towns of Chatham, Orleans, Eastham, Wellfleet, Truro and Provincetown, pursuant to sections 303(d) and 305(b) of the Clean Water Act. English units in source data are retained. (Source: MA DEP 2007)

WATER	TOWN	AREA	IMPAIRMENT
"Waters Attaining All Designated Uses" (Category 1 Water)			
None – because of statewide health advisory pertaining to consumption of finfish			
"Waters Attaining Some Uses; Other Uses Not Assessed" (Category 2 Waters)			
No waters in these 6 towns			
"No Uses Assessed" (Category 3 Waters)			
Clapps Pond (96035)	Provincetown	39.9 acres	
Depot Pond (96061)	Eastham	25.4 acres	
Goose Pond (96106)	Chatham	35.4 acres	
Gull Pond (96123)	Wellfleet	103 acres	
Herring Pond (96133)	Eastham	42.3 acres	
Pilgrim Lake (96246)	Orleans	38.1 acres	
Schoolhouse Pond (96281)	Chatham	20.1 acres	
Village Pond (96329)	Truro	2.7 acres	
"TMDL is Completed" (Category 4a Waters)			
Areys Pond (96003)	Orleans	13 acres	Nutrients
Baker Pond (96008)	Orleans	26.9 acres	Metals
Crows Pond (96049)	to BassingHarbor,Chatham.	122 acres	Nutrients
Duck Pond (96068)	Wellfleet	10.6 acres	Metals
Dyer Pond (96070)	Wellfleet	10.5 acres	Metals
Frost Fish Creek (9661900)	Chatham	13 acres	Metals & pathogens
Great Pond (96114)	Truro	17.0 acres	Metals
Great Pond (96117)	Wellfleet	40.5 acres	Metals
Little Pleasant Bay (96933)	Orleans and Chatham	2112 acres	Nutrients
Long Pond (96179)	Wellfleet	34.3 acres	Metals
Mill Pond (96203)	Chatham	38 acres	Nutrients
Muddy Creek (9661875)	Chatham	32 acres	Metals & pathogens
Namequoit River (9661850)	Orleans	38 acres	Nutrients
Paw Wah Pond (96241)	Orleans	6 acres	Nutrients
Pleasant Bay (96932)	Chatham, Orleans	1856 acres	Nutrients
Pochet Neck (96930)	Orleans	154 acres	Nutrients
Quanset Pond (96252)	Orleans	13 acres	Nutrients
The River (9661825)	Orleans	262 acres	Nutrients
Slough Pond (96298)	Truro	28.5 acres	Nutrients
Snow Pond (96303)	Truro	6.7 acres	Metals
"Impairment Not Caused by a Pollutant" (Category 4c Waters)			
No waters in these 6 towns			

Table 34.2, Continued.

"Waters Requiring a TMDL" (Category 5 Waters)			
Boat Meadow River (9661450)	Eastham	429 acres	Metals
Bucks Creek (9662025)	Chatham	13 acres	Nutrients & pathogens
Crystal Lake (96050)	Orleans	33.1 acres	Organic enrichment, low DO
Duck Creek (9661625)	Wellfleet	96 acres	Pathogens
Great Pond (96115)	Eastham	109 acres	Nutrients, organic enrichment / low DO
Harding Beach Pond (96128)	Chatham	45 acres	Nutrients & pathogens
Herring River (9661650)	Wellfleet	250 acres	Pathogens
Herring River (9662150)	Wellfleet	2304 acres	Metals, pH
Little Namskaket Creek (9661400)	Orleans	6 acres	Pathogens
Mill Creek (9662075)	Chatham	19 acres	Nutrients & pathogens
Oyster Pond (96234)	Chatham	134 acres	Nutrients & pathogens
Oyster Pond River (9662000)	Chatham	90 acres	Nutrients & pathogens
Pamet River (9661725)	Truro	90 acres	Pathogens
Provincetown Harbor (96915)	Provincetown	2752 acres	Pathogens
Rock Harbor Creek (9661425)	Eastham, Orleans	13 acres	Pathogens
Ryder Cove (96920)	Chatham	109 acres	Nutrients & pathogens
Stage Harbor (96907)	Chatham	371 acres	Nutrients & pathogens
Taylors Pond (96311)	Chatham	13 acres	Nutrients & pathogens
Town Cove (96929)	Orleans, Eastham	512 acres	Pathogens
Wellfleet Harbor (96916)	Wellfleet	5440 acres	Pathogens

Denitrification (microbial conversion of nitrate to gaseous nitrogen) can potentially reduce nitrogen loading to receiving waters by removing nitrogen from groundwater inflows. In Nauset Marsh, however, this does not appear to occur. Although a significant positive correlation was observed between denitrification rates and organic content in sediment cores, denitrification rates were not correlated with nitrate concentrations. Most of the nitrogen from contaminated groundwaters reaches the estuary where it is available for plant production (Nowicki et al. 1999).

National Coastal Assessment: The National Coastal Assessment (NCA) provides a supplementary picture of water and sediment quality in Cape Cod waters. The NCA is designed to evaluate the condition of coastal waters of the U.S. The survey design is probabilistic so that data from suites of sampling sites can be extrapolated to provide statistically robust regional estimates of condition. With the exception of Nauset Harbor (1 site) and Chatham Harbor (3 sites), all NCA sites near CACO are located in Cape Cod Bay (19 sites).

Data collected by the NCA include surface water dissolved inorganic nitrogen and phosphorus, bottom dissolved oxygen, transparency, sediment toxicity, sediment contaminants, and benthic invertebrate assemblages. The most recent National Coastal Condition Report uses data through 2002 (U.S. EPA 2008) (Massachusetts did not participate in the NCA in 2002). More recent data have not yet been published.

Although the NCA is designed to make regional assessments of environmental condition, site-specific data are of interest to audiences with a more local focus. NCA data for Massachusetts from 2000 and 2001 were provided by J. Kiddon, U.S. EPA (personal communication, November 2009). Figure 34.4 summarizes these data. All sites within Cape Cod Bay were ranked Good for all metrics. The Nauset and Chatham Harbor sites

Water & sediment quality, continued

Table 34.3. Major indicators of impairment in the Pleasant Bay system. H – Healthy – healthy habitat conditions. MI – Moderately Impaired – slight to reasonable change from normal conditions. SI – Significantly Impaired- considerably and appreciably changed from normal conditions. SD – Severely Degraded – critically or harshly changed from normal conditions. NS - Non-supportive habitat. No eelgrass was present in 1951 Survey data. NO – none observed during study period. (From MA DEP 2007)

Embayment/ Sub-embayment	Eelgrass Loss[1]	Dissolved Oxygen Depletion	Chlorophyll a[2]	Macro-algae	Benthic Fauna[3]
Pleasant Bay System					
Meetinghouse Pond	NS	<6 mg/L up to 98% of time <4 mg/L up to 72% of time SI/SD	>10ug/L up to 21% of time >20 ug/L up to 1% of time SI/MI	MI	SI
Lonnies Pond	NS	<6 mg/L up to 99% of time <4 mg/L up to 73% of time SI	>10ug/L up to 20% of time >20 ug/L up to 1% of time MI	MI	SI
Areys Pond	NS	<6 mg/L up to 87% of time <4 mg/L up to 76% of time SD	>10ug/L up to 50% of time >20 ug/L up to 14% of time SI	SI/SD	SD
The River	MI	MI/SI	MI	MI/SI	SI
Paw Wah Pond	NS	<6 mg/L up to 97% of time <4 mg/L up to 91% of time SD	SI	SI	SD
Quanset Pond	NS	<6 mg/L up to 48% of time <4 mg/L up to 18% of time SI	>10ug/L up to 37% of time >20 ug/L up to 1% of time SI	NO	SD
Round Cove	NS	<6 mg/L up to 13% of time <4 mg/L up to 1% of time MI	>10ug/L up to 48% of time >20 ug/L up to 1% of time SI	NO	SI
Muddy Creek Up-per	NS	<6 mg/L up to 88% of time <4 mg/L up to 76% of time SI/SD	>10ug/L up to 91% of time >20 ug/L up to 67% of time SD	MI[4]	SD
Muddy Creek Lower	SI	<6 mg/L up to 85% of time <4 mg/L up to 60% of time SI/SD	>10ug/L up to 88% of time >20 ug/L up to 84% of time SI	MI[4]	SI
Ryders Cove	MI	<6 mg/L up to 73% of time <4 mg/L up to 7% of time SI/SD	>10ug/L up to 74% of time >20 ug/L up to 18% of time SI/MI	MI	MI
Crows Pond	H/MI	NO	>10ug/L up to 69% of time >20 ug/L up to 2% of time H/MI	MI	MI
Bassing Harbor Lower	H/MI	<6 mg/L up to 7% of time <4 mg/L 0% of time H	>10ug/L up to 23% of time >20 ug/L 0% of time H/MI	NO	MI
Frost Fish Creek	NS	SI	SI	SI	SI
Pochet	NS	H/MI	>10ug/L up to 4% of time >20 ug/L 0% of time H	NO	H/MI
Little Pleasant Bay	MI	MI	H	NO	MI
Pleasant Bay	MI/SI	<6 mg/L up to 29% of time <4 mg/L up to 4% of time MI	>10ug/L up to 4% of time >20 ug/L 0% of time MI	NO	MI/SI
Chatham Harbor	H	<6 mg/L up to 7% of time <4 mg/L 0% of time H	>10ug/L 0% of time >20 ug/L 0% of time H	NO	H

[1] Based on comparison of present conditions to 1951 Survey data.

[2] Algal blooms are consistent with chlorophyll a levels above 20ug/L

[3] Based on observations of the types of species, number of species, and number of individuals

[4] Observation by the Pleasant Bay Association

Table 34.4. Summary nutrient concentrations in groundwater in shoreline seeps and springs around Nauset Marsh. (Data from Portnoy et al. 1998)

Area	Development Level	NO3-N (μM)	PO4-P (μM)	N
Salt Pond Bay	Undeveloped	6 ± 7	3 ± 2	47
Salt Pond	Moderately developed	109 ± 75	5 ± 1	16
Town Cove	Highly developed	203 ± 164	1 ± 2	149

were ranked Poor for the benthic index and Good for dissolved inorganic nitrogen, sediment contaminants and mercury. Other metrics from this group of sites were assigned a mix of Poor, Fair and Good rankings.

Trends

Regional trend data have been published by the National Coastal Assessment (U.S. EPA 2008). Figure 34.5 provides one example of trends. For several water quality and sediment metrics there has been an increase in areas which are ranked as Poor. This trend statement, however, applies to the NCA focus area as a whole. Trends for site-specific data have not been published – as noted above, the NCA is designed to assess regional, rather that site-specific, condition.

Another study of water quality in Cape Cod Bay (PCCS 2009) suggests that nitrate levels are increasing in the Bay – concentrations in 2008 were over three times those recorded in 2006 (PCCS 2009). The higher nitrate levels in 2008 are from the months of January through March (PCCS 2009). However, it appears that data from these same three months in 2006 were not presented, so perhaps a statistical comparison between the three years is not appropriate.

Factors influencing water & sediment quality

- Increasing residential development. Studies on estuaries on Cape Cod and elsewhere in the Northeast have documented a positive correlation between population density and anthropogenic nitrogen levels (e.g , Bannon and Roman 2008).
- Under-performing septic systems.
- Fertlizers used on lawns and golf courses.
- Atmospheric deposition.

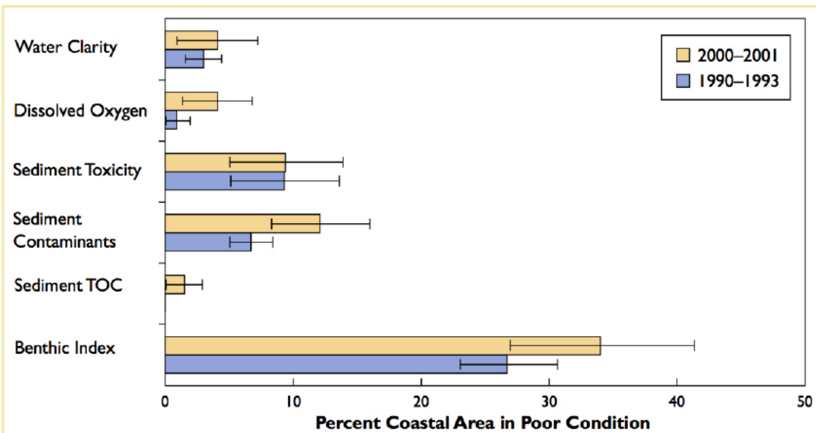


Figure 34.5. Percent area of Northeast Coast coastal waters that were rated "poor" for a suite of ecological indicators during two time periods, 1990-1993 and 2000-2001. Error bars are 95% confidence intervals. (Figure from U.S. EPA 2008).

35. Coastal geomorphology: Nauset Beach & Pleasant Bay sediment dynamics

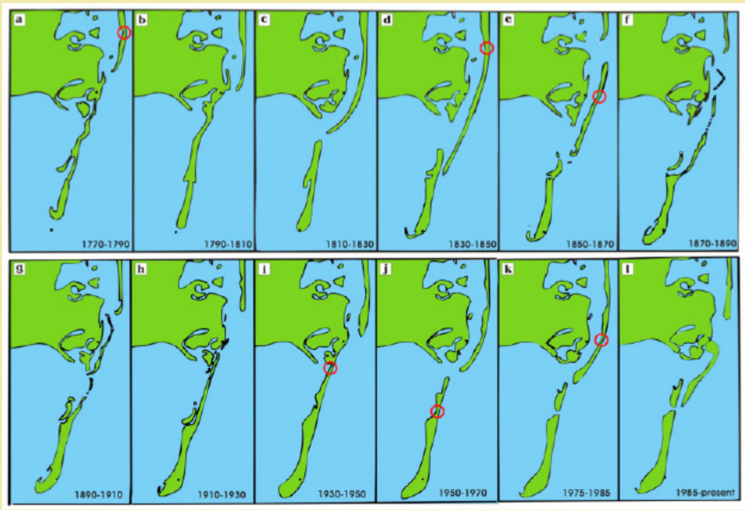


Figure 35.1. Evolution of the Nauset-Monomoy barrier beach and estuary system, from the 1700s to 2006. Figure from Elizabeth Pendleton after Giese, 1988.

Key Points

- Nauset Beach undergoes multi-decadal cycles of elongation and subsequent breaching. The most recent breach occurred during the Patriot's Day storm of 2007.
- Changes in the geomorphology of this barrier beach system influence sediment dynamics and tidal amplitude within Pleasant Bay.
- Sediment dynamics of Pleasant Bay may also be influenced by erosion control structures, in turn potentially impacting critical habitats in the Seashore.
- In 1998, it was estimated that 8% of the Pleasant Bay was armored with erosion control structures (133 structures). In 2008 the number of structures was estimated at 165, an increase of 24%.

Figure 35.2a. Aerial view of the Nauset Beach and Pleasant Bay system (looking south), showing the breach in Nauset beach caused by the Patriot's Day storm of 2007, the "North Inlet" shown in Figure 35.3. (Photo from Adams and Giese 2008).

Figure 35.2b. View of the Nauset spit before and after the 1987 breach that formed the "South Inlet". (Photos by D. Fitzgerald, from Hammer-Klose et al. 2003)

Assessment statement

Good. Nauset Beach and Pleasant Bay represent one of the very few remaining largely 'unmanaged' barrier complexes in the Northeast (C. Roman, NPS, pers. comm.). Nauset Beach is a naturally dynamic system (Figure 35.1) and will continue to evolve through processes of sediment transport and deposition. Changes in beach morphology influence sediment dynamics within Pleasant Bay. Anthropogenic factors, especially erosion control structures, also influence sediment dynamics and, in turn, the Pleasant Bay ecosystem.

Rationale

Nauset Beach forms the eastern boundary of Pleasant Bay and Chatham Harbor (Figures 35.1, 35.2). Pleasant Bay is a shallow estuarine system covering an area of approximately 2630 ha (Pleasant Bay Resource Alliance 2008). The beach is a system of barriers and spits formed of material that has been transported and re-deposited during seasonal and multi-decadal cycles (Figure 35.1). The most recent cycle in the elongation and subsequent breaching of the barrier extended over a period of approximately 140 years, culminating in the breaches that occurred during severe northeasterly storms in 1987 and 2007 (Figure 35.2, 35.3; Adams and Giese 2008).

The position and size of the coastal inlets to Pleasant Bay influence both sediment dynamics within the bay and also patterns of tidal flushing, including tidal amplitude. Changing sediment dynamics also probably influence the accretion and sedimentation rates of the marshes in Pleasant Bay. Erosion control (hardened shoreline) structures may be influencing the pattern of sediment dynamics within the Bay. These structures may also negatively affect faunal species that require access to beaches, for example horseshoe crabs (see Topic 29- Horseshoe crabs: population status & dynamics).

Benchmarks

The configuration of the Nauset-Monomoy barrier beach system over the past ca. 250 years has been described. Tidal amplitude data from Pleasant Bay exist from 2005 on. The earliest survey of hardened structures in Pleasant Bay apparently dates from 1998.

Condition

Status

Nauset Beach dynamics. Nauset Beach consists of sand from the eroding bluff coast of Eastham, Wellfleet and Truro. However, this sand supply has diminished or completely ceased as more sediment has been directed toward the Provincetown hook in the last 6000 years. The decrease in sand supply has

Figure 35.3. Changes in Nauset beach from 1960 to 2007. The panel on the left shows the 1960 shoreline and the location of the new inlet of 2007. The right panel compares the shoreline at the end of the Nauset spit in 1987 and 2007.

Coastal geomorphology: sediment dynamics, continued

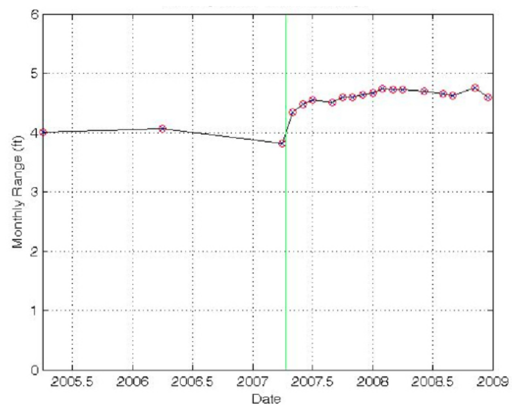


Figure 35.4. Mean monthly tidal amplitude at the Meetinghouse Pond gauge from 2005 through 2009. Each point in the graph represents the mean tidal range for the (approximately) 30-day period (in 2005 and 2006 data were collected during a single month). The occurrence of the 2007 breach is indicated by the vertical line. The tidal range increased abruptly immediately following the breach and subsequently leveled off at a value of just under one foot greater than the pre-breach range. Graph from Giese 2010.

enhanced the cyclic growth of change in the barrier spits enclosing Pleasant Bay. Storm driven overwash events are commonplace and facilitate sediment movement into Pleasant Bay and the maintenance of marsh elevations as sea level rises.

Some of these overwash events have threatened or damaged both public- and private-owned structures. For example, an overwash in 1978 damaged a beach-front parking lot in the Town of Eastham. Although this structure was subsequently not rebuilt, this decision continues to be questioned by some local residents (Adams and Giese 2008). In 1987, the southern inlet to Pleasant Bay formed as a result of a breach of Nauset Beach in the region of the Chatham lighthouse. This event was followed by installation of an extensive series of revetments opposite the breach, a process that may have contributed to the most recent breach of Nauset Beach during the Patriots Day storm of 2007 (Figure 35.2, 35.3; Adams and Giese 2008). The size of this breach has increased since initial formation. Closing it using artificial means, although originally contemplated by some, is not now feasible – a proposal to further explore this option was defeated by Chatham voters in 2007(Adams and Giese 2008).

Overwash events and other hydrologic changes leading to breaching of the barrier beach near Pochet Inlet/Pochet Island, have resulted in a new overwash area that provides nesting habitat for Piping plovers and spawning habitat for Horseshoe crabs (M.J. James-Pirri, personal observation). The influence of these overwash events on Pleasant Bay ecosystems has not been fully assessed.

Several on-going studies are contributing to further understanding the coastal geomorphic processes that are acting on the Nauset Beach - Pleasant Bay system. These include analyses of LIDAR data (Adams and Giese 2008) and re-surveys of coastal profiles originally surveyed in the 1880s (see Topic 36- Coastal geomorphology: bluff erosion).

Tidal amplitude in Pleasant Bay. Tidal amplitude appears to have changed following the 2007 breach. Data for the Meetinghouse Pond gauge are shown in Figure 35.4, reflecting a change of approximately 0.2 m (0.7 feet) post-breach. Because the tide is damped over the length of the system, the change in tidal amplitude at Fish Pier (at the southern end of the Bay) was larger than at Meetinghouse Pond. The mean tidal range at Fish Pier was 1.3 m (4.3 feet) before the breach (2004) and 1.7 m (5.6 feet) after the 2007 breach (Kelley and Ramsey 2008). The change in tidal amplitude has caused a loss of sand from beaches in the northern section of the bay, resulting in a loss of spawning habitat for Horseshoe crabs in some areas (e.g., transformation of sandy beaches to cobble beaches for spawning).

Hardened structures in Pleasant Bay. In 1998, the Pleasant Bay Resource Alliance estimated that 6.8 km (or 8%) of the Pleasant Bay shoreline was armored by about 133 individual erosion control structures (e.g., bulkheads, revetments, soft solutions). In 2008, the estimated number of erosion control structures increase to 165 structures (Figure 35.5). A proliferation of hard structures could diminish the Bay’s natural erosion and nourishment processes, resulting in the loss of beach height and vitality, and vegetated marsh as well as an increased turbulence associated with breaking waves. These impacts may contribute to lowering the profile of beach fronting the structure. Within Pleasant Bay there is indication of beach loss from erosion control structures. Regular beach nourishment is occasionally a mitigation requirement for the licensing of hard structures. In practice, however, beach nourishment is often unfeasible, neglected, or poorly executed, resulting in expenses for owners without the intended mitigation effects. Among the areas experiencing a loss of sand and a change to a stony shoreline is the southern portion of shoreline around "Big" Pleasant Bay. This is occurring because the erosion of the protected bluffs no longer provides fresh sediment (Pleasant Bay Resource Alliance 2008). While all of these structures are outside the boundary of CACO, there are likely some impacts to areas within CACO related to the proliferation of erosion control structures in the Bay.

Nauset Marsh. Further north on Nauset Beach, sand overwash has resulted in a loss of approximately 7% marsh area within the Nauset Marsh system between 1947 and 1994 (Figures 35.6; Erwin et al. 2004). This overwash-mediated loss represents about one third of the total percentage loss of marsh in this system during the 47 year period (see also Topic 27- Salt marsh landscape changes).

Trends

There has been an increase in erosion control structures in Pleasant Bay over the past two decades. Although no erosion control structures are present on Park property in the Bay, these structures can change sediment dynamics throughout the Pleasant Bay ecosystem and may therefore have an impact on some habitats within the Seashore.

Factors influencing coastal geomorphology

- Many of the changes in coastal geomorphology in the CACO region are natural, influenced by ocean currents, weather events and other factors.
- Coastal structures negatively impact Pleasant Bay's resources by blocking wind and tidal flow, shading of vegetation, chemical leaching from materials, and impacts from construction and removal.

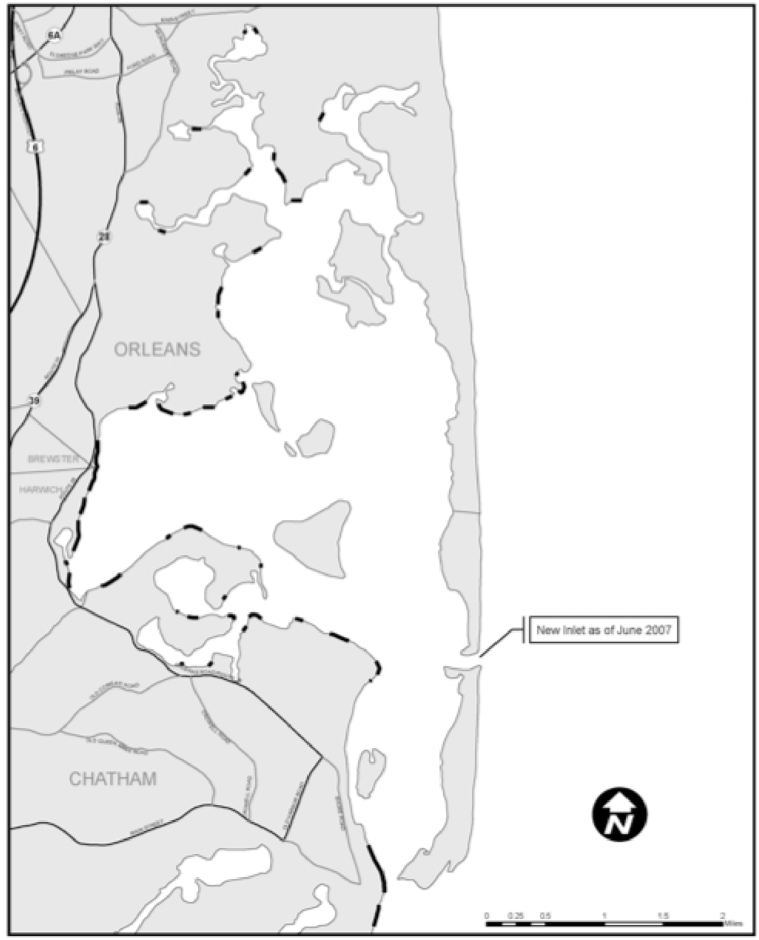


Figure 35.5 Hardened shoreline structures in Pleasant Bay. (Figure from Pleasant Bay Resource Alliance 2008.)

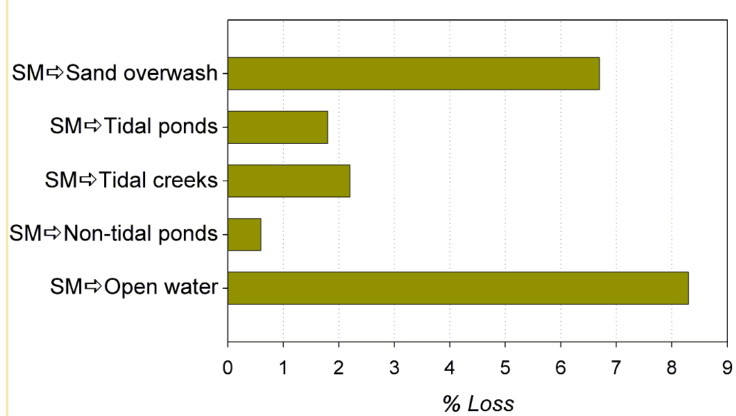


Figure 35.6. Percent of habitat transition at Nauset Marsh from salt marsh to sand overwash, ponds, creeks and open water. (Data source: Erwin et al. 2004)

- Hard structures interfere with the natural erosion and re-nourishment processes in the Bay (Pleasant Bay Resource Alliance 2008).

36. Coastal geomorphology: bluff erosion

Figure 36.1. Eroding bluff on Cape Cod (Photo credit: Cape Cod National Seashore)

Key Points

- Erosion of coastal bluffs north of Nauset Beach is a natural process that is being influenced by changes in sea level.
- The century-scale average erosion rate is 0.8 m/yr.
- Erosion rates are highest in the area just north of Nauset Beach and decrease in a northward direction.
- The coast of the outer Cape is rotating clockwise as sea level rise changes the wave climate, in turn influencing the pattern of longshore sediment transport.

Assessment statement

Good. Although bluff erosion sometimes impacts coastal infrastructure, this erosion is an important natural process that supplies sediment for outer Cape Cod beaches and dunes.

Rationale

"Coastal bluff erosion [Figure 36.1] is significant to environmental management largely due to two concerns: the threat it poses to coastal development, and the quantity and quality of sediment that it supplies to the littoral system.…..[T]he eroding east-facing bluffs of outer Cape Cod …. lie within the Cape Cod National Seashore…. and for that reason their impact on coastal development is a relatively minor concern. They are critically important, however, as a sediment source….Erosion of the bluffs and shoreface is the sole source of sediment, not only for the beaches along the shoreline of the escarpment, but also for the spits and barrier beaches which make up the landforms north and south of the escarpment [Figure 36.2]…. Management of these depositional features and the bays, harbors and marshes associated with them is a matter of major concern for [CACO] and the region's municipalities" (Giese and Adams 2007).

Highland Light, circa 1994, prior to its move back from the bluff's edge in 1996. Photos courtesy S. Nelson, UMaine.

Benchmarks

Henry L. Marindin (1889, 1891) surveyed 229 coastal profiles normal to the shoreline of outer Cape Cod, and reported latitude, longitude, azimuth and elevation for each line. These profiles (Figure 36.3) have recently been used to document erosion rates of outer Cape Cod. The profiles and the calculated erosion rates provide an excellent quantitative baseline from which to document future shoreline erosion.

Condition

Status and trends

The bluffs of the outer Cape, along with the beach and shoreface, represent an escarpment extending for 24 km north of Coast Guard Beach and formed by wave action cutting into unconsolidated Pleistocene glacial deposits (Figure 36.1; Giese and Adams 2007). A recent study by G. Giese (Provincetown Center for Coastal Studies) and Mark Adams (CACO) has documented bluff erosion by re-surveying the Marindin transects of the 1880s.

Between 1887 and 1889, Henry L. Marindin of the U.S. Coast and Geodetic Survey established a series of 229 cross-shore transects along the outer coast of Cape Cod for the expressed purpose of producing a geographic baseline as a reference for future resurveys (Figure 36.3; Marindin, 1889, 1891). These transects, spaced approximately 300 m apart, extended alongshore from the southern extremity of Nauset Beach in Chatham to Long Point in Provincetown, and they extended across-shore from terrestrial upland or high dunes to depths of 10 m or more. Marindin reported the location and azimuth direction of his transects for use by future investigators, and by comparing his results to earlier - but less accurate - surveys, estimated that the bluff section of outer Cape Cod eroded at an average rate of 0.98 m (3.2 feet) per year.

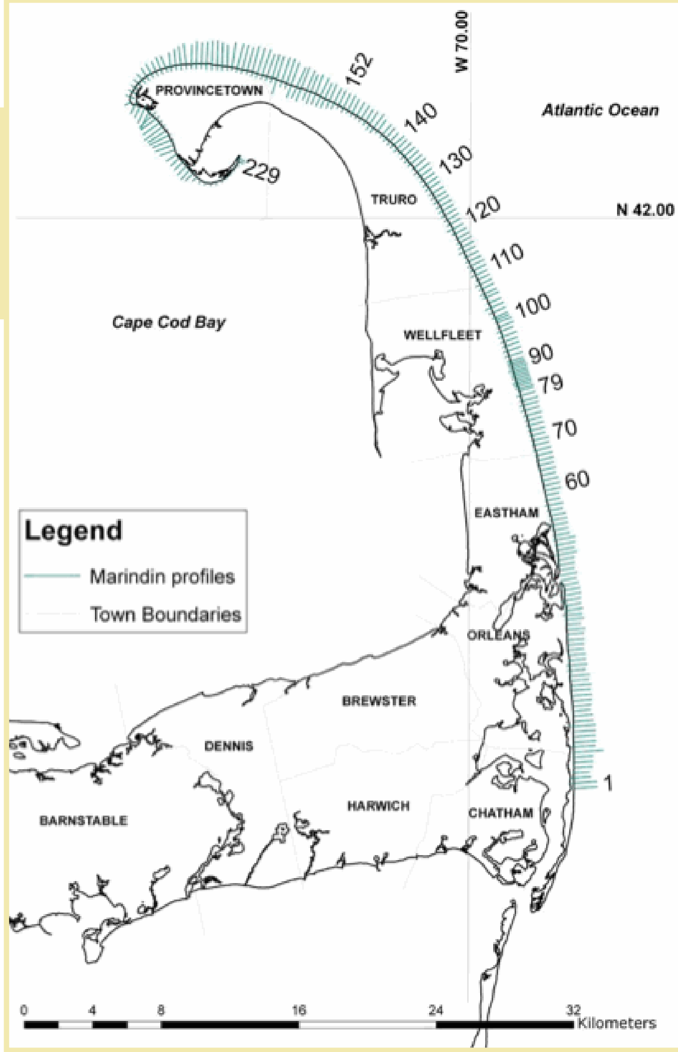
During the 20th Century, a number of investigators resurveyed some of the terrestrial sections of Marindin's transects, (e.g., Zeigler et al., 1964a, 1964b; Leatherman et al., 1981; Miller and Aubrey, 1985). Most studies concentrated on the bluff section of the coast and reported long term retreat rates of between 0.67 m/yr and 0.91 m/yr (or 2.2 ft/yr and 3 ft/yr, respectively), but none managed a complete repetition of the original survey.

Figure 36.2. Parabolic dunes on Cape Cod. This area represents the first accretion 'peak' shown in Figure 36.4.

Recently however, Allen et al. (2001), noting the availability of advanced landform survey techniques and data management methods as well as the importance of re-examining century-scale changes, developed a coastal change protocol for the National Park Service's Inventory and Monitoring Program that makes use of the new methods. Following that lead, CACO has initiated a study that uses a variety of techniques such as differential GPS, lidar and sonar to determine Cape Cod coastal change since the late 19th Century.

Coastal geomorphology: bluff erosion, continued

Figure 36.3. Location of the Marindin coastal profiles originally surveyed in the 1880s and re-surveyed by G. Giese and M. Adams in 2006. (Figure courtesy of M. Adams and G. Giese)



Preliminary results of bluff section surveys (Giese and Adams, 2007) have confirmed an overall century-scale erosion rate of about 0.8 m/yr, but unlike earlier studies they indicated that the bluff erosion rate increases alongshore north-to-south by a factor of two (Figures 36.4, 36.5). South of Marindin transect 155, the shoreline is actively eroding. At transects past this point, both negative (eroding) and positive (accreting) shoreline changes are found. The longitudinal trend in erosion rates, coupled with increasing sea level, are thought to be producing a clockwise rotation of this section of the outer Cape, as first hypothesized by Giese (1964). Rising sea level, accompanied by the continuing submergence of the Georges Bank shoal on the outer continental shelf southeast of Cape Cod, is thought to be changing the wave climate, in turn increasing the net flux of sediments in a northward direction. An estimated 18 % of the eroding glacial "source" material is lost offshore and does not contribute to shoreline deposition (Zeigler et al. 1964a).

Factors influencing bluff erosion

- Erosion of coastal bluffs is a natural process and, given the protected status of much of this section of Cape coastline, is unlikely to be influenced by human activities – with the exception of sea level rise associated with climate change.

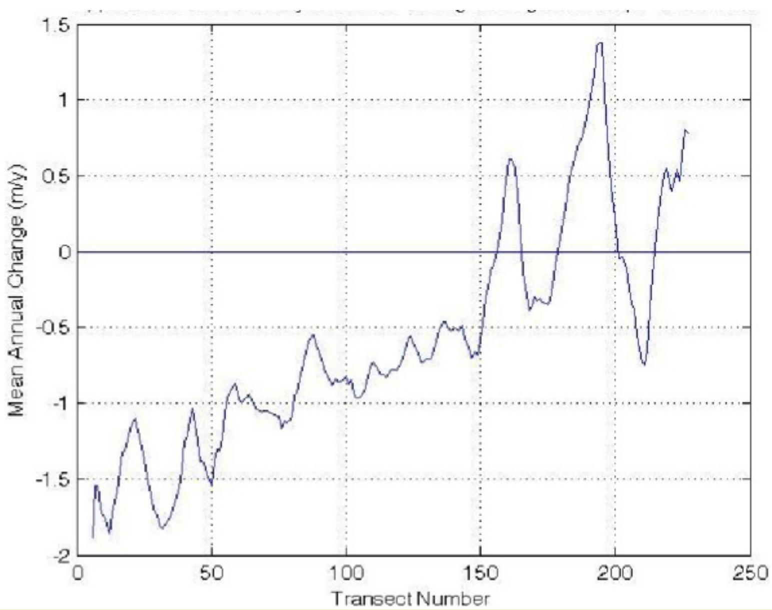


Figure 36.4. Shoreline change along the 67 km shoreline from Nauset Beach to Long Point. Transect numbers refer to the Marindin locations, shown in Figure 36.3. The first peak in shoreline accretion is centered around transect # 160. The second peak is in the vicinity of Race Point. The third zone of accretion is in the vicinity of Wood End and Long Point.

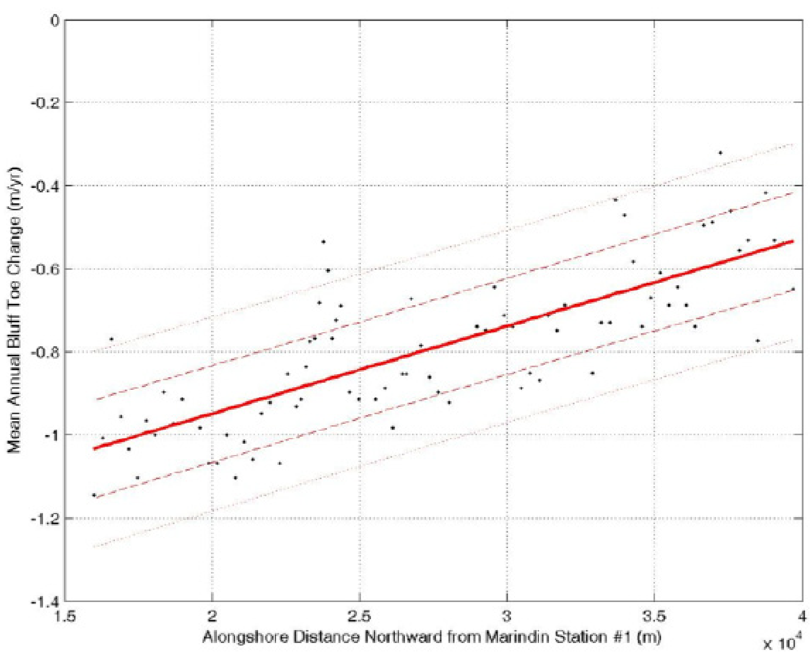


Figure 36.5. Scatter plot of century-scale bluff retreat rate, illustrating the reduced rates of erosion in a northerly direction. The solid red line is the linear regression line; the other sets of lines represent one and two standard deviation units (from Giese and Adams 2007).

37. Coastal vulnerability to sea-level rise

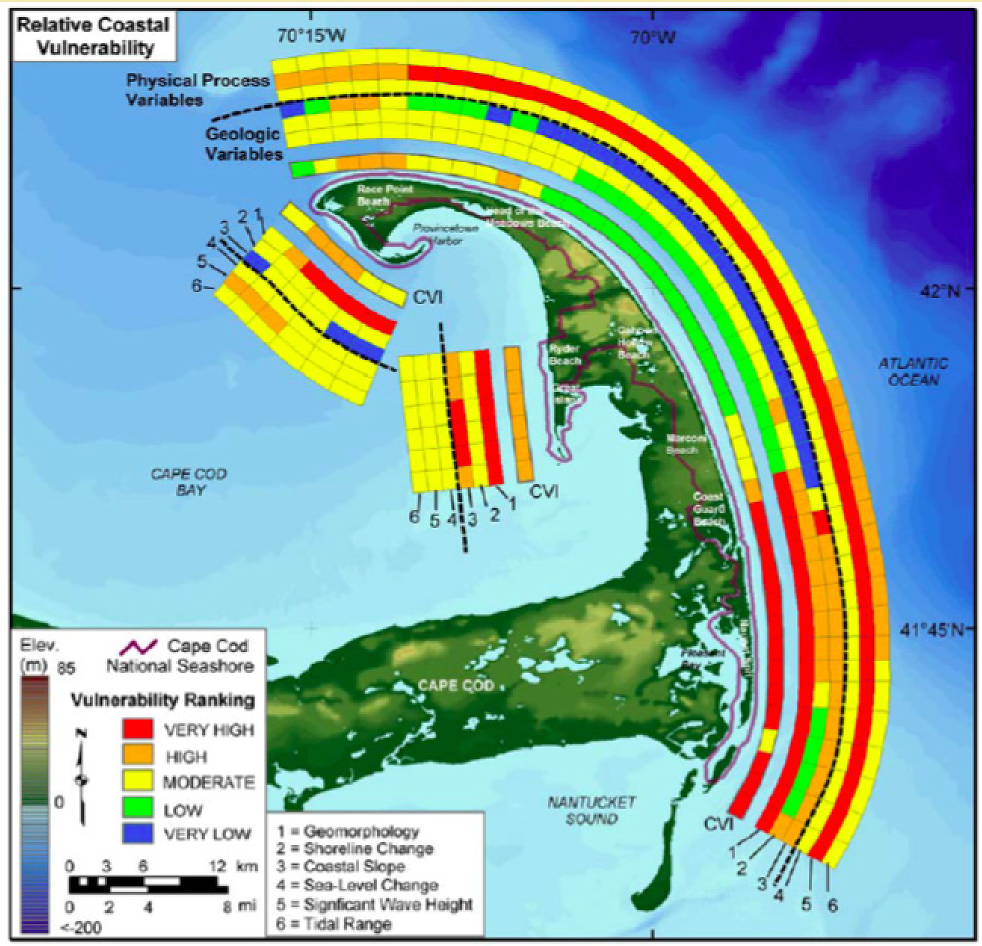


Figure 37.1. Relative Coastal Vulnerability for the CACO shoreline. The inner bar shows the composite vulnerability index (CVI), while the other bars display the component index variables. Nauset beach / spit is the shoreline section with the highest overall vulnerability. (Image from Hammer-Klose et al. 2003).

Key Points

- The vulnerability of CACO coastal areas to sea-level rise was evaluated using six metrics: geomorphology, shoreline erosion/accretion rates, coastal slope, relative sea-level change, mean wave height, and mean tide range.
- The most vulnerable area is Nauset Beach and spit.
- Least vulnerable coastal segments extend from Head of the Meadow Beach to Marconi Beach.
- Coastal vulnerability to sea-level rise reflects largely natural patterns of geomorphology. Consequently, this vulnerability index does not closely translate to a measure of resource condition, per se.

Assessment statement

Approximately 25% of the CACO shoreline is predicted to be highly vulnerable to sea-level rise. Note, however, that high coastal vulnerability does not equate poor resource condition - they are distinct concepts.

Rationale

Global sea-level has risen by approximately 18 cm (7.1 inches) over the past century. Climate models predict that the rate of rise observed during the 20th century will more than double over the next century. Sea-level rise will have a range of impacts on coastal areas, including shoreline erosion, intrusion of saltwater into aquifers, flooding of wetlands and estuaries, and damage to and/or destruction of cultural and historic resources and infrastructure (Hammer-Klose et al. 2003). Human modifications of natural shorelines, including beach nourishment, seawalls, jetties and groins, influence how coasts will respond to sea-level change. A Coastal Vulnerability Index (CVI) is a prioritization tool, informing resource managers of which areas are predicted to be most susceptible to rising sea levels.

Table 37.1. Variables used in development of the Coastal Vulnerability Index, with values indicative of various vulnerability states. (Table from Hammer-Klose et al. 2003).

Variables	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Geomorphology	Rocky cliffed coasts, Fjords	Medium cliffs, indented coasts	Low cliffs, Glacial drift, Alluvial plains	Cobble beaches, Estuary, Lagoon	Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangrove, Coral reefs
Shoreline erosion/accretion (m/yr)	> 2	1 - 2	-1 - 1	-2 - -1	< -2
Coastal slope (%)	> 1.2	1.2 - 0.9	0.9 - 0.6	0.6 - 0.3	< 0.3
Relative sea level change (mm/yr)	< 1.8	1.8 - 2.5	2.5 - 3.0	3.0 - 3.4	> 3.4
Mean wave height (m)	< 0.55	0.55 - 0.85	0.85 - 1.05	1.05 - 1.25	> 1.25
Mean tide range (m)	> 6	4 - 6	2 - 4	1 - 2	< 1

We include the vulnerability model data in this assessment to more fully address climate change impacts on CACO natural resources. However, the vulnerability index should not be inferred to be a measure of resource condition, per se.

Benchmarks

Not applicable for this topic. The CVI represents one modeling approach to predict vulnerability. Other models / assessments, using a different set of metrics, may be developed in the future.

Condition

Status

Hammer-Klose et al. (2003) used six variables that strongly influence coastal erosion to characterize the vulnerability of CACO shorelines to sea-level rise (Table 37.1). Their CVI was calculated as the "square root of the product of the ranked variables divided by the total number of variables" (see Hammer-Klose et al. 2003, and references therein, for details of the index derivation).

Values of CVI for CACO range from 6.7 to 31.6. Figure 37.1 displays index values for coastal segments. The section of coastline with highest vulnerability to sea-level rise is the Nauset beach and spit. Shorelines within Cape Cod Bay exhibit high vulnerability. The area with the lowest vulnerability to sea-level rise extends from Head of the Meadow Beach to Marconi Beach. Glacial cliff morphology and steep coastal slopes both contribute to this section's low vulnerability indeed. Overall, approximately equal lengths of shoreline fall within each of the four CVI classes: very high, high, moderate and low. As discussed above (Rationale), the vulnerability index should not be inferred to be a measure of resource condition per se.

Trends

Not applicable.

Factors influencing vulnerability to sea level rise

Listed in Table 37.1:

- Geomorphology.
- Shoreline erosion/accretion rates.
- Coastal slope.
- Relative sea-level change.
- Mean wave height.
- Mean tide range.

Summary of Information Gaps

The long-term monitoring program at CACO (Table I.3) provides a rigorous framework for quantifying status and trends of natural resource conditions in the Park. Beyond the indicators and other metrics that are the focus of the long-term monitoring program, this assessment has identified a number of information gaps – areas where additional data would enhance the ability to characterize and evaluate natural resource conditions in the Park. These gaps are summarized below:

- Land-use changes and habitat fragmentation. Although Park staff have informally assessed "unfragmented" blocks of land within CACO and the surrounding area (M. Adams, pers. comm.), no formal assessments of fragmentation or connectivity have been performed, to our knowledge. These analyses would be useful in assessing future conservation strategies, particularly if provided to town planning groups working outside Park boundaries where development is occurring.

- Atmospheric deposition of sulfur and nitrogen. Although there are extensive data on wet deposition, there are currently no data on dry deposition in the CACO area. Data from elsewhere suggest that dry deposition of sulfur may equal or exceed wet deposition. Results of current study regarding nitrogen dry deposition near roadways should be evaluated when available to determine whether more research is warranted.

- Mercury in freshwater and estuarine systems. Mercury concentration of freshwaters (ponds) at CACO has not been studied. Although sensitivity to methylation is probably a more critical metric to evaluate, a survey of pondwater mercury and methylmercury concentrations would better complete the picture of mercury cycling in CACO freshwaters. Importantly, measurements of dissolved organic carbon, sulfate, and pH are crucial data that inform sensitivity models and are especially useful when sampled concurrently with mercury and methylmercury.

- Mercury in biota. As at most other sites, there are few data for mercury in biota besides fish at CACO. Common loons (Gavia immer) have been proposed as sentinel species for Hg in other northeast sites. Finally, little is known about the effects (on individuals or populations) of mercury on biota, and thresholds are unclear. Studies that will assess body burdens of mercury at CACO should consider incorporating elements of toxicological assays into their research as feasible.

- Rare plant & animal species. This assessment was not able to locate published data on the population status of rare plant species in the Park. For rare non-marine vertebrates, the long-term monitoring program and other research appear to developing quantitative data that will permit evaluation of population status and trends. For rare invertebrate species, there are few available data on population status and trends.

- Invasive species. For many invasive species, there appear to be few quantitative data on trends in distribution and abundance. Exceptions include black locust and species in salt marshes that are undergoing restoration.

- Terrestrial vegetation. Although the long-term monitoring program for forest and other terrestrial vegetation includes numerous metrics, it appears that, for some of these metrics, criteria used to define condition are either still under evaluation or have yet to be published.

- Forest health: disease incidence. There appear to be no published benchmarks relating to disease incidence in forest vegetation at CACO.

- Terrestrial mammals – population dynamics. Although baseline data on small mammal abundance and habitat preferences are available from the early 2000s, it appears that trend data on population status do not exist.

- Bird assemblages. There are extensive population data on some of the bird species at CACO. The development (and testing) of a multi-metric index (index of biotic integrity) to evaluate terrestrial and other bird assemblages at CACO would represent a valuable tool for evaluating assemblage conditions (as opposed to single-species population status) in the Park.

- Amphibians & reptiles. There appear to be few published data on snakes at CACO. Data on the population status of the Eastern hognose snake and the Northern water snake would be of particular interest. Collection of population data on amphibians and some turtles is included in CACO's long-term monitoring program.

- Dune slack & vernal pool wetlands. Quantitative baseline data describing dune slack wetland extent and vegetation assemblages are available from the early 2000s. However, benchmarks for evaluating the condition of dune slack and vernal pool wetlands do not appear to have been published.

- Kettle pond vegetation assemblages. The long-term monitoring program includes documentation of multiple metrics for pond plant assemblages. The development and testing of a multi-metric index (index of biotic integrity) to 'integrate' some or all of these metrics would represent a valuable tool for evaluating the condition of aquatic plant assemblages in the Park.

- Fish assemblages (ponds and estuaries). Evaluation of the condition of these assemblages would be enhanced by the development and testing of multi-metric indices of biotic condition tailored to CACO.

- Salt marsh flora & fauna. Because much of the data from the salt marsh monitoring programs are currently being analyzed and/or remain to be published, we do not attempt to evaluate information gaps for these assemblages.

- Eelgrass population status. The contribution of wasting disease to recent changes in eelgrass populations has not been evaluated.

- Harmful algal blooms. Although published data on trends in paralytic shellfish poisoning are currently unavailable, the Massachusetts Division of Marine Fisheries is analyzing trends at the time of this writing.

- Climate change. Climate change and sea-level rise are likely to influence many ecosystem components at CACO. Although some of these possible impacts have been investigated – and are discussed in this assessment – a more detailed and integrated evaluation of how climate change will affect CACO ecosystems and their management would be a valuable resource.

Summary of Natural Resource Status & Trends

In this section we provide a concluding summary of the attributes used to describe the status and trends of natural resources at CACO and in adjacent areas of the Cape.

This Assessment is based on a rich, but very heterogeneous, information base. Some of the studies we have reviewed provide quantitative data for one or more ecosystem attributes that yield clearly interpretable measures of resource condition. Examples include nitrogen deposition, mercury content in abiotic and biotic media, surface water chemistry, groundwater quality, groundwater quantity (particularly modeled responses to various pumping scenarios), and changes in coastal geomorphology.

Other data, while describing facets of the Park's natural resources, may not explicitly include measures of condition. For example, biological assemblage data are available for most of the Park's ecosystems. However, multi-metric indices designed to quantify the condition of these assemblages have not, to our knowledge, been developed for CACO. In the absence of quantitative, published, benchmarks with which to characterize condition, our discussion has focused on a summary of the descriptive information, with inferences about condition based on a variety of supporting data – for example, proportions of non-native species, documented trends in species composition or relative abundance, and an evaluation of the susceptibility of the attribute(s) to the suite of threats or stressors that are likely to be acting on the system..

Given the heterogeneous nature of the available information base, a consistent and fully quantitative assessment of resource conditions at CACO is an unrealistic goal at this time. For some attributes, it was only possible to make general, qualitative, statements about condition. In some cases, we had to conclude that insufficient information was available to assess condition at any level of confidence at the present time. As noted above, for other attributes we were able to use well-defined benchmarks against which to evaluate CACO data.

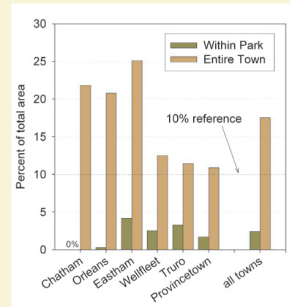
In the following table we summarize the key conclusions from our review as they pertain to the status and trends of each resource attribute. In most cases, a thumbnail graphic or other information product is included to illustrate (in part) these conclusions. The reader is encouraged not to rely solely on this summary table, but rather to refer back to the full discussion for each topic. We have elected not to include here an overall summary of the number of resource attributes by each condition level. While it would be simple to derive these totals, they are potentially misleading for several reasons. First, as already noted, there is substantial variation among resource attributes in the level of information richness available to characterize condition, including the relative contributions of qualitative and quantitative data. Second, the number of attributes used to describe condition in this assessment varies by resource; the number was determined by ecological science as well as by data availability. Using multiple attributes to characterize resource condition has the benefit of providing a more complete picture of status and trends. A disadvantage is that it makes it less easy to derive a simple, unambiguous characterization of condition. Third, even when there is a consensus on which attributes are most relevant to condition assessment, there may not be published opinions for how multiple metrics should be weighted when contributing to a composite index of condition. Multi-metric indices of biotic condition (IBI), for example, have proved to be a useful assessment tool in many parts of the U.S. and elsewhere. However, this tool needs to be tailored to the area in which it is being used. From published research, it appears that, in general, IBIs have not been developed for CACO ecosystems.

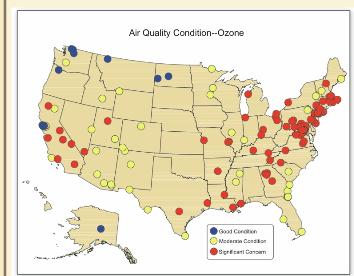
Photos courtesy C. Schmitt, Maine Sea Grant

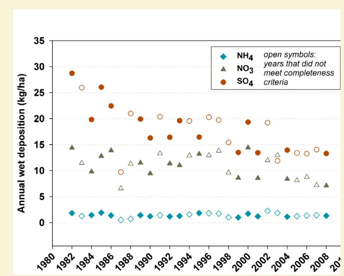
Condition assessment summary table

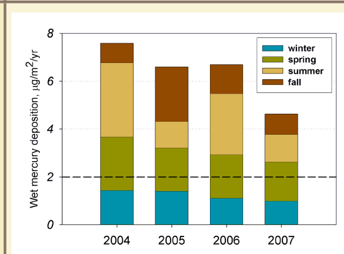
(following pages)

<table>
<tr><th>Resource Attribute</th><th>Key points</th><th>Thumbnail</th></tr>
<tr><td>1. Land cover / land use: status & change

Condition: Good within park; significant concern in surrounding areas</td><td>• Approximately one half of Park lands are forested. The next two most common land-cover types are saltwater beaches and open water.
• Within the Park, anthropogenic land use ranged from 0% (Chatham) to 4.2% (Eastham).
• Including non-park lands, anthropogenic land use in the six eastern Cape towns ranged from 10.9% (Provincetown) to 25.1% (Eastham).
• Anthropogenic land use on the eastern Cape increased by 44% in the period 1971-1999.</td><td>
</td></tr>
<tr><td>2. Atmosphere: ozone & visibility

Condition: Significant concern (ozone)
Fair (visibility)</td><td>• Although trends suggest improvement in meeting ozone standards, ozone concentrations are still a significant concern, with respect to both national standards and in terms of risk to ozone-sensitive plants.
• Visibility at CACO is considered “Moderate”, as it is at other New England coastal parks.</td><td>
</td></tr>
<tr><td>3. Nitrogen & sulfur: atmospheric deposition

Condition: Fair (sulfate); significant concern (nitrogen)</td><td>• Sulfate deposition has declined since 1982.
• The decline in sulfate and lack of pattern in nitrogen are consistent with patterns observed across the northeast region.</td><td>
</td></tr>
<tr><td>4. Mercury: atmospheric deposition

Condition: Significant concern</td><td>• Wet-only mercury deposition has been monitored at CACO by MDN. Long-term monitoring will allow assessment of changes.
• Currently, wet-only deposition of mercury is 2.5-4 times greater than probable pre-industrial mercury deposition.
• Wet-only deposition does not take into account dry or fog deposition, which could be 1.5-3 times the reported value for wet-only deposition; we are not aware of direct measurements of dry or fog deposition to the Park.</td><td>
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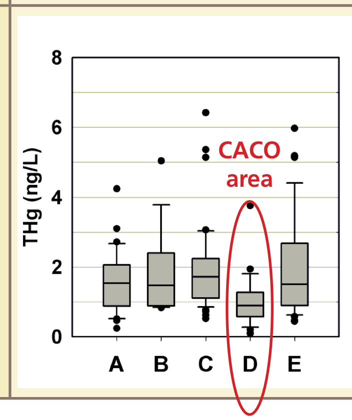
<tr><td>5. Mercury: freshwater & estuaries

Condition: Significant concern</td><td>• In a regional study, lakes on Cape Cod and in southeastern New England typically had low total mercury concentrations.
• Estuarine and marine systems have been studied less frequently than freshwaters, but new research on Cape Cod is providing mass balance estimates.
• In Waquoit Bay, groundwater was a potential source of mercury; sandy, low-organic content soils could allow mercury to pass into groundwater, atypical for the Northeast.</td><td>
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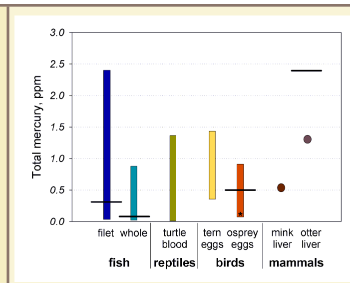
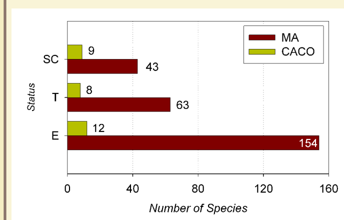
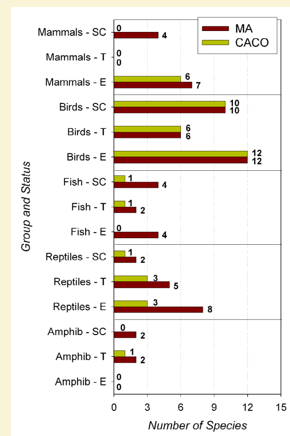
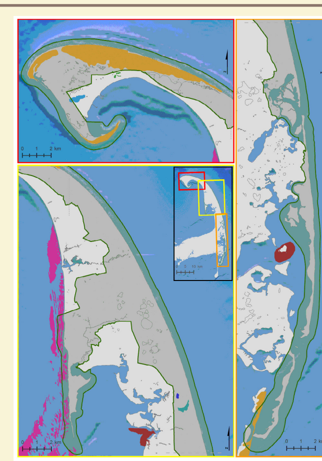
6. Mercuy: biota ***Condition:*** *Significant concern (fish); insufficient data (other biota)*	• Concentrations of mercury in fish filets at CACO in the 1990s and 2000s typically exceed human health consumption thresholds; eight ponds at CACO have fish consumption advisories. • Whole-body fish concentrations of mercury sampled in the 1990s at CACO were usually greater than levels thought to be protective of piscivorous wildlife. • Although some data are available for other biota, the tissues sampled or reporting method do not allow for comparison to thresholds or effects levels for mercury. Future sampling would benefit from ensuring the sampling approach will be comparable to such thresholds.	
7. Rare species: flora ***Condition:*** *Unknown. Information is not available on the current status or trends for populations of these state-listed species.*	• 29 state-listed plant species are present in CACO, representing 11% of all MA-listed flora. • Only three federally-listed plant species are present in Massachusetts. None of these has been recorded from CACO.	
8. Rare species: fauna ***Condition:*** *Species lists: good - fair. Population status: fair - significant concern - unknown (depending on group - see group-specific discussions for more information).*	• 65% (44/68) of the Massachusetts-listed vertebrate species are known to occur in CACO. • Of these 44 state-listed species, 6 are marine mammals; there are 28 listed birds, 2 fish, 7 reptiles and 1 amphibian. • A total of 13 federally-listed species occur at CACO (and offshore waters). • Extensive Lepidoptera and Odonata surveys have been conducted in the CACO area. Although the NPSpecies database for the Park does not currently (2010) include many of these taxa, data have been compiled for this assessment from multiple sources.	
9. Critical terrestrial & aquatic habitats ***Condition:*** *Good for marine natural communities, based on assessment by MA Natural Habitat & Endangered Species Program. High value of other core habitats is recognized by designation within this program.*	• All of CACO upland areas are contained within two state-designated critical habitats (BioMap Core Habitats). • The Pamet River and many of CACO's kettle ponds have been identified by the Living Waters Program as critical habitats within the state. • Large areas of critical marine habitat (intertidal zone, marsh and tidal flats) are found within CACO along the back barrier of the Nauset beach spit on Pleasant Bay. • Large portions of Pleasant Bay and Wellfleet Bays are contained within designated Areas of Critical Environmental Concern. • Several state-designated high-value natural communities are found in CACO.	

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10. Flora & fauna: non-native & invasive species

Condition: *Significant concern*

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• 19% of vascular plant species listed in NPSpecies are considered non-native to CACO; nativity status of another 16% is unspecified
• 2% (21 species) of plant species listed in NPSpecies for CACO are considered invasive/likely invasive. This total represents 34% of the plant species considered to be invasive or likely so in Massachusetts
• Only 2% (11 species) of animal species at CACO are considered to be native transplants or exotic; 10 of these species are fish and they comprise 15% of the fish species in CACO
• Another 19 invasive species have been recorded in the vicinity of CACO and these may pose emerging threats to CACO
• 16/30 the insect pests tracked by the USDA that are present in Barnstable County pose either an extreme or medium risk of infestation based on the basal area of host plant species.
• Invertebrates are poorly represented in the NPSpecies database; it is not possible to assess levels of nativity for these groups.

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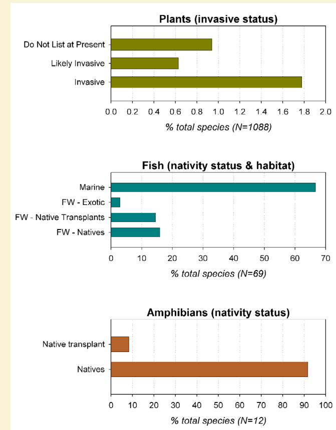

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11. Terrestrial vegetation assemblages

Condition: *Cannot be evaluated at this time*

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• Contemporary vegetation assemblages on Cape Cod reflect historic patterns of land-use, as well as geomorphology and surficial geology.
• Forest cover on the Cape has been increasing since the 1800s following abandonment of agriculture. Increases in the basal area of several forest tree species at monitoring sites over the past quarter century reflect this trend of forest expansion.
• Heathland and grassland communities are currently uncommon at CACO. Their restoration will require management strategies that mimic the effects of past agricultural activity.
• Baseline data on dune vegetation have recently been collected. Environmental variables related to salt and wind influence are the best predictors of dune assemblage composition.
• Metric value classes that could be used to define condition 'ranks' or 'grades' have not yet been published for terrestrial vegetation assemblages at CACO.

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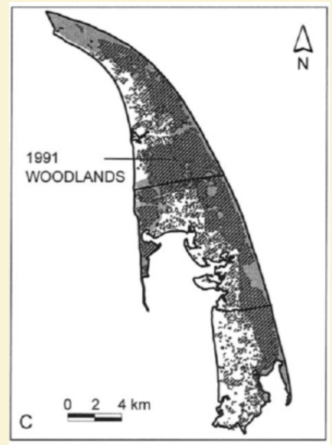

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12. Forest health: disease incidence

Condition: *Significant concern*

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• Non-indigenous forest pests could pose threats to CACOs forest.
• Published information on the spatial and temporal patterns of disease incidence in CACO trees and shrubs is unavailable.

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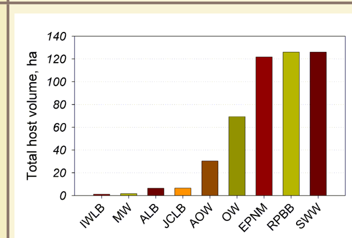

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13. Terrestrial mammals: population dynamics

Condition: *Condition cannot be evaluated at this time.*

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• Mammals interact in multiple ways with CACO's animal and plant communities. Large mammals exert significant predation pressure on shorebird species.
• Baseline data on small mammal abundance and habitat preferences are available from 2000 and 2001.
• Published data are not available to document temporal trends in population size.
• No terrestrial mammals are state- or federal- listed.

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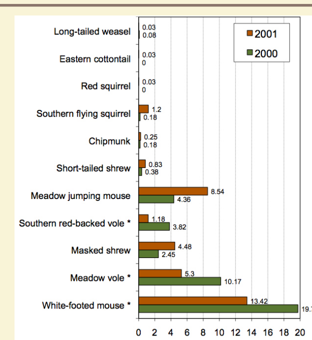

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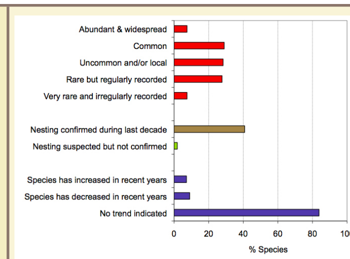
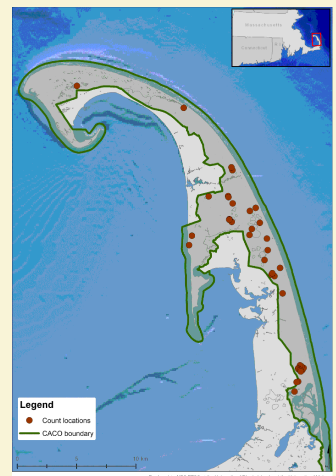
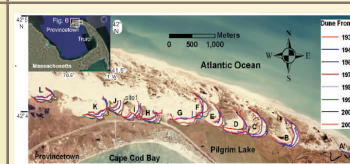
14. Birds: assemblage structure & population dynamics ***Condition:*** *Significant concern – some species, only. See full topic for more information*	• CACO was nominated in 2001 as an Important Bird Area. • The NPSpecies database (as of 2010) includes 376 bird species for CACO. 28% are breeders at CACO, while 47% are migratory. • In waterfowl surveys from 1984 through the present, six species have been most abundant. Over this period, there were apparent declines in the abundance of some taxa, including Canvasback, Northern Pintail and Scaup. • CACO provides important habitat for several shorebird species. Numbers of nesting pairs of Piping Plover have been relatively stable over the past decade. However, the number of other species has declined markedly. • Grassland species have declined regionally and at CACO as open areas revert to forest. Grasshopper and Vesper Sparrows were both historically present at CACO. However, the former appears to be now extirpated from the outer Cape, while the population of the latter has declined by over half in recent years. • Overwash and changes in beach morphology, while natural processes, can have substantial impacts on shorebird species. Predation and habitat loss influence both shorebirds and other species.	
15. Amphibians & reptiles: population status & trends ***Condition:*** *Fair. Most amphibian and reptile species are threatened by a range of factors at CACO, including changes in hydrology, development and road traffic.*	• One amphibian and seven (five of which are marine) reptile species at CACO are state-listed. All five marine turtles are also federally listed. • Most (11/12) amphibians at CACO are dependent on temporary or permanent freshwater habitat. One species is terrestrial. • The distribution and abundance of amphibians and non-marine turtles have been well documented since about 2003. Based on published data, a few trends in population parameters (egg mass counts) are apparent. However, the period of methodologically consistent monitoring data is relatively short. • There appear to be few published data on the snakes of CACO. • Future monitoring will provide a good foundation from which to examine amphibian and reptile population trends and to further study the role of these taxa as indicators of environmental condition.	
16. Parabolic dunes & associated wetlands ***Condition:*** *Caution. Dune slack wetlands appear to be in good and relatively unimpacted condition at the present time. However, their hydrologic regimes and, in turn, their biological communities may be highly susceptible to future reductions in groundwater levels.*	• Over the past seven decades, parabolic dunes in the Province Lands have migrated at average rates ranging from 1-4 m/yr. • Dune migration is more rapid in drier periods and less so in wetter periods. • There are approximately 350 wetlands within this system of parabolic dunes. These dune slack wetlands provide critically important habitat for many species. • The wetlands are threatened by several stressors, the most important of which is reductions in groundwater levels.	

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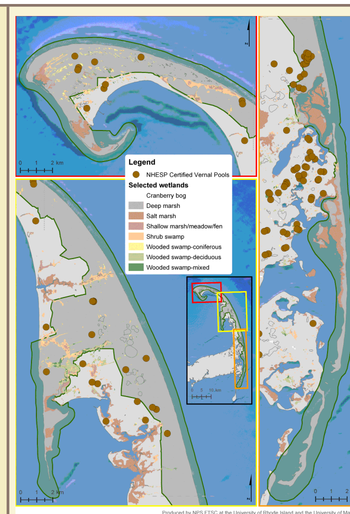
<td>17. Wetlands: distribution, hydrology and biology

Condition: Fair – Significant Concern, in view of documented wetland losses and the influence of possible future changes in hydrologic regimes.</td>
<td>• Forested vernal pools of the glacial outwash plain are one of two freshwater wetland groups that occur on the outer Cape and in Wellfleet. The other is the dune slack wetlands. These wetlands provide critical habitat to many plant and animal species.
• Vernal pools typically reach their largest areal extent in June and smallest in January.
• Pool water levels are sensitive to water table draw-down, but responses of multiple pools to changing groundwater levels have not yet been modeled.
• Vegetation assemblages of the forested wetlands are relatively pristine with low incidence of exotic species.
• Inter-annual variations in plant assemblage appear to be quite large and are likely related to hydrologic factors.
• Both within and outside the park, small (<0.25 ha) wetland change has occurred at a few sites, typically associated with commercial or residential development, or road building.</td>
<td>
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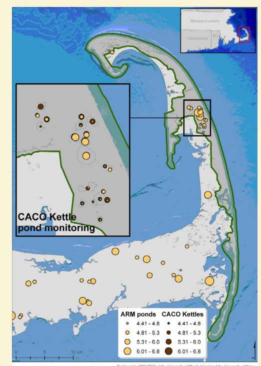
<td>18. Ponds: acid-base chemistry

Condition: Good</td>
<td>• CACO Kettle ponds are naturally acidic (pH ~4-6), and pH has changed little through time.
• Trend analyses suggest little change in alkalinity for ponds at CACO, probably due to their dilute chemistry and naturally-acidic status.
• CACO ponds' ionic composition is dominated by sodium and chloride, which appear to be from marine aerosol deposition and not road salt or other anthropogenic sources.</td>
<td>
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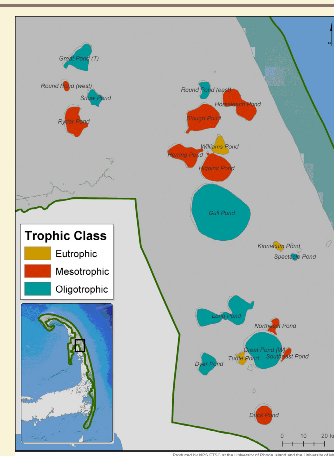
<td>19. Ponds: nutrients & trophic condition

Condition: Fair - significant concern. N loading is a potential issue.</td>
<td>• In 1999, of 20 CACO kettle ponds, 3 were eutrophic, 9 were mesotrophic, and 8 were oligotrophic. Overall, trophic indicators suggest more desirable conditions in these ponds than in statewide surveys, based on limited available data.
• Though lakes were thought to be phosphorus-limited, newer data suggest that they may be susceptible to nitrogen loading as well.
• Most sources of phosphorus to the ponds are probably human-associated (swimmers, septic systems). Gulls have been shown to provide significant P loading to one pond.
• Though not a major source of phosphorus, nitrogen loading from the atmosphere could be affecting these ponds.
• Many of CACO's kettle ponds have been identified by the states Living Waters Program as critical habitats within the state.</td>
<td>
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20. Ponds: aquatic vegetation assemblages

Condition: *Fair. Pond plant assemblages may be influenced by eutrophication and changes in hydrology.*

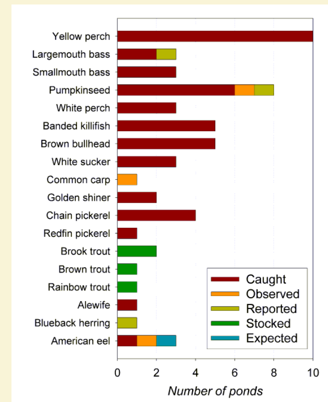
- Plant assemblage data are available from the two groups of permanently flooded ponds at CACO: kettle ponds and Province Lands ponds.
- Species richness in surveyed kettle ponds ranged from 12-30, while in the Province Lands ponds richness was in the range 14-37.
- Plant assemblages of kettle ponds are a good indicator of trophic condition.
- Plant assemblage structure in these ponds will be a valuable indicator of responses to future changes in key environmental attributes, such as nutrient loading, climatic variables and hydrologic regimes.

Variable	% Cumulative Variance
Depth	31
Sediment organic matter	50
Sediment % sand	61
Porewater PO_4-P	69
Bottom slope	77
Porewater NO_3-N	84
Sediment bulk density	90
Sediment % cobble and gravel	95
Porewater NH_4-N	98
Sediment % silt and clay	99

21. Ponds: fish assemblages

Condition: *Good (?). There appears to be no published information suggesting concern about the condition of fish assemblages in CACO ponds.*

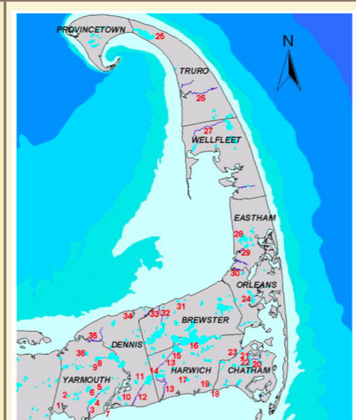
- At least 65% of fish species recorded at CACO occur in ponds.
- These ponds are characterized by warmwater fish assemblages. Pumpkinseed, yellow perch and banded killifish are among the most abundant species.
- Environmental variables thought to play a role in structuring these fish assemblages include pH, pond depth and macrophyte (plant) density.
- There are currently no published multi-metric indices that evaluate the overall biological integrity of pond fish assemblages at CACO.



22. Diadromous fish:connectivity issues

Condition: *Fair. In some watersheds of the outer Cape, there are barriers to fish passage. However, because of the size of these watersheds, the amount of habitat that is currently unavailable to migratory fish is relatively modest.*

- In eight catchments of the outer Cape, there are in-stream structures that might interfere with fish migration.
- In approximately one half of these watersheds, one or more barriers have been judged to significantly reduce fish passage.
- In view of declining populations throughout the Northeast, Alewife harvests have been prohibited throughout Massachusetts.
- Historical data on the run sizes for migratory fish are largely absent for outer Cape watersheds.

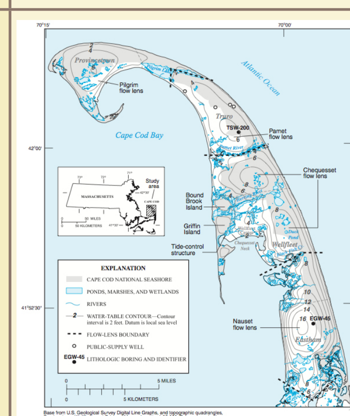


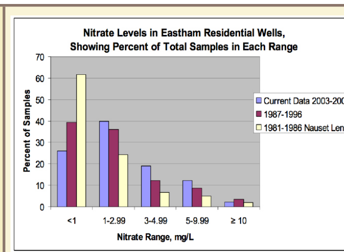
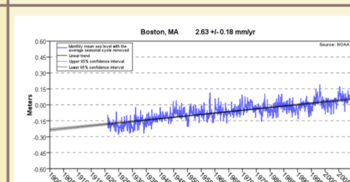
Major streams and ponds of eastern Cape Cod

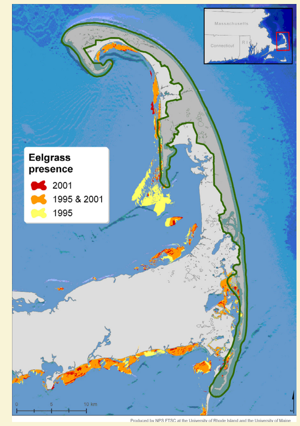
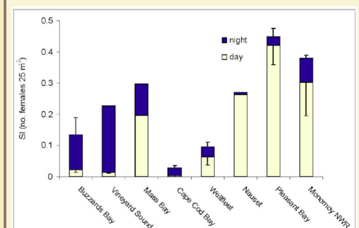
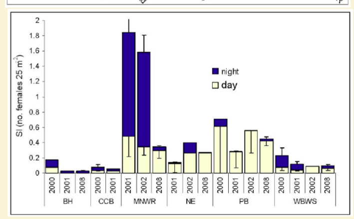
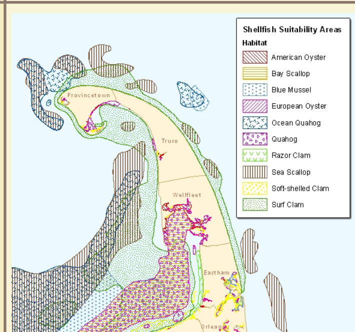
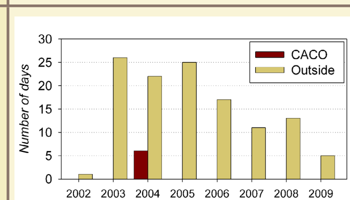
23. Groundwater: quantity

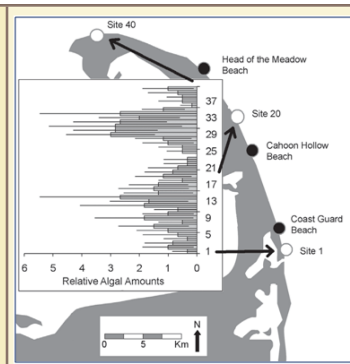
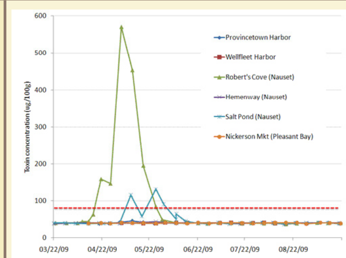
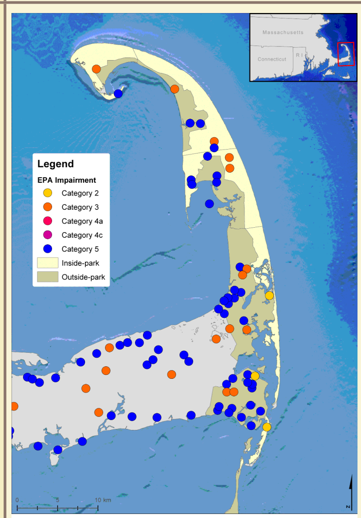
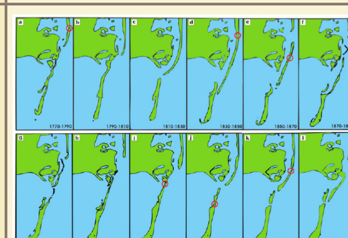
Condition: *Significant concern. Development pressures and climate change threaten a series of adverse impacts on a critically important resource for the Lower Cape.*

- Four groundwater lenses on Lower Cape Cod supply all drinking water, provide numerous ecosystem services and receive septic effluent.
- Municipal water withdrawals from the Pamet lens represent 7% of the entire hydrologic budget for that section of the aquifer.
- Changes in water extraction regimes will likely affect kettle-hole ponds, some streams and some wetlands.
- Sea-level rise is affecting groundwater levels and is predicted to result in a thinning of the Pamet lens as well as other lenses.



24. Groundwater: quality ***Condition:*** *Signficant concern. There is evidence that nitrate concentrations are increasing in groundwater.*	• Wastewater and landfills are the primary contaminant sources for groundwater in the outer Cape. Although all landfills are now closed, they continue to leach contaminants. • Nitrate concentrations in wells have increased over the past two decades • Increasing development has the potential to further increase groundwater nitrogen levels, which in turn may contribute to nutrient enrichment of surface waters. • Leaking underground storage tanks almost certainly exist. However, these tanks are external to CACO. Furthermore, their contribution to groundwater contamination in the CACO region has not been quantified.	
25. Tidal restrictions: occurrence, impacts & restoration ***Condition:*** *Significant Concern – for systems that are still tide-restricted. Improving / Good – for systems that are being restored.*	• Since the 1800s, dikes and other structures have resulted in tidal restrictions at over 30 sites on the outer Cape. • Ecological impacts from these restrictions vary but can be substantial, involving loss of large areas of salt marsh, conversion of estuarine plant and animal assemblages to more freshwater or upland types. • At CACO, large-scale restoration of tidally-restricted systems has begun at two sites (Hatches Harbor and East Harbor Lagoon) and is planned for another (Herring River).	
26. Salt marsh: flora & fauna ***Condition:*** *Fauna: Good, except for in marshes that remain tide-restricted. Flora: Good in some marshes (e.g. Nauset). Caution in other marshes where vegetation loss has been occurring over the last several decade.*	• Nekton and vegetation data are collected as part of the CACO long-term monitoring program. While initial data are available for Hatches Harbor and Nauset Marsh, most of the data have not yet been published. • Half the marshes on the outer Cape have experienced vegetation losses of over 30% during the past half century. • Vegetation at Nauset marsh appears to have been stable over the last century.	
27. Salt marsh landscape changes ***Condition:*** *Fair (based on 1997 study of Nauset Marsh). Current condition at Nauset and other sites in CACO is unknown; data analyses are ongoing.*	• Nauset marsh appears to be keeping pace with the relative rate of sea level rise from 1921 to 1993 of 2.4 mm/yr. • There is also evidence of wetland submergence at Nauset marsh. Changes in plant species in the past indicate the marsh is getting wetter. • The NPS is currently monitoring salt marsh elevation and accretion at several sites within the Seashore. Data from this study have not yet been published. • One half of marshes of the outer Cape experienced high-marsh losses of >30% over the past half century.	

28. Eelgrass distribution & population status ***Condition:*** *Significant concern. Eelgrass beds have decreased in extent over the past 50 years.*	• Eelgrass beds on the Cape decreased by about 30% between 1995 and 2001. • The most recent data (from 2006-2007) suggest that this reduction in eelgrass extent has continued in Pleasant Bay. Since the 1950s, eelgrass beds in this system have decreased by about one quarter. • Nutrient enrichment is thought to be one of the primary factors causing declines in eelgrass populations at both regional and global levels. Storm-mediated disturbance is thought to influence spatial patterns of eelgrass cover in Pleasant Bay and Cape Cod Bay. • Wasting disease was recorded on Cape Cod in the 1980s but its contribution to current eelgrass declines is uncertain.	
29. Horseshoe crabs: population status & dynamics ***Condition:*** *Overall Condition: Fair - Significant concern (latter based on increasingly male-biased spawning sex ratios).*	• State managers have become increasingly concerned about horseshoe crab spawning densities throughout the state and have instituted more regulations regarding the harvest of crabs. • Sex ratios for spawning horseshoe crab were strongly skewed towards males within Pleasant Bay, and were much higher than those in the 1950's, possibly suggesting that spawning dynamics have changed in this embayment. • Evidence from tagging studies done in 2000 to 2002 suggests that horseshoe crab populations may be localized within embayments on Cape Cod. • Spawning "hot spots" within the Seashore in Pleasant Bay may be responsible for a significant percent of all spawning Cape-wide.	
30. Shellfish resources ***Condition:*** *Good (increased or sustainable landings)- razor clam, soft shell clam, Atlantic surf clam, ocean quahog, sea scallop. Potential Significant Concern (decreased landings)- quahog, bay scallop Unknown (Cape Cod)- American oyster, blue mussel.*	• Cape Cod waters provide habitat for several commercially important shellfish species. • Some species have experienced local declines in harvest (e.g., quahog and bay scallop); while others have experienced local increases in harvest (e.g., razor clam and soft shell clam). • NOAA fisheries managers have concluded that for the three Atlantic Coast commercially shellfish species assessed by NOAA (Atlantic surf clam, ocean quahog, and sea scallop) overfishing was not occurring in the most recent stock assessment in 2006. • Shellfish aquaculture is practiced in waters adjacent to CACO (e.g., Pleasant Bay)	
31. Beach Closures ***Condition:*** *Good (for CACO beach water quality)*	• The NPS has sampled bathing beach waters for NPS ocean beaches since 2006. Additional data are available from a Massachusetts Department of Public Health monitoring program. • From June 2002 to June 2009, CACO beaches have only been closed (exceedances of 104 CFU/100ml) on 6 dates. All of these closures occurred in 2004. In August 2009, Race Point Beach was closed on two occasions in response to elevated bacterial levels. • Beaches in towns adjacent to the Park have been closed on a total of 120 days over this same time period. • The majority of the closures outside of CACO have occurred in Provincetown Harbor (46 closures) and Cape Cod Bay (56 closures) since 2002.	

32. Beach fouling: marine macroalgae accumulations ***Condition:*** *Unknown. Data are unavailable to permit assessment of trends in beach fouling from macroalgal accumulations in the CACO area.*	• Accumulations of nuisance drift macroalgae along the open-coast Atlantic beaches of the Cape Cod have been observed on an anecdotal basis for over 50 years and have historically caused beach closures. • Detailed data on macroalgal abundance at CACO are available only from a study conducted in 2006. • In 2006, peak macroalgal biomass occurred in early August. Highest algal densities were found at Head of the Meadow beach, in both intertidal and subtidal habitats. • Macroalgae probably originate in northern New England and are transported south by Gulf of Maine currents. It is unlikely that accumulations are associated with nutrient availability.	
33. Harmful algal blooms & shellfish closures ***Condition:*** *Fair*	• The state of Massachusetts monitors for paralytic shellfish poisoning (PSP) to determine the safety of shellfish harvested from state waters. • Elevated biotoxin levels are usually detected every year, forcing the closure of waters to shellfish harvesting. • In 2009, elevated biotoxin levels were detected in Nauset Estuary. • Currently there are no published trend analyses for PSP data (the Division of Marine Fisheries is in the process of analyzing data).	
34. Water and sediment quality: coastal & surface freshwaters ***Condition:*** *Good – Significant Concern, depending on location and metric.*	• Reporting for the Clean Water Act includes a list of 19 waterbodies (or sections thereof) on the outer Cape that are impaired. • A study of Pleasant Bay has quantified nitrogen loading sources and identified load reductions needed to bring this system back into attainment. • The National Coastal Assessment evaluates water and sediment quality at coastal sites around the U.S. A total of 23 sites have been surveyed in Cape Cod Bay, Nauset Harbor and Chatham Harbor. • All Cape Cod Bay sites are ranked as being in 'good' condition for all metrics. • Nauset and Chatham Harbor sites are ranked 'poor' for some metrics and 'fair' or 'good' for others.	
35. Coastal geomorphology: Nauset Beach & Pleasant Bay sediment dynamics ***Condition:*** *Good.*	• Nauset Beach undergoes multi-decadal cycles of elongation and subsequent breaching. The most recent breach occurred during the Patriot's Day storm of 2007. • Changes in the geomorphology of this barrier beach system influence sediment dynamics and tidal amplitude within Pleasant Bay. • Sediment dynamics of Pleasant Bay may also be influenced by erosion control structures, in turn potentially impacting critical habitats in the Seashore. • In 1998, it was estimated that 8% of the Pleasant Bay was armored with erosion control structures (133 structures). In 2008 the number of structures was estimated at 165, an increase of 24%.	

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<tr>
<td>36. Coastal geomorphology: bluff erosion

Condition: Good</td>
<td>• Erosion of coastal bluffs north of Nauset Beach is a natural process that is being influenced by changes in sea level.This erosion supplies sediment for outer Cape Cod beaches and dunes.
• The century-scale average erosion rate is 0.8 m/yr.
• Erosion rates are highest in the area just north of Nauset Beach and decrease in a northward direction.
• The coast of the outer Cape is rotating clockwise as sea level rise changes the wave climate, in turn influencing the pattern of longshore sediment transport.</td>
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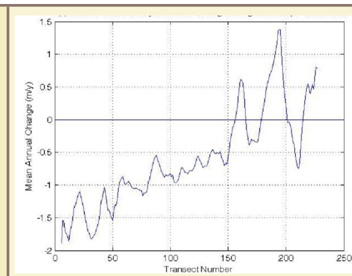

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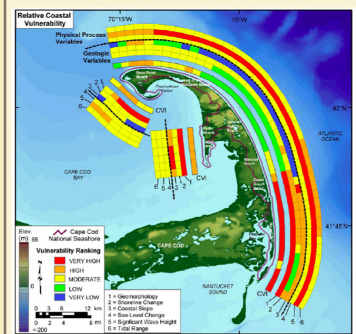
<td>37. Coastal vulnerability to sea-level rise

Condition: Coastal vulnerability to sea-level rise is not a true measure of resource condition, per se - rather it (largely) reflects natural geomorphology within the context of both anthropogenic and natural drivers of sea-level change.</td>
<td>• The vulnerability of CACO coastal areas to sea-level rise was evaluated using six metrics: geomorphology, shoreline erosion/accretion rates, coastal slope, relative sea-level change, mean wave height, and mean tide range.
• The most vulnerable area is Nauset Beach and spit.
• Least vulnerable coastal segments extend from Head of the Meadow Beach to Marconi Beach.
• Coastal vulnerability to sea-level rise reflects largely natural patterns of geomorphology. Consequently, this vulnerability index does not closely translate to a measure of resource condition, per se.</td>
<td>


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Appendix A: Species lists for CACO and the surrounding area

Vertebrate and plant species lists were derived primarily from the NPSpecies database. Invertebrate lists are restricted to Lepidoptera and Odonata because it is only for these two groups that there have been extensive surveys in the CACO area. Lists for these two groups were derived from multiple sources and include records that, in some cases, are attributed only to the broader Cape Cod or Barnstable County areas. As of October 2010, the NPSpecies database contained very few invertebrate records. In some cases, the NPSpecies database (accessed October 2010) had invalid synonymns and incorrect nativity status. These errors have been corrected where noted in this appendix.

Group	Data Source(s)
Non-vascular plants	NPSpecies database, last accessed October 2010. This list is probably very incomplete.
Vascular plants	NPSpecies database, last accessed October 2010. (Note: given scientific names are the park-accepted names.)
Crustaceans	NPSpecies database (last accessed October 2010) and Able et al. (2002). Note: this list does not include micro-crustaceans.
Butterflies & moths	(1) Mello (1990) – records from CACO. Family determinations are from Bar Code of Life database of Lepidoptera (www.barcodeoflife.org)
	(2) Mello and Hansen (2004) – records from Cape Cod.
	(3) Opler et al. (2010) – records from Barnstaple County. Species referenced to this source appear in the Barnstable County list but not in the lists of Mello or Mello and Hansen.
	(4) Elkinton et al. (2010).
	(5) Massachusetts Natural Heritage and Endangered Species Program database (data for individual towns).
Dragonflies & damselflies	(1) Nikula – unpublished data for CACO, provided by Robert Cook [CACO]; data are through 2004.
	(2) Carpenter (1991) – records for Cape Cod.
	(3) Massachusetts Natural Heritage and Endangered Species Program database (data for individual towns).
Fish	NPSpecies database, last accessed October 2010.
Amphibians	NPSpecies database, last accessed October 2010.
Reptiles	NPSpecies database, last accessed October 2010.
Mammals	NPSpecies database, last accessed October 2010.
Birds	NPSpecies database, last accessed October 2010.
Fungi	The NPSpecies database contained 17 fungi species (as of October 2010). This list appears very incomplete and is therefore not included here in this appendix.

(Unavailable data are indicated by NA)

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Aceraceae	*Acer rubrum*	red maple	Present in Park	Abundant	Native	NA
Acoraceae	*Acorus americanus*	sweet flag	Present in Park	Uncommon	Native	NA
Agavaceae	*Yucca filamentosa*	Spanish bayonet	Present in Park	Occasional	Non-Native	Not cultivated
Agavaceae	*Yucca filamentosa*		NA	NA	NA	NA
Alismataceae	*Sagittaria latifolia*	common arrow-head	Present in Park	Common	Native	NA
Alismataceae	*Sagittaria teres*	slender arrowhead	Present in Park	Rare	Native	NA
Amaranthaceae	*Amaranthus albus*	pale amaranth	Present in Park	Uncommon	Native	NA
Amaranthaceae	*Amaranthus blitoides*	prostrate amaranth	Present in Park	Occasional	Non-Native	Not cultivated
Anacardiaceae	*Rhus copallinum*	winged sumac	NA	NA	NA	NA
Anacardiaceae	*Rhus copallinum*	winged sumac	Present in Park	Common	Native	NA
Anacardiaceae	*Rhus copallinum var. latifolia*	shining sumac	Present in Park	Unknown	Native	NA
Anacardiaceae	*Rhus glabra*	smooth sumac	Present in Park	Occasional	Native	NA
Anacardiaceae	*Rhus hirta*	staghorn sumac	Present in Park	Occasional	Native	NA
Anacardiaceae	*Toxicodendron radicans*	poison ivy	NA	NA	NA	NA
Anacardiaceae	*Toxicodendron radicans*	poison ivy	Present in Park	Abundant	Native	NA
Anacardiaceae	*Toxicodendron vernix*	poison sumac	Present in Park	Occasional	Native	NA
Apiaceae	*Angelica lucida*	seaside angelica	NA	NA	NA	NA
Apiaceae	*Angelica lucida*	seaside angelica	Present in Park	Uncommon	Native	NA
Apiaceae	*Cicuta bulbifera*	bulblet water hemlock	Present in Park	Common	Native	NA
Apiaceae	*Cicuta maculata*	water hemlock	Present in Park	Common	Native	NA
Apiaceae	*Daucus carota*	Queen Anne's lace	Present in Park	Abundant	Non-Native	Not cultivated
Apiaceae	*Heracleum maximum*	cow-parsnip	Present in Park	Occasional	Native	NA
Apiaceae	*Hydrocotyle umbellata*	water pennywort	Present in Park	Occasional	Native	NA
Apiaceae	*Ligusticum scoticum*	sea-lovage	Present in Park	Unknown	Native	NA
Apiaceae	*Pastinaca sativa*	wild parsnip	Present in Park	Unknown	Non-Native	Not cultivated
Apiaceae	*Ptilimnium capillaceum*	mock bishop's-weed	Present in Park	Occasional	Native	NA
Apiaceae	*Sanicula marilandica*	black snakeroot	Present in Park	Unknown	Native	NA
Apiaceae	*Sium suave*	water-parsnip	Present in Park	Occasional	Native	NA
Apocynaceae	*Apocynum androsaemifolium*	spreading dogbane	Present in Park	Uncommon	Native	NA
Apocynaceae	*Apocynum cannabinum*	Indian hemp	Present in Park	Uncommon	Native	NA
Apocynaceae	*Vinca minor*	common periwinkle	Present in Park	Unknown	Non-Native	Not cultivated
Aquifoliaceae	*Ilex aquifolium*	English holly	Present in Park	Unknown	Non-Native	Not cultivated
Aquifoliaceae	*Ilex glabra*	inkberry	Present in Park	Common	Native	NA
Aquifoliaceae	*Ilex laevigata*	smooth winterberry	Present in Park	Common	Native	NA
Aquifoliaceae	*Ilex opaca*	American holly	Present in Park	Occasional	Native	NA
Aquifoliaceae	*Ilex verticillata*	winterberry	Present in Park	Abundant	Native	NA
Araceae	*Arisaema triphyllum*	jack-in-the-pulpit	Present in Park	Uncommon	Native	NA
Araceae	*Orontium aquaticum*	golden club	Present in Park	Rare	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Araceae	*Peltandra virginica*	arrow-arum	Present in Park	Occasional	Native	NA
Araliaceae	*Aralia hispida*	bristly sarsaparilla	Present in Park	Common	Native	NA
Araliaceae	*Aralia nudicaulis*	wild sarsaparilla	Present in Park	Abundant	Native	NA
Araliaceae	*Hedera helix*	English Ivy	Present in Park	Occasional	Non-Native	Not cultivated
Asclepiadaceae	*Asclepias amplexicaulis*	blunt-leaved milkweed	Present in Park	Uncommon	Native	NA
Asclepiadaceae	*Asclepias incarnata ssp. pulchra*	downy swamp milkweed	Present in Park	Unknown	Native	NA
Asclepiadaceae	*Asclepias incarnata var. pulchra*	downy swamp milkweed	Present in Park	Unknown	Native	NA
Asclepiadaceae	*Asclepias syriaca*	common milkweed	Present in Park	Common	Native	NA
Asclepiadaceae	*Asclepias tuberosa*	butterfly weed	Present in Park	Rare	Native	NA
Aspleniaceae	*Asplenium platyneuron*	ebony spleenwort	Present in Park	Unknown	Native	NA
Asteraceae	*Achillea millefolium*	common yarrow	Present in Park	Common	Non-Native	Not cultivated
Asteraceae	*Achillea millefolium var. millefolium*	yarrow	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Ambrosia artemisiifolia*	common ragweed	Present in Park	Common	Native	NA
Asteraceae	*Ambrosia artemisiifolia var. elatior*	ragweed	Present in Park	Occasional	Native	NA
Asteraceae	*Ambrosia psilostachya*	western ragweed	Present in Park	Unknown	Native	NA
Asteraceae	*Ambrosia psilostachya*	western ragweed	NA	NA	NA	NA
Asteraceae	*Anaphalis margaritacea*	pearly everlasting	Present in Park	Common	Native	NA
Asteraceae	*Anaphalis margaritacea var. angustior*	pearly everlasting	Present in Park	Unknown	Native	NA
Asteraceae	*Antennaria howellii ssp. neodioica*	Howell's pussytoes	Present in Park	Unknown	Native	NA
Asteraceae	*Antennaria plantaginifolia*	plantain-leaved pussytoes	Present in Park	Common	Native	NA
Asteraceae	*Antennaria X oblancifolia*	pussytoes	Present in Park	Unknown	Native	NA
Asteraceae	*Anthemis arvensis*	dog chamomile	NA	NA	NA	NA
Asteraceae	*Anthemis arvensis*	dog chamomile	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Anthemis cotula*	mayweed	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Artemisia campestris ssp. caudata*	seaside wormwood	NA	NA	NA	NA
Asteraceae	*Artemisia campestris ssp. caudata*	seaside wormwood	Present in Park	Common	Native	NA
Asteraceae	*Artemisia campestris ssp. caudata*	seaside wormwood	NA	NA	NA	NA
Asteraceae	*Artemisia stelleriana*	dusty miller	Present in Park	Common	Non-Native	Not cultivated
Asteraceae	*Aster dumosus*	rice button aster	Present in Park	Unknown	Native	NA
Asteraceae	*Aster linariifolius*	stiff aster	Present in Park	Occasional	Native	NA
Asteraceae	*Baccharis halimifolia*	groundsel-tree	Present in Park	Common	Native	NA
Asteraceae	*Bidens connata*	swamp beggar-ticks	Present in Park	Common	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Asteraceae	*Bidens connata*	swamp beggartick	NA	NA	NA	NA
Asteraceae	*Centaurea bieber-steinii*	spotted knapweed	NA	NA	NA	NA
Asteraceae	*Centaurea bieber-steinii*	spotted knapweed	Present in Park	Common	Non-Native	Not cultivated
Asteraceae	*Centaurea jacea*	brown knapweed	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Centaurea nigra*	black knapweed	Present in Park	Common	Non-Native	Not cultivated
Asteraceae	*Cichorium intybus*	chicory	Present in Park	Common	Non-Native	Not cultivated
Asteraceae	*Cirsium arvense*	Canada thistle	Present in Park	Occasional	Non-Native	Not cultivated
Asteraceae	*Cirsium arvense*	Canada thistle	NA	NA	NA	NA
Asteraceae	*Cirsium discolor*	field thistle	Present in Park	Common	Native	NA
Asteraceae	*Cirsium horridulum*	yellow thistle	Present in Park	Occasional	Native	NA
Asteraceae	*Cirsium pumilum*	pasture thistle	Present in Park	Unknown	Native	NA
Asteraceae	*Cirsium vulgare*	bull-thistle	Present in Park	Occasional	Non-Native	Not cultivated
Asteraceae	*Coreopsis lanceolata*	lanceleaf-tickseed	Present in Park	Occasional	Native	NA
Asteraceae	*Coreopsis rosea*	pink tickseed	Present in Park	Occasional	Native	NA
Asteraceae	*Doellingeria umbellata var. umbellata*	parasol whitetop	Present in Park	Unknown	Native	NA
Asteraceae	*Erechtites hieracifolia*	fireweed	Present in Park	Common	Native	NA
Asteraceae	*Erechtites hieraciifolia*	fireweed	Present in Park	Abundant	Native	NA
Asteraceae	*Erigeron annuus*	daisy fleabane	Present in Park	Occasional	Native	NA
Asteraceae	*Erigeron canadensis*	Canadian horse-weed	Present in Park	Unknown	Native	NA
Asteraceae	*Erigeron canadensis var. pusillus*	Canadian horse-weed	Present in Park	Occasional	Native	NA
Asteraceae	*Erigeron philadelphi-cus*	pink fleabane	Present in Park	Occasional	Native	NA
Asteraceae	*Erigeron strigosus var. beyrichii*	rough fleabane	Present in Park	Occasional	Native	NA
Asteraceae	*Eupatorium dubium*	Atlantic joe-pye-weed	Present in Park	Common	Native	NA
Asteraceae	*Eupatorium hyssopi-folium*	hyssop-leaved boneset	Present in Park	Common	Native	NA
Asteraceae	*Eupatorium hyssopifo-lium var. calcaratum*	hyssopleaf thor-oughwort	Present in Park	Unknown	Native	NA
Asteraceae	*Eupatorium perfolia-tum*	boneset	Present in Park	Common	Native	NA
Asteraceae	*Eupatorium pilosum*	rough boneset	Present in Park	Common	Native	NA
Asteraceae	*Eupatorium rotundifo-lium var. ovatum*	hairy boneset	NA	NA	NA	NA
Asteraceae	*Eupatorium rotundifo-lium var. ovatum*	hairy boneset	Present in Park	Unknown	Native	NA
Asteraceae	*Eurybia divaricata*	white wood aster	NA	NA	NA	NA
Asteraceae	*Eurybia divaricata*	white wood aster	Present in Park	Occasional	Native	NA
Asteraceae	*Eurybia spectabilis*	western showy aste	Present in Park	Unknown	Native	NA
Asteraceae	*Eurybia spectabilis*	showy aster	NA	NA	NA	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Asteraceae	*Euthamia graminifolia var. graminifolia*		NA	NA	NA	NA
Asteraceae	*Euthamia graminifolia var. graminifolia*	flat-top goldentop	Present in Park	Common	Native	NA
Asteraceae	*Euthamia tenuifolia*	slender goldentop	NA	NA	NA	NA
Asteraceae	*Euthamia tenuifolia*	slender goldentop	Present in Park	Common	Native	NA
Asteraceae	*Gaillardia pulchella*	firewheel	Present in Park	Uncommon	Native	NA
Asteraceae	*Gnaphalium obtusi-folium*	fragrant cudweed	Present in Park	Unknown	Native	NA
Asteraceae	*Helenium flexuosum*	purple-headed sneezeweed	Present in Park	Unknown	Native	NA
Asteraceae	*Helenium flexuosum*	purplehead sneeze-weed	NA	NA	NA	NA
Asteraceae	*Helianthus divaricatus*	woodland sunflower	Present in Park	Unknown	Native	NA
Asteraceae	*Hieracium canadense*	Canadian hawk-weed	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Hieracium canadense var. fasciculatum*	Canada hawkweed	Present in Park	Unknown	Native	NA
Asteraceae	*Hieracium gronovii*	hairy hawkweed	Present in Park	Unknown	Native	NA
Asteraceae	*Hieracium pilosella*	mouse-ear hawk-weed	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Hieracium pilosel-loides*	tall hawkweed	NA	NA	NA	NA
Asteraceae	*Hieracium pilosel-loides*	smooth hawkweed	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Hieracium sabaudum*	New England hawk-weed	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Hieracium scabrum*	rough hawkweed	Present in Park	Unknown	Native	NA
Asteraceae	*Hieracium venosum*	rattlesnakeweed	Present in Park	Unknown	Native	NA
Asteraceae	*Hieracium venosum*	rattlesnake weed	NA	NA	NA	NA
Asteraceae	*Hieracium X mari-anum*	Maryland hawkweed	Present in Park	Unknown	Native	NA
Asteraceae	*Hypochaeris radicata*	spotted catsear	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Ionactis linariifolius*	stiff aster	Present in Park	Common	Native	NA
Asteraceae	*Iva frutescens*	Jesuit's bark	Present in Park	Unknown	Native	NA
Asteraceae	*Iva frutescens ssp. oraria*	saltmarsh-elder	Present in Park	Common	Native	NA
Asteraceae	*Krigia virginica*	dwarf dandelion	Present in Park	Unknown	Native	NA
Asteraceae	*Lactuca biennis*	tall blue lettuce	Present in Park	Unknown	Native	NA
Asteraceae	*Lactuca canadensis*	Canada lettuce	NA	NA	NA	NA
Asteraceae	*Lactuca canadensis*	Canada lettuce	Present in Park	Unknown	Native	NA
Asteraceae	*Lactuca canadensis*	Canada lettuce	NA	NA	NA	NA
Asteraceae	*Lactuca hirsuta var. sanguinea*	hairy wild lettuce	Present in Park	Unknown	Native	NA
Asteraceae	*Lactuca scariola*	Morss' wild lettuce	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Lactuca serriola*	prickly lettuce	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Lactuca X morssii*	Morss' wild lettuce	Present in Park	Unknown	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Asteraceae	*Leontodon autumnalis*	fall dandelion	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Leontodon hastilis var. vulgaris*	bristly hawkbit	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Leontodon hispidus*	big hawkbit	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Leucanthemum vulgare*	oxeye daisy	NA	NA	NA	NA
Asteraceae	*Leucanthemum vulgare*	oxeye daisy	Present in Park	Occasional	Non-Native	Not cultivated
Asteraceae	*Matricaria discoidea*	pineapple-weed	Present in Park	Occasional	Non-Native	Not cultivated
Asteraceae	*Matricaria matricari-oides*	pineappleweed	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Mikania scandens*	climbing hempweed, climbing hempvine	Present in Park	Uncommon	Native	NA
Asteraceae	*Packera aurea*	golden ragwort	Present in Park	Uncommon	Native	NA
Asteraceae	*Packera aurea*	golden ragwort	NA	NA	NA	NA
Asteraceae	*Pityopsis falcata*	Sickle-leaved golden aster	NA	NA	NA	NA
Asteraceae	*Pityopsis falcata*	sickle-leaf golden aster	Present in Park	Common	Native	NA
Asteraceae	*Pluchea odorata var. succulenta*	saltmarsh-fleabane	Present in Park	Common	Native	NA
Asteraceae	*Pluchea purpurascens var. succulenta*		Present in Park	Unknown	Native	NA
Asteraceae	*Prenanthes trifoliata*	gall of the earth	False Report	NA	Unknown	NA
Asteraceae	*Prenanthes trifoliolata*	gall of the earth	Present in Park	Unknown	Native	NA
Asteraceae	*Pseudognaphalium obtusifolium*	rabbit tobacco	Present in Park	Common	Native	NA
Asteraceae	*Sericocarpus aster-oides*	toothed whitetop aster	Present in Park	Occasional	Native	NA
Asteraceae	*Sericocarpus aster-oides*	white-topped aster	NA	NA	NA	NA
Asteraceae	*Sericocarpus linifolius*	narrowleaf whitetop aster	Present in Park	Unknown	Native	NA
Asteraceae	*Sericocarpus linifolius*	narrow-leaved white-topped aster	NA	NA	NA	NA
Asteraceae	*Solidago asperula*		Present in Park	Unknown	Unknown	NA
Asteraceae	*Solidago bicolor*	white goldenrod	Present in Park	Occasional	Native	NA
Asteraceae	*Solidago canadensis*	Canada goldenrod	Present in Park	Occasional	Native	NA
Asteraceae	*Solidago juncea*	early goldenrod	Present in Park	Unknown	Native	NA
Asteraceae	*Solidago latissimifolia*	coastal goldenrod	Present in Park	Common	Native	NA
Asteraceae	*Solidago latissimifolia*	coastal goldenrod	NA	NA	NA	NA
Asteraceae	*Solidago latissimifolia*	coastal goldenrod	NA	NA	NA	NA
Asteraceae	*Solidago macrophylla*	big-leaved golden-rod	Present in Park	Unknown	Native	NA
Asteraceae	*Solidago nemoralis*	gray goldenrod	Present in Park	Unknown	Native	NA
Asteraceae	*Solidago odora*	sweet goldenrod	Present in Park	Common	Native	NA
Asteraceae	*Solidago puberula*	downy goldenrod	Present in Park	Unknown	Native	NA
Asteraceae	*Solidago rigida*	stiff goldenrod	Present in Park	Unknown	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Asteraceae	*Solidago rugosa*	wrinkleleaf golden-rod	Present in Park	Common	Native	NA
Asteraceae	*Solidago rugosa ssp. rugosa var. rugosa*	wrinkle-leaved gold-enrod	Present in Park	Unknown	Native	NA
Asteraceae	*Solidago sempervirens*	seaside goldenrod	Present in Park	Abundant	Native	NA
Asteraceae	*Solidago uliginosa var. linoides*	slender swamp goldenrod	Present in Park	Unknown	Native	NA
Asteraceae	*Sonchus arvensis ssp. uliginosus*	swamp sowthistle	NA	NA	NA	NA
Asteraceae	*Sonchus arvensis ssp. uliginosus*	swamp sow-thistle	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Sonchus asper*	spiny sow-thistle	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Symphyotrichum dumosum var. subuli-folium*	long-stalked aster	Present in Park	Unknown	Native	NA
Asteraceae	*Symphyotrichum ericoides*	white heath aster	Present in Park	Occasional	Native	NA
Asteraceae	*Symphyotrichum ericoides*	heath aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum laeve var. laeve*	smooth blue aster	Present in Park	Unknown	Native	NA
Asteraceae	*Symphyotrichum laeve var. laeve*	smooth aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum novae-angliae*	New England aster	Present in Park	Occasional	Native	NA
Asteraceae	*Symphyotrichum novi-belgii*	New York aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum novi-belgii*	New York aster	Present in Park	Common	Native	NA
Asteraceae	*Symphyotrichum patens var. patens*	late purple aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum patens var. patens*	late purple aster	Present in Park	Occasional	Native	NA
Asteraceae	*Symphyotrichum phlogifolium*	thinleaf late purple aster	Present in Park	Unknown	Native	NA
Asteraceae	*Symphyotrichum phlogifolium*	phlox-leaf aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum pilo-sum var. pilosum*	hairy white oldfield aster	Present in Park	Occasional	Native	NA
Asteraceae	*Symphyotrichum pilo-sum var. pilosum*	heath aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum pilo-sum var. pringlei*	Pringle's aster	Present in Park	Unknown	Native	NA
Asteraceae	*Symphyotrichum subulatum*	eastern annual salt-marsh aster	Present in Park	Occasional	Native	NA
Asteraceae	*Symphyotrichum subulatum*	small-flowered aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum undulatum*	waxyleaf aster	Present in Park	Unknown	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Asteraceae	*Symphyotrichum undulatum*	wavy-leaved aster	NA	NA	NA	NA
Asteraceae	*Symphyotrichum undulatum*	waxy-leaved aster	NA	NA	NA	NA
Asteraceae	*Tanacetum parthe-nium*	feverfew	Present in Park	Uncommon	Non-Native	Not cultivated
Asteraceae	*Tanacetum parthe-nium*	feverfew	NA	NA	NA	NA
Asteraceae	*Tanacetum vulgare*		NA	NA	NA	NA
Asteraceae	*Tanacetum vulgare*	tansy	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Taraxacum laevigatum*	red-seeded dande-lion	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Taraxacum officinale*	dandelion	Present in Park	Common	Native	NA
Asteraceae	*Tragopogon porrifo-lius*	oysterplant	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Tragopogon pratensis*	showy goat's beard	Present in Park	Unknown	Non-Native	Not cultivated
Asteraceae	*Xanthium strumarium var. canadense*	Canada cockleburr	NA	NA	NA	NA
Asteraceae	*Xanthium strumarium var. canadense*	Canada cocklebur	Present in Park	Occasional	Native	NA
Balsaminaceae	*Impatiens capensis*	orange jewel weed	Present in Park	Common	Native	NA
Balsaminaceae	*Impatiens glandulifera*	ornamental jewel-weed	Present in Park	Unknown	Non-Native	Not cultivated
Berberidaceae	*Berberis thunbergii*	Japanese barberry	Present in Park	Occasional	Non-Native	Not cultivated
Berberidaceae	*Berberis vulgaris*	European barberry	Present in Park	Unknown	Non-Native	Not cultivated
Betulaceae	*Alnus incana ssp. rugosa*	speckled alder	Present in Park	Common	Native	NA
Betulaceae	*Alnus incana ssp. rugosa*	speckled alder	NA	NA	NA	NA
Betulaceae	*Alnus serrulata*	smooth alder	Present in Park	Occasional	Native	NA
Betulaceae	*Betula lenta*	silver birch	Present in Park	Occasional	Native	NA
Betulaceae	*Betula papyrifera*	paper birch	Present in Park	Occasional	Native	NA
Betulaceae	*Betula pendula*	European white birch	Present in Park	Occasional	Non-Native	Cultivated
Betulaceae	*Betula populifolia*	gray birch	Present in Park	Common	Native	NA
Betulaceae	*Betula pubescens*	white birch	Present in Park	Unknown	Non-Native	Not cultivated
Betulaceae	*Betula pubescens*	downy birch	NA	NA	NA	NA
Betulaceae	*Corylus americana*	hazelnut	Present in Park	Rare	Native	NA
Betulaceae	*Corylus cornuta*	beaked hazelnut	Present in Park	Rare	Native	NA
Betulaceae	*Ostrya virginiana*	hop-hornbeam	Present in Park	Occasional	Native	NA
Bignoniaceae	*Campsis radicans*	trumpet-creeper	Present in Park	Rare	Native	NA
Blechnaceae	*Woodwardia areolata*	netted chain-fern	Present in Park	Unknown	Native	NA
Blechnaceae	*Woodwardia virginica*	Virginia chain-fern	Present in Park	Common	Native	NA
Boraginaceae	*Echium vulgare*	blue devil	Present in Park	Common	Non-Native	Not cultivated
Boraginaceae	*Mertensia maritima*	oysterleaf	Present in Park	Rare	Native	NA
Brassicaceae	*Alliaria petiolata*	garlic mustard	Present in Park	Common	Non-Native	Not cultivated
Brassicaceae	*Arabidopsis thaliana*	mouse-ear cress	Present in Park	Unknown	Non-Native	Not cultivated

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Brassicaceae	*Armoracia rusticana*	horse-radish	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Armoracia rusticana*	horse-radish	NA	NA	NA	NA
Brassicaceae	*Barbarea verna*	early winter-cress	Present in Park	Common	Non-Native	Not cultivated
Brassicaceae	*Barbarea vulgaris*	winter-cress	Present in Park	Common	Non-Native	Cultivated
Brassicaceae	*Berteroa incana*	hoary alyssum	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Brassica campestris*	field mustard	Present in Park	Common	Non-Native	Not cultivated
Brassicaceae	*Brassica juncea*	brown mustard	Present in Park	Common	Non-Native	Cultivated
Brassicaceae	*Brassica nigra*	black mustard	Present in Park	Common	Non-Native	Not cultivated
Brassicaceae	*Brassica rapa*	field mustard	Present in Park	Common	Non-Native	Not cultivated
Brassicaceae	*Cakile edentula*	sea rocket	Present in Park	Common	Native	NA
Brassicaceae	*Capsella bursa-pastoris*	shepherd's purse	Present in Park	Common	Non-Native	Not cultivated
Brassicaceae	*Cardamine parviflora var. arenicola*	narrow-leaved bittercress	Present in Park	Common	Native	NA
Brassicaceae	*Cardamine pensylvanica*	bittercress	Present in Park	Common	Native	NA
Brassicaceae	*Draba verna*	whitlow-grass	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Erysimum repandum*	treacle mustard	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Lepidium campestre*	cow-cress	Present in Park	Common	Non-Native	Not cultivated
Brassicaceae	*Lepidium densiflorum*	prairie-peppergrass	Present in Park	Unknown	Native	NA
Brassicaceae	*Lepidium virginicum*	poor-man's pepper-grass	Present in Park	Common	Native	NA
Brassicaceae	*Lunaria annua*	money-plant	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Raphanus raphanistrum*	wild radish	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Rorippa nasturtium-aquaticum*	water-cress	Present in Park	Uncommon	Non-Native	Not cultivated
Brassicaceae	*Rorippa palustris ssp. fernaldiana*	marsh yellowcress	Present in Park	Unknown	Native	NA
Brassicaceae	*Sinapis arvensis*	wild mustard	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Sisymbrium officinale*	hedge-mustard	Present in Park	Unknown	Non-Native	Not cultivated
Brassicaceae	*Teesdalia nudicaulis*	shepherd's cress	Present in Park	Common	Non-Native	Not cultivated
Cabombaceae	*Brasenia schreberi*	water-shield	Present in Park	Common	Native	NA
Cactaceae	*Opuntia humifusa*	prickley pear	Present in Park	Rare	Native	NA
Callitrichaceae	*Callitriche heterophylla*	water-starwort	Present in Park	Unknown	Native	NA
Callitrichaceae	*Callitriche stagnalis*	water-chickweed	Present in Park	Unknown	Non-Native	Not cultivated
Campanulaceae	*Jasione montana*	sheep's bit	Present in Park	Unknown	Non-Native	Not cultivated
Campanulaceae	*Lobelia cardinalis*	cardinal flower	Present in Park	Rare	Native	NA
Campanulaceae	*Lobelia dortmanna*	water lobelia	Present in Park	Common	Native	NA
Campanulaceae	*Triodanis perfoliata*	Venus' looking glass	Present in Park	Unknown	Native	NA
Cannabaceae	*Humulus lupulus*	common hop	Present in Park	Unknown	Non-Native	Not cultivated
Caprifoliaceae	*Linnaea borealis*	twinflower	Present in Park	Unknown	Native	NA
Caprifoliaceae	*Lonicera japonica*	Japanese honeysuckle	Present in Park	Occasional	Non-Native	Not cultivated
Caprifoliaceae	*Lonicera morrowii*	Morrow's honeysuckle	Present in Park	Common	Non-Native	Not cultivated

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Caprifoliaceae	*Lonicera tatarica*	Tartarian honey-suckle	Present in Park	Common	Non-Native	Not cultivated
Caprifoliaceae	*Lonicera xylosteum*	dwarf honeysuckle	Present in Park	Unknown	Non-Native	Not cultivated
Caprifoliaceae	*Sambucus canadensis*	common elderberry	Present in Park	Uncommon	Native	NA
Caprifoliaceae	*Sambucus nigra ssp. canadensis*	common elderberry	Present in Park	Uncommon	Native	NA
Caprifoliaceae	*Viburnum dentatum*	arrow-wood	Present in Park	Common	Native	NA
Caprifoliaceae	*Viburnum lentago*	nannyberry	Present in Park	Unknown	Native	NA
Caprifoliaceae	*Viburnum nudum var. cassinoides*	withe-rod	Present in Park	Common	Native	NA
Caprifoliaceae	*Viburnum nudum var. cassinoides*	withe-rod	NA	NA	NA	NA
Caprifoliaceae	*Viburnum recognitum*	northern arrow-wood	Present in Park	Unknown	Native	NA
Caprifoliaceae	*Viburnum recognitum*	southern arrow-wood	NA	NA	NA	NA
Caryophyllaceae	*Arenaria serpyllifolia*	thyme-leaf sandwort	Present in Park	Unknown	Non-Native	Not cultivated
Caryophyllaceae	*Cerastium fontanum*	common chickweed	Present in Park	Unknown	Non-Native	Cultivated
Caryophyllaceae	*Cerastium fontanum ssp. vulgare*	mouseear chickweed	NA	NA	NA	NA
Caryophyllaceae	*Cerastium fontanum ssp. vulgare*	mouse-ear chick-weed	Present in Park	Unknown	Non-Native	Not cultivated
Caryophyllaceae	*Dianthus armeria*	deptford pink	Present in Park	Occasional	Non-Native	Not cultivated
Caryophyllaceae	*Dianthus deltoides*	maiden pink	Present in Park	Occasional	Non-Native	Not cultivated
Caryophyllaceae	*Dianthus plumarius*	garden pink	Present in Park	Occasional	Non-Native	Not cultivated
Caryophyllaceae	*Honckenya peploides ssp. robusta*	sea-purslane	Present in Park	Uncommon	Native	NA
Caryophyllaceae	*Lychnis alba*	white cockle	Historic	NA	Unknown	NA
Caryophyllaceae	*Moehringia lateriflora*	grove-sandwort	NA	NA	NA	NA
Caryophyllaceae	*Moehringia lateriflora*	grove-sandwort	Present in Park	Unknown	Native	NA
Caryophyllaceae	*Sagina procumbens*	matted pearlwort	Present in Park	Unknown	Non-Native	Not cultivated
Caryophyllaceae	*Saponaria officinalis*	bouncing bet	Present in Park	Common	Non-Native	Not cultivated
Caryophyllaceae	*Scleranthus annuus*	annual knawel	Present in Park	Unknown	Non-Native	Not cultivated
Caryophyllaceae	*Silene antirrhina*	sleepy catchfly	Present in Park	Unknown	Native	NA
Caryophyllaceae	*Silene dioica*	red campion	Present in Park	Unknown	Non-Native	Not cultivated
Caryophyllaceae	*Silene latifolia*	bladder campion	Present in Park	Unknown	Non-Native	Not cultivated
Caryophyllaceae	*Silene vulgaris*	maidenstears	NA	NA	NA	NA
Caryophyllaceae	*Silene vulgaris*	bladder campion	Present in Park	Unknown	Non-Native	Not cultivated
Caryophyllaceae	*Spergula arvensis*	corn spurry	Present in Park	Unknown	Non-Native	Cultivated
Caryophyllaceae	*Spergula arvensis*		NA	NA	NA	NA
Caryophyllaceae	*Spergularia canadensis*	sand-spurrey	Present in Park	Occasional	Native	NA
Caryophyllaceae	*Spergularia marina*		Present in Park	Unknown	Unknown	NA
Caryophyllaceae	*Spergularia rubra*	red sand-spurrey	Present in Park	Occasional	Non-Native	Not cultivated
Caryophyllaceae	*Spergularia salina*		NA	NA	NA	NA
Caryophyllaceae	*Spergularia salina*	saltmarsh sand-spurrey	Present in Park	Occasional	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Caryophyllaceae	*Stellaria graminea*	common-stitchseed	Present in Park	Unknown	Non-Native	Not cultivated
Celastraceae	*Celastrus orbiculata*	Oriental bittersweet	Present in Park	Abundant	Non-Native	Not cultivated
Celastraceae	*Euonymus europaea*	European spindle-tree	NA	NA	NA	NA
Celastraceae	*Euonymus europaea*	European spindle-tree	Present in Park	Uncommon	Non-Native	Not cultivated
Ceratophyllaceae	*Ceratophyllum demersum*	Hornwort	Present in Park	Common	Native	NA
Chenopodiaceae		glasswort	NA	NA	NA	NA
Chenopodiaceae	*Atriplex cristata*	sea-beach orache	NA	NA	NA	NA
Chenopodiaceae	*Atriplex cristata*	crested saltbush	Present in Park	Occasional	Native	NA
Chenopodiaceae	*Atriplex cristata*	sea-beach orache	NA	NA	NA	NA
Chenopodiaceae	*Atriplex glabriuscula*	spearscale	Present in Park	Unknown	Native	NA
Chenopodiaceae	*Atriplex patula*	spear saltbush	Present in Park	Unknown	Native	NA
Chenopodiaceae	*Atriplex prostrata*	halberd-leaf orache	Present in Park	Common	Native	NA
Chenopodiaceae	*Atriplex prostrata*	halberd-leaf orache	NA	NA	NA	NA
Chenopodiaceae	*Bassia hirsuta*	downy seablite	Present in Park	Uncommon	Non-Native	Not cultivated
Chenopodiaceae	*Chenopodium album*	lambsquarters	Present in Park	Unknown	Non-Native	Not cultivated
Chenopodiaceae	*Chenopodium album var. album*	lamb's quarters	Present in Park	Unknown	Non-Native	Not cultivated
Chenopodiaceae	*Chenopodium glaucum*	oak-leaf goosefoot	Present in Park	Occasional	Non-Native	Not cultivated
Chenopodiaceae	*Chenopodium pumilio*	pigweed	Present in Park	Unknown	Non-Native	Not cultivated
Chenopodiaceae	*Chenopodium pumilio*	Tasmanian goosefoot	NA	NA	NA	NA
Chenopodiaceae	*Salicornia bigelovii*	dwarf glasswort	Present in Park	Occasional	Native	NA
Chenopodiaceae	*Salicornia maritima*	slender glasswort	NA	NA	NA	NA
Chenopodiaceae	*Salicornia maritima*	slender grasswort	NA	NA	NA	NA
Chenopodiaceae	*Salicornia maritima*	slender glasswort	Present in Park	Common	Native	NA
Chenopodiaceae	*Salicornia virginica*	perennial saltwort	Present in Park	Common	Native	NA
Chenopodiaceae	*Salsola kali*	seabeach saltwort	Present in Park	Uncommon	Non-Native	Not cultivated
Chenopodiaceae	*Suaeda linearis*	slender sea-blite	Present in Park	Common	Native	NA
Chenopodiaceae	*Suaeda maritima*	sea-blite	Present in Park	Common	Native	NA
Chenopodiaceae	*Suaeda maritima ssp. richii*	Rich's seepweed	Present in Park	Rare	Native	NA
Chenopodiaceae	*Suaeda richii*	Rich's sea-blite	Present in Park	Rare	Native	NA
Cistaceae	*Helianthemum canadense*	Canadian rockrose	Present in Park	Rare	Native	NA
Cistaceae	*Helianthemum dumosum*	bushy rockrose	Present in Park	Rare	Native	NA
Cistaceae	*Helianthemum propinquum*	low rockrose	Present in Park	Occasional	Native	NA
Cistaceae	*Hudsonia ericoides*	golden heather	Present in Park	Common	Native	NA
Cistaceae	*Hudsonia tomentosa*	beach heather	Present in Park	Common	Native	NA
Cistaceae	*Hudsonia tomentosa var. intermedia*	sand goldenheather	Present in Park	Unknown	Native	NA
Cistaceae	*Lechea intermedia*	pinweed	Present in Park	Occasional	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Cistaceae	*Lechea maritima*	beach pinweed	Present in Park	Common	Native	NA
Cistaceae	*Lechea maritima var. subcylindrica*	beach pinweed	False Report	NA	Unknown	NA
Cistaceae	*Lechea mucronata*	hairy pinweed	Present in Park	Unknown	Native	NA
Cistaceae	*Lechea mucronata*	hairy pinweed	NA	NA	NA	NA
Cistaceae	*Lechea pulchella var. pulchella*	Leggett's pinweed	Present in Park	Occasional	Native	NA
Clethraceae	*Clethra alnifolia*	coastal sweetpep-perbush	Present in Park	Abundant	Native	NA
Clusiaceae	*Hypericum boreale*	northern dwarf St. John's-wort	Present in Park	Occasional	Native	NA
Clusiaceae	*Hypericum canadense*	Canadian St. John's-wort	Present in Park	Common	Native	NA
Clusiaceae	*Hypericum dissimu-latum*	Bicknell's St. John's-wort	Present in Park	Unknown	Native	NA
Clusiaceae	*Hypericum gentia-noides*	orange-grass	Present in Park	Unknown	Native	NA
Clusiaceae	*Hypericum mutilum*	dwarf St. John's-wort	Present in Park	Unknown	Native	NA
Clusiaceae	*Hypericum perfora-tum*	common St. John's-wort	Present in Park	Common	Non-Native	Not cultivated
Clusiaceae	*Triadenum virginicum*	Virginia marsh St. Johnswort	NA	NA	NA	NA
Clusiaceae	*Triadenum virginicum*	marsh St. John's-wort	Present in Park	Common	Native	NA
Commelinaceae	*Commelina communis*	Asiatic dayflower	Present in Park	Occasional	Non-Native	Not cultivated
Commelinaceae	*Tradescantia virginiana*	Virginia spiderwort	Present in Park	Unknown	Native	NA
Convolvulaceae	*Calystegia sepium*	hedge bindweed	Present in Park	Common	Native	NA
Convolvulaceae	*Calystegia sepium*	hedge falsebind-weed	NA	NA	NA	NA
Convolvulaceae	*Calystegia sepium*	hedge false bind-weed	NA	NA	NA	NA
Cornaceae	*Cornus canadensis*	bunchberry	Present in Park	Uncommon	Native	NA
Cornaceae	*Cornus sericea*	red-osier dogwood	Present in Park	Rare	Native	NA
Cornaceae	*Cornus sericea*	red-osier dogwood	NA	NA	NA	NA
Crassulaceae	*Hylotelephium telephium ssp. telephium*	witch's moneybags	Present in Park	Unknown	Non-Native	Not cultivated
Crassulaceae	*Sedum acre*	mossy stonecrop	Present in Park	Unknown	Non-Native	Not cultivated
Crassulaceae	*Sedum telephium*	live-forever	Present in Park	Unknown	Non-Native	Not cultivated
Cupressaceae	*Chamaecyparis thy-oides*	Atlantic white cedar	Present in Park	Uncommon	Native	NA
Cupressaceae	*Juniperus virginiana*	eastern red cedar	Present in Park	Common	Native	NA
Cuscutaceae	*Cuscuta cephalanthi*	buttonbush dodder	Present in Park	Unknown	Native	NA
Cuscutaceae	*Cuscuta gronovii*	common dodder	Present in Park	Unknown	Native	NA
Cyperaceae		beaksedge	NA	NA	NA	NA
Cyperaceae	*Bulbostylis capillaris*	sand-sedge	Present in Park	Uncommon	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Cyperaceae	*Carex albicans var. albicans*	variable sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex albicans var. emmonsii*	Emmon's sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex annectens*	yellow fox-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex atlantica ssp. atlantica*	Atlantic prickly sedge	Present in Park	Occasional	Native	NA
Cyperaceae	*Carex atlantica ssp. capillacea*	Howe's prickly sedge	Present in Park	Occasional	Native	NA
Cyperaceae	*Carex canescens ssp. disjuncta*	silvery bog-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex comosa*	bristly sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex debilis var. rudgei*	norhtern stalked sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex echinata*	prickly sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex hormathodes*	saltmarsh straw-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex intumescens*	swamp-sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex limosa*	mud-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex longii*	Long's sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex lurida*	sallow sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex mitchelliana*	Mitchell's awned-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex muehlenbergii var. enervis*	Muhlenberg's sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex muehlenbergii var. muehlenbergii*	Muhlenberg's sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex nigra*	black sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex novae-angliae*	New England sedge	Present in Park	Uncommon	Native	NA
Cyperaceae	*Carex oligosperma*	few-fruited sedge	Present in Park	Rare	Native	NA
Cyperaceae	*Carex pensylvanica*	Pennsylvania sedge	Present in Park	Abundant	Native	NA
Cyperaceae	*Carex retrorsa*	hooked sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex scoparia*	broom-sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex silicea*	seabeach sedge	Present in Park	Common	Native	NA
Cyperaceae	*Carex stipata*	awl-fruited sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex striata var. brevis*	Walter's sedge	Present in Park	Rare	Native	NA
Cyperaceae	*Carex subnigricans*	nearlyblack sedge	Present in Park	Unknown	Non-Native	Not cultivated
Cyperaceae	*Carex swanii*	Swan's sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex tenera*	slender straw-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex trisperma var. billingsii*	three-seeded bog-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex umbellata*	parasol sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Carex utriculata*	bottle-sedge	Present in Park	Occasional	Native	NA
Cyperaceae	*Carex vulpinoidea*	fox-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Cladium mariscoides*	twig-rush	Present in Park	Occasional	Native	NA
Cyperaceae	*Cyperus dentatus*	toothed flatsedge	Present in Park	Common	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Cyperaceae	*Cyperus diandrus*	red-edged flatsedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Cyperus esculentus*	yellow flatsedge	Present in Park	Occasional	Native	NA
Cyperaceae	*Cyperus filicinus*	saltpond flatsedge	Present in Park	Rare	Native	NA
Cyperaceae	*Cyperus grayi*	Gray's flatsedge	Present in Park	Common	Native	NA
Cyperaceae	*Cyperus lupulinus ssp. lupulinus*	slender sand flat-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Cyperus lupulinus ssp. lupulinus*	slender sand flat-sedge	NA	NA	NA	NA
Cyperaceae	*Cyperus lupulinus ssp. macilentus*	sand flatsedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Cyperus odoratus*	saltmarsh flatsedge	Present in Park	Rare	Native	NA
Cyperaceae	*Cyperus polystachyos*	manyspike flatsedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Cyperus polystachyos var. texensis*	Texas flatsedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Cyperus strigosus*	straw-colored flat-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Dulichium arundina-ceum*	threeway sedge	Present in Park	Common	Native	NA
Cyperaceae	*Eleocharis acicularis*	needle spike-sedge	Present in Park	Common	Native	NA
Cyperaceae	*Eleocharis elliptica*	orange-fruited spike-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis halophila*	saline spike-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis melano-carpa*	black-fruited spike-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis obtusa*	Wright's spikerushh	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis olivacea*	olive spike-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis ovata*	ovate spikerush	Present in Park	Rare	Unknown	NA
Cyperaceae	*Eleocharis ovata*	ovate spikerush	NA	NA	NA	NA
Cyperaceae	*Eleocharis palustris*	creeping spike-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis parvula*	dwarf spike-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis robbinsii*	Robbin's spike-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis rostellata*	spike-rush	Present in Park	Unknown	Native	NA
Cyperaceae	*Eleocharis tenuis*	slender spike-rush	Present in Park	Common	Native	NA
Cyperaceae	*Eriophorum tenellum*	rough cotton-grass	Present in Park	Unknown	Native	NA
Cyperaceae	*Eriophorum virgini-cum*	Virginia cotton-grass	Present in Park	Occasional	Native	NA
Cyperaceae	*Fimbristylis autumnalis*	autumn fimbry	Present in Park	Unknown	Native	NA
Cyperaceae	*Fuirena pumila*	annual umbrella-grass	Present in Park	Unknown	Native	NA
Cyperaceae	*Rhynchospora alba*	white beak-sedge	Present in Park	Common	Native	NA
Cyperaceae	*Rhynchospora capitel-lata*	brown beak-sedge	Present in Park	Common	Native	NA
Cyperaceae	*Rhynchospora fusca*	sooty beak-sedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Rhynchospora scir-poides*	long-beaked bald-sedge	NA	NA	NA	NA
Cyperaceae	*Rhynchospora scir-poides*	long-beaked bald-sedge	Present in Park	Rare	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Cyperaceae	*Schoenoplectus americanus*	chairmaker's bulrush	NA	NA	NA	NA
Cyperaceae	*Schoenoplectus americanus*	chairmaker's bulrush	Present in Park	Occasional	Native	NA
Cyperaceae	*Schoenoplectus maritimus*	cosmopolitan bulrush	Present in Park	Unknown	Native	NA
Cyperaceae	*Schoenoplectus pungens*	common three-square	NA	NA	NA	NA
Cyperaceae	*Schoenoplectus pungens*	common three-square	Present in Park	Common	Native	NA
Cyperaceae	*Schoenoplectus robustus*	saltmarsh bullsedge	NA	NA	NA	NA
Cyperaceae	*Schoenoplectus robustus*	sturdy bulrush	Present in Park	Unknown	Native	NA
Cyperaceae	*Schoenoplectus subterminalis*		NA	NA	NA	NA
Cyperaceae	*Schoenoplectus subterminalis*	swaying bulrush	Present in Park	Occasional	Native	NA
Cyperaceae	*Schoenoplectus tabernaemontani*	softstem bulrush	Present in Park	Unknown	Native	NA
Cyperaceae	*Scirpus atrocinctus*	northern bullsedge	Present in Park	Unknown	Native	NA
Cyperaceae	*Scirpus cyperinus*	wool grass	Present in Park	Common	Native	NA
Cyperaceae	*Scirpus expansus*	spreading bullsedge	Present in Park	Unknown	Native	NA
Dennstaedtiaceae	*Dennstaedtia punctilobula*	hay-scented fern	Present in Park	Unknown	Native	NA
Dennstaedtiaceae	*Pteridium aquilinum*	western brackenfern	Present in Park	Unknown	Native	NA
Dennstaedtiaceae	*Pteridium aquilinum var. latiusculum*	bracken fern	Present in Park	Common	Native	NA
Dennstaedtiaceae	*Pteridium aquilinum var. pseudocaudatum*	Pine Barrens bracken	Present in Park	Unknown	Native	NA
Droseraceae	*Drosera filiformis*	thread-leaved sundew	Present in Park	Rare	Native	NA
Droseraceae	*Drosera intermedia*	spoonleaf sundew	Present in Park	Occasional	Native	NA
Droseraceae	*Drosera rotundifolia*	round-leaved sundew	Present in Park	Occasional	Native	NA
Dryopteridaceae		woodsia, cliff fern	NA	NA	NA	NA
Dryopteridaceae	*Athyrium filix-femina ssp. asplenioides*	asplenium ladyfern	Present in Park	Unknown	Native	NA
Dryopteridaceae	*Dryopteris carthusiana*	spinulose wood-fern	NA	NA	NA	NA
Dryopteridaceae	*Dryopteris carthusiana*	spinulose wood-fern	Present in Park	Unknown	Native	NA
Dryopteridaceae	*Dryopteris cristata*	crested wood-fern	Present in Park	Unknown	Native	NA
Dryopteridaceae	*Dryopteris intermedia*	intermediate wood-fern	Present in Park	Unknown	Native	NA
Dryopteridaceae	*Dryopteris marginalis*	marginal wood-fern	Present in Park	Unknown	Native	NA
Dryopteridaceae	*Dryopteris X boottii*	Boott's wood fern	Present in Park	Unknown	Native	NA
Dryopteridaceae	*Onoclea sensibilis*	sensitive fern	Present in Park	Common	Native	NA
Ebenaceae	*Diospyros virginiana*	persimmon	Present in Park	Rare	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Elaeagnaceae	*Elaeagnus umbellata*	autumn-olive	Present in Park	Common	Non-Native	Not cultivated
Elatinaceae	*Elatine minima*	lesser waterwort	Present in Park	Unknown	Native	NA
Empetraceae	*Corema conradii*	broom crowberry	Present in Park	Occasional	Native	NA
Empetraceae	*Empetrum eamesii ssp. atropurpureum*	purple crowberry	Present in Park	Unknown	Native	NA
Empetraceae	*Empetrum eamesii ssp. atropurpureum*	crowberry	NA	NA	NA	NA
Empetraceae	*Empetrum nigrum*	black crowberry	Present in Park	Unknown	Native	NA
Equisetaceae	*Equisetum arvense*	common horsetail	Present in Park	Rare	Native	NA
Ericaceae	*Anaphalis margarita-cea var. angustior*	bog rosemary	NA	NA	NA	NA
Ericaceae	*Andromeda polifolia var. glaucophylla*	bog-rosemary	Present in Park	Unknown	Native	NA
Ericaceae	*Arctostaphylos uva-ursi*	bearberry	NA	NA	NA	NA
Ericaceae	*Arctostaphylos uva-ursi*	bearberry	Present in Park	Abundant	Native	NA
Ericaceae	*Chamaedaphne ca-lyculata*	leatherleaf	Present in Park	Abundant	Native	NA
Ericaceae	*Chamaedaphne ca-lyculata var. angusti-folia*	leatherleaf	Present in Park	Unknown	Native	NA
Ericaceae	*Epigaea repens*	trailing arbutus	Present in Park	Common	Native	NA
Ericaceae	*Gaultheria procum-bens*	wintergreen	Present in Park	Common	Native	NA
Ericaceae	*Gaylussacia baccata*	black huckleberry	Present in Park	Abundant	Native	NA
Ericaceae	*Gaylussacia dumosa*	dwarf huckleberry	NA	NA	NA	NA
Ericaceae	*Gaylussacia dumosa*	dwarf huckleberry	Present in Park	Uncommon	Native	NA
Ericaceae	*Gaylussacia frondosa*	dangleberry	Present in Park	Uncommon	Native	NA
Ericaceae	*Kalmia angustifolia*	sheep laurel	Present in Park	Common	Native	NA
Ericaceae	*Leucothoe racemosa*	swamp fetterbush	Present in Park	Unknown	Native	NA
Ericaceae	*Lyonia ligustrina*	maleberry	Present in Park	Common	Native	NA
Ericaceae	*Rhododendron visco-sum*	swamp azalea	Present in Park	Abundant	Native	NA
Ericaceae	*Vaccinium angustifo-lium*	lowbush blueberry	Present in Park	Abundant	Native	NA
Ericaceae	*Vaccinium angustifo-lium*	lowbush blueberry	NA	NA	NA	NA
Ericaceae	*Vaccinium caesariense*	New Jersey blue-berry	Present in Park	Unknown	Native	NA
Ericaceae	*Vaccinium corymbo-sum*	highbush blueberry	Present in Park	Common	Native	NA
Ericaceae	*Vaccinium fuscatum*	black highbush blueberry	Present in Park	Uncommon	Native	NA
Ericaceae	*Vaccinium fuscatum*	black highbush blueberry	NA	NA	NA	NA
Ericaceae	*Vaccinium macrocar-pon*	American cranberry	Present in Park	Abundant	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Ericaceae	*Vaccinium oxycoccos*		NA	NA	NA	NA
Ericaceae	*Vaccinium oxycoccos*	small cranberry	Present in Park	Unknown	Native	NA
Ericaceae	*Vaccinium pallidum*	Blue Ridge blueberry	Present in Park	Common	Native	NA
Ericaceae	*Vaccinium pallidum*	Blue Ridge blueberry	NA	NA	NA	NA
Ericaceae	*Vaccinium stamineum*	deerberry	Present in Park	Unknown	Native	NA
Ericaceae	*Vaccinium vacillans X angustifolium*		Present in Park	Unknown	Native	NA
Ericaceae	*Vaccinium vicinum*		False Report	NA	Unknown	NA
Eriocaulaceae	*Eriocaulon aquaticum*	pipewort	Present in Park	Common	Native	NA
Eriocaulaceae	*Eriocaulon septangu-lare*	pipewort	Present in Park	Common	Native	NA
Euphorbiaceae	*Chamaesyce maculata*	spotted spurge	NA	NA	NA	NA
Euphorbiaceae	*Chamaesyce maculata*	spotted spurge	Present in Park	Unknown	Native	NA
Euphorbiaceae	*Chamaesyce polygoni-folia*	Seaside spurge	NA	NA	NA	NA
Euphorbiaceae	*Chamaesyce polygoni-folia*	seaside spurge	Present in Park	Common	Native	NA
Euphorbiaceae	*Euphorbia cyparissias*	cypress-spurge	Present in Park	Abundant	Non-Native	Not cultivated
Fabaceae	*Apios americana*	groundnut	Present in Park	Uncommon	Native	NA
Fabaceae	*Baptisia tinctoria*	yellow wild indigo	Present in Park	Common	Native	NA
Fabaceae	*Cytisus scoparius*	Scotch broom	Present in Park	Occasional	Non-Native	Not cultivated
Fabaceae	*Desmodium obtusum*	stiff tick-trfoil	Present in Park	Unknown	Native	NA
Fabaceae	*Lathyrus japonicus*	Beach Pea	Present in Park	Abundant	Native	NA
Fabaceae	*Lathyrus japonicus var. maritimus*	beach pea	Present in Park	Unknown	Native	NA
Fabaceae	*Lathyrus japonicus var. maritimus*	beach pea	NA	NA	NA	NA
Fabaceae	*Lathyrus japonicus var. pellitus*	beach pea	Present in Park	Unknown	Native	NA
Fabaceae	*Lathyrus latifolius*	everlasting pea	Present in Park	Occasional	Non-Native	Not cultivated
Fabaceae	*Lathyrus palustris*	marsh vetchling	Present in Park	Unknown	Native	NA
Fabaceae	*Lespedeza capitata*	round-headed bush-clover	Present in Park	Common	Native	NA
Fabaceae	*Lespedeza cuneata*	Chinese bush-clover	Present in Park	Common	Non-Native	Not cultivated
Fabaceae	*Lespedeza hirta*	hairy bush-clover	Present in Park	Common	Native	NA
Fabaceae	*Lespedeza procum-bens*	trailing bush-clover	Present in Park	Unknown	Native	NA
Fabaceae	*Lespedeza stuevei*	velvety bush-clover	Present in Park	Unknown	Native	NA
Fabaceae	*Lespedeza virginica*	slender lespedeza	Present in Park	Unknown	Native	NA
Fabaceae	*Lupinus perennis*	wild lupine	Present in Park	Rare	Native	NA
Fabaceae	*Medicago lupulina*	black medick	Present in Park	Unknown	Non-Native	Not cultivated
Fabaceae	*Medicago sativa*	blue alfalfa	Present in Park	Unknown	Non-Native	Not cultivated
Fabaceae	*Medicago sativa ssp. sativa*	blue alfalfa	Present in Park	Unknown	Non-Native	Not cultivated
Fabaceae	*Melilotus officinalis*	yellow sweet-clover	Present in Park	Common	Non-Native	Not cultivated
Fabaceae	*Melilotus officinalis*	yellow sweet clover	NA	NA	NA	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Fabaceae	*Melilotus officinalis*	yellow sweet-clover	NA	NA	NA	NA
Fabaceae	*Robinia hispida*	bristly locust	Present in Park	Common	Native	NA
Fabaceae	*Robinia pseudoacacia*	black locust	Present in Park	Common	Non-Native	Not cultivated
Fabaceae	*Robinia pseudoacacia*	black locust	NA	NA	NA	NA
Fabaceae	*Strophostyles helvola*	amberique-bean	Present in Park	Occasional	Native	NA
Fabaceae	*Strophostyles helvula*	amberique-bean	Present in Park	Unknown	Native	NA
Fabaceae	*Tephrosia virginiana*	goat's rue	Present in Park	Unknown	Native	NA
Fabaceae	*Trifolium arvense*	rabbit-foot clover	Present in Park	Common	Non-Native	Not cultivated
Fabaceae	*Trifolium aureum*	yellow hop-clover	NA	NA	NA	NA
Fabaceae	*Trifolium aureum*	yellow hop-clover	Present in Park	Common	Non-Native	Not cultivated
Fabaceae	*Trifolium pratense*	red clover	Present in Park	Common	Non-Native	Not cultivated
Fabaceae	*Trifolium pratense*		NA	NA	NA	NA
Fabaceae	*Trifolium repens*	white clover	Present in Park	Common	Non-Native	Not cultivated
Fabaceae	*Trifolium striatum*	knotted clover	Present in Park	Unknown	Non-Native	Not cultivated
Fabaceae	*Vicia cracca*	cow-vetch	Present in Park	Occasional	Non-Native	Not cultivated
Fabaceae	*Vicia cracca ssp. tenuifolia*	cow vetch	Present in Park	Unknown	Non-Native	Not cultivated
Fagaceae	*Fagus grandifolia*	American beech	Present in Park	Occasional	Native	NA
Fagaceae	*Quercus alba*	white oak	Present in Park	Abundant	Native	NA
Fagaceae	*Quercus alba X pri-noides*		Present in Park	Unknown	Native	NA
Fagaceae	*Quercus bicolor*	swamp white oak	Unconfirmed	NA	Unknown	NA
Fagaceae	*Quercus borealis*	northern red oak	Present in Park	Rare	Native	NA
Fagaceae	*Quercus ilicifolia*	scrub oak	Present in Park	Common	Native	NA
Fagaceae	*Quercus ilicifolia X velutina*		Present in Park	Unknown	Native	NA
Fagaceae	*Quercus palustris*	pin oak	Present in Park	Uncommon	Native	NA
Fagaceae	*Quercus prinoides*	dwarf chinquapin oak	Present in Park	Common	Native	NA
Fagaceae	*Quercus prinoides*	chinkapin oak	Present in Park	Uncommon	Native	NA
Fagaceae	*Quercus prinoides*		NA	NA	NA	NA
Fagaceae	*Quercus robur*	English oak	Present in Park	Uncommon	Non-Native	Cultivated
Fagaceae	*Quercus rubra*	northern red oak	Present in Park	Uncommon	Native	NA
Fagaceae	*Quercus velutina*	black oak	Present in Park	Abundant	Native	NA
Gentianaceae	*Bartonia paniculata*	screw-stem	Present in Park	Unknown	Native	NA
Gentianaceae	*Bartonia virginica*	yellow screw-stem	Present in Park	Unknown	Native	NA
Gentianaceae	*Sabatia kennedyana*	Plymouth gentian	Present in Park	Rare	Native	NA
Geraniaceae	*Erodium cicutarium*	redstem-filaree	Present in Park	Unknown	Non-Native	Not cultivated
Geraniaceae	*Geranium carolinia-num var. carolinianum*	Carolina geranium	Present in Park	Unknown	Native	NA
Geraniaceae	*Geranium maculatum*	spotted crane's bill	Present in Park	Unknown	Native	NA
Grossulariaceae	*Ribes hirtellum*	swamp gooseberry	NA	NA	NA	NA
Grossulariaceae	*Ribes hirtellum*	swamp gooseberry	Present in Park	Occasional	Native	NA
Grossulariaceae	*Ribes rubrum*	cultivated currant	NA	NA	NA	NA
Grossulariaceae	*Ribes rubrum*	garden red current	Present in Park	Unknown	Non-Native	Not cultivated

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Haloragaceae	*Myriophyllum humile*	lowly water-milfoil	Present in Park	Occasional	Native	NA
Haloragaceae	*Myriophyllum tenellum*	leafless water-milfoil	Present in Park	Uncommon	Native	NA
Haloragaceae	*Myriophyllum verticillatum*	whorl-leaf water-milfoil	Present in Park	Unknown	Native	NA
Haloragaceae	*Proserpinaca palustris*	mermaid weed	Present in Park	Occasional	Native	NA
Hamamelidaceae	*Hamamelis virginiana*	witch-hazel	Present in Park	Common	Native	NA
Hippocastanaceae	*Aesculus hippocastanum*	horse-chestnut	Present in Park	Occasional	Non-Native	Cultivated
Hydrangeaceae	*Hydrangea paniculata*	hydrangea	Present in Park	Uncommon	Non-Native	Not cultivated
Hydrocharitaceae	*Elodea nuttallii*	Nuttall's water-weed	Present in Park	Occasional	Native	NA
Hydrocharitaceae	*Vallisneria americana*	tape grass	Present in Park	Common	Native	NA
Hydrophyllaceae	*Hydrophyllum virginianum*	Eastern waterleaf	Present in Park	Unknown	Native	NA
Iridaceae	*Iris pseudacorus*	yellow iris	Present in Park	Uncommon	Non-Native	Not cultivated
Iridaceae	*Iris versicolor*	wild iris	Present in Park	Occasional	Native	NA
Iridaceae	*Sisyrinchium angustifolium*	stout blue-eyed grass	Present in Park	Occasional	Native	NA
Iridaceae	*Sisyrinchium atlanticum*	eastern blue-eyed grass	Present in Park	Unknown	Native	NA
Iridaceae	*Sisyrinchium fuscatum*	coastal plain blue-eyed grass	NA	NA	NA	NA
Iridaceae	*Sisyrinchium fuscatum*	sandplain blue-eyed grass	Present in Park	Unknown	Native	NA
Isoetaceae	*Isoetes lacustris*	lake quillwort	Present in Park	Occasional	Native	NA
Isoetaceae	*Isoetes tuckermanii*	Tuckerman's quillwort	Present in Park	Common	Native	NA
Juglandaceae	*Carya alba*	mockernut	Present in Park	Uncommon	Native	NA
Juglandaceae	*Carya alba*	mockernut hickory	NA	NA	NA	NA
Juglandaceae	*Carya glabra*	pignut hickory	Present in Park	Uncommon	Native	NA
Juncaceae	*Juncus acuminatus*	sharp-fruited rush	Present in Park	Common	Native	NA
Juncaceae	*Juncus articulatus*	jointed rush	Present in Park	Unknown	Native	NA
Juncaceae	*Juncus balticus*	brackish rush	Present in Park	Unknown	Native	NA
Juncaceae	*Juncus bufonius*	toad-rush	Present in Park	Occasional	Native	NA
Juncaceae	*Juncus canadensis*	Canadian rush	Present in Park	Common	Native	NA
Juncaceae	*Juncus debilis*	weak rush	Historic	NA	Native	NA
Juncaceae	*Juncus dichotomus*	forked rush	Present in Park	Unknown	Native	NA
Juncaceae	*Juncus effusus*	lamp rush, common rush	Present in Park	Common	Native	NA
Juncaceae	*Juncus effusus var. conglomeratus*	common rush	Present in Park	Unknown	Native	NA
Juncaceae	*Juncus effusus var. pylaei*	common rush	NA	NA	NA	NA
Juncaceae	*Juncus effusus var. pylaei*	common rush	Present in Park	Unknown	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Juncaceae	*Juncus effusus var. solutus*	common rush	Present in Park	Unknown	Native	NA
Juncaceae	*Juncus gerardii*	black rush	NA	NA	NA	NA
Juncaceae	*Juncus gerardii*	black rush	Present in Park	Occasional	Native	NA
Juncaceae	*Juncus greenei*	Greene's rush	Present in Park	Common	Native	NA
Juncaceae	*Juncus marginatus*	grass-leaf rush	Present in Park	Unknown	Native	NA
Juncaceae	*Juncus militaris*	bayonet rush	Present in Park	Abundant	Native	NA
Juncaceae	*Juncus pelocarpus*	pondshore rush	Present in Park	Common	Native	NA
Juncaceae	*Juncus tenuis*	path rush	Present in Park	Common	Native	NA
Juncaceae	*Luzula echinata*	hedgehog wood-rush	Present in Park	Unknown	Native	NA
Juncaceae	*Luzula multiflora ssp. frigida*	boreal wood-rush	Present in Park	Unknown	Native	NA
Juncaceae	*Luzula multiflora ssp. multiflora*	common wood-rush	Present in Park	Unknown	Native	NA
Juncaginaceae	*Triglochin maritimum*	saltmarsh arrow-grass	Present in Park	Uncommon	Native	NA
Lamiaceae	*Glechoma hederacea*	gill-over-the-ground	Present in Park	Unknown	Non-Native	Not cultivated
Lamiaceae	*Lamium amplexicaule*	henbit	Present in Park	Unknown	Non-Native	Not cultivated
Lamiaceae	*Leonurus cardiaca*	motherwort	Present in Park	Unknown	Non-Native	Not cultivated
Lamiaceae	*Lycopus americanus*	American water-horehound	Present in Park	Common	Native	NA
Lamiaceae	*Lycopus amplectens*	sessile water-hore-hound	Present in Park	Unknown	Native	NA
Lamiaceae	*Lycopus europaeus*	European water-horehound	Present in Park	Unknown	Non-Native	Not cultivated
Lamiaceae	*Lycopus rubellus*	swamp water-hore-hound	Present in Park	Occasional	Native	NA
Lamiaceae	*Lycopus uniflorus*	northern water-horehound	Present in Park	Unknown	Native	NA
Lamiaceae	*Lycopus virginicus*	Virginia water-hore-hound	Present in Park	Common	Native	NA
Lamiaceae	*Melissa officinalis*	balm	Present in Park	Occasional	Non-Native	Not cultivated
Lamiaceae	*Mentha arvensis*	field mint	Present in Park	Common	Native	NA
Lamiaceae	*Mentha arvensis*	field mint	Present in Park	Unknown	Native	NA
Lamiaceae	*Mentha piperita*	water mint	Present in Park	Unknown	Non-Native	Not cultivated
Lamiaceae	*Mentha X piperita*	field mint	Present in Park	Unknown	Non-Native	Not cultivated
Lamiaceae	*Nepeta cataria*	catnip	Present in Park	Unknown	Non-Native	Not cultivated
Lamiaceae	*Prunella vulgaris*	common selfheal	Present in Park	Unknown	Native	NA
Lamiaceae	*Prunella vulgaris ssp. lanceolata*	lance selfheal	Present in Park	Occasional	Native	NA
Lamiaceae	*Scutellaria galericulata*	common skullcap	NA	NA	NA	NA
Lamiaceae	*Scutellaria galericulata*	common skullcap	Present in Park	Occasional	Native	NA
Lamiaceae	*Scutellaria lateriflora*	mad-dog skullcap	Present in Park	Occasional	Native	NA
Lamiaceae	*Stachys hyssopifolia*	hyssop hedge-nettle	Present in Park	Occasional	Native	NA
Lamiaceae	*Teucrium canadense*	American german-der	Present in Park	Common	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Lamiaceae	*Trichostema dichotomum*	blue curls	Present in Park	Unknown	Native	NA
Lauraceae	*Sassafras albidum*	sassafras	Present in Park	Common	Native	NA
Lemnaceae	*Lemna minor*	duckweed	Present in Park	Occasional	Native	NA
Lentibulariaceae		bladderwort	NA	NA	NA	NA
Lentibulariaceae	*Utricularia cornuta*	horned bladderwort	Present in Park	Occasional	Native	NA
Lentibulariaceae	*Utricularia geminiscapa*	hidden-fruited bladderwort	Present in Park	Uncommon	Native	NA
Lentibulariaceae	*Utricularia gibba*	humped bladderwort	NA	NA	NA	NA
Lentibulariaceae	*Utricularia gibba*	chumped bladderwort	Present in Park	Uncommon	Native	NA
Lentibulariaceae	*Utricularia gibba*	humped bladderwort	NA	NA	NA	NA
Lentibulariaceae	*Utricularia gibba*	humped bladderwort	NA	NA	NA	NA
Lentibulariaceae	*Utricularia purpurea*	purple bladderwort	Present in Park	Occasional	Native	NA
Lentibulariaceae	*Utricularia radiata*	little floating bladderwort	Present in Park	Common	Native	NA
Lentibulariaceae	*Utricularia resupinata*	resupinate bladderwort	Present in Park	Rare	Native	NA
Lentibulariaceae	*Utricularia subulata*	subulate bladderwort	Present in Park	Rare	Native	NA
Liliaceae	*Allium canadense*	wild onion	Present in Park	Unknown	Native	NA
Liliaceae	*Allium vineale*	field garlic	Present in Park	Unknown	Non-Native	Not cultivated
Liliaceae	*Asparagus officinalis*	wild asparagus	Present in Park	Uncommon	Non-Native	Not cultivated
Liliaceae	*Convallaria majalis*	lily-of-the-valley	Present in Park	Unknown	Non-Native	Not cultivated
Liliaceae	*Hemerocallis fulva*	orange day lily	Present in Park	Occasional	Non-Native	Not cultivated
Liliaceae	*Lilium lancifolium*	tiger-lily	Present in Park	Occasional	Non-Native	Cultivated
Liliaceae	*Lilium philadelphicum*	wood-lily	Present in Park	Occasional	Native	NA
Liliaceae	*Maianthemum canadense*	Canada mayflower	Present in Park	Common	Native	NA
Liliaceae	*Maianthemum racemosum*	false Solomon's seal	Present in Park	Common	Native	NA
Liliaceae	*Maianthemum stellatum*	starry Solomon's seal	Present in Park	Occasional	Native	NA
Liliaceae	*Medeola virginiana*	Indian cucumber	Present in Park	Unknown	Native	NA
Liliaceae	*Polygonatum pubescens*	Solomon's seal	Present in Park	Uncommon	Native	NA
Liliaceae	*Smilacina stellata*		Present in Park	Common	Native	NA
Lycopodiaceae	*Lycopodiella inundata*	bog clubmoss	Present in Park	Occasional	Native	NA
Lycopodiaceae	*Lycopodium complanatum*	Northern ground-cedar	Present in Park	Occasional	Native	NA
Lycopodiaceae	*Lycopodium obscurum*	princess-pine	Present in Park	Occasional	Native	NA
Lythraceae	*Decodon verticillatus*	water-willow	Present in Park	Abundant	Native	NA
Lythraceae	*Lythrum salicaria*	purple loosestrife	Present in Park	Occasional	Non-Native	Not cultivated
Malvaceae	*Hibiscus moscheutos*	swamp rosemallow	NA	NA	NA	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Malvaceae	*Hibiscus moscheutos*	rose mallow	Present in Park	Occasional	Native	NA
Malvaceae	*Malva moschata*	musk-mallow	Present in Park	Unknown	Non-Native	Not cultivated
Malvaceae	*Malva neglecta*	common mallow	Present in Park	Unknown	Non-Native	Not cultivated
Melastomata-ceae	*Rhexia mariana*	Maryland meadow-beauty	Present in Park	Uncommon	Native	NA
Melastomata-ceae	*Rhexia virginica*	northern meadow beauty	Present in Park	Uncommon	Native	NA
Menyanthaceae	*Menyanthes trifoliata*	buckbean	Present in Park	Uncommon	Native	NA
Menyanthaceae	*Menyanthes trifoliata*	buckbean	NA	NA	NA	NA
Menyanthaceae	*Nymphoides cordata*	little floating heart	Present in Park	Common	Native	NA
Molluginaceae	*Mollugo verticillata*	carpetweed	Present in Park	Uncommon	Native	NA
Monotropaceae	*Monotropa hy-popithys*	pinesap	Present in Park	Occasional	Native	NA
Monotropaceae	*Monotropa uniflora*	Indian pipe	Present in Park	Unknown	Native	NA
Moraceae	*Morus alba*	white mullberry	Present in Park	Uncommon	Non-Native	Not cultivated
Myricaceae	*Comptonia peregrina*	sweet fern	Present in Park	Common	Native	NA
Myricaceae	*Morella pensylvanica*	northern bayberry	Present in Park	Common	Native	NA
Myricaceae	*Morella pensylvanica*	northern bayberry	NA	NA	NA	NA
Myricaceae	*Myrica gale*	sweet gale	Present in Park	Uncommon	Native	NA
Nyctaginaceae	*Mirabilis nyctaginea*	four-o'clock	Present in Park	Unknown	Native	NA
Nymphaeaceae	*Nuphar lutea ssp. variegata*	varigated yellow water-lily	NA	NA	NA	NA
Nymphaeaceae	*Nuphar lutea ssp. variegata*	varigated yellow pond-lily	Present in Park	Common	Native	NA
Nymphaeaceae	*Nymphaea odorata*	American white waterlily	Present in Park	Abundant	Native	NA
Nymphaeaceae	*Nymphaea odorata ssp. odorata*	white water lily	Present in Park	Unknown	Native	NA
Nyssaceae	*Nyssa sylvatica*	black gum	Present in Park	Common	Native	NA
Oleaceae	*Ligustrum vulgare*	common privet	Present in Park	Occasional	Non-Native	Not cultivated
Oleaceae	*Syringa vulgaris*	common lilac	Present in Park	Unknown	Non-Native	Not cultivated
Onagraceae	*Chamerion angusti-folium*	fireweed	Present in Park	Occasional	Native	NA
Onagraceae	*Chamerion angusti-folium*	fireweed	NA	NA	NA	NA
Onagraceae	*Circaea lutetiana ssp. canadensis*	enchanter's night-shade	Present in Park	Uncommon	Native	NA
Onagraceae	*Epilobium ciliatum*	fringed willowherb	NA	NA	NA	NA
Onagraceae	*Epilobium ciliatum*	American willow-herb	Present in Park	Unknown	Native	NA
Onagraceae	*Epilobium coloratum*	purple-leaved willow-herb	Present in Park	Occasional	Native	NA
Onagraceae	*Epilobium leptophyl-lum*	narrow-leaved willow-herb	Present in Park	Occasional	Native	NA
Onagraceae	*Ludwigia palustris*	water purslane	Present in Park	Occasional	Native	NA
Onagraceae	*Ludwigia palustris*	water purslane	NA	NA	NA	NA
Onagraceae	*Oenothera biennis*	common evening primrose	Present in Park	Common	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Onagraceae	*Oenothera fruticosa*	southern sundrops, sundrop	Present in Park	Unknown	Native	NA
Onagraceae	*Oenothera parviflora*	northern evening-primrose	Present in Park	Unknown	Native	NA
Onagraceae	*Oenothera perennis*	small sundrops	Present in Park	Unknown	Native	NA
Ophioglossaceae	*Botrychium dissectum*	cut-leaved grape fern	Present in Park	Uncommon	Native	NA
Ophioglossaceae	*Botrychium lanceolatum*	lance-leaved grape fern	Present in Park	Uncommon	Native	NA
Ophioglossaceae	*Botrychium matricariifolium*	daisy-leaf grape fern	Present in Park	Uncommon	Native	NA
Ophioglossaceae	*Botrychium multifidum*	leathery grape-fern	Present in Park	Uncommon	Native	NA
Ophioglossaceae	*Ophioglossum pusillum*	northern adder's-tongue fern	Historic	NA	Native	NA
Ophioglossaceae	*Ophioglossum pusillum*	northern adder's-tongue fern	NA	NA	NA	NA
Orchidaceae	*Arethusa bulbosa*	arethusa	Present in Park	Rare	Native	NA
Orchidaceae	*Calopogon tuberosus*	grass pink	Present in Park	Occasional	Native	NA
Orchidaceae	*Cypripedium acaule*	pink lady-slipper	Present in Park	Occasional	Native	NA
Orchidaceae	*Liparis loeselii*	green twayblade	Present in Park	Unknown	Native	NA
Orchidaceae	*Platanthera blephariglottis*	white-fringed orchid	Present in Park	Uncommon	Native	NA
Orchidaceae	*Platanthera lacera*	ragged-fringed orchid	Present in Park	Uncommon	Native	NA
Orchidaceae	*Pogonia ophioglossoides*	rose pogonia	Present in Park	Uncommon	Native	NA
Orchidaceae	*Spiranthes cernua*	nodding ladies-tresses	Present in Park	Occasional	Native	NA
Orchidaceae	*Spiranthes lacera*	northern slender lady's tresses	NA	NA	NA	NA
Orchidaceae	*Spiranthes lacera*	slender ladies-tresses	Present in Park	Unknown	Native	NA
Orchidaceae	*Spiranthes tuberosa*	little ladies-tresses	Present in Park	Rare	Native	NA
Orchidaceae	*Spiranthes tuberosa*	little ladies-tresses	NA	NA	NA	NA
Orobanchaceae	*Epifagus virginiana*	beech-drops	Present in Park	Occasional	Native	NA
Orobanchaceae	*Orobanche uniflora*	one-flowered cancer-root	Present in Park	Occasional	Native	NA
Osmundaceae	*Osmunda cinnamomea*	cinnamon fern	Present in Park	Common	Native	NA
Osmundaceae	*Osmunda regalis*	royal fern	Present in Park	Occasional	Native	NA
Oxalidaceae	*Oxalis stricta*	yellow wood sorrel	Present in Park	Common	Native	NA
Oxalidaceae	*Oxalis stricta*	yellow wood sorrel	NA	NA	NA	NA
Papaveraceae	*Chelidonium majus*	celandine	Present in Park	Unknown	Non-Native	Not cultivated
Phytolaccaceae	*Phytolacca americana*	American pokeweed	Present in Park	Common	Native	NA
Pinaceae	*Abies balsamea*	balsam fir	Present in Park	Rare	Native	NA
Pinaceae	*Picea abies*	Norway spruce	Present in Park	Occasional	Non-Native	Not cultivated
Pinaceae	*Picea glauca*	white spruce	Present in Park	Uncommon	Native	NA
Pinaceae	*Picea rubens*	ed spruce	Present in Park	Rare	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Pinaceae	*Pinus banksiana*	jack pine	Present in Park	Occasional	Native	NA
Pinaceae	*Pinus mugo*	mugo pine	Present in Park	Uncommon	Non-Native	Not cultivated
Pinaceae	*Pinus nigra*	Austrian pine	Present in Park	Occasional	Non-Native	Not cultivated
Pinaceae	*Pinus rigida*	pitch pine	Present in Park	Abundant	Native	NA
Pinaceae	*Pinus strobus*	eastern white pine	Present in Park	Uncommon	Native	NA
Pinaceae	*Pinus sylvestris*	Scotch pine	Present in Park	Occasional	Non-Native	Not cultivated
Pinaceae	*Pinus thunbergiana*	japanese black pine	Present in Park	Occasional	Non-Native	Not cultivated
Plantaginaceae	*Plantago aristata*	largebracted plantain	Present in Park	Unknown	Native	NA
Plantaginaceae	*Plantago lanceolata*	narrowleaf plantain	Present in Park	Common	Non-Native	Not cultivated
Plantaginaceae	*Plantago major*	common plantain	Present in Park	Common	Native	NA
Plantaginaceae	*Plantago maritima var. juncoides*	goose tongue	NA	NA	NA	NA
Plantaginaceae	*Plantago maritima var. juncoides*	seaside plantain	Present in Park	Common	Native	NA
Plumbaginaceae	*Limonium carolinianum*	sea lavander	NA	NA	NA	NA
Plumbaginaceae	*Limonium carolinianum*	sea lavander	Present in Park	Common	Native	NA
Poaceae		grasses	NA	NA	NA	NA
Poaceae		hairgrass	NA	NA	NA	NA
Poaceae	*Agrostis capillaris*	Rhode Island bentgrass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Agrostis gigantea*	redtop	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Agrostis gigantea*	redtop	NA	NA	NA	NA
Poaceae	*Agrostis hyemalis*	southern ticklegrass	Present in Park	Common	Native	NA
Poaceae	*Agrostis perennans*	upland bentgrass	Present in Park	Common	Native	NA
Poaceae	*Agrostis scabra*	northern ticklegrass	Present in Park	Unknown	Native	NA
Poaceae	*Agrostis stolonifera*	creeping bentgrass	Present in Park	Unknown	Native	NA
Poaceae	*Agrostis stolonifera*	creeping bentgrass	NA	NA	NA	NA
Poaceae	*Aira caryophyllea*	silvery hairgrass	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Ammophila arenaria*	European beachgrass	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Ammophila breviligulata*	American beachgrass	Present in Park	Abundant	Native	NA
Poaceae	*Andropogon glomeratus var. glomeratus*	bunched broomsedge	Present in Park	Unknown	Native	NA
Poaceae	*Anthoxanthum odoratum*	sweet vernal grass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Aristida dichotoma*	poverty-grass	Present in Park	Unknown	Native	NA
Poaceae	*Aristida purpurascens*	purple needlegrass	Present in Park	Rare	Native	NA
Poaceae	*Bromus hordeaceus*	soft chess	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Bromus inermis*	smooth brome	Present in Park	Unknown	Native	NA
Poaceae	*Bromus tectorum*	cheatgrass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Calamagrostis canadensis*	bluejoint reedgrass	Present in Park	Common	Native	NA
Poaceae	*Cenchrus longispinus*	mat sandbur	Present in Park	Common	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Poaceae	*Cinna arundinacea*	wood reedgrass	Present in Park	Unknown	Native	NA
Poaceae	*Dactylis glomerata*	orchard grass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Danthonia spicata*	poverty oatgrass	Present in Park	Common	Native	NA
Poaceae	*Deschampsia flexuosa*	common hairgrass	Present in Park	Common	Native	NA
Poaceae	*Dichanthelium acuminatum*	western panicgrass	NA	NA	NA	NA
Poaceae	*Dichanthelium acuminatum*	tapered rosette grass	Present in Park	Common	Native	NA
Poaceae	*Dichanthelium acuminatum*	western panicgrass	NA	NA	NA	NA
Poaceae	*Dichanthelium acuminatum var. lindheimeri*	panic grass	NA	NA	NA	NA
Poaceae	*Dichanthelium acuminatum var. lindheimeri*	Lindheimer panic-grass	Present in Park	Unknown	Native	NA
Poaceae	*Dichanthelium clandestinum*	riverside panic-grass	Present in Park	Unknown	Native	NA
Poaceae	*Dichanthelium commonsianum*	common's panic-grass	Present in Park	Rare	Native	NA
Poaceae	*Dichanthelium commutatum*	changeable panic-grass	Present in Park	Unknown	Native	NA
Poaceae	*Dichanthelium depauperatum*	depauperate panic-grass	Present in Park	Common	Native	NA
Poaceae	*Dichanthelium dichotomum*	forked panic-grass	Present in Park	Unknown	Native	NA
Poaceae	*Dichanthelium meridionale*	pondshore panic-grass	Present in Park	Unknown	Native	NA
Poaceae	*Dichanthelium oligosanthes*	Scribner's panic-grass	Present in Park	Occasional	Native	NA
Poaceae	*Dichanthelium ovale var. addisonii*	common's panic-grass	Present in Park	Rare	Native	NA
Poaceae	*Dichanthelium sabulorum*	hemlock rosette grass	Present in Park	Unknown	Native	NA
Poaceae	*Dichanthelium sphaerocarpon*	roundseed panic-grass	Present in Park	Unknown	Native	NA
Poaceae	*Digitaria sanguinalis*	northern crab-grass	Present in Park	Common	Native	NA
Poaceae	*Distichlis spicata*	marsh spikegrass	Present in Park	Common	Native	NA
Poaceae	*Echinochloa walteri*	water-millet	Present in Park	Occasional	Native	NA
Poaceae	*Elymus repens*	quack grass	NA	NA	NA	NA
Poaceae	*Elymus repens*	quackgrass	NA	NA	NA	NA
Poaceae	*Elymus repens*	quackgrass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Elymus virginicus*	wild rye	Present in Park	Common	Native	NA
Poaceae	*Eragrostis cilianensis*	stink-grass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Eragrostis curvula*	weeping lovegrass	Present in Park	Occasional	Non-Native	Not cultivated
Poaceae	*Eragrostis pectinacea*	Carolina lovegrass	Present in Park	Unknown	Native	NA
Poaceae	*Eragrostis pilosa*	India lovegrass	Present in Park	Unknown	Native	NA
Poaceae	*Eragrostis spectabilis*	purple lovegrass	Present in Park	Abundant	Native	NA
Poaceae	*Festuca filiformis*	hair fescue	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Festuca filiformis*	fineleaf sheep fescue	Present in Park	Unknown	Non-Native	Not cultivated

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Poaceae	*Festuca filiformis*	hair fescue	NA	NA	NA	NA
Poaceae	*Festuca heteromalla*	Chewing's fescue	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Festuca heteromalla*	Chewing's fescue	NA	NA	NA	NA
Poaceae	*Festuca ovina*	sheep-fescue	Present in Park	Abundant	Non-Native	Not cultivated
Poaceae	*Festuca rubra*	red fescue	Present in Park	Common	Native	NA
Poaceae	*Festuca rubra ssp. rubra*	red fescue	Present in Park	Common	Native	NA
Poaceae	*Glyceria canadensis*	rattlesnake grass	Present in Park	Common	Native	NA
Poaceae	*Glyceria obtusa*	coastal mannagrass	Present in Park	Occasional	Native	NA
Poaceae	*Hierochloe odorata*		Present in Park	Unknown	Native	NA
Poaceae	*Holcus lanatus*	velvet grass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Leersia oryzoides*	rice cut-grass	Present in Park	Occasional	Native	NA
Poaceae	*Leymus mollis*	sea lyme-grass	NA	NA	NA	NA
Poaceae	*Leymus mollis*	sea lyme-grass	Historic	NA	Unknown	NA
Poaceae	*Lolium perenne*	English rye grass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Lolium pratense*	meadow fescue	NA	NA	NA	NA
Poaceae	*Lolium pratense*	meadow fescue	Present in Park	Occasional	Non-Native	Not cultivated
Poaceae	*Lolium pratense*	meadow fescue	NA	NA	NA	NA
Poaceae	*Muhlenbergia mexicana*	satin muhly	Present in Park	Unknown	Native	NA
Poaceae	*Muhlenbergia uniflora*	pondshore muhly	Present in Park	Rare	Native	NA
Poaceae	*Panicum capillare*	witchgrass	Present in Park	Occasional	Native	NA
Poaceae	*Panicum dichotomiflorum var. puritanorum*	Svenson's panic-grass	Present in Park	Unknown	Native	NA
Poaceae	*Panicum lanuginosum*	western panicgrass	Present in Park	Common	Native	NA
Poaceae	*Panicum rigidulum var. rigidulum*	flat-stemmed panic grass	Present in Park	Unknown	Native	NA
Poaceae	*Panicum virgatum*	switchgrass	Present in Park	Occasional	Native	NA
Poaceae	*Panicum virgatum var. spissum*	saltmarsh switch-grass	Present in Park	Common	Native	NA
Poaceae	*Paspalum setaceum*	bead-grass	Present in Park	Unknown	Native	NA
Poaceae	*Paspalum setaceum*	bead-grass	NA	NA	NA	NA
Poaceae	*Pennisetum glaucum*	pearl millet	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Pennisetum glaucum*	pearl millet	NA	NA	NA	NA
Poaceae	*Phalaris arundinacea*	reed canarygrass	Present in Park	Occasional	Native	NA
Poaceae	*Phleum pratense*	timothy	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Phragmites australis*	common reed	Present in Park	Abundant	Native	NA
Poaceae	*Phragmites communis*	common reed	Present in Park	Abundant	Non-Native	Not cultivated
Poaceae	*Piptochaetium avenaceum*	blackseed speargrass	NA	NA	NA	NA
Poaceae	*Piptochaetium avenaceum*	blackseed speargrass	Present in Park	Unknown	Native	NA
Poaceae	*Poa annua*	annual bluegrass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Poa compressa*	Canada bluegrass	Present in Park	Common	Non-Native	Not cultivated
Poaceae	*Poa pratensis*	Kentucky bluegrass	Present in Park	Common	Unknown	NA
Poaceae	*Puccinellia distans*	weeping alkaligrass	Present in Park	Common	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Poaceae	*Puccinellia fasciculata*	saltmarsh alkaligrass	Present in Park	Occasional	Native	NA
Poaceae	*Puccinellia langeana*	Northern alkali-grass	Historic	NA	Native	NA
Poaceae	*Puccinellia langeana alaskana*	tundra alkaligrass	Historic	NA	Native	NA
Poaceae	*Puccinellia tenella ssp. langeana*	tundra alkaligrass	Present in Park	Occasional	Native	NA
Poaceae	*Schizachyrium sco-parium*	little bluestem	Present in Park	Common	Native	NA
Poaceae	*Schizachyrium sco-parium*	little bluestem	NA	NA	NA	NA
Poaceae	*Setaria viridis*	green foxtail	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Spartina alterniflora*	smooth cordgrass	Present in Park	Abundant	Native	NA
Poaceae	*Spartina cynosuroides*	big cordgrass	NA	NA	NA	NA
Poaceae	*Spartina cynosuroides*	salt reedgrass	Historic	NA	Native	NA
Poaceae	*Spartina patens*	salt meadow cord-grass	Present in Park	Abundant	Native	NA
Poaceae	*Spartina pectinata*	prairie cordgrass	Present in Park	Uncommon	Native	NA
Poaceae	*Sphenopholis pensyl-vanica*	swamp oats	Present in Park	Rare	Native	NA
Poaceae	*Stipa avenacea*		Present in Park	Unknown	Native	NA
Poaceae	*Thinopyrum pycnan-thum*	tick quackgrass	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Thinopyrum pycnan-thum*	coastal quackgrass	NA	NA	NA	NA
Poaceae	*Torreyochloa pallida var. pallida*	pale mannagrass	Present in Park	Unknown	Native	NA
Poaceae	*Triplasis purpurea*	purple sand-grass	Present in Park	Unknown	Native	NA
Poaceae	*Vulpia myuros*	rat-tail fescue	Present in Park	Unknown	Non-Native	Not cultivated
Poaceae	*Vulpia octoflora*	six-weeks fescue	Present in Park	Unknown	Native	NA
Poaceae	*Zizania aquatica*	wild rice	Present in Park	Occasional	Native	NA
Polygalaceae	*Polygala cruciata*	cross-leaved milk-wort	Present in Park	Unknown	Native	NA
Polygalaceae	*Polygala paucifolia*	flowering winter-green	Present in Park	Unknown	Native	NA
Polygalaceae	*Polygala polygama*	bitter milkwort	Present in Park	Occasional	Native	NA
Polygalaceae	*Polygala sanguinea*	purple milkwort	Present in Park	Unknown	Native	NA
Polygonaceae	*Fagopyrum esculen-tum*	buckwheat	Present in Park	Occasional	Non-Native	Not cultivated
Polygonaceae	*Polygonella articulata*	jointweed	Present in Park	Common	Native	NA
Polygonaceae	*Polygonum amphibi-um var. emersum*	erect water smart-weed	Present in Park	Unknown	Native	NA
Polygonaceae	*Polygonum arifolium*	halberd-leaf tear-thumb	Present in Park	Common	Native	NA
Polygonaceae	*Polygonum aubertii*	silver lace-vine	Present in Park	Unknown	Non-Native	Not cultivated
Polygonaceae	*Polygonum aviculare*	prostrate knotweed	Present in Park	Unknown	Non-Native	Not cultivated
Polygonaceae	*Polygonum buxiforme*	box-leaf knotweed	Present in Park	Unknown	Native	NA
Polygonaceae	*Polygonum cuspida-tum*	Japanese knotweed	Present in Park	Occasional	Non-Native	Not cultivated

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Polygonaceae	*Polygonum glaucum*	seabeach knotweed	Present in Park	Rare	Native	NA
Polygonaceae	*Polygonum hydropiper*	water-pepper	Present in Park	Common	Non-Native	Not cultivated
Polygonaceae	*Polygonum hydropiperoides*	false water-pepper	Present in Park	Common	Native	NA
Polygonaceae	*Polygonum lapathifolium*	curlytop knotweed	Present in Park	Occasional	Native	NA
Polygonaceae	*Polygonum pensylvanicum*	Pennsylvania smartweed	Present in Park	Common	Native	NA
Polygonaceae	*Polygonum persicaria*	lady's thumb	Present in Park	Common	Non-Native	Not cultivated
Polygonaceae	*Polygonum punctatum var. confertiflorum*	annual water-smartweed	Present in Park	Occasional	Native	NA
Polygonaceae	*Polygonum punctatum var. punctatum*	perennial water-smartweed	Present in Park	Unknown	Native	NA
Polygonaceae	*Polygonum ramosissimum var. prolificum*	bushy knotweed	Present in Park	Unknown	Native	NA
Polygonaceae	*Polygonum sagittatum*	arrow-leaf tear-thumb	Present in Park	Occasional	Native	NA
Polygonaceae	*Polygonum scandens*	climbing false buckwheat	Present in Park	Unknown	Native	NA
Polygonaceae	*Polygonum scandens var. cristatum*	winged bindweed	Present in Park	Unknown	Native	NA
Polygonaceae	*Polygonum scandens var. scandens*	climbing false buckwheat	Present in Park	Unknown	Native	NA
Polygonaceae	*Rumex acetosella*	sheep sorrel	Present in Park	Abundant	Non-Native	Not cultivated
Polygonaceae	*Rumex crispus*	curly dock	Present in Park	Occasional	Non-Native	Not cultivated
Polygonaceae	*Rumex maritimus*	bristle dock, golden dock	Present in Park	Occasional	Native	NA
Polygonaceae	*Rumex maritimus var. maritimus*	golden dock	Present in Park	Unknown	Native	NA
Polygonaceae	*Rumex obtusifolius*	bitter dock	Present in Park	Unknown	Non-Native	Not cultivated
Polygonaceae	*Rumex orbiculatus*	great water dock	Present in Park	Common	Native	NA
Polypodiaceae	*Polypodium virginianum*	common polypody	Present in Park	Unknown	Native	NA
Pontederiaceae	*Eichhornia crassipes*	common water-hyacinth	Present in Park	Unknown	Non-Native	Not cultivated
Pontederiaceae	*Pontederia cordata*	pickerel weed	Present in Park	Common	Native	NA
Portulacaceae	*Portulaca oleracea*	common purslane	Present in Park	Uncommon	Native	NA
Potamogetonaceae	*Potamogeton amplifolius*	big-leaved pondweed	Present in Park	Occasional	Native	NA
Potamogetonaceae	*Potamogeton bicupulatus*	hairlike pondweed	Present in Park	Uncommon	Native	NA
Potamogetonaceae	*Potamogeton epihydrus*	surface pondweed	Present in Park	Common	Native	NA
Potamogetonaceae	*Potamogeton perfoliatus*	clasping pondwed	Present in Park	Unknown	Native	NA
Potamogetonaceae	*Potamogeton pusillus ssp. tenuissimus*	small pondweed	Present in Park	Unknown	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Potamogetonaceae	*Potamogeton spirillus*	spiral pondweed	Present in Park	Unknown	Native	NA
Primulaceae	*Anagallis arvensis*	scarlet pimpernel	Present in Park	Unknown	Non-Native	Not cultivated
Primulaceae	*Glaux maritima*	sea-milkwort	Present in Park	Uncommon	Native	NA
Primulaceae	*Lysimachia ciliata*	fringed loosestrife	Present in Park	Unknown	Native	NA
Primulaceae	*Lysimachia quadrifolia*	whorled loosestrife	Present in Park	Occasional	Native	NA
Primulaceae	*Lysimachia terrestris*	yellow loosestrife	Present in Park	Unknown	Native	NA
Primulaceae	*Samolus valerandi ssp. parviflorus*	seaside brookweed	Present in Park	Unknown	Native	NA
Primulaceae	*Samolus valerandi ssp. parviflorus*	water-pimpernel	NA	NA	NA	NA
Primulaceae	*Trientalis borealis*	starflower	Present in Park	Common	Native	NA
Pyrolaceae	*Chimaphila maculata*	spotted wintergreen	Present in Park	Common	Native	NA
Pyrolaceae	*Chimaphila umbellata*	pipsissewa	Present in Park	Unknown	Native	NA
Pyrolaceae	*Chimaphila umbellata ssp. cisatlantica*	pipsissewa	Present in Park	Unknown	Native	NA
Pyrolaceae	*Pyrola americana*	glossy pyrola	Present in Park	Occasional	Native	NA
Pyrolaceae	*Pyrola chlorantha*	greenflowered wintergreen	NA	NA	NA	NA
Pyrolaceae	*Pyrola chlorantha*	green pyrola	Present in Park	Unknown	Native	NA
Pyrolaceae	*Pyrola elliptica*	elliptic pyrola	Present in Park	Unknown	Native	NA
Ranunculaceae	*Anemone quinquefolia*	wood-anemone	Present in Park	Unknown	Native	NA
Ranunculaceae	*Clematis terniflora*	yam-leaf clematis	Present in Park	Unknown	Non-Native	Not cultivated
Ranunculaceae	*Clematis terniflora*	yam-leaf clematis	NA	NA	NA	NA
Ranunculaceae	*Ranunculus abortivus*	kidney-leaf buttercup	Present in Park	Unknown	Native	NA
Ranunculaceae	*Ranunculus acris*	meadow buttercup	Present in Park	Unknown	Native	NA
Ranunculaceae	*Ranunculus cymbalaria*	seaside crowfoot	Present in Park	Unknown	Native	NA
Ranunculaceae	*Ranunculus repens*	creeping buttercup	Present in Park	Unknown	Non-Native	Not cultivated
Ranunculaceae	*Ranunculus sceleratus*	celery-leaf crowfoot	Present in Park	Unknown	Native	NA
Ranunculaceae	*Thalictrum pubescens*	tall meadow-rue	NA	NA	NA	NA
Ranunculaceae	*Thalictrum pubescens*	tall meadow-rue	Present in Park	Unknown	Native	NA
Rhamnaceae	*Rhamnus cathartica*	common buckthorn	Present in Park	Occasional	Non-Native	Not cultivated
Rosaceae	*Amelanchier arborea var. laevis*	serviceberry	Present in Park	Common	Native	NA
Rosaceae	*Amelanchier canadensis*	juneberry	Present in Park	Common	Native	NA
Rosaceae	*Amelanchier laevis*	Allegheny serviceberry	Present in Park	Unknown	Native	NA
Rosaceae	*Amelanchier laevis X canadensis*		False Report	NA	Unknown	NA
Rosaceae	*Amelanchier stolonifera*	running shadbush	Present in Park	Unknown	Native	NA
Rosaceae	*Amelanchier stolonifera*	running serviceberry	Present in Park	Unknown	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Rosaceae	*Aronia virginiana*	chokecherry	False Report	NA	Unknown	NA
Rosaceae	*Crataegus chrysocarpa*	Hawthorn	Present in Park	Unknown	Native	NA
Rosaceae	*Fragaria vesca*	woodland straw-berry	Present in Park	Unknown	Native	NA
Rosaceae	*Fragaria virginiana*	wild strawberry	Present in Park	Common	Native	NA
Rosaceae	*Geum canadense*	white avens	Present in Park	Unknown	Native	NA
Rosaceae	*Malus floribunda*	Japanese flowering crabapple	Present in Park	Uncommon	Non-Native	Not cultivated
Rosaceae	*Malus pumila*	domestic apple	Present in Park	Occasional	Non-Native	Not cultivated
Rosaceae	*Malus pumila*	paradise apple	NA	NA	NA	NA
Rosaceae	*Photinia floribunda*	black chokeberry	NA	NA	NA	NA
Rosaceae	*Photinia floribunda*		NA	NA	NA	NA
Rosaceae	*Photinia floribunda*	purple chokeberry	Present in Park	Common	Native	NA
Rosaceae	*Photinia melanocarpa*	purple chokeberry	NA	NA	NA	NA
Rosaceae	*Photinia melanocarpa*	black chokeberry	NA	NA	NA	NA
Rosaceae	*Photinia melanocarpa*	black chokeberry	Present in Park	Common	Native	NA
Rosaceae	*Photinia pyrifolia*	red chokeberry	Present in Park	Occasional	Native	NA
Rosaceae	*Photinia pyrifolia*	red chokeberry	NA	NA	NA	NA
Rosaceae	*Potentilla argentea*	silvery cinquefoil	Present in Park	Occasional	Non-Native	Not cultivated
Rosaceae	*Potentilla canadensis*	common cinquefoil	Present in Park	Occasional	Native	NA
Rosaceae	*Potentilla inclinata*	cinquefoil	Present in Park	Occasional	Non-Native	Not cultivated
Rosaceae	*Potentilla inclinata*	ashy cinquefoil	NA	NA	NA	NA
Rosaceae	*Potentilla norvegica*	rough cinquefoil	Present in Park	Occasional	Native	NA
Rosaceae	*Potentilla recta*	rough-fruited cinquefoil	Present in Park	Unknown	Non-Native	Not cultivated
Rosaceae	*Potentilla simplex*	old field cinquefoil	Present in Park	Unknown	Native	NA
Rosaceae	*Potentilla tridentata*	shrubby fivefingers	Present in Park	Unknown	Native	NA
Rosaceae	*Prunus maritima*	beach plum	Present in Park	Abundant	Native	NA
Rosaceae	*Prunus pensylvanica*	fire-cherry	Present in Park	Uncommon	Native	NA
Rosaceae	*Prunus serotina*	black cherry	Present in Park	Abundant	Native	NA
Rosaceae	*Prunus spinosa*	blackthorne	Present in Park	Rare	Non-Native	Not cultivated
Rosaceae	*Prunus virginiana*	choke-cherry	Present in Park	Rare	Native	NA
Rosaceae	*Rosa carolina*	pasture rose	Present in Park	Common	Native	NA
Rosaceae	*Rosa carolina*	Carolina rose	NA	NA	NA	NA
Rosaceae	*Rosa multiflora*	multiflora rose	Present in Park	Common	Non-Native	Not cultivated
Rosaceae	*Rosa palustris*	swamp rose	Present in Park	Common	Native	NA
Rosaceae	*Rosa rugosa*	wrinkled rose, salt spray rose	Present in Park	Common	Non-Native	Not cultivated
Rosaceae	*Rosa virginiana*	Virginia rose	Present in Park	Common	Native	NA
Rosaceae	*Rubus allegheniensis*	common blackberry	Present in Park	Common	Native	NA
Rosaceae	*Rubus flagellaris*	northern dewberry	Present in Park	Common	Native	NA
Rosaceae	*Rubus hispidus*	swamp dewberry	Present in Park	Common	Native	NA
Rosaceae	*Rubus idaeus*	American red rasp-berry	Present in Park	Unknown	Native	NA
Rosaceae	*Rubus idaeus ssp. strigosus*	wild red raspberry	Present in Park	Unknown	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Rosaceae	*Rubus occidentalis*	black raspberry	Present in Park	Common	Native	NA
Rosaceae	*Rubus pensilvanicus*	highbush blackberry	Present in Park	Unknown	Native	NA
Rosaceae	*Rubus recurvicaulis*	arching sand black-berry	Present in Park	Unknown	Native	NA
Rosaceae	*Sibbaldiopsis tridentata*	three-toothed cinquefoil	Present in Park	Unknown	Native	NA
Rosaceae	*Sorbaria sorbifolia*	false spirea	Present in Park	Unknown	Non-Native	Cultivated
Rosaceae	*Spiraea alba var. latifolia*		NA	NA	NA	NA
Rosaceae	*Spiraea alba var. latifolia*	meadowsweet	Present in Park	Common	Native	NA
Rosaceae	*Spiraea tomentosa*	steeplebush	Present in Park	Common	Native	NA
Rubiaceae	*Cephalanthus occidentalis*	buttonbush	Present in Park	Common	Native	NA
Rubiaceae	*Galium aparine*	cleavers	Present in Park	Unknown	Native	NA
Rubiaceae	*Galium circaezans var. hypomalacum*	wild licorice	Present in Park	Unknown	Native	NA
Rubiaceae	*Galium palustre*	marsh bedstraw	Present in Park	Common	Native	NA
Rubiaceae	*Galium pilosum*	hairy bedstraw	Present in Park	Unknown	Native	NA
Rubiaceae	*Galium tinctorium*	stiff marsh bedstraw	Present in Park	Unknown	Native	NA
Rubiaceae	*Galium trifidum*	bedstraw	Present in Park	Unknown	Native	NA
Rubiaceae	*Galium triflorum*	sweet-scented bed-straw	Present in Park	Unknown	Native	NA
Rubiaceae	*Galium verum*	yellow bedstraw	Present in Park	Unknown	Non-Native	Not cultivated
Rubiaceae	*Mitchella repens*	partridge-berry	Present in Park	Unknown	Native	NA
Ruppiaceae	*Ruppia maritima*	widgeongrass	Present in Park	Common	Native	NA
Salicaceae	*Populus alba*	white poplar	Present in Park	Occasional	Non-Native	Cultivated
Salicaceae	*Populus grandidentata*	big-toothed aspen	Present in Park	Occasional	Native	NA
Salicaceae	*Populus tremuloides*	quaking aspen	Present in Park	Common	Native	NA
Salicaceae	*Populus X jackii*	balm-of-gilead	Present in Park	Uncommon	Native	NA
Salicaceae	*Salix bebbiana*	Bebb's willow	Present in Park	Unknown	Native	NA
Salicaceae	*Salix cordata*	heartleaf willow	Present in Park	Unknown	Native	NA
Salicaceae	*Salix discolor*	pussy-willow	Present in Park	Common	Native	NA
Salicaceae	*Salix eriocephala*	heart-leaf willow	Present in Park	Unknown	Native	NA
Salicaceae	*Salix fragilis*	brittle willow	Present in Park	Unknown	Non-Native	Not cultivated
Salicaceae	*Salix humilis*	upland willow	Present in Park	Unknown	Native	NA
Salicaceae	*Salix lucida*	shining willow	Present in Park	Unknown	Native	NA
Salicaceae	*Salix nigra*	black willow	Present in Park	Occasional	Native	NA
Santalaceae	*Comandra umbellata*	bastard toad-flax	Present in Park	Unknown	Native	NA
Sarraceniaceae	*Sarracenia purpurea*	pitcher plant	Present in Park	Uncommon	Native	NA
Scrophulariaceae	*Agalinis maritima*	seaside gerardia	Present in Park	Common	Native	NA
Scrophulariaceae	*Agalinis paupercula*	small-flowered gerardia	Present in Park	Uncommon	Native	NA
Scrophulariaceae	*Agalinis paupercula*		NA	NA	NA	NA
Scrophulariaceae	*Agalinis paupercula var. borealis*	smooth agalinis	Present in Park	Unknown	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Scrophulariaceae	*Agalinis purpurea var. parviflora*	smooth agalinis	Present in Park	Uncommon	Native	NA
Scrophulariaceae	*Aureolaria flava*	smooth yellow foxglove	NA	NA	NA	NA
Scrophulariaceae	*Aureolaria flava*	smooth false fox-glove	Present in Park	Unknown	Native	NA
Scrophulariaceae	*Aureolaria pedicularia*	fernleaf yellow false foxglove	NA	NA	NA	NA
Scrophulariaceae	*Aureolaria pedicularia*	fern-leaf false fox-glove	Present in Park	Unknown	Native	NA
Scrophulariaceae	*Aureolaria virginica*	downy false fox-glove	Present in Park	Unknown	Native	NA
Scrophulariaceae	*Gerardia purpurea*	purple false foxglove	Present in Park	Occasional	Native	NA
Scrophulariaceae	*Gratiola aurea*		NA	NA	NA	NA
Scrophulariaceae	*Gratiola aurea*	yellow hedge-hyssop	Present in Park	Common	Native	NA
Scrophulariaceae	*Linaria repens*	creeping toadflax	Present in Park	Unknown	Non-Native	Not cultivated
Scrophulariaceae	*Linaria vulgaris*	butter-and-eggs	Present in Park	Common	Non-Native	Not cultivated
Scrophulariaceae	*Lindernia dubia var. anagallidea*	yellowseed false pimpernel	NA	NA	NA	NA
Scrophulariaceae	*Lindernia dubia var. anagallidea*	false pimpernel	Present in Park	Uncommon	Native	NA
Scrophulariaceae	*Melampyrum lineare*	narrowleaf cow-wheat	Present in Park	Unknown	Native	NA
Scrophulariaceae	*Melampyrum lineare var. latifolium*	broad-leaved cow-wheat	Present in Park	Occasional	Native	NA
Scrophulariaceae	*Melampyrum lineare var. lineare*	common cow-wheat	Present in Park	Occasional	Native	NA
Scrophulariaceae	*Melampyrum lineare var. lineare*	common cow-wheat	NA	NA	NA	NA
Scrophulariaceae	*Melampyrum lineare var. pectinatum*	pine barrens cow-wheat	Present in Park	Unknown	Native	NA
Scrophulariaceae	*Nuttallanthus canadensis*	blue toad-flax	Present in Park	Common	Native	NA
Scrophulariaceae	*Nuttallanthus canadensis*	Canada toadflax	NA	NA	NA	NA
Scrophulariaceae	*Scrophularia lanceolata*	American figwort	Present in Park	Unknown	Native	NA
Scrophulariaceae	*Verbascum thapsus*	common mullein	Present in Park	Occasional	Non-Native	Not cultivated
Scrophulariaceae	*Veronica arvensis*	corn-speedwell	Present in Park	Unknown	Non-Native	Not cultivated
Simaroubaceae	*Ailanthus altissima*	tree of heaven	Present in Park	Occasional	Non-Native	Cultivated
Smilacaceae	*Smilax glauca*	catbrier	Present in Park	Unknown	Native	NA
Smilacaceae	*Smilax herbacea*	carrion flower	Present in Park	Unknown	Native	NA
Smilacaceae	*Smilax rotundifolia*	common catbrier	Present in Park	Abundant	Native	NA
Smilacaceae	*Smilax tamnoides*	bristly greenbrier	Present in Park	Occasional	Native	NA
Smilacaceae	*Smilax tamnoides*	bristly greenbrier	NA	NA	NA	NA
Solanaceae	*Datura stramonium*	jimson-weed	Present in Park	Occasional	Non-Native	Not cultivated
Solanaceae	*Petunia violacea*	violetflower petunia	Present in Park	Rare	Non-Native	Not cultivated
Solanaceae	*Petunia X atkinsiana*	garden petunia	Present in Park	Unknown	Non-Native	Not cultivated

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Solanaceae	*Petunia X atkinsiana*	garden petunia	NA	NA	NA	NA
Solanaceae	*Physalis heterophylla*	clammy ground-cherry	Present in Park	Unknown	Native	NA
Solanaceae	*Physalis heterophylla var. ambigua*	clammy ground-cherry	Present in Park	Unknown	Native	NA
Solanaceae	*Physalis pubescens var. integrifolia*	downt ground-cherry	Present in Park	Unknown	Native	NA
Solanaceae	*Solanum dulcamara*	bittersweet night-shade	Present in Park	Occasional	Non-Native	Not cultivated
Solanaceae	*Solanum nigrum*	black nightshade	Present in Park	Unknown	Non-Native	Not cultivated
Solanaceae	*Solanum nigrum*	black nightshade	NA	NA	NA	NA
Solanaceae	*Solanum ptychan-thum*	West Indian night-shade	Present in Park	Unknown	Native	NA
Sparganiaceae	*Sparganium america-num*	American burreed	Present in Park	Common	Native	NA
Sparganiaceae	*Sparganium andro-cladum*	shinning bur-reed	Present in Park	Unknown	Native	NA
Thelypteridaceae	*Phegopteris connec-tilis*	northern beech-fern	Present in Park	Unknown	Native	NA
Thelypteridaceae	*Thelypteris novebora-censis*	New York fern	Present in Park	Occasional	Native	NA
Thelypteridaceae	*Thelypteris palustris*	marsh fern	Present in Park	Abundant	Native	NA
Thelypteridaceae	*Thelypteris palustris*	eastern marsh fern	NA	NA	NA	NA
Thelypteridaceae	*Thelypteris simulata*	Massachusetts fern	Present in Park	Unknown	Native	NA
Tiliaceae	*Tilia americana var. americana*	American basswood	Present in Park	Occasional	Native	NA
Typhaceae	*Typha angustifolia*	narrow-leaved cattail	Present in Park	Abundant	Non-Native	Not cultivated
Typhaceae	*Typha latifolia*	common cattail	Present in Park	Occasional	Native	NA
Ulmaceae	*Ulmus americana*	American elm	Present in Park	Uncommon	Native	NA
Urticaceae	*Boehmeria cylindrica*	false nettle	Present in Park	Common	Native	NA
Urticaceae	*Urtica dioica*	stinging nettle	Present in Park	Uncommon	Native	NA
Verbenaceae	*Verbena hastata*	blue vervain	Present in Park	Occasional	Native	NA
Violaceae	*Viola cucullata*	blue marsh-violet	Present in Park	Unknown	Native	NA
Violaceae	*Viola fimbriatula*	arrowleaf violet	Present in Park	Unknown	Native	NA
Violaceae	*Viola lanceolata*	bog white violet	Present in Park	Common	Native	NA
Violaceae	*Viola lanceolata ssp. lanceolata*	bog white violet	Present in Park	Unknown	Native	NA
Violaceae	*Viola macloskeyi ssp. pallens*	smooth white violet	NA	NA	NA	NA
Violaceae	*Viola macloskeyi ssp. pallens*	northern white violet	Present in Park	Unknown	Native	NA
Violaceae	*Viola sagittata*	arrow-leaf violet	Present in Park	Unknown	Native	NA
Vitaceae	*Parthenocissus inserta*	Virginia creeper	Present in Park	Common	Native	NA
Vitaceae	*Parthenocissus quin-quefolia*	Virginia creeper	Present in Park	Common	Native	NA
Vitaceae	*Parthenocissus vitacea*	grape-woodbine	Present in Park	Unknown	Native	NA
Vitaceae	*Vitis aestivalis*	summer grape	Present in Park	Occasional	Native	NA

Family	*Scientific Name*	Common Name	Occurrence	Abundance	Nativity	Cultivation
Vitaceae	*Vitis labrusca*	fox-grape	Present in Park	Common	Native	NA
Xyridaceae	*Xyris difformis*	yellow-eyed grass	Present in Park	Common	Native	NA
Xyridaceae	*Xyris smalliana*	quagmire yellow-eyed grass	Present in Park	Unknown	Native	NA
Zosteraceae	*Zostera marina*	eelgrass	Present in Park	Common	Native	NA

Family	Scientific Name	Common Name	Occurrence	Abundance	Nativity	Cultivation
Bryopsidaceae	*Bryopsis plumosa*		Present in Park	NA	NA	NA
Cephaloziellaceae	*Cephaloziella*	cephaloziella	Present in Park	NA	NA	NA
Ceramiaceae	*Ceramium rubrum*		Present in Park	NA	NA	NA
Chordaceae	*Chorda filum*		Present in Park	NA	NA	NA
Cladophoraceae	*Cladophora sericea*		Present in Park	NA	NA	NA
Codiaceae	*Codium fragile*		Present in Park	NA	NA	NA
Derbesiaceae	*Derbesia marina*		Present in Park	NA	NA	NA
Dicranaceae	*Dicranum drummondii*		Present in Park	NA	NA	NA
Dicranaceae	*Dicranum polysetum*	dicranum moss	Present in Park	NA	NA	NA
Dicranaceae	*Dicranum scoparium*	dicranum moss	Present in Park	NA	NA	NA
Dicranaceae	*Oncophorus virens*	oncophorus moss	Present in Park	NA	NA	NA
Ectocarpaceae	*Ectocarpus siliculosus*		Present in Park	NA	NA	NA
Ectocarpaceae	*Giffordia granulosa*		Present in Park	NA	NA	NA
Ectocarpaceae	*Pylaiella littoralis*		Present in Park	NA	NA	NA
Entodontaceae	*Entodon cladorrhizans*	entodon moss	Present in Park	NA	NA	NA
Fucaceae	*Ascophyllum nodosum*		Present in Park	NA	NA	NA
Fucaceae	*Ascophyllum nodosum scorpioides*		Present in Park	NA	NA	NA
Fucaceae	*Fucus vesiculosis var. spiralis*		Present in Park	NA	NA	NA
Fucaceae	*Fucus vesiculosus*		Present in Park	NA	NA	NA
NA	*Lecridea peliaspris*		Present in Park	NA	NA	NA
NA	*Pseudoparmelia caperata*		Present in Park	NA	NA	NA
Polytrichaceae	*Polytrichum commune*	polytrichum moss	Present in Park	NA	NA	NA
Punctariaceae	*Desmotrichum undulatum*		Present in Park	NA	NA	NA
Rhodomelaceae	*Polysiphonia fibrillosa*		Present in Park	NA	NA	NA
Rhodomelaceae	*Polysiphonia urceolata*		Present in Park	NA	NA	NA
Sphagnaceae	*Sphagnum*	sphagnum	Present in Park	NA	NA	NA
Ulvaceae	*Enteromorpha erecta*		Present in Park	NA	NA	NA
Ulvaceae	*Enteromorpha linza*		Present in Park	NA	NA	NA
Ulvaceae	*Ulva lactuca*		Present in Park	NA	NA	NA

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Family	Scientific Name	Common Name	Source
Arctiidae	*Apantesis figurata*		(1)
Arctiidae	*Apantesis nais*		(1)
Arctiidae	*Apantesis parthenice*		(1)
Arctiidae	*Apantesis phalerata*	Harnessed moth	(1) (2)
Arctiidae	*Apantesis virgo*		(1)
Arctiidae	*Cisseps fulvicollis*		(1)
Arctiidae	*Cisthene packardi*		(1)
Arctiidae	*Crambidia nov. sp.*		(1)
Arctiidae	*Crambidia pallida*		(1)
Arctiidae	*Ctenucha virginica*		(1)
Arctiidae	*Estigmene acrea*		(1)
Arctiidae	*Halysidota tessellaris*		(1)
Arctiidae	*Haploa clymeme*		(1)
Arctiidae	*Haploa lecontei*		(1)
Arctiidae	*Holomelina aurantiaca*		(1)
Arctiidae	*Holomelina laeta*		(1)
Arctiidae	*Holomelina opella*		(1)
Arctiidae	*Hyphantria cunea*		(1)
Arctiidae	*Hypoprepia fucosa*		(1)
Arctiidae	*Phragmatobia fuliginosa*		(1)
Arctiidae	*Phragmatobia assimilans*		(1)
Arctiidae	*Pyrrharctia isabella*		(1)
Arctiidae	*Spilosoma congrua*		(1)
Arctiidae	*Spilosoma virginica*		(1)
Arctilidae	*Grammia parthenice*	Parthenice tiger moth	(3)
Geometridae	*Anacamptodes vellivolata*		(1)
Geometridae	*Anagoga occiduaria*		(1)
Geometridae	*Besma endropiaria*		(1)
Geometridae	*Besma quercivoraria*		(1)
Geometridae	*Biston betularia*		(1)
Geometridae	*Campaea perlata*		(1)
Geometridae	*Caripeta nov. sp.*		(1)
Geometridae	*Chlorochlamys chlorleucaria*		(1)
Geometridae	*Cingilia caternaria*		(5)
Geometridae	*Cladara limitaria*		(1)
Geometridae	*Coryphista meadii*		(1)
Geometridae	*Cyclophora packardi*		(1)
Geometridae	*Cyclophora pendulinaria*		(1)
Geometridae	*Dichorda iridaria*		(1)
Geometridae	*Ectropis crepuscularia*		(1)
Geometridae	*Euchlaena irraria*		(1)
Geometridae	*Euchlaena madusaria*		(1)
Geometridae	*Euchlaena marginaria*		(1)
Geometridae	*Euchlaena muzaria*		(1)

Family	Scientific Name	Common Name	Source
Geometridae	*Euchlaena serrata*		(1)
Geometridae	*Eufidonia notataria*		(1)
Geometridae	*Eugonobapta nivosaria*		(1)
Geometridae	*Eulithis diversilineata*		(1)
Geometridae	*Eulithis explanata*		(1)
Geometridae	*Eumacaria latiferrugata*		(1)
Geometridae	*Eupithecia sp.*		(1)
Geometridae	*Eusarca confusaria*		(1)
Geometridae	*Eutrapela clemataria*		(1)
Geometridae	*Glena cognataria*		(1)
Geometridae	*Glena cribrataria*		(1)
Geometridae	*Heliomata cycladata*		(1)
Geometridae	*Hydria prunivorata*		(1)
Geometridae	*Hydriomena renunciata*		(1)
Geometridae	*Hydriomena sp.*		(1)
Geometridae	*Hypagyrtis esther*		(1)
Geometridae	*Hypagyrtis unipunctata*		(1)
Geometridae	*Hypomecis umbrosaria*		(1)
Geometridae	*Iridopsis larvaria*		(1)
Geometridae	*Itame pustularia*		(1)
Geometridae	*Lamdina fervidaria*		(1)
Geometridae	*Lamdina pellucidaria*		(1)
Geometridae	*Lobophora nivigerata*		(1)
Geometridae	*Lomographa vestaliata*		(1)
Geometridae	*Lytrosis unitaria*		(1)
Geometridae	*Melanolophia canadarai*		(1)
Geometridae	*Melanolophia signataria*		(1)
Geometridae	*Metarranthis broweri*		(1)
Geometridae	*Metarranthis hypocharia*		(1)
Geometridae	*Metarranthis nov. sp. nr. lateritiaria*		(1)
Geometridae	*Metarranthis pilosaria*		(5)
Geometridae	*Nematocampa limbata*		(1)
Geometridae	*Nemoria bistriaria*		(1)
Geometridae	*Operophtera brumata*	Winter moth	(4)
Geometridae	*Orthonama centrostrigaria*		(1)
Geometridae	*Orthonama obstipata*		(1)
Geometridae	*Patalene olyzonaria*		(1)
Geometridae	*Pero honestaria*		(1)
Geometridae	*Pero hubneraria*		(1)
Geometridae	*Plagodis alcoolaria*		(1)
Geometridae	*Plagodis fervidaria*		(1)
Geometridae	*Plagodis serinaria*		(1)
Geometridae	*Pleuroprucha insulsaria*		(1)
Geometridae	*Probole alienaria*		(1)

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Family	Scientific Name	Common Name	Source
Geometridae	*Prochoerodes transversata*		(1)
Geometridae	*Protoboarmia porcelaria*		(1)
Geometridae	*Scophula limboundata*		(1)
Geometridae	*Scopula inductata*		(1)
Geometridae	*Semiothisa aemulitaria*		(1)
Geometridae	*Semiothisa bicolorata*		(1)
Geometridae	*Semiothisa bisignata*		(1)
Geometridae	*Semiothisa distribuaria*		(1)
Geometridae	*Semiothisa fissinotata*		(1)
Geometridae	*Semiothisa granitata*		(1)
Geometridae	*Semiothisa minorata*		(1)
Geometridae	*Semiothisa ocellinata*		(1)
Geometridae	*Semiothisa sexmaculata*		(1)
Geometridae	*Tetracis cachexiata*		(1)
Geometridae	*Xanthorhoe labradorensis*		(1)
Geometridae	*Xanthorhoe lacustrata*		(1)
Geometridae	*Xanthotype sospeta*		(1)
Hesperiidae	*Amblysciites hegon*	Pepper and salt skipper	(3)
Hesperiidae	*Anatrytone logan*	Delaware skipper	(2)
Hesperiidae	*Ancyloxypha numitor*	Least skipper	(2)
Hesperiidae	*Atrytonopsis hianna*	Dusted skipper	(2)
Hesperiidae	*Epargyreus clarus*	Spread-winged skipper	(2)
Hesperiidae	*Erynnis baptisiae*	Wild indigo duskywing	(2)
Hesperiidae	*Erynnis brizo*	Sleepy duskywing	(2)
Hesperiidae	*Erynnis horatius*	Horace's duskywing	(2)
Hesperiidae	*Erynnis icelus*	Dreamy duskywing	(2)
Hesperiidae	*Erynnis juvenalis*	Juvenal's duskywing	(2)
Hesperiidae	*Euphyes vestris*	Dun skipper	(2)
Hesperiidae	*Hesperia leonardus*	Leonard's skipper	(2)
Hesperiidae	*Hesperia metea*	Cobweb skipper	(2)
Hesperiidae	*Hesperia sassacus*	Indian skipper	(2)
Hesperiidae	*Pholisora catullus*	Common sooty wing	(2)
Hesperiidae	*Poanes hobomok*	Hobomok skipper	(2)
Hesperiidae	*Poanes viator*	Broad-winged skipper	(2)
Hesperiidae	*Polites mystic*	Long dash	(2)
Hesperiidae	*Polites origenes*	Crossline skipper	(2)
Hesperiidae	*Polites peckius*	Peck's skipper	(2)
Hesperiidae	*Polites themistocles*	Tawny-edged skipper	(2)
Hesperiidae	*Pompeius verna*	Little glassywing	(2)
Hesperiidae	*Thorybes bathyllus*	Southern cloudywing	(2)
Hesperiidae	*Thorybes pylades*	Northern cloudywing	(2)
Hesperiidae	*Thymelicus lineola*	European skipper	(2)
Hesperiidae	*Wallengrenia egeremet*	Northern broken dash	(2)
Lasiocampidae	*Malacosoma americana*		(1)

Family	Scientific Name	Common Name	Source
Lasiocampidae	*Malacosoma disstria*		(1)
Lasiocampidae	*Phyllodesma americana*		(1)
Lasiocampidae	*Tolype laricis*		(1)
Lasiocampidae	*Tolype velleda*		(1)
Lycaenidae	*Callophrys augustinus*	Brown elfin	(2)
Lycaenidae	*Callophrys gryneus*	Juniper hairstreak	(2)
Lycaenidae	*Callophrys henrici*	Henry's elfin	(2)
Lycaenidae	*Callophrys irus*	Frosted elfin	(2)
Lycaenidae	*Callophrys niphon*	Eastern pine elfin	(2)
Lycaenidae	*Callophrys polios*	Hoary elfin	(2)
Lycaenidae	*Celastrina ladon*	Spring azure	(2)
Lycaenidae	*Celastrina lanon "neglecta"*	Summer azure	(2)
Lycaenidae	*Everes comyntas*	Eastern tailed-blue	(2)
Lycaenidae	*Lycaena epixanthe*	Bog copper	(2)
Lycaenidae	*Lycaena phlaeas*	American copper	(2)
Lycaenidae	*Parrhasius m-album*	White M hairstreak	(2)
Lycaenidae	*Satyrium acadica*	Acadian hairstreak	(2)
Lycaenidae	*Satyrium calanus*	Banded hairstreak	(2)
Lycaenidae	*Satyrium edwardsii*	Edwards' hairstreak	(2)
Lycaenidae	*Satyrium favonius*	Oak hairstreak	(2)
Lycaenidae	*Satyrium liparops*	Striped hairstreak	(2)
Lycaenidae	*Satyrium titus*	Coral hairstreak	(2)
Lycaenidae	*Strymon melinus*	Gray hairstreak	(2)
Lymantriidae	*Dasychira obliquata*		(1)
Lymantriidae	*Dasychira plagiata*		(1)
Lymantriidae	*Euproctis chrysorrhoea*		(1)
Lymantriidae	*Lymantria dispar*		(1)
Lymantriidae	*Orgyia definita*		(1)
Lymantriidae	*Orgyia leucostigma*		(1)
Mimallonidae	*Cicinnus melsheimeri*		(5)
N/A	*Ecpantheria scribonia*		(1)
N/A	*Heropleon diversicolor*		(1)
N/A	*Hetemia pistasciaria*		(1)
N/A	*Orosagrotis perpolita*		(1)
N/A	*Phoeberia atomaris*		(1)
N/A	*Pygarctia eglenensis*		(1)
Noctuidae	*Abagrotis alternata*		(1)
Noctuidae	*Abagrotis crumbi*		(1)
Noctuidae	*Abagrotis nefascia*		(5)
Noctuidae	*Achatia distincta*		(1)
Noctuidae	*Acronicta afflicta*		(1)
Noctuidae	*Acronicta americana*		(1)
Noctuidae	*Acronicta haesitata*		(1)
Noctuidae	*Acronicta hasta*		(1)

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Family	Scientific Name	Common Name	Source
Noctuidae	*Acronicta increta*		(1)
Noctuidae	*Acronicta innotata*		(1)
Noctuidae	*Acronicta lithospila*		(1)
Noctuidae	*Acronicta lobeliae*		(1)
Noctuidae	*Acronicta longa*		(1)
Noctuidae	*Acronicta modica*		(1)
Noctuidae	*Acronicta noctivaga*		(1)
Noctuidae	*Acronicta ovata*		(1)
Noctuidae	*Acronicta sperata*		(1)
Noctuidae	*Acronicta tristis*		(1)
Noctuidae	*Acronicta tritona*		(1)
Noctuidae	*Agriopodes fallax*		(1)
Noctuidae	*Agrotia vetusta*		(1)
Noctuidae	*Agrotis ipsilon*		(1)
Noctuidae	*Agrotis manifesta*		(1)
Noctuidae	*Agrotis stigmosa*		(1)
Noctuidae	*Agrotis venerabilis*		(1)
Noctuidae	*Aletia oxygala*		(1)
Noctuidae	*Amolita roseola*		(1)
Noctuidae	*Amphipoea americana*		(1)
Noctuidae	*Amphipoea velata*		(1)
Noctuidae	*Amphipryra pyramidoides*		(1)
Noctuidae	*Anagrapha falcifera*		(1)
Noctuidae	*Anaplectoides prasina*		(1)
Noctuidae	*Anaplectoides pressus*		(1)
Noctuidae	*Anathix ralla*		(1)
Noctuidae	*Anomogyna dilucida*		(1)
Noctuidae	*Anomogyna elimata*		(1)
Noctuidae	*Anorthodes tarda*		(1)
Noctuidae	*Apamea alia*		(1)
Noctuidae	*Apamea amputatrix*		(1)
Noctuidae	*Apamea cariosa*		(1)
Noctuidae	*Apamea finitima*		(1)
Noctuidae	*Apamea inebriata*		(1)
Noctuidae	*Apamea inordinata*		(1)
Noctuidae	*Apamea lignicolora*		(1)
Noctuidae	*Apamea nigrior*		(1)
Noctuidae	*Apamea vulgaris*		(1)
Noctuidae	*Apharetra purpurea*		(1)
Noctuidae	*Aplectoides condita*		(1)
Noctuidae	*Argyrostrotis anilis*		(1)
Noctuidae	*Autographa ampla*		(1)
Noctuidae	*Autographa precationis*		(1)
Noctuidae	*Balsa labecula*		(1)

Family	Scientific Name	Common Name	Source
Noctuidae	*Bellura obliqua*		(1)
Noctuidae	*Bleptina caradrinalis*		(1)
Noctuidae	*Bomolocha baltimoralis*		(1)
Noctuidae	*Caenurgina crassiuscula*		(1)
Noctuidae	*Caenurgina erechtea*		(1)
Noctuidae	*Callopistria cordata*		(1)
Noctuidae	*Callopistria mollissima*		(1)
Noctuidae	*Catocala amatrix*		(1)
Noctuidae	*Catocala andromedae*		(1)
Noctuidae	*Catocala antinympha*		(1)
Noctuidae	*Catocala badia*		(1)
Noctuidae	*Catocala coccinata*		(1)
Noctuidae	*Catocala gracilis*		(1)
Noctuidae	*Catocala grynea*		(1)
Noctuidae	*Catocala herodias*		(1)
Noctuidae	*Catocala ilia*		(1)
Noctuidae	*Catocala lineella*		(1)
Noctuidae	*Catocala micronympha*		(1)
Noctuidae	*Catocala praeclara*		(1)
Noctuidae	*Catocala relicta*		(1)
Noctuidae	*Catocala similis*		(1)
Noctuidae	*Catocala sordida*		(1)
Noctuidae	*Catocala ultronia*		(1)
Noctuidae	*Cerma cerintha*		(1)
Noctuidae	*Chaetaglaea cerata*		(5)
Noctuidae	*Chaetaglaea sericea*		(1)
Noctuidae	*Chaetaglaea tremula*		(1)
Noctuidae	*Charadra deridens*		(1)
Noctuidae	*Chrysanympha formosa*		(1)
Noctuidae	*Chytolita morbidalis*		(1)
Noctuidae	*Chytonix palliatricula*		(1)
Noctuidae	*Chytonix sensilis*		(1)
Noctuidae	*Cosmia calami*		(1)
Noctuidae	*Crocigrapha normani*		(1)
Noctuidae	*Crymodes burgessi*		(1)
Noctuidae	*Derrima stellata*		(1)
Noctuidae	*Diachrysia balluca*		(1)
Noctuidae	*Diarsia jucunda*		(1)
Noctuidae	*Drasteria graphica*		(1)
Noctuidae	*Drasteria occulta*		(1)
Noctuidae	*Dyspyralis illocata*		(1)
Noctuidae	*Egira alternans*		(1)
Noctuidae	*Elaphria festivoides*		(1)
Noctuidae	*Elaphria versicolor*		(1)

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Family	Scientific Name	Common Name	Source
Noctuidae	*Euagrotis forbesii*		(1)
Noctuidae	*Euagrotis illapsa*		(1)
Noctuidae	*Eueretagrotis attentus*		(1)
Noctuidae	*Eugraphe subrosea*		(1)
Noctuidae	*Euparthenos nubilis*		(1)
Noctuidae	*Eurois occulta*		(1)
Noctuidae	*Euxoa tessellata*		(1)
Noctuidae	*Exyra rolandiana*		(1)
Noctuidae	*Faronta diffusa*		(1)
Noctuidae	*Feltia geniculata*		(1)
Noctuidae	*Feralia major*		(1)
Noctuidae	*Gabara subnivosella*		(1)
Noctuidae	*Harrisimemna trisignata*		(1)
Noctuidae	*Helicoverpa zea*		(1)
Noctuidae	*Helotropha reniformis*		(1)
Noctuidae	*Hemipachnobia subporphyrea*		(1)
Noctuidae	*Heptagrotis phyllophora*		(1)
Noctuidae	*Himella intractata*		(1)
Noctuidae	*Homorthodes furfurata*		(1)
Noctuidae	*Hyperstrotia villificans*		(1)
Noctuidae	*Hypocoena enervata*		(1)
Noctuidae	*Hyppa xylinoides*		(1)
Noctuidae	*Idia aemula*		(1)
Noctuidae	*Idia americalis*		(1)
Noctuidae	*Idia diminuendis*		(1)
Noctuidae	*Idia forbesi*		(1)
Noctuidae	*Idia julia*		(1)
Noctuidae	*Idia rotundalis*		(1)
Noctuidae	*Lacanobia grandis*		(1)
Noctuidae	*Lacanobia legitima*		(1)
Noctuidae	*Lacanobia lilacina*		(1)
Noctuidae	*Lacanobia lutra*		(1)
Noctuidae	*Lacinipolia renigera*		(1)
Noctuidae	*Lacinipolia teligera*		(1)
Noctuidae	*Leucania commoides*		(1)
Noctuidae	*Leucania extincta*		(1)
Noctuidae	*Leucania inermis*		(1)
Noctuidae	*Leucania insueta*		(1)
Noctuidae	*Leucania linita*		(1)
Noctuidae	*Leucania pseudargyria*		(1)
Noctuidae	*Leuconyta diphtheroides*		(1)
Noctuidae	*Lithacodia carneola*		(1)
Noctuidae	*Lithocodia synochitis*		(1)
Noctuidae	*Lithomoia solidaginis*		(1)

Family	Scientific Name	Common Name	Source
Noctuidae	*Lithophane grotei*		(1)
Noctuidae	*Lithophane viridipallens*		(5)
Noctuidae	*Magusa orbifera*		(1)
Noctuidae	*Marathyssa basalis*		(1)
Noctuidae	*Meganola minuscula*		(1)
Noctuidae	*Meganola sp.*		(1)
Noctuidae	*Melanchra adjuncta*		(1)
Noctuidae	*Melanchra assimilis*		(1)
Noctuidae	*Metalepsis fishii*		(1)
Noctuidae	*Metaxaglaea semitaria*		(1)
Noctuidae	*Morrisonia evicta*		(1)
Noctuidae	*Nedra ramosula*		(1)
Noctuidae	*Neoligia semicana*		(5)
Noctuidae	*Nephelodes minians*		(1)
Noctuidae	*Noctua pronuba*	European yellow underwing	(1) (2)
Noctuidae	*Oligia bridghami*		(1)
Noctuidae	*Oligia illocatia*		(1)
Noctuidae	*Oncocnemis riparia*		(1)
Noctuidae	*Orthodes cynica*		(1)
Noctuidae	*Orthosia hibisci*		(1)
Noctuidae	*Orthosia revicta*		(1)
Noctuidae	*Orthosia rubescens*		(1)
Noctuidae	*Oruza albocostaliata*		(1)
Noctuidae	*Pangrapta decoralis*		(1)
Noctuidae	*Panopoda rufimargo*		(1)
Noctuidae	*Panthea pallescens*		(1)
Noctuidae	*Papaipema stenocelis*		(5)
Noctuidae	*Papaipema sulphurata*		(1)
Noctuidae	*Parallelia bistriaris*		(1)
Noctuidae	*Phalaenostola eumelusalis*		(1)
Noctuidae	*Phlogophora iris*		(1)
Noctuidae	*Phlogophora periculosa*		(1)
Noctuidae	*Phosphila turbulenta*		(1)
Noctuidae	*Plathypena scabra*		(1)
Noctuidae	*Platysenta sutor*		(1)
Noctuidae	*Platysenta videns*		(1)
Noctuidae	*Plusia putnami*		(1)
Noctuidae	*Polia detracta*		(1)
Noctuidae	*Polia latex*		(1)
Noctuidae	*Polygrammate hebraeicum*		(1)
Noctuidae	*Protolampra brunneicollis*		(1)
Noctuidae	*Protorthodes oviducta*		(1)
Noctuidae	*Proxenus miranda*		(1)
Noctuidae	*Psectraglaea carnosa*		(1)

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Family	Scientific Name	Common Name	Source
Noctuidae	*Pseudaletia unipuncta*		(1)
Noctuidae	*Pseudoplusia includens*		(1)
Noctuidae	*Raphia frater*		(1)
Noctuidae	*Renia "adspergillus"*		(1)
Noctuidae	*Renia "nemoralis"*		(1)
Noctuidae	*Renia discoloralis*		(1)
Noctuidae	*Renia factiosalis*		(1)
Noctuidae	*Renia flavipunctalis*		(1)
Noctuidae	*Renia salusalis*		(1)
Noctuidae	*Renia sobrialis*		(1)
Noctuidae	*Rhynchagrotis cupida*		(1)
Noctuidae	*Rhynchagrotis nov. sp.*		(1)
Noctuidae	*Scoliopteryx libatrix*		(1)
Noctuidae	*Sideridis maryx*		(1)
Noctuidae	*Spaelotis clandestina*		(1)
Noctuidae	*Spodoptera frugiperda*		(1)
Noctuidae	*Spodoptera ornithigalli*		(1)
Noctuidae	*Sunira bicolorago*		(1)
Noctuidae	*Syngrapha epigaea*		(1)
Noctuidae	*Syngrapha viridisigma*		(1)
Noctuidae	*Ulolonche culea*		(1)
Noctuidae	*Ulolonche modesta*		(1)
Noctuidae	*Xestia "c-nigrum" complex*		(1)
Noctuidae	*Xestia badinodis*		(1)
Noctuidae	*Xestia bicarnea*		(1)
Noctuidae	*Xestia smithii*		(1)
Noctuidae	*Xylotype capax*		(1)
Noctuidae	*Xystopeplus rufago*		(1)
Noctuidae	*Zale curema*		(1)
Noctuidae	*Zale horrida*		(1)
Noctuidae	*Zale lunata*		(1)
Noctuidae	*Zale metatoides*		(1)
Noctuidae	*Zale minerea*		(1)
Noctuidae	*Zale obliqua*		(1)
Noctuidae	*Zale sp. 1 nr. Lunifera*		(5)
Noctuidae	*Zale submediana*		(1)
Noctuidae	*Zale undularis*		(1)
Noctuidae	*Zale unilineata*		(1)
Noctuidae	*Zanclognatha jacchusalis*		(1)
Noctuidae	*Zanclognatha laevigata*		(1)
Noctuidae	*Zanclognatha lituralis*		(1)
Noctuidae	*Zanclognatha ochreipennis*		(1)
Noctuidae	*Zanclognatha protumnusalis*		(1)
Noctuidae	*Zanclognatha sp.*		(1)

Family	Scientific Name	Common Name	Source
Noctuidae	*Zanclognatha theralis*		(1)
Notodontidae	*Dasylophia anguina*	Black-spotted prominent	(1) (2)
Notodontidae	*Datana ministra*		(1)
Notodontidae	*Datana sp.*		(1)
Notodontidae	*Furcula borealis*		(1)
Notodontidae	*Furcula occidentalis*	Furcula occidentalis	(3)
Notodontidae	*Gluphisia septentionis*	Common gluphisia	(3)
Notodontidae	*Gluphisia septentrionis*		(1)
Notodontidae	*Heterocampa biundata*		(1)
Notodontidae	*Heterocampa guttivitta*	Maple prominent	(1) (2)
Notodontidae	*Heterocampa obliqua*	Oblique heterocampa	(1) (2)
Notodontidae	*Heterocampa umbrata*	White-blotched heterocampa	(1) (2)
Notodontidae	*Heterocampa varia*	Heterocampa varia	(3)
Notodontidae	*Hyparpax aurora*		(1)
Notodontidae	*Hyperaeschra georgica*	Georgian prominent	(1) (2)
Notodontidae	*Lochmaeus bilineata*	Double-lined prominent	(1) (2)
Notodontidae	*Lochmaeus manteo*		(1)
Notodontidae	*Macrurocampa marthesia*	Mottled prominent	(1) (2)
Notodontidae	*Nadata gibbosa*		(1)
Notodontidae	*Oligocentria lignicolor*	White-streaked prominent	(1) (2)
Notodontidae	*Peridea angulosa*		(1)
Notodontidae	*Peridea ferruginea*	Chocolate promient	(3)
Notodontidae	*Pheosia rimosa*	Black-rimmed prominent	(1) (2)
Notodontidae	*Schizura apicalis*	Plain schizura	(1) (2)
Notodontidae	*Schizura badia*	Chestnut schizura	(1) (2)
Notodontidae	*Schizura ipomoeae*	Morning-glory prominent	(1) (2)
Notodontidae	*Schizura unicornis*		(1)
Notodontidae	*Symmerista albifrons*		(1)
Nymphalidae	*Boloria selene*	Silver-bordered fritillary	(2)
Nymphalidae	*Cercyonis pegala*	Common wood nymph	(2)
Nymphalidae	*Coenonympha tullia*	Common ringlet	(2)
Nymphalidae	*Danaus plexippus*	Monarch	(2)
Nymphalidae	*Enodia anthedon*	Northern pearly eye	(2)
Nymphalidae	*Euphydryas phaeton*	Baltimore checkerspot	(2)
Nymphalidae	*Euptoieta claudia*	Variegated fritillary	(2)
Nymphalidae	*Junonia coenia*	Common buckeye	(2)
Nymphalidae	*Libytheana carinenta*	American snout	(3)
Nymphalidae	*Limenitis archippus*	Viceroy	(2)
Nymphalidae	*Limenitis arthemis arthemis*	White admiral	(2)
Nymphalidae	*Limenitis arthemis astyanax*	Red-spotted purple	(2)
Nymphalidae	*Megisto cymela*	Little wood satyr	(2)
Nymphalidae	*Nymphalis antiopa*	Mourning cloak	(2)
Nymphalidae	*Phyciodes tharos*	Pearl crescent	(2)
Nymphalidae	*Polygonia comma*	Eastern comma	(3)

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Family	Scientific Name	Common Name	Source
Nymphalidae	*Polygonia interrogationis*	Question mark	(2)
Nymphalidae	*Satyrodes appalachia*	Appalachian brown	(2)
Nymphalidae	*Satyrodes eurydice*	Eyed brown	(2)
Nymphalidae	*Speyeria cybele*	Great spangled fritillary	(2)
Nymphalidae	*Speyeria idalia*	** Regal fritillary	(2)
Nymphalidae	*Vanessa atalanta*	Red admiral	(2)
Nymphalidae	*Vanessa cardui*	Painted lady	(2)
Nymphalidae	*Vanessa virginiensis*	American lady	(2)
Papilionidae	*Battus philenor*	Pipevine swallowtail	(2)
Papilionidae	*Papilio glaucus*	Eastern tiger swallowtail	(2)
Papilionidae	*Papilio polyxenes asterias*	Black swallowtail	(2)
Papilionidae	*Papilio troilus*	Spicebush swallowtail	(2)
Pieridae	*Colias eurytheme*	Orange sulphur	(2)
Pieridae	*Colias philodice*	Clouded sulphur	(2)
Pieridae	*Phoebis sennae*	Cloudless sulphur	(2)
Pieridae	*Pieris rapae*	Cabbage white	(2)
Pieridae	*Pyrisitia lisa*	Little yellow	(3)
Saturniidae	*Actias luna*	Luna moth	(3)
Saturniidae	*Anisota senatoria*	Orange-tipped oakworm moth	(1) (2)
Saturniidae	*Anisota stigma*	Spiny oakworm moth	(3)
Saturniidae	*Anisota virginiensis*		(1)
Saturniidae	*Antheraea polyphemus*	Polyphemus moth	(3)
Saturniidae	*Automeris io*	Io moth	(1) (2)
Saturniidae	*Citheronia sepulcralis*	Pine-devil moth	(3)
Saturniidae	*Dryocampa rubicunda*		(1)
Saturniidae	*Hemileuca maia*		(5)
Saturniidae	*Hyalophora cecropia*	Cecropia silkmoth	(1) (2)
Sphingidae	*Agrius cingulata*	Pink-spotted hawkmoth	(3)
Sphingidae	*Ceratomia undulosa*	Waved sphinx	(3)
Sphingidae	*Darapsa choerilus (pholius))*	Azalea sphinx	(3)
Sphingidae	*Darapsa myron*	Virginia creeper sphinx	(3)
Sphingidae	*Darapsa pholus*		(1)
Sphingidae	*Darapsa versicolor*	Hydrangea sphinx	(3)
Sphingidae	*Dolba hyloeus*	Pawpaw sphinx	(3)
Sphingidae	*Eumorpha achemon*	Achemon sphinx	(3)
Sphingidae	*Eumorpha pandorus*		(1)
Sphingidae	*Lapara bombycoides*	Northern pine sphinx	(1) (2)
Sphingidae	*Lapara coniferarum*	Southern pine sphinx	(1) (2)
Sphingidae	*Paonias astylus*	Huckleberry sphinx	(1) (2)
Sphingidae	*Paonias excaecatus*		(1)
Sphingidae	*Paonias myops*		(1)
Sphingidae	*Paratrea plebeja*		(1)
Sphingidae	*Sphecodina abbottii*		(1)
Sphingidae	*Sphinx drupiferarum*	Wild cherry sphinx	(1) (2)

Family	Scientific Name	Common Name	Source
Sphingidae	*Sphinx gordius*	Apple sphinx	(1) (2)
Sphingidae	*Sphinx kalmiae*	Laurel sphinx	(3)
Sphingidae	*Xylophanes tersa*	Tersa sphinx	(3)
Thyatiridae	*Pseudothyatira cymapophoroides*		(1)

ODONATA

Suborder	Family	Scientific Name	Common Name	Source(s)
Anisoptera	Aeshnidae	*Aeshna canadensis*	Canada Darner	(1) (2)
Anisoptera	Aeshnidae	*Aeshna clepsydra*	Mottled Darner	(1) (2)
Anisoptera	Aeshnidae	*Aeshna constricta*	Lance-tipped Darner	(2)
Anisoptera	Aeshnidae	*Aeshna mutata (=Rhionaeshna mutata) (#)*	Spatterdock Darner	(1) (2)
Anisoptera	Aeshnidae	*Aeshna tuberculifera*	Black-tipped Darner	(1) (2)
Anisoptera	Aeshnidae	*Aeshna umbrosa*	Shadow Darner	(1) (2)
Anisoptera	Aeshnidae	*Aeshna verticalis*	Green-striped Darner	(1) (2)
Anisoptera	Aeshnidae	*Anax junius*	Common Green Darner	(1) (2)
Anisoptera	Aeshnidae	*Anax longipes (#)*	Comet Darner	(1) (2)
Anisoptera	Aeshnidae	*Basiaeschna janata*	Springtime Darner	(2)
Anisoptera	Aeshnidae	*Boyeria vinosa*	Fawn Darner / Stream Darner	(2)
Anisoptera	Aeshnidae	*Epiaeschna heros*	Swamp Darner	(1) (2)
Anisoptera	Aeshnidae	*Gomphaeschna furcillata*	Harlequin Darner	(2)
Anisoptera	Corduliidae	*Dorocordulia lepida*	Petite Emerald	(1) (2)
Anisoptera	Corduliidae	*Epitheca cynosura*	Common Baskettail	(1) (2)
Anisoptera	Corduliidae	*Epitheca princeps*	Prince Baskettail	(1) (2)
Anisoptera	Corduliidae	*Somatochlora tenebrosa*	Clamp-tipped Emerald	(2)
Anisoptera	Corduliidae	*Somatochlora walshii*	Brush-tipped Emerald	(2)
Anisoptera	Gomphidae	*Dromogomphus spinosus*	Black-shouldered Spinyleg	(2)
Anisoptera	Gomphidae	*Gomphus abbreviatus (#)*	Spine-crowned Clubtail	(2)
Anisoptera	Gomphidae	*Gomphus exilis*	Lancet Clubtail	(1) (2)
Anisoptera	Gomphidae	*Gomphus fraternus (#)*	Midland Clubtail	(2)
Anisoptera	Gomphidae	*Gomphus spicatus* *	Dusky Clubtail	(2)
Anisoptera	Gomphidae	*Progomphus obscurus*	Common Sanddragon	(1) (2)
Anisoptera	Libellulidae	*Celithemis elisa*	Calico Pennant	(1) (2)
Anisoptera	Libellulidae	*Celithemis eponina*	Halloween Pennant	(1) (2)
Anisoptera	Libellulidae	*Celithemis fasciata*	Banded Pennant	(2)
Anisoptera	Libellulidae	*Celithemis martha*	Martha's Pennant	(1) (2)
Anisoptera	Libellulidae	*Erythemis simplicicollis*	Eastern Pondhawk	(1) (2)
Anisoptera	Libellulidae	*Erythrodiplax berenice*	Seaside Dragonlet	(1) (2)
Anisoptera	Libellulidae	*Leucorrhinia frigida*	Frosted Whiteface	(1) (2)
Anisoptera	Libellulidae	*Leucorrhinia intacta*	Dot-tailed Whiteface	(1) (2)
Anisoptera	Libellulidae	*Libellula auripennis*	Golden-winged Skimmer	(1) (2)
Anisoptera	Libellulidae	*Libellula axilena*	Bar-winged Skimmer	(1) (2)
Anisoptera	Libellulidae	*Libellula cyanea*	Spangled Skimmer	(1) (2)
Anisoptera	Libellulidae	*Libellula deplanata*	Blue Corporal	(2)
Anisoptera	Libellulidae	*Libellula exusta*	White Corporal	(1) (2)
Anisoptera	Libellulidae	*Libellula incesta*	Slaty Skimmer	(1) (2)
Anisoptera	Libellulidae	*Libellula luctuosa*	Widow Skimmer	(2)
Anisoptera	Libellulidae	*Libellula lydia*	Common Whitetail	(1) (2)
Anisoptera	Libellulidae	*Libellula needhami*	Needham's Skimmer	(1) (2)
Anisoptera	Libellulidae	*Libellula pulchella*	Twelve-spotted Skimmer	(1) (2)
Anisoptera	Libellulidae	*Libellula quadrimaculata*	Four-spotted Skimmer	(1) (2)
Anisoptera	Libellulidae	*Libellula semifasciata*	Painted Skimmer	(1) (2)

Suborder	Family	Scientific Name	Common Name	Source(s)
Anisoptera	Libellulidae	*Libellula vibrans*	Great Blue Skimmer	(1) (2)
Anisoptera	Libellulidae	*Nannothemis bella*	Elfin Skimmer	(2)
Anisoptera	Libellulidae	*Pachydiplax longipennis*	Blue Dasher	(1) (2)
Anisoptera	Libellulidae	*Pantala flavescens*	Wandering Glider	(1) (2)
Anisoptera	Libellulidae	*Pantala hymenaea*	Spot-winged Glider	(1) (2)
Anisoptera	Libellulidae	*Perithemis tenera*	Eastern Amberwing	(1) (2)
Anisoptera	Libellulidae	*Sympetrum corruptum*	Variegated Meadowhawk	(2)
Anisoptera	Libellulidae	*Sympetrum costiferum*	Saffron-winged Meadowhawk	(1) (2)
Anisoptera	Libellulidae	*Sympetrum obtrusum* *	White-faced Meadowhawk	(2)
Anisoptera	Libellulidae	*Sympetrum rubicundulum*	Ruby Meadowhawk	(1) (2)
Anisoptera	Libellulidae	*Sympetrum semicinctum*	Band-winged Meadowhawk	(2)
Anisoptera	Libellulidae	*Sympetrum vicinum*	Yellow-legged Meadowhawk	(1) (2)
Anisoptera	Libellulidae	*Tramea calverti*	Striped Glider	(1) (2)
Anisoptera	Libellulidae	*Tramea carolina*	Carolina Saddlebags	(1) (2)
Anisoptera	Libellulidae	*Tramea lacerata*	Black Saddlebags	(1) (2)
Anisoptera	Macromiidae	*Didymops transversa*	Stream Cruiser	(1) (2)
Anisoptera	Macromiidae	*Macromia illinoisensis*	Illinois River Cruiser	(1) (2)
Zygoptera	Calopterygidae	*Calopteryx maculata*	EbonyJewelwing	(1) (2)
Zygoptera	Calopterygidae	*Hetaerina americana*	American Rubyspot	(2)
Zygoptera	Coenagrionidae	*Amphiagrion saucium*	Eastern Red Damsel	(1) (2)
Zygoptera	Coenagrionidae	*Argia fumipennis*	Variable Dancer / Violet Dancer	(1) (2)
Zygoptera	Coenagrionidae	*Argia moesta*	Powdered Dancer	(2)
Zygoptera	Coenagrionidae	*Chromagrion conditum*	Aurora Damsel	(2)
Zygoptera	Coenagrionidae	*Coenagrion resolutum*	Taiga Bluet	(2)
Zygoptera	Coenagrionidae	*Enallagma aspersum*	Azure Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma boreale*	Boreal Bluet	(1)
Zygoptera	Coenagrionidae	*Enallagma carunculatum (#)*	Tule Bluet	(2)
Zygoptera	Coenagrionidae	*Enallagma civile*	Familiar Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma cyathigerum*	Northern Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma daeckii (#)*	Attenuated bluet	(3)
Zygoptera	Coenagrionidae	*Enallagma divagans*	Turquoise Bluet	(2)
Zygoptera	Coenagrionidae	*Enallagma doubledayi*	Atlantic Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma durum*	Big Bluet	(2)
Zygoptera	Coenagrionidae	*Enallagma exsulans*	Stream Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma geminatum*	Skimming Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma hageni* *	Hagen's Bluet	(2)
Zygoptera	Coenagrionidae	*Enallagma laterale (#)*	New England Bluet	(2)
Zygoptera	Coenagrionidae	*Enallagma minusculum*	Little Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma pictum (#)*	Scarlet Bluet	(2)
Zygoptera	Coenagrionidae	*Enallagma recurvatum (#)*	Pine Barrens Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma signatum*	Orange Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma traviatum*	Slender Bluet	(1) (2)
Zygoptera	Coenagrionidae	*Enallagma vesperum*	Vesper Bluet / Evening Bluet	(2)
Zygoptera	Coenagrionidae	*Ischnura hastata*	Citrine Forktail	(1) (2)

ODONATA

ODONATA

Suborder	Family	Scientific Name	Common Name	Source(s)
Zygoptera	Coenagrionidae	*Ischnura kellicotti*	Lilypad Forktail	(1) (2)
Zygoptera	Coenagrionidae	*Ischnura posita*	Fragile Forktail	(1) (2)
Zygoptera	Coenagrionidae	*Ischnura prognata*	Furtive Forktail	(1) (2)
Zygoptera	Coenagrionidae	*Ischnura ramburii*	Rambur's Forktail	(2)
Zygoptera	Coenagrionidae	*Ischnura verticalis*	Eastern Forktail	(1) (2)
Zygoptera	Coenagrionidae	*Nehalennia gracilis*	Sphagnum Sprite	(1) (2)
Zygoptera	Coenagrionidae	*Nehalennia irene*	Sedge Sprite	(1) (2)
Zygoptera	Lestidae	*Lestes congener*	Spotted Spreadwing	(1) (2)
Zygoptera	Lestidae	*Lestes disjunctus*	Common Spreadwing	(1) (2)
Zygoptera	Lestidae	*Lestes dryas* *	Emerald Spreadwing	(2)
Zygoptera	Lestidae	*Lestes eurinus*	Amber-winged Spreadwing	(1) (2)
Zygoptera	Lestidae	*Lestes forcipatus*	Sweetflag Spreadwing	(1) (2)
Zygoptera	Lestidae	*Lestes inaequalis*	Elegant Spreadwing	(2)
Zygoptera	Lestidae	*Lestes rectangularis*	Slender Spreadwing	(1) (2)
Zygoptera	Lestidae	*Lestes unguiculatus*	Lyre-tipped Spreadwing	(1) (2)
Zygoptera	Lestidae	*Lestes vigilax*	Swamp Spreadwing	(1) (2)

(*) Historic record; (#) Massachusetts-listed species

Order	Family	Scientific Name	Common Name
Decapoda	Crangonidae	*Crangon septemspinosa*	Sevenspine Bay Shrimp
Decapoda	Hippolytidae	*Hippolyte zostericola*	Zostera shrimp
Decapoda	Nephropidae	*Homarus americanus*	American lobster
Decapoda	Ocypodidae	*Uca pugnax*	Atlantic Marsh Fiddler Crab
Decapoda	Paguridae	*Pagurus acadianus*	a hermit crab
Decapoda	Paguridae	*Pagurus longicarpus*	Longwrist Hermit Crab
Decapoda	Palaemonidae	*Palaemonetes pugio*	Daggerblade Grass Shrimp
Decapoda	Palaemonidae	*Palaemonetes vulgaris*	Common American prawn
Decapoda	Panopeidae	*Dyspanopeus sayi*	Say Mud Crab
Decapoda	Panopeidae	*Eurypanopeus depressus*	Flatback mud crab
Decapoda	Panopeidae	*Neopanope spp*	Grassflat Crab Spp
Decapoda	Panopeidae	*Panopeus herbstii*	Atlantic Mud Crab
Decapoda	Pisidae	*Libinia dubia*	Longnose Spider Crab
Decapoda	Portunidae	*Carcinus maenas*	Green Crab
Decapoda	Portunidae	*Ovalipes ocellatus*	Lady Crab
Xiphosura	Limulidae	*Limulus polyphemus*	Atlantic Horseshoe Crab

FISH

Park Accepted Name	Common Name	Park Presence	Abundance	Residency	Nativity	Habitat
Alosa aestivalis	Blueback herring	Probable	NA	NA	Native	F/M
Alosa mediocris	Hickory shad	Probable	NA	NA	NA	M
Alosa pseudoharengus	Alewife	Present	C	Breeder	Native transplant [4]	F
Alosa sapidissima	American shad	Present	NA	NA	Native	F/M
Ameiurus nebulosus	Brown bullhead	Present	A	Breeder	Native	F
Ammodytes americanus	American sand lance	Present	NA	NA	NA	M
Anchoa hepsetus	Striped anchovy	Probable	NA	NA	NA	M
Anchoa mitchilli	Bay anchovy	Probable	NA	NA	NA	M
Anguilla rostrata	American eel	Present	C	Breeder	Native	F/M
Apeltes quadracus	Fourspine stickleback	Present	A	Breeder	Native	F
Brevoortia tyrannus	Atlantic menhaden	Present	A	Breeder	Native	M
Caranx hippos	Crevalle jack	Probable	NA	NA	NA	M
Catostomus commersoni	White sucker	Present	NA	NA	Native	F
Centropristis striata	Black sea bass	Probable	NA	NA	NA	M
Clupea harengus	Atlantic herring	Present	NA	NA	Native	M
Conger oceanicus	Conger eel	Probable	NA	NA	NA	M
Cyclopterus lumpus	Lumpfish	Probable	NA	NA	NA	M
Cyprinodon variegatus	Sheepshead minnow	Present	U	Breeder	Native	F
Decapterus punctatus	Round robin	Probable	NA	NA	NA	M
Enchelyopus cimbrius	Fourbeard rockling	Present	NA	NA	NA	M
Esox niger	Chain pickerel	Present	C	Breeder	Native	F
Etropus microstomus	Smallmouth flounder	Present	NA	NA	NA	M
Fundulus diaphanus	Banded killifish	Present	C	Breeder	Native	F
Fundulus heteroclitus	Mummichog	Present	A	Breeder	Native	F
Fundulus majalis	Striped killifish	Present	C	Breeder	Native	F
Gadus morhua	Atlantic cod	Probable	NA	NA	NA	M
Gasterosteus aculeatus [1]	Three-spined stickleback	Present	NA	NA	NA	F
Gasterosteus wheatlandi	Black-spotted stickleback	Probable	NA	NA	NA	F
Gobiosoma bosc	Naked goby	Probable	NA	NA	NA	M
Hippoglossoides platessoides	American plaice	Probable	NA	NA	NA	M
Leiostomus xanthurus	Spot	Probable	NA	NA	NA	M
Lepomis gibbosus	Pumpkinseed	Present	A	Breeder	NA	F
Leucoraja (Raja) erinacea [3]	Little skate	Present	NA	NA	NA	M
Menidia beryllina	Inland silverside	Probable	NA	NA	NA	M
Menidia menidia	Atlantic silverside	Present	A	Breeder	Native	M
Menticirrhus saxatilis	Northern kingfish	Present	NA	NA	Native	M
Microgadus tomcod	Atlantic tomcod	Probable	NA	NA	NA	M
Micropterus dolomieu	Smallmouth bass	Present	C	Breeder	Native transplant [4]	F
Micropterus salmoides	Largemouth Bass	Present	C	Breeder	Native transplant [4]	F
Monacanthus hispidus	Planehead filefish	Probable	NA	NA	NA	M

Park Accepted Name	Common Name	Park Presence	Abundance	Residency	Nativity	Habitat
Morone americana	White perch	Present	C	Breeder	Native	F
Morone saxatilis	Striped bass	Present	NA	Migratory	Native	M
Mugil cephalus	Striped mullet	Probable	NA	NA	NA	M
Mugil curema	White mullet	Probable	NA	NA	NA	M
Myoxocephalus aenaeus	Grubby	Probable	NA	NA	NA	M
Myoxocephalus scorpius	Shorthorn sculpin	Present	NA	Breeder	Native	M
Notemigonus crysoleucas	Golden shiner	Present	A	Breeder	NA	F
Notropis bifrenatus [2]	Bridle Shiner	Probable	NA	NA	NA	F
Oncorhynchus mykiss	Rainbow trout	Present	NA	NA	Native transplant (stocked) [4]	F
Paralichthys dentatus	Summer flounder	Probable	NA	NA	NA	M
Peprilus (Poronotus) triacanthus [3]	Butterfish	Present	NA	NA	NA	M
Perca flavescens	Yellow perch	Present	C	Breeder	Native	F
Pholis gunnellus	Rock gunnel	Probable	NA	NA	NA	M
Pollachius virens	Pollock	Probable	NA	NA	NA	M
Pomatomus saltatrix	Bluefish	Present	C	Migratory	Native	M
Prionotus evolans	Striped sea robin	Probable	NA	NA	NA	M
Pseudopleuronectes americanus	Winter flounder	Present	U	Breeder	Native	M
Pungitius pungitius	Ninespine stickleback [5]	Present	C	Breeder	Native	F
Salmo trutta	Brown Trout	Present	NA	NA	Exotic (stocked) [4]	F
Salvelinus fontinalis	Brook trout	Present	NA	NA	Native (stocked)	F
Scomber scombrus	Atlantic mackerel	Unconfirmed	NA	NA	NA	M
Scophthalmus aquosus	Windowpane flounder	Present	NA	NA	Native	M
Selene vomer	Lookdown	Probable	NA	NA	NA	M
Sphoeroides maculatus	Northern puffer	Probable	NA	NA	NA	M
Squalus acanthias	Dogfish	Present	NA	Vagrant	Native	M
Stenotomus chrysops	Scup	Probable	NA	NA	NA	M
Stichaeus punctatus	Arctic shanny	Probable	NA	NA	NA	M
Syngnathus fuscus	Northern pipefish	Present	C	Breeder	Native	M
Tautoga onitis	Tautog	Present	NA	NA	Native	M
Tautogolabrus adspersus	Cunner	Present	NA	NA	NA	M
Trinectes maculatus	Hogchoker	Present	NA	NA	NA	M
Ulvaria subbifurcata	Radiated shanny	Probable	NA	NA	NA	M
Urophycis chuss	Red hake	Probable	NA	NA	NA	M
Urophycis tenuis	White hake	Probable	NA	NA	NA	M

Abbreviations: Abundance: A: abundant, C: common, U: uncommon, NA: unknown; Water M: marine, F: freshwater. Occurrence, abundance, residency, and nativity information from NPSpecies (accessed 8 October 2010) unless otherwise noted.

1 Massachusetts listed species status: threatened (freshwater populations only).
2 Massachusetts listed species status: special concern.
3 NPSspecies had invalid synonym (in parentheses).
4 NPSspecies had wrong nativity, correct nativity (USGS-NAS) for the Cape Cod area is given.
5 NPSspecies had wrong common name.

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Amphibians					
Ambystoma maculatum	Spotted salamander	Present	A	Breeder	Native
Anaxyrus (Bufo) fowleri [5]	Fowler's toad	Present	A	Breeder	Native trans-plant [6]
Hemidactylium scutatum	Four-toed salamander	Present	R	Breeder	Native
Hyla versicolor	Gray treefrog	Present	R	Breeder	Native
Lithobates (Rana) catesbeiana	Bullfrog	Present	C	Breeder	Native
Notophthalmus viridescens viridescens	Red-spotted newt	Present	R	Breeder	Native
Plethodon cinereus	Eastern red-backed Sala-mander	Present	A	Breeder	Native
Pseudacris crucifer	Spring peeper	Present	A	Breeder	Native
Rana clamitans melanota	Green frog	Present	A	Breeder	Native
Rana palustris	Pickerel frog	Present	U	Breeder	Native
Rana sylvatica	Wood frog	Present	C	Breeder	Native
Scaphiopus holbrookii (holbrookii hol-brooki) [1, 5, 7]	Eastern spadefoot toad	Present	C	Breeder	Native
Reptiles					
Caretta caretta [2]	Loggerhead sea turtle	Present	U	Resident	Native
Chelonia mydas (mydas mydas) [2, 5, 7]	Green sea turtle	Present	R	Resident	Native
Chelydra serpentina	Snapping turtle	Present	C	Breeder	Native
Chrysemys picta	Painted Turtle	Present	C	Breeder	Native
Clemmys guttata	Spotted turtle	Present	R	Breeder	Native
Coluber constrictor constrictor	Northern black racer	Present	C	Breeder	Native
Dermochelys coriacea coriacea [3, 7]	Leatherback sea turtle	Present	R	Migratory	Native
Diadophis punctatus edwardsii	Northern ringneck snake	Present	A	Breeder	Native
Eretmochelys imbricata imbricata [3, 7]	Atlantic hawksbill sea turtle	Present	O	Vagrant	Native
Heterodon platirhinos	Eastern hognose snake	Present	R	Breeder	Native
Lampropeltis triangulum triangulum	Eastern milk snake	Present	U	Breeder	Native
Lepidochelys kempii [3]	Kemp's ridley sea turtle	Present	U	Resident	Native
Malaclemys terrapin terrapin [1]	Northern diamondback terrapin	Present	C	Breeder	Native
Nerodia sipedon sipedon	Northern water snake	Present	R	Breeder	Native
Sternotherus odoratus	Common musk turtle	Present	U	Breeder	Native
Terrapene carolina carolina [4]	Eastern box turtle	Present	C	Breeder	Native
Thamnophis sauritus sauritus	Eastern ribbon snake	Present	C	Breeder	Native
Thamnophis sirtalis sirtalis	Eastern garter snake	Present	U	Breeder	Native

Abundance: A: abundant, C: common, U: uncommon, NA: unknown Occurrence, abundance, residency, and nativity information from NPSpecies (accessed 8 October 2010) unless otherwise noted.

1 Massachusetts listed species status: threatened.
2 Federal and Massachusetts listed species status: threatened.
3 Federal and Massachusetts listed species status: endangered.
4 Massachusetts listed species status: special concern.
5 NPSspecies had invalid synonym (in parentheses).
6 NPSspecies had wrong nativity, correct nativity (USGS-NAS) is given.
7 NPSspecies was missing threatened and endangered status.

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Accipiter cooperii	Cooper's hawk	Present	Uncommon	Breeder	Native
Accipiter gentilis	Northern goshawk	Present	Rare	Migratory	Native
Accipiter striatus [1]	Sharp-shinned hawk	Present	Occasional	Breeder	Native
Actitis macularia (macularia) [6]	Spotted sandpiper	Present	Uncommon	Breeder	Native
Aechmophorus occidentalis	Western grebe	Present	Occasional	Vagrant	Native
Aegolius acadicus	Northern Saw-whet owl	Present	Rare	Breeder	Native
Agelaius phoeniceus	Red-winged blackbird	Present	Abundant	Breeder	Native
Aix sponsa	Wood duck	Present	Uncommon	Breeder	Native
Alca torda	Razorbill	Present	Common	Migratory	Native
Alle alle	Dovekie	Present	Rare	Migratory	Native
Ammodramus caudacutus	Saltmarsh Sharp-tailed sparrow	Present	Common	Breeder	Native
Ammodramus henslowii [3]	Henslow's sparrow	Present	Occasional	Vagrant	Native
Ammodramus leconteii	Leconte's sparrow	Present	Occasional	Vagrant	Native
Ammodramus maritimus	Seaside sparrow	Present	Rare	Migratory	Native
Ammodramus nelsoni	Nelson's sharp-tailed sparrow	Present	Rare	Migratory	Native
Ammodramus savannarum [2]	Grasshopper sparrow	Present	Rare	Migratory	Native
Anas acuta	Northern pintail	Present	Uncommon	Migratory	Native
Anas americana	American wigeon	Present	Uncommon	Resident	Native
Anas clypeata	Northern shoveler	Present	Rare	Migratory	Native
Anas crecca	Green-winged teal	Present	Uncommon	Migratory	Native
Anas discors	Blue-winged teal	Present	Uncommon	Migratory	Native
Anas penelope	Eurasian wigeon	Present	Occasional	Vagrant	Native
Anas platyrhynchos	Mallard	Present	Common	Breeder	Native
Anas rubripes	American black duck	Present	Abundant	Breeder	Native
Anas strepera	Gadwall	Present	Rare	Migratory	Native
Anser albifrons	Greater White-fronted goose	Present	Occasional	Vagrant	Native
Anthus rubescens	American pipit	Present	Uncommon	Migratory	Native
Anthus spragueii	Sprague's pipit	Present	Occasional	Vagrant	Native
Aquila chrysaetos	Golden eagle	Present	Occasional	Vagrant	Native
Archilochus colubris	Ruby-throated hummingbird	Present	Uncommon	Breeder	Native
Ardea alba	Great egret	Present	Uncommon	Migratory	Native
Ardea herodias	Great blue heron	Present	Common	Resident	Native
Arenaria interpres	Ruddy turnstone	Present	Common	Migratory	Native
Asio flammeus [3]	Short-eared owl	Present	Occasional	Migratory	Native
Asio otus [1]	Long-eared owl	Present	Occasional	Migratory	Native
Aythya affinis	Lesser scaup	Present	Uncommon	Resident	Native
Aythya americana	Redhead	Present	Occasional	Migratory	Native
Aythya collaris	Ring-necked duck	Present	Uncommon	Resident	Native
Aythya marila	Greater scaup	Present	Uncommon	Resident	Native
Aythya valisineria	Canvasback	Present	Rare	Migratory	Native
Baeolophus (Parus) bicolor [6]	Tufted titmouse	Present	Common	Breeder	Native
Bartramia longicauda [3]	Upland sandpiper	Present	Rare	Migratory	Native
Bombycilla cedrorum	Cedar waxwing	Present	Common	Breeder	Native
Bombycilla garrulus	Bohemian waxwing	Present	Rare	Migratory	Native

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Bonasa umbellus	Ruffed grouse	Present	Rare	Breeder	Native
Botaurus lentiginosus [3]	American bittern	Present	Rare	Migratory	Native
Branta bernicla	Brant	Present	Common	Resident	Native
Branta canadensis	Canada goose	Present	Abundant	Breeder	Native
Bubo (Nyctea) scandiaca [6]	Snowy owl	Present	Rare	Migratory	Native
Bubo virginianus	Great horned owl	Present	Common	Breeder	Native
Bubulcus ibis	Cattle egret	Present	Occasional	Vagrant	Native
Bucephala albeola	Bufflehead	Present	Common	Resident	Native
Bucephala clangula	Common goldeneye	Present	Common	Resident	Native
Bucephala islandica	Barrow's goldeneye	Present	Occasional	Migratory	Native
Buteo jamaicensis	Red-tailed hawk	Present	Common	Breeder	Native
Buteo lagopus	Rough-legged hawk	Present	Occasional	Migratory	Native
Buteo lineatus	Red-shouldered hawk	Present	Rare	Migratory	Native
Buteo platypterus	Broad-winged hawk	Present	Uncommon	Breeder	Native
Buteo swainsoni	Swainson's hawk	Present	Occasional	Vagrant	Native
Butorides virescens	Green heron	Present	Uncommon	Breeder	Native
Calamospiza melanocorys	Lark bunting	Present	Occasional	Vagrant	Native
Calcarius lapponicus	Lapland longspur	Present	Uncommon	Migratory	Native
Calcarius ornatus	Chestnut-collared longspur	Present	Occasional	Vagrant	Native
Calidris alba	Sanderling	Present	Abundant	Migratory	Native
Calidris alpina	Dunlin	Present	Abundant	Migratory	Native
Calidris bairdii	Baird's sandpiper	Present	Rare	Migratory	Native
Calidris canutus	Red knot	Present	Common	Migratory	Native
Calidris ferruginea	Curlew sandpiper	Present	Occasional	Vagrant	Native
Calidris fuscicollis	White-rumped sandpiper	Present	Uncommon	Migratory	Native
Calidris himantopus	Stilt sandpiper	Present	Rare	Migratory	Native
Calidris maritima	Purple sandpiper	Present	Occasional	Migratory	Native
Calidris mauri	Western sandpiper	Present	Uncommon	Migratory	Native
Calidris melanotos	Pectoral sandpiper	Present	Uncommon	Migratory	Native
Calidris minutilla	Least sandpiper	Present	Abundant	Migratory	Native
Calidris pusilla	Semipalmated sandpiper	Present	Abundant	Migratory	Native
Calidris ruficollis	Red-necked stint	Present	Occasional	Vagrant	Native
Calonectris diomedea	Cory's shearwater	Present	Rare	Migratory	Native
Caprimulgus carolinensis	Chuck-will's-widow	Present	Rare	Resident	Native
Caprimulgus vociferus	Whip-poor-will	Present	Common	Breeder	Native
Cardinalis cardinalis	Northern cardinal	Present	Common	Breeder	Native
Carduelis flammea	Common redpoll	Present	Rare	Migratory	Native
Carduelis hornemanni	Hoary redpoll	Present	Occasional	Vagrant	Native
Carduelis pinus	Pine siskin	Present	Uncommon	Migratory	Native
Carduelis tristis	American goldfinch	Present	Common	Breeder	Native
Carpodacus mexicanus	House finch	Present	Common	Breeder	Non-Native
Carpodacus purpureus	Purple finch	Present	Uncommon	Breeder	Native
Cathartes aura	Turkey vulture	Present	Uncommon	Migratory	Native

BIRDS

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Catharus bicknelli	Bicknell's thrush	Present	Rare	Migratory	Native
Catharus fuscescens	Veery	Present	Uncommon	Migratory	Native
Catharus guttatus	Hermit thrush	Present	Uncommon	Breeder	Native
Catharus minimus	Gray-cheeked thrush	Present	Rare	Migratory	Native
Catharus ustulatus	Swainson's thrush	Present	Uncommon	Migratory	Native
Catoptrophorus semipalmatus	Willet	Present	Common	Breeder	Native
Cepphus grylle	Black guillemot	Present	Rare	Migratory	Native
Certhia americana	Brown creeper	Present	Uncommon	Breeder	Native
Chaetura pelagica	Chimney swift	Present	Uncommon	Breeder	Native
Charadrius melodus [4]	Piping plover	Present	Uncommon	Breeder	Native
Charadrius montanus	Mountain plover	Historic	Occasional	Vagrant	Native
Charadrius semipalmatus	Semipalmated plover	Present	Abundant	Migratory	Native
Charadrius vociferus	Killdeer	Present	Rare	Breeder	Native
Charadrius wilsonia	Wilson's plover	Present	Occasional	Vagrant	Native
Chen caerulescens	Snow goose	Present	Rare	Migratory	Native
Chlidonias niger	Black tern	Present	Uncommon	Migratory	Native
Chondestes grammacus	Lark sparrow	Present	Rare	Vagrant	Native
Chordeiles minor	Common nighthawk	Present	Rare	Migratory	Native
Circus cyaneus [2]	Northern harrier	Present	Uncommon	Breeder	Native
Cistothorus palustris	Marsh wren	Present	Rare	Breeder	Native
Cistothorus platensis [3]	Sedge wren	Present	Occasional	Migratory	Native
Clangula hyemalis	Long-tailed duck	Present	Common	Resident	Native
Coccothraustes vespertinus	Evening grosbeak	Present	Rare	Migratory	Native
Coccyzus americanus	Yellow-billed cuckoo	Present	Uncommon	Breeder	Native
Coccyzus erythropthalmus	Black-billed cuckoo	Present	Uncommon	Breeder	Native
Colaptes auratus	Northern flicker	Present	Common	Breeder	Native
Colinus virginianus	Northern bobwhite	Present	Uncommon	Breeder	Native
Columba livia	Rock dove	Present	Uncommon	Breeder	Non-Native
Contopus cooperi (borealis) [6]	Olive-sided flycatcher	Present	Rare	Migratory	Native
Contopus virens	Eastern wood-pewee	Present	Common	Breeder	Native
Coragyps atratus	Black vulture	Present	Occasional	Vagrant	Native
Corvus brachyrhynchos	American crow	Present	Common	Breeder	Native
Corvus corax	Common raven	Present	Occasional	Vagrant	Native
Corvus ossifragus	Fish crow	Present	Uncommon	Breeder	Native
Coturnicops noveboracensis	Yellow rail	Present	Occasional	Vagrant	Native
Cyanocitta cristata	Blue jay	Present	Common	Breeder	Native
Cygnus columbianus	Tundra swan	Present	Occasional	Vagrant	Native
Cygnus olor	Mute swan	Present	Uncommon	Breeder	Non-Native
Dendrocygna bicolor	Fulvous whistling-duck	Present	Occasional	Vagrant	Native
Dendroica caerulescens	Black-throated Blue warbler	Present	Uncommon	Migratory	Native
Dendroica castanea	Bay-breasted warbler	Present	Uncommon	Migratory	Native
Dendroica cerulea	Cerulean warbler	Present	Rare	Migratory	Native

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Dendroica coronata	Yellow-rumped warbler	Present	Abundant	Migratory	Native
Dendroica discolor	Prairie warbler	Present	Uncommon	Breeder	Native
Dendroica dominica	Yellow-throated warbler	Present	Occasional	Vagrant	Native
Dendroica fusca	Blackburnian warbler	Present	Uncommon	Migratory	Native
Dendroica magnolia	Magnolia warbler	Present	Common	Migratory	Native
Dendroica palmarum	Palm warbler	Present	Common	Migratory	Native
Dendroica pensylvanica	Chestnut-sided warbler	Present	Uncommon	Migratory	Native
Dendroica petechia	Yellow warbler	Present	Common	Breeder	Native
Dendroica pinus	Pine warbler	Present	Common	Breeder	Native
Dendroica striata [1]	Blackpoll warbler	Present	Common	Migratory	Native
Dendroica tigrina	Cape May warbler	Present	Uncommon	Migratory	Native
Dendroica townsendi	Townsend's warbler	Present	Occasional	Vagrant	Native
Dendroica virens	Black-throated green warbler	Present	Common	Migratory	Native
Dolichonyx oryzivorus	Bobolink	Present	Rare	Breeder	Native
Dumetella carolinensis	Gray catbird	Present	Common	Breeder	Native
Egretta caerulea	Little blue heron	Present	Rare	Migratory	Native
Egretta rufescens	Reddish egret	Present	Occasional	Vagrant	Native
Egretta thula	Snowy egret	Present	Uncommon	Migratory	Native
Egretta tricolor	Tricolored heron	Present	Rare	Migratory	Native
Elanoides forficatus	Swallow-tailed kite	Present	Occasional	Vagrant	Native
Empidonax alnorum	Alder flycatcher	Present	Rare	Migratory	Native
Empidonax flaviventris	Yellow-bellied flycatcher	Present	Rare	Migratory	Native
Empidonax minimus	Least flycatcher	Present	Uncommon	Migratory	Native
Empidonax traillii	Willow flycatcher	Present	Rare	Breeder	Native
Empidonax virescens	Acadian flycatcher	Present	Rare	Migratory	Native
Eremophila alpestris	Horned lark	Present	Common	Breeder	Native
Eudocimus albus	White ibis	Present	Occasional	Vagrant	Native
Euphagus carolinus	Rusty blackbird	Present	Uncommon	Migratory	Native
Euphagus cyanocephalus	Brewer's blackbird	Present	Occasional	Vagrant	Native
Falco columbarius	Merlin	Present	Uncommon	Migratory	Native
Falco peregrinus [3]	Peregrine falcon	Present	Uncommon	Migratory	Native
Falco rusticolus	Gyrfalcon	Present	Occasional	Vagrant	Native
Falco sparverius	American kestrel	Present	Rare	Breeder	Native
Fratercula arctica	Atlantic puffin	Present	Occasional	Migratory	Native
Fregata magnificens	Magnificent frigatebird	Present	Occasional	Vagrant	Native
Fulica americana	American coot	Present	Common	Migratory	Native
Fulmarus glacialis	Northern fulmar	Present	Rare	Migratory	Native
Gallinago gallinago	Common (Wilson's) snipe	Present	Uncommon	Migratory	Native
Gallinula chloropus [1]	Common moorhen	Present	Rare	Migratory	Native
Gavia immer [1]	Common loon	Present	Common	Resident	Native
Gavia pacifica	Pacific loon	Present	Occasional	Vagrant	Native
Gavia stellata	Red-throated Loon	Present	Abundant	Migratory	Native
Geothlypis trichas	Common yellowthroat	Present	Common	Breeder	Native
Grus canadensis	Sandhill crane	Present	Occasional	Vagrant	Native

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Haematopus palliatus	American oystercatcher	Present	Uncommon	Breeder	Native
Haliaeetus leucocephalus [3]	Bald eagle	Present	Rare	Migratory	Native
Helmitheros vermivorum (vermivorus) [6]	Worm-eating warbler	Present	Rare	Migratory	Native
Hirundo rustica	Barn swallow	Present	Uncommon	Breeder	Native
Histrionicus histrionicus	Harlequin duck	Present	Rare	Resident	Native
Hylocichla mustelina	Wood thrush	Present	Rare	Breeder	Native
Icteria virens	Yellow-breasted chat	Present	Rare	Migratory	Native
Icterus bullockii	Bullock's oriole	Present	Occasional	Vagrant	Native
Icterus galbula	Baltimore oriole	Present	Common	Breeder	Native
Icterus spurius	Orchard oriole	Present	Uncommon	Breeder	Native
Ictinia mississippiensis	Mississippi kite	Present	Rare	Vagrant	Native
Ixobrychus exilis [3]	Least bittern	Present	Rare	Breeder	Native
Ixoreus naevius	Varied thrush	Present	Occasional	Vagrant	Native
Junco hyemalis	Dark-eyed junco	Present	Common	Migratory	Native
Lanius excubitor	Northern shrike	Present	Rare	Migratory	Native
Lanius ludovicianus	Loggerhead shrike	Present	Occasional	Vagrant	Native
Larus argentatus	Herring gull	Present	Abundant	Breeder	Native
Larus atricilla	Laughing gull	Present	Common	Breeder	Native
Larus canus	Mew gull	Present	Occasional	Vagrant	Native
Larus delawarensis	Ring-billed gull	Present	Common	Migratory	Native
Larus fuscus	Lesser Black-backed gull	Present	Rare	Migratory	Native
Larus glaucoides	Iceland gull	Present	Uncommon	Migratory	Native
Larus hyperboreus	Glaucous gull	Present	Rare	Migratory	Native
Larus marinus	Great Black-backed gull	Present	Abundant	Breeder	Native
Larus minutus	Little gull	Present	Rare	Migratory	Native
Larus philadelphia	Bonaparte's gull	Present	Common	Migratory	Native
Larus pipixcan	Franklin's gull	Present	Occasional	Vagrant	Native
Larus ridibundus	Black-headed gull	Present	Rare	Migratory	Native
Laterallus jamaicensis	Black rail	Historic	Occasional	Vagrant	Native
Limnodromus griseus	Short-billed dowitcher	Present	Abundant	Migratory	Native
Limnodromus scolopaceus	Long-billed dowitcher	Present	Rare	Migratory	Native
Limnothlypis swainsonii	Swainson's warbler	Present	Occasional	Vagrant	Native
Limosa fedoa	Marbled godwit	Present	Rare	Migratory	Native
Limosa haemastica	Hudsonian godwit	Present	Uncommon	Migratory	Native
Limosa lapponica	Bar-tailed godwit	Present	Occasional	Vagrant	Native
Lophodytes cucullatus	Hooded merganser	Present	Uncommon	Resident	Native
Loxia curvirostra	Red crossbill	Present	Rare	Migratory	Native
Loxia leucoptera	White-winged crossbill	Present	Rare	Migratory	Native
Megaceryle (Ceryle) alcyon [6]	Belted kingfisher	Present	Uncommon	Breeder	Native
Megascops (Otus) asio [6]	Eastern screech-owl	Present	Uncommon	Breeder	Native
Melanerpes carolinus	Red-bellied woodpecker	Present	Rare	Breeder	Native
Melanerpes erythrocephalus	Red-headed woodpecker	Present	Occasional	Vagrant	Native
Melanitta fusca	White-winged scoter	Present	Abundant	Resident	Native

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Melanitta nigra	Black scoter	Present	Common	Resident	Native
Melanitta perspicillata	Surf scoter	Present	Common	Resident	Native
Meleagris gallopavo	Wild turkey	Present	Uncommon	Breeder	Native
Melospiza georgiana	Swamp sparrow	Present	Common	Migratory	Native
Melospiza lincolnii	Lincoln's sparrow	Present	Uncommon	Migratory	Native
Melospiza melodia	Song sparrow	Present	Common	Breeder	Native
Mergus merganser	Common merganser	Present	Common	Resident	Native
Mergus serrator	Red-breasted merganser	Present	Abundant	Resident	Native
Mimus polyglottos	Northern mockingbird	Present	Common	Breeder	Native
Mniotilta varia	Black-and-white warbler	Present	Uncommon	Breeder	Native
Molothrus ater	Brown-headed cowbird	Present	Common	Breeder	Native
Morus bassanus	Northern gannet	Present	Abundant	Migratory	Native
Myiarchus cinerascens	Ash-throated flycatcher	Present	Occasional	Vagrant	Native
Myiarchus crinitus	Great crested flycatcher	Present	Common	Breeder	Native
Numenius americanus	Long-billed curlew	Present	Occasional	Vagrant	Native
Numenius borealis	Eskimo curlew	Historic			Native
Numenius phaeopus	Whimbrel	Present	Common	Migratory	Native
Nycticorax nycticorax	Black-crowned night-heron	Present	Uncommon	Breeder	Native
Nycticorax violaceus	Yellow-crowned night-heron	Present	Rare	Migratory	Native
Oceanites oceanicus	Wilson's storm-petrel	Present	Common	Migratory	Native
Oceanodroma leucorhoa [3]	Leach's storm-petrel	Present	Rare	Migratory	Native
Oenanthe oenanthe	Northern wheatear	Present	Occasional	Vagrant	Native
Oporornis agilis	Connecticut warbler	Present	Occasional	Migratory	Native
Oporornis formosus	Kentucky warbler	Present	Rare	Migratory	Native
Oporornis Philadelphia [1]	Mourning warbler	Present	Rare	Migratory	Native
Oxyura jamaicensis	Ruddy duck	Present	Rare	Migratory	Native
Pandion haliaetus	Osprey	Present	Uncommon	Breeder	Native
Parula americana [2]	Northern parula	Present	Common	Migratory	Native
Passer domesticus	House sparrow	Present	Common	Breeder	Non-Native
Passerculus sandwichensis	Savannah sparrow	Present	Common	Breeder	Native
Passerella iliaca	Fox sparrow	Present	Uncommon	Migratory	Native
Passerina (Guiraca) caerulea [6]	Blue grosbeak	Present	Rare	Migratory	Native
Passerina ciris	Painted bunting	Present	Occasional	Vagrant	Native
Passerina cyanea	Indigo bunting	Present	Uncommon	Migratory	Native
Pelecanus erythrorhynchos	American white pelican	Present	Occasional	Vagrant	Native
Petrochelidon (Hirundo) pyrrhonota [6]	Cliff swallow	Present	Rare	Migratory	Native
Phalacrocorax auritus	Double-crested cormorant	Present	Abundant	Resident	Native
Phalacrocorax carbo	Great cormorant	Present	Uncommon	Resident	Native
Phalaropus fulicaria	Red phalarope	Present	Rare	Migratory	Native
Phalaropus lobatus	Red-necked phalarope	Present	Rare	Migratory	Native
Phalaropus tricolor	Wilson's phalarope	Present	Rare	Migratory	Native
Phasianus colchicus	Ring-necked pheasant	Present	Uncommon	Resident	Non-Native

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Pheucticus ludovicianus	Rose-breasted grosbeak	Present	Uncommon	Migratory	Native
Philomachus pugnax	Ruff	Present	Occasional	Vagrant	Native
Picoides arcticus	Black-backed woodpecker	Present	Occasional	Vagrant	Native
Picoides pubescens	Downy woodpecker	Present	Common	Breeder	Native
Picoides villosus	Hairy woodpecker	Present	Uncommon	Breeder	Native
Pinicola enucleator	Pine grosbeak	Present	Rare	Migratory	Native
Pipilo erythrophthalmus	Eastern towhee	Present	Common	Breeder	Native
Piranga ludoviciana	Western tanager	Present	Occasional	Vagrant	Native
Piranga olivacea	Scarlet tanager	Present	Uncommon	Breeder	Native
Piranga rubra	Summer tanager	Present	Rare	Migratory	Native
Plectrophenax nivalis	Snow bunting	Present	Common	Migratory	Native
Plegadis falcinellus	Glossy ibis	Present	Rare	Migratory	Native
Pluvialis dominica	American golden-plover	Present	Rare	Migratory	Native
Pluvialis squatarola	Black-bellied plover	Present	Abundant	Migratory	Native
Podiceps auritus	Horned grebe	Present	Uncommon	Migratory	Native
Podiceps grisegena	Red-necked grebe	Present	Uncommon	Migratory	Native
Podiceps nigricollis	Eared grebe	Present	Occasional	Vagrant	Native
Podilymbus podiceps [3]	Pied-billed grebe	Present	Uncommon	Migratory	Native
Poecile (Parus) atricapillus [6]	Black-capped chickadee	Present	Common	Breeder	Native
Poecile (Parus) hudsonicus [6]	Boreal chickadee	Present	Occasional	Vagrant	Native
Polioptila caerulea	Blue-gray cnatcatcher	Present	Rare	Breeder	Native
Pooecetes gramineus [2]	Vesper sparrow	Present	Rare	Breeder	Native
Porzana carolina	Sora	Present	Uncommon	Breeder	Native
Progne subis	Purple martin	Present	Rare	Migratory	Native
Protonotaria citrea	Prothonotary warbler	Present	Rare	Migratory	Native
Puffinus gravis	Greater shearwater	Present	Common	Migratory	Native
Puffinus griseus	Sooty shearwater	Present	Common	Migratory	Native
Puffinus puffinus	Manx shearwater	Present	Uncommon	Migratory	Native
Quiscalus quiscula	Common grackle	Present	Abundant	Breeder	Native
Rallus elegans [2]	King rail	Present	Occasional	Migratory	Native
Rallus limicola	Virginia rail	Present	Uncommon	Breeder	Native
Rallus longirostris	Clapper rail	Present	Rare	Migratory	Native
Recurvirostra americana	American avocet	Present	Occasional	Vagrant	Native
Regulus calendula	Ruby-crowned kinglet	Present	Common	Migratory	Native
Regulus satrapa	Golden-crowned kinglet	Present	Common	Migratory	Native
Riparia riparia	Bank swallow	Present	Uncommon	Breeder	Native
Rissa tridactyla	Black-legged kittiwake	Present	Abundant	Migratory	Native
Rynchops niger	Black skimmer	Present	Rare	Breeder	Native
Sayornis phoebe	Eastern phoebe	Present	Rare	Breeder	Native
Sayornis saya	Say's phoebe	Present	Occasional	Vagrant	Native
Scolopax minor	American woodcock	Present	Uncommon	Breeder	Native
Seiurus aurocapilla (aurocapillus) [6]	Ovenbird	Present	Common	Breeder	Native
Seiurus motacilla	Louisiana waterthrush	Present	Occasional	Migratory	Native

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Seiurus noveboracensis	Northern waterthrush	Present	Uncommon	Migratory	Native
Setophaga ruticilla	American redstart	Present	Common	Breeder	Native
Sialia currucoides	Mountain bluebird	Present	Occasional	Vagrant	Native
Sialia sialis	Eastern bluebird	Present	Uncommon	Breeder	Native
Sitta canadensis	Red-breasted nuthatch	Present	Uncommon	Breeder	Native
Sitta carolinensis	White-breasted nuthatch	Present	Common	Breeder	Native
Somateria mollissima	Common eider	Present	Abundant	Resident	Native
Somateria spectabilis	King eider	Present	Occasional	Migratory	Native
Sphyrapicus varius	Yellow-bellied sapsucker	Present	Uncommon	Migratory	Native
Spiza americana	Dickcissel	Present	Rare	Migratory	Native
Spizella arborea	American tree sparrow	Present	Uncommon	Migratory	Native
Spizella pallida	Clay-colored sparrow	Present	Rare	Migratory	Native
Spizella passerina	Chipping sparrow	Present	Common	Breeder	Native
Spizella pusilla	Field sparrow	Present	Uncommon	Breeder	Native
Stelgidopteryx serripennis	Northern Rough-winged swallow	Present	Uncommon	Breeder	Native
Stercorarius (Catharacta) mac-cormicki [6]	South polar skua	Present	Occasional	Vagrant	Native
Stercorarius (Catharacta) skua [6]	Great skua	Present	Occasional	Migratory	Native
Stercorarius longicaudus	Long-tailed jaeger	Present	Occasional	Migratory	Native
Stercorarius parasiticus	Parasitic jaeger	Present	Uncommon	Migratory	Native
Stercorarius pomarinus	Pomarine jaeger	Present	Uncommon	Migratory	Native
Sterna anaethetus	Bridled tern	Present	Occasional	Vagrant	Native
Sterna antillarum [1]	Least tern	Present	Common	Breeder	Native
Sterna caspia	Caspian tern	Present	Rare	Migratory	Native
Sterna dougallii [5, 7]	Roseate tern	Present	Common	Breeder	Native
Sterna elegans	Elegant tern	Present	Occasional	Vagrant	Native
Sterna forsteri	Forster's tern	Present	Uncommon	Migratory	Native
Sterna fuscata	Sooty tern	Present	Occasional	Vagrant	Native
Sterna hirundo [1]	Common tern	Present	Common	Breeder	Native
Sterna maxima	Royal tern	Present	Rare	Migratory	Native
Sterna nilotica	Gull-billed tern	Present	Occasional	Vagrant	Native
Sterna paradisaea [1]	Arctic tern	Present	Rare	Breeder	Native
Sterna sandvicensis	Sandwich tern	Present	Occasional	Vagrant	Native
Strix (Asio) varia [6]	Barred owl	Present	Occasional	Vagrant	Native
Sturnella magna	Eastern meadowlark	Present	Uncommon	Migratory	Native
Sturnella neglecta	Western meadowlark	Present	Occasional	Vagrant	Native
Sturnus vulgaris	European starling	Present	Common	Breeder	Non-Native
Tachycineta bicolor	Tree swallow	Present	Uncommon	Breeder	Native
Tachycineta thalassina	Violet-green swallow	Present	Occasional	Vagrant	Native
Thryothorus ludovicianus	Carolina wren	Present	Common	Breeder	Native
Toxostoma rufum	Brown thrasher	Present	Uncommon	Breeder	Native
Tringa flavipes	Lesser yellowlegs	Present	Common	Migratory	Native
Tringa melanoleuca	Greater yellowlegs	Present	Abundant	Migratory	Native

Park Accepted Name	Common Name	Occurrence	Abundance	Residency	Nativity
Tringa solitaria	Solitary sandpiper	Present	Uncommon	Migratory	Native
Troglodytes aedon	House wren	Present	Uncommon	Breeder	Native
Troglodytes troglodytes	Winter wren	Present	Uncommon	Migratory	Native
Tryngites subruficollis	Buff-breasted sandpiper	Present	Rare	Migratory	Native
Turdus migratorius	American robin	Present	Common	Breeder	Native
Tyrannus forficatus	Scissor-tailed flycatcher	Present	Occasional	Vagrant	Native
Tyrannus savana	Fork-tailed flycatcher	Present	Occasional	Vagrant	Native
Tyrannus tyrannus	Eastern kingbird	Present	Common	Breeder	Native
Tyrannus verticalis	Western kingbird	Present	Rare	Vagrant	Native
Tyrannus vociferans	Cassin's kingbird	Present	Occasional	Vagrant	Native
Tyto alba [1]	Barn owl	Present	Occasional	Migratory	Native
Uria aalge	Common murre	Present	Rare	Migratory	Native
Uria lomvia	Thick-billed murre	Present	Rare	Migratory	Native
Vermivora celata	Orange-crowned warbler	Present	Rare	Migratory	Native
Vermivora chrysoptera [3]	Golden-winged warbler	Present	Occasional	Migratory	Native
Vermivora peregrina	Tennessee warbler	Present	Rare	Migratory	Native
Vermivora pinus	Blue-winged warbler	Present	Rare	Migratory	Native
Vermivora ruficapilla	Nashville warbler	Present	Uncommon	Migratory	Native
Vireo flavifrons	Yellow-throated vireo	Present	Rare	Migratory	Native
Vireo gilvus	Warbling vireo	Present	Rare	Migratory	Native
Vireo griseus	White-eyed vireo	Present	Rare	Migratory	Native
Vireo olivaceus	Red-eyed vireo	Present	Common	Breeder	Native
Vireo philadelphicus	Philadelphia vireo	Present	Uncommon	Migratory	Native
Vireo solitarius	Solitary vireo	Present	Common	Migratory	Native
Wilsonia canadensis	Canada warbler	Present	Uncommon	Migratory	Native
Wilsonia citrina	Hooded warbler	Present	Rare	Migratory	Native
Wilsonia pusilla	Wilson's warbler	Present	Uncommon	Migratory	Native
Xanthocephalus xanthocephalus	Yellow-headed blackbird	Present	Rare	Vagrant	Native
Xema sabini	Sabine's gull	Present	Occasional	Migratory	Native
Zenaida asiatica	White-winged dove	Present	Occasional	Vagrant	Native
Zenaida macroura	Mourning dove	Present	Abundant	Breeder	Native
Zonotrichia albicollis	White-throated sparrow	Present	Common	Migratory	Native
Zonotrichia leucophrys	White-crowned sparrow	Present	Uncommon	Migratory	Native

Occurrence, abundance, residency, and nativity information from NPSpecies (accessed 8 October 2010) unless otherwise noted.

1 Massachusetts listed species status: special concern.
2 Massachusetts listed species status: threatened.
3 Massachusetts listed species status: endangered.
4 Federal listed and Massachusetts listed species status: threatened.
5 Federal listed and Massachusetts listed species status: endangered.
6 NPSspecies had invalid synonym (in parentheses).
7 NPSspecies was missing federal threatened and endangered status.

Scientific Name	Common Name	Occurrence	Abundance	Residency	Nativity
Terrestrial mammals					
Blarina brevicauda	Short-tailed shrew	Present	U	Breeder	Native
Canis latrans	Coyote	Present	U	Breeder	Native
Clethrionomys gapperi	Southern red-backed vole	Present	C	Breeder	Native
Condylura cristata	Star-nosed mole	Present	NA	Breeder	Native
Didelphis virginiana	Virginia Opossum	Present	U	Breeder	Native
Eptesicus fuscus	Big brown bat	Present	NA	Unknown	Native
Glaucomys volans	Southern flying squirrel	Present	U	Breeder	Native
Lasionycteris noctivagans	Silver-haired bat	Present	NA	Unknown	Native
Lasiurus borealis	Red bat	Present	NA	Migratory	Native
Lasiurus cinereus cinereus	Hoary Bat	Present	NA	Migratory	Native
Lepus americanus	Snowshoe hare	Present	R	Breeder	Unknown
Lontra (Lutra) canadensis [3]	River otter	Present	U	Breeder	Native
Marmota monax	Woodchuck	Present	R	Breeder	Native
Mephitis mephitis nigra	Striped skunk	Present	C	Breeder	Native
Microtus pennsylvanicus	Meadow vole	Present	A	Breeder	Native
Mus musculus	House mouse	Present	NA	Breeder	Non-Native
Mustela erminea	Ermine	Unconfirmed	NA	NA	Native
Mustela frenata	Long-tailed weasel	Present	R	Breeder	Native
Neovison (Mustela) vison [3]	Mink	Present	R	Breeder	Native
Myotis lucifugus	Little brown bat	Present	NA	Breeder	Native
Odocoileus virginianus virginianus (virgin-ianus borealis) [3]	Whitetail deer	Present	C	Breeder	Native
Ondatra zibethicus	Muskrat	Present	C	Breeder	Native
Peromyscus leucopus	White-footed mouse	Present	A	Breeder	Native
Procyon lotor	Raccoon	Present	A	Breeder	Native
Rattus norvegicus	Norway rat	Present	NA	Breeder	Non-Native
Scalopus aquaticus aquaticus	Eastern mole	Present	NA	Breeder	Native
Sciurus carolinensis	Eastern gray squirrel	Present	A	Breeder	Native
Sorex cinereus cinereus	Masked shrew	Present	C	Breeder	Native
Sylvilagus floridanus	Eastern cottontail	Present	C	Breeder	Non-Native
Sylvilagus transitionalis	New England Cottontail	Historic	NA	Breeder	Native
Tamias striatus	Eastern chipmunk	Present	C	Breeder	Native
Tamiasciurus hudsonicus	Red squirrel	Present	C	Breeder	Native
Vulpes vulpes	Red fox	Present	U	Breeder	Non-Native
Zapus hudsonius	Meadow jumping mouse	Present	C	Breeder	Native

Scientific Name	Common Name	Occurrence	Abundance	Residency	Nativity
Marine mammals					
Balaenoptera acutorostrata	Minke whale	Present	U	Resident	Native
Balaenoptera borealis [1]	Sei whale	Present	O	Vagrant	Native
Balaenoptera musculus [2]	Blue Whale	Present	O	Vagrant	Native
Balaenoptera physalus [1]	Finback whale	Present	C	Resident	Native
Cystophora cristata	Hooded seal	Present	O	Vagrant	Native
Delphinus delphis	Common dolphin	Present	R	Migratory	Native
Eubalaena glacialis [1]	Northern right whale	Present	U	Resident	Native
Globicephala melas (melaena) [3]	Pilot whale	Present	R	Migratory	Native
Grampus griseus	Gray grampus	Present	O	Vagrant	Native
Halichoerus grypus	Gray seal	Present	C	Resident	Native
Lagenorhynchus acutus	Atlantic white-sided dolphin	Present	C	Migratory	Native
Lagenorhynchus albirostris	White-beaked Dolphin	Present	O	Migratory	Native
Megaptera novaeangliae [1]	Humpback whale	Present	C	Resident	Native
Orcinus orca	Orca	Present	O	Vagrant	Native
Pagophilus groenlandicus	Harp seal	Present	O	Vagrant	Native
Phoca vitulina	Harbor seal	Present	C	Resident	Native
Phocoena phocoena	Harbor porpoise	Present	C	Resident	Native
Physeter macrocephalus (catodon) [2, 3]	Sperm whale	Present	O	Vagrant	Native
Stenella coeruleoalba	Striped Dolphin	Present	O	Vagrant	Native
Tursiops truncatus	Atlantic Bottlenose Dolphin	Present	O	Vagrant	Native

Abundance: A: abundant, C: common, O: Occasional; R: Rare, U: uncommon; NA: unknown. Occurrence, abundance, residency, and nativity information from NPSpecies (accessed 8 October 2010) unless otherwise noted.

1 Federal and Massachusetts listed species status: endangered.
2 Massachusetts listed species status: endangered.
3 NPSspecies had invalid synonym (in parentheses).

Appendix B. Checklist of the birds of Cape Cod, Massachusetts.

CHECKLIST OF THE BIRDS OF CAPE COD, MASSACHUSETTS

PUBLISHED BY THE CAPE COD BIRD CLUB

This checklist contains 322 species that have been recorded on Cape Cod at least 10 times over the last 20 years. The taxonomic sequence follows the 7th edition of the *American Ornithologist's Union Checklist of the Birds of North America* (1998) and subsequent supplements. Each species' status through the seasons is shown by means of a bar graph.

KEY:

= Abundant and widespread; easily found and often in very large numbers.

= Common; easily found in the proper habitat.

= Uncommon and/or local; generally seen only in small numbers or within very restricted habitats.

= Rare but regular; recorded every year but usually hard to find.

= Very rare and irregular; not seen every year.

CODES:

- ✱ = Nesting confirmed during the last decade.
- ✚ = Nesting suspected but not confirmed during the last decade.
- E = Erratic; numbers highly variable from year to year.
- P = Pelagic; checklist indicates status near shore, including Stellwagen Bank, rather than offshore.
- ↑ = Species has increased locally in recent years.
- ↓ = Species has decreased locally in recent years.

Report sightings of any rare species to:

Wellfleet Bay Wildlife Sanctuary, South Wellfleet (508-349-2615)
Birdwatcher's General Store, Orleans (508-255-6974)

Checklist Prepared by Blair Nikula

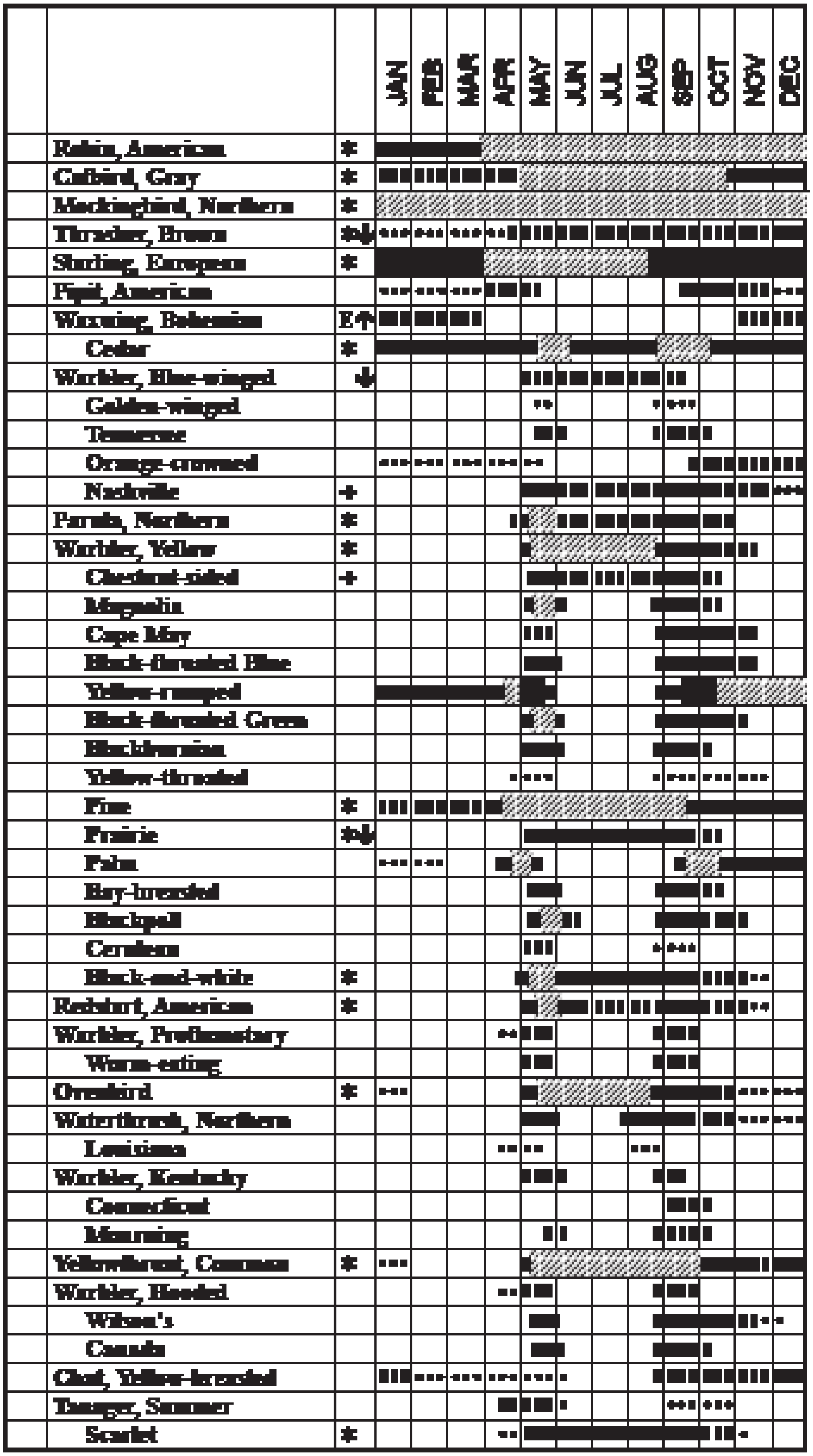
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	Goose, Snow													
	Atlantic Brant													
	Goose, Canada	*												
	Swan, Mute	*												
	Duck, Wood	*												
	Gadwall	*												
	Wigeon, Eurasian													
	American	*												
	Duck, American Black	*												
	Mallard	*												
	Teal, Blue-winged	*↓												
	Shoveler, Northern	*												
	Pintail, Northern	*												
	Teal, Green-winged	*												
	Canvasback	↓												
	Redhead													
	Duck, Ring-necked													
	Scaup, Greater													
	Lesser													
	Eider, King													
	Common													
	Duck, Harlequin													
	Scoter, Surf													
	White-winged													
	Black													
	Duck, Long-tailed													
	Bufflehead													
	Goldeneye, Common													
	Barrow's													
	Merganser, Hooded	↑												
	Common													
	Red-breasted													
	Duck, Ruddy	*												
	Pheasant, Ring-necked	*↓												
	Grouse, Ruffed	*↓												
	Turkey, Wild	*↑												
	Bobwhite, Northern	*↓												
	Loon, Red-throated													
	Pacific													
	Common													
	Grebe, Pied-billed	↓												
	Horned													
	Red-necked													
	Fulmar, Northern	PE												
	Shearwater, Cory's	P												
	Greater	P												

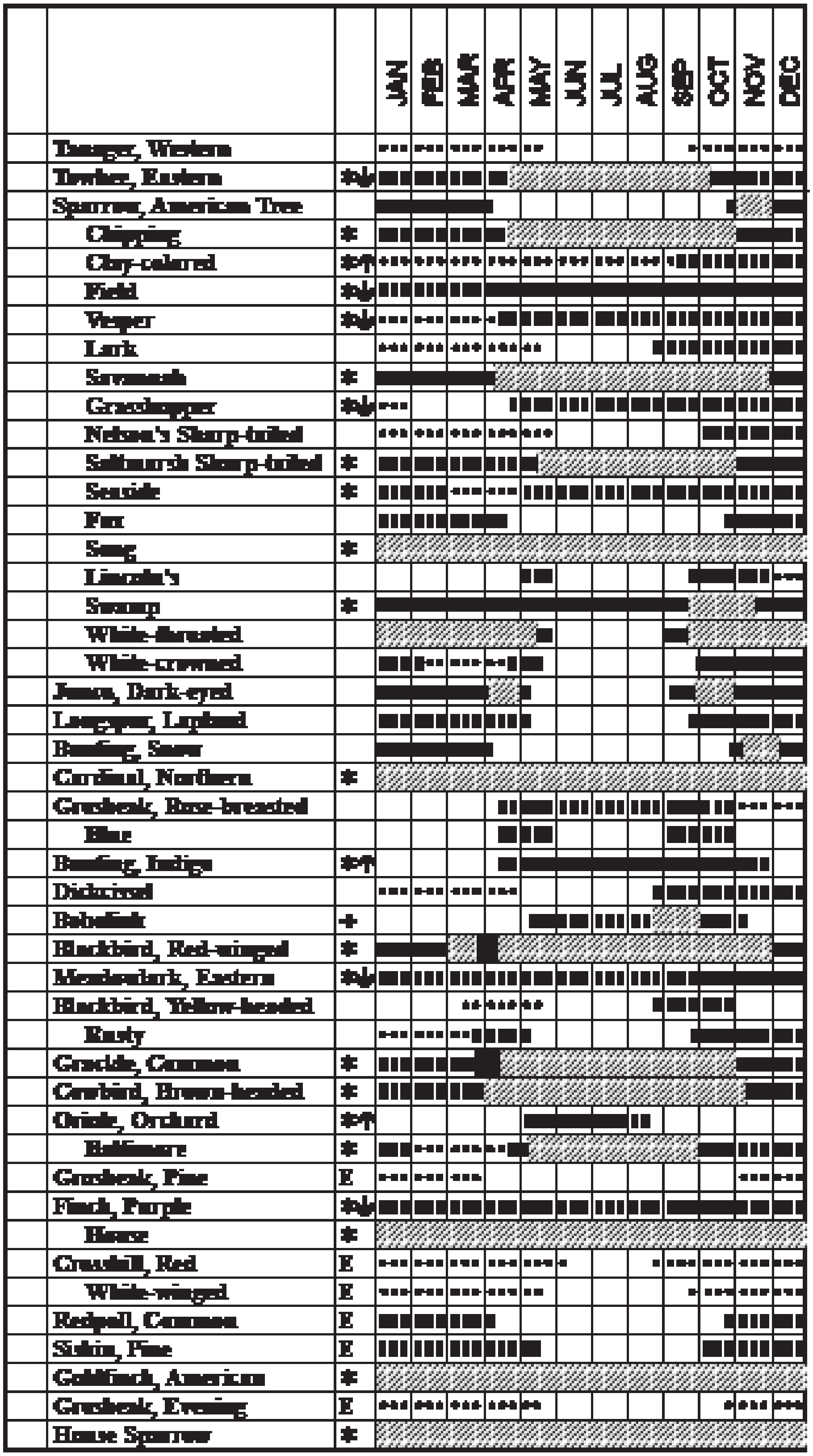
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	Sooty	P												
	Manx	P												
	Storm-Petrel, Wilson's	P												
	Leach's	P												
	Gannet, Northern													
	Cormorant, Double-crested	*↑												
	Great													
	Bittern, American													
	Least													
	Heron, Great Blue													
	Egret, Great	*↑												
	Snowy	*↓												
	Heron, Little Blue													
	Tricolored													
	Egret, Cattle													
	Heron, Green	*↓												
	Night-Heron, Black-crowned	*↓												
	Yellow-crowned													
	Ibis, Glossy	*												
	Vulture, Black	↑												
	Turkey	*↑												
	Osprey	*↑												
	Kite, *Swallow-tailed*													
	Mississippi	↑												
	Eagle, Bald	↑												
	Harrier, Northern	*↓												
	Hawk, Sharp-shinned	*												
	Cooper's	*↑												
	Goshawk, Northern													
	Hawk, Red-shouldered	*												
	Broad-winged	*												
	Red-tailed	*												
	Rough-legged	E												
	Kestrel, American	*↓												
	Merlin													
	Falcon, Peregrine	↑												
	Rail, Clapper	+												
	King	*												
	Virginia	*												
	Sora	+												
	Moorhen, Common	↓												
	Coot, American													
	Plover, Black-bellied													
	Golden-Plover, American													
	Plover, Semipalmated													
	Piping	*												

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	Killdeer	*												
	Oystercatcher, American	*												
	Avocet, American													
	Sandpiper, Spotted	*↓												
	Yellowlegs, Greater													
	Willet	*												
	Yellowlegs, Lesser													
	Sandpiper, Solitary													
	Upland	*↓												
	Whimbrel													
	Godwit, Hudsonian	↓												
	Marbled													
	Turnstone, Ruddy													
	Knot, Red	↓												
	Sanderling													
	Sandpiper, Semipalmated													
	Western													
	Least													
	White-rumped													
	Baird's													
	Pectoral													
	Purple													
	Dunlin													
	Sandpiper, Curlew													
	Stilt													
	Buff-breasted													
	Ruff													
	Dowitcher, Short-billed													
	Long-billed													
	Snipe, Wilson's													
	Woodcock, American	*												
	Phalarope, Wilson's													
	Red-necked	P												
	Red	P												
	Gull, Laughing	*												
	Little													
	Black-headed													
	Bonaparte's													
	Ring-billed													
	Herring	*												
	Iceland													
	Lesser Black-backed	↑												
	Glaucous													
	Great Black-backed	*												
	Sabine's													
	Kittiwake, Black-legged													

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Tern, Least	*												
Caspian													
Black													
Roseate	*												
Common	*												
Arctic	*↓												
Forster's													
Royal													
Sandwich													
Skimmer, Black	*												
Great Skua	P												
Jaeger, Pomarine	P												
Parasitic	P												
Long-tailed	P												
Dovekie	P,E												
Murre, Common	P												
Thick-billed	P												
Razorbill													
Black Guillemot													
Puffin, Atlantic	P												
Pigeon, Rock	*												
Dove, Mourning	*												
Cuckoo, Yellow-billed	*												
Black-billed	*												
Screech-Owl, Eastern	*												
Owl, Great Horned	*												
Snowy	E												
Barred	*↑												
Long-eared													
Short-eared	↓												
Northern Saw-whet	*												
Nighthawk, Common													
Chuck-will's-widow	*↑												
Whip-poor-will	*↓												
Swift, Chimney	*												
Hummingbird, Ruby-throated	*												
Rufous	↑												
Kingfisher, Belted	*												
Woodpecker, Red-headed													
Red-bellied	*↑												
Sapsucker, Yellow-bellied													
Woodpecker, Downy	*												
Hairy	*												
Flicker, Northern	*												
Flycatcher, Olive-sided													
Wood-Pewee, Eastern	*												

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	Flycatcher, Yellow-bellied													
	Acadian	*↑												
	Alder													
	Willow	*												
	Least													
	Phoebe, Eastern	*												
	Great Crested	*												
	Kingbird, Western													
	Eastern	*												
	Flycatcher, Scissor-tailed													
	Shrike, Northern	E												
	Vireo, White-eyed													
	Yellow-throated													
	Blue-headed													
	Warbling	+												
	Philadelphia													
	Red-eyed	*												
	Jay, Blue	*												
	Crow, American	*												
	Fish	*↑												
	Lark, Horned	*												
	Martin, Purple	*												
	Swallow, Tree	*												
	Northern Rough-winged	*												
	Bank	*												
	Cliff													
	Barn	*												
	Chickadee, Black-capped	*												
	Titmouse, Tufted	*												
	Nuthatch, Red-breasted	*E												
	White-breasted	*												
	Creeper, Brown	*												
	Wren, Carolina	*												
	House	*												
	Winter													
	Marsh	*												
	Kinglet, Golden-crowned	*												
	Ruby-crowned													
	Gnatcatcher, Blue-gray	*												
	Bluebird, Eastern	*↑												
	Veery													
	Thrush, Gray-cheeked													
	Bicknell's													
	Swainson's													
	Hermit	*												
	Wood	*↓												


JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Robin, American
Catbird, Gray
Mockingbird, Northern
Thrasher, Brown
Starling, European
Pipit, American
Waxwing, Bohemian
Cedar
Warbler, Blue-winged
Golden-winged
Tennessee
Orange-crowned
Nashville
Parula, Northern
Warbler, Yellow
Chestnut-sided
Magnolia
Cape May
Black-throated Blue
Yellow-rumped
Black-throated Green
Blackburnian
Yellow-throated
Pine
Prairie
Palm
Bay-breasted
Blackpoll
Cerulean
Black-and-white
Redstart, American
Warbler, Prothonotary
Worm-eating
Ovenbird
Waterthrush, Northern
Louisiana
Warbler, Kentucky
Connecticut
Mourning
Yellowthroat, Common
Warbler, Hooded
Wilson's
Canada
Chat, Yellow-breasted
Tanager, Summer
Scarlet


JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Tanager, Western
Towhee, Eastern *↓
Sparrow, American Tree
Chipping *
Clay-colored *↑
Field *↓
Vesper *↓
Lark
Savannah *
Grasshopper *↓
Nelson's Sharp-tailed
Saltmarsh Sharp-tailed *
Seaside *
Fox
Song *
Lincoln's
Swamp *
White-throated
White-crowned
Junco, Dark-eyed
Longspur, Lapland
Bunting, Snow
Cardinal, Northern *
Grosbeak, Rose-breasted
Blue
Bunting, Indigo *↑
Dickcissel
Bobolink +
Blackbird, Red-winged *
Meadowlark, Eastern *↓
Blackbird, Yellow-headed
Rusty
Grackle, Common *
Cowbird, Brown-headed *
Oriole, Orchard *↑
Baltimore *
Grosbeak, Pine E
Finch, Purple *↓
House *
Crossbill, Red E
White-winged E
Redpoll, Common E
Siskin, Pine E
Goldfinch, American *
Grosbeak, Evening E
House Sparrow *

NPS 609/118309, December 2012

National Park Service
U.S. Department of the Interior

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