The Ecology of Coastal Salt Ponds

A Pilot Study at Long Point Wildlife Refuge

West Tisbury and Chilmark, Martha's Vineyard

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Photographs and Maps
Cover background: Tisbury Great Pond and Long Point Wildlife Refuge shoreline.
Cover photographs, clockwise from top left: coastal salt pond shoreline with Switchgrass, Red Maple Shrub Swamp at the head of Long Cove Pond, and 1858 map of Tisbury Great Pond showing Long Cove Pond as attached to Tisbury Great Pond (see section 4.1).

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Executive Summary

- Coastal salt ponds are rare habitats that are restricted to the shores of southern New England and Long Island. The health of these ponds is threatened throughout this region by air pollution, exotic species, pathogens, jetty constuction, excessive pond uses, and excess nitrogen from septic systems, sewage treatment plants, fertilizers, and other sources. The ponds surrounding Long Point Wildlife Refuge—Tisbury Great Pond, Long Cove Pond, and Big Homer's Pond—are home to a wide variety of interesting plants and animals, and people have used these ponds for thousands of years.

- This study, conducted in 2000, investigates the relationships between the ponds' physical conditions and the patterns of plants and animals found living within these unique aquatic systems. Seventeen sampling stations were established in the coastal salt ponds surrounding Long Point to sample salinity, temperature, oxygen availability, nutrient and phytoplankton concentrations, bottom sediment characteristics, presence and types of submerged aquatic vegetation, composition of invertebrates, and composition of the fish community.

- For thousands of years Wampanoag populations, and later, European settlers, used coastal salt ponds for sustenance. Shellfish and fish comprised a significant part of the Wampanoag diet. In the 1800s, European settlers harvested massive numbers of Striped Bass, American Eel, Smelts, and Alewife, and White Perch was introduced to the pond in 1869. American Eel were still harvested using methods similar to those of the Wampanoag. Today, American Oysters continue to be harvested from Tisbury Great Pond and account for over half of Martha's Vineyard's total oyster harvest.

- European settlers have opened Tisbury Great Pond's barrier beach since 1694, to maintain salt hay meadows for livestock grazing and to allow anadramous and catadramous fish to enter and leave the ponds. Today, the barrier beach is opened to manage salinities for a healthy oyster fishery, prevent flooded cellars and pondshore erosion, and for swimming, crabbing, and boating.

- Coastal salt ponds and their ecology are a result of physical processes occurring over thousands of years. Many of these are dynamic processes that are still undergoing change today, as the sea level continues to rise, the climate changes, and land-use patterns in their watersheds are changing through succession, development, and habitat management.

- These ponds are highly dynamic in nature, with their physical properties varying considerably in space and time. Salinities range from fresh to brackish, and vary depending upon human management practices and the size of their watershed.

- Water, and any nutrients or chemicals carried in that water, enters these coastal salt ponds from their watersheds, through groundwater flow, surface water (tributary streams), direct precipitation onto the ponds, and storm runoff.

- The ponds' bottom sediments are highly patchy, with a variety of conditions—sands of various textures, organic matter, and shell fragments—creating a variety of microhabitats.

- The summer of 2000 was unusually cloudy and rainy. Water temperatures peaked in mid-July and then fell to their mid-June levels again by late August. Water temperatures were cooler than most years, when solar radiation and warm summer air temperatures cause a warming of water temperatures throughout the summer months.

- Oxygen levels were consistently high in the coastal salt ponds at Long Point in 2000. Oxygen saturation was typically above 100% for Tisbury Great Pond, and the lowest reading for the freshwater ponds was 109% saturation. No low oxygen conditions were encountered while sampling in the coves.

- Dissolved inorganic nitrogen (DIN) is an important measure of nutrient enrichment. Dissolved nitrogen is rapidly used by aquatic plants and remain at low levels during the growing season. In the summer of 2000, DIN spikes in the coves of Tisbury Great Pond and freshwater ponds after heavy rains reveal the importance of land-derived inorganic nitrogen contribution to these areas through surface streams and groundwater.

- Silicate enters the ponds through streams, and high levels indicate a large influence of ground and stream water recharge to these ponds. Silicate levels rose and peaked in late August, when Tisbury Great Pond refilled with fresh water, and fell again after a pond opening, when seawater diluted the pond.

- Particulate organic nitrogen and carbon—suspended detritus from cellular breakdown—increase throughout the growing season. Particulate matter is flushed out of the coves by heavy rains and diluted in the center of Tisbury Great Pond by newly entering seawater after an opening, or accumulates on the bottom of the freshwater ponds as a thin flocculant layer.

- Excess delivery of nutrients from watershed land uses to coastal ponds can lead to algal blooms, low oxygen conditions, and even fish kills. A combination of high levels of nitrogen, high concentrations of phytoplankton, low water clarity, and low oxygen saturation are used as indicators of an unhealthy pond. Tisbury Great Pond and the upper reaches of Long Cove Pond exhibit some of these features—high concentrations of phytoplankton and low transparency—during the growing season. This is consistent with results from the Martha's Vineyard Commission that suggests that these ponds will become unhealthy if nitrogen inputs into these ponds continue to increase. The watershed of Big Homer's Pond, on the other hand, is relatively free of development and exhibits high water clarity and low phytoplankton levels throughout the summer.

- Submerged aquatic vegetation communities vary depending upon pond salinities and water depth. Communities include Eelgrass beds, Dwarf Spike Rush and Water Lobelia glades, algae-dominated sediments, and pondweed and tapegrass beds. Thirteen species of aquatic plants were found growing on the pond bottoms, and were dense at mid-depths where light was sufficient, but declined in size and abundance in deeper waters where light penetration was limited.

- Almost 100 species of plants live along the five miles of pond shores at Long Point. These plants exist along a gradient of conditions, and occur as recognizable vegetation communities. These include grass-dominated associations, Sea Rocket associations, Mudwort associations, Water Willow swamps, and shrub swamps.

- The types of invertebrate life present in the salt ponds depend upon the salinity of the individual pond. The brackish Tisbury Great Pond and its coves have a diverse community of filter-feeding shellfish in addition to detritivorous and predacous worms and crustaceans. Blue Crab are the largest and most numerous crustacean present, and its population varies from year to year, depending upon the timing and duration of the pond opening. American

Oyster is the most abundant shellfish, and juvenile Soft-Shell Clam and Baltic Macoma are common in the sandy bottom community. Many insects, such as waterstriders, live in the freshwater ponds as adults, while others, such as flies and dragonflies, live and feed in the pond as aquatic juveniles.

- Twenty-three species of fish were caught in the salt ponds around Long Point in the summer and fall of 2000. Common residents include the small but abundant Mummichogs, Atlantic Silversides, and Four-spine Sticklebacks, while migratory fishes include American Eel, Atlantic Menhaden, Striped Cusk-Eel, Summer Flounder, and Winter Flounders. The presence of any one fish species depends greatly on the timing of the pond openings and closings, and how these relate to each species' life-cycle. Spring pond openings are important to the entry of catadramous spawners, such as alewives, and the fall openings are crucial to fishes that use the pond as a nursery, such as Menhaden and the flounders, to allow the departure of juveniles to the ocean.

- The freshwater fish fauna of eastern Massachusetts is relatively poor in the number of fish species, due to our recent history of glaciation. Seven species of native freshwater fishes live in streams of the Tisbury Great Pond, including American Eel, Tesselated Darter, and American Brook Lamprey, a threatened species in Massachusetts. Small ponds of the watershed have another four species, including Banded Sunfish and Bluegills.

- A wide variety of reptiles, birds and mammals feed, breed, and take refuge in and around the ponds at Long Point. They are constantly changing with the seasons. Large rafts of waterfowl winter in ice-free areas of the ponds, and terns and shorebirds, including the federally threatened Piping Plover, use the beaches, shores and shallow waters to nest and forage in the summer. Spring brings loud Spring Peeper choruses, and newly born River Otter to the ponds.

- Development within the entire watershed can be a significant source of excess nutrients to coastal ponds, which can result in eutrophication. A rising number of houses can contribute directly to the cumulative nitrogen loading in the watershed through an increase in the number of on-site septic systems. These systems, especially if poorly constructed or maintained, discharge nitrogen into the groundwater. The control of nitrogen inputs in the watershed is a crucial part of preventing eutrophication and its undesirable consequences to the scenic, recreational, and economic resources within the salt ponds.

- Nutrient loading to a coastal pond can be partly managed by controlling nutrient sources within the watershed. The protection of open space through land conservation, and implementing pollution prevention methods, such as vegetated buffer strips between livestock and the pond shore, all help to reduce the impacts on pond water quality. Other means to reduce nitrogen loading could include adopting an annual nitrogen loading limit for Tisbury Great Pond, changes in regulations to manage contributions within the watershed at or below that limit, requiring advanced on-site nitrogen-removing septic systems in future construction, and encouraging retention of native plant communities around homes, rather than planting lawns that require fertilizers to maintain them.

- Flexible, adaptive management that is regularly updated and evaluated by current science and monitoring results and based on land-use demographics may be the most viable management option for coastal salt ponds around Long Point and on Martha's Vineyard. Linking concepts of nitrogen management and available site-specific knowledge to establish operational and sustainable management goals is the challenge that faces the residents of the ponds' watersheds.

- Tisbury Great Pond is currently managed to support an active oyster fishery. This has become a greater challenge since a new disease, called Dermo, was found in the pond. Management of this disease to maintain a viable recreational and commercial oyster fishery may involve future efforts to maintain low salinity conditions that inhibit the spread of the disease, or may involve a more rapid grow-out of the oysters to commercial size, as is being tried in Edgartown Great Pond. Ongoing monitoring will be crucial to any future management decisions.

- Dams built in the past three hundred years have created barriers to the uninterrupted water flow in the streams entering Tisbury Great Pond that is needed by native anadromous and catadromous fishes to reproduce and maintain viable populations and fisheries. American Eel, Herring, and Alewive would benefit from the provision of structures to allow for upstream and downstream migration and passage at barriers.

- Non-native species have been introduced to local coastal waters from other continents for centuries, and a variety of these live in the coastal salt ponds surrounding Long Point, including Common Atlantic Slippersnail, Green Crab, Asian Shore Crab, and Mute Swan. Others, such as the Zebra Mussel and Eurasian Water-milfoil, do not currently occur here, but could be introduced through careless boating practices. Monitoring of the presence and effects of these species is recommended for the future.

- Future research needs on the conditions and relationships occurring in these ponds include surveying for eelgrass bed distribution and screening for wasting disease; determining the macroalgal species composition and biomass; determining the flushing rate of the ponds; and studying the variety, abundance, seasonality, and habitat associations of the invertebrates and insects found along the pond shores.

- Ongoing monitoring needed to inform management in the watershed includes monitoring the groundwater at the head of Long Cove Pond for nitrogen inputs; establishing monitoring sites for invertebrate populations as another measure of health in the ponds; monitoring for development of hypoxic bottom conditions; monitoring the shoreline intensively to identify problem areas of high DIN input into the ponds; monitoring for the presence of nuisance exotic species; monitoring and documenting changes in land-use patterns and demographics in the watershed on a ten-year cycle; and continuing to monitor oyster beds for shellfish diseases.

1 Introduction

Coastal salt ponds are rare habitats, restricted to areas of New England and Long Island where outwash plains formed.[1] Three coastal salt ponds lie within and adjacent to The Trustees of Reservations' Long Point Wildlife Refuge on the south shore of West Tisbury, Massachusetts: Tisbury Great Pond (800 acres; partly in Chilmark, MA), Long Cove Pond (86 acres), and Big Homer's Pond (32 acres; see figure 1.1[2]). Although they derive their name from their proximity to and relationship with the ocean, coastal salt ponds have a continuous freshwater source, through rainfall, stream flow, and groundwater flow from the watersheds. Their physical properties, therefore, vary considerably in time and space.

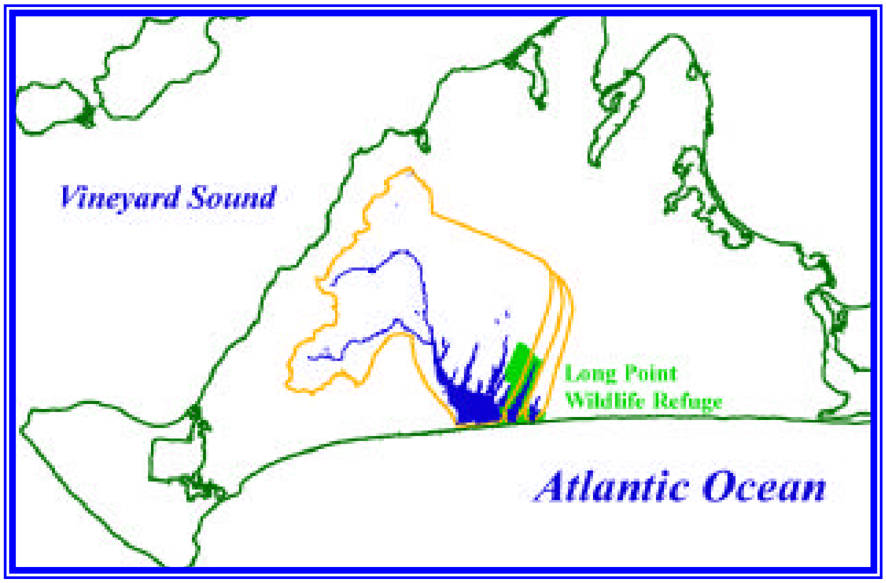

Figure 1.1: Locus map of the coastal salt ponds, their tributaries (blue), and their watersheds (boundaries in yellow; see section 3.3 and see figure 2.1 for detailed waterbody names) on Martha's Vineyard, MA. Tisbury Great Pond is the largest, western-most pond; Long Cove Pond is to its east; and Big Homer's Pond is the eastern-most and smallest pond. Long Point Wildlife Refuge is located to the east of Tisbury Great Pond and encompasses Long Cove Pond and the southern half of Big Homer's Pond.

These habitats are threatened region-wide by nutrient loading from development in their watersheds, jetty construction, exotic species, pathogens, and excessive pond uses. The ponds surrounding Long Point are home to a wide variety of interesting plants and animals, and people have used these ponds for thousands of years for recreation and sustenance.

These ponds and their tributaries are home to a wide array of wildlife—River Otter (*Lutra canadensis*), Muskrat (*Ondatra zibethica*), Great Blue Heron (*Ardea herodias*), Belted Kingfisher (*Ceryle alcyon*), wintering ducks, Osprey (*Pandion haliaetus*), over 30 species of finfish, dragonflies, anemone, grass shrimp, Blue Crab (*Callinectes sapidus*), clams, Eastern Oyster (*Crassostrea virginica*), an abundance of midges, and many species of shellfish and worms.

[1] The Natural Heritage and Endangered Species Program considers these habitats to be ranked threatened state-wide (S2). Swain. P. C. and J. B. Kearsley. 2000 Draft. *Classification of the Natural Communities of Massachusetts*. The Natural Heritage and Endangered Species Program, MA Division of Fisheries and Wildlife, Westborough, MA. These habitats, however, do not occur outside of Long Island and New England.

[2] Tisbury Great Pond outwash plain boundaries derived from: Wilcox, W. 1996. *Tisbury Great Pond Watershed Study*. Martha's Vineyard Commission, Oak Bluffs, MA. 21 pp. and appendices. Morainal boundaries were derived from topographic map analyses. Note: watershed boundaries in some cases need further refining as groundwater boundaries are often difficult to interpret.

They also support a wide variety of vegetation—algae, over a dozen submerged aquatic vegetation species, and almost 100 species of pond shore plants. These plants include interesting species ranging from Eelgrass (*Zostera marina*) to Swamp Rose Mallow (*Hibiscus palustris*). These species and ecosystem dynamics are threatened, however, by exotic species such as the Mute Swan (*Cygnus olor*), Common Periwinkle (*Littorina littorea*), Green Crab (*Carcinus maenas*), and Asian Shore Crab (*Hemigrapsus sanguineus*).

Regionally, salt pond ecosystems are threatened by an increase of nitrogen delivery from the watershed, due to a twenty-fold increase in nitrogen input from the atmosphere (i.e. acid rain) since prehistoric times,[3] and land-use and development (see figure 1.2) in the surrounding watersheds that contribute rising volumes of nutrients and pollutants into the ponds.[4] High fecal coliform levels have caused repeated closure to shell fishing in parts of Tisbury Great Pond in the past.[5] Likewise, bioaccumulation of roadway runoff has become a concern.[6] Although Tisbury Great Pond is presently only showing a few early signs of cultural eutrophication, increased nitrogen and phosphorous levels have adversely affected coastal bays and estuaries on Cape Cod[7] and Rhode Island.[8] The threat of eutrophication through nitrogen loading is tangible on Martha's Vineyard as well.[9]

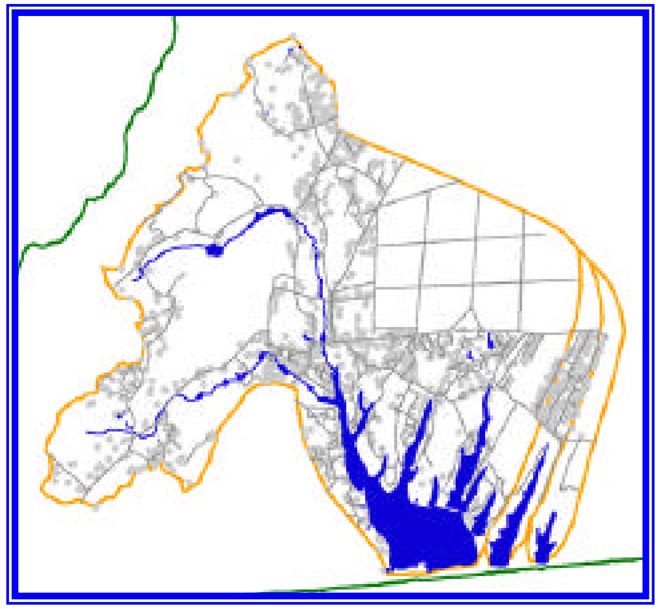

Figure 1.2: Development in the watersheds is increasing. Structures (light grey squares) are being built at a rapid rate along the road systems of West Tisbury and Chilmark on Martha's Vineyard.

The salt ponds on Martha's Vineyard are ecologically significant, in part, because of a comparably low level of human impact. Jetties have been constructed at the opening of many coastal salt ponds in the region, to maintain a permanent, tidal opening in the ponds for boating, navigation, shellfish management, and nutrient management. These permanent openings allow a continuous exchange of seawater

[3] Nixon, S.W. 1997. Prehistoric nutrient inputs and productivity in Narragansett Bay. *Estuaries* 20(2):253-261.
[4] Wilcox, W. 1996, and Culliton, T.J. et al. 1990. *50 years of Population Change Along the Nation's Coasts 1960-2010*. NOAA, NOS, OMA, Strategic Assessment Branch.
[5] West Tisbury Planning Board. July 20, 1986.
[6] Martha's Vineyard Commission and J. Taylor. 1994. *Great Pond Management on Martha's Vineyard.* Martha's Vineyard Commission, Oak Bluffs, MA. 56 pp.
[7] Caraco, N., A. Tamse, O. Boutros, and I. Valiela. 1987. Nutrient limitation of phytoplankton growth in brackish coastal ponds. *Can. J. Fish. Aquat. Sci*. 44:473-476.
[8] Imperial, M. 1999. Analyzing Institutional Arrangement for Ecosystem-based Management: Lessons from the Rhode Island Salt Ponds SAM Plan. *Coastal Management* 27:31-56.
[9] Wilcox, W. 1999. *Island Coastal Ponds Water Quality Survey. Final Report. 1995-1996 Survey Data*. The Island Ponds Consortium, Oak Bluffs, MA. 84 pp. & Appdc.
Martha's Vineyard Commission. 2000. *Nutrient Loading to Tisbury Great Pond*. Martha's Vineyard Commission, Oak Bluffs, MA. 66 pp. & Appdx.

between the pond and ocean, changing the environment to create a more saline-adapted community. However, jetties have not been built to maintain permanent, navigable openings in the more remote south shore of Martha's Vineyard. Today, the salt ponds of Martha's Vineyard's south shore are some of the few seasonally opened, dynamic salt ponds remaining in this region. By contrast with development in Cape Cod and Rhode Island's coastal pond watersheds, the density of human settlement is relatively low within many watersheds on Martha's Vineyard.[10] In recent years, however, the coastal salt ponds around Long Point Wildlife Refuge and elsewhere are becoming threatened by growing development pressures within their watersheds.[11] This has the potential to create eutrophic[12] conditions, changing the ecology of the salt ponds.

The spatial and temporal distribution of plants and animals in a salt pond is largely controlled by its physical characteristics—salinity, temperature, sediments, turbidity, nutrients, dissolved oxygen, and many other factors. The coastal salt ponds at Long Point Wildlife Refuge range in salinity from fresh to brackish. Larger ponds, such as Tisbury Great Pond, that are regularly opened to the ocean by humans or storm events[13] have a rapidly shifting salinity regime and experience abrupt changes in water levels and thus, volume and shoreline location. These openings can affect water mixing and stratification within a pond, currents and sediment movement, turbidity and thus available light levels for aquatic plants, and nutrient and oxygen distribution.[14] The seasonal timing of these openings is also an important determinant of the ponds' fauna, as they provide the opportunity for invertebrates and fish to enter through the inlet and for migration of adults, juveniles, and larvae out into the open ocean. A wide variety of sediments and soils provide homes for different species. Groundwater seepage areas, streams, and pond shorelines all provide additional microhabitats for wildlife.

This report is based on extensive fieldwork, lab analysis, and literature reviews, synthesizing current knowledge about coastal salt ponds, focusing on the ponds at Long Point. The report is holistic and describes the following— geological history of the ponds; history of human use of the ponds; physical characteristics of the ponds; submerged aquatic vegetation; bottom sediments; pond shore vegetation; invertebrates, with a focus on benthic invertebrates; vertebrates, with a focus on finfish; nitrogen inputs and land use in the watersheds; fisheries management; exotic species management; and nutrients and their effects on coastal salt ponds. As this report is the result of a pilot study, it should raise more questions about these subjects than it answers.

2 Objectives and Methods of the Coastal Salt Ponds Study

The objectives of the coastal salt ponds study were to determine what plants and animals live in the ponds, to see what patterns exist and how the biota interact with the physical environment, to determine the threats to the biological, scenic, and recreational quality of the ponds, and to ascertain what measures may be needed to ensure the long-term survival of healthy coastal salt

[10] Martha's Vineyard also has highly developed watersheds: Sengekontacket and Lagoon Ponds, for example.
[11] Martha's Vineyard Commission, 2000.
[12] Eutrophication, a process of nutrient enrichment resulting in phytoplankton blooms and other ecological changes, is a greater problem in areas with more human activity due to increased land-use and nitrogen inputs.
[13] If humans did not open the ponds they would typically breach every two to three years due to the buildup of high water level behind the beach and the erosive power of storm events. M. Jones, personal communication.
[14] Emery, K.O., B.L. Howes and S.R. Hart. 1997. *A Coastal Pond Studied by Oceanographic Methods. Epilogue: Oyster Pond—Three Decades of Change*. Oyster Pond Environmental Trust Inc. 111 pp.

ponds. The study builds on past water chemistry studies[15] and takes a holistic and ecological approach. To track the range of dynamic conditions present in Tisbury Great Pond and the effects upon the distribution of flora and fauna, a multi-tiered approach was chosen in which multiple physical and biological parameters were sampled at stations ranging from the center of Tisbury Great Pond to its brackish coves, as well as nearby freshwater ponds that are now isolated from the larger salt pond system. Seventeen buoy-marked stations were randomly established in June 2000, across Tisbury Great Pond and its coves (Town Cove, Tiah's Cove, Deep Bottom Cove, and Middle Point Cove), Long Cove Pond, and Big Homer's Pond (figure 2.1).[16] At each station, water quality parameters such as salinity, temperature, oxygen availability, and nutrient and phytoplankton concentrations were tested;[17] the benthos was sampled for sediment characteristics, presence and types of submerged aquatic vegetation, and composition of the benthic fauna; and fish traps were deployed to characterize the benthic fish community. Additionally, deeper waters of the main body and coves of Tisbury Great Pond were sampled for larger, pelagic fishes using a small otter-trawl and gill nets, and the pond shores were sampled for fish using seine nets. Fauna living in the freshwater seeps at the head of Long Cove Pond and Middle Point Cove were also sampled using seine nets, and the springs at the head of Long Cove Pond were sampled for groundwater-associated fauna using baited sink traps. Vegetation and invertebrates were also sampled on the ponds' shorelines.[18]

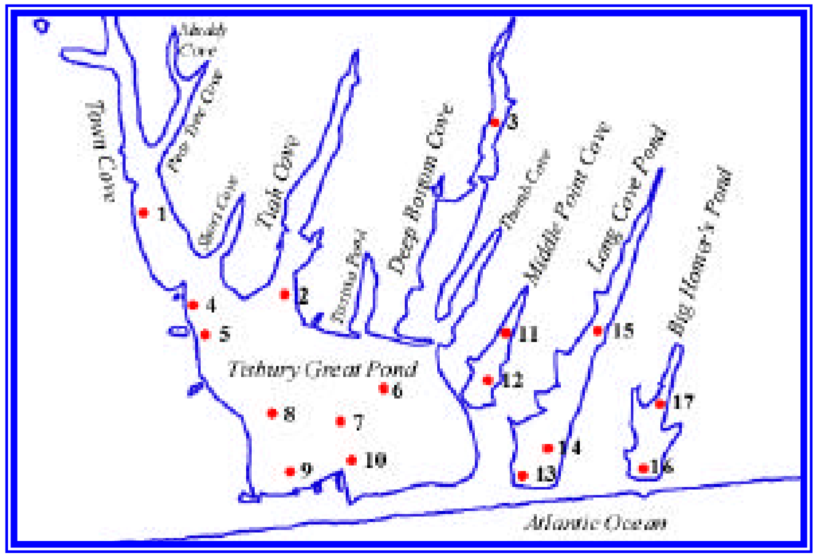

Figure 2.1: Seventeen stations placed in Tisbury Great Pond and its coves (stations 1-12), Long Cove Pond (stations 13-15) and Big Homer's Pond (stations 16-17).

3 The Physical Foundation of Coastal Salt Ponds

Coastal salt ponds and their ecology are a result of physical processes occurring over thousands of years. This section describes the geological formation of the coastal salt ponds, their watershed characteristics and hydrology, bathymetry, bottom sediment characteristics, and the local climate. Many of these are dynamic processes that are still undergoing change today, as the

[15] Wilcox, 1999 and MVC, 2000. The Martha's Vineyard Commission has sampled numerous ponds since 1995, including Tisbury Great Pond and Long Cove Pond, for a full year on a monthly basis, and twice monthly in the growing season, and identified areas needing further work.
[16] Stations were randomly stratified across the ponds. Freshwater ponds, due to their small size, were sampled with twice the coverage of Tisbury Great Pond. This ensured that we had enough data points for the freshwater ponds.
[17] Sampling dates were: June 20th, July 5th, July 12th, July 24th, August 3rd, August 16th, August 23rd, October 4th, October 17th, and November 9th
[18] For more detailed methods, see individual sections below or contact the authors.

sea level continues to rise, the climate changes, and land-use patterns in the watershed are changing through succession, development, and habitat management.

3.1 Coastal Salt Pond Formation

The regional geology underlying the formation of the coastal salt ponds is a reflection of glacial activity that reached its peak 21,000 years ago during the ice ages, as well as more recent oceanic processes that created barrier beaches along the shores of Long Island and southern New England. Twenty-five thousand years ago the Laurentide ice sheet advanced across New England, reaching the southernmost extent 21,000 years ago. Glacial retreat began 18,000 years ago, as conditions became warmer. This ice sheet had several lobes, two of which—Buzzards Bay Lobe and Cape Cod Bay Lobe—formed the moraines[19] of Martha's Vineyard. During this most recent ice age, sea level was almost 60 meters lower than today and a wide coastal plain existed on the continental shelf edge, far beyond the location of Martha's Vineyard and Nantucket, today.[20] As the Laurentide ice sheet advanced and then retreated, it deposited and thrust up an end moraine on what is now Martha's Vineyard. As a result, the island's western moraine is composed of Cretaceous clays, Pleistocene tills and kames.[21] Melt waters rich in sediment flowed out of the melting glacier and down from the moraine in braided streams. The sediments deposited from these braiding melt water streams created a southward dipping outwash plain composed of discontinuous lenses of sand and gravel that are elongated in the direction of stream flow.[22]

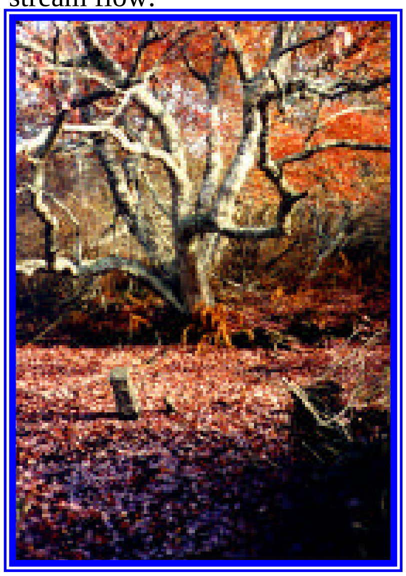

Figure 3.1: A historic property boundary marker (lower left), flooded over time by Long Cove Pond as the sea level rose.

The coastal salt ponds were subsequently created as sea level rose and a barrier beach was deposited along Martha's Vineyard's south shore by the continual movement and deposition of eroded upland sands by currents and waves. When the barrier beach was offshore, an estuary would have existed along the southern coast of Martha's Vineyard, similar to that created by Fire Island on Long Island, today. Ponds were formed as water became dammed behind this extensive barrier beach and flooded the remnant "sapping valleys", called "bottoms" today, created by glacial streams.[23] The barrier beach has continuously migrated north as the south shore of Martha's Vineyard has been subject to overwash during storm events and relative sea level rise,[24] resulting in the current topography: the ponds divided in many places into finger-like coves in the flooded valleys of the outwash plain (see figure 3.1). This barrier beach migrated north and began to overwash Long Point, once a peninsula jutting between Tisbury Great Pond and Long Cove, separating Long Cove from Tisbury Great Pond (see map on the cover page).

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[19] A moraine is formed from sand, clay, rock, and other materials deposited by a glacier.
[20] Till is unsorted material laid down by a glacier. A kame is a knoll or hill of glacial deposits deposited in a hole in the glacial ice. Oldale, R.N. 1992. *Cape Cod and the Islands. The Geologic Story*. Parnassus Imprints, E. Orleans, MA. 208 pp.
[21] Wilcox, W. 1996.
[22] Wilcox, W. 1996.
[23] Oldale, R.N. 1992.
[24] Overwash is the process by which a barrier beach recedes landward. Storms drive this process as waves scour sand from the existing barrier beach, depositing it landward. A rising sea level is a large-scale process determined both by global sea-level changes and the relative action (rising or subsidance) of the local coastline. A relative sea-level rise can augment rates of barrier beach erosion.

Despite continual overwash, landowners maintained a ditch that connected Long Cove and Tisbury Great Pond into the early 1900's. This creek does not exist today and Long Cove is now a separate pond. The resulting pond and other smaller ponds along the south shore are primarily fresh, but receive some salt input from periodic overwash and salt spray.[25]

3.2 Watershed and Hydrological Characteristics

Water enters coastal salt ponds through direct precipitation into the ponds and groundwater, surface water (streams), and storm runoff within their watersheds. The watershed of Tisbury Great Pond encompasses approximately 12,000 acres, the largest on Martha's Vineyard. Between 13 and 23 million gallons a day (Mg/d) of water enter Tisbury Great Pond, and 11.3 Mg/d leave via groundwater through the barrier beach and evaporation.[26] The difference, 1.7 to 11.7 Mg/d, is responsible for filling the pond when the barrier is closed.[27] Big Homer's Pond and Long Cove Pond, on the other hand, have much smaller watersheds. The watersheds of Tisbury Great Pond, Big Homer's Pond, and Long Cove Pond are primarily forested (6,000 acres), with almost 1,000 acres of agricultural lands, almost 500 acres of wetlands, and approximately 1,000 acres of ruderal areas, with almost 1,000 houses in 2000 (see figure 1.2). Approximately 3,000 acres of rare and uncommon upland habitats occur within these watersheds as well.[28] Many of the houses are located within or adjacent to these rare areas, ultimately destroying or deteriorating these previously functional habitats over time.

When the barrier beach is opened to the ocean, surface water discharge from Tisbury Great Pond can reach levels of 900 Mg/d during the initial breach. During and after the breach, the water level rapidly drops in both the pond and the groundwater. When this happens, flushing rates are elevated through increased groundwater inputs in addition to the outflow of surface water. Neighboring ponds are also affected as the groundwater elevation changes, causing their water levels to drop as well. Once the pond has flushed, the rate of inflows and outflows are still higher than when the pond is closed to the ocean.[29] While the pond is still open, the increase in flow is due to both the effects of a lowered pond level, a lowered regional groundwater table, and flushing through the tidal cycle.

Long Cove Pond and Big Homer's Pond are both freshwater bodies that receive most of their input from groundwater seeps, located in the sandy soils along the shoreline at the head of the coves. After a rain event, the water flows from these seeps quite rapidly, creating channels through the detritus-littered bottom. After a period of low rainfall, the seeps are less evident. In fact, the raising and lowering of the local water table level is quite responsive to rainfall events, and has an effect on the placement of the seeps, as well. At a relatively high water level, the multiple seeps occur along the forested embankments and have a larger surface area than they do at lower water levels, when the seeps are concentrated along a lower, narrower expanse of shrub swamp.

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[25] As ponds are breached naturally only when sufficient water pressure builds behind the barrier beach, smaller ponds with small watersheds and therefore less water recharge normally do not breach as often.

[26] Fugro-McClelland (East), Inc. 1992. *Water Quality Study of Tisbury Great Pond.* Prepared for Towns of West Tisbury and Chilmark, Martha's Vineyard, MA. 37 pp. When the pond is closed to the ocean, major inflows include (on average) 5.5 Mg/d from groundwater, and 5.5 Mg/d from streamflow from the Tiasquam River and Mill Brook.

[27] The range in water flow through the pond's system is due to the uncertainty in the amount of groundwater from the watershed that actually flows through the pond.

[28] Raleigh, E.L. and K. Fauteux. 2001. *Terrestrial Plant Communities of the Tisbury Great Pond, Long Cove Pond, and Big Homer's Pond Watersheds*. The Trustees of Reservations, Vineyard Haven, MA.

[29] Fugro-McClelland (East), Inc. 1992. The rate of inflow ranges between 10 and 15 Mg/d when the pond is open to the ocean.

3.3 Pond Bathymetry

Tisbury Great Pond's greatest depth ranges from 2.7 meters when the pond is open to the Atlantic Ocean, to 3.6 meters when the pond is closed and filled by fresh water.[30] It shallows towards the western and eastern shores, where broad, flat beaches exist at low pond levels. A tidal delta formed by sediment deposition during pond openings is evident on the south shore's barrier beach.[31] As ocean waves and currents carry water through the opening to Tisbury Great Pond, sediment is deposited in the pond just inside of the barrier beach, forming a shallow sandy delta that extends scores of meters to the north. Superimposed upon this is the process of barrier beach retreat, where the ever-retreating barrier beach encroaches upon the deeper portions of the pond. This results in steep slopes on the southern shores of the great pond on the western and eastern edges of the inlet delta. This process of barrier beach migration is also quite apparent when one visits the barrier beach at the southern end of Long Cove Pond and Big Homers Pond. Here, the sandy barrier beach lies contiguous to the deepest portions of the ponds, at approximately three meters depth, and the shoreline drop-off is abrupt.

The finger-like coves on the northern end of the ponds are deepest in the center, with Deep Bottom Cove having the deepest channel, up to three meters deep for much of the length of the cove. Sand bars have formed at the opening of the coves and along portions of the shoreline. These bars act to varying degrees as barriers to circulation with the main body of Tisbury Great Pond, especially at times of low pond levels, affecting the water chemistry (see section 5). The sandbar at the opening of Middle Point Cove restricts water flow at high pond levels, and almost completely isolates Middle Point Cove from Tisbury Great Pond at times of low pond levels, when the pond is open. This also occurs at the mouth of Tississa Cove, and Deep Bottom Cove to a lesser degree.

3.4 Bottom Sediment Characteristics

Figure 3.2: Bare sand from groundwater flow into the head of Long Cove Pond. Along the edge of the sand is organic matter covering sand.

The bottom sediments of coastal salt ponds are highly patchy, with a variety of conditions often present within a small area. These conditions create microhabitats for plants and animals. Sand from the outwash plain underlies all the ponds, and bare sand exists in some areas such as in groundwater seepage channels (see Fig. 3.2) or other areas with moving water flow and low rates of organic matter deposition. Other areas, specifically those where the pond openings occur, are covered by bare sand deltas or overwash materials. Black, clay-like organic matter underlies the sand in many cases, an indicator of anoxic conditions in the sediment.[32] In some cases, a flocculent layer of organic particulate matter occurs. In other cases, algae coat the pond benthos. In some coves, a thick layer of silts and organic material covers the bottom. Shell fragments and stones litter the surface, sometimes

[30] Fugro-McClelland (East), Inc., 1992, figure 8. A bathymetric survey of Tisbury Great Pond was performed by Fugro-McClelland in February 1992, at a high pond level, 0.06' above the Manter nail.
[31] Fugro-McClelland (East), Inc., 1992, figure 8.
[32] Due to the well-mixed water column, however, the surface of the sediment is likely oxygenated. In addition, burrowing species, through their activity, may oxygenate deeper areas as well.

densely. In general, the bottom sediments are characterized by sand with organic matter, yet they are highly patchy in nature.

3.5 Climate

Rainfall, wind, solar radiation, and temperature are all climatic factors that affect the ecology of a coastal salt pond. Long Point's climate remains heavily influenced by the Atlantic Ocean, Vineyard Sound, and other waters that surround the shores of Martha's Vineyard. The oceans store heat and keep Martha's Vineyard moderated compared with more inland areas, which show a greater fluctuation in annual temperature. Coastal salt ponds also warm more rapidly through solar radiation than the ocean due to their smaller size and shallow depths (see section 5.2). Conversely, coastal salt ponds cool more rapidly than the ocean during cloudy conditions, at night, or in the fall. Regular winds arrive on Martha's Vineyard predominately from the west, with a southerly component during summer months and a northerly component during the winter. Winds affect horizontal and vertical circulation patterns in the ponds, often determining the degree of water column mixing, as well as wildlife, as seen in leeward bird resting areas. Due to the shallow nature of the ponds and the regular winds, the ponds are well mixed.[33] Rainfall influences not only the volume of water, but also affects nutrient additions to the pond through runoff or groundwater flow, pond clarity, and the depth of the pond and, consequently, the area of the pond and the configuration of the shoreline.[34]

4 Human History and Uses of Coastal Salt Ponds

The ponds of Long Point have a long history of use, from the Native Americans to the present. Recently, recreation has become a large focus for the pond, with boaters and beachcombers arriving by the thousands. Less than a century ago, however, Long Point was an exclusive hunting club. Fishing and shellfishing have sustained people around the ponds for hundreds of years and Tisbury Great Pond has traditionally been opened to accommodate that and other uses.

4.1 Pond Openings

European settlers have opened the barrier beach along Tisbury Great Pond since 1694.[35] By the 1900s, the opening of the pond was legally mandated in "An Act to Provide for the Drainage of the Lowlands and Meadows around certain Great Ponds in the County of Dukes County." Two of the main reasons for opening the ponds were to maintain the lowland meadows and to allow anadramous and catadramous fish to enter and leave the ponds.[36] Lowland meadows provided a source of Black Grass (*Juncus gerardii*), which was excellent fodder for livestock.[37] Flooded

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[33] On July 31st, after a 10-day period of overcast days, salinity, temperature, and dissolved oxygen were measured at one foot increments from the bottom to the water surface at stations 6 and 7, to test for evidence of temperature or salinity stratification, and for low oxygen levels. A series of overcast days and a stratified (layered) water column, combined, would create optimal conditions for a low oxygen event in the pond, when net oxygen consumption by plants (i.e. respiration) can exceed net oxygen production (i.e. photosynthesis). This usually occurs overnight, and is detectable in the early morning hours. Both stations showed remarkably uniform salinity, conductivity, temperature, and dissolved oxygen concentration throughout the water column, demonstrating the predominance of wind mixing and lack of a density stratified water column in the center of Tisbury Great Pond.

[34] Wilcox, W. 1999.

[35] Whiting, J.W.M. 1997. Tisbury Great Pond. *The Dukes County Intelligencer* 38(4):155-174. Only anecdotal evidence of Native Americans opening the ponds exist.

[36] King, S. 1961. Sand Dunes and Sea Law. *The Dukes County Intelligencer* 3(1).

[37] Daniel Manter, for example, cut _ acre of Black Grass at Quansoo for his cows. George Manter, personal communication.

Black Grass, however, would eventually die and decompose, creating mud flats.[38] Eel and herring also required the opening to move between their breeding and feeding grounds. Later, other interests would include preventing flooded cellars, oyster spat propagation, pond shore erosion, swimming, crabbing, and harboring boats. "Sewers" were elected to oversee the opening of the pond, with these interests in mind.

In addition to aiding the migration of fish, opening the barrier beach regulates physical attributes that are necessary for a successful shellfishing season. Not only does the salinity and flushing rate increase when the pond is open, but also the lowered pond level (i.e. water column depth) means that the regular wind mixing of the water column now reaches to the bottom over a broader area of the pond, bringing a steady supply of oxygen to those organisms living on the bottom. This process aids in preventing areas of the bottom from becoming hypoxic (low oxygen, <4 mg/L) or even anoxic (no oxygen, 0 mg/L). The composition of the pond community can be altered by shifts in salinity, as changes in water chemistry favor one species over another. For instance, the Oyster Drill (*Urosalpinx cinerea*), a predatory snail, survives in brackish and saline waters, but not fresh waters. If the salinity in the pond remains too high, the Oyster Drill's population can respond by increasing in number. This can result in a decline in the Eastern Oyster population, due to higher Oyster Drill predation. Also, certain Eastern Oyster diseases, such as Dermo, can cause higher mortality and spread more rapidly in saline waters, whereas lower salinities are stressful for the organisms causing these diseases, and benefits the Eastern Oyster population as a whole.[42] The timing and frequency of pond openings is crucial to the control of these many factors, and can be used to carefully meet management goals for the pond.

Date Opened[39]	**Date Closed**	**No. Days Open**	**No. Days Closed**	**Water Level**[40]
March 31, 1999	May 24	54	112	1.79 m
September 13	September 19	6[41]	95	1.5 m
December 23	January 6, 2000	14	86	1.6 m
April 1	April 27	26	44	1.67 m
June 10	June 26	16	56	1.5 m
August 21	September 15	25	122	4.5 m
January 15, 2001	February 5	21	54	1.5 m

Table 4.1: An example of pond openings and closings at Tisbury Great Pond, March 1999 to February 2001.

Today, Tisbury Great Pond is opened mechanically when its water level reaches or exceeds the Manter Nail, which is located slightly over one meter above mean low tide, at the discretion of the pond sewers (table 4.1).[43] Traditionally, horses and oxen were used to dig a trench in the barrier beach connecting Tisbury Great Pond to the Atlantic Ocean. Within twenty-four hours from the time the cut is made the energy of the water flowing out of the pond expands the opening to a width of approximately 30 meters, the pond level typically drops 1.2 meters,[44] and the pond loses roughly 40-45% of its water volume.[45] A small delta is formed first on the ocean side of the cut as water flows out of the pond and then on the pond side of the beach, due to tidal

[38] High pond levels and the associated high water table also affect low-lying homes and septic systems, and shellfishing becomes more difficult.
[39] K. Healy, personal communication. 2001.
[40] water level = pond elevation (in meters) prior to opening the pond above USGS datum on opening date, as measured by Kent Healy at a dock located in Town Cove, at the end of Runners Road.
[41] Hurricane Floyd caused the pond to close unusually early on September 19, 1999.
[42] R. Karney, personal communication. 2000.
[43] The higher the water level, the greater chance that an opening will be successful because of increased water pressure. The Manter Nail was created to simplify matters of timing the opening of the pond.
[44] Whiting, J.W.M. 1997.
[45] Fugro-McClelland (East), Inc. 1992, p. 19.

currents. In the summer of 2000, unusually high rainfall led to more rapid filling of Tisbury Great Pond and, therefore, shorter intervals between openings.[46]

The pond can also open naturally when pond water levels are high and winds and storm waves help to destabilize the beach sand. The hurricane of 1954 reportedly caused a natural breach in the barrier beach.[47] Today, this happens rarely, as the pond is usually opened before the water level becomes high enough for a natural breach. In 1991, the pond was opened mechanically on July 19th, after which the opening narrowed. Hurricane Bob then created a huge breach several hundred feet wide on August 19th, and the pond stayed open until this gradually shoaled and closed, in late December.[48] The barrier beach openings close naturally during storm events or as the long shore currents fill the break with sand deposits, after which the pond begins to refill as the local groundwater level rises.

4.2 Fishing and Shellfishing

Tisbury Great Pond's shores are a popular destination for recreational fishing, including crabbing, shellfishing for Eastern Oysters, and fishing for Striped Bass and Bluefish during the fall fishing derby. For thousands of years, both European settlers and Wampanoag have used coastal salt ponds for sustenance.

Shellfish and fish comprised a significant part of the Wampanoag diet. Many species of shellfish were cooked in their shells or dried and preserved.[49] Ample shellfish were found in the many ponds of the south shore, although signs of over harvesting were found, evidenced by a decline in shallow water clams and a corresponding increase in deeper water, harder to harvest scallop and oyster.[50] Herring were caught as follows: "A passage was opened from the sea into the pond and through it the fish entered. There are many coves on this pond. At the entrance of the coves, the Indians placed hurdles underwater in a horizontal position; and when the fish had run over them into the coves, they went in their canoes, lifted the hurdles upright, by means they prevented the escape of the fish, and with their spears stuck them in the mud."[51] Eel were caught using eel pots made of wood withes.[52] Fishing using hooks, nets, spears, bow and arrows, and fish weir were also techniques the Wampanoag used.[53]

European settlers also harvested fish and shellfish. Records of this harvest abound. In the 1800s, massive harvests of Striped Bass, American Eel, Smelts, and Alewife occurred. In addition,

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[46] In August, 2000, 24.6 centimeters of precipitation were recorded compared to an average of 10.4 centimeters. J. Varkonda, personal communication, 2001. Delaney, D.F. 1980. *Ground-water Hydrology of Martha's Vineyard, Massachusetts*. Hydrologic Investigations Atlas, U.S. Geological Survey. Atlas MA-618.1:48,000. 2 pp.

[47] Tompkins, W. 1958. *Fisheries Report for Some Southeastern Massachusetts Lakes, Ponds, and Reservoirs, 1951-1952*. Massachusetts Division of Fisheries and Game, Boston, MA. 87 pp.

[48] Fugro-McClelland (East), Inc. 1992, p. 32.

[49] Ritchie, W. A. 1969. *The Archaeology of Martha's Vineyard: A Framework for the Prehistory of Southern New England, A Study in Coastal Ecology and Adaptation*. The Natural History Press, Garden City, NY, p. 24.

[50] Ritchie, Pratt site. The abundance of clam shells in the Pratt midden decreased, with a corresponding increase in the number of oyster and scallop shells. Species list, p. 47.

[51] Freeman, J. 1807. A Description of Dukes County. Pp. 38-95 in *Collections of the Massachusetts Historical Society, Vol. 3*. Second Series. 1815. John Eliot, Boston.

[52] Travers, M. 1960. *The Wampanoag Indian Tribute Tribes of Martha's Vineyard*, p. 20. For a good review of eel fishing, see: MacKenzie, C.L., Jr. 1995. The Eel Fishery of Martha's Vineyard. *The Dukes County Intelligencer* 36(3):120-144.

[53] Ritchie; Cheever, 1848, pp. 35, 69, 71, 73, in Ritchie.

White Perch were introduced to the pond in 1869.[54] American Eel were still harvested using methods similar to those of the Wampanoag.[55] Shares in seines and fishing and shellfishing rights were historically common and were traded in deeds, along with access to the ponds.[56] Rights to fishing continued throughout the historical period when the Towns of Chilmark and Tisbury leased commercial fishing rights yet retained the management of the eel, clam, quahog, and scallop fisheries. The public was granted the right to fish as well.[57] Between 1916 and 1944, an "astronomical number of fish" were stocked in Tisbury Great Pond: in this 28 years 4,415,700 fish were stocked, including 3,600,000 smelt eggs and fry, 810,000 Walleye Pike, 3,500 Brook Trout, 1,500 Rainbow Trout, 400 Brown Trout, and 300 White Perch.[58] In the 1950s, fishing shacks were established on the south shore for surfcasting, as recreational fishing became more popular. Clams were also harvested at this time using hydraulic pumping, which forced high pressure water into the sediments and brought the clams to the surface as the sediments settled; in short order clams were over harvested and the pond floor was altered considerably.[59] In addition, the Vineyard Shellfish Company and the Quansoo Shellfish Company received leases from the towns of Chilmark and Tisbury for purposes of harvesting oysters. Camps made of driftwood that washed ashore from boats carrying lumber or shipwrecks served as shucking shacks. Today, oysters continue to be harvested from Tisbury Great Pond and account for over half of the total oyster harvest for Martha's Vineyard.[60] In addition, recreational fishing, crabbing, and shellfishing are popular in and around the shores of Tisbury Great Pond, particularly when the pond is open to the ocean.

4.1: Members of the Tisbury Pond Club after a day's 1913. This photo is from the Tisbury Pond Club ‹ (see section 4.3).

[54] Kendall, W.C. 1906. *An Account of Tisbury Great Pond, Martha's Vineyard, with a List of Fishes Collected in October and November, 1906*. United States Bureau of Fisheries. 8 pp. In 1848, two schooners were needed to ship 18,000 Striped Bass caught in a long shore seine in Tisbury Great Pond to New York. Allen Look and his sons introduced White Perch. Eventually, catches of approximately 200 barrels a season were feasible.

[55] Kendall, W.C. 1906.

[56] Raleigh, L. 2000. *Land-use History of Long Point Wildlife Refuge*. The Trustees of Reservations, Vineyard Haven, MA. 30 pp.

[57] Belding, D.L. 1921. *A Report Upon the Alewife Fisheries of Massachusetts*. Massachusetts Division of Fisheries and Game, Boston, MA. 135 pp. (reprinted 1964)

[58] Tompkins, W.A. 1958. A recommendation was made to discontinue this management due to the pond's "periodic flooding by the sea". There is no evidence today that the freshwater species stocked in this period survived as self-sustaining populations.

[59] Mal Jones, personal communication, 2000.

[60] Fugro-McClelland (East), Inc. 1992. In 1999, 1,200 bushels (or 84,000 pounds) of oysters turned a profit of around $50,000 for nine West Tisbury fishermen, while recreational shellfishermen removed an additional 8,600 pounds. The Chilmark side typically harvests an additional 300 to 400 bushels of oysters a year. Ray Houle, personal communication.

4.3 Waterfowl Hunting

Between 1903 and 1968, waterfowl hunting clubs existed at and around Long Point (see figure 4.1).[61] The focal point for hunting was the coastal salt ponds, where hundreds of ducks would arrive in the fall. At Long Point, the Tisbury Pond Club hunted in the autumn until the ponds froze, which forced the waterfowl further south. To the east, the Watcha Club hunted at Big Homer's Pond and other smaller ponds. These hunting clubs were primarily composed of wealthy industrialists from northern urban centers. Today, waterfowl hunting still exists, but at a much smaller scale and, where allowed, through the permission of various landowners.

4.4 Recreation

Recreational use of the coastal salt ponds around Long Point has become more popular during the latter parts of the twentieth century, as Martha's Vineyard became a focal point for New England summer tourism. Over 40,000 people visit Long Point every year, using the barrier beach south of Long Cove Pond and swimming in the pond's fresh waters. In 1994, the Martha's Vineyard Land Bank Commission created a public boat launch and canoe slide on the shores of Tiah's Cove at Sepiessa Point Reservation. Summer visitors as well as year-round residents use the pond and its coves increasingly for recreation, including canoeing, kayaking, sailing, horseback riding, and municipal swimming lessons from 1997 to 1999.[62] Kayak and canoe tours of the ponds are given by The Trustees from Long Point, which attract almost 1,000 people every year. Additionally, Tisbury Great Pond's barrier beach is a popular destination for homeowners and beach lot owners to sunbathe and swim in summer months, and many boat from their homes along the coves to the barrier beach on a sunny day.

5 Water Chemistry

Water chemistry is the basis of all life in the coastal salt ponds. The form, concentration, and distribution of chemical compounds determines, in part, what plants and animals will exist. This section describes the water chemistry of Long Point's coastal salt ponds by looking at a snapshot in time during 2000.[63]

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[61] Raleigh, L. 2000.

[62] Moore, A. 1999. *Summer 1999 Use at Sepiessa Point Reservation, West Tisbury, Massachusetts*. Martha's Vineyard Land Bank Commission, Edgartown, MA. 3 pp.

[63] Physical parameters of the ponds were measured to describe the range of conditions that organisms experience while living in these dynamic water bodies. *In situ* sampling for temperature (˚C), salinity (o/oo = parts per thousand), and conductivity (milliSiemens) was performed at each marked sampling station using a hand-held battery-operated YSI 85 meter. Also measured was dissolved oxygen concentration in mg/L and its percent saturation, a measure of the amount of oxygen dissolved in water as compared to that expected to be dissolved in water of the same temperature and salinity. A saturation greater than 100% reflects the production of oxygen by plants in the water column, through photosynthesis, while oxygen saturation values lower than 100% reflects the use of oxygen in the water column, through respiration, by both plants (in the dark) and animals. A secchi disk and calibrated line were used to measure the water depth at each station (in meters) and the clarity of the water, or how deep below the water surface light will penetrate (called transparency, and also measured in meters below the surface). Sampling methods and protocal were styled after Taylor (1999) to maximize the comparability of this data to previous and future MVC water quality monitoring. Water samples were collected for off-site analysis of various parameters by Dr. Brian Howes' laboratory at the UMass-Dartmouth Center for Marine Science and Technology (CMAST), in New Bedford, MA. Parameters analyzed by this lab include salinity, the phytoplankton pigments chlorophyll a and pheophytin a, and the nutrients ammonium (NH_4), nitrate and nitrite (NO_3 and NO_2), dissolved organic nitrogen (DON), particulate organic nitrogen (PON), particulate organic carbon (POC), phosphate (PO_4), and silicate (SiO_4). Based on the monitoring from Howes et al., 1999, we measured all parameters from mid water column depth, assuming a uniformly mixed system. Howes, B.L.,

Location	Average (ppt.)	Standard Deviation (ppt.)
Tisbury Great Pond	17.9	5.4
Town Cove	18.7	4.7
Tiah's Cove	18.5	5.7
Deep Bottom Cove	10.7	5.5
Middle Point Cove	5.5	2.0
Long Cove Pond	0.1	0.1
Big Homer's Pond	0.2	0.2

Table 5.1: Average salinity in the coastal salt ponds varies tremendously by location.

5.1 Salinity

Salinity varies considerably within the coastal salt ponds of Long Point, ranging from completely saline at the mouth of a pond opening to completely fresh at the groundwater seepage areas. Some areas exhibit large temporal fluctuations, such as within the central parts of Tisbury Great Pond, whereas other areas remain fairly constant in salinity levels. The ranges in salinity can affect species present depending on their tolerance of either salinity or fresh water (table 5.1).

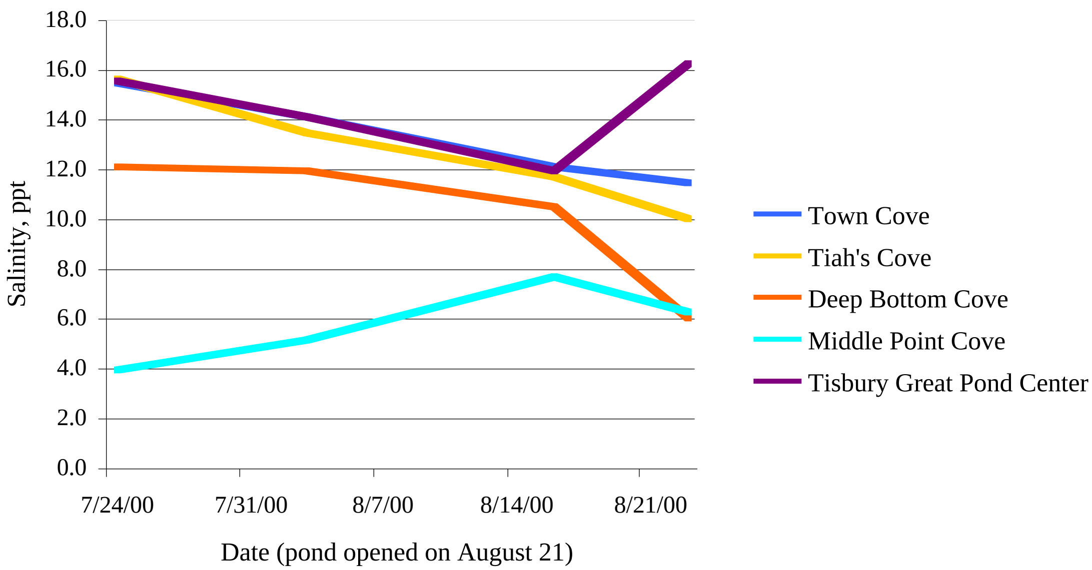

Figure 5.1: Before and after an opening in Tisbury Great Pond, the salinity in the pond and its coves changes dramatically. Salinity increases following an opening in the pond center, whereas it decreases in the coves, where fresh groundwater enters the pond at accelerated rates. The freshwater input is most pronounced at the head of the coves, such as at Deep Bottom Cove (station 3; see figure 2.1). Also note the increase in salinity in Middle Point Cove. As the water level of the pond rises, the brackish waters in Tisbury Great Pond influence this cove to a greater extent. At low water levels, a sand bar significantly reduces connectivity between these ponds.

Salinity changes are most rapid following a pond opening and after a pond closes (see figure 5.1). For example, when Tisbury Great Pond closed in the summer of 2000, within two months, the salinity of the pond fell from 22 parts per thousand by weight (ppt) to 12 ppt.[64] The main body of

T. Williams, and M. Rasmussen. 1999. *Baywatchers II: Nutrient Related Water Quality of Buzzards Bay Embayments: A Synthesis of Baywatchers Monitoring 1992-1998*. The Coalition for Buzzards Bay, New Bedford, MA. 127 pp. Datasets may be requested through direct correspondance with the authors.

[64] By contrast with these salinities, the salinity of seawater is approximatel 35 ppt. The primary elements comprising seawater are (in decreasing order of importance) chlorine, sodium, magnesium, sulphur, calcium, and potassium.

the pond had good horizontal circulation and mixing, with slight salinity differences throughout.[65] In the coves of Tisbury Great Pond, however, sandbars at the lower end of the coves restricted circulation with the main pond body. At Middle Point Cove, this effect was pronounced as the sandbar caused an almost complete closure between the cove and the pond when the pond was open and water levels were low. Therefore, this cove became fresher in nature (4 ppt) as the local flow of groundwater into the coves increased and circulation decreased. Once the pond closed and the water level rose, the sandbar slowly flooded and Middle Point Cove was influenced once again by the salinity in Tisbury Great Pond, and slowly became more brackish (8 ppt; see figure 5.1). In the first days following a pond opening, the salinity of Tisbury Great Pond initially decreased, due to an influx of groundwater, followed by a salinity increase as the pond became tidal. In the coves, the effect of groundwater inputs was heightened. Deep Bottom Cove, for example, had a salinity of 1.4 ppt following this groundwater influx by contrast with a salinity of 12.2 ppt when the pond was closed and more circulation was occurring. This process likely occurs in other coves of coastal salt ponds with shallow sandbars, whose waters are more restricted and are influenced by groundwater inputs.

Salinity was negligible in the freshwater ponds. Long Cove Pond was fresh, with values ranging between 0.1 and 0.3 ppt, while Big Homer's Pond had a marginally higher salinity of between 0.2 and 0.5 ppt. Salt spray and storm wave washover on the barrier beach can contribute some salt ions to this pond, as well as the interface between the salt and fresh groundwater lenses intersecting along the barrier beach.

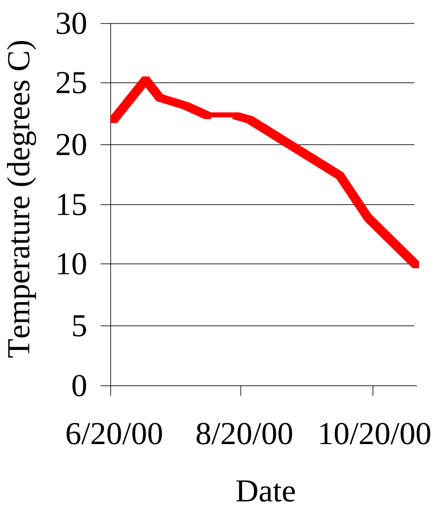

Figure 5.2: Summer and fall temperature changes for 2000 (average for all stations). Note the atypical drop in temperature during the late summer.

5.2 Water Temperature

Pond temperatures change dramatically through the seasons, with rapid changes in the fringe months due to the shallowness of the ponds. In the winter, the ponds regularly freeze, sometimes with several inches of ice developing. In July of 2000, the temperature reached a high of 27.4º C in Town Cove, with the ponds averaging over 25.0º C (see figure 5.2). Unusual this year was the early fall in water temperatures below 25º C. In most years, solar radiation and warm summer air temperatures cause a warming of water temperatures throughout the summer months. The cloudy, cool, and rainy conditions of the summer of 2000, however, retarded the warming of the waters in all of the ponds and coves. By late August, the water temperatures were back to their mid-June levels at all stations, and below 10º C by early November.

Groundwater entering the ponds through seepage areas is approximately 12˚C and warms as it flows south towards the ocean during summer months and cools in the winter. Even when the ponds are frozen, groundwater seepage areas remain ice-free. This provides a relatively stable, highly oxygenated freshwater environment for plants and animals.

[65] Of the seven stations within the central pond, the greatest difference between stations was 4.5 ppt.

5.3 Transparency of the Water Column

Location	Transparency (meters)
Tisbury Great Pond	1.3
Town Cove	1.1
Tiah's Cove	1.1
Deep Bottom Cove	1.1
Middle Point Cove	1.2
Long Cove Pond	1.8
Big Homer's Pond	No extinction of light

Table 5.2: Transparency (average values) throughout the coastal salt ponds. Waters were clear at Big Homer's Pond: the bottom could be seen throughout the year.

The penetration of light into the water column measures the water clarity, or transparency, and is controlled by the amount of phytoplankton in the water (see table 5.2).[66] Turbidity[67] in the water column is an indicator of two factors: the cloudiness created in the water column by plankton, and the amount of suspended material in the water column, such as sediment and detritus. Winds, dragging the bottom for oysters, and heavy boating traffic are all causes of sediment resuspension. Declines in transparency can reduce the ability of a bay to support bottom plants, and is also a measure of the response of phytoplankton to nutrient conditions.

Pond openings improve the transparency of the water column. Just after Tisbury Great Pond opened in June, the transparency at pond stations ranged from 1.9 to 2.2 meters depth, with the bottom visible throughout most of the pond. Transparency subsequently declined rapidly, and by mid-August the transparency was less than one meter throughout Tisbury Great Pond. Transparency increased once again, however, following an opening on August 21. A similar pattern occurred in the coves: a transparency of 1.4 meters in late June declined to 0.5 meters in Town Cove and one meter in Tiah's Cove and Middle Point Cove. A sharp decrease in transparency was even more dramatic in Long Cove Pond, where transparency declined at station 15 from 2.6 in June to 0.95 meters in mid-August. By October, transparency was back up to 2.5 meters. By contrast with these changes in transparency, changes in Big Homer's Pond readings were slight, with a high transparency occurring throughout the summer. Transparency in these cases was directly correlated with the amount of phytoplankton in the water (see section 7).[68]

5.4 Dissolved Oxygen

Dissolved oxygen is necessary to support all aquatic animal life in the coastal salt ponds. When dissolved oxygen levels decline below 5 mg per liter (mg/L), organisms begin to be stressed, and some can die. Hypoxic levels (between 3 and 5 mg/L) are most likely to occur in the early morning, when the night oxygen deficit created by respiring plants and animals can exceed the oxygen being produced by plants.[69] This is most likely to occur in warm waters that hold less oxygen, in turbid waters where light cannot penetrate to many plants, and after many consecutive cloudy days, when the oxygen deficit in the water column accumulates due to lowered photosynthesis rates.

[66] Howes, B.L., T. Williams, and M. Rasmussen, 1999, p. 18.
[67] Measured in this study as transparency, using a secchi disk.
[68] S-PLUS linear regression F-statistic: 15.78 on 1 and 15 degrees of freedom, and a p-value of 0.001225.
[69] Howes, B.L., T. Williams, and M. Rasmussen, 1999, p. 14.

The coastal salt ponds at Long Point were highly oxygenated in 2000 (see table 5.3). The physical shape of Tisbury Great Pond—a broad, shallow basin—in combination with southwesterly prevailing winds in the warm, biologically active months of the year, acts to prevent low oxygen events that could easily occur with a long period of overcast days and a strong phytoplankton bloom. In more restricted coves with high nutrient input levels, however, low oxygen events are more likely. For example, the lowest morning oxygen saturation at Town Cove was 77.4%.[70] Oxygen saturation was typically above 100% for Tisbury Great Pond, and the lowest reading for the freshwater ponds was 109% saturation. Oxygen levels are very high in the freshwater ponds and do not appear to be low enough in the great pond and coves to stress benthic organisms.

Location	Dissolved Oxygen (% sat.)	Dissolved Oxygen (mg/L)
Tisbury Great Pond	115.7	9.4
Town Cove	103.2	8.3
Tiah's Cove	116.5	9.5
Deep Bottom Cove	111.8	9.8
Middle Point Cove	106.9	9.4
Long Cove Pond	117.3	10.1
Big Homer's Pond	122.5	10.3

Table 5.3: Dissolved oxygen levels, average values, throughout the coastal salt ponds exhibit highly oxygenated conditions, with lower levels in Town Cove.

5.5 Nutrients

Nutrients such as phosphate, nitrogen in its various forms, silica, and carbon, are important to the growth of aquatic plants, including both microscopic algae—plankton—in the water column and larger, more visible algae called macro algae.[71] Generally, the supply of nitrogen is limited in coastal waters, as it is readily absorbed and used by many forms of life for nutrition and growth. However, activities in the watershed such as application of fertilizers to lawns, building of homes and their on-site septic systems, and agricultural practices that allow livestock wastes to enter coastal waters can all contribute to an increase in the available nitrogen in coastal waters. The level of nutrients, in turn, controls the productivity of these near shore waters. Although nutrients are essential for growth of plants and the organisms that feed on them, an overabundance of nutrients can cause large and rapid changes in coastal ecosystems, including plankton blooms that cloud the water, reducing water clarity, and wide swings in the available oxygen found in the water column. Rapid changes like these can stress the resident animals, such as shellfish, and plants, and cause die-offs of rooted bottom plants such as Eelgrass.

Physical conditions found in the ponds can also determine whether increased nutrient levels have a detrimental effect on pond life. For instance, depth of the pond, mixing of the water column by wind, stratification of waters due to differing water densities (caused by differing temperatures and salinities), and the physical circulation and flushing of the pond all moderate the effects of nutrient loading from the watershed. Thus, it is important to look at all these factors and how they interact in different portions of the salt pond system to evaluate the current condition or "health" of these ponds.

An important measure of nutrient enrichment, dissolved inorganic nitrogen (DIN) is readily available for uptake by plant cells and can rapidly stimulate plant growth.[72] Inorganic nitrogen

[70] Corresponding to 6.17 mg/L of oxygen. Town Cove is the area with the highest potential for nutrient inputs from the watershed and therefore has the highest potential for hypoxic conditions. No hypoxic conditions were encountered while sampling in the coves, but few samples were taken in the coves during morning hours. Thus, this sampling was inadequate to assess oxygen conditions in the coves.
[71] Also known as seaweed.
[72] DIN is found in three forms ammonium, nitrate, and nitrite.

usually enters bays and estuaries from the land and surrounding watershed through surface and/or groundwater flow, and high levels occur in nutrient enriched, eutrophic waters. Plants assimilate and convert inorganic nitrogen into organic nitrogen, which is present in water as both dissolved organic nitrogen (DON), from cell leakage and lysis, and particulate organic nitrogen (PON), formed from the fragmentation of plant and animal tissues. Organic nitrogen reflects the amount of biological production occurring in these waters, and can be used as a general measure of the relative productivity, or trophic state, of an aquatic system. High levels of organic nitrogen are a symptom of overall nutrient enrichment, rather than a cause.[73]

In addition to nitrogen (N), phosphorus (P), silica (Si), and carbon (C) are also important nutrients needed for plant cellular growth. They occur in a ratio of 1P:16N:16Si:106C in plant cells, and are needed in this ratio for growth. Thus, when one nutrient becomes lower than this ratio to the others, it will become the limiting factor to growth. If the total nitrogen/total phosphorus ratio is greater than 15:1 (the Redfield ratio) then phytoplankton productivity becomes limited by phosphorus rather than nitrogen levels. In Tisbury Great Pond, the ratio is generally above 15:1. However, this ratio occasionally falls below 15:1, suggesting that both nitrogen and phosphorus can be limiting under different conditions.[74] In most coastal waters nitrogen is usually limiting, except where it is excessively abundant, and then phosphate usually limits growth. Silicate and carbon are rarely limiting in coastal waters, as they are readily supplied through runoff from the coastal watershed.

Location	Ammonium (_M, section 5.5.1)	Nitrate and Nitrite (_M, section 5.5.2)	Dissolved Inorganic Nitrogen (_M, section 5.5.3)	Dissolved Organic Nitrogen (_M, section 5.5.4)	Phosphate (_M, section 5.5.5)	Silicate (_M, section 5.5.6)	Particulate Organic Nitrogen (mg/L, section 5.5.7)	Particulate Organic Carbon (mg/L, section 5.5.8)
Tisbury Great Pond	1.1	0.5	1.6	23.3	0.9	108.0	0.1	0.8
Town Cove	0.5	0.4	1.0	27.4	0.8	111.4	0.2	1.0
Tiah's Cove	2.0	0.5	2.4	22.3	0.8	105.2	0.2	0.9
Deep Bottom Cove	1.3	0.6	1.9	26.3	0.4	136.0	0.3	1.4
Middle Point Cove	2.2	0.6	2.8	24.7	0.1	50.8	0.2	1.0
Long Cove Pond	2.2	0.6	2.8	26.8	0.5	6.9	0.2	1.3
Big Homer's Pond	0.9	0.4	1.4	16.6	0.2	1.2	0.1	0.4

Table 5.4: Nutrients in the coastal salt ponds, average values by site.

5.5.1 Ammonium

Ammonium (NH_4) is one component of DIN entering coastal waters from surface and groundwater of the watershed. It is usually not considered to be an important source of inorganic nitrogen as it is quickly oxidized within the region's porous, sandy soils to another form of nitrogen—nitrate (NO_3)—and is also readily assimilated by growing plant cells.[75] Ammonium may peak during periods of high rainfall (see figure 5.3).[76] A peak also may occur following a pond opening. The higher ammonium concentrations just after pond openings can be explained by two factors: first, ammonium concentrations are higher in the spring in the ocean waters that have just entered the pond through the opening[77], and second, the draw down of the regional

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[73] Howes, B., T. Williams, and M. Rasmussen. 1999, p.15.
[74] Fugro-McClelland (East), Inc. 1992, p. 10.
[75] Wilcox, W. 1999, p. 30.
[76] Rainfall occurred August 15 (3 inches) just prior to sampling; most sites showed an ammonium peak. Concentrations were normally between 0 and 4 _M/L; the spike at Tiah's Cove registered 9.3 _M/L.
[77] Wilcox, W. 1999, p. 30.

water table during an opening causes an accelerated rate of delivery of DIN to the ponds in groundwater.[78] This is apparent as the peaks occur in the Tisbury Great Pond coves, where groundwater first enters the pond.

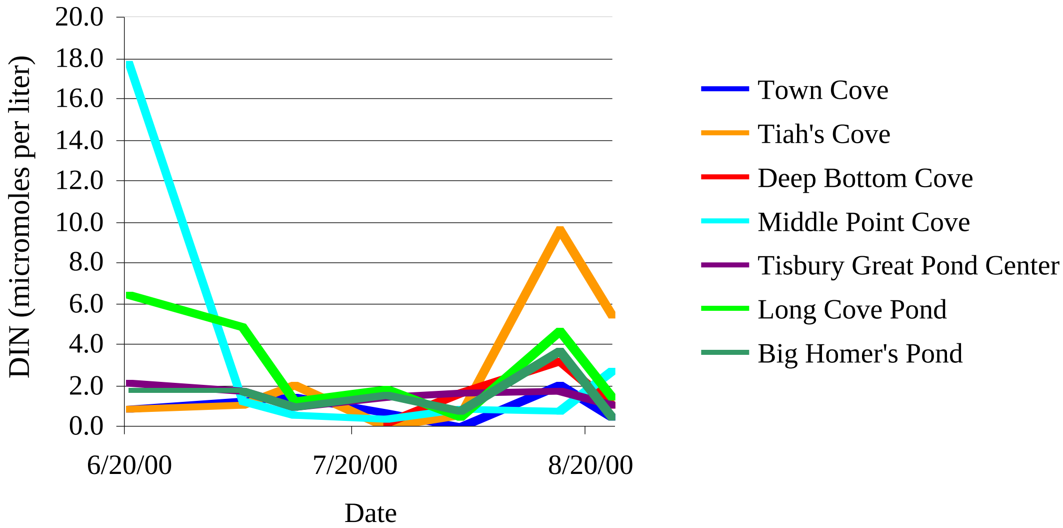

Figure 5.3: Dissolved inorganic nitrogen (DIN) in the coastal salt ponds remains low for most of the summer, except for spikes occurring during rain events such as the one on August 15. The DIN level drops rapidly thereafter, however. In the spring, nitrate levels were higher for Long Cove Pond and Middle Point Cove.

5.5.2 Nitrate and Nitrite

The more common forms of DIN, nitrate (NO_3) and nitrite (NO_2) quickly change forms depending on the oxygen availability at a site,[79] and are usually measured together. Normally, nitrite concentrations are so low that they are difficult to measure.[80] Dissolved nitrates are present at all the pond and cove stations at low levels—less than 2 _M/L (micromoles per liter[81])—except on June 20th, when a recent pond opening raised the levels in Middle Point Cove to 2.8 _M/L, and other locally occurring peaks. Dissolved nitrates are rapidly taken up by aquatic plants such as phytoplankton, algae, or submerged aquatic vegetation, and occur at very low levels (<0.5 _M/L) during the growing season. Small, locally occurring peaks may be explained by a die back of a phytoplankton bloom, which releases inorganic forms of nitrogen upon decay. Several of these peaks occurred in 2000.[82]

5.5.3 Dissolved Inorganic Nitrogen (DIN)

DIN is the sum of ammonium, nitrate, and nitrite concentrations: the amount of nitrogen readily available as a nutrient to stimulate plant growth.[83] Again, levels of DIN remained low (< 4 _M/L) at all Tisbury Great Pond stations, and showed peaks to 18 _M/L in Middle Point Cove

[78] Wilcox, W. 1999, p. 27.
[79] Nitrate, with three oxygen molecules, is the most oxidized version, whereas nitrite would occur primarily under reducing, low-oxygen conditions.
[80] Wilcox, W. 1999, p. 30.
[81] A mole is a chemistry term describing the mass of a compound. A micromole (_M) is a thousandth of a mole.
[82] Stations 7 and 9 on July 24th and August 16th, respectively.
[83] Howes, B.L., T. Williams, and M. Rasmussen. 1999, p. 15.

and 7.8 _M/L in Long Cove Pond. Town, Tiah's, and Deep Bottom Coves, as well as the freshwater ponds, all showed peaks in DIN the day after 7.8 centimeters of rainfall (August 16th), and this can be explained by the contribution of land-derived inorganic nitrogen to these areas through surface stream flow and groundwater flow (see figure 5.3).

5.5.4 Dissolved Organic Nitrogen (DON)

DON is derived from living things, and exists as complex organic nitrogen compounds such as amino acids, urea, and other products released by decaying organic matter.[84] Because these are large molecular weight compounds that are difficult to assimilate, they are not as readily available to plants as inorganic nitrogen. Inorganic forms of nitrogen are used first, and organic nitrogen can accumulate where biological productivity is high, such as in eutrophic waters. Dissolved organic nitrogen is essentially the by-product of life, and indicates that the uptake and conversion of inorganic nitrogen has occurred. In order to be available again as a nutrient, it must be broken down through decay to inorganic nitrogen.[85] DON levels in Tisbury Great Pond and its coves generally range from 12 to 40 _M/L in the summer months, with some peaks occurring (table 5.4).[86]

5.5.5 Phosphate (PO_4)

The growth of plants in coastal waters is generally nitrogen-limited, while plant growth is generally phosphorus-limited in freshwater ponds. Phosphorus levels declined to values ranging from 0 to 0.5 _M/L in Long Cove Pond and Big Homer's Pond during the growing season, but showed a peak on August 16th, the day after almost eight centimeters of rain fell. Again, this can be explained by the contribution of land-derived phosphorus to these areas through elevated rates of surface stream flow and groundwater flow caused by this heavy rainfall.

5.5.6 Silicate (SiO_4)

Silicate is also an important nutrient for plant growth, but is not limiting to plant growth in Tisbury Great Pond.[87] Silicate is delivered to the ponds through streams, and high levels are generally an indicator of the large influence of ground and stream water recharge to these ponds.[88] Diatoms use silicates to build their skeletons, and winter diatom blooms can cause a reduction in silicate levels in coastal waters.

Silicate levels rise and fall in Tisbury Great Pond depending on whether or not the pond is opened or closed to the ocean. The lowest silicate levels (just below 50 _M/L) occurred after the pond opened to the ocean in June. After the pond closed, silicate levels begin to rise, reaching a peak ranging from 151 to 194 _M/L in August.

Silicate levels remained very low—less than 25 _M/L—in both Long Cove Pond and Big Homer's Pond throughout the summer and fall (table 5.4), although they also had a slight peak in values just after the heavy rainfall event in August.

5.5.7 Particulate Organic Nitrogen (PON)

Generally, biologically productive, eutrophic waters contain more organic particles. PON (particulate organic nitrogen) and POC (particulate organic carbon) are a measure of the detritus

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[84] Howes, B.L., T. Williams, and M. Rasmussen. 1999, p. 15.
[85] Wilcox, W. 1999, p. 22.
[86] A small peak of 67.7 _M/L is seen at station 4 on July 12th, and another small peak of 52 _M/L occurs in Deep Bottom Cove on August 16th. A large peak of 90 _M/L is seen on July 12th in Town Cove.
[87] Wilcox, W. 1999, p. 32.
[88] Wilcox, W. 1999, p. 29.

suspended in the water column after the death and breakdown of live cells. The levels of PON in all the ponds and coves are fairly low, under 0.5 mg/L. A gradual rise in this value occurs throughout the growing season, and the highest values occur in late August at all stations except Town Cove, which reached its peak one week earlier than the other stations.

5.5.8 Particulate Organic Carbon (POC)

Particulate organic carbon appears to have been flushed out of the pond system by the June opening. After the pond closed in late June, POC gradually accumulated, rising from around 1.0 mg/L to a mid August peak ranging from 1.3 to 2.6 mg/L. Pond waters near the opening and Town and Tiah's Cove show a decline in POC levels on August 23rd, two days after a pond opening. This can be attributed to dilution by mixing with ocean waters near the opening, and the flushing of particulate matter out of the coves by a strong freshwater flow, after the heavy August 15th rainfall. POC may also accumulate as a thin flocculent layer on the bottom of the ponds. This was apparent in several places with low levels of wind mixing (e.g. Long Cove Pond). This settling process would provide a sink for the particulate organic carbon produced by plankton blooms in the water column.

5.6 Indicators of Water Quality and Nutrient Enrichment

Nitrogen levels in coastal waters and phosphorus levels in freshwater ponds affect the productivity and growth of phytoplankton and macro algae. When additions of nitrogen or phosphorus cause phytoplankton levels to increase rapidly, an algal bloom occurs, and can result in a eutrophic environment. On Cape Cod, for example, the nitrates in fertilizer and septic systems were found to seep into the groundwater and eventually into coastal salt ponds, where eutrophic conditions existed in two of five ponds studied.[89] An algal bloom can affect submerged aquatic plants by increasing the turbidity of the water, which effectively diminishes the depth to which light can penetrate the water column (see sections 5.3 and 8.1).

Location	**Long Cove Pond**	**Big Homer's Pond**
Structures within the watershed	95, including the Martha's Vineyard Airport sewage treatment plant	11
Nitrogen inputs from structures	641 kg N per year	64 kg N per year
Phytoplankton pigments	8.0 _M/L	3.0 _M/L
Dissolved inorganic nitrogen	2.8 _M/L	1.4 _M/L
Dissolved organic nitrogen	29.4 _M/L	18.0 _M/L
Transparency	1.8 meters	No extinction

Table 5.5: A comparison of indicators (average values) of water quality and nutrient enrichment between Long Cove Pond and Big Homer's Pond, two similar coastal salt ponds. Long Cove Pond, with a more highly developed watershed, shows a much higher level of phytoplankton, DIN, organic nitrogen, and turbidity. This is an example of the relationship between development in the watershed and water quality (see section 5.7).

While phytoplankton produce oxygen during the day through photosynthesis, they also use oxygen at night through respiration. If the algal biomass is too great in either the water column or on the bottom, or both, it can cause extreme day-night swings in dissolved oxygen levels that result in hypoxic or anoxic conditions on the bottom, and even in the water column.[90] This becomes obvious when fish and shellfish kills occur, and is a strong indicator of eutrophic conditions in an estuary.

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[89] Caraco, 1987.

[90] D'Avanzo, C. and J. N. Kremer. 1994. Diel Oxygen Dynamics and Anoxic Events in an Eutrophic Estuary of Waquoit Bay, Massachusetts. *Estuaries* 18(1B):131-139.

A number of indices are used to evaluate whether an estuary is showing signs of eutrophication. These include measures of nutrients in the water, as well as symptoms of too many nutrients, such as changes in oxygen saturation in the water, water column clarity (i.e. transparency), and the amount of phytoplankton pigments dissolved in the water. Indicators used for shallow Buzzard's Bay coastal embayments include:[91]

- oxygen saturation: good health when the lowest 20% of observations average 90% saturation, poor health when they average 40% saturation.
- transparency (secchi disk depth): good health with an average of 3 meters, poor health with an average of 0.6 meters.
- phytoplankton pigments (see section 7): good health with an average of 3 ug/L, poor health with an average of 10 ug/L.
- dissolved inorganic nitrogen: good health with an average of 1 uM, poor health with an average of 10 uM.
- total organic nitrogen (DON + PON): good health with an average of 0.28 ppm, poor health with an average of 0.60 ppm.

Comparing Long Cove Pond, a pond with a high level of development and nutrient inputs in its watershed, to Big Homer's Pond, a pond with low development, indicators of water quality are substantially better in Big Homer's Pond (table 5.5). This may have an impact on the plants and animals present in the ponds (see sections 8, 9, and 10).

Overall, the indicators of water quality show that Tisbury Great Pond and Long Cove Pond display some aspects of eutrophication. In terms of phytoplankton, Tisbury Great Pond, its coves, and the upper reaches of Long Cove Pond rate poorly during summer months (see section 7). Transparency values (see section 5.3 and Table 5.2) in Tisbury Great Pond and its coves also indicate deteriorating pond conditions. On the other hand, dissolved inorganic nitrogen values (see section 5.5.3 and Table 5.4) were low for all ponds, which rates as good. Since the DIN is readily available for uptake, however, the high phytoplankton values may account for low DIN values.

5.7 Sources of Nitrogen to the Coastal Salt Ponds

Nitrogen enters coastal salt ponds in three ways: groundwater seepage, streams, and direct precipitation. Direct precipitation comprises 10% (806 kg/year) of the nitrogen added to Tisbury Great Pond. Streams are responsible for 20% (1,018 to 2,372 kg/year) of the nitrogen, and groundwater contributes the majority, around 70% (4,522 to 6,006 kg/year).[92] Combining the 7,700 kilograms of inorganic nitrogen added to the pond each year by groundwater and surface water with the nitrogen estimated from rain sources, the pond's total nitrogen load is estimated to be at around 60% of the pond's nitrogen load limit.[93]

Sources of nitrogen contribution to the Tisbury Great Pond watershed from various land uses include: rain (5,589 kg/year), septic systems (4,722 kg/year), farms (2,671 kg/year), and lawn fertilizers (461 kg/year).[94] The amount of nitrogen entering the pond from each source is affected by both season and the source's proximity to the pond. For example, nitrogen levels are elevated during the growing season, when there is more agricultural and lawn care activity. Also, when the pond is opened, nitrogen levels increase due to a higher rate of groundwater inflow. This effect is particularly noted at the northern end of the pond in the coves. Another source of

[91] Howes, B.L., T. Williams, and M. Rasmussen. 1999, p. 17.
[92] Wilcox, W. 1996.
[93] Wilcox, W. 1999.
[94] Martha's Vineyard Commission. 2000.

nitrogen within the system comes from ammonia released from wetland areas. The high level of ammonium and organic nitrogen released is caused by the breakdown of organic matter in the anaerobic wetland.[95]

One of the fastest growing sources of nitrogen comes from septic systems. Neither West Tisbury nor Chilmark are sewered: all residences and businesses are served by private, on-site septic systems, which contribute a leachate from the septic system's leaching field directly into the groundwater, below the soil. Thus, the amount of nitrogen added to the groundwater from residences can be directly estimated by multiplying the number of residences by the estimated occupancy rate to derive a seasonal nutrient contribution from all the towns' septic systems. Larger populations translate into more septic systems and fertilizer use, and therefore more pollution concerns.

To the east of the Tisbury Great Pond watershed lie the watersheds of Long Cove Pond and Big Homer's Pond (see figure 1.2). Although a total annual nitrogen load has not yet been calculated for these ponds, an estimate of nitrogen loading from residential septic systems alone has been calculated, and this can be compared to the contribution estimated from the Martha's Vineyard Airport sewage treatment plant, lying at the north end of the Long Cove Pond watershed, as estimated using surface topographic features. The delineation of these two watersheds needs further refinement, with knowledge of groundwater travel direction and rate; this is a first approximation. Using the nitrogen loading coefficients used in the MVC nitrogen loading study of the Tisbury Great Pond watershed,[96] the 95 houses present in the Long Cove Pond watershed deliver an estimated 543.8 kg nitrogen per year to the groundwater. In comparison, the Martha's Vineyard Airport sewage treatment plant, with an effluent volume of 3,186,000 gallons in 2000 and an average total nitrogen concentration of 8 mg/L,[97] delivered an estimated 96.6 kg nitrogen per year to the groundwater. The sewage treatment plant was converted to a tertiary level of treatment in 1992, and currently this treatment denitrifies the effluent by approximately 78%, using a rotating biological contactor. With only a primary level of treatment, the nitrogen delivered would be 4.5 times greater, on an annual basis. The Massachusetts Department of Environmental Protection has required tertiary treatment since the late 1980's for facilities discharging to rivers, waterbodies, or groundwater.[98] Currently, this nitrogen contribution is only one fifth of the nitrogen load contributed by the residential septic systems lying to the north of Long Cove Pond (see table 5.5).

Another factor to consider is the effect that historic nitrogen loading within the watershed may be having on the water quality in the ponds today. Due to the lag in travel-time of groundwater from the head of the watershed to the receiving ponds, nitrogen contributed to the watershed's groundwater in the past one hundred years may still be contributing to nitrogen loading in these coastal ponds.[99] In the case of the Martha's Vineyard Airport sewage treatment plant, peak discharges occurred in the 1940s, when the treatment plant serviced military barracks and a mess hall. Peak effluent discharge rates were approximately 44,000 gallons per day, with an effluent that had undergone primary treatment only, thus having a total nitrogen concentration of 36 mg/L.[100] This daily discharge converts to an annual effluent volume of 16,060,000 gallons, and a

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[95] Wilcox, W. 1996.
[96] Martha's Vineyard Commission. 2000.
[97] Kann, D., Operator, M.V. Airport sewage treatment plant, personal communication. 2001.
[98] Kann, D. 2001.
[99] Sham et al. In: Geist, M.A. (Editor). 1996. *The Ecology of the Waquoit Bay National Estuarine Research Reserve*. NOAA, OCRM, Sanctuaries and Reserves Division, MA DEM, Forests and Parks, Waquoit, MA.
[100] Kann, D. 2001.

loading of approximately 2,191.2 kg nitrogen per year to the groundwater. Without considering the number of residences present in the 1940s, this represents historical annual nitrogen loading to the Long Cove Pond watershed of more than three times that which is occurring today, from the combination of residential septic systems and a tertiary-treating sewage treatment plant.

5.8 Pollutants

The water quality in the salt ponds is also threatened by bioaccumulation of chemicals in roadway runoff. Chromium, lead, copper, cadmium, zinc, mercury, hydrocarbon, glycol, road salt, and organic matter from roads may eventually enter the pond through direct runoff. As with nitrogen and phosphorus, these contaminants may have a profound effect on the ecology of the pond. Contaminants such as zinc, mercury and copper bioaccumulate in the tissue of living matter, and are potential problems for both organisms living in the pond, and those that use the pond as a food source, including waterfowl and humans.[101] After pollution became a concern in the 1980's, West Tisbury and Chilmark worked to solve many of its road runoff problems through the installation of catchment basins or the diversion of runoff away from streams and into vegetated areas. These actions have solved many of the pollution problems relating to road runoff.[102] Coastal salt ponds are not only affected by runoff from roads, but also may receive enhanced levels of nitrogen from groundwater sources such as residential on-site septic systems and the airport wastewater treatment plant in the Long Cove Pond watershed.

5.9 Effect of Nutrient Enrichment in a Coastal Pond: Producers and Consumers

At any one location in the water column, there are two major sources of nutrients available to phytoplankton for growth. First, nutrients are delivered from the surrounding watershed, where they enter the pond through streams, runoff, and groundwater sources, and mix into the pond waters through diffusion. This outside source of nutrients is greatest closer to the delivery point, such as along the margins of the pond and in the streams at the heads of the coves. Second, dead and decaying organic matter from plankton blooms is fragmented, decomposed and dissolved by a host of grazers, detritivores, and bacteria on the bottom of the pond, where the organic matter has settled. Turbulent mixing of the water column—a process common to Tisbury Great Pond—resuspends this organic matter, making its nutrients readily available again to water-column organisms such as phytoplankton. In general, places in the world's oceans where upwelling currents resuspend nutrients are some of the most biologically productive places on earth, and support large fisheries (i.e. the west coast of South America and South Africa). Nutrient delivery from the watershed is probably responsible for rapid plankton blooms and seasonal overgrowth of benthic macrophytes, including the green algae sea lettuce, on the margins of the pond, while nutrient resuspension is most likely the more important factor in the center of the pond, and would be especially prevalent in the shallower waters of the opening's delta. Rates of nutrient resuspension can be exacerbated by benthic dredging used in shellfishing, and by careless boating, when motors "ground" in shallow waters, creating sediment clouds in the water column.

The resuspension of organic matter creates a feedback loop, in which a plankton bloom can actually enrich its nutrient environment through its own decay, thus fueling even more cellular production. This is part of the reason that eutrophication in a water body can be such a serious issue. Once the process has begun, it may continue until the system is no longer in equilibrium, and rapid and chaotic shifts can occur in elements so essential to life, such as oxygen. However, most coastal ponds have a very active community of consumers—predators on phytoplankton include zooplankton, filter-feeding shellfish, such as oysters and soft-shell clams, and filter-

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[101] Martha's Vineyard Commission and J. Taylor. 1994.
[102] R. Houle, personal communication. 2001.

feeding fish, such as Alewife and Menhaden—that very efficiently consume the excess production by plankton and algae. A diverse community of shellfish, large and small, inhabits the sediments of Tisbury Great Pond, and plays a large role in filtering the pond water of its plankton, thus acting as a sink for the plankton bloom's biomass. In essence, the shellfish and finfish that consume the plankton, and the predators higher in the food chain that consume these filter feeders, are essential to harvesting this production driven by nutrient delivery, and thus in maintaining the health of the pond waters.

6 Disease and Bacteria

Bacteria (fecal coliform, such as *Escherichia coli*, and fecal streptococcus) densities are another concern for Tisbury Great Pond and Long Cove Pond, as they are indicators of potentially unsafe conditions for swimming and contaminated shellfish. Although fecal bacteria are typically harmless, a direct correlation exists between fecal coliform density and associated illnesses—ear and nasal infections, Hepatitis A, and dysentery, for example. Bacteria densities typically rise in July and August, as water temperature and wildlife activity increases.[103] Elevated levels of bacteria were particularly evident in the northern reaches of Town Cove in 1991, at the entrance of the Mill Brook and Tiasquam River. These high readings were attributable in part to storm water runoff, as sampling during a rainstorm at locations directly receiving road runoff resulted in samples that ranged from 40 to 440 colonies/100 ml.[104] Other likely sources for fecal coliform bacteria found in runoff just after rainfall events include livestock on nearby pastures and dense waterfowl populations.[105] Regular pond water testing for fecal coliform bacteria was conducted at the Sepiessa Point Reservation beach in the summers of 1998 and 1999, when the Town of West Tisbury held public swimming lessons here. Bacterial levels exceeded state standards for swimming beaches on two dates in 1998, and caused a beach closure for several days. The source of contamination appeared to be horse manure in the pond, from trail riders, and the hot weather conditions.[106] On both dates, the water tested clean a few days later, and equestrians were requested to not ride on the beach. Bacterial levels were healthy for the entire summer of 1999, with no horses allowed on the beach.[107] In the past, high bacteria levels have also affected swimming in Long Cove Pond. For the past few summers the pond has been closed for a couple of weeks while total bacteria levels were high, although coliform bacteria levels were low.[108]

The Massachusetts Division of Marine Fisheries and the West Tisbury Shellfish Department sample water from 12 stations in Tisbury Great Pond on a monthly basis to monitor shellfish harvest areas for coliform bacteria pollution.[109] When fecal coliform bacteria levels reach 14 colonies per 100 ml on two consecutive sampling dates, an area is closed to shellfish harvesting.[110] Contaminated oysters first caused shellfishing to be closed in Tisbury Great Pond in the fall of 1982. During the 1980's the pond experienced regular closures.[111] Today, coliform bacteria levels are only occasionally found above 14 colonies per 100 ml, and rarely on consecutive dates. During the summer, however, shellfish beds in the northwest side of Tisbury

[103] Fugro-McClelland (East), Inc., 1992, p. 17.
[104] Saunders Associates (1990) In: Fugro-McClelland (East), Inc., 1992, p. 17.
[105] Fugro-McClelland (East), Inc., 1992, p. 18.
[106] Moore, A. 1998. *Summer 1998 Use at Sepiessa Point Reservation, West Tisbury, Massachusetts*. Martha's Vineyard Land Bank Commission, Edgartown, MA. 5 pp.
[107] Moore, A. 1999.
[108] C. Egan, personal communication. 2000.
[109] R. Houle, personal communication. 2001.
[110] Fugro-McClelland (East), Inc., 1992, p. 1.
[111] West Tisbury Planning Board. July 20, 1986.

Great Pond and Town Cove are often posted for closure, due to regularly high fecal coliform levels in this area, derived from contamination delivered by the Tiasquam River.[112] This does not interfere with harvests, as oysters are harvested during the late fall and winter.

7 Phytoplankton

Phytoplankton, or "drifting plants", is composed of single-celled creatures that are able to photosynthesize. They include bacteria, diatoms, other protistans, and single-celled plants and comprise an important part of the ecology of coastal salt ponds and other aquatic ecosystems.

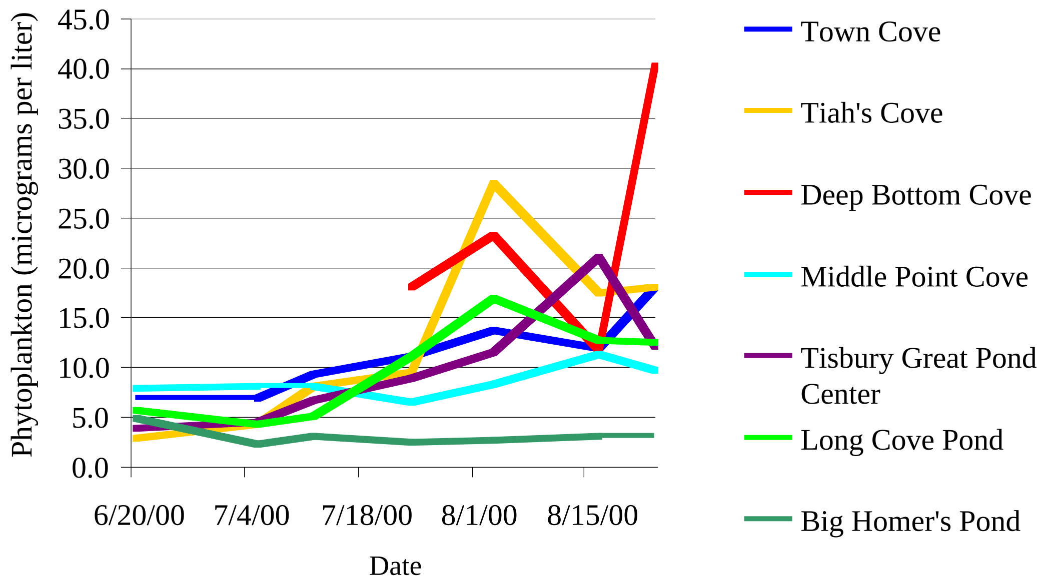

Figure 7.1: Phytoplankton concentration (based on chlorophyll a and phaeophytin a in _g per liter) in various locations of the coastal salt ponds. As the summer progressed, phytoplankton increased in all stations except for Big Homer's Pond. Following a pond opening on August 21, phytoplankton decreased in the center of Tisbury Great Pond yet increased in Deep Bottom Cove, potentially indicating a bloom arising from a flush of available nutrients from the groundwater. Note that on July 5, the phytoplankton concentration in Deep Bottom Cove was 5.9 _g per liter yet does not show due to disjunct sampling at that remote station. Also note the earlier blooms in the coves as compared with Tisbury Great Pond.

[112] R. Houle, personal communication. 2001.

Phytoplankton can rapidly convert available nutrients into biomass, and is a good indicator of the relative level of nutrients entering a pond. The relative phytoplankton biomass for different areas of the ponds can be inferred by measures of the concentration of its major cellular pigment, chlorophyll a, and its immediate breakdown product, phaeophytin a (see figure 7.1).[113]

Tisbury Great Pond and its coves exhibited sharp rises in chlorophyll a (chl a) concentrations in August. However, this phytoplankton bloom differed in its timing, magnitude and rapidity between stations. Tiah's Cove had the earliest plankton bloom of the summer, with chl a concentration peaking by August 3rd at 28.5 micrograms per liter (_g/L), a three-fold increase from 9.5 _g/L on July 24th. All the remaining pond stations showed peak chl a concentrations by August 16th, with a range of values.

By contrast with Tisbury Great Pond, Big Homer's Pond did not exhibit any significant phytoplankton growth. Big Homer's Pond had the lowest values for phytoplankton of all the ponds, possibly due to a low level of development within the small watershed (see section 5.6 and 5.7 and table 5.5). Long Cove Pond, however, showed a gradual yet significant increase over the summer, peaking in mid-August.

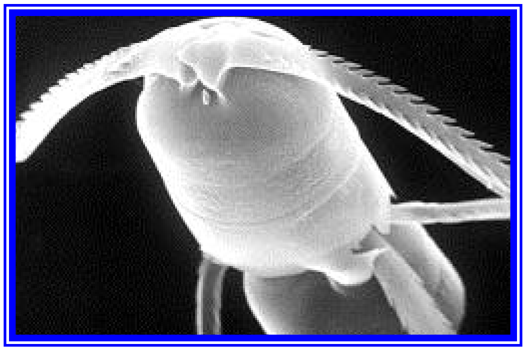

Figure 7.2: *Chaetoceros* diatom courtesy of: http://www.hmsc.orst.edu/classes/MB492/Greg chaetoceros/

Seasonal trends occur in the composition of phytoplankton communities.[114] The density of phytoplankton cells ranged from less than 4,000 natural units per milliliter to 30,000 natural units per milliliter in one year. The dominant species included *Chaetoceros* (see figure 7.2),[115] *Microcystis*,[116] and flagellates, with different species abundant at different times. *Chaetoceros* and flagellates were most easily found through March, when *Microcystis* became dominant. Then, in May through September, *Euglena* and other flagellates attained the highest density. *Skeletonema*[117] and *Chaetoceros*, which can be found easily in the summer, dominated the pond water in September and October. However, by December, *Rhizosolenia*[118] joined *Chaetoceros* again as the dominant phytoplankton species.[119]

[113] Howes, B.L., T. Williams, and M. Rasmussen. 1999.
[114] Fugro-McClelland (East), Inc., 1992, p. 13.
[115] *Chaetoceros* is a common marine diatom genus, with several hundred species. They have long setae and are usually colonial, living as long strands of cells. Diatoms are photosynthetic algae that make their cell walls out of silica. These little glass "houses" are called frustules and have many beautiful shapes.
[116] *Microcystis* is a single-celled, blue-green alga (also called cyanobacteria) that is usually found in colonies in both fresh and salt water. These algae have existed for over 3.5 billion years, and were the earth's first oxygen producers. It is a common bloom-forming alga, found primarily in nutrient enriched waters. When large blooms occur in freshwater, toxins produced by *Microcystis* can kill fish and animals that drink the water, such as birds and livestock.
[117] *Skeletonema* is a common marine diatom genus found worldwide. Single cells composed of silica are linked into long chains.
[118] *Rhizosolenia* is a long cylindrical diatom with spines on each end, and is solitary or in pairs, sometimes in chains. It is found in brackish waters and in the northeastern coastal region of the U.S.
[119] Fugro-McClelland (East), Inc., 1992, p. 16.

More recent sampling of the phytoplankton community from April 1995 to March 1996 showed an overall dominance of microflagellates throughout the year in the center of Tisbury Great Pond, a secondary dominance of Cryptophytes in the summer, and a diatom bloom composing half the phytoplankton cells in late fall and winter. [120] Town Cove showed a similar pattern of species composition, with a small component of Cryptophytes in the spring and summer and a significant diatom bloom in the fall and winter. However, the total cell counts in Town Cove were generally twice those of the central pond stations.

Examination of the phytoplankton from the center of Long Cove Pond showed two dramatic peaks in total abundance; the first in July and split between Chrysophytes and microflagellates, and the second in October and split between microflagellates and diatoms.[121]

8 Vegetation

The wide variety of conditions in and around coastal salt ponds creates a home for over 100 species of vegetation, most of which are flowering plants found along the pond shores, where diversity is highest (for a plant species list, see appendix A). These plants form patterns on the landscape, living in communities ranging from shrub swamps to underwater pondweed habitats.

8.1 Submerged Aquatic Vegetation

Submerged aquatic vegetation of the coastal salt ponds occurs in distinct communities based on pond salinities, light levels, and other factors. Communities include Eelgrass beds (figure 8.1), Dwarf Spike Rush (*Eleocharis parvula*) and Water Lobelia (*Lobelia dortmanna*) glades, algae-dominated sediments, and pondweed and tape grass beds. Plants provide habitat for animals and perform other ecosystem functions as well.

Figure 8.1: An Eel grass bed. Courtesy of http://www.vims.edu/cbnerr.

Aquatic plants are important producers of oxygen, and their roots can change sediment chemistry. Deep-rooted tape grass, for example, can oxidize sediments around roots, which is beneficial to benthic invertebrates, for example.[122]

These aquatic plants also provide a habitat for many invertebrate species that graze upon algae and detritus, and a refuge for many species of invertebrates and fish from other predatory invertebrates, fishes, birds, and mammals.

Light is an important factor when determining the distribution and density of aquatic vegetation.[123] Some aquatic plants can alter their morphology in response to changing turbidity and light levels, increasing shoot growth to reach more light as needed.[124] Young plants growing in high light levels can increase their biomass many times that of plants growing with little light

[120] Wilcox, W. 1999, p. 45.
[121] Wilcox, W. 1999, p. 49.
[122] Wigand, C., J.C. Stevenson, and J.C. Cornwell. 1997. Effects of Different Submersed Macrophytes on Sediment Biogeochemistry. *Aquatic Botany* 56(3-4):233-244.
[123] Blanch, S.J., G.G. Ganf, and K.F. Walker. 1998. Growth and Recruitment in *Vallisneria americana* as Related to Average Irradiance in the Water Column. *Aquatic Botany* 61(3):181-205.
[124] Blanch, S.J., G.G. Ganf, and K.F. Walker. 1998.

from persistent algal blooms or wind-driven sediment resuspension.[125] Thus, the spread and survival of young plants is highly dependent on ambient light levels.

Salinity is another important factor determining the distribution of aquatic vegetation; in brackish ponds, Eelgrass is commonly one of the only plants present. Tisbury Great Pond, for example, is mostly unvegetated, with only small areas of algae such as Sea Lettuce (*Ulva lactuca*) and filamentous green algae (*Enteromorpha* spp.) and beds of Eelgrass.[126] Eelgrass, like all seagrasses, is an important component of coastal ecosystems, not only because it maintains an environment for shellfish by binding bottom sediment, but also because Eelgrass provides food for waterfowl. The amount of sunlight reaching the bottom of the water column plays a large role in determining the local depth to which the plant can grow.[127] Eelgrass beds slow local water currents and vertical mixing, resulting in less suspended sediment in the water column, reducing the recycling of nutrients available for a plankton bloom, and ultimately allowing light to penetrate to a greater depth.[128] With more sunlight, a more favorable environment exists for the colonization and growth of Eelgrass. Likewise, the absence of Eelgrass results in a reverse set of conditions: more wave mixing and resuspension of sediments and nutrients, plankton blooms, and lower light penetration. Eelgrass appears to have been more abundant in Tisbury Great Pond in the early twentieth century.[129] Disturbance to bottom sediments through intensive clamming efforts in the mid twentieth century may have reduced these Eelgrass beds considerably.

Although the species composition of aquatic plants in Long Cove Pond and Big Homer's Pond is similar[130], the degree of plant zonation and species dominance vary (see Table 8.1). Long Cove Pond is deeper in the center, and showed a more pronounced zonation, with only a few sparse clumps of plants present in the deepest areas.[131] Middle Point Cove is also highly vegetated, although other brackish coves are typically less vegetated.[132] In clear, sun-drenched shallow waters along the sandy shores of Middle Point Cove, Long Cove Pond, and Big Homer's Pond, emergent Twigrush (*Cladium mariscoides*) scattered Waterwort (*Elatine* sp.), Water Lobelia, Leafless Water-milfoil (*Myriophyllum tenellum*), and Fragrant Waterlily (*Nymphaea odorata*) grow rooted in the sand. Surface Pondweed (*Potamogeton epihydrus*) can occur at all depths, and

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[125] Carter, V., N.B. Rybicki, and M. Turtora. 1996. Effect of Increasing Photon Irradiance on the Growth of *Vallisneria americana* in the Tidal Potomac River. *Aquatic Botany* 54(4):337-345.
[126] No rooted aquatic vegetation was found during this study at any of the marked stations in Tisbury Great Pond. Eelgrass beds are evidently still present in some portion of the great pond, as a small accumulation of sloughed leaves was observed in the wrackline on the eastern pondshore in late summer and early fall, a period when older leaves begin to wither from the plants and die. A comprehensive survey of Tisbury Great Pond for Eelgrass beds was not conducted in this study; this could be valuable in the future to a further understanding of water quality and habitat availability in the pond.
[127] Hempy, K. and W. Wilcox. 1997. *A survey of the Eelgrass beds of Lake Tashmoo, Vineyard Haven, MA*. Martha's Vineyard Commission, Oak Bluffs, MA. 13 pp.
Hempy, K. and W. Wilcox. 1998. *A survey of the Eelgrass beds of Sengekontacket and Farm Ponds, Edgartown and Oak Bluffs, MA*. Martha's Vineyard Commission, Oak Bluffs, MA. 21 pp. & Appdx.
[128] Howes, B.L., T. Williams, and M. Rasmussen. 1999.
[129] Kendall, W.C. 1906.
[130] Sources used for plant identification include Crow and Hellquist (2000), Fernald (1950), Gleason and Cronquist (1991), Holmgren et al. (1998), and Kelly (1999).
[131] The marked stations were located in the deepest, central portions of the pond, where few plant species occurred.
[132] No rooted aquatic vegetation was present at any of the marked stations in Town Cove, Tiah's Cove, and Deep Bottom Cove. These stations were located in deeper portions of the coves, however, where light does not penetrate as well. As a case study of vegetation patterns in the brackish coves, a transect was surveyed at Middle Point Cove.

is patchy in distribution. Dwarf Spike Rush is also common, and covers large patches of the shallow sandy bottom.

Much of the shallow waters of the freshwater ponds are also composed of green alga (*Nitella tenuissima*)-covered sediments. The green alga forms a dense brown mat through vast areas of the ponds and may be the most abundant photosynthesizer in the freshwater ponds.

Taller species such as Wild Celery or Tapegrass (*Vallisneria americana*) are abundant below depths of two feet. Common Naiad (*Najas flexilis*), Waterwort, and Red-headed Pondweed (*Potamogeton perfoliatus*) live in deeper parts of the ponds, where they grow in sporadic but dense clusters. Northern Water-milfoil (*Myriophyllum sibiricum*)[133] and sparse clumps of Red-head Pondweed occur together in more brackish coves.

Scientific Name	**Common Name**	**0 – 0.6 m.**	**0.6-1.2 m.**	**1.2-1.8 m.**	**1.8-2.4 m.**
Cladium mariscoides	Twigrush	X			
Elatine minima/triandra	a waterwort	X			
Lobelia dortmanna	Water Lobelia	X			
Myriophyllum tenellum	Leafless Water-milfoil	X			
Nymphaea odorata	Fragrant Waterlily	X			
Nitella tenuissima	a green alga	X	X	X	
Eleocharis parvula	Dwarf Spike-rush	X	X	X	X
Potamogeton epihydrus	Surface Pondweed	X	X	X	X
Vallisneria americana	Wild Celery		X	X	X
Myriophyllum sibiricum	Northern Water-milfoil		X	X	X
Potamogeton perfoliatus	Clasping Pondweed			X	X
Najas flexilis	Common Naiad			X	

Table 8.1: Presence and absence of plant species, by depth (presence is indicated by "X"). The submerged aquatic pond vegetation occurs in a zonation pattern, taller plant species found in the deeper waters, where growth and reproduction is limited by available light. Shorter plants such as Water Lobelia are only found in shallow waters.

With increasing depth the area of unvegetated bottom increases and the sediment is increasingly fine and muddy. Most of the southern central parts of Long Cove Pond are deep, turbid, and devoid of vegetation, yet low light levels do not appear to be a limiting factor to plant growth in most parts of Big Homer's Pond, which is shallow and clear.

8.2 Pond Shore Vegetation Communities

Vegetation communities found along the coastal salt pond shores include grass-dominated associations (see front cover), Sea Rocket (*Cakile edentula*) associations, Mudwort (*Limosella subulata*) associations, Water Willow (*Decodon verticillatus*) swamps, and shrub swamps. Each

[133] Northern water-milfoil is a tall plant, growing from the bottom to a height of around five feet, and has whorls of fan-shaped leaves. Morphologically, it is very similar to the non-native and invasive Eurasian water-milfoil (*M. spicatum*). Since a characteristic of *M. sibiricum*—the formation of winter buds in the fall—was evident on the collected specimens, they have been identified as Northern Water-milfoil. However, confirmation by the collection of specimens with aerial foliage and fruit is recommended for the future, where and when possible. A dense population of Eurasian Water-milfoil was recently identified as a problem and harvested from Edgartown Great Pond. As these two species are so similar, there is a small possibility that this population could also be the native Northern Water-milfoil (*M. sibiricum*). Curiously, the recently published flora of Massachusetts (Sorrie, B.A. and P. Somers. 1999. *The Vascular Plants of Massachusetts: A County Checklist*. Natural Heritage and Endangered Species Program, MA Division of Fisheries and Wildlife, Westborough, MA. 186 pp.) lists Northern Water-milfoil as present in coastal Essex county, but not in any of the five coastal counties of southeastern Massachusetts. Thus, the future confirmation of this species is also important to the knowledge of the range of this species in New England.

of these plant associations has a number of different processes acting upon them. Exposure to marine processes such as pond openings or overwash, the proportion of organic matter in the soil, the stability of the surrounding waters and pond edges, as well as man-made and other animal perturbations appear to be the most significant factors affecting the development of plant associations on these shores.

Overall, almost 100 species of plants live along the five miles of pond shores at Long Point. These plants exist along a gradient of conditions, although certain trends are evident. Most of the pond shores are typified by a sandy embankment that ranges in height from five feet to flush with the pond waterline. The height of the embankment varies as the surrounding terrain undulates. In areas where an embankment exists, wetland vegetation typically only occupies a narrow sandy strip. Where the terrain is lower, wetland vegetation often grades into the surrounding sandplain vegetation. Periodically, a swale is present in these locations, producing a more diverse community due to an increased diversity of microhabitats with species such as Switchgrass (*Panicum virgatum*; see front cover photograph), Prairie Cordgrass (*Spartina pectinata*), Three-square Swordgrass (*Scirpus americanus*), and Canada Rush (*Juncus canadensis*). Further north at Long Cove Pond, wetlands below sandy embankments are very diverse. Three-square Swordgrass is a common element in these areas with Marsh Skullcap (*Scutellaria galericulata*), Jewelweed (*Impatiens capensis*), Twigrush, Water Millet (*Echinocloa walteri*), Shining Bur-reed (*Sparganium androcladum*), Pondshore Pennywort (*Hydrocotyl umbellata*), and Northern Bugleweed (*Lycopus uniflorus*) as other associated species. At Thumb Cove and Middle Point Cove, however, embankments are much shorter and more gradual in slope, but also the water is often more brackish. Here, Canada Bluejoint (*Calamagrostis canadensis*) often dominates, with Switchgrass at the higher elevations and Salt Meadow Cordgrass partially flooded within the pond. Prairie Cordgrass exists here but is much more stunted, most likely due to dramatic changes in salinity and water level, as the pond opens and closes to the ocean.

Another vegetation type occurs along more stable shores protected from wave action. Often this type of vegetation is found in the fingers of the ponds, where a small cove or pocket is formed. In some ways these areas can be considered submerged drainage valleys. This habitat type is dominated by Water Willow, with Swamp Rose Mallow, Pickerelweed (*Pontederia cordata*), and cattails (*Typha* spp.) as typical associated species.

At the head of Middle Cove Pond lies a wetland dominated by Soft Rush (*Juncus effusis*), Canada Rush, and Woolgrass (*Scirpus cyperinus*). Other species include *Sphagnum*, sundews (*Drosera* spp.), Twigrush, Threadstem Sedge (*Carex atlantica var. capillacea*), other sedges (*Cyperus* spp.), and Marsh Fern (*Thelypteris palustris*). A muskrat den has historically been present in this habitat. This animal species has likely affected plant composition—Soft Rush is unpalatable and is typical of some wetland areas dominated by herbivores (grazed wet meadows, for example), where the palatable species are reduced or eliminated. Its trails create depressions in the wetlands, adding more niches for different species to fill. A road impedes the flow of more brackish waters from Tisbury Great Pond and allows fresh groundwater to seep in behind it, creating different habitats. A sharp contrast can be seen between the vegetation on the two sides of the road.

At the head of Long Cove Pond is a shrub swamp dominated by Sweet Pepperbush (*Clethra alnifolia*), Sweet Gale (*Myrica gale*), Winterberry Holly (*Ilex verticillata*), Scrub Oak (*Quercus ilicifolia*), Swamp Azalea (*Rhododendron viscosum*), Red Chokeberry (*Aronia arbutifolia*), and highbush blueberries (*Vaccinium* spp.). Within the tall shrub matrix are low-lying shrub and herbaceous species—Rose Pogonia (*Pogonia ophioglossoides*), sundews, violets (*Viola* spp.), Sheep Laurel (*Kalmia angustifolia*), Swamp Dewberry (*Rubus hispidus*), Cinnamon Fern

(*Osmunda cinnamomea*), and Royal Fern (*Osmunda regalis*)—with a mat of *Sphagnum* and cranberries (*Vaccinium macrocarpon*), indicators of the acidic waters. The cranberries are symbolic of the cranberry bog that occurred here historically. Red Maple (*Acer rubrum*) and Tupelo or Beetlebung (*Nyssa sylvatica*) add a sparse tree layer along the edges of the shrub swamp. Other shrubby habitats dominated by Sweet Gale are fairly common throughout the shores of Long Cove Pond. In some areas, mats of bare ground covered with organic debris are present.

Towards the south ends of the coastal salt ponds, the habitats become more disturbed due to marine processes. These soils are typically sandy but can contain large amounts of organic matter. Mudwort is associated with more flooded, flat areas high in organic matter, whereas Sea Rocket is associated with drier overwash sand habitats. Sea Rocket associations are found at the interface of the coastal salt pond and beach habitats. Other species in this habitat include Seaside Spurge (*Euphorbia polygonifolia*), orach (*Atriplex* spp.), Beach Grass (*Ammophila breviligulata*), Seabeach Knotweed (*Polygonum glaucum*), and Lady's Thumb (*Polygonum persicaria*). Saltpond Dock (*Rumex maritimus* var. *fueginus*) blankets patches of the overwash in its golden hues. Mudwort habitats are home to Salt Marsh Aster (*Aster subulatus*), Swamp Beggar Ticks (*Bidens connata*), sedges (*Cyperus* spp. and *Carex* spp.), Dwarf Spike Rush, Golden Hedge Hyssop (*Gratiola aurea*), Sea Lavender (*Limonium carolinianum*), Salt Marsh Fleabane (*Pluchea purpurascens*), Mock Bishop's Weed (*Ptilimnium capillaceum*), and Water Pimpernel (*Samolus parviflorus*).

9 Invertebrates

Invertebrate life in the coastal salt ponds is defined by environmental conditions and by functional diversity—species occupying niches based on ecosystem functions. In Tisbury Great Pond, filter-feeding invertebrates, such as the Eastern Oyster, and detritivores, such as Capitellid Threadworms (*Mediomastus ambiseta*) dominate the fauna.[134] Along freshwater shores are dragonfly larvae and a large, branching green sponge, *Spongilla lacustre*. Midges (Chironomidae) are abundant and often swarm around the pond edges (for an invertebrate species list, see appendix B).

9.1.1 Invertebrates in Tisbury Great Pond

The benthic community at Tisbury Great Pond is dominated by salt-tolerant, sediment-dwelling filter feeding bivalves such as Baltic Macoma (*Macoma balthica*), [135] deposit feeding worms,

[134] Stations were sampled for benthic invertebrates using benthic cores. The benthic core was fashioned from a ten-inch long, 4-inch diameter galvanized steel pipe, capped with a PVC cap for safe handling. Sediment cores were taken using SCUBA, and then placed in a zip lock bag for later rinsing. The samples were rinsed with a hose through a 0.5 mm mesh sieve to capture the macroinvertebrates. The remaining organisms were scraped into containers and preserved with 90% alchohol. Invertebrates were identified to species, whenever possible, using faunal keys to this region (Heuer, 1970; Peckarsky et al., 1990; Smith, 1995; Smith, 1964; Weiss, 1995). Due to the difficulty in identifying several invertebrate groups, some organisms were identified to the family or genus level, rather than species level. Many of the marine worms and some bivalves were sent for identification and confirmation to an outside expert, George Hampson, of the Woods Hole Oceanographic Institution's Biology Department. Baited traps were set at groundwater seepage areas and actively swimming invertebrates were also collected throughout the summer.

[135] The Baltic Macoma was found in 73% of benthic cores in Tisbury Great Pond. The Baltic Macoma is a burrowing, opportunistic feeder that can change its mode of feeding depending upon the local current regime and risk of predation. When currents are fast, it will extend its siphon high into the water column and filter feed. Conversely, when currents are slow or when abundant predators could nip off the siphon,

detritivorous snails, and predatory worms. The sheltered pond environment buffers the subtidal sediment-dwelling organisms from the physical extremes experienced on more exposed shorelines, with smaller fluctuations in temperature and no threat of dessication.[136] Also, because the habitat is three-dimensional and burrowing worms and shellfish can live at a variety of depths, competition for living and feeding space is not high.[137] However, competition for food among filter feeders such as bivalves can occur at high densities, and can be seen in declines in growth rate and fecundity.[138] Food supply must be limited for this to occur, and this does not appear to be the case in Tisbury Great Pond, where plankton blooms and their decay supply a rich and regular source of biomass to both filter feeders and deposit feeders. Also, food depletion is more likely to occur where deposit feeders live, as they feed on the surrounding bottom, than where filter feeders live, where currents readily resupply the area with more food.[139] Although physical stresses due to dessication and shifting temperatures, as well as competition, are unlikely to have an impact upon the muddy and sandy bottom community in Tisbury Great Pond, rapidly changing salinities and predation are likely to be important on the sandy bottom, where many motile predators, including Blue Crab (*Callinectes sapidus*), clam worms, fishes, and even birds, patrol the bottom for a meal.

Many of the invertebrates common to Tisbury Great Pond are sediment-dwellers. The high density of Blue Crabs and fish makes small, surface-dwelling invertebrates vulnerable to predation; thus those successful in this environment must be adapted to the safer life in the sediment. Sediment dwellers include Atlantic Surf Clam (*Spisula solidissima*), Softshell Clam (*Mya arenaria*), Razor Clam (*Ensis directus*), Gould Peanut Worm (*Phascolopsis gouldii*) and Capitellid Threadworm.[140] Predatory Spotted Moon Snails (*Euspira triseriata*) also burrow through the sediments, searching for thin-shelled bivalves such as *Mya* and *Mytilus*, into whose shells they drill a hole to eat the meat inside. The predatory burrowing anemone (*Actinothoe* sp.) extends its tentacles from muddy sands. The polychaete Ice-cream-cone (or Trumpet) Worm

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the clam acts more risk-averse and extends its palps onto the sediment, feeding on particulate matter as a deposit feeder. This flexible behavioral repertoire allows this highly adaptable clam to suceed in a variety of physical and biological conditions, such as those found in the dynamic Tisbury Great Pond.

[136] Bertness, M.D. 1999. *The Ecology of Atlantic Shorelines*. Sinauer Associates, Inc. Sunderland, MA. 417 pp.

[137] Bertness, M.D. 1999.

[138] Bertness, M.D. 1999.

[139] Bertness, M.D. 1999.

[140] The commonly occurring Capitellid Threadworm (*Mediomastus ambiseta*) found in Tisbury Great Pond cores are reportedly some of the largest and most robust worms of this species seen in the region (G. Hampson, personal communication.), evidence of a nutrient-rich environment without a limited food supply. This worm species was found to be common in nearshore samples from organically enriched New Bedford harbor (Howes, B.L. and D.D. Goehringer. 1996. *Ecology of Buzzards Bay: An Estuarine Profile*. National Biological Service Biological Report 31. 141 pp.). In general, this threadworm is an opportunistic colonizer of polluted sediments, and is also tolerant of stresses, as it is also found where disturbance limits the recruitment of other benthic organisms (Mannino, A. and P.A. Montagna. 1997. Small-scale Spatial Variation of Macrobenthic Community Structure. *Estuaries* 20(1):159-173.). Threadworms resemble earthworms in that they have no appendages and are ribbed, and have mucous-lined tubes through which they move as they eat their way through the sediment. They ingest mud and digest available organic matter, then produce mud fecal pellets that are deposited on the surface at the entrance to burrows (Lippson, A.J. and R.L. Lippson. 1984. *Life in the Chesapeake Bay*. Johns Hopkins University Press, Baltimore, MD. 229 pp.). As a more stress-tolerant species, *Mediomastus* may be able to persist during periods of low oxygen levels periodically found in nutrient enriched environments, when other less stress-tolerant members of the benthic community would perish. Also, this stress tolerant species may simply be able to better tolerate the abrupt shifts in the salinity regime that occur in Tisbury Great Pond after a pond opening, when salinity and water depth change rapidly.

(*Pectinaria gouldii*) lives head down in a cone-shaped tube and uses anterior tentacles for feeding.[141]

Other invertebrates in Tisbury Great Pond are adapted to life above the sediments. Mudsnails—Eastern and Threeline Mudsnail (*Ilyanassa obsoleta* and *I. trivittata*)—feed on the surface, but have strong, thick shells difficult for Blue Crabs to crush. The Eastern Oyster is vulnerable to predators when young and small, but soon reach a size and thickness where they are difficult to crush or drill. They also settle on other shells, where they can hide in crevices and obtain some shelter from predation. Common and Yellow-jawed Clamworms (*Nereis virens* and *N. succinea*) construct sandy tubes, but are active predators that often leave their tubes to forage on the open bottom, returning to their tubes when danger nears.[142] They also can burrow through the sediment, and are adapted to a range of bottom conditions. The Spine-backed Scud (*Gammarus mucronatus*, a gammarid amphipod) also lives on the surface, where it grazes on algae and detritus. Attaching itself to the sediment, the small Green-striped Anemone (*Diadumene lineata*) feeds in the water column with its tentacles. Another attaching animal, the Sea Squirt (*Molgula manhattensis*) filters plankton from the currents. Slender Isopod (*Cyathura polita*), typical of shallow, sandy-bottom areas, feeds on settled debris.[143] Channeled Barrel-bubble (*Acteocina canaliculata*), Atlantic Slippersnail (*Crepidula fornicata*), and Common Jingle (*Anomia simplex*) are also present in Tisbury Great Pond.

Crustaceans, which feed on plankton, benthic algae, and detritus, as well as other invertebrates, are a major part of the food web in Tisbury Great Pond. The most common crustacean in the pond, and the most visible, is the Blue Crab, an active predator. The Blue Crab probably enters the pond through the spring opening, to spawn in fresher waters and to feed on the pond's rich source of worms, shellfish, crustaceans and small fishes. Other common crustaceans include three species of grass shrimp (*Palaemonetes intermedius*, *P. pugio*, and *P. vulgaris*), the Sevenspine Bay Shrimp, also called Sand Shrimp (*Crangon septemspinosa*), and a nocturnal-feeding mysid shrimp (*Neomysis americana*). The Green Crab (*Carcinus maenus*), and a few Black-fingered Mud Crabs (*Panopeus* or *Eurypanopeus*) also forage in Tisbury Great Pond.

9.1.2 Invertebrates in Long Cove Pond and Big Homer's Pond

By contrast with the invertebrates of Tisbury Great Pond, characterized by a high diversity of bivalves and crustaceans, the invertebrates of the freshwater ponds are characterized by a high diversity of predatory insects such as dragonflies, an absence of sediment-dwelling organisms, a large sponge population, and large swarms of midges.

Predatory and scavenging invertebrates are common in the freshwater ponds. Dragonflies and damselflies are abundant, the adults patrolling the coastal salt pond shores for unsuspecting prey—White Corporal (*Libellula exusta*), Golden-winged Skimmer (*Libellula auripennis*), Spangled Skimmer (*Libellula cyanea*), Slaty Skimmer (*Libellula incesta*), Eastern Amberwing (*Perithemis tenera*), Comet Darner (*Anax longipes*), Spot-winged Glider (*Pantala hymenea*), meadowhawks (*Sympetrum* spp.), and Bluets (*Enallagma* spp.), for example. During midsummer, bluet adults numbers in the thousands, covering pond shore vegetation with their

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[141] A few species of shellfish were present in the benthic cores only as empty shells (not live) or as shell fragments. These could have lived and died within the pond itself, or could have been transported into the pond from the Atlantic Ocean on currents during pond openings, where they then settled onto the bottom of the quieter pond. These species include the blue mussel (*Mytilus edulis*), false angelwing (*Petricola pholadiformis*), angelwing (*Cyrtopleura costata*), and fragments of the ivory barnacle (*Balanus eburneus*).
[142] Lippson, A.J. and R.L. Lippson. 1984.
[143] Lippson, A.J. and R.L. Lippson. 1984. This species was found only in Deep Bottom Cove.

sapphire bodies. On the surface of the ponds, Water Striders (*Gerris remigis*) skate around and whirligig beetles (*Dineutus* sp.) swim rapidly in search of insects that fall in the water. Fishflies (*Chauliodes* sp.) fly around the shrub swamps and pond periphery in the summer; as larvae, they are aggressive aquatic predators known as hellgrammites. Planarian flatworms (*Phagocata woodworthi*) and leeches[144] (*Helobdella stagnalis*) live amongst the detritus in search of a meal. Caddisfly larvae (*Setodes* sp.) are scavengers that design protective cases from sand grains.

Herbivores, detritivores, and filter feeders are abundant as well. A branching freshwater sponge, *Spongilla lacustris,* is the largest invertebrate biomass found in the freshwater ponds. This plankton feeder is a widespread sponge in North America, and is common to ponds of eastern Massachusetts, where it can grow in large colonies on any substrate, including rocks and submerged debris.[145] The large sponge community in the freshwater ponds may help to moderate plankton blooms. Fingernail clams (*Musculium securis*) are also filter feeders that live in detritus. Their young are brooded by the parent. Grazers such as Pouch snails (*Physella* sp.) and other snails (*Planorbella* sp.) feed on the dense algae.[146] Along the pond shores in the summer are swarms of midges. The larvae of these species are herbivorous and are an important food source for predators due to their sheer numbers. Mosquitoes, whose larvae feed on algae and organic debris, are also common. Other scavengers and herbivores are freshwater amphipods, *Hyalella azteca* and *Gammarus tigrinus,* a mayfly (*Caenis* sp.), and Slender Isopod.[147] Along the pond shores are the grass feeding Least Skipper (*Ancyloxypha numitor*), one of the smallest butterflies. These species all comprise the rich biodiversity of invertebrates in and around the ponds.

10 Vertebrates

Many species of vertebrates live in and around the ponds of Long Point. River Otter and Common Snapping Turtle (*Chelydra serpentina serpentina*) are year-round residents. In the winter, when the ponds are frozen, River Otter will frolic on the ice whereas the Common Snapping Turtle will be hibernating in the sediments below. Hundreds of birds arrive with the seasons. Fish species each have their own niche as based on salinity and other physical and biological parameters.

10.1 Fish

At least thirty fish species live in the ponds and streams surrounding Long Point. These range from species confined to freshwater, such as Striped Killifish, to migratory species such as the Atlantic Menhaden (see appendices C, D, E, F, and G).[148]

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[144] This leech is described as the most cosmopolitan (widespread) leech species in North America (Peckarsky et al., 1990).
[145] Smith, D.G. 1995.
[146] *Physella* is common throughout the northeastern U.S. and *Planorbella* is common in eastern Massachusetts (Smith, D.G., 1995).
[147] The presence of *Gammarus tigrinus* in Big Homer's Pond is interesting by itself. This species typically inhabits upper reaches of brackish systems, moving into fresh water for periods, and is known from the entire Massachusetts coast (Smith, D.G., 1995.). However, only one other population of fully landlocked *G. tigrinus* is currently known in Massachusetts above a dam in the Egypt River, Ipswich (Smith, D.G., 1995), and it is not known how long a landlocked population can persist. Although Big Homer's Pond periodically receives salt input through salt spray and storm wave overwash, it is maintained as a fresh water body by groundwater recharge. When dipnetting, half a dozen amphipods were caught at one time, leading to the conclusion that they are not rare in the aquatic vegetation of Big Homer's Pond. They have a well-oxygenated environment with a dense, three-dimensional habitat for refuge from fish predators.
[148] Methods of fish sampling: Five otter trawls were done on July 13 with Greg Skomal, DMF Fisheries Biologist - each approximately 4 minutes long. Three trawls were in the body of Tisbury Great. One trawl was along the west side moving from south to north in a line approximately between stations 8 and 5.

10.1.1 Resident Species

Resident, small schooling and bottom-dwelling fishes are the most common fish in the coastal salt ponds of Long Point.[149] The most abundant fish (see appendix G), in decreasing order, are Banded Killifish (*Fundulus diaphanus*), Four-spine Stickleback (*Apeltes quadracus*), Atlantic Silverside (*Menidia menidia*), Inland Silverside (*Menidia beryllina*), and Mummichog (*Fundulus heteroclitus*). Other less common resident fishes are White Perch (*Morone americana*), Sheepshead Minnow (*Cyprinodon variegatus)*, Rainwater Killifish, Seaboard Goby (*Gobiosoma ginsburgi*), Nine-spine Stickleback (*Pungitius pungitius*), Striped Killifish (*Fundulus majalis*), and Northern Pipefish (*Syngnathus fuscus*).

Some species are more habitat-specific than others. For example, Sheepshead Minnow and Rainwater Killifish live in the shallow shoreline habitats of Tisbury Great Pond.[150] Likewise, all of the Nine-spine Stickleback and Striped Killifish were sampled from the northern end of Long Cove Pond, where a small stream and fresh groundwater seeps feed into this cove.[151] The Banded Killifish occurs only in Long Cove Pond and Big Homer's Pond. The Inland Silverside occurs in all ponds. Four-spine Sticklebacks were most common in shallow vegetated areas and many were found among clumps of filamentous green algae. Living in oyster bar communities in Tisbury Great Pond is the Seaboard Goby, a typically solitary fish.[152] They are reclusive bottom-dwellers, prefer cavities, and attach eggs to empty oyster shells, in which the territorial males remain to guard their eggs.[153] These fish are active predators, feeding on crustaceans, marine worms and small fishes.[154] White Perch, which are semi-anadramous and migrate to freshwater habitats to spawn, are resident and abundant in Long Cove Pond and Tisbury Great Pond, where they were stocked in the mid 1800s,[155] but were not captured in Big Homer's Pond.

Another was along the southeast section of the pond farther inshore. The last was along the north end of the pond moving from west to east. Two tows were done in coves, the first in Deep Bottom Cove moving from south to north, and the second in Town Cove from south to north. The eel pots were baited with fish scraps or lunch meat. Minnow pots were baited with bread. Baited traps were set for between 24 and 48 hours, to maximise catches and minimize stress to the organisms and predation within the pots, especially where blue crabs were common. The traps were set from two to four times per site, to track any seasonal changes or species that entered on a pond opening. Beach seining occurred at groundwater seepage areas at the heads of Long Cove Pond and Middle Point Cove. Seining was also performed in the southern end of Long Cove Pond in order to determine if there is segregation of fish species by habitat type within the ponds. Two gillnet sets were done on August 11, with Greg Skomal, DMF Fisheries Biologist, using a 300', 2" mesh net, for 1 hour across the mouth of Deep Bottom Cove and along the SE shoreline of Tisbury Great Pond. Two gillnet sets were also done on October 10, for 45 minutes (due to an approaching storm) across Town Cove at Pear Tree Cove, and west to east north of station 8, in the center of Tisbury Great Pond.

[149] These species accounted for 1,231, or 67%, of all the fish caught in this study. All resident fish, save for White Perch, were less than 10 cm. in size.

[150] This habitat preference occurred during all seasons of the year in Edgartown Great Pond. Skomal, G.B. 1998. *Massachusetts Division of Marine Fisheries Finfish Survey, Edgartown Great Pond. 4th Quarterly Report-April 1998, Final Report*. Prepared for Edgartown Ponds Committee, Edgartown, MA. 24 pp.

[151] Identification guides we used were Eddy (1969) and Page and Burr (1991).

[152] Lippson, A.J. and R.L. Lippson. 1984.

[153] Robins, C.R., G.C. Ray, and J. Douglass. 1986. *A Field Guide to Atlantic Coast Fishes of North America*. The Peterson Field Guide Series. Houghton Mifflin Company, Boston, MA. 354 pp.

[154] Lippson, A.J. and R.L. Lippson. 1984.

[155] Kendall, W.C. 1906.

10.1.2 Migratory Species

Migratory species that enter Tisbury Great Pond and its coves as adults to spawn, or enter as juveniles to feed and grow in this rich nursery habitat, are less common than resident species, yet are typically larger and comprise at least twelve species.[156] The most common are Alewife (*Alosa pseudoharengus*) and Winter Flounder (*Pleuronectes americanus*). Winter Flounder is a highly migratory species that spawns in estuaries when the water temperatures are cold during the winter months, and uses estuaries as nursery areas in its first two to three years.[157] The Alewife is an anadramous fish that enters coastal rivers and estuaries from April to July to spawn, after waters have warmed to 51ºF.[158] Young-of-the-year Alewives use the pond as a nursery area until the fall, when they begin to migrate to the ocean in response to rainfall, and falling water temperatures.[159]

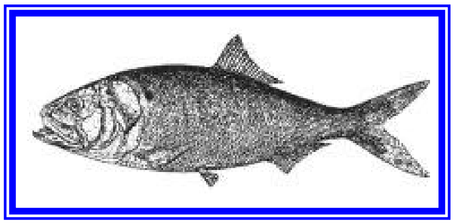

Figure 10.1: Atlantic Menhaden courtesy of http://www.vims.edu

Other less common visitors found utilizing Tisbury Great Pond or its brackish coves include migratory adult Three-spine Stickleback (*Gasterosteus aculeatus*), Spot (*Leiostomus xanthurus*), Atlantic Menhaden (*Brevoortia tyrannus*), Summer Flounder (*Paralichthys dentatus*), Hogchoker (*Trinectes maculatus*), and Striped Cusk-eel (*Ophidion marginatum*). Species using the pond as a nursery include American Eel (*Anguilla rostrata*), Cunner (*Tautogolabrus adspersus*), and Tautog (*Tautoga onitis*). Three-spine Sticklebacks are migratory as adults, moving into estuaries in late winter and early spring to spawn, and live in offshore, oceanic waters during the rest of the year. This species builds nests, has courtship rituals, and spawns in shallow, vegetated waters, where the males remain into the early summer, guarding the eggs in the nest and the demersal larvae just after hatching.[160]

Spot is an abundant marine and estuarine bottom forager and is tolerant of the wide range of salinities found in coastal bays and estuaries.[161] It is only found as far north as Massachusetts Bay, and has wide annual population fluctuations. This species is a major predator on shallow water benthic invertebrates and is known to be an important regulator of benthic communities in the Chesapeake Bay.[162]

Atlantic Menhaden is an abundant estuarine and coastal fish species, is usually found in large schools, and, unlike other species in the herring family, spawns in coastal oceanic waters.[163]

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[156] Including 33% of sampled individuals. The species in Tisbury Great Pond are similar to those found in Edgartown Great Pond. Skomal, G.B. 1998.

[157] Ross, M.R., Thorpe, L.A. and R.C. Biagi. 1987a. Winter Flounder. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.

[158] Ross, M.R. and R.C. Biagi. 1990a. River Herring. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.

[159] Ross, M.R. and R.C. Biagi. 1990a.

[160] Able, K.W. and M.P. Fahay. 1998. *The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight*. Rutgers University Press, New Brunswick, NJ. 342 pp.

[161] Able, K.W. and M.P. Fahay. 1998.

[162] Funderburk, S. L., S.J. Jordan, J.A. Mihursky, and D. Riley (Eds.). 1991. *Habitat Requirements for Chesapeake Bay Living Resources*. 2nd Edition. Chesapeake Research Consortium, Inc, Solomons, MD.

[163] Lippson, R. L. 1991. Atlantic menhaden (*Brevoortia tyrannus*). Chapter 7, In: Funderburk, S. L., S.J. Jordan, J.A. Mihursky, and D. Riley (Eds.). *Habitat requirements for Chesapeake Bay living resources*. 2nd Edition. Chesapeake Research Consortium, Inc, Solomons, MD.

They are euryhaline—able to withstand wide variations in salinity—and juveniles can also tolerate rapid shifts in salinity.[164] These filter feeders consume phytoplankton and plant detritus and are preyed upon by larger piscivores such as Bluefish, Striped Bass, herons, Osprey, and River Otter. One individual fish can filter plankton from one million gallons of water in a six-month period.[165] Menhaden are famous for their large-scale die-offs in coastal waters, although this usually occurs in small coves and creeks in warm summer months where large numbers of fish literally exhaust their local oxygen supply. This can happen at dissolved oxygen concentrations below 1.1 mg/L.[166]

American Eel, which occur in all ponds surrounding Long Point, is a catadramous fish, breeding in the Sargasso Sea, in the South Atlantic Ocean, and migrating as larvae into fresh and brackish waters to feed and grow to maturity.[167] The American Eel has a number of life stages, changing in form, color, and habitat use with age. Transparent, planktonic larvae are called leptocephali, and drift northwards on the Gulf Stream, where they develop into juvenile glass eels.[168] Glass eels enter bays and river mouths in late winter months, transforming into dark brown elvers upon entrance into brackish waters.[169] Males remain in this stage for 7 to 12 years, while females remain thus for 9 to 19 years, before transforming into sexually mature green eels and migrating back to the Sargasso Sea to spawn as black eels, after which they are thought to die.[170]

A lone Striped Cusk-eel was encountered and collected on the mudflat at the opening of Deep Bottom Cove on August 22nd. This nocturnal species lives in shallow bays, estuaries, and inshore shelf waters from New York to Florida,[171] where it burrows tail first into mud during the day and emerges to feed at night.[172] Striped Cusk-eels spawn in the summer, and courtship involves tandem swimming and sound production.[173]

Juvenile and small adult Summer Flounder typically live in inshore areas during the warm months of the year, where they seek shelter and food on the sandy and muddy bottoms of bays and harbors.[174] Larger adult fish remain in deeper inshore waters, where they spawn in fall months.

In the late fall, warm eddies from the Gulf Stream may bring southern species to Tisbury Great Pond, if it is opened to the ocean for extended periods of time. Some southern species or species at the northern limit of their range that have been recorded in Tisbury Great Pond include Trumpetfish (*Fistularia tabaccaria*), Barracuda (*Sphyræna borealis*), and Inshore Lizardfish

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[164] Lippson, R. L. 1991.
[165] Lippson, R. L. 1991.
[166] Lippson, R. L. 1991.
[167] Ross, M.R. and R.C. Biagi. 1990b. American Eel. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.
[168] McKay, B. 1999. The Life of an American Eel. *Tidal Exchange, Newsletter of the Waquoit Bay NERR*, Waquoit, MA. Fall, 1999.
[169] Able, K.W. and M.P. Fahay. 1998.
[170] Able, K.W. and M.P. Fahay. 1998.
[171] Martha's Vineyard therefore represents the northern edge of this species' range (Robins, Ray, and Douglass, 1986).
[172] Able, K.W. and M.P. Fahay. 1998.
[173] Able, K.W. and M.P. Fahay. 1998.
[174] Ross, M.R., Thorpe, L.A. and R.C. Biagi. 1987b. Summer Flounder. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.

(*Synodus foetens*).[175] Eighty-five species of fish, many of them uncommon pond visitors have been historically reported in Tisbury Great Pond.[176]

10.1.3 Freshwater Stream and Pond Fishes

A number of freshwater streams and ponds occur in the Tisbury Great Pond watershed, including the Tiasquam River and the impounded Douglas Farm Pond, Looks Pond, and Davis Pond, and the Mill Brook and the impounded Old Mill Pond, Priester's Pond, Crocker Pond and its tributary Witch Brook, and Fisher Pond. Also, small tributary streams feed the heads of the coves, including Tiah's Cove, Deep Bottom Cove, and Middle Point Cove. Seven species of freshwater fishes live in freshwater streams of the Tisbury Great Pond watershed: American Eel, Redfin Pickerel (*Esox americanus*), Tesselated Darter (*Etheostoma olmstedi*), Brown Bullhead (*Ictalurus nebulosus*), American Brook Lamprey (*Lampetra appendix*), Golden Shiner (*Notemigonus crysoleucas*), and Eastern Brook Trout (*Salvelinus fontinalis*).[177] All these species are native fish to Martha's Vineyard, and have been here since the melting of the last glaciers.[178] Additionally, fish sampled near the head of the coves include Nine-spine Stickleback, Four-spine Stickleback, Banded Killifish, and White Perch.

In the small ponds of the watershed are Banded Sunfish (*Enneacanthus obesus*), Golden Shiner, Tesselated Darter, and Bluegill (*Lepomis macrochirus*). Of these, all but the Bluegill are native Martha's Vineyard fish species. Bluegill; in addition to Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), and Brown Trout (*Salmo trutta*); is stocked in local ponds by the Division of Fisheries and Wildlife for recreational fishing. Other native freshwater fish found on Martha's Vineyard include Chain Pickerel (*Esox niger*), Swamp Darter (*Etheostoma fusiforme*), and Yellow Perch (*Perca flavescens*). These species occur in other West Tisbury and Chilmark ponds outside of this watershed, including Uncle Seth's and Old House Ponds, and Harlock's Pond.

The freshwater fish fauna of eastern Massachusetts is relatively poor in the number of fish species, compared to areas to the west and south. This is solely due to our recent history of glaciations. While this region was covered by ice and the sea level was lower, the ancestors of today's Vineyard fishes lived in two regions of the broad coastal plain of the continental shelf—one area is believed to have been centered where Georges Bank lies today, and the other was to the south, just offshore of the Virginia coastline.[179] The fish present on Martha's Vineyard today could not have survived at the edge of the glacial ice, as the streams would have been too cold to support the plant and insect life they need for forage.[180] As climate warmed and glaciers retreated, these fish gradually recolonized streams to the north and west, until about 5,000 years ago, when sea level rise would have cut off the remaining freshwater routes. Temporary glacial lakes that existed in the landscape, such as the one that occupied Vineyard Sound, would have provided connecting links to freshwater drainage systems that are now isolated from one another.[181]

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[175] Kendall, W.C. 1906.
[176] Kendall, W.C. 1906.
[177] Stream and pond fishes were collected using electroshock and seining by Karston Hartell, David Halliwell, Doug Smith, and Greg Skomal, Tim Simmons, and others in October 1988. This data is available on the Harvard University MCZ fish collections website, catalogued under Dukes County.
[178] MacKenzie, C., Jr. and T.J. Andrews. 1997. Origin of Fresh and Brackish-water Ponds and Fishes on the Vineyard. *The Dukes County Intelligencer* 39(2):59-76.
[179] MacKenzie, C., Jr. and T.J. Andrews. 1997.
[180] MacKenzie, C., Jr. and T.J. Andrews. 1997.
[181] MacKenzie, C., Jr. and T.J. Andrews. 1997.

One of these species—the American Brook Lamprey—is a threatened species in Massachusetts, with a limited range in only a few streams. This small lamprey, usually less than eight inches in length, is a nonparasitic lamprey that lives its whole life in freshwater streams. This fish requires clear, cool streams that are more than 15 feet wide, and a sandy or gravel bottom for nest construction and spawning.[182] Lampreys are eel-like, cartilaginous fish that also lack true jaws, scales, and paired fins. This species has a circular mouth with blunt teeth on the tongue and oral disc, and seven pairs of gill pores. The Brook Lamprey lives for five to six years, spending the first four or five as a blind, larval ammocetes that lives in the bottom mud, feeding on microscopic detritus. Metamorphosis into adults occurs in the fall, when adults emerge from the bottom and spend the remaining winter in the stream. During this time, sexual development occurs in preparation for the spawning season, when waters reach 62°F in the gravel riffles next to the larval pools. Adults spawn in groups, and then build nests in the gravel by carrying the rocks in their mouths. Eggs hatch within a few days, when the larvae drift downstream into silty pools to begin their life burrowed into the sand and silt. After spawning, the adults die.[183] Larval lampreys are sensitive to stream siltation and pollution, and lowered stream levels could also cause mortality. Also, stream alterations that cause damming can block the migration between larval and adult breeding habitats; this needs to be avoided to maintain healthy populations of the regionally rare fish.[184]

10.2 Birds

A wide variety of birds feed, breed, and take refuge in and around the ponds at Long Point. The composition of bird populations is constantly changing: from winter ducks to summer terns. The coming and going of these birds, as with the spawning fish, signal the changing seasons. Each of these birds fit into the pond ecosystems in their own way.

The most conspicuous fish eaters are Belted Kingfisher, Great Blue Heron, Osprey, Double-crested and Great Cormorants (*Phalacrocorax auritus* and *P. carbo*, summer and winter, respectively), and Common, Red-breasted, and Hooded Mergansers (*Mergus merganser, M. serrator, and Lophodytes cucullatus*). Each of these predators has their own method of hunting: Belted Kingfisher feed from perches and dive into the water; Great Blue Heron wait in stillness along the shore until an unsuspecting fish swims by; Osprey hover above the water, diving rapidly for larger fish; Cormorants and Mergansers, with their graceful bodies and sharp beaks, are underwater divers, chasing after fish. Common Merganser often number in the hundreds, huddling together in the sheltered heads of coves. Periodically, Least Terns (*Sterna antillarum*) will establish a colony along the banks of Tisbury Great Pond, in which they will feed upon silversides and other small fish. Great Blue Heron are common on the shores of the coastal salt ponds, often a dozen or so can be seen in the canopy of nearby woodlands. Osprey nest on poles established to increase their numbers following their precipitous decline because of DDT and other pesticide spraying, which caused their eggshells to thin and crack. In the winter, Common Loon (*Gavia immer*) pursue fish underwater in Tisbury Great Pond.

Other birds are more generalists, feeding on invertebrates, fish, and plants. Gulls and the many winter ducks fall into this category. In the winter, the ponds are covered with ducks taking refuge in the unfrozen ponds. As the ponds freeze, these birds become even more concentrated into the relatively warmer heads of coves, or they may fly further south. These birds include American

[182] MA Natural Heritage and Endangered Species Program, 1994. American Brook Lamprey (*Lampetra appendix*): Threatened Species of Massachusetts. Fact Sheet, MA Division of Fisheries and Wildlife, Westborough, MA, 2 pp.
[183] MA Natural Heritage and Endangered Species Program, 1994.
[184] MA Natural Heritage and Endangered Species Program, 1994.

Black Duck (*Anas rubripes*), Mallard (*A. platyrhynchos*), Scaup (*Aythya* spp.), Common Eider (*Somateria mollissima*), Bufflehead (*Bucephala albeola*), Common Goldeneye (*Bucephala clangula*), and gulls (*Larus* spp.). When gulls find shellfish or crustaceans, they will rise into the air and drop them on the beach, breaking their shell for easier eating.

In the summer, breeding birds return to specific habitats. Yellow Warbler (*Dendroica petechia*), Red-winged Blackbird (*Agelaius phoeniceus*), and Common Yellowthroat (*Geothlypis trichas*) dart among the shrub swamps. Piping Plover (*Charadrius melodus*) and terns make their nests on beaches around the ponds. Bank Swallow (*Riparia riparia*) burrow into the embankments around the ponds and feed on the insects flying above the pond surfaces.

10.3 Other Vertebrates

Several mammals, reptiles, and amphibians make the coastal salt ponds their home. River Otter require extensive aquatic areas for their home range. Their trails, which connect the ponds of the south shore, weave throughout the southern outwash plain. Fish scales are often present along these trails, reminders of the otter's presence and one of their food sources. River Otter (figure 10.2) build their dens in coastal salt pond embankments. Muskrat build conical homes made of vegetation in the marshes of the coastal salt ponds. They feed on the marsh vegetation as well as fish and invertebrates. In the winter, Common Snapping Turtle may hibernate in the Muskrat home. Common Snapping Turtle are omnivorous and will eat invertebrates and fish as well as vegetation. Eastern Painted Turtle (*Chrysemys picta picta*) also make the freshwater ponds their home, feeding primarily on invertebrates and vegetation. Green Frog (*Rana clamitans melanota*) and Spring Peeper (*Pseudacris crucifer*) call from the shores in the spring.

Figure 10.2: River Otter courtesy of http://www.luddist.com

11 Management Issues

Active management and monitoring is necessary to maintain a healthy coastal salt pond ecosystem for shellfishing, swimming, fishing, hunting, and to provide a suitable environment for salt pond plants and animals. Management issues of the pond discussed in this section include exotic species management, fisheries management, and pollution and nutrient input management.

11.1 Pollution and Nutrient Input Management: The Land-use Connection

Management of coastal salt ponds includes the control of pollution, including point sources and non-point source nutrient loading from the watershed. Unlike other great ponds on Martha's Vineyard, Tisbury Great Pond receives much of its recharge from stream flow, in addition to recharge from groundwater sources (see section 3.2). Because of this, these ponds have the potential to be heavily impacted by nutrient contributions from the many land-uses within the watershed (see section 5.7), affecting plants, animals, recreation, fishing, and shellfishing. Nutrient loading within the entire watershed determines most of the nutrients that eventually enter the ponds, and is the driving force behind cultural eutrophication in coastal ponds and estuaries (see section 5.6).

Originally a farming and seafaring town as part of Tisbury,[185] West Tisbury today has evolved into a busy residential community, and road traffic, business district activity, classroom size, and

[185] In 1892, the Town of West Tisbury was incorporated, splitting from Tisbury.

the need for recreational and government services have all increased.[186] Between 1970 and 1997, the town's combined year-round and seasonal population has risen from just above 5,000 to around 11,000 persons, making West Tisbury the fastest growing town on Martha's Vineyard since 1970.[187] A rising number of houses can contribute directly to the nitrogen-loading in the watershed through an increase in the number of on-site septic systems, and contributes indirectly to nutrient-loading through the conversion of natural, nitrogen-intercepting vegetation cover into impervious surfaces (roofs, driveways, roads) and lawns and gardens. The cumulative loading from development is a source of excess nutrients to coastal ponds that can result in eutrophication.

As human activity within the coastal salt ponds' watersheds has changed, the effects of these changes are becoming visible in the coastal ponds that receive land-derived nitrogen. Currently, a total of 13,443 kg of nitrogen is contributed to Tisbury Great Pond's watershed annually (see section 5.7).[188] Using the flushing characteristics of the pond and using MA DEP guidelines for clean water,[189] the Martha's Vineyard Commission estimated that annual nitrogen inputs greater than 15,000 kg per year would cause water quality in the pond to degrade too much to support swimming and shellfishing.[190] A projected low growth scenario for the watershed projects future nitrogen loading to be 15,491 kg N/year, while the moderate and high growth scenarios project loads of 19,327 and 23,204 kg N/year, respectively.[191] Future growth, therefore, may adversely affect Tisbury Great Pond.[192] Several management techniques, however, can help to protect the ponds:[193]

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[186] West Tisbury Conservation Commission. 1999. *West Tisbury Open Space and Recreation Plan. Draft.* West Tisbury, MA. 87 pp

[187] West Tisbury Conservation Commission. 1999.

[188] Martha's Vineyard Commission. 2000. By knowing the size of the watershed, examining the patterns of land use in the watershed, and assigning nitrogen-loading coefficients to various land uses, Jo-ann Taylor of the Martha's Vineyard Commission estimated the current nitrogen loading from activities in the watershed, as well as projecting future nitrogen loading rates to the watershed based upon low, moderate, and high community growth rate scenarios. Nitrogen-loading coefficients for each land use (residential septic systems, commercial and municipal uses, lawns, and agriculture) in the watershed were based upon published estimates, and are added to nutrient loading from naturally occurring rainfall for an estimate of the total mass load of nitrogen entering Tisbury Great Pond annually.

[189] The contribution of nitrogen to waters classified as "SA" by the MA DEP—waters suitable for contact recreation such as swimming, and shellfish harvesting for human consumption in open areas—is recommended to be no more than 150 mg/m3/year.

[190] Martha's Vineyard Commission. 2000. In order to manage the nutrient inputs within a watershed to protect a pond from the effects of eutrophication, a nitrogen-loading limit needs to be established for the waterbody in question. This is a complicated number, and is based upon the volume of the pond, the tidal flushing rate, and the residence period of nutrients in the pond. Using formulas developed by the Buzzards Bay Project, the MVC determined the watershed nutrient loading limit for Tisbury Great Pond under two conditions: a closed pond condition and an open pond condition. The loading limit is estimated to be 5,182 kg N/year for a closed pond, and 21,441 kg N/year for an open pond. Of course, Tisbury Great Pond fluctuates between the two conditions, so an average 147 open days and 218 closed days was used to arrive at 15,000 kg N/year.

[191] Martha's Vineyard Commission. 2000.

[192] Another consideration in modeling nitrogen loading within a watershed is the amount of time that septic system-derived nitrogen takes to travel to the coastal pond—this is called travel-time. Since groundwater travels at a rate of about one to three feet per year, nitrogen-loading estimates can lag behind development rates in the watershed by almost a decade. Pond openings, which cause a localized drawdown in groundwater level, may accelerate the travel-time and shorten this lag-time. Also, nitrogen inputs from development will continue to increase for 100 years after development has ceased, due to the time it takes the nutrient-rich groundwater to travel from the top of the watershed to the receiving ponds. Sham et al.

11.1.1 Land Conservation and Nutrient Loading Management

The protection of open space as well as implementing pollution prevention methods, such as vegetated buffer strips between livestock and the pondshore, will help to reduce the impacts of added nitrogen to pond water quality. West Tisbury has already identified the need to moderate growth and retain the Town's rural character, as well as protect ground and surface waters within the town.[194] Means to consider for accomplishing these goals may include:

- Protecting or acquiring critical remaining open space in the watershed.[195]
- Adopting 15,000 kg N/year as an annual load limit for Tisbury Great Pond.[196]
- Where appropriate, requiring advanced on-site nitrogen-removing septic systems on new construction and in system upgrades. [197]
- Revising zoning and board of health regulations to support the nitrogen-loading limit, with consideration of a watershed-wide DCPC designation to develop and implement these regulations.[198]
- Focusing water quality planning on protection of immediate shoreline from direct, point-source contamination such as from farm animals.[199]
- Encouraging low-nitrogen farm activities, such as growing hay and legume crops, in conjunction with open-space protection.[200]
- Encouraging native plant communities around home sites, rather than converting land cover to lawns that require fertilizer applications.
- Using research to relate different nitrogen loading rates to average annual nitrogen concentrations in different portions of the ponds, and relating these in turn to average annual production and biomass levels of vegetation and phytoplankton. This will allow land management goals to be defined in terms of the end-point measures.[201]

(1995) In: Geist, M.A. (Editor). 1996. *The Ecology of the Waquoit Bay National Estuarine Research Reserve*. NOAA, OCRM, Sanctuaries and Reserves Division, MA DEM, Waquoit, MA.

193 Currently, the Martha's Vineyard Commission is working with the Town of Edgartown to implement or explore some of these strategies, include creating a wider, deeper inlet channel, by dredging, to extend the time that the pond remains open, to increase the tidal flushing; and decreasing the future amount of nitrogen entering Edgartown Great Pond from residential on-site septic systems through the use of denitrifying systems in new developments within the watershed. W. Wilcox, personal communication. 2001.

194 West Tisbury Conservation Commission. 1999.

195 In forests of the Waquoit Bay watershed on Cape Cod, almost 65% of the total dissolved nitrogen (TDN) falling on the forests in rain is retained and used by the forest vegetation and microbes within the soils. Since 42% of the nitrogen loading to the Tisbury Great Pond watershed is derived from rainfall, these uptake processes occurring within forested and other native habitats could potentially remove almost 27% of the watershed's total nitrogen loading (Lajtha et al., 1995). This highlights the need for protecting and conserving open space in the watershed.

196 Martha's Vineyard Commission. 2000.

197 Martha's Vineyard Commission. 2000. Martha's Vineyard Commission. 1999. *Edgartown Great Pond: Nutrient loading and recommended management program*. 1996-1998. Prepared for MA DEP, Bureau of Resource Protection, and U.S. Environmental Protection Agency, Region I.

198 Martha's Vineyard Commission. 2000.

199 Martha's Vineyard Commission. 2000.

200 Martha's Vineyard Commission. 2000.

201 After defining a desired end-point, or set of optimal conditions within the estuary, a model can be used to examine the varying impact of different management scenarios on nitrogen loading rates and assess whether they will meet the resource goals. In other words, the effects of each management option on loading rates to levels that meet agreed-upon goals can be assessed. This allows the testing and use of practical and acceptable management techniques, including many different options, into an agreeable solution, and allows scientific, social, and economic factors to be taken into account in the decision-making

11.1.2 Nitrogen Management in the Ponds

Within the ponds, nitrogen can be managed in several ways. Some of this management, however, may change the species composition of the coastal salt ponds and are therefore not an ideal method to manage nitrogen. Examples of this type of management are:

- Dredging to maintain a channel to increase the flushing rate of a pond.[202]
- Harvesting excess biomass through seaweed removal, shellfish harvesting, or harvest of planktivorous fishes such as alewives and menhaden from the pond itself.[203]
- Creating permanent jetties such as those at Lake Tashmoo.

Flexible, adaptive management that is regularly updated and evaluated by current science and monitoring results and based on land-use demographics remains the most viable management option for coastal salt ponds around Long Point and Martha's Vineyard. Linking concepts of nitrogen management and the available knowledge as best we can to establish operational and sustainable management goals is the challenge that faces the residents of the ponds' watersheds.

11.2 Fisheries Management

Fishing and shellfishing in the ponds of Martha's Vineyard has been occurring for thousands of years. Originally named Ukquieset by Native Americans, Tisbury Great Pond, as well as Long Cove Pond and Big Homer's Pond, was surrounded by Wampanoag settlements.[204] Fishing and shellfishing were a large part of the Wampanoag diet and also became a source of food for European settlers.[205] Currently, the management of fisheries is becoming more science-based, as resources become scarce with a growing human population.

11.2.1 American Eel

American Eel populations have declined in the western Atlantic Ocean since the 1950's, and can be seen in a decline in the statewide catch from 365,132 pounds in 1928 to 35,798 pounds in 1992. The reasons for this decline are not clear, and may be due to many factors, including barriers to migration, a regional decline in habitat quality or loss of habitat, hydro turbine mortality, changing oceanic conditions, over fishing, parasitism, or pollution.[206] The complex life history and lack of management of this fishery has made the cause of the decline difficult to distinguish. A new management initiative by the Atlantic States Marine Fisheries Commission, however, has established objectives to limit sources of mortality caused by humans and to restore available habitat. Objectives include improving the knowledge of eel use through better harvest reporting, gaining knowledge of eel population dynamics, providing migratory passage and access to historic eel freshwater habitat, and monitoring the abundance of various eel life stages.[207]

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process. Valiela, I. et al. 2000. Operationalizing Sustainability: Management and Risk Assessment of Land-derived Nitrogen Loads to Estuaries. *Ecological Applications* 10(4):1006-1023.

[202] Martha's Vineyard Commission. 1999.

[203] Geist, M.A. (Editor). 1996.

[204] Raleigh, L. 2000.

[205] Raleigh, L. 2000.

[206] Haro et al. 2000. Population Decline of the American Eel:Implications for Research and Management. *Fisheries* 25 (9):7-16.

[207] Haro et al. 2000.

11.2.2 American Oyster Fishery in Tisbury Great Pond

Most of the commercial fishermen use dredges to harvest oysters from the pond.[208] The oyster beds today are smaller than they were in the 1950's when John Murphy harvested an average of 2,000 bushels a year, equivalent to the total current harvest.[209] Oyster beds were managed by private companies with leases from the towns in the past, but are open to the public today and are now managed by the towns as a public recreational and commercial resource.[210] There is no known reason for the decline in oysters, although some believe that it may be connected to the increase in acid rain over the last 50 years. The lower pH could inhibit the formation of calcium shells (high pH), in the larvae.[211] Others blame eutrophication, connected with increased levels of nitrogen delivered from the watershed.[212]

The towns and fishermen presently work to maintain the oyster population through the rotational closing of sections of the pond to fishing each year, and augment juvenile recruitment and survival through the use of aquaculture techniques. Adult oyster brood stock are taken from the pond and spawned by the Martha's Vineyard Shellfish Group at their Lagoon Pond hatchery. Larval oysters nearing the end of their swimming stage are transferred from the hatchery to tanks on the shore of Tisbury Great Pond, where bags of shell substrate are "seeded" with larvae in a process called remote setting. The oyster larvae are spread over shell bags in tanks of aerated seawater. The larvae settle and cement themselves to the shells and undergo a metamorphosis into juvenile oysters.[213] The shell bags are then removed from the tanks and suspended from rafts in the pond, where the young oysters are allowed to grow. When they reach about a _" in length, the juvenile oysters attached to the shell cultch are distributed on the pond bottom for final growth to harvestable size.[214]

11.2.3 A New Oyster Disease in Tisbury Great Pond

Dermo, a pernicious oyster tissue disease caused by the protozoan parasite *Perkinsus marinus*, was first detected in Tisbury Great Pond oysters in the fall of 1999. In a routine health check on oysters collected by the Martha's Vineyard Shellfish Group (MVSG) for spawning brood stock, veterinarian pathologists at MBL detected a small infection. Subsequent sampling in the fall of 2000 detected infection in 53% of tested oysters from the center of the Great Pond, 100% infection of oysters on the Chilmark side, north of Little Sandy, and 75% infection rate of oysters on the southern Chilmark side.[215] This disease was discovered in Edgartown Great Pond in 1997, but is not present to date in Squibnocket Pond, Oyster Pond or Katama Bay.[216]

Although this disease does not harm human health, it has caused the collapse of oyster fisheries from the Gulf of Mexico to Delaware Bay, where it was previously known to be restricted primarily to southern waters. Since 1990 and a series of warm winters, it has extended its range to oyster beds north of Delaware Bay.[217] It is not known whether this range extension is due to

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[208] S. Larsen, personal communication, 2000.
[209] J. Murphy, personal communication, 2000.
[210] R. Karney, personal communication, 2001.
[211] S. Larsen, personal communication, 2000.
[212] West Tisbury Planning Board. July 20, 1986.
[213] R. Karney, personal communication, 2000.
[214] R. Houle, personal communication, 2000.
[215] R. Karney, personal communication, 2001.
[216] Lovewell, M.A. 2000. Killing Disease Hits Oyster Fisheries in Tisbury Great Pond. November 3, 2000, p.1. *The Vineyard Gazette*, Edgartown, MA.
[217] Ewart, J.W. and S.E. Ford. 1993. *History and Impact of MSX and Dermo Diseases on Oyster Stocks in the Northeast Region*. NRAC Fact Sheet No. 200. Northeastern Regional Aquaculture Center, Umass-Dartmouth, N. Dartmouth, MA. 8 pp.

recent oyster stock introductions, small infestations that have flourished in higher local temperatures in bays and estuaries, or the rise of a new low-temperature tolerant strain.[218] After initial infection, this parasite spreads rapidly within an oyster's tissues. Mortality begins within a couple months of exposure. After death, these dead and infected tissues are released into the water column, where they are then ingested by nearby filter-feeding oysters. The parasite then invades the lining of the healthy oyster's digestive system, to repeat the cycle of infection.[219] The radiation of the disease from an initial infected area to surrounding oysters results in a fairly rapid spread of the disease. This warm-water parasite spreads most rapidly in temperatures above 25˚C, so most infections are induced in the warm summer months.[220] Mortality rates in a population then peak in the fall, which is the best time to sample oyster beds for the disease.[221] Heavily infected oysters will have died by the following spring, and lightly infected oysters will be heavily infected by the following fall.[222]

A large decline in the oyster population will hurt the commercial oyster industry, but it could also spell the beginning of a serious decline in water quality in the pond as the abundant native oysters play an important role in filtering excess phytoplankton from the water column.[223] With a diminished filtering role, the pond may see larger phytoplankton blooms that could result in even less visibility in the water column, and a greater use of oxygen as the decaying plankton settles to the bottom. Today, oysters play a large role in mediating the results of current nutrient loading levels in Tisbury Great Pond.

Once a population is infected, the best management course is to remove infected adult oysters and to try to inhibit the rate of spread of the disease into healthy, uninfected oyster beds.[224] To this end, the commercial season was opened in early November 2000, and the daily limit was increased from three bushels to five, and fishing was permitted three days per week, to encourage the harvest of large, marketable oysters.[225] Factors that slow the spread of the disease include lower salinity (<15 ppt), cold over-winter water temperatures, and the development of disease-resistant strains.[226] Mildly infected oysters might survive a cold winter in which the disease activity is suppressed. Otherwise, the following spring would see a significant die-off of oysters. Dermo activity is depressed at salinities below 8 to 9 ppt, and a complete outbreak in a population cannot occur in salinities below 12 ppt.[227]

Bill Wilcox of the Martha's Vineyard Commission, Rick Karney of the MVSG, and the Tisbury Pond Sewers have proposed to manage Tisbury Great Pond in 2001 for a lower overall growing season salinity regime, by reducing the number of man-made openings in the pond to allow the salinity to drop and remain low in the warm months of June to September.[228] By delaying the summer opening until late September it may be possible to lower salinity levels throughout the pond to below 10 ppt, in the crucial warm months in which Dermo needs higher salinities to grow

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[218] Ewart, J.W. and S.E. Ford. 1993.
[219] Ewart, J.W. and S.E. Ford. 1993.
[220] Ewart, J.W. and S.E. Ford. 1993.
[221] Ewart, J.W. and S.E. Ford. 1993; R. Karney, personal communication, 2001.
[222] R. Karney, personal communication, 2001.
[223] W. Wilcox, personal communication, 2001.
[224] Ewart, J.W. and S.E. Ford. 1993.
[225] Lovewell, M.A. *The Vineyard Gazette*. 2000.
[226] Ewart, J.W. and S.E. Ford. 1993.
[227] Ewart, J.W. and S.E. Ford. 1993.
[228] W. Wilcox, personal communication, 2000.

and spread.[229] Once this disease is resident in a pond, the pond will need to be managed carefully to regulate this disease in order to continue to support a healthy oyster fishery.

Another disease, called MSX, has infected oysters and damaged the fishery all along the eastern coast of the US.[230] This disease is not currently known to infect oysters in Vineyard waters. However, a less virulent parasite called seaside organism (SSO) has been detected in the tissues of oysters in Katama Bay. [231]

11.2.4 Soft-shell Clam Fishery in Tisbury Great Pond

Soft-shell clams were reported to be fairly abundant in Tisbury Great Pond in 1906.[232] Additionally, quahogs were probably never found here, as no old or dead shells were found in the pond at that time.[233] Quahogs were seeded into the pond in the early 1980's, but did not survive to marketable size due to low salinities.[234] Today, small soft-shell clams abound, but commercially harvestable clams are scarce. Some suggest that past methods of commercial-scale soft-shell clam harvesting may have been destructive to the pond bottom: "Clams were harvested using hydraulic pumping, which forced water under pressure into the sediments and brought the clams to the surface as the sediments settled; in short order clams were over harvested and the pond floor was altered considerably."[235] Other views on the use of this technique suggest that this sediment disturbance and resorting resulted in an increase in soft-shell clam productivity by providing aeration to the sediment that improved settlement and thus recruitment of young spat into the population.[236] Although the effects of past harvesting methods on today's shellfish productivity are ambiguous, Tisbury Great Pond cannot support a viable soft-shell clam fishery today due to the presence of soft-shell clam leukemia.[237] This disease has affected soft-shell clam populations and fisheries all over the east coast of the United States.[238] In addition to Tisbury Great Pond, Edgartown Great Pond also suffers from this clam leukemia.[239] This disease stresses and slowly kills the clams, just as they are reaching marketable size at 2-3 years of age.[240] Today, the pond has dense populations of juvenile clams, as evident in benthic cores at Tisbury Great Pond stations 1-10, but the leukemia prevents the clams from growing to harvestable size. Although the clams are still present in large numbers in the pond, this disease has effectively decimated the recreational and commercial fishery in Tisbury Great Pond.

11.2.5 Stream Restoration

The streams entering the coves of Tisbury Great Pond—the Tiasquam River, the Mill Brook, and the stream entering the head of Pear Tree Cove—have been altered extensively in the past three hundred years by the building of impoundments and dams to supply power to mills, and by roads and culverts built to allow stream crossings for first foot and horse traffic, and later automobiles. These impoundments and dams, while creating still pond waters for pond-dwelling fishes and farm ponds for livestock, have interrupted the water flow and contiguous habitats needed by

[229] W. Wilcox, personal communication, 2000.
[230] Ewart, J.W. and S.E. Ford. 1993.
[231] R. Karney, personal communication, 2001.
[232] Kendall, W.C. 1906.
[233] Kendall, W.C. 1906.
[234] R. Karney, personal communication, 2001.
[235] M. Jones, personal communication, 2000.
[236] R. Houle, personal communication, 2000; R. Karney, personal communication, 2001.
[237] R. Karney, personal communication, 2001.
[238] Crago, T.I. 1993. Getting to Why: Understanding Leukemia in Soft-shell Clams. *Nor'Easter, Magazine of the Northeast Sea Grant Programs* 5(1):20-23.
[239] P. Bagnall, personal communication, 2001.
[240] R. Karney, personal communication, 2001.

native anadromous and catadromous fish to successfully reproduce, and to maintain viable populations and fisheries in this watershed. As mentioned previously, the state-endangered American Brook Lamprey requires uninterrupted connections between downstream wetlands and upstream gravel beds to be able to swim upstream to nesting habitat. With a dam or interrupted flow, the larvae could repopulate downstream areas, but adults are blocked from reaching upstream gravel beds where they nest, resulting in a slow loss and possibly even local extirpation of this species in the upper reaches of the stream systems.

Of possibly greater importance is the protection of the historically important American Eel and Herring fisheries in this watershed. American Eels are declining throughout the north Atlantic region for a complex set of reasons, which includes the obstruction of freshwater stream headwaters from their connection with bays and estuaries, breaking the link between the habitats needed for the growth of juveniles into mature adults and the adult spawning habitat at sea.[241] As well as the provision of structures to allow for upstream juvenile migration and passage at barriers, equally important to this fishes' life cycle and the maintenance of a sustainable Atlantic population is the availability of adult downstream passage to the sea to complete the species' reproductive cycle in the Sargasso Sea. Where structures cannot be removed or modified, trap-and-transport methods have been used to circumnavigate dams, and increased flow over dams or at power structures can be timed to allow for downstream migration at peak migration times.[242]

Historically, herring runs and the fishery for Alewife and Blueback Herring were important commercially and socially in the Tisbury Great Pond watershed. Today, planktivorous fish such as Menhaden and the anadromous herring are an important energy sink, using the nitrogen that is converted into phytoplankton blooms as a food source and playing a role in removing much of this recent overproduction. Thus, these species are important modulators of pond nutrient and energy cycling that can experience wide fluctuations when a pond becomes subject to increasing development pressures in its watershed and develops many of the early signs of eutrophication, as has been seen in Tisbury Great Pond. Not only does herring reproduction depend upon successful timing of pond openings, but also it also depends upon the availability of upstream freshwater spawning habitat. This is currently restricted in area in this watershed, due to the barriers and impoundments that limit access to freshwater by migrating fish. Some spawning habitat may also be available at the heads of the smaller coves, where freshwater seeps occur, such as Muddy Cove, Pear Tree Cove, Tiah's Cove, Deep Bottom Cove, and Middle Point Cove. Currently, the maintenance of a clear migratory channel between Tisbury Great Pond and fresher pond environments is critical to providing spawning habitat. This includes the stream channel between the great pond and Black Point Pond, and the possible re-establishment of such a connection to Long Cove Pond. Also critical to the removal of plankton biomass and energy from this system is to also provide an opening from the pond to the sea when these fish need to migrate into oceanic waters. Without allowing the release of these fish from the pond, their death and decay will simply trap the nutrients they have harvested and converted into fish protein within the pond ecosystem, and would not benefit the control and management of nitrogen levels within the pond. Another way to increase removal of this nitrogen would be to develop a larger local fishery and market for these herring, so a larger biomass is harvested from the pond each year.

Critical to restoring any stream habitats or stream-dependent fish populations is the management of road and storm-water runoff to prevent organic and metal pollution to the streams and to also create structures that prevent the siltation of stream bottom habitats required in the fishes' reproductive cycle. Also, channelized marshes at the head of Town Cove may act to decrease the

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[241] Haro et al. 2000.
[242] Haro et al. 2000.

area of habitat available to these fishes. Before undertaking any restoration activities, a survey and review of present conditions needs to be performed, identifying locations and seasonal barriers to migration, and a range of management activities that could be used to mitigate these.

11.3 Exotic Species Management

Non-native species have been introduced to local coastal waters from other continents for centuries, often transported on the outer hull of a ship or as larvae in the ballast waters taken on in a foreign port and then released in our harbors.[243] This introduction of a non-native species, also called an exotic or alien species, can disrupt the balance of a local ecosystem. Exotic invertebrates or fish often have few or no natural predators in a new location, allowing the new species' to multiply unchecked. This can cause a decline in local food resources for local, native species, crowd sessile animals and plants from their usual space, and even be a vector for the spread of disease.[244] Since some of these exotic species were introduced in New England hundreds of years ago and have been successful in our shallow, near shore habitats, we have adjusted to their presence and often assume they are native to our fauna and flora.

Some of the species introduced here through shipping might take you by surprise. They include a grazer, the Common Periwinkle (*Littorina littorea*), the predatory Atlantic Dogwinkle (*Nucella lapilus*), Common Atlantic Slippersnail (*Crepidula fornicata*), and the Green Crab (*Carcinus maenas*). All now common, they have each wrought changes in our ecosystem. Other native periwinkles were formerly more abundant in the intertidal zone, and a wide band of ephemeral green algae was formerly present in the upper intertidal zone.[245] Today, newly settled barnacle larvae and this band of algae are rapidly removed by this effective grazer, the Common Periwinkle.[246] Also, many species of native, thin-shelled snails have declined from the combined effects of the Atlantic Dogwinkle, effective at drilling into other snails for food, and the Green Crab, effective at crushing these snails. Green Crabs are also voracious predators in the intertidal zone and more tolerant of air exposure; they have effectively monopolized a space previously occupied by other crabs and small tide pool fishes. Only one small Green Crab was encountered in Tisbury Great Pond during this study. This species is more common on hard substrates, and is probably limited in its success here by the limited availability of hard bottom habitats. Slippersnails are extremely common in sandy bay bottoms in our region. They do not seem to have an obvious effect, and certainly serve as food to larger predators, but may also be competing with local grazers and detritivores for a limited food supply.

Even more recent introductions include Green Fleece (*Codium fragile tomentosoides*), Asian Shore Crab (*Hemigrapsus sanguineus*), and Mute Swan (*Cygnus olor*).[247] Green Fleece was brought from Japan to Europe, and then to New York Harbor in the 1950's, probably hitchhiking as a fouling organism, or in oyster spat.[248] This alga grows rapidly and attaches to hard substrates, including the shells of shellfish, providing a "sail" to waves. This has contributed to the uprooting and ultimate stranding of large numbers of shellfish in shore wrack lines during storms, causing a higher than normal mortality to young shellfish. *Codium* is rare in Tisbury Great Pond, probably due to the changing salinity and the paucity of hard substrates for

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[243] MIT Sea Grant College Program. 1998. *A quick guide to marine bioinvasions.* MIT, Cambridge, MA. 8 pp.
[244] MIT Sea Grant College Program. 1998.
[245] Bertness, M.D. 1999.
[246] Carlton, J. 1992. Introduced Marine and Estuarine Mollusks of North America: An End-of-the-20th-century Perspective. *J. Shellfish Res.* 11(2):489-505.
[247] MIT Sea Grant College Program. 1998.
[248] Bertness, M.D. 1999.

attachment. The Asian Shore Crab was introduced to New Jersey around 1987, as larvae in ballast water, and has since spread as far north as Massachusetts.[249] This crab is an omnivore that preys on young clams, scallops, oysters, and fish, among others. Where found, it can be very numerous, but seems to prefer the intertidal regions of rocky shores. The effects this species can have on local ecosystems are not yet known, but researchers at the University of Massachusetts at Dartmouth are currently tracking the spread of this species.[250] Asian Shore Crabs were first discovered on Martha's Vineyard in 1996 in Lagoon Pond, and were then seen in 1997 in Sengekontacket Pond, and are now found in Cape Pogue Pond, as well.[251] Although not found in this study along the sandy shores and muddy bottoms of Tisbury Great Pond, this crab has been found among the oyster shells in oyster spat floats suspended in Tisbury Great Pond.[252] Where found, it is frequently numerous, but seems to be restricted primarily to rocky or shell-strewn bottoms that provide a spatially complex habitat with many crevices. The Asian Shore Crab has a very high fecundity, extruding eggs three times per year in its native Japan; in US waters it produces eggs two times in a year.[253]

Another possible invasive species that would be important to monitor in Tisbury Great Pond and its surrounding fresh ponds is the Zebra Mussel (*Dreissena polymorpha*). Although this species occurs mostly in large freshwater bodies such as the Great Lakes, estuarine populations have been found in the Hudson River in salinities below 5 ppt.[254] This highly invasive mussel, if introduced, could possibly become established along the shores of Tisbury Great Pond in the upper, fresher portions of the coves or in nearby fresh ponds. This species is highly invasive and has outcompeted many native freshwater mussels in North America. If ever established here, a population of this species would probably remain small, as the varying salinity regime of Tisbury Great Pond would impose a physiological limit on its distribution. The installation and regular monitoring of larval settling plates offshore from boat launching sites in Tisbury Great Pond would be effective in detecting the presence or establishment of this species. A simple cleaning and visual inspection of boat bottoms at launch sites will prevent the spread of this mussel. It is also important to drain the water from the motor, transom and bilge away from the pond, and wash the boat with water above 104 F with a high-pressure spray, or use chlorinated tap water. To ensure that no exotic species have survived to be spread to another water body, allow everything to dry for at least five days.[255]

In general, the effects newly introduced species have on an ecosystem can be subtle and nearly impossible to predict. Also, a new species may take many years to establish a wide-ranging population, so the effects may take many years to appear. This is the case for Mute Swans, which have spread slowly from the Long Island area, where they were introduced as estate pets in the late 1800's. After escaping captivity, these natives of Europe and Asia have established themselves from Virginia to New England, and in some midwestern states, as well.[256] Being large and non-migratory, once they establish a territory in a pond they are effective at excluding other native ducks, through territorial aggression and by grazing the shallow areas of a pond of its underwater vegetation. These swans can reach deeper grass beds with their longer necks, allowing access to a wider resource and giving them dominance over the native geese and ducks. Additionally, a pair of Mute Swans can live up to 45 years and produces four to eight eggs each

[249] MIT Sea Grant College Program. 1998.
[250] MIT Sea Grant College Program. 1998.
[251] D. Grunden, personal communication, 2001.
[252] R. Karney, personal communication, 2001.
[253] R. Karney, personal communication, 2001.
[254] Carlton, J. 1992.
[255] MIT Sea Grant College Program. 1998.
[256] Delorey, B. 2001. *Beast or beauty?* Massachusetts Wildlife 51(1):30-35.

year, with very few predators on these eggs and young, and no effective predators on the adults.[257] This results in rapid population growth, which has been seen in the doubling of the number of pairs in Massachusetts from 400 to 816 between 1985 and 1999.[258] As coastal waterbodies become saturated with nesting pairs, younger Mute Swan pairs are now dispersing inland to nest in freshwater ponds and lakes.[259] Large numbers of the birds can cause substantial change to wetland habitats through their destructive foraging habitats; rather than grazing blades and shoots of submerged aquatic plants, they rip the entire plant out of the mud.[260] This prevents regeneration of the plants that provide habitat and oxygen for fish, especially important in small waterbodies that may already be stressed from nutrient loading in rapidly developing coastal watersheds.

The coves and ponds around Tisbury Great Pond have resident pairs of Mute Swans nesting on their shores; in 2000, Middle Point Cove had one and possibly two nesting pairs, and Long Cove Pond had two pairs present all summer. A resident pair was not seen on Homer's Pond, but individuals appeared there from time-to-time to forage. An island of high marsh in nearby Chilmark Pond has a large concentration of mute swan nests, and a flotilla of over 80 swans regularly moves up and down the pond in the summer, when the young are still gray in plumage and preparing to fledge. This safe nesting site may be a source for swans that have expanded into other nesting areas on Martha's Vineyard.

Non-native plant species may also respond differently than native species to nutrient enrichment and pollution in the coastal environment. Non-point source pollution from development within the coastal salt pond watershed may increase nutrient levels and contamination within the ponds.[261] Wetlands are particularly sensitive to increased nitrates because wetland plants have typically evolved within a specific range of environmental conditions and excess nutrients can favor non-native species tolerant of these new conditions. Two invasive species often found in disturbed wetlands include Common Reed (*Phragmites australis*) and Purple Loosestrife (*Lythrum salicaria*). Debate exists as to whether Common Reed is native or introduced in North America; many believe that both American and European strains now occur here, and that the European arrivals behave differently than the original natives.[262] In recent decades, Common Reed has begun to dominate brackish and tidal wetland areas to the exclusion of other native wetland grasses. This is often associated with a site disturbance, such as an alteration in the topography or hydrology by road-building, tidal restriction, or wetland drainage such as saltmarsh ditching.

Common Reed can dominate marshes and exclude other native wetland grasses through nutrient use and shading. Common reed's root zone reaches deeper into marsh soils than do native marsh grasses (*Spartina* spp.), where the roots pump water to the aboveground plant tissues, removing more pore water ammonium than do native grasses. This can reduce local water levels by up to 10 cm. and cause a reduction in subsurface water flow from the marsh to nearby tidal creeks.[263] As common reed colonizes the drier upland margins of the saltmarsh, this plant dries the marsh, creating more suitable habitat for itself and allowing its spread over time from the margins into

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[257] Delorey, B. 2001.
[258] Delorey, B. 2001.
[259] Delorey, B. 2001.
[260] Delorey, B. 2001.
[261] Martha's Vineyard Commission. 2000.
[262] Kiviat, E. 1994. Reed , Sometimes a Weed. *News from Hudsonia*, Vol. 10 (3):4-6.
[263] Windham, L. 1999. *Effects of Phragmites on Rates of Nitrogen Cycling in Brackish Tidal Marsh*. Talk presented at the Greater New England Symposium on the Ecology of Invasive Species, February 27, 1999, Yale University, New Haven, CT.

the center of a marsh. Common Reed also acts as a nutrient pump, sequestering nitrogen into its large aboveground biomass, and reducing the nutrients available in the surrounding soils to other plants.[264] Although research shows that the breakdown of leaves into detritus occurs at an equal rate in common reed and native marsh grasses, a much higher proportion of common reed's biomass is stored in the tall, woody stems that accumulate in the marsh as thatch, taking longer to decompose and become available as particulate organic matter to estuarine grazers and detritivores.[265] Common Reed is an especially successful colonizer where tidal flows are restricted, as is evident along the tidal creek and banks of Black Point Pond, to the west of Tisbury Great Pond. A small colony of Common Reed has also established on the western shore of Sepiessa Point, around a small cove that is often isolated from the pond by a sand spit, restricting tidal inundation when the pond is open.

Purple Loosestrife arrived and became established in the Hudson Valley in the early 1800's, probably by the transport of its small seeds in ship ballast or materials shipped from Europe. It has grown and spread across New England, benefiting from the deforestation, wetland drainage, siltation, eutrophication, and road construction in this region in the past two centuries.[266] A small colony occurred on the banks of the Old Mill Pond, along the roadside, but was eradicated through local control efforts by the use of cutting and herbicide treatment.[267]

Eurasian Water-milfoil, which may be present in Middle Point Cove, is a real problem in freshwater ponds, where it can quickly monopolize a pond, replacing the native species and choking navigable waters. It can become so dense that it impedes travel by fish and waterfowl, and is very difficult to eradicate, as it spreads through fragmentation. It has only recently become established in brackish waters of eastern Massachusetts.[268] Edgartown Great Pond is reported to have had a dense growth of Eurasian Water-milfoil at the head of Wintucket Cove, which was harvested and has presently declined.[269] Harvesting is a temporary control measure, as all remaining fragments can root to form new plants, and must be repeated to be entirely effective.[270]

The main vector that distributes this plant to new locations is trailered boats that carry fragments from one pond to another. This is most important at the public boat launch site on Tisbury Great Pond, at Sepiessa Point Reservation, where boats that have been trailered from other water bodies can be launched into the pond, providing a vector for spread. Smaller watercraft such as canoes and kayaks that are moved from pond to pond can also spread these plants. Simply performing a thorough cleaning of vegetation off the boat and trailer after leaving the water will prevent the spread of nuisance aquatic weeds. The MA Public Access Board has furnished signage to remind boaters of this responsibility, and these are posted at the public boat launch. Further education about invasive aquatic plants and their spread would be valuable for preventing the spread of these plants to uncolonized locations.

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[264] Meyerson, L., R. Chambers, and K. Vogt. 1999. *Phragmites Effects on Porewater Chemistry in Two Connecticut Freshwater Tidal Marshes*. Talk presented at the Greater New England Symposium on the Ecology of Invasive Species, February 27, 1999, Yale University, New Haven, CT.
[265] Warren, R. and P. Fell. 1999. *Rates, Patterns, and Impacts of Phragmites australis Spread and Experimental Phragmites Control within the Tidelands of the Lower Connecticut River*. Talk presented at the Greater New England Symposium on the Ecology of Invasive Species, February 27, 1999, Yale University, New Haven, Ct.
[266] Kiviat, E. 1996. Tangled Locks: The Purple Loosestrife Invasion and Biological Diversity. *News from Hudsonia*, Bard College, Annandale, NY.
[267] R. Williams, personal communication, 2001.
[268] Hellquist, C.B. 1994. Exotic Aquatic Plants of Massachusetts. *Massachusetts Wildlife* 44(2):10-16.
[269] P. Bagnall, personal communication, 2001.
[270] Hellquist, C.B. 1994.

12 Future Research Needs

As expected, this study has raised more issues about our gaps in knowledge than it has answered questions. This study was designed to extend, in both space and time, the existing knowledge of the resources and dynamics of ecosystem function within the salt ponds surrounding Long Point Wildlife Refuge. Here are some of the suggested areas for further research into the conditions and relationships occurring in these ponds that remain to be studied:

- Monitor the groundwater at the head of Long Cove Pond for nitrogen that might indicate the presence of a sewage treatment plant effluent plume;[271]
- Survey the Tisbury Great Pond for Eelgrass bed distribution and biomass, screen for wasting disease, and assess epiphytic growth on Eelgrass plants;[272]
- Establish monitoring plots for invertebrate populations as another measure of health in the ponds;[273]
- Determine the flushing rate of the Tisbury Great Pond and the water-level restricted coves;[274]
- Investigate possible development of hypoxic bottom conditions by deploying remote recording dissolved oxygen probes at locations where stratification is likely to occur following a summer pond opening (near opening);[275]
- Monitor the shoreline intensively, along and at the terminus of coves, to identify problem areas of highest DIN input into the ponds through shoreline groundwater seeps and rainwater runoff (see technique used in Gaines, 1998);
- Further study of the variety, abundance, seasonality, and habitat associations of the invertebrates found along the pond shores, with a focus on dragonflies, damselflies, and other little-studied groups;
- Determine the macroalgal species composition and biomass within Tisbury Great Pond by season and depth (i.e. incident radiation) zone;
- Monitor the pond and pond shores for the presence or establishment of nuisance exotic, aquatic species, including Asian Shore Crab, Zebra Mussel, and Eurasian Water-milfoil;
- Monitor and document changes in land-use patterns and demographics in the watershed on a ten-year cycle;
- Determine the species composition and abundance of zooplankton, especially larval fish ichthyoplankton, entrained and brought into the pond on an opening, and their growth within the pond;
- Determine diversity and abundance of southern fish species entering and suffering winter mortality in Tisbury Great Pond in fall openings;
- Determine interannual variations in Blue Crab population and production within Tisbury Great Pond;
- Continue to monitor oyster beds for shellfish diseases, to inform management decisions;
- Compare rates of nutrient resuspension in oyster harvest areas versus non-harvest areas;
- Implement a boating-use survey for Tisbury Great Pond, to determine if the use of motorboats is contributing to nutrient resuspension to a detrimental degree.

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[271] Wilcox, W. 1999, p. 53.
[272] Wilcox, W. 1999, p. 53.
[273] Wilcox, W. 1999, p. 53.
[274] Wilcox, W. 1999, p. 53.
[275] Wilcox, W. 1999, p. 53.

Literature Cited

Able, K.W. and M.P. Fahay. 1998. *The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight*. Rutgers University Press, New Brunswick, NJ. 342 pp.

Belding, D.L. 1921. *A Report upon the Alewife Fisheries of Massachusetts*. Massachusetts Division of Fisheries and Game, Boston, MA. 135 pp. (reprinted 1964)

Bertness, M.D. 1999. *The Ecology of Atlantic Shorelines.* Sinauer Associates, Inc. Sunderland, MA. 417 pp.

Blanch, S.J., G.G. Ganf, and K.F. Walker. 1998. Growth and Recruitment in Vallisneria americana as Related to Average Irradiance in the Water Column. *Aquatic Botany* 61(3):181-205.

Caraco, N., A. Tamse, O. Boutros, and I. Valiela. 1987. Nutrient Limitation of Phytoplankton Growth in Brackish Coastal Ponds. *Can. J. Fish. Aquat. Sci.* 44:473-476.

Carlton, J. 1992. Introduced Marine and Estuarine Mollusks of North America: An End-of-the-20th-century perspective. *J. Shellfish Res*. 11(2):489-505.

Carter, V., N.B. Rybicki, and M. Turtora. 1996. Effect of Increasing Photon Irradiance on the Growth of *Vallisneria americana* in the Tidal Potomac River. *Aquatic Botany* 54(4):337-345.

Crago, T.I. 1993. Getting to Why: Understanding Leukemia in Soft-shell Clams. *Nor'Easter, Magazine of the Northeast Sea Grant Programs* 5(1):20-23.

Crow, G.E. and C.B. Hellquist. 2000. *Aquatic and Wetland Plants of Northeastern North America. Volume 1: Pteridophytes , Gymnosperms, and Angiosperms: Dicotyledons*. [a revised and enlarged edition of Norman C. Fassett's A manual of aquatic plants.] University of Wisconsin Press, Madison, WI.

Culliton, T.J., M.A. Warren, T.R. Goodspeed, D.G. Remer, C.M. Blackwell, and J. McDonough. 1990. *50 years of Population Change Along the Nation's Coasts 1960-2010*. NOAA, NOS, OMA, Strategic Assessment Branch.

D'Avanzo, C. and J. N. Kremer. 1994. Diel Oxygen Dynamics and Anoxic Events in an Eutrophic Estuary of Waquoit Bay, Massachusetts. *Estuaries* 18(1B):131-139.

Delaney, D.F. 1980. *Ground-water Hydrology of Martha's Vineyard, Massachusetts*. Hydrologic Investigations Atlas, U.S. Geological Survey. Atlas MA-618.1:48,000. 2 pp.

Delorey, B. 2001. Beast or Beauty? *Massachusetts Wildlife* 51(1):30-35.

Eddy, S. 1969. *How To Know the Freshwater Fishes*. Second Edition. Pictured Key Nature Series. W. C. Brown Company Publishers, Dubuque, Iowa. 286 pp.

Emery, K.O., B.L. Howes and S.R. Hart. 1997. *A Coastal Pond Studied by Oceanographic Methods. Epilogue: Oyster Pond – Three Decades of Change*. Oyster Pond Environmental Trust Inc. 111 pp.

Ewart, J.W. and S.E. Ford. 1993. *History and Impact of MSX and Dermo Diseases on Oyster Stocks in the Northeast Region*. NRAC Fact Sheet No. 200. Northeastern Regional Aquaculture Center, Umass-Dartmouth, N. Dartmouth, MA. 8 pp.

Fernald, M.L. 1950. *Gray's Manual of Botany*, Vol. 2. Eighth Edition – Illustrated. Dioscorides Press, Portland, Oregon. 1632 pp.

Freeman, J. 1807. A Description of Dukes County. Pp. 38-95 in *Collections of the Massachusetts Historical Society, Vol. 3*. Second Series. 1815. John Eliot, Boston.

Fugro-McClelland (East), Inc. 1992. *Water Quality Study of Tisbury Great Pond.* Prepared for Towns of West Tisbury and Chilmark, Martha's Vineyard, MA. 37 pp.

Funderburk, S. L., S.J. Jordan, J.A. Mihursky, and D. Riley (Eds.). 1991. *Habitat Requirements for Chesapeake Bay Living Resources*. 2nd Edition. Chesapeake Research Consortium, Inc, Solomons, MD.

Gaines, A.G. 1998. *Nutrient Loading Limits of Edgartown Great Pond, Edgartown, Massachusetts*. Prepared for Martha's Vineyard Commission, Oak Bluffs, MA. 48 pp.

Geist, M.A. (Editor). 1996. *The Ecology of the Waquoit Bay National Estuarine Research Reserve*. NOAA, OCRM, Sanctuaries and Reserves Division, MA DEM, Forests and Parks, Waquoit, MA.

Gleason, H.A. and A. Cronquist. 1991. *Manual of Vascular Plants of Northeastern United States and Adjacent Canada*. The New York Botanical Garden, Bronx, NY. 910 pp.

Haro et al. 2000. Population Decline of the American Eel: Implications for Research and Management. *Fisheries* 25(9):7-16.

Hellquist, C.B. 1994. Exotic Aquatic Plants of Massachusetts. *Massachusetts Wildlife* 44(2):10-16.

Hempy, K. and W. Wilcox. 1997. *A Survey of the Eelgrass Beds of Lake Tashmoo, Vineyard Haven, MA.* Martha's Vineyard Commission, Oak Bluffs, MA. 13 pp.

Hempy, K. and W. Wilcox. 1998. *A Survey of the Eelgrass Beds of Sengekontacket and Farm Ponds, Edgartown and Oak Bluffs, MA.* Martha's Vineyard Commission, Oak Bluffs, MA. 21 pp. & Appdx.

Heuer, R.J., Jr. 1970. *Exploring for Sea Shells on Martha's Vineyard*. Felix Neck Wildlife Trust, Inc., Vineyard Haven, MA. 102 pp.

Holmgren, N.H., P. Holmgren, R. Jess, K. McCauley, and L. Vogel. 1998. *The Illustrated Companion to Gleason and Cronquist's Manual*. The New York Botanical Garden, Bronx, NY. 937 pp.

Howes, B.L., T. Williams, and M. Rasmussen. 1999. *Baywatchers II: Nutrient Related Water Quality of Buzzards Bay Embayments: A Synthesis of Baywatchers Monitoring 1992-1998*. The Coalition for Buzzards Bay, New Bedford, MA. 127 pp.

Howes, B.L. and D.D. Goehringer. 1996. *Ecology of Buzzards Bay: An Estuarine Profile*. National Biological Service Biological Report 31. 141 pp.

Imperial, M. 1999. Analyzing Institutional Arrangement for Ecosystem-based Management: Lessons from the Rhode Island Salt Ponds SAM Plan. *Coastal Management* 27:31-56.

Kelly, Wanda. 1999. *A Guide to the Aquatic Plants in Massachusetts*. MA Dept. of Environmental Management, Lakes and Ponds Program and the New England Aquarium, Boston, MA. 32 pp.

Kendall, W.C. 1906. *An Account of Tisbury Great Pond, Martha's Vineyard, with a List of Fishes Collected in October and November, 1906*. United States Bureau of Fisheries. 8 pp.

King, S. 1961. Sand Dunes and Sea Law. *The Dukes County Intelligencer* 3(1).

Kiviat, E. 1994. Reed , Sometimes a Weed. *News from Hudsonia*, Vol. 10 (3):4-6.

Kiviat, E. 1996. Tangled Locks: The Purple Loosestrife Invasion and Biological Diversity. *News from Hudsonia*, Bard College, Annandale, NY.

Lajtha, K., B. Seely, and I. Valiela. 1995. Retention and Leaching Losses of Atmospherically-derived Nitrogen in the Aggrading Coastal Watershed of Waquoit Bay, MA. *Biogeochemistry* 28:33-54.

Lippson, A.J. and R.L. Lippson. 1984. *Life in the Chesapeake Bay*. Johns Hopkins University Press, Baltimore, MD. 229 pp.

Lippson, R. L. 1991. Atlantic Menhaden (*Brevoortia tyrannus*). Chapter 7, In: Funderburk, S. L., S.J. Jordan, J.A. Mihursky, and D. Riley (Eds.). *Habitat Requirements for Chesapeake Bay Living Resources*. 2nd Edition. Chesapeake Research Consortium, Inc, Solomons, MD.

Lovewell, M.A. 2000. Killing Disease Hits Oyster Fisheries in Tisbury Great Pond. November 3, 2000, p.1. *The Vineyard Gazette*, Edgartown, MA.

MacKenzie, C.L., Jr. 1995. The Eel Fishery of Martha's Vineyard. *The Dukes County Intelligencer* 36(3):120-144.

MacKenzie, C.L., Jr. and T.J. Andrews. 1997. Origin of Fresh and Brackish-water Ponds and Fishes on the Vineyard. *The Dukes County Intelligencer* 39(2):59-76.

Mannino, A. and P.A. Montagna. 1997. Small-scale Spatial Variation of Macrobenthic Community Structure. *Estuaries* 20(1):159-173.

Martha's Vineyard Commission and J. Taylor. 1994. *Great Pond Management on Martha's Vineyard*. Martha's Vineyard Commission, Oak Bluffs, MA. 56 pp.

Martha's Vineyard Commission. 1999. *Edgartown Great Pond: Nutrient Loading and Recommended Management Program*. 1996-1998. Prepared for MA DEP, Bureau of Resource Protection, and U.S. Environmental Protection Agency, Region I.

Martha's Vineyard Commission. 2000. *Nutrient Loading to Tisbury Great Pond*. Martha's Vineyard Commission, Oak Bluffs, MA. 66 pp. & Appdx.

MA Natural Heritage and Endangered Species Program, 1994. American Brook Lamprey (*Lampetra appendix*): Threatened Species of Massachusetts. Fact Sheet, MA Division of Fisheries and Wildlife, Westborough, MA, 2 pp.

McKay, B. 1999. The Life of an American Eel. *Tidal Exchange, Newsletter of the Waquoit Bay NERR*, Waquoit, MA. Fall, 1999.

Meyerson, L., R. Chambers, and K. Vogt. 1999. *Phragmites Effects on Porewater Chemistry in Two Connecticut Freshwater Tidal Marshes*. Talk presented at the Greater New England Symposium on the Ecology of Invasive Species, February 27, 1999, Yale University, New Haven, Ct.

MIT Sea Grant College Program. 1998. *A Quick Guide to Marine Bioinvasions*. MIT, Cambridge, MA. 8 pp.

Moore, A. 1999. *Summer 1999 Use at Sepiessa Point Reservation, West Tisbury, Massachusetts*. Martha's Vineyard Land Bank Commission, Edgartown, MA. 3 pp.

Moore, A. 1998. *Summer 1998 Use at Sepiessa Point Reservation, West Tisbury, Massachusetts*. Martha's Vineyard Land Bank Commission, Edgartown, MA. 5 pp.

Nixon, S.W. 1997. Prehistoric Nutrient Inputs and Productivity in Narragansett Bay. *Estuaries* 20(2):253-261.

Oldale, R.N. 1992. *Cape Cod and the Islands. The Geologic Story*. Parnassus Imprints, E. Orleans, MA. 208 pp.

Page, L.M. and B.M. Burr. 1991. *A Field Guide to Freshwater Fishes*. The Peterson Field Guide Series. Houghton Mifflin Company, Boston, MA. 432 pp.

Peckarsky, B.L., P.R. Fraissinet, M.A. Penton, and D.J. Conklin, Jr. 1990. *Freshwater Macroinvertebrates of Northeastern North America*. Cornell University Press, Ithaca, NY. 442 pp.

Raleigh, E.L. 2000. *Land-use History of Long Point Wildlife Refuge*. The Trustees of Reservations, Vineyard Haven, MA. 30 pp.

Raleigh, E.L. and K. Fauteux. 2001. *Terrestrial Plant Communities of the Tisbury Great Pond, Long Cove Pond, and Big Homer's Pond Watersheds*. The Trustees of Reservations, Vineyard Haven, MA.

Ritchie, W.A. 1969. *The Archaeology of Martha's Vineyard: A Framework for the Prehistory of Southern New England, A study in Coastal Ecology and Adaptation*. The Natural History Press, Garden City, NY.

Robins, C.R., G.C. Ray, and J. Douglass. 1986. *A Field Guide to Atlantic Coast Fishes of North America*. The Peterson Field Guide Series. Houghton Mifflin Company, Boston, MA. 354 pp.

Ross, M.R. and R.C. Biagi. 1990a. River Herring. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.

Ross, M.R. and R.C. Biagi. 1990b. American Eel. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.

Ross, M.R., Thorpe, L.A. and R.C. Biagi. 1987a. Winter Flounder. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.

Ross, M.R., Thorpe, L.A. and R.C. Biagi. 1987b. Summer Flounder. *Marine Recreational Fisheries of Massachusetts Series*. Univ. of Massachusetts Cooperative Extension and MA Division of Marine Fisheries, Boston, MA. 4 pp.

Skomal, G.B. 1998. *Massachusetts Division of Marine Fisheries Finfish Survey, Edgartown Great Pond. 4th Quarterly Report-April 1998, Final Report*. Prepared for Edgartown Ponds Committee, Edgartown, MA. 24 pp.

Smith, D.G. 1995. *Keys to the Freshwater Macroinvertebrates of Massachusetts*. 2nd Edition. Sunderland, MA. 243 pp.

Smith, R.I. 1964. *Keys to the Marine Invertebrates of the Woods Hole Region*. Contribution No. 11, Marine Biological Laboratory, Woods Hole, MA. 208 pp.

Sorrie, B.A. and P. Somers. 1999. *The Vascular Plants of Massachusetts: A County Checklist*. Natural Heritage and Endangered Species Program, MA Division of Fisheries and Wildlife, Westborough, MA. 186 pp.

Swain, P.C. and J. B. Kearsley. 2000. Draft. *Classification of the Natural Communities of Massachusetts*. The Natural Heritage and Endangered Species Program, MA Division of Fisheries and Wildlife, Westborough, MA.

Taylor, J. 1999. *Quality Assurance Project Plan for Nutrient Loading to Two Great Ponds: Tisbury Great Pond and Lagoon Pond*. Submitted to Massachusetts DEP, Project 604b No. 99-02/604.

Tompkins, W.A. 1958. *Fisheries Report for Some Southeastern Massachusetts Lakes, Ponds, and Reservoirs, 1951-1952*. Massachusetts Division of Fisheries and Game, Boston, MA. 87 pp.

Travers, M. 1960. *The Wampanoag Indian Tribute Tribes of Martha's Vineyard*.

Valiela, I., G. Tomasky, J. Hauxwell, M.L. Cole, J. Cebrian, and K.D. Kroeger. 2000. Operationalizing Sustainability: Management and Risk Assessment of Land-derived Nitrogen Loads to Estuaries. *Ecological Applications* 10(4):1006-1023

Warren, R. and P. Fell. 1999. *Rates, Patterns, and Impacts of Phragmites australis Spread and Experimental Phragmites Control Within the Tidelands of the Lower Connecticut River*. Talk presented at the Greater New England Symposium on the Ecology of Invasive Species, February 27, 1999, Yale University, New Haven, CT.

Weiss, H.M. 1995. *Marine Animals of Southern New England and New York. Identification Keys to Common Nearshore and Shallow Water Macrofauna*. Bulletin 115, State Geological and Natural History Survey of Connecticut, Dept. of Environmental Protection, Hartford, CT.

West Tisbury Conservation Commission. 1999. *West Tisbury Open Space and Recreation Plan. Draft*. West Tisbury, MA. 87 pp.

Whiting, J.W.M. 1997. Tisbury Great Pond. *The Dukes County Intelligencer* 38(4):155-174.

Wigand, C., J.C. Stevenson, and J.C. Cornwell. 1997. Effects of Different Submersed Macrophytes on Sediment Biogeochemistry. *Aquatic Botany* 56(3-4):233-244.

Wilcox, W. 1999. *Island Coastal Ponds Water Quality Survey*. *Final Report. 1995-1996 Survey Data*. The Island Ponds Consortium, Oak Bluffs, MA. 84 pp. & Appdc.

Wilcox, W. 1996. *Tisbury Great Pond Watershed Study*. Martha's Vineyard Commission, Oak Bluffs, MA. 21 pp. & Appdc.

Windham, L. 1999. *Effects of Phragmites on Rates of Nitrogen Cycling in Brackish Tidal Marsh*. Talk presented at Greater New England Symposium on the Ecology of Invasive Species, February 27, 1999, Yale University, New Haven, CT.

Appendices

Appendix A: Plant species list

Common Name	*Scientific Name*
Red Maple	*Acer rubrum*
Creeping Bentgrass	*Agrostis stolonifera*
Beach Grass	*Ammophila breviligulata*
Pimpernel	*Anagallis arvensis*
Red Chokeberry	*Aronia arbutifolia*
Dusty Miller	*Artemesia stelleriana*
Downy Swamp Milkweed	*Asclepias incarnata*
New York Aster	*Aster novi-belgii*
Salt Marsh Aster	*Aster subulatus*
Seabeach Orach	*Atriplex arenaria*
Halberd-leaved Orach	*Atriplex patula*
Swamp Beggar Ticks	*Bidens connata*
Sea Rocket	*Cakile edentula*
Canada Bluejoint	*Calamagrostis canadensis*
Threadstem Sedge	*Carex atlantica var. capillacea*
Broomsedge	*Carex scoparia*
Seabeach Sedge	*Carex silicea*
Ribbed Sedge	*Carex virescens*
Oak-leaved Goosefoot	*Chenopodium glaucum*
Twigsedge	*Cladium mariscoides*
Sweet Pepperbush	*Clethra alnifolia*
Field Bindweed	*Convolvulus arvensis*
sedge sp.	*Cyperus esculentus*
sedge sp.	*Cyperus filicinus*
Water Willow	*Decodon verticilatus*
Water Millet	*Echinocloa walteri*
a waterwort	*Elatine minima or triandra*
Dwarf Spike Rush	*Eleocharis parvula*
A green algae	*Enteromorpha intestinalis*
Daisy Fleabane	*Erigeron annuus*
Hyssop-leaved Boneset	*Eupatorium hyssopifolium*
Seaside Spurge	*Euphorbia polygonifolia*
Marsh Bedstraw	*Galium palustre*
Small Bedstraw	*Galium trifidum*
Golden Hedge Hyssop	*Gratiola aurea*
Cow Parsnip	*Heracleum lanatum*
Swamp Rose Mallow	*Hibiscus palustris*

Pondshore Pennywort	*Hydrocotyl umbellata*
Dwarf St. John's Wort	*Hypericum mutilum*
Winterberry Holly	*Ilex verticillata*
Jewelweed	*Impatiens capensis*
Slender Blue Flag	*Iris prismatica*
Wild Iris	*Iris verticillata*
Canada Rush	*Juncus canadensis*
Soft Rush	*Juncus effusus*
Sea Lavender	*Limonium carolinianum*
Mudwort	*Limosella subulata*
Water Lobelia	*Lobelia dortmanna*
Northern Bugleweed	*Lycopus uniflorus*
Virginia Water-horehound	*Lycopus virginicus*
Maleberry	*Lyonia ligustrina*
Sweet Gale	*Myrica gale*
Northern Water-milfoil	*Myriophyllum sibiricum*
Leafless Water-milfoil	*Myriophyllum tenellum*
Common Naiad	*Najas flexilis*
a green alga	*Nitella tenuissima*
Fragrant Waterlily	*Nymphaea odorata*
Tupelo	*Nyssa sylvatica*
Evening Primrose	*Oenothera fruiticosa*
Sensitive Fern	*Onoclea sensibilis*
Cinnamon Fern	*Osmunda cinnamomea*
Royal Fern	*Osmunda regalis*
Switchgrass	*Panicum virgatum*
a panic grass	*Dichanthelium sp.*
Virginia Creeper	*Parthenocissus quinquefolia*
Annual Salt Marsh Fleabane	*Pluchea purpurascens*
Rose Pogonia	*Pogonia ophioglossoides*
Seabeach Knotweed	*Polygonum glaucum*
Nodding Smartweed	*Polygonum lapathifolium*
Lady's Thumb	*Polygonum persicaria*
Pickerelweed	*Pontederia cordata*
Surface Pondweed	*Potamogeton epihydrus*
Clasping Pondweed	*Potamogeton perfoliatus*
Mock Bishop's Weed	*Ptilimnium capillaceum*
Wild Radish	*Raphanus raphanistrum*
Swamp Azalea	*Rhododendron viscosum*
Common Yellow-cress	*Rorippa palustris var. palustris*
Blackberry	*Rubus allegheniensis*

Bristly Dewberry	*Rubus hispidus*
Curly Dock	*Rumex crispus*
Saltpond Dock	*Rumex maritimus var. fueginus*
Bebb's Willow	*Salix Bebbiana*
Pussy Willow	*Salix discolor*
Water Pimpernel	*Samolus parviflorus*
Three-square Swordgrass	*Scirpus americanus*
Wool Grass	*Scirpus cyperinus*
Marsh Skullcap	*Scutellaria galericulata*
Bristly Foxtail	*Setaria geniculata*
European Black Nightshade	*Solanum nigrum*
Elliott's Goldenrod	*Solidago Elliottii*
Seaside Goldenrod	*Solidago sempervirens*
Sphagnum species	*Sphagnum spp.*
Shining Bur-reed	*Sparganianium drocladum*
Salt Meadow Cordgrass	*Spartina patens*
Prairie Cordgrass	*Spartina pectinata*
Sand Spurrey	*Spergularia rubra*
Steeplebush	*Spiraea tomentosa*
Saltmarsh Seablite	*Suaeda maritima*
American Germander	*Teucrium canadense*
Marsh Fern	*Thelypteris palustris*
Poison Ivy	*Toxicodendron radicans*
Marsh St. John's Wort	*Triadenum virginicum*
Narrow-leaved Cattail	*Typha angustifolia*
Broad-leaved Cattail	*Typha latifolia*
Sea Lettuce	*Ulva lactuca*
Highbush Blueberry	*Vaccinium corymbosum*
Black Highbush Blueberry	*Vaccinium fuscatum*
Cranberry	*Vaccinium macrocarpon*
Wild Celery	*Vallisneria americana*
Clotbur	*Xanthium strumarium*

Appendix B: Invertebrate species list

Family	**Common Name**	***Scientific Name***
Sagartidae	a burrowing anemone	*Actinothoe modesta*
Diadumenidae	Orangestriped Green Anemone	*Diadumene lineata*
Aiptasiomorphidae	Lined Anemone	*Fagesia lineata*
Attyidae	Eastern Paper Bubble	*Haminoea solitaria*
Calyptraeidae	Common Atlantic Slippersnail	*Crepidula fornicata*
Nassariidae	Eastern Mudsnail	*Ilyanassa obsoleta*

Family	**Common Name**	***Scientific Name***
Nassariidae	Threeline Mudsnail	*Ilyanassa trivittata*
Naticidae	Spotted Moonsnail	*Euspira triseriata*
Physidae	Pouch Snail	*Physella species*
Planorbidae	a snail	*Planorbella species*
Scaphandridae	Channeled Barrel-bubble	*Acteocina canaliculata*
Anomiidae	Common Jingle	*Anomia simplex*
Mactridae	Atlantic Surfclam	*Spisula solidissima*
Myidae	Softshell Clam, Steamer	*Mya arenaria*
Mytilidae	Blue Mussel	*Mytilus edulis*
Ostreidae	Eastern Oyster	*Crassotrea virginica*
Petricolidae	False Angelwing	*Petricola pholadiformis*
Pholadidae	Angelwing	*Cyrtopleura costata*
Solenidae	Common Razor Clam	*Ensis directus*
Sphaeriidae	Fingernail Clam	*Musculium securis*
Tellinidae	Baltic Macoma	*Macoma balthica*
Planariidae	a planarian worm	*Phagocata woodworthi*
	Peanut Worm	*Phascolopsis gouldii*
Glossiphoniidae	a leach	*Helobdella stagnalis*
Capitellidae	a capitellid threadworm	*Capitella capitata*
Capitellidae	a threadworm	*Mediomastus ambiseta*
Nereidae	Yellow-jawed Clam Worm	*Nereis succinea*
Nereidae	Common Clam Worm	*Nereis virens*
Orbiniidae	a worm	*Scoloplos species*
Pectinariidae	Cone Worm, Trumpet Worm	*Pectinaria gouldii*
	an oligochaete worm	*unidentified. oligochaete*
SO. Balanomorpha	Ivory Barnacle	*Balanus eburneus*
Mysidae	a mysid shrimp	*Neomysis americana*
Gammaridae	Spine-backed Scud	*Gammarus mucronatus*
Gammaridae	gammarid amphipod	*Gammarus species*
Gammaridae	a freshwater amphipod	*Gammarus tigrinus*
Hyalellidae	a freshwater amphipod	*Hyalella azteca*
Anthuridae	Slender Isopod	*Cyathura polita*
Asellidae	a freshwater isopod	*Caecidotea communis*
Crangonidae	Sevenspine Bay Shrimp, Sand Shrimp	*Crangon septemspinosa*
Palaemonidae	Brackish Grass Shrimp	*Palaemonetes intermedius*
Palaemonidae	Daggerblade Grass Shrimp	*Palaemonetes pugio*
Palaemonidae	Marsh Grass Shrimp	*Palaemonetes vulgaris*
Portunidae	Blue Crab	*Callinectes sapidus*
Portunidae	Green Crab	*Carcinus maenus*
Xanthidae	Black-fingered Mud Crab	*Panopeus herbstii*

Family	**Common Name**	***Scientific Name***
Caenidae	a mayfly larvae	*Caenis species*
Coenagrionidae	Northern Bluet	*Enallagma cyathigerum*
Coenagrionidae	Orange Bluet	*Enallagma signatum*
Corduliidae	a dragonfly nymph	*Tetragoneuria species*
Libellulidae	a dragonfly nymph	*Ladona species*
Libellulidae	Golden-winged Skimmer	*Libellula auripennis*
Libellulidae	Spangled Skimmer	*Libellula cyanea*
Libellulidae	White Corporal	*Libellula exusta*
Libellulidae	Slaty Skimmer	*Libellula incesta*
Libellulidae	Eastern Amberwing nymph	*Perithemis teneris*
Gerridae	Water Strider	*Gerris remigis*
Leptoceridae	a long-horned caddisfly	*Setodes species*
Gyrinidae	a large whirligig beetle	*Dineutus species*
Hesperiidae	Least Skipper	*Ancyloxypha numitor*
Chironomidae	unidentified midge larvae	*??*
Molgulidae	Sea Grape	*Molgula manhattensis*

Appendix C: Frequency of occurrence of organisms trapped in minnow traps set at stations.

Common Name	***Scientific Name***	**All Stations**	**Tisbury Great Pond**	**Brackish Coves**	**Freshwater Ponds**
A grass shrimp	*Palaemonetes* sp.	22.1%	42.7%	8.3%	0%
Blue Crab	*Callinectes sapidus*	22.1%	36.5%	20.8%	0%
Four-spine Stickleback	*Apeltes quadracus*	16.7%	18.8%	16.7%	13.3%
Inland Silverside	*Menidia beryllina*	15.7%	6.3%	25%	23.3%
Banded Killifish	*Fundulus diaphanus*	11.8%	0%	0%	40%
Mummichog	*Fundulus heteroclitus*	10.8%	10.4%	25%	0%
Winter Flounder	*Pleuronectes americanus*	9.8%	12.5%	16.7%	0%
Atlantic Silverside	*Menidia menidia*	8.8%	6.3%	25%	0%
Spine-backed Scud	*Gammarus mucronatus*	8.3%	13.5%	8.3%	0%
Seaboard Goby	*Gobiosoma ginsburgi*	7.4%	15.6%	0%	0%
A mudsnail	*Ilyanassa species*	6.9%	6.3%	16.7%	0%
American Eel	*Anguilla rostrata*	4.9%	0%	20.8%	0%
Seven-spine Bay Shrimp	*Crangon septemspinosa*	2.9%	6.3%	0%	0%
Cunner	*Tautogolabrus adspersus*	2.9%	6.3%	0%	0%
Northern Pipefish	*Syngnathus fuscus*	1.5%	3.1%	0%	0%

Appendix D: Frequency of occurrence of organisms trapped in eel pots set at stations.

Common Name	***Scientific Name***	**All Stations**	**Tisbury Great Pond**	**Brackish Coves**	**Freshwater Ponds**
Blue Crab	*Callinectes sapidus*	53.4%	84.4%	58.3%	0%
White Perch	*Morone americana*	16.2%	0%	0%	55.0%
American Eel	*Anguilla rostrata*	13.2%	7.3%	20.8%	16.7%
Cunner	*Tautogolabrus adspersus*	9.8%	20.8%	0%	0%
A grass shrimp	*Palaemonetes* sp.	8.8%	14.6%	8.3%	0%
Striped Killifish	*Fundulus majalis*	6.9%	0%	0%	23.3%
Mummichog	*Fundulus heteroclitus*	5.4%	11.5%	0%	0%
Banded Killifish	*Fundulus diaphanus*	4.9%	0%	0%	16.7%
Summer Flounder	*Paralichthys dentatus*	2.9%	0%	12.5%	0%
dragonfly nymph	*Tetragoneuria (Epitheca)* sp.	2.0%	0%	0%	6.7%
mud crab	*Panopeus* sp.	2.0%	4.2%	0%	0%
Winter Flounder	*Pleuronectes americanus*	2.0%	4.2%	0%	0%
Atlantic Silverside	*Menidia menidia*	1.5%	3.1%	0%	0%
Tautog	*Tautoga onitis*	1.5%	3.1%	0%	0%

Appendix E: Frequency of occurrence of organisms trapped in gill nets set at various sites.

Common Name	***Scientific Name***	**All Sites**	**Tisbury Great Pond**	**Brackish Coves**
Alewife	*Alosa pseudoharengus*	50.0%	50%	50%
Atlantic Menhaden	*Brevoortia tyrannus*	50.0%	0%	100%
Blue Crab	*Callinectes sapidus*	25.0%	0%	50%
White Perch	*Morone americana*	25.0%	0%	50%
Spot	*Leiostomus xanthurus*	25.0%	50%	0%

Appendix F: Frequency of occurrence of organisms trapped in otter trawls at various sites.

Common Name	***Scientific Name***	**All Sites**	**Tisbury Great Pond**	**Brackish Coves**
Blue Crab	*Callinectes sapidus*	100.0%	100%	100%
Atlantic Silverside	*Menidia menidia*	100.0%	100%	100%
Winter Flounder	*Pleuronectes americanus*	100.0%	100%	100%
Alewife	*Alosa pseudoharengus*	80.0%	66.7%	100%
Four-spine Stickleback	*Apeltes quadracus*	80.0%	100%	50%
White Perch	*Morone americana*	80.0%	66.7%	100%
Orange-striped Green Anemone	*Diadumene lineata*	40.0%	0%	100%
Spine-backed Scud	*Gammarus mucronatus*	40.0%	33.3%	50%

Common Name	***Scientific Name***	**All Sites**	**Tisbury Great Pond**	**Brackish Coves**
a mysid shrimp	*Neomysis americana*	40.0%	33.3%	50%
a grass shrimp	*Palaemonetes species*	40.0%	33.3%	0%
a peanut worm	*Phascolopsis gouldii*	20.0%	33.3%	0%
a burrowing anemone	*Actinothoe species*	20.0%	0%	50%
Brackish Grass Shrimp	*Palaemonetes intermedius*	20.0%	33.3%	0%
Marsh Grass Shrimp	*Palaemonetes vulgaris*	20.0%	33.3%	0%
a clamworm	*Nereis succinea*	20.0%	33.3%	0%
Eastern Mudsnail	*Ilyanassa obsoleta*	20.0%	66.7%	0%
Baltic Macoma	*Macoma balthica*	20.0%	33.3%	0%
Seven-spine Bay Shrimp	*Crangon septemspinosa*	20.0%	33.3%	0%
Green Crab	*Carcinus maenus*	20.0%	33.3%	0%
mud crab	*Panopeus sp.*	20.0%	33.3%	0%
Mummichog	*Fundulus heteroclitus*	20.0%	0%	50%
Inland Silverside	*Menidia beryllina*	20.0%	33.3%	0%
Northern Pipefish	*Syngnathus fuscus*	20.0%	33.3%	0%
Summer Flounder	*Paralichthys dentatus*	20.0%	33.3%	0%
Hogchoker	Trinectes maculatus	20.0%	0%	50%

Appendix G: Total fish catch for the various sites in the coastal salt ponds.

	All Stations		**Tisbury Grt. Pd.**		**Coves of TGP**		**Freshwater Ponds**	
23 species	#	% total	#	% total	#	% total	#	% total
Banded Killifish	665	33.4	0	0	0	0	665	100
Four-spine Stickleback	190	9.5	121	64	65	34	4	2
Atlantic Silverside	155	7.8	95	61	60	39	0	0
Inland Silverside	101	5.1	3	3	8	8	90	89
Mummichog	100	5.0	60	60	40	40	0	0
White Perch	88	4.4	20	23	34	39	34	39
Alewife	79	4.0	21	27	58	73	0	0
Winter Flounder	51	2.6	21	41	30	59	0	0
Three-spine Stickleback	30	1.5	30	100	0	0	0	0
Spot	21	1.1	21	100	0	0	0	0
Sheepshead Minnow	20	1.0	20	100	0	0	0	0
American Eel	15	0.8	1	7	12	80	2	13
Atlantic Menhaden	14	0.7	0	0	14	100	0	0
Cunner	11	0.6	11	100	0	0	0	0
Rainwater Killifish	10	0.5	10	100	0	0	0	0
Seaboard Goby	7	0.4	7	100	0	0	0	0
Nine-spine Stickleback	5	0.3	0	0	0	0	5	100
Northern Pipefish	3	0.2	3	100	0	0	0	0

Striped Killifish	3	0.2	0	0	0	0	3	100
Summer Flounder	2	0.1	1	50	1	50	0	0
Striped Cusk-eel	1	0.1	0	0	1	100	0	0
Hogchoker	1	0.1	0	0	1	100	0	0
Tautog	1	0.1	1	100	0	0	0	0
Total # of fish	1573		446		324		803	
# species			17		12		7	