Massachusetts Office of Coastal Zone Management

MASSACHUSETTS OFFICE OF COASTAL ZONE MANAGEMENT
TECHNICAL REPORT

GLOUCESTER HARBOR CHARACTERIZATION: Environmental History, Human Influences, and Status of Marine Resources

Massachusetts Office of Coastal Zone Management
Executive Office of Environmental Affairs
Commonwealth of Massachusetts

May 2004

MASSACHUSETTS OFFICE OF COASTAL ZONE MANAGEMENT
TECHNICAL REPORT

GLOUCESTER HARBOR CHARACTERIZATION:
Environmental History, Human Influences, and Status of Marine Resources

CONTRIBUTING AUTHORS

Anthony R. Wilbur
Massachusetts Office of Coastal Zone Management

Fara Courtney
Good Harbor Consulting

Robert P. Glenn
Massachusetts Division of Marine Fisheries

May 2004

Commonwealth of Massachusetts
Mitt Romney, Governor
Kerry Healey, Lieutenant Governor

Executive Office of Environmental Affairs
Ellen Roy Herzfelder, Secretary

Massachusetts Office of Coastal Zone Management
Tom Skinner, Director

Commonwealth of
Massachusetts

Executive Office of
Environmental Affairs

Massachusetts Office of
Coastal Zone Management

National Oceanic and
Atmospheric Administration

Citation for this document:
Wilbur, A.R. 2004. Gloucester Harbor Characterization: Environmental History, Human Influences, and Status of Marine Resources. Massachusetts Office of Coastal Zone Management, Boston, MA.

Citation for chapters in this document:
Author(s). 2004. Chapter Title. In Gloucester Harbor Characterization: Environmental History, Human Influences, and Status of Marine Resources. Massachusetts Office of Coastal Zone Management, Boston, MA.

The Massachusetts Office of Coastal
Zone Management (CZM)
251 Causeway Street, Suite 800
Boston, MA 02114-2136
(617) 626-1200

CZM Information Line - (617) 626-1212

CZM Web Site - www.mass.gov/czm

A publication of the Massachusetts Office of Coastal Zone Management (CZM) pursuant to National Oceanic and Atmospheric Administration Award No. NA170Z1125 and the Massachusetts Seaport Bond. This publication is funded (in part) by a grant/cooperative agreement from the National Oceanic and Atmospheric Administration (NOAA). The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies.

May, 2004

This information is available in alternate formats upon request.

Printed on recycled paper.

Gloucester Harbor Characterization: Environmental History, Human Influences, and Status of Marine Resources

Massachusetts Office of Coastal Zone Management, Boston, Massachusetts

The heritage, history, and economic prosperity of the Commonwealth of Massachusetts are closely connected to the ocean. The relationship with the ocean is unmistakably pronounced in the harbors and ports scattered along the Massachusetts coastline. Harbors played a critical role in the establishment of successful and thriving communities in Massachusetts. Gloucester Harbor is America's oldest fishing port and has endured substantial changes in economic, cultural, and environmental conditions since the 15^{th} century.

The sheltered embayment of what is now Gloucester Harbor was discovered by European explorers in 1606. Located on Cape Ann, Gloucester is surrounded by historically and contemporary productive fishing grounds of Massachusetts Bay. Gloucester Harbor has a fabulous landscape, ranging from the sandy beaches and rocky shoreline of the outer harbor to the working waterfront in the inner harbor. Current and traditional uses of the harbor's and Massachusetts Bay's marine resources, such as fishing industries, seafood processing operations, water-based tourism, and historical and cultural attractions, are found throughout the harbor. Gloucester Harbor did not always exist as a maritime port that supports a diversity of industries. The current shape of the harbor, condition of the economic environment, and status of the natural resources are the result of a 400-year history of human development and resource exploitation.

The harbor was inhabited by native Americans, and the protected waters were immediately recognized as a resource by European explorers. The sheltered harbor provided the foundation for the development of a productive working waterfront, and marine resources supported and sustained commercial and sustenance fisheries for centuries. The harbor, fishing industries, and marine environmental quality have dramatically changed, since Gloucester was settled by Europeans in 1623. The importance of harbor and port infrastructure and marine resources, however, remain an important commodity to the maritime heritage, economic prosperity, and ecological sustainability of Massachusetts.

The Gloucester Harbor Characterization is a resource guide that describes human and natural resources of one of Massachusetts oldest and productive harbors. The resource guide is a tool to support resource management strategies and interdisciplinary planning by investigating and characterizing historic and current anthropogenic alterations and influences, present-day environmental quality, and marine resources in the harbor. The goals of this guide are to:

(1) Integrate and synthesize data to describe the harbor environment. The assessment of key biological, physical, chemical, social, and economic features within the harbor documents the status of human and natural resources. The resource characterization is not an all-inclusive review of existing information but summarizes important features in the harbor. The assimilation of monitoring, survey, mapping, and research data that were collected for diverse reasons provides baseline information and identifies gaps in the understanding of Massachusetts coastal resources.

(2) Establish a framework for data integration to characterize coastal waters. The analysis and description of a variety of regional and harbor data sources provides efficient access to human and natural resource information for coastal

communities, resource managers, and scientists. Evaluation of environmental and societal issues, ranging from local development decisions to national and global resource concerns, requires readily accessible information for effective marine resource management. A concerted characterization effort that supplies and distributes diverse coastal resource data supports the Commonwealth's coastal management efforts to conserve important environmental features and develop (or re-develop) working waterfronts.

(3) Support harbor resource management, planning, and implementation. The characterization provides baseline information to evaluate management strategies (e.g., predicting impacts of existing and proposed activities), encourage innovative management plans, develop mitigation options, foster interagency and interdisciplinary planning, investigate spatial and temporal trends in environmental quality that are associated with human influences, and promote stewardship of human and natural resources. The harbor characterization contributes to the understanding of the marine environment and the influences of human activities and coastal development to environmental quality.

The Gloucester Harbor Characterization examines and describes the environmental history of development and human influences, characterizes current understanding of environmental quality, examines lobster fishing and lobster population structure, investigates fish community structure, and describes seafloor habitat. The following individual studies are formatted as discrete chapters:

Chapter 1: The environmental history and current characteristics of Gloucester Harbor

Chapter 2: Synthesis and review of environmental conditions in Gloucester Harbor

Chapter 3: Lobstering in Gloucester Harbor: Distribution, relative abundance, and population characteristics of American lobster (*Homarus americanus*)

Chapter 4: The relative abundance, distribution, composition, and life history characteristics of fishes in Gloucester Harbor

Chapter 5: Identification of the type and quality of Gloucester Harbor coastal and seafloor habitats: Synthesis of harbor and regional studies

CHAPTER ONE

The Environmental History and Current Characteristics of Gloucester Harbor

Anthony R. Wilbur
Massachusetts Office of Coastal Zone Management

Fara Courtney
Good Harbor Consulting, Gloucester, MA

Abstract

Gloucester Harbor is known for its prolific fishing industry and currently supports a range of fisheries and maritime businesses. Through the 400-year history of the development of this protected embayment of Cape Ann into a productive maritime port, Gloucester Harbor has endured dramatic economic, social, and physical changes. This report identifies discrete development periods to chronologically characterize economic and social development, physical alteration of the harbor shoreline and waters, progression of public and environmental policy, and changes in human influences. Gloucester Harbor has an interesting history that reflects the development of a nation and remains a key asset to current and future maritime industry of the Commonwealth of Massachusetts.

Introduction

Gloucester, Massachusetts is known as a prolific fishing port, and the historic abundance of fishery resources found in the coastal waters of Cape Ann greatly contributed to the colonization of New England. Cape Ann has a rugged coastline characterized by rocky shores, sandy beaches, and protected embayments. Gloucester Harbor is located on the eastern shore of Cape Ann in a natural embayment. The natural harbor and productive, nearshore fishing grounds were essential and defining characteristics of the development of Gloucester Harbor.

Gloucester's natural resources sustained populations of indigenous Americans before European settlement. Agawam tribes inhabited Gloucester, cultivated land for agriculture, and harvested fish and shellfish. When European explorers discovered the abundant fishery resources of Cape Ann waters, they recognized the need for a harbor. The protected embayment and rich fishing grounds provided the fundamental elements to develop Gloucester into a productive maritime port. The four hundred year history of Gloucester Harbor, including the marine resources and environmental quality of harbor waters, reflects an evolving economy, advances in technology, and transition of public policy.

The economy and society of Gloucester was directly or indirectly dependent on fishery resources from the 1600s to 1900s. Technological advances in the 19th and 20th centuries, such as seafloor dredging, refrigeration, and railroad transportation, stimulated the industrialization of Gloucester's waterfront and diversified the economy. Shoreline structures were built to accommodate the use of the waterway for transportation, trade, and fishing industries. Properties were extended seaward to reach navigable waters. Public works projects, such as the construction of the Blynman Canal (1600s), deep navigation channels (1800s), and Dog Bar Breakwater (1904), aimed to enhance the safety and utility of Gloucester Harbor. These projects altered coastal, intertidal, and submerged habitats and redefined the shoreline.

Population was stable during initial European colonization and dramatically increased with the industrialization of Gloucester in the late 1800s. Direct manipulations to the harbor were coupled with impacts from waste disposal. Sewage, fish processing by-products, and toxic materials associated with maritime businesses were largely unregulated and polluted waterways for over two centuries. Industrialization and centuries of resource exploitation resulted in cumulative degradation of the marine environment.

Public opinion and environmental policy shifted in the 1970s. The transition in policy was fueled by the understanding of natural systems and risks to human health associated with pollution. The passage of the Water Pollution Control Act amendments in 1972 (Clean Water Act) demonstrated recognition of waterways for their ecological and economic values, and public investment turned to pollution abatement. Public policy and resource management strategies sought to reclaim environmental quality and balance economic and ecological values. Environmental conditions rebounded from a period of extreme degradation at the height of unregulated maritime industrial activity and waste disposal to a point that water and sediment quality problems and related human health risks appear to be restricted to specific harbor locations. Environmental issues currently remain to be evaluated and addressed, including combined sewer overflows, stormwater, fuel spills, vessel discharge, contaminated seafloor sediments, invasive species, and sea level rise.

The objective of this report is to trace the history of harbor development and describe current characteristics in Gloucester Harbor. To achieve this objective, development time periods are identified to chronologically characterize economic and social development, physical alteration of the harbor shoreline and waters, progression of public and environmental policy, and changes in human influences.

Historical Context

The history of Gloucester Harbor parallels the development of the Northwest Atlantic fisheries and reflects United States industrialization. Economic development, urbanization, technological advances, and maturation of public policy influenced the harbor environment. Three periods of development were identified: (1) colonial settlement and establishment of the port, 1623-1850; (2) early industrialization and fisheries dominance, 1850-1920; and (3) modernization and transition, 1920-2000.

Colonial Settlement and Establishment of the Port (1623-1850)

Abundant inshore fisheries stimulated early English settlement of Cape Ann. Limited agricultural prospects, rich marine resources, harbor physical features, and the importance of waterways for moving people and goods led to the development of Gloucester's waterfront. Gloucester Harbor became an international trading center. Changes in technology and trade policy pushed the port to fully turn to the fishing industry as stimulus for the local economy by the mid-1800s.

Social and Economic Development

French explorer Samuel Champlain landed in Gloucester Harbor in 1606, and English settlers from Dorchester returned in 1623 to establish the first permanent fishing station in the Massachusetts Bay Colony (Pringle 1892). Before the English settlement, a community of Agawams—tribe of the Algonquin—lived in a village along the Gloucester shoreline. The Agawam village contained cleared land used for cultivating corn, and fish and shellfish harvest was important (Pringle 1892). Plagues eliminated the native population by the 1620s. Small colonial villages were well established on Gloucester Harbor, the Annisquam River, and the north side of Cape Ann on Ipswich Bay by the 1640s (Pringle 1892).

Local fishery resources supported community growth, and soil was sufficient to support subsistence farming and grazing. Fishing Cape Ann waters was very productive, provided fresh food supply to early settlers, and sustained an important foreign trade (Howe 1969). Timber was an important natural resource for home construction and shipbuilding in Gloucester and supported a timber trade with neighboring colonies (Boston and Salem). The timber industry was short-lived because concern that woodlands were being depleted led the community to pass laws limiting wood cutting for export (Pringle 1892).

By 1700, Gloucester's population was approximately

650. Fishing and farming were equally important for supplying local needs (Pringle 1892). Fishermen gradually fished offshore waters as coastal resources were depleted, and fishing vessels were fishing as far east as Cape Sable in 1711 (Howe 1969). The first two-masted schooner of the English colony was built in Gloucester in 1713. The schooner design dominated the vessels of offshore fisheries for close to 200 years (Matchak 1989). Population growth and coastal development was concentrated around the harbor by 1750, with the population expanding to 2,700. Large boats fished, primarily for cod, as far out as the Grand Banks (Pringle 1892). The inshore mackerel fishery became important in the 1830s, and salt cod was a lucrative commodity for trade with Europe, the West Indies, and Surinam (Matchak 1989).

International trade and supporting industries (e.g., fishing, shipbuilding, and brokering) was the foundation of Gloucester's economy after the Revolutionary War, until the 1840s. Trade laws and taxation policies, during the 1840s, forced Gloucester merchants to funnel exports through Boston to import foreign goods. These changes stimulated a shift from foreign trade to the already-successful fisheries as the center of the Gloucester economy (Matchak 1989).

Two technological changes in the 1840s and 1850s revolutionized the fishing industry. The railroad was extended north from Boston to Gloucester in 1846, providing direct and efficient access for fish landed in Gloucester to New England. Refrigeration was introduced in the 1850s, and vessels began targeting new species, such as halibut and haddock, that were suitable for freezing rather than salting (Matchak 1989). The expansion of the fresh fish market supplemented the prosperous salt cod industry.

Rail transportation also brought visitors to Gloucester for summer retreat and recreation, leading to hotel development on the outer harbor and summer estates at Eastern Point. The natural beauty of Cape Ann attracted artists and writers to Gloucester's waterfront to establish the first art colony in America on Rocky Neck (Pringle 1892).

Physical Changes and Shoreline Development

Natural features and geographic location of Gloucester were key to the city's initial growth as a center for maritime trade and its dominance as a fishing port in the mid-to-late 1800s. In addition to a deep water and sheltered harbor, Gloucester had an important geographic advantage over Boston in the days of sail. Cape Ann was closer to the principle fishing grounds, and vessels could avoid sailing against the typical westerly winds encountered on route to Boston (National Park Service 1994).

Fishing vessels and other craft needed a protected and shorter route between the harbor and Ipswich Bay. Reverend Blynman, a religious and political leader of the time, received permission in 1642 to dig a canal between the harbor and Annisquam River. Referred to as "the Cut" and later called the Blynman Canal, the passage was periodically filled in over the years due to storms and was intentionally filled after periods of disuse (Babson 1860). By the late 1800s,the canal was ultimately maintained as a permanent maritime highway.

Shoreline construction initially included filling, wharfs, piers, docks, and cobbs (i.e., log-cabin-like wooden frames filled with refuse, rubble, and soil). Stone seawalls and docks on piles were constructed, but solid fill was the preferred method of coastal development (Matchak 1989). Inner harbor water depth around Harbor Cove was 20 feet at low tide. Initial development was concentrated in Harbor Cove, which was the center of maritime commerce on Gloucester Harbor until about 1830. Vincent's Cove and areas around the Head of the Harbor (northeast portion of the inner harbor) were relatively shallow and eventually were sites of substantial filling (Matchak 1989). Present-day Rogers Street did not exist, and Main Street (then Front Street) was the waterfront road.

In 1836, 274 large vessels and hundreds of smaller boats were berthed in Gloucester (Matchak 1989). The fishing vessels primarily targeted mackerel and cod (Howe 1969; Matchak 1989). The waterfront supported hundreds of wooden buildings and acres of fish flakes, that is, racks for drying and salting fish fillets. As ship size and tonnage increased, new shoreline and harbor construction was required to access adequate water depth (Matchak 1989). Filling allowed access to deeper waters and expanded the shore-side area available to support the working waterfront. The following 50 years (1850-1900) of harbor development was characterized by substantial harbor growth with extensive filling and shoreline development (Matchak 1989) that permanently reshaped the waterfront of Gloucester Harbor.

Early Industrialization & Dominance of the Fisheries: 1850 – 1920

The urbanization of Gloucester occurred between the late 1800s and early 1900s, characterized by rapid population growth, economic prosperity, and diversification of maritime businesses related to the fishing industry. Technological advances encouraged large-scale change to the harbor for industrial needs. Harbor development was supported by public policy and public works projects. Fisheries and maritime trade remained important, but Gloucester's geographic advantage over Boston was diminished with the invention of steam- and diesel-powered vessels. Nevertheless, the well-developed harbor economy weathered several recessions and continued to prosper as a productive New England port.

Social and Economic Development

Productive fisheries encouraged substantial emigration of skilled labor from the Canadian Maritimes, Portugal, and Ireland, and Gloucester's population grew to 10,000 by 1860. By the time Gloucester was incorporated as a city in 1873, the number of residents increased to approximately 16,000 (Pringle 1872). Gloucester was a full-service port by the end of the Civil War (1865), with a high concentration of maritime labor, vessel service, and supply operations. Tarr and Wonson Paint Factory was established on Rocky Neck (1863). The paint factory was the first copper paint factory in the country and supplied anti-fouling bottom paints for vessels throughout the northeastern United States. Cape Ann Anchorworks, Gloucester Net & Twine, and Gloucester Marine Railway started operation in the 1880s (National Park Service 1994).

Gloucester was the fishing center of North America in the 1870s and 1880s, setting fish prices for the region. Until early 20th century, the most efficient method for moving fish from Gulf of Maine fishing grounds to the growing inland U.S. population was by sailing to Gloucester, unloading the catch, and transporting the catch by train to Boston (National Park Service 1994). The prosperity of Gloucester's fisheries declined in the beginning of the 20th century. The use of steam and internal combustion engines, increased foreign competition, and changing target species decreased fishery productivity and affected Gloucester's economy.

By World War I (1914-1918), steam and internal combustion engines ultimately replaced wind vessels, weakening Gloucester's geographic advantage over Boston. Fishing practices also dramatically changed with the advent of diesel-powered boats. Diesel-powered boats towed nets through the water and efficiently caught haddock. Haddock replaced cod as the popular fresh fish (Garland 1972). Foreign fishing fleets were harvesting large volumes of cod and saturated the market with cod, substantially decreasing prices for salt cod. The Gloucester fleet was slow to modernize and adapt to changing economics and fishery situations. The port, for a period, lost a considerable volume of the fresh fish landings sold in Boston. Gloucester, however, developed fish processing infrastructure, marketing networks, and skilled labor, which helped retain its share of the market. Local entrepreneurs commenced national markets for new seafood products, including canned chowder, pet food, and processed mackerel, to replace lost economic activity (National Park Service 1994).

Physical Changes and Shoreline Development

Public policy supported private construction on tidelands to encourage the growth of maritime industry. Chapter 279 of the Massachusetts Acts of 1867 authorized all persons owning flats in Gloucester Harbor to "extend and maintain wharves upon the same, or to fill up and build upon the same, but not beyond the harbor lines there now established" (Matchak 1989). This law reflected the view of the harbor as an economic resource, but also recognized the need to establish limits of seaward development to protect navigation.

Roger's Street—along the inner harbor—was constructed on fill between 1854 and 1865, creating a new coastal road with wharves and piers immediately abutting. Harbor Cove was shallow and larger ships could not access docks, making the practice of building out to reach deep water less practical (Matchak 1989). The 1855 map (Figure 1.1) provided a picture of the harbor before several major changes to the inner harbor. The federal government realized

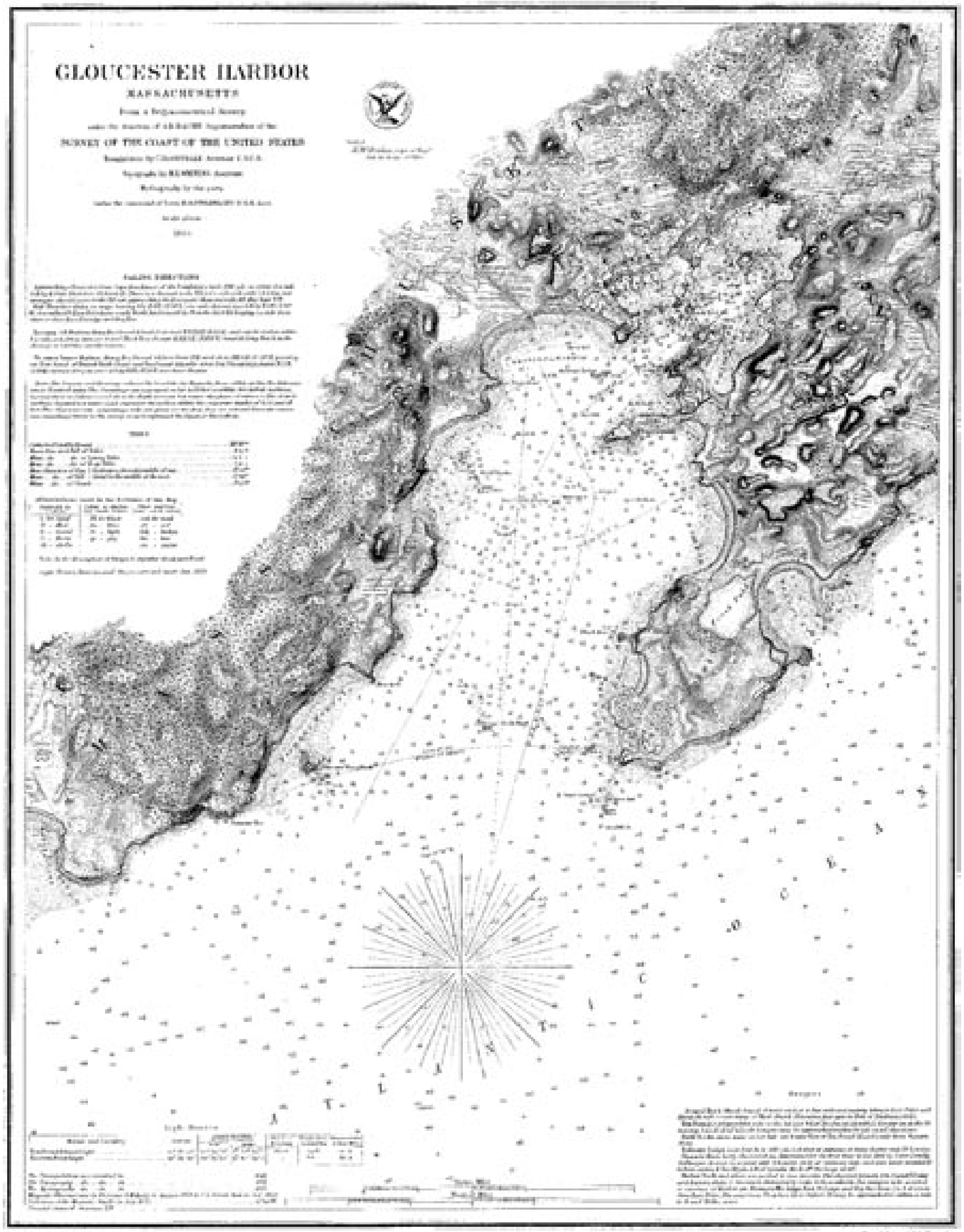


FIGURE 1.1 1855 map of Gloucester Harbor. From the Image Archives of the Historical Map & Chart Collection. Office of Coast Survey/National Ocean Service/NOAA.

that investment to harbor infrastructure was required to maintain safe and navigable harbors and dredging became economically viable after the Civil War (1865). Key dredging technologies, such as steam engines, hydraulic pumps, and underwater explosives, were developed which initiated a history of federal investment for navigation improvements. The U.S. Army Corps of Engineers studied water depth of the inner and outer harbor in 1870, and ledge removal and dredging occurred between 1873 and 1890 throughout the harbor (USACE 1995). The Rivers and Harbors Act of 1892 authorized federal improvements to navigable waters, including Gloucester Harbor, and led to the examination of the inner harbor navigation infrastructure and Vincent's Cove. Vincent's Cove was determined too small to warrant further federal investment in dredging and was eventually filled. Navigation channels were delineated and dredged in the inner harbor to provide deep water for safe navigation in Gloucester Harbor (USACE 1995).

Dog Bar Breakwater was constructed between 1894 and 1904 by the Army Corps of Engineers to provide sheltered waters in the outer harbor. The breakwater protects outer harbor waters from southerly storms. The breakwater is 2,250 feet, running west from Eastern Point toward the western shore (USACE 1995).

Modernization and Transition 1920 – 2000

New fishing technologies, increased harvest effort, and foreign competition impacted fish stocks and Gloucester's standing as a fresh fish port. Innovative processing technologies presented new opportunities for the fishing industry, and maritime business continued to diversify. Frozen fish was imported for processing and dominated fish handling in the local economy. Public policy shifted from unchecked exploitation of natural resources to sustainable use and environmental restoration. Dredging, filling, and waste disposal became heavily regulated, and environmental quality of the harbor was recognized as an economic asset for tourism and recreation.

Social and Economic Development

The early 1930s and the onset of the Depression were distinguished by dramatic decreases in the fishing fleet, volume of fish landed, and number of people employed in Gloucester's fisheries. Fortunes improved with the development of a new method for filleting redfish. Redfish became a target species because of the similarity to freshwater perch and the huge market in Midwestern United States. Redfish was traditionally discarded as a trash species, but by 1943 Gloucester surpassed Boston in volume of fresh fish landed and exceeded all New England ports as a seafood producer. At this time, an estimated 70 percent of Gloucester's population depended on fishing (Haberland 1946). The success was relatively short-lived, however, because the slow growing redfish stock was quickly overfished and could not sustain the market by the late 1950s.

The processing and harvesting sector began to diverge during the early-to-mid 1900s. In 1929, Gloucester businessman Clarence Birdseye invented quick-freeze technology which maintained the appearance and quality of fresh fish. The technology inspired the next stage of fish processing, which was less dependent on local catch. Local vessels could not supply an adequate volume of fresh fish to processing plants, so fish was imported from other sources. The Gloucester fishing-related industry continued to shift from locally landed fish to processing imported fillets (National Park Service 1994). Landings continued to decline through the 1960s and 1970s, and the processing of imported frozen fish was Gloucester's most important industry.

Foreign competition and overfishing was a problem in the 1970s. Foreign fleets were equipped with new fishing vessels, navigational electronics, and fish detection equipment. These fleets traveled longer distances than U.S. vessels and took huge quantities of groundfish from domestic waters. Groundfish stocks (e.g., cod and flounder) declined by almost 70 percent between 1963 and 1974 (NMFS 1998). Gloucester fishermen could not afford to take advantage of new technologies because the U.S. fishing industry was limited under federal law to buy U.S.-built boats, which were more expensive than boats built overseas. Foreign fishing and decimated fish stocks hindered the economy of New England fisheries, particularly in Gloucester.

The Magnuson-Stevens Fisheries Conservation Act (1976) (Magnuson-Stevens Act) ended competition from foreign fishing fleets in domestic waters by establishing the 200-mile U.S. territorial sea (i.e., Exclusive Economic Zone [EEZ]). Foreign vessels were excluded from the EEZ, and U.S. fishermen were sole proprietors of EEZ fishery resources. The Magnuson-Stevens Act encouraged domestic investment—supported by federal loan and tax incentives—that provided larger, technologically sophisticated vessels with greater and more efficient harvesting capacity.

Groundfish landings dramatically increased with the elimination of foreign pressure, and Gloucester landed the most fish in the Northeast United States (Mason personal communication). Fish populations could not sustain the effort, and peak landings in 1978 were followed by sharp population declines to record low levels by the early 1990s (NMFS 1998). Subsequent management restrictions, over the past two decades, decreased groundfish landings to half of port revenues (Kearney 1994).

Physical Changes and Shoreline Development

The filling of intertidal and submerged lands to create the State Fish Pier and Vincent's Cove completed the harbor's contemporary shoreline. The State Fish Pier, encompassing 12 acres, was constructed in 1938 to accommodate businesses in the seafood industry. Pier construction filled the shallow area at the Head of the Harbor, extending a 380-foot-wide pier from land approximately 1,100 feet into the harbor, covering Fivepound Island. The State Pier expanded 100 square feet in 1989. In 1962, the Gloucester Housing Authority (GHA)—the local urban renewal agency—designated an urban renewal area extending from Harbor Cove to the State Fish Pier. The preparation of these urban renewal parcels included the virtual elimination of Vincent's Cove and constituted the last major fill project in Gloucester Harbor (GHA 1971).

The urban renewal and State Pier project, extension of highway access (Route 128) to Gloucester, and construction of a fixed-span bridge over Blynman Canal in the 1950s paralleled a regional shift from trains to trucks for freight handling. The waterfront changed to meet the demands of the new transportation system. The city received federal funding to overhaul sections of the inner harbor. The redevelopment included acquiring and creating large development parcels, clearing buildings, widening Rogers Street, and replacing pile supported finger piers with bulkhead and wharves. The project created a working waterfront that accommodated freighters and truck traffic.

Wastewater Management

There was no centralized sewage collection system in Gloucester before 1928. Industrial and residential wastes were directly discharged into waterways. The original sewage interceptor system was constructed over a 20-year period and included eight miles of combined sewers, fifteen miles of sanitary sewers, and numerous private and combined sewers in the downtown area (Whitman and Howard 1958). This infrastructure served as the wastewater management system for downtown Gloucester, and wastes were discharged to the outer harbor. The original wastewater system did not include all developed areas. A 1967 survey found 129 pipes discharging into the waters of Gloucester Harbor and Annisquam River, including 84 pipes releasing raw sewage (Jerome et al. 1969).

The Gloucester Water Pollution Control Facility (WPFC) began operation in 1984 and advanced wastewater management in Gloucester. This plant performed primary treatment (e.g., solids and sludge removed from wastewater), and the treated waste was initially discharged to the outer harbor. The outfall was extended southwest of Dog Bar Breakwater in 1991 to eliminate discharge directly to the harbor, and a chemical enhanced treatment process (i.e., ferris chloride added to settle small solids) started in 1993. Through the 1990s, the sewering system was constructed for most of Gloucester. There are currently areas of Gloucester that are not part of the sewer system. These areas are reliant on residential septic systems for small-scale wastewater treatment.

Current Harbor Characteristics

Despite recent declines in the fishing industry and a broadening local economy, the harbor is the defining component of Gloucester's character and remains a key asset and the primary economic force in the community. Gloucester's population is currently 29,000 and has not substantially fluctuated during the past century (Pringle 1892; US Census Bureau 1995) (Figure 1.2). The population slightly increased over the last several decades, and the summer population

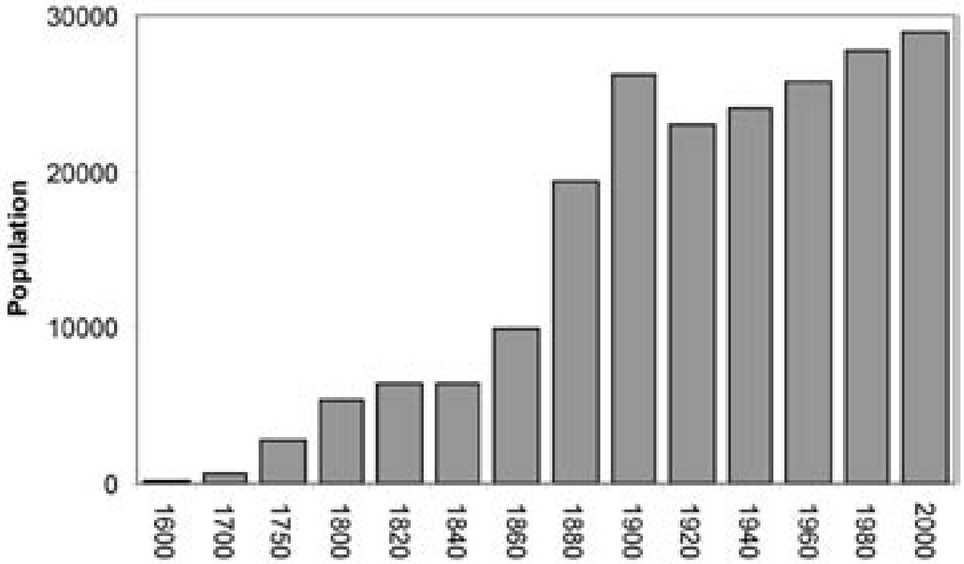


FIGURE 1.2 Human population for the City of Gloucester (US Census Bureau 2000).

FIGURE 1.3 Color orthophotograph of Gloucester Harbor (1:5,000m; MassGIS 2001a).

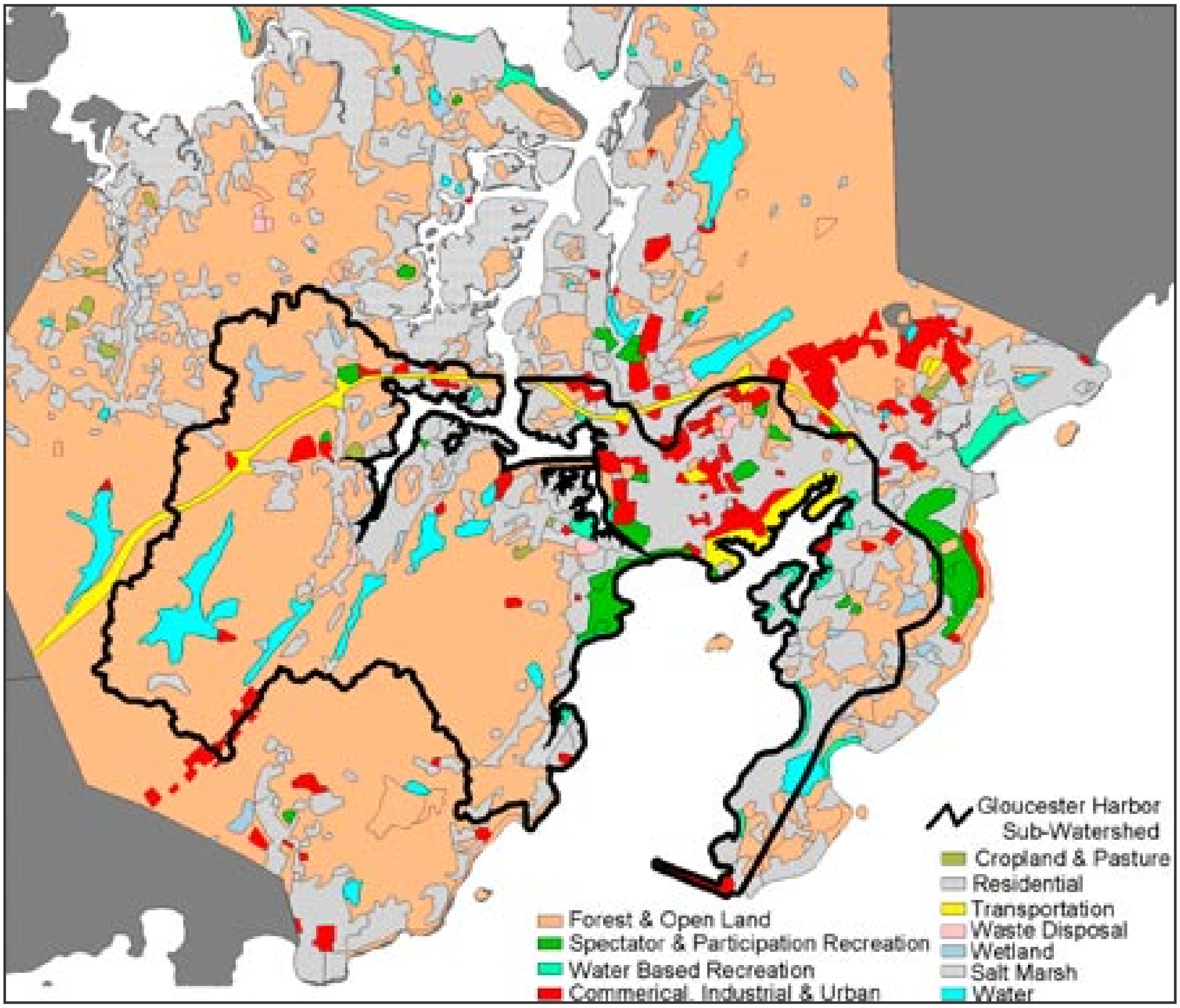


FIGURE 1.4 Land-use (MassGIS 2001b) in City of Gloucester and Gloucester sub-watershed (Buchsbaum personal communication).

is considerably larger (City of Gloucester 1993). The population is distributed throughout Gloucester and heaviest around the inner harbor (Figure 1.3).

The area surrounding the inner harbor, including the working waterfront and downtown business center, is a densely populated urban core. The majority of industrial activity is located on the inner harbor and industrial parks (i.e., Blackburn Industrial Park on Blackburn Circle, Kettle Cove Industrial Park on Western Avenue, and Cape Ann Industrial Park on Magnolia Avenue). Commercial operation surrounds the central business district which is located northwest of the harbor. The high-density residential zone is also concentrated around the downtown and west side of the harbor.

Gloucester as a whole is dominated by undeveloped land (i.e., open land and forest, 58%) and protected through public ownership (Figure 1.4) (MPC 1998; MassGIS 2001b). Residential land constitutes a considerable portion (24 percent) of Gloucester (MPC 1998). Outside the downtown area, rural residential and medium density villages reflect historic development patterns that centralized activity along the city's 64-mile coastline and tidal waterways (City of Gloucester 1993). Commercial and industrial land represents less than 2 percent of the city's land area. East Gloucester and the area southwest of Blynman Canal is medium-density residential. Current development is proposed in outlying residential areas and on vacant lots downtown (Cleaves personal communication).

Economic Features

Gloucester's business profile has diversified, including high technology, light industrial, and tourism sectors. A large portion of residents (~52 percent) commute out of the city to work (Cleaves personal communication). Despite economic change, the fishing and traditional maritime industries remain an important part of local economics, and waterfront-related visitor and recreational services continue to expand. The Gloucester Harbor Plan (1999) describes Gloucester Harbor as a mixed-use port, with expanding fisheries-related and tourism businesses. Maritime industry (e.g., fresh fish, frozen fish processing, vessel support services, and waterfront tourism) currently provides important local employment and revenue (ICON 1999).

Fisheries continue to evolve despite lower landings, changing target species, and management restrictions. Traditional harvesting sectors, such as groundfishing, are important to Gloucester's fishing industry, but specialized niche markets and quality marketing, such as live fish, are supplementing traditional fisheries. Lobster is the most productive fishery in Gloucester (Pava et al. 1998), and 218 lobster boats berth in Gloucester Harbor (1998).

Three vessel classes fish from the port, including day boats, offshore draggers, and transient vessels. Small day boats (under 75 feet) fish inshore and seasonally target different species, such as specialty export markets for sea urchins, hagfish, and dogfish. There are twelve offshore draggers (larger than 75 feet) that fish year-round on multi-day trips and are primarily groundfish boats. Numerous transient vessels fish out of Gloucester, including tuna, swordfish, and herring boats (ICON 1999).

Recreational fishing, including individual sport boats and charter vessels, tremendously expanded in the last 50 years (USDOC 1975; NMFS 1998). Seventeen sport fishing boats (i.e., charter and party) harbor in Gloucester, ranging from 19 to 100 feet. There are nine party boats (65-100 feet) working from Gloucester Harbor (MDMF 2001). There are approximately 2,100 recreational vessels registered in Gloucester, and many of these engage in fishing (Tulik personal communication). Shore-side angling is also popular in the outer harbor, particularly along Dog Bar Breakwater.

FIGURE 1.5 Generalized mooring areas in Gloucester Harbor and Annisquam River. Moorings are found throughout the Annisquam River and are organized by area (Caulket personal communication).

Non-traditional maritime activities are a growing component of waterfront economics. There are whale watch operations, fishing charters, harbor tour boats, the Gloucester to Provincetown ferry, and excursions operating between Gloucester, Salem, and Boston. Cruise companies occasionally use Gloucester as a port-of-call, anchoring in the outer harbor and shuttling passengers shore-side for day trips. In 1999, Gloucester hosted the first gambling cruise in the Commonwealth. The specific operations are highly changeable, and visitor accommodations on the water are an expanding market that is attracting investment (ICON 1999).

Shoreline Infrastructure and Navigation

There is an estimated 13,195 linear feet of commercial wharves and piers on the inner harbor that can accommodate 76 commercial vessels, ranging in size from 20 to 60 feet. The State Fish Pier has dockage for 17 larger fishing vessels (over 60 feet) and berths for 43 smaller (30-40 feet) vessels (Urban Harbors Institute 1994). The city manages two facilities for commercial fishing boats, providing 24 berths for vessels from 25 to 45 feet. The outer harbor mooring is available for larger, transient vessels.

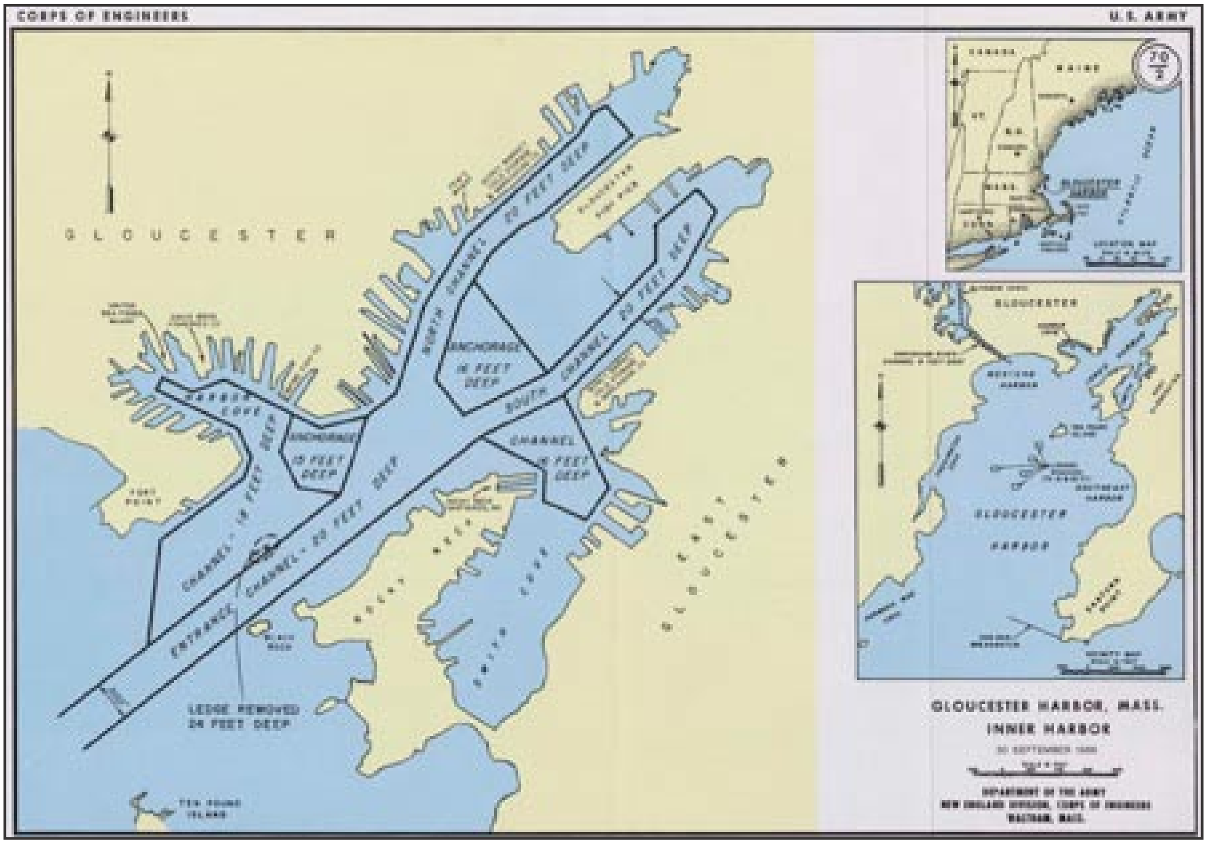


FIGURE 1.6 Federal navigation channels and anchorage areas in Gloucester Harbor (USACE 1995).

Seven recreational marinas and a yacht club provide services and facilities for recreational boaters on the east side of the harbor, including Smith Cove and Eastern Point. Gloucester's Harbormaster manages 1,168 private moorings; 376 located in the inner and outer harbor and 742 on the Annisquam River and Lobster Cove (Figure 1.5). The majority of the moorings accommodate recreational vessels. Twenty-five transient moorings accommodate visiting boaters. There are 25 public landings in Gloucester, ranging from a major boat launching facility at Dunfudgin Landing located on the Annisquam River to small, undeveloped access points that are useable only during certain tides (e.g., Lanes Cove). The smaller landings are important access points for commercial clammers, using skiffs to reach the clam-flats in the Annisquam River. New floats, dinghy docks, and long- and short-term tie-up opportunities were recently obtained in the inner harbor (i.e., Cripple Cove and Solomon Jacobs Landings; Caulkett personal communication)

The U.S. Army Corps of Engineers maintains federal navigation channels, turning areas, and anchorages (Figure 1.6). The navigation channels include the 300-foot wide main channel running from the outer harbor to inner harbor and two 200-foot wide branch channels in the inner harbor (North and South Channels). There are turning areas in the inner harbor and anchorages at Fort Point-Harbor Cove, Harbor Cove, two State Pier anchorage areas, lower Smith Cove, and Annisquam River (Figure 1.6). Adjacent to the federal channels, many privately owned maritime facilities maintain navigation into the facilities. The Corps also maintains Dog Bar Breakwater and Blynman Canal.

The Blynman Canal allows efficient north-south passage between Ipswich Bay and Gloucester Harbor, avoiding the open ocean route around Cape Ann. The drawbridge was electrified and the canal initially dredged by the state in 1907. The Annisquam River is one of the busiest stretches of water in New England (Duncan and Ware 1987), and the navigation channel is managed by the Army Corps of Engineers. The canal and drawbridge is maintained by the Massachusetts Department of Environmental Management (DEM) and is under Massachusetts Highway Department (MHD) jurisdiction.

Wastewater and Stormwater Management

Wastewater treatment began in 1984 with the construction of the WPCF. The plant has a design flow of 7.2 million gallons per day and discharges approximately five million gallons of treated effluent per day through a 36-inch outfall south of Dog Bar Breakwater. Gloucester is one of 45 communities nationwide, and the only one in Massachusetts, with a waiver of the Clean Water Act requirement (section 301[h]) to provide secondary or biological treatment for wastewater before discharge. The 301(h) waiver required the treatment plant to institute an industrial pre-treatment program that sets specific local limits for the 20 industrial users, of which 16 industrial users are fish processing operations (Millhouse personal communication). Oil and grease violations were a problem during the first few years of treatment plant operation, so an enhanced primary treatment process was instituted in 1993. The enhanced process improved oil and grease removal and reduced biological oxygen demand and total suspended solids.

Stormwater (i.e., surface runoff due to precipitation) drains to the harbor through two conveyance systems: 1) combined sewers and 2) direct stormwater discharges. Combined sewers carry sanitary sewage and stormwater to the WPCF. A mixture of stormwater and sewage are discharged to the harbor through combined sewer overflows (CSOs) when the capacity of the wastewater system is exceeded. Stormwater overflows collect surface water, such as rain, and discharge into the harbor during every rain event. Run-off from roads, parking lots, roofs, and cultivated land also directly contributes an uncertain volume of stormwater to harbor waters.

There are six CSOs located around the harbor. Four of the CSOs periodically discharge in response to storm events, and the remaining two discharge only under extreme conditions (e.g., excessive rains that cause a flood). The CSO system receives stormwater from approximately 375 acres through 2,500 catch basins, annually discharging approximately 26 million gallons (Metcalf and Eddy 1992). The CSO found on Pavilion Beach discharges 80% of the total CSO volume (Metcalf and Eddy 1992). Stormwater directly enters inner and outer harbor waters through 17 storm drains, contributing 575 million gallons of effluent to the harbor (Metcalf and Eddy 1992).

Summary

Gloucester Harbor is an important resource for the Commonwealth of Massachusetts. The harbor provides a major center for the fishing industry, maritime business, and future opportunities to expand marine-based uses. The harbor has drastically changed since European colonization to support the working waterfront. Coastal development, dredging and filling, and increased human population altered the shape of the harbor. The fishing industry remains an important component of Gloucester Harbor. The fisheries, including target species and fishing practices, changed through time, but the economy and society of Gloucester endure these changes. Environmental quality was largely unchecked until the mid-to-late 1900s, and long-term effects of pollution entering the harbor and the development of Gloucester are largely unknown. Gloucester's economy and environment weathered many challenges through the development of this protected embayment of Cape Ann into a productive maritime port.

Acknowledgments

This study was funded by the Massachusetts Office of Coastal Zone Management Grant. Fara Courtney (Good Harbor Consulting) spent hours with Gloucester officials and staff searching for historic records. CZM staff, particularly thank you to Anne Donovan, reviewed earlier versions of the report.

Literature Cited

Babson, J.J. 1860. History of the Town of Gloucester, Cape Ann. 350th Anniversary Edition. Peter Smith Publisher, Inc.

City of Gloucester. 1993. Zoning Code. Gloucester, MA.

Duncan, R.F. and J.P. Ware. 1987. A Cruising Guide to the New England Coast. Dodd, Mead & Company, NY.

Garland, J.E. 1972. Introduction and Historical Review. In History of the Town of Gloucester, Cape Ann. 350th Anniversary Edition. Peter Smith Publisher, Inc.

Gloucester Housing Authority (GHA). 1971. Urban Renewal Plan, Second Waterfront Project. Gloucester, MA.

Haberland, H. 1946. Commercial Fisheries Review. US Fish and Wildlife Service.

Howe, A.B. 1969. Historical Background. In, W.C. Jerome, A.P. Chesmore and C.O. Anderson, A study of the marine resources of the Annisquam River-Gloucester Harbor coastal system. Massachusetts Department of Natural Resources Monograph Series No. 8. Boston, MA.

ICON Architecture, Inc. 1999. Gloucester Harbor Plan. Prepared for the Gloucester Harbor Plan Committee. Gloucester, MA.

Jerome, W.C., A.P. Chesmore, and C.O. Anderson Jr. 1969. A study of the marine resources of the Annisquam River – Gloucester Harbor coastal system. Monograph Series Number 8. Division of Marine Fisheries, Boston, MA. 62 pp.

Kearney, A.T. 1994. Comprehensive Industry Assessment and Pier Development Plan. Submitted to the Massachusetts Government Land Bank. Gloucester, MA.

Massachusetts Division of Marine Fisheries (MDMF). 2001. Massachusetts Saltwater Sport Fishing Guide. Sport Fish Program, Division of Marine Fisheries, Department of Fisheries, Wildlife and Environmental Law Enforcement. Boston, MA 51pp.

Massachusetts Geographic Information Systems (MassGIS). 2001a. Black and white orthophotographs. http://www.state.ma.us/mgis/.

Massachusetts Geographic Information Systems (MassGIS). 2001b. Zoned Land Use. http://www.state.ma.us/mgis/.

Matchak, S. 1989. Historic Harbor Report: Beverly, Massachusetts; Gloucester, Massachusetts; Lynn, Massachusetts. The Resource Center for Business, Salem State College, Salem, MA.

Metcalf and Eddy. 1992. Final Report to the City of Gloucester: Combined sewer overflow facilities plan. Vol. I, II, III.

Metropolitan Planning Council (MPC). 1998. Build Out Analysis for the City of Gloucester. Gloucester, MA.

National Marine Fisheries Service (NMFS). 1998. Status of Fishery Resources off the Northeastern United States for 1998. S.H. Clark, editor. NOAA Technical Memorandum NMFS-NE-115. Woods Hole, MA.

National Park Service. 1994. Special Resources Study, Gloucester, Massachusetts. Division of Planning, North Atlantic Office, Boston, MA.

Pava, J.A., D.C. McCarron and T.B. Hoopes. 1998. 1998 Massachusetts Lobster Fishery Statistics. Massachusetts Division of Marine Fisheries, Gloucester, MA. Technical Series 31. 22 pp.

Pringle, J.R. 1892. History of the Town and City of Gloucester, Cape Ann, Massachusetts. New Indexed Edition, Tenpound Island Book Co.

U.S. Army Corp of Engineers (USACE). 1995. Navigation Improvement Study: Gloucester, Massachusetts. Reconnaissance Report, US Army Corp of Engineers, New England District. Concord, MA.

U.S. Department of Commerce (USDOC). 1975. A proposal to restore economic stability to the Port of Gloucester fishing industry. Overall Economic Development Committee of Cape Ann, Inc. Submitted to the Assistant Secretary of Economic Development.

U.S. Census Bureau. 1995. Population of Counties by Decennial Census: 1900 to 1990. http://www.census.gov/population/cencounts/ma190090.txt

Urban Harbors Institute. 1994. Gloucester Waterfront Study: Land Use and Economics. Companion volume to the Gloucester Resources Study, prepared for Division of Planning, North Atlantic Regional Office, National Park Service, Boston, MA.

Whitman and Howard. 1958. Report on the Existing Sewerage System and Improvements: City of Gloucester, Massachusetts.

Personal Communication

Buchsbaum, Robert. Massachusetts Audubon Society.

Caulkett, Jim. Harbormaster, City of Gloucester.

Cleaves, Sam. Planning Director, City of Gloucester.

Mason, Don. National Marine Fisheries Service (NMFS). 1967-1997 Landing and Values for Gloucester, Massachusetts. Gloucester, MA.

Tulik, Lt. John. Massachusetts Environmental Police. Division of Fisheries, Wildlife and Environmental Law Enforcement.

CHAPTER TWO

Synthesis and Review of Environmental Conditions in Gloucester Harbor

Anthony R. Wilbur
Massachusetts Office of Coastal Zone Management

Fara Courtney
Good Harbor Consulting, Gloucester, MA

Abstract

The environmental quality of Gloucester Harbor is typical of an urban port, characterized by areas of degradation and areas of limited human perturbation. Recent studies and monitoring of Gloucester Harbor provide the foundation to evaluate current environmental quality, pollution sources, and contaminant threats. The current status of Gloucester's marine environment is the product of nearly 400 years of anthropogenic stress from point (wastewater discharge) and non-point (urban runoff) sources of pollutants, coastal development, and hydrologic modification. The inner harbor shows substantial human-induced degradation, indicated by prevalent sediment contamination and episodic low dissolved oxygen levels. The outer harbor exhibits human influences, but to a lesser degree than the inner harbor. Environmental quality has improved to current conditions from a severely degraded period of unregulated discharge and harbor use, but Gloucester Harbor still bears evidence of its industrial history.

Effects of Development and Industrialization

The combination of historic and recent human activities contributes to the environmental integrity of Gloucester Harbor. Environmental resources were altered and are threatened by direct (e.g., hydrologic modification), indirect (e.g., loss of prey or degradation of habitat condition), harbor-specific (e.g., contaminated sediments), and regional (e.g., sea level rise) impacts. These anthropogenic and natural threats vary through time and space. The individual, cumulative, and/or synergistic nature of threats affect biotic and abiotic properties of Gloucester Harbor waters.

The marine environment of Gloucester is influenced by point discharges (e.g., wastewater outfall and combined sewer overflows) and non-point sources, such as urban and residential runoff, groundwater inputs, and vessel-related discharges. The foundation and development of Gloucester, unregulated and regulated effluent, and coastal alteration during the past four centuries modified the natural landscape and environmental conditions. Seafloor sediments, in particular, provide evidence of historic pollutant loadings to Gloucester Harbor (Maguire 1997; Valente et al. 1999; MCZM 2000). Contaminants found in seafloor sediments and the water column introduce acute and/or chronic effects on marine life and pose potential risk to human health.

The Gloucester waterfront supports a productive maritime industry and a concentrated human population. The Clean Water Act (1972) initiated environmental awareness and regulation, and environmental quality improved to current conditions from a period of unregulated harbor use. Contemporary resource management attempts to balance the protection of natural resources and promotion of sustainable use. Despite dramatic improvements in environmental conditions since the 1970s, Gloucester Harbor still bears evidence of its industrial history. Environmental implications of creating a working waterfront were

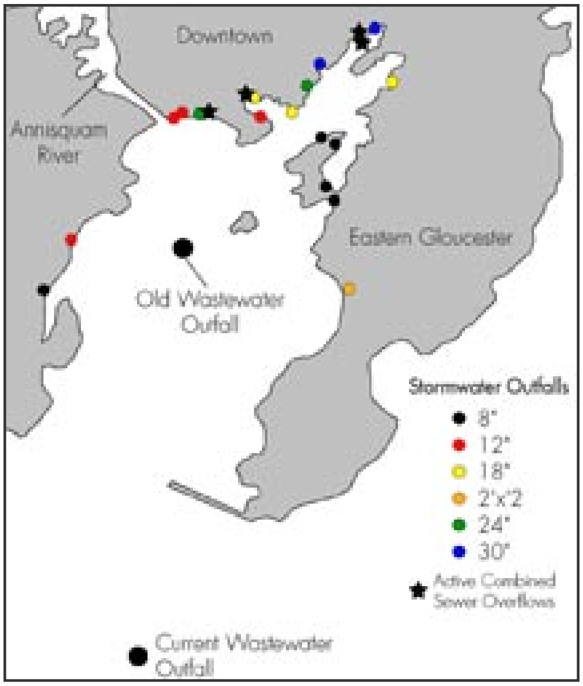


FIGURE 2.1 Pollution sources, previous and existing wastewater outfall, combined sewer overflows (CSOs), and stormwater drains (Metcalf and Eddy 1992).

not thoroughly evaluated through time, but human population growth, incremental filling of tidelands, construction and alteration of the harbor shoreline and seafloor, and development of the harbor watershed affected harbor environmental quality.

Environmental resources are sporadically evaluated, through time and area, for Gloucester Harbor. The patchy network of studies and assessments are not summarized to describe the current status of resources and environmental quality. The objective of this report is to identify sources pollution and physical disturbance, describe impacts and threats from human perturbation, and evaluate the current environmental quality of Gloucester Harbor. The report also discusses cumulative impacts and environmental attributes that require further evaluation to determine status and trends.

Pollution Sources and Threats

Forty-one discharges are located within Gloucester Harbor that require a National Pollutant Discharge Elimination System (NPDES) permit. Forty of the permits are classified as minor discharge facilities (i.e., discharge less than 1 million gallons per day) and are predominately found in the inner harbor. The only major facility is the Water Pollution Control Facility (WPCF) on the Annisquam River with the outfall located south of Dog Bar Breakwater (Figure 2.1).

Regulated point discharges include the wastewater treatment facility and four active combined sewer overflows (CSOs) (Figure 2.1). CSOs are located in the North Channel (2), Harbor Cove, and Pavilion Beach. The four active CSOs discharge urban and residential runoff during wet weather.

Seventeen storm drains are located around the harbor and annually discharge an estimated 575 million gallons of stormwater (Figure 2.1; Metcalf and Eddy 1992). Stormwater influences environmental conditions by discharging untreated sewage and urban and residential runoff into Gloucester waters. Runoff and stormwater contain a number of pollutants, including heavy metals, organic compounds, and hydrocarbons.

Spills, landfills, and historic waste disposal activities were investigated to determine pollution sources to Gloucester Harbor (Figure 2.2; Maguire 1997). Three substantial aquatic spills (accidental discharge of contaminant directly to water) occurred since 1990, including petroleum and diesel fuel. Hundreds of spills on land occurred in Gloucester during the past 10 years. Spills (on land) and Emergency Response Notification System (ERNS, Environmental Protection Agencies response database) reports included petroleum products (e.g., diesel fuel) and contaminants, including benzene, ammonia, and lead.

Approximately 20 Comprehensive Environmental Response Compensation and Liability Information System (CERCLIS) sites are located on and near the shoreline of the Gloucester (three mapped). The CERCLIS sites are classified as NFRA (no further remedial action); however, sites may contain a measure of contamination. Fifty state hazardous waste sites are found throughout Gloucester, predominately characterized as areas contaminated by petroleum and associated products, and may release polychlorinated biphenyls (PCBs), petroleum hydrocarbons,

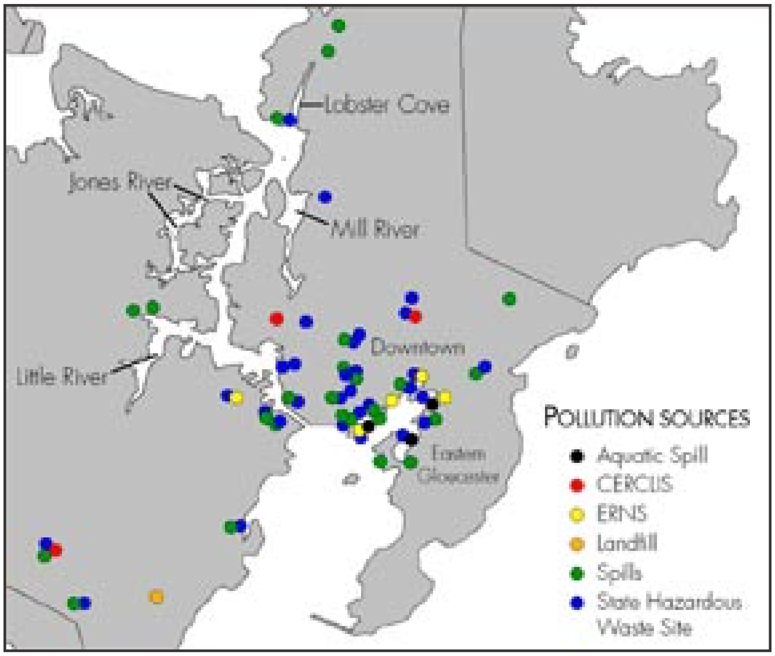


FIGURE 2.2 Pollution sources in Gloucester (Maguire 1997). CERCLIS (Comprehensive Environment Response Compensation and Liability Information System); ERNS (Emergency Response Notification System).

volatile organic compounds, and heavy metals to the soil, surface water and groundwater (DeCasare et al. 2000). These pollutants potentially settle to the seafloor and bind to sediments.

Coastal development and changes to the harbor environment dramatically altered Gloucester Harbor's landscape and marine resources. Vegetation was cleared, coastal and intertidal habitats were filled, and land was developed around the naturally deep harbor to create a working waterfront. The harbor attracted a concentrated population and industrial development. Non-point source pollutants are associated with industrial, commercial, and residential land use, intense waterfront development, and waterside use by recreational and commercial vessels.

Organic waste, hydrocarbons, heavy metals (e.g., tin- and copper-based paints), fertilizers and pesticides, pathogens, and suspended solids threaten environmental conditions in Gloucester Harbor. In addition to identified sources, fish processing, land-based and water-side transportation, vessel servicing activities, landscaping and lawn care, marine head discharges, urban and residential runoff, and atmospheric deposition potentially contribute to environmental stress (Maguire 1997). Contaminated seafloor sediments are a reservoir of pollutants that can be disturbed and resuspended, presenting an additional threat. Centuries of development created impervious surfaces (e.g., roads, parking lots, roofs, cultivated fields) that exacerbate the runoff and associated pollutants entering Gloucester Harbor. Areas within the Gloucester watershed are unsewered, and septic systems present a source of contamination. Historic, unregulated industrial and sewage effluent contributes to current environmental conditions, and threats continue to be conveyed by point and non-point sources.

Hydrologic Modification

Coastal, intertidal, and subtidal habitats were filled and dredged, and portions of the coast were armored to create the modern shoreline of Gloucester Harbor (ICON 1999). It is estimated that over 80 acres of intertidal and submerged habitat was filled to create the present-day harbor (ICON 1999). The change from natural conditions is dramatic, particularly the elimination of Vincent's Cove and Fivepound Island. Filling intertidal and subtidal habitats resulted in permanent loss of natural resources and potentially caused substantial changes to hydrologic properties (e.g., removal of coastal vegetation eliminated the function of vegetation to uptake pollutants). There is no quantitative assessment through time of specific wetlands or coastal habitat loss or other potential impacts from dredging, filling, or construction in Gloucester Harbor.

Fill and construction throughout the inner harbor, particularly the development of the State Fish Pier, is assumed to have affected circulation. Low elevation lands, possibly wetlands, were armored and filled between Rocky Neck and East Gloucester. The Blynman Canal created a permanent connection between Gloucester Harbor and the Annisquam River, expanding the harbor watershed to include an estimated 4.61 km^2 drainage area (i.e., Little River subwatershed) (Kooken et al. 2000). Hydrologic

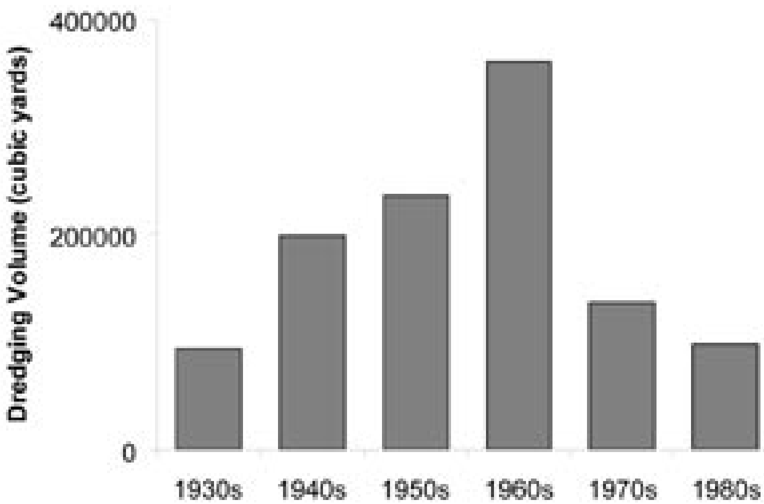


FIGURE 2.3 Dredging volume from Gloucester Harbor and Annisquam River from 1930-1990. Dredging volume is based on permitted operations (USACE 1996).

analysis does not exist to illustrate the extent of Annisquam River flow to Gloucester Harbor, but river drainage to the harbor contributes a volume of water that influences circulation, tidal patterns, and overall water quality. Dog Bar Breakwater also altered water circulation in the outer harbor.

Channels and anchorage areas were created to improve and maintain navigation. Larger vessels harboring in Gloucester necessitated substantial dredging by the late 1800s. Navigation channels were constructed and deepened by the U.S. Army Corps of Engineers. The creation of navigation channels inherently impacted seafloor conditions and water movement. Channel dredging is a periodic maintenance activity associated with port and harbor development (see Barr 1987 for review), and navigation channel maintenance, city dredging of smaller parcels, and private dredging (e.g., marinas) routinely occurred during the development of Gloucester Harbor. A total of 1,178,370 cubic yards were dredged since 1932 in Gloucester Harbor and Annisquam River (Figure 2.3; USACE 1996). This figure does not incorporate dredging that occurred prior to 1932, which included a substantial volume of dredged material.

Dredging, including maintenance and improvement projects, resuspends sediments and associated contaminants, alters seafloor structure (i.e., sediment type and topography), and removes surficial flora and fauna (Messieh et al. 1991). Short-term impacts may be substantial to local biota and habitat conditions. Dredging and port development results in the congregation of marine industries and aggregates contaminates derived from maritime industry. Harbor development also congregates coastal development that can concentrate pollutants entering harbor waters. The identifiable pollutant sources found on working waterfronts can contribute to seafloor sediment contamination.

Mooring fields are found throughout Gloucester Harbor and Annisquam River. Smith Cove is covered by moorings, and Tenpound Island, Niles Beach, Dog Bar Breakwater, and Freshwater Cove provide moorings for recreational boaters. The Annisquam River, including areas adjacent to the navigation channel, Lobster Cove, and Little River, are crowded with moorings. Mooring chains scour seafloor habitats, including eelgrass, potentially altering and impairing benthic resources.

WATER QUALITY

Water quality is influenced by historic and existing harbor industries and watershed land use characteristics. Fish processing plants and domestic sewage currently present problems, and sediment contamination influences water quality (Kooken et al. 2000). The earliest evaluation of Gloucester water quality occurred during a period of severe degradation (Whitman and Howard 1958), when untreated wastes were directly discharged to the harbor. The original wastewater system centralized the downtown effluent, and 4 million gallons of wastewater (sanitary sewage and industrial waste) were released to the middle of the outer harbor per day (Whitman and Howard 1958; Kooken et al. 2000). The majority of industrial waste was generated by fish processing plants, containing fish waste, oils, and grease by-products. There were also a number of private and combined sewers in the downtown area directly discharging waste to the harbor (Whitman and Howard 1958).

The 1958 report included a visual survey and described the area near Pavillion Beach and the Harbor Cove shoreline as clearly polluted with water discolored by industrial waste and floating solids. Banks of sludge (i.e., mix of organic matter and fine-grained sediments) formed along the shoreline and produced gas bubbles, indicating active decomposition of organic material. Boats maneuvering in Harbor Cove stirred up fish scales. The study noted that residential areas on the east side of the harbor, including Rocky Neck, were directly discharging sanitary sewage to harbor waters (Whitman and Howard 1958).

Water quality during that period may be a snapshot of the poorest environmental quality in Gloucester Harbor's environmental history. The "Swim for a Clean Harbor" started in 1979 to raise public awareness of the harbor's poor water quality, and during the first few years participants described swimming through oil, raw sewage, and gasoline (Flemming 1982). The situation improved through time with the implementation of environmental regulations to protect resources. Water quality assessments are currently focused on the WPCF, CSOs, and bacterial contamination (e.g., fecal coliform) of shellfish (Kooken et al. 2000).

Parameters monitored to evaluate water quality are nutrients and chlorophyll, dissolved oxygen, oil and grease, toxics, and pathogens. Water quality is infrequently monitored in Gloucester Harbor, and long-term data sets do not exist.

Nutrients

Excessive loading of nutrients (primarily nitrogen and phosphorus) in coastal embayments causes eutrophication, resulting in low dissolved oxygen levels, loss of eelgrass beds, increased algal growth, loss of benthic community diversity, and diminished shellfish and finfish productivity (Bricker et al. 1999). The ability of a particular embayment to assimilate nitrogen is a function of tidal flushing, water column mixing characteristics, and land-based nutrient inputs (Bricker et al. 1999). Gloucester was identified as an embayment with high nutrient loading and moderate nitrogen sensitivity (Menzie-Cura 1996).

Chlorophyll a (photosynthetic pigment found in all plants, used as a measure of the biomass of phytoplankton, and used as an indicator of nitrogen presence) concentrations were reported in the annual monitoring reports for Gloucester Harbor (Michaels 1999; 2000a; 2000b) and 1982 and 1989 state water quality survey reports (DEQE 1982; Duerring 1989). Chlorophyll a was found in higher concentration than would be expected in the open waters of Massachusetts Bay, but levels were not substantially higher (Duerring 1989; Kooken et al. 2000).

Eelgrass is susceptible to high nutrient levels, and eelgrass observed in the outer harbor indicated no unusual growth of epiphytes that would suggest eutrophic conditions (Buchsbaum personal communication). Excessive amounts of macroalgae or drift algae (signal of nutrient problems) were not observed during fish sampling, SCUBA surveys, or a benthic habitat assessment (NAI 1999a; 1999b; Valente et al. 1999). Nutrient inputs may be higher than baseline historic levels, and sources of nutrients entering Gloucester waters exist (e.g., wastewater, septic systems, fish waste, and runoff). Impacts associated with nutrient over-enrichment are not obvious; however, there is no focused monitoring to evaluate nutrient loading or impacts to habitat conditions.

Dissolved Oxygen

Low dissolved oxygen levels in aquatic systems stress marine biota (Diaz and Rosenberg 1995; Diaz and Rosenberg 2001). Several factors contribute to oxygen depletion in harbor waters, including: 1) the introduction of excess organic matter and nutrients (e.g., fertilizers, sewage and fish waste); 2) poor flushing characteristics that limit oxidation through water column mixing; and 3) high salinity and/or temperatures, both of which decrease oxygen solubility (NCSU 2001).

Monitoring in Gloucester Harbor indicated that low dissolved oxygen is not a major problem, although occasional violations of the state standards (i.e., 6.0 mg/l) occurred in the inner harbor (Kooken et al. 2000). Inner harbor experienced low dissolved oxygen episodes, with a range from 0.2 mg/l to 14.1 mg/l (average = 8.6 mg/l) (Rouse 1990). Low dissolved oxygen periods may occur in summer when the water temperature is at a maximum, and water is more likely to be stratified (Rouse 1990). Evidence of depressed oxygen levels, including low seafloor sediment oxidation and colonization of benthos by opportunistic surface-dwelling fauna, was observed in the inner harbor (Valente et al. 1999). Outer harbor measurements of the water column dissolved oxygen were consistently above 6.0 mg/l (DEQE 1982; Duerring 1989; Rouse 1990; Michaels 1999, 2000a, 2000b), and seafloor conditions improved along a gradient from the inner to outer harbor (Valente et al. 1999; SAIC 2001).

Short-term episodes of depressed dissolved oxygen substantially impact sessile and slow-moving creatures, and localized mortality of benthic macrofauna (e.g., polychaetes, crabs, and lobster) result from hypoxic and anoxic conditions (Diaz and Rosenberg 1995; Diaz and Rosenberg 2001). Indirect impacts to higher trophic levels (i.e., fishes) may also be severe, due to the loss of prey species and alteration of seafloor habitat function. Episodic low dissolved oxygen in the inner harbor stress marine organisms and contribute to degraded benthic conditions. Increased oxygen-depleting pollutants, such as organic matter, and reduced water circulation in the inner harbor exacerbate degraded dissolved oxygen conditions.

Oil, Grease and Toxics

Massachusetts Office of Coastal Zone Management (2001) reviewed ecological effects of various contaminant classes potentially present in Gloucester Harbor. Generalized impacts from a range of pollutants include behavioral (e.g., inhibited spawning), physiological (e.g., reduced respiration rate), cellular (e.g., depressed enzyme function), and life history (e.g., altered growth rates) considerations. Toxic chemicals, including petroleum hydrocarbons, PCBs, pesticides, organic compounds, and heavy metals, enter the marine environment through point discharges and non-point sources.

Oil and grease is a recurring problem for Gloucester Harbor because of fish processing, and WPCF's NPDES permit limits for oil and grease are occasionally exceeded (Kooken et al. 2000). Monitoring associated with the wastewater treatment outfall and CSOs identified copper, nickel, mercury, silver, zinc, and lead in water samples (Metcalf and Eddy 1992; Michaels 2000a; 2000b). Based on water quality criteria (at the wastewater treatment outfall and CSOs), contaminant levels do not indicate acute impacts (Metcalf and Eddy 1992; Michaels 2000a; 2000b). Contaminant levels in seafloor sediments are influenced by centuries of anthropogenic inputs and existing inputs add to pollutant levels. Seafloor sediments are potentially disturbed by commercial and recreational vessels, and elevated wakes erode and agitate shallow water sediments. The presence of oil, grease, and contaminants in the water column and subsequent accumulation of chemicals in seafloor sediments potentially disrupt environmental resources, such as water quality, and processes (e.g., behavior and growth of organisms) (Wilbur and Pentony 1999).

Pathogens

Diseases affect marine creatures and humans and are an environmental concern for coastal waters throughout Massachusetts. Diseases are caused by viruses, bacteria, fungi, protozoa, and other parasites (marine pathogens are thoroughly reviewed by Sindermann 1996). The prevalence of diseases in coastal waters is often associated with habitat degradation and pollution. Marine organisms, including fish and shellfish, and plants (e.g., eelgrass) are weakened, disabled, or killed by a variety of diseases. Fin erosion, ulceration, decreased pathogen resistance, abnormal development, and depressed metabolism are examples of the consequences of disease to fishes (Sindermann 1996). Shell disease and black gill, for example, affect crustaceans (e.g., American lobster), and reduced growth rates and abnormal shell development are observed in diseased mollusks (e.g., softshell clam and blue mussels). Diseases found in fishes, crabs, and mollusks are not regularly monitored in Massachusetts. Water quality monitoring normally focuses on bacterial contamination (e.g., fecal coliform and Enterococcus). These bacteria are used as an indicator of the presence of pathogens for the purposes of shellfish management and bathing beach assessment. Human illness (or death) can occur from consumption of contaminated seafood or direct contact with contaminated water.

Potential sources of pathogen contamination in Gloucester waters include the wastewater outfall, CSOs, failing septic systems, sewage discharge from vessels, stormwater runoff, and marine sediments. Bacterial contamination was a problem throughout the harbor prior to WPCF construction (DEQE 1982). No shellfishing is allowed in Gloucester Harbor, so bacterial sampling is limited to the Annisquam River (which is a state-designated conditionally approved shellfish area). High fecal coliform concentrations were found in small streams feeding into Freshwater Cove and Thurston Creek along the Annisquam River (Kooken et al. 2000).

CSO discharges contained levels of fecal coliform and floatables, particularly after precipitation (Metcalf and Eddy 1992). Contamination levels in the inner harbor, which is poorly flushed, often exceed the swimming standard following rain events. The contamination was due to CSOs and stormwater inputs (Duerring 1989). Recent surveys (1995-present) indicate that harbor beaches (i.e., Pavilion, Cressy, Niles, and Half Moon) consistently meet Massachusetts fecal coliform standard (Kooken et al. 2000).

Sediment Quality

The chemical and physical properties of seafloor sediments are summarized from existing data sets to describe sediment quality. The investigation of pollution sources and historic sediment data coupled with recent sediment sampling provides a general characterization of sediment quality in the inner harbor and federal channel of Gloucester Harbor and portions of the Annisquam River (Maguire 1997; MCZM 2000). Sediment chemistry and seafloor conditions were examined, as part of the statewide Dredged Material Management Plan (MCZM 2000). Historic sediment samples supplemented the description of sediment chemistry for the Dredged Material Management Plan (Duerring 1989). Sediment cores were collected in the inner harbor and Annisquam River (Figure 2.4).

Identified pollution sources and land-use characteristics of Gloucester contributed levels of contaminants to surficial sediments observed in Gloucester Harbor. To improve previous studies and investigate specific levels of contaminants, 54 cores were collected in the harbor (32 cores) and Annisquam River (22 cores) (Figure 2.4; Maguire 1998). Two samples were analyzed for each core in the North Channel and adjacent to the State Pier to examine chemical characteristics at different sediment layers below the seafloor surface (64 total samples). Samples were analyzed by grain size for chemical composition and compared to reference samples (i.e., sediment samples from Massachusetts Bay that are considered pristine) (Maguire 1998).

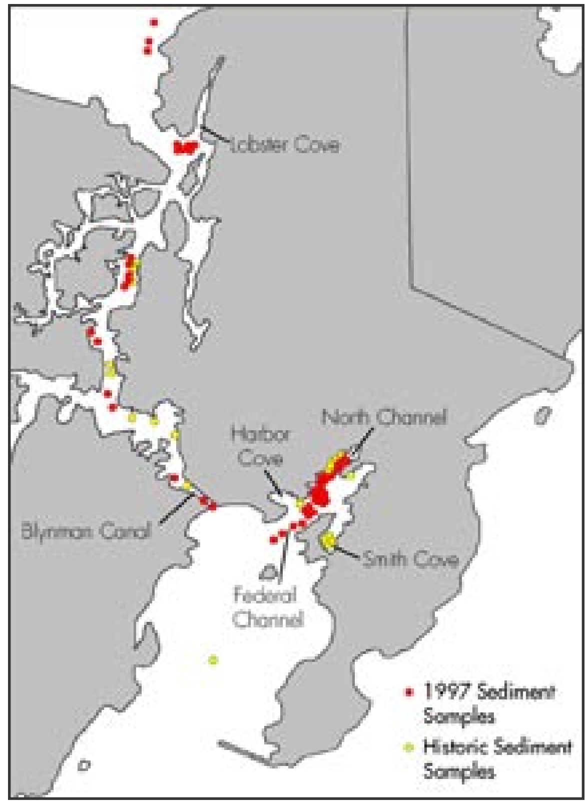


FIGURE 2.4 Sediment sampling locations. 1997 sampling stations (Maguire 1998; MCZM 2000) and 1987-1988 stations (Duerring 1989).

Surficial sediments (top 1 meter) at the entrance of the federal channel heading into the inner harbor and the North Channel were fine-grained, gray to black and anoxic, and high in organic carbon content. Subsurface sediments (- 2 m to depth) were fine-grained, lean clays, gray, and homogeneous. Thin sand layers were found in subsurface sediments. Outer harbor sediments were predominately very fine sand or silt clay with low organic carbon composition, except areas around the old outfall and inside Dog Bar Breakwater (SAIC 2001). Surficial sediments (top 20 cm) surrounding the old outfall and breakwater were fine-grained with low surficial sediment oxidation, suggesting elevated organic matter and sulfide concentration (SAIC 2001). Annisquam River sediments were composed primarily of sand, but Lobster Cove sediment was characterized by higher fine-grained content.

TABLE 2.1 Summary of sediment chemistry of selected contaminates in Gloucester Harbor – Federal Channel, Annisquam River, and Massachusetts Bay Disposal Site (MBDS) Reference (reproduced from MCZM 2000).

	Annisquam River		Federal Channel		MBDS Reference
Analytes	Mean	Range	Mean	Range	Mean
Arsenic	0.97	0.25 - 3.20	12.00	1.90 - 24.00	28.70
Cadmium	0.17	0.05 - 1.10	0.98	0.15 - 2.40	2.74
Chromium	0.13	4.0 - 70	35.00	11.00 - 41.00	152.00
Copper	9.70	0.50 - 35.0	62.00	10.00 - 140.0	31.70
Mercury	0.05	0.025 - 0.23	0.24	0.025 - 0.43	0.277
Nickel	4.00	1.00 - 10.00	16.70	8.00 - 27.00	40.50
Lead	19.30	1.00 - 71.00	86.00	7.00 - 190.0	66.30
Zinc	55.60	7.0 - 350.0	127.80	48.0 - 310.0	146.00
Total PAH[a]	2670.00	15 - 6803	12372.00	14 - 32670	2996.00
Total PCB[b]	38.00	6.0 - 136.0	113.00	0.0 - 259.0	ng[c]

[a]PAH = polycyclic aromatic hydrocarbon
[b]PCB = polychlorinated biphenyl
[c]ng = no guideline.

Chemicals introduced to environment through human activities were found in harbor sediments (Table 2.1). Copper and lead were the most prevalent metals in the federal channel, North Channel, and adjacent to Rocky Neck (MCZM 2000). Zinc, lead, and arsenic were also found during 1987-1988 sampling in the inner harbor (Duerring 1989), and Smith Cove was characterized by elevated concentrations of lead, zinc, copper, and oil and grease (USACE 1990). Total polycyclic aromatic hydrocarbons (PAHs) were substantially higher than reference samples in the North and South Channels (Duerring 1989; MCZM 2000). Pesticides (i.e., dichloro-diphenyl-trichloro-ethane [DDT] and derivatives) and PCBs were found at detectable levels throughout the federal channel (MCZM 2000) and Harbor Cove (Duerring 1989).

PAHs were not detected at uncommon levels in the outer harbor (Duerring 1989). Sediment around the wastewater treatment plant outfall and old outfall location indicate levels of metals at the low end of Massachusetts Bay reference levels (Michaels 2000a; 2000b). Substantial levels of PAHs were found throughout the federal channel (MCZM 2000).

Annisquam River sediments were characterized by low levels of metals, low to moderate PAH concentrations, and notable PCB levels. Lobster Cove generally presented higher contaminant levels than other areas in the Annisquam. This may be a function of reduced flushing and higher fine-grained sediment composition. Fine-grained sediments tend to accumulate and bind chemicals from the water column.

Highest contaminant levels were generally located in the North Channel, federal channel adjacent to Rocky Neck, and Lobster Cove. Contaminants released into the environment, historic and current, adhere to fine-grained sediments. The presence of copper and lead are common pollutants in nearshore sediments because of upland characteristics, such as the past use of lead in gasoline that enters the marine environment through surface runoff. PAH presence is a result of the incomplete combustion of fuel from power generation, and PAHs are found in runoff, industrial discharge, and atmospheric deposition. Pesticides were widely used to control undesirable organisms and are very stable (i.e., pesticides do not easily decompose), which allows pesticides to persist in the environment. Industrial use of PCBs (e.g., cooling fluids for transformers) may have contributed this pollutant to Gloucester waters, and the PCBs subsequently adhered to seafloor sediments.

The quality of Gloucester's inner harbor seafloor sediments appears fairly typical for an urban waterfront. Nearshore, urbanized coastlines generally

TABLE 2.2 Non-native marine and estuarine species known to inhabit Massachusetts waters (MCZM 2002; Baker personal communication).

Established Species	Threatening Species
European Green Crab	Chinese Mitten Crab
Japanese or Asian Shore Crab	Veined Rapa Whelk
Lace Bryozoan	Pacific Oyster
Periwinkle Snail	European mussel
Ascidians (tunicates and sea squirts)	Shipworm (*Toredo* spp.)
Colonial Hydroid	*Caulerpa* (aquatic plant)
Sea slug	*Nori* (red algae)
Shellfish Pathogens: MSX, Sea Side Organism (SSO),Dermo, Quahog Parasite Unknown, (QPX)	
Dead Man's Fingers (*Codium fragile*)	
Common Reed (*Phragmites* spp.)	
Purple Loosestrife	

present higher concentration of contaminants than reference areas that are not heavily influenced by anthropogenic sources (Gould et al. 1994). Elevated levels of contaminants were also found in seafloor sediments of the nearby urban waterways of Salem Harbor (Wilbur and Babb-Brott 2000). Toxics, at particular concentrations in seafloor sediments or suspended in the water column, pose several potential risks to ecological integrity and human health, including: 1) acute and chronic toxicity to marine life; 2) bioaccumulation, causing a public health risk; and 3) long-term contaminant source. Long-term exposure to contaminants found in seafloor sediment present a range of reproductive, behavior, physiological, cellular, and survivorship effects to marine creatures (MCZM 2001).

INVASIVE SPECIES

Gloucester Harbor contains possible transport mechanisms that intentionally or unintentionally introduce nonindigenous (or invasive) creatures. Vectors include the seafood industry, commercial fisheries, industrial shipping, and recreational boating. The introduction of nonindigenous species is associated with human activities and may congregate in areas of active port operations. The release of nonindigenous species into Massachusetts waters started during early colonization and continues (and is possibly expanding) with globalization and rapid movement of people and goods (MCZM 2002). Established and threatening species are found throughout Massachusetts waters (Table 2.2; MCZM 2002).

Gloucester Harbor was assessed to determine the presence of macroinvertebrate and algal invasive species at the State Pier and Cape Ann Marina. Twelve and nine invasive species were found at the State Pier and Cape Ann Marina, respectively (Pederson personal communication). Nonindigenous creatures can change natural community structure and dynamics by competing with native species, degrading existing conditions, and transmitting or introducing disease (Wilbur and Pentony 1999). Invasive species present serious economic implications, including the displacement of fishery and forage species and destruction of coastal infrastructure by fouling organisms, and ecological consequences (e.g., decline in biological diversity and alteration of community structure).

CUMULATIVE IMPACTS

Environmental quality is not exclusively influenced by individual threats. Pollutants, physical alteration, and introduced threats can individually or simultaneously alter and degrade environmental conditions. Cumulative impacts are the combined outcome of numerous actions and stresses that alone may present limited implications but combine to substantially impact environmental resources (Vestal et al. 1995). The urban nature of Gloucester Harbor presents many human-induced threats and pollutants. Traditional harbor development, exploitation of resources, and current pollutant sources dictate environmental quality. Dock and pier construction, wetland filling, channel dredging, and coastal development each impacted Gloucester resources. Runoff, CSO and stormwater discharges, and contaminated sediments—for example—continue to influence harbor conditions. Efforts to understand individual impacts associated with one pollutant improve resource management decisions to limit or eliminate a particular threat. However, there are many threats, and each warrants attention and consideration in the discussion of Gloucester Harbor's environmental integrity.

Summary

The environmental quality and integrity of Gloucester Harbor is typical for an urban port, characterized by areas of degradation and areas of limited human perturbation. The inner harbor, including Harbor Cove and Smith Cove, reflects a higher degree of human impacts than the outer harbor, as indicated by prevalent sediment contamination and episodic low dissolved oxygen levels. The physical characteristics (i.e., restricted coves with poor flushing) and the intensity of development influence the environmental conditions of the inner harbor. Lobster Cove accumulated contaminants due to reduced tidal action and pollutant input. The outer harbor exhibits human influences, but to a lesser degree than the inner harbor. Systematic, long-term monitoring of water quality, sediment quality, or habitat function does not exist for Gloucester waters. Trends of the environmental integrity and quality of Gloucester Harbor are difficult to ascertain or describe with the lack of monitoring and targeted research.

Acknowledgments

This study was funded by the Massachusetts Office of Coastal Zone Management Grant. Fara Courtney (Good Harbor Consulting) spent hours with Gloucester officials and staff searching for historic records. CZM staff (Anne Donovan) reviewed earlier versions of the report.

Literature Cited

Barr, B.W. 1987. Dredging handbook: A primer for dredging in the coastal zone of Massachusetts. Massachusetts Coastal Zone Management, Boston.

Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.R.G. Farrow. 1999. National Estuarine Eutrophication Assessment: Effects of nutrient enrichment in the nation's estuaries. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science. Silver Spring, MD. 71pp.

DeCasare, G. J., L. E. Kennedy and M. J. Weinstein. 2000. North Coastal Watershed 1997/1998 Water Quality Assessment Report. Massachusetts Department of Environmental Protection, Division of Watershed Management.

Department of Environmental Water Quality Engineering (DEQE). 1982. Gloucester Harbor Water Quality Data 1980 & 1982. Massachusetts Division of Water Pollution Control, Westborough, MA.

Diaz, R.J. and R. Rosenberg. 1995. Marine Benthic Hypoxia: A review of its ecological effects and the behavioral responses of benthic macrofauna. Oceanography and Marine Biology 33:245-303.

Diaz, R.J. and R. Rosenberg. 2001. Overview of Anthropogenically-Induced Hypoxic Effects on Marine Benthic Fauna. In Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies. 129-146,

Duerring , C. L. 1989. North Coastal Water Quality Surveys 1987 and 1988. Massachusetts Department of Environmental Quality Engineering, Westborough, MA.

Flemming, G. 1982. Join Harbor Swim: Make a Point and Then…. Gloucester Daily Times, August 13, 1982.

Gould, E., P.E. Clark, and F.P. Thurberg. 1994.

Pollutant effects on demersal fishes. In, R.W. Langton, J.B. Pearce, and J.A. Gibson, editors. Selected living resources, habitat conditions, and human perturbations of the Gulf of Maine. NOAA Technical Memorandum NMFS-NE-106, Woods Hole, MA.

ICON Architecture, Incorporated (ICON). 1999. Gloucester Harbor Plan. Prepared for the Gloucester Harbor Plan Committee, Gloucester, MA.

Kooken, V., C. Dunn, C. DelPapa, and R. Buchsbaum. 2000. Water Quality Assessment: Gloucester Harbor, North River, Salem/Peabody, Saugus River, Smallpox Brook, Salisbury. Prepared for: The Massachusetts Executive Office of Environmental Affairs. 55pp.

Maguire Group Inc. (Maguire). 1997. Dredged Material Management Plan Phase 1, Volume I, Gloucester, Salem, New Bedford and Fall River. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Maguire Group Inc. (Maguire). 1998. Massachusetts Dredged Material Management Plan – Sediment Chemistry Results: Fall River, Gloucester, New Bedford-Fairhaven and Salem. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Massachusetts Office of Coastal Zone Management (MCZM). 2000. Dredged Material Management Plan (DMMP) EOEA No. 11534. Draft Environmental Impact Report (DEIR) for Gloucester, Massachusetts. Prepared by: Maguire Group Inc., Foxborough, MA.

Massachusetts Office of Coastal Zone Management (MCZM). 2001. Essential Fish Habitat (EFH) Assessment: Gloucester Harbor, Massachusetts. Prepared by: Maguire Group, Foxborough, MA. Prepared for: Massachusetts Office of Coastal Zone Management, Boston, MA.

Massachusetts Office of Coastal Zone Management (MCZM). 2002. Draft – Massachusetts Aquatic Invasive Species Management Plan. Prepared by Massachusetts Office of Coastal Zone Management. Boston, MA.

Menzie-Cura & Associates, Inc. 1996. Identification of Massachusetts Bays Embayments at Risk of Eutrophication. Prepared for the Massachusetts Bays Program. Boston, MA.

Messieh, S.N., T.W. Rowell, D.L. Peer, and P.J. Cranford. 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. Continental Shelf Research 11:1237-1263.

Metcalf & Eddy Incorporated. 1992. Final Report to the City of Gloucester: Combined Sewer Overflow Facilities Plan. Vols. I, II, III. Gloucester, MA.

Michaels, A.D. 1999. Gloucester 301(h) Monitoring Program 1996 Annual Report. Magnolia, MA.

Michaels, A.D. 2000a. Gloucester 301(h) Monitoring Program 1998 Annual Report. Magnolia, MA.

Michaels, A.D. 2000b. Gloucester 301(h) Monitoring Program 1997 Annual Report. Magnolia, MA.

Normandeau Associates Incorporated (NAI). 1999a. Dredged Material Management Plan – Fisheries resources survey for New Bedford. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 28pp. + append.

Normandeau Associates Incorporated (NAI). 1999b. Dredged Material Management Plan – Fisheries resources survey for Gloucester. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 28pp. + append.

North Carolina State University Water Quality Group (NCSU). 2001. Internet site: http://h2osparc.wq.ncsu.edu. February 2001.

Rouse, L. A.. 1990. Gloucester Harbor Monitoring Report 1982-1989. Massachusetts Audubon Society: North Shore. Wenham, MA.

Science Applications International Corporation (SAIC). 2001. Results of the March 2001 subbottom profiling and sediment profile imaging survey of the outer Gloucester Harbor. Prepared for: Massachusetts Office of Coastal Zone Management, Boston, MA.

Sindermann, C.J. 1996. Ocean Pollution: Effects on Living Resources and Humans. The CRC Marine Science Series. CRC Press, Boca Raton, FL.

Valente, R.M., M.C. Swanson, and C.L. Seidel. 1999. Dredged Material Management Plan: Habitat characterization of the DMMP potential aquatic disposal sites. Science Applications International Corporation Report No. 463. Prepared for Massachusetts Office of Coastal Zone Management.

Vestal, B.A. Rieser, M. Ludwig, J. Kurland, C. Collins, and J. Ortiz. 1995. Methodologies and mechanisms for management of cumulative coastal environmental impacts. Part I – synthesis, with annotated bibliography; Part II – development and application of cumulative impacts assessment protocol. NOAA Coastal Ocean Program Decision Analysis Series No. 6. NOAA Coastal Ocean Office, Silver Spring, MD.

Whitman & Howard. 1958. Report on the Existing Sewerage System and Improvements Thereto: City of Gloucester, MA.

U.S. Army Corps of Engineers (USACE). 1990. Small Navigation Project Detailed Project Report: Smith Cove. Department of the Army Corps of Engineers, New England Division. Concord, MA.

U.S. Army Corps of Engineers (USACE). 1996. Inventory of dredging needs in the Designated Port Areas of Massachusetts: 1996-2016. Conducted by the USACE, New England Division for Massachusetts Office of Coastal Zone Management.

Wilbur, A.R. and D. Babb-Brott. 2000. Sediment quality and seafloor features. Presentation at State of the Sound: Current Knowledge and Future Directions. A symposium on the health of the Salem Sound Ecosystem. 25 May 2000, Salem State College, Salem, MA.

Wilbur, A.R. and M.W. Pentony. 1999. Human-induced nonfishing threats to Essential Fish Habitat in the New England region. In, L. Benaka, editor. Fish Habitat: Essential Fish Habitat and Rehabilitation. American Fisheries Society Symposium Proceedings 22:299-321.

Personal Communication

Baker, Jason. Massachusetts Office of Coastal Zone Management. Boston, MA.

Buchsbaum, Robert. Personal Communication. North Shore – Massachusetts Audubon Society. Wenham, MA.

Pederson, Judith. Massachusetts Institute of Technology Sea Grant College Program. Cambridge, MA.

CHAPTER THREE

Lobstering in Gloucester Harbor: Distribution, Relative Abundance, and Population Characteristics of American Lobster (*Homarus americanus*)

Anthony R. Wilbur
Massachusetts Office of Coastal Zone Management, Boston, MA

Robert P. Glenn
Massachusetts Division of Marine Fisheries, Pocasset, MA

Abstract

Fishing patterns and population characteristics of the American lobster were examined in Gloucester Harbor. A commercial lobsterman was contracted to collect lobster, using standard lobster gear, in Gloucester Harbor from June 1998 to May 1999. Otter trawl and scuba surveys supplemented the lobsterman survey. Fishing effort centered around Tenpound Island, Paint Factory Channel, Blynman Canal (Annisquam River), and the North Channel in the inner harbor. The harbor catch rates of legal-size lobster (0.8 ± 0.1 CTH_3) were comparable to Massachusetts-wide and Cape Ann assessments. Lobster were collected from June to November 1998 and April and May 1999 (peak catches from June to September), and no lobster were captured during the otter trawl sampling in winter. Relative abundance and length characteristics were variable throughout the harbor. Inner harbor samples yielded higher catch rates of total (3.7 ± 0.5 CTH_3) and legal-size lobster (2.7 ± 0.4 CTH_3) compared to outer harbor waters. Distinct spatial patterns of fishing effort allowed the grouping of samples into five sub-areas. The Inner Harbor sub-area mean carapace length (87.5 ± 0.3 mm) was larger, including larger male and female lobster, than all sub-areas. Lobster length in outer harbor sub-areas was truncated at 83 mm CL (harvestable size limit). Male-to-female ratio was higher in the Inner Harbor and Paint Factory Channel, and a higher percentage of ovigerous females and fewer injured lobster were observed in the Inner Harbor and Annisquam River. The study showed differences in population characteristics between the inner and outer harbor, and identified specific areas targeted by commercial lobster harvest.

Introduction

The harvest of American lobster (*Homarus americanus*) represents the most valuable single-species fishery in Massachusetts waters (Pava et al. 1998). The waters within and surrounding Gloucester Harbor and Cape Ann support an active inshore lobstering fleet (218 active permits, including territorial and offshore fishermen, landing 915,109 pounds in territorial waters during 1998) and recreational fishery (38% of state-wide seasonal landings) (Pava et al. 1998). Lobster is extensively researched (see Phillips et al. 1980 for review), and studies continue because of the ecologic and economic importance and potential anthropogenic impacts to lobster and lobster habitat.

Factor (1995) describes the life history of the American lobster. American lobster is a benthic marine decapod crustacean, widely distributed over the continental shelf of the western North Atlantic. Lobster distribution ranges from Labrador to Virginia in nearshore waters and from Georges Bank to North Carolina in deep waters, inhabiting water depth of 700 meters to the intertidal zone. The lobster population is most abundant within the coastal

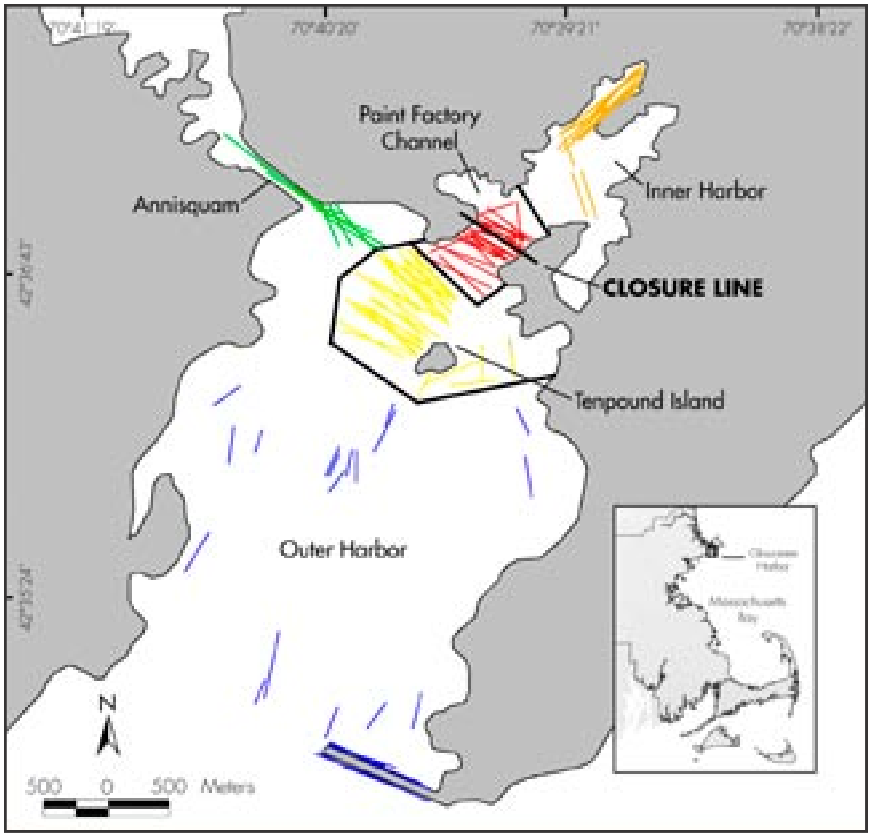


FIGURE 3.1 Lobster trawl locations for the June-November 1998 and May 1999 surveys. Sub-areas are identified by different colors and were used to investigate spatial features. Approximate location of fishing closure line identified.

waters of the Gulf of Maine, New Brunswick, and Nova Scotia. The United States distribution is concentrated in coastal waters (to 40 m) from Maine to Massachusetts.

Gloucester Harbor is an urban port with an active fishery, presenting an interesting environment to study lobster. Recent studies describe lobster behavior in Gulf of Maine coastal waters (e.g., Estrella and Morrissey 1997; Watson et al. 1999; Short et al. 2001), and the Massachusetts Division of Marine Fisheries conducts statewide monitoring of lobster stocks (Estrella and Glenn 1999). The identification of lobster fishing patterns are lacking, and few embayment-specific studies document population structure of lobster in Massachusetts, particularly in waters heavily influenced by human activities. Impacts of coastal urbanization and pollution to lobster harvesting, population structure, and behavior is not thoroughly described and warrants further study. The understanding of human perturbations, including harvesting and pollution effects, requires fundamental information on valuable fishing grounds and lobster biology to evaluate the influence and magnitude of human impacts. This study examines local fishing patterns by monitoring the catch of a commercial lobsterman and investigates seasonal and spatial population characteristics of lobster in Gloucester Harbor.

Materials and Methods

During the development of the Massachusetts Dredged Material Management Plan (MCZM 2001), American lobster was studied to provide basic lobster biological attributes and describe fishing areas in Gloucester Harbor. Information was obtained to compare the environmental suitability of in-water dredged material disposal options. The focus of this study is to examine the population characteristics and fishing activity of lobster in Gloucester Harbor.

Study Area

Gloucester Harbor is an embayment in northwestern Massachusetts Bay, characterized by an urbanized inner harbor and less-developed outer harbor. The inner harbor is a traditional working waterfront with substantial port and navigation infrastructure that supports a range of maritime industries (e.g., commercial fisheries, marine transportation and trade, fish processing, and vessel maintenance operations). Lobster fishing is intense from March to November along the Gloucester shoreline, including harbor and open coastal waters. The harvest of lobster is prohibited in the inner harbor (closure line is from Cape Pond Ice on Fort Point to a point on Rocky Neck – see Figure 3.1) for several reasons, including the maintenance of a safe navigation channel. The inner harbor is armored by man-made structures, and the outer harbor coastline is a range of boulder outcrops and beaches. The seafloor is predominantly unconsolidated, soft sediment with several areas of ledge, except for the western shore that is rocky (NAI 1999a; Valente et al. 1999; USGS 2000; SAIC 2001; Malkoski personal communication).

Commercial Lobsterman Sampling

Standard commercial lobster gear (i.e., wire mesh traps) was deployed and sampled bimonthly from June to November 1998 and May 1999 (14 sample periods; 116 trawls; 2091 pots). Lobster trawls consisted of 5 to 20 baited traps and were distributed throughout the harbor (Figure 3.1). Approximately 150 traps were set each sampling event. The lobsterman was directed to fish at least one trawl per sampling period in the inner harbor. Regions of the harbor actively fished by commercial lobstermen were sampled with the remaining trawls. The inner harbor sampling was important to study design because this area is closed to the harvest of lobster through town ordinance.

Data, consisting of carapace length (CL) (mm), sex, reproductive condition, and pathological observation, were gathered for each trawl (NAI 1999b). Lobster trawl tract location was documented using Differential Geographic Position System (DGPS) and plotted with Geographic Information System (GIS) software (ArcView). Catch per unit effort was calculated as catch per trap per three set-over days (CTH_3) (i.e., gear in the water for three days) for the lobster potting data and is interpreted as relative abundance. Catch rates were analyzed for the inner harbor, outer harbor, and harbor-wide. Adolescent and adult lobster (> 50 mm CL) are effectively sampled by lobster gear. Length categories were classified according to lobster fishery regulations. The analyses distinguished between sub-legal (< 83 mm CL), legal (≥ 83 mm CL), and total lobster (sub-legal and legal combined). Descriptive statistics are used to describe the catch data and spatial features of the collections.

Spatial Assessment

Differences in catch rates between the inner and outer harbor and identifiable spatial patterns of fishing effort resulted in more detailed spatial examination of harbor characteristics of lobster population structure. The harbor-wide data were divided into four sub-areas in the outer harbor and one sub-area in the inner harbor (Figure 3.1). Area comparison was unplanned, and there was unequal fishing effort distributed across the sub-areas. The sub-areas were identified in GIS by detecting geographic clusters of fishing effort throughout the sampling regime and were not identified before the survey. The sub-areas include Inner Harbor (IH - 15 trawls, 330 pots), Paint Factory Channel (PFC - 28 trawls, 469 pots), Tenpound Island (TI - 32 trawls, 608 pots), Annisquam River (AR - 11 trawls, 191 pots) and Outer Harbor (OH - 30 trawls, 493 pots). The sub-areas are identified by capital letters throughout the study. The IH sub-area is the same throughout the study. Catch rates, life history characteristics, and pathological condition were examined for the sub-areas.

Otter Trawl and Scuba Transect Surveys

The otter trawl survey, designed to examine the juvenile fish and crab community in Gloucester Harbor, and scuba observation provided supplemental information on the distribution and abundance of lobster. Four otter trawl stations, located in the Inner Harbor, Western Harbor, Southeast Harbor, and Outer Harbor, were sampled for 12 months (18 sample periods). Otter trawl length was standardized to 400 m (catch per unit effort [CPUE] = #/400m). Otter trawl collections were separately analyzed from the lobsterman survey to further describe seasonal and spatial features in Gloucester Harbor (NAI 1999b). Scuba transects targeted areas in the inner and outer harbor on 21 October 1999 during daylight. Ten metered transects were located in the IH, PFC, and TI sub-areas, totaling 3450 linear meters. Divers swam the length of each transect and noted substrate type and recorded the number of lobster and biotic features. Counts of lobsters were totaled for transect length (NAI 1999a).

RESULTS

Lobster Fishing Patterns

The distribution of lobster pots described the fishing pattern of the commercial lobsterman (Figure 3.1). Fishing effort was focused around TI (29.1% of total pots fished) and the PFC (22.4% of total pots fished). A cluster occurred near the Blynman Canal (AR sub-area = 9.1%). Effort was dispersed throughout the OH (23.6%). The majority of effort within the targeted IH was in the North Channel (15.8%). The clusters of fishing effort were used to identify the sub-areas. Seasonal effort was relatively equal among the sub-areas, except for limited AR sampling during the fall (September-November).

Harbor and Seasonal Relative Abundance

The lobsterman collected a total of 4,208 lobster for the study period, and 340 lobster were obtained by the otter trawl survey. Total relative abundance was 2.0 ± 0.2 CTH_3 (study mean CTH_3 ± standard error) for the entire harbor (Table 3.1); 54.8% were sub-legal (< 83mm CL) and 45.2% were legal (> 83mm CL). Distinct spatial patterns emerged from lobster catch data between the inner and outer harbor. The total catch of lobsters was greater in the inner harbor (3.7 ± 0.5 CTH_3) compared to the outer harbor (1.7 ± 0.2 CTH_3), with substantially higher catches of legal lobsters in the inner harbor (2.7 ± 0.4 CTH_3) compared with the outer harbor catches (0.5 ± 0.04 CTH_3). Catch rates for sub-legal lobsters were analogous among inner (1.0 ± 0.1 CTH_3) and outer (1.1 ± 0.1 CTH_3) harbor waters for the study with diminutive seasonal differences observed between the areas.

Harbor-wide data were pooled to describe seasonal abundance. The catch of sub-legal lobster was higher than legal lobster from June to the beginning of October 1998. Legal lobster catch was greater from mid-October to the end of November 1998 and May 1999 (Figure 3.2). Catch of sub-legals ranged from 0.4 CTH_3 (May 1999) to 1.9 CTH_3 (September 1998). Legal catches ranged from 0.6 CTH_3 (October 1998 and May 1999) to 1.3 CTH_3 (September 1998). Overall, the total catch of lobster was highest from June to the end of September, peaking in mid-September (3.2 CTH_3). CTH_3 for both legal and sub-legal lobsters was highest in September 1998.

TABLE 3.1 Lobster catch (catch per trap per three set over days [CTH_3]) for all legal (≥83 mm carapace length), sub-legal (<83 mm carapace length), and total lobsters collected in Gloucester Harbor during June - November 1998 and May 1999. Means (SE) included where relevant.

	Annual Mean CTH_3		
Area	Sub-Legal	Legal	Total
Gloucester	1.1 (0.1)	0.8 (0.1)	2.0 (0.2)
Inner Harbor	1.0 (0.1)	2.7 (0.3)	3.7 (0.4)
Outer Harbor	1.1 (0.1)	0.5 (0.04)	1.7 (0.2)

Otter Trawl and Scuba Transect Surveys

Although the otter trawl survey was not specifically designed to harvest lobster, samples demonstrated seasonal and spatial features of lobster abundance

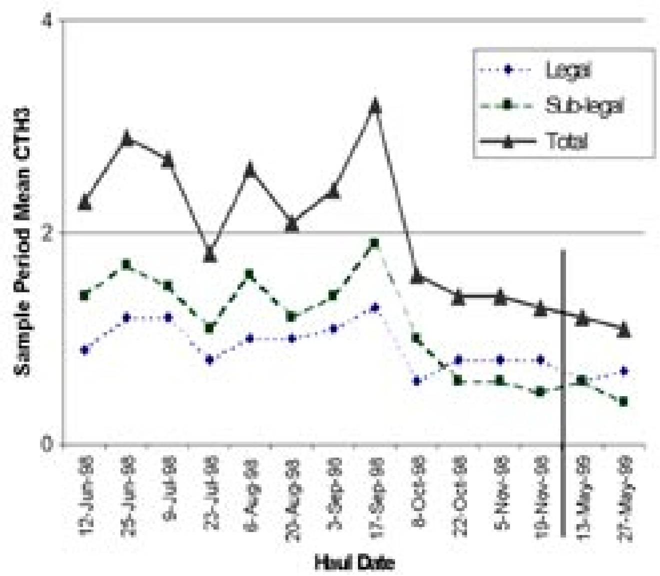


FIGURE 3.2 Catch per trap per three set-over days (CTH_3) for all lobster (total), legal, and sub-legal lobster during June-November 1998 and May 1999.

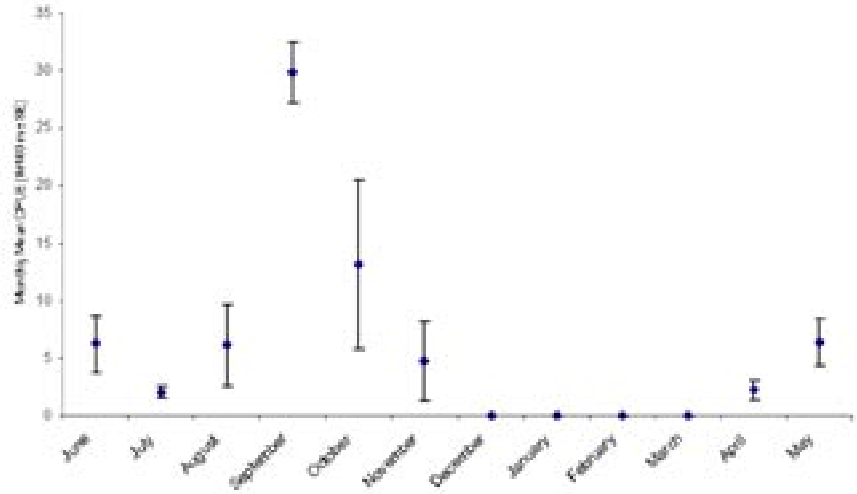


FIGURE 3.3 Seasonal collections (#/400 m; monthly mean ± standard error) of lobster from otter trawl survey, June 1998 to May 1999.

and supplemented the lobsterman data. The Inner Harbor otter trawl station presented the highest annual CPUE and variability (study mean ± standard error; 19.9 ± 7.5 / 400 m), and collections were substantially greater than other otter trawl stations. The Western Harbor station (near the mouth of the Blynman Canal) illustrated the second highest catch (4.5 ± 1.3 / 400 m), and the Southeast and Outer Harbor stations were similar (2.4 ± 0.9 / 400 m and 1.8 ± 0.6 / 400 m, respectively). Scuba transects located in the PFC (three transects totaling 1,100 linear m) demonstrated the highest density of lobster (0.16 lobster / linear m). Five transects were searched in the IH (1,300 linear meters), finding 0.13 lobsters / linear m. TI transects, surveying 1,050 linear m, yielded the lowest lobster density (0.08 lobster / linear m).

Seasonal abundance observed during the otter trawl sampling appeared similar to the lobster potting data (Figure 3.3). Lobster were collected from June to November 1998 and April and May 1999. The catches ranged from 2.1 ± 0.6 / 400 m (July) to 29.9 ± 2.6 / 400 m (September), peaking in September and October. The high abundance in September and October was dominated by large catches at the Inner Harbor station (total [N] = 180 and 64, respectively). No lobster were caught from December to March.

Sub-Area Examination and Population Structure

Total catches (study average CTH_3) were substantially different among the sub-areas (Table 3.2). Catches were largest in IH, and PFC (2.1 ± 0.3 CTH_3) was relatively higher than other sub-areas (Figure 3.4). The IH sub-area demonstrated considerably greater numbers of legal-size lobster. PFC sub-legal lobster catches were slightly larger than other sub-areas. Catches of sub-legal lobster were comparable among other sub-areas (Table 3.2).

Length frequency distribution assessed size of lobsters collected by the lobsterman (efficiency of lobster gear is biased toward larger lobster; 99.5% of catch was > 50 mm CL) (Figure 3.5). Harbor-wide length ranged from 30 to 130 mm CL. The majority of lobsters collected during the lobsterman sampling were between the 70 to 99 mm size classes (60% of total catch), averaging 81.0 ± 0.2 mm CL (mean CL ± SE). Lobster collected in the IH sub-area (87.5 ± 0.3 mm) were larger than all other sub-areas (Table 3.2). Nearly 50% of the legal lobster collected during the study were caught in the IH. IH also presented the largest size range (30 – 130 mm CL). The otter trawl collected notable numbers sub-legal lobster in the study area (mean CL ± SE of total [N] = 60.7 ± 0.6 mm CL), especially at the Inner Harbor station.

TABLE 3.2 Sub-area lobster catches of total, legal, and sub-legal lobster, average carapace length, male:female ratio, percent of ovigerous, and percent of missing claw in Gloucester Harbor during June - November 1998 and May 1999. Means (SE) included where relevant.

Statistic	IH	PFC	AR	TI	OH	Study Average
Catch Data						
Total CTH_3	3.7 (0.5)	2.1 (0.3)	1.4 (0.3)	1.4 (0.2)	1.8 (0.2)	2.0 (0.2)
Legal lobster CTH_3	2.7 (0.4)	0.6 (0.1)	0.5 (0.2)	0.4 (0.1)	0.6 (0.1)	0.8 (0.1)
Sub-legal lobster CTH_3	1.0 (0.1)	1.5 (0.2)	0.9 (0.1)	1.0 (0.1)	1.2 (0.2)	1.2 (0.1)
Length						
Total mean CL	87.5 (0.3)	75.9 (0.4)	79.1 (0.7)	77.1 (0.4)	81.3 (0.4)	81.0 (0.2)
Male mean CL	89.5 (0.4)	77.0 (0.5)	80.1 (0.9)	78.4 (0.5)	82.2 (0.6)	82.4 (0.3)
Female mean CL	84.6 (0.5)	74.2 (0.6)	77.7 (0.9)	75.6 (0.6)	80.3 (0.4)	79.1 (0.3)
Condition						
Male : female ratio	1.5	1.6	1.3	1.2	1.2	1.4
% Ovigerous	14.1	5.5	12.0	8.3	11.4	10.4
% Missing claw	7.3	16.9	9.6	14.9	12.9	12.2

Size distribution generally overlapped among the PFC, TI, AR and OH sub-areas, and IH was unique. The mean CL (mm) (± SE) of OH (81.3 ± 0.4), AR (79.1 ± 0.7), TI (77.1 ± 0.4), and PFC (75.9 ± 0.4) was below legal size (Table 3.2), and length frequency were truncated at the legal size limit. The higher catch rates of legal lobsters at IH produced the reverse trend (Figure 3.5).

Male lobster were larger than female lobster (Table 3.2). This trend was apparent in all sub-areas. The largest male and female lobster were found in IH (mean CL = 89.5 mm and 84.6 mm , respectively). PFC was characterized by the smallest male (77.0 mm CL) and female (74.2 mm CL). The male-to-female ratio was 1.4, with the highest ratio found at PFC (1.6) and IH (1.5) and lowest in the OH (1.2) (Table 3.2). Percentage of ovigerous lobster for the study was 10.4%. The IH percentage of ovigerous lobster (14.1%) was higher than other

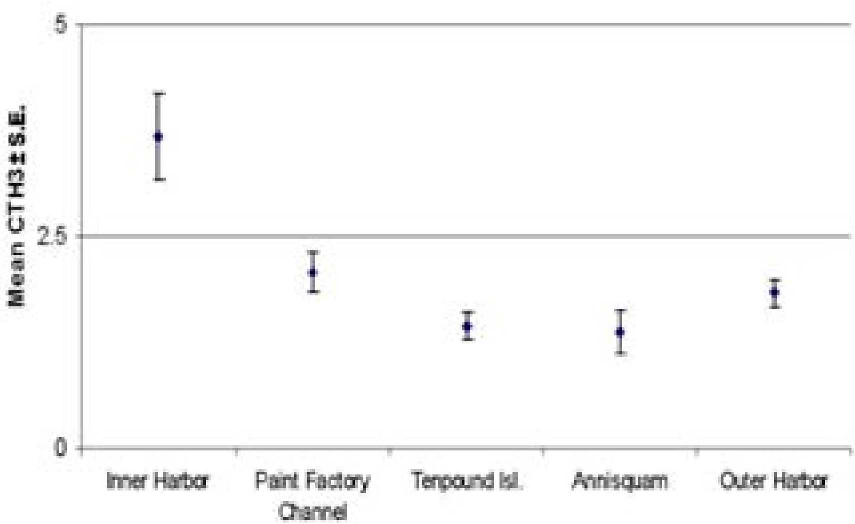


FIGURE 3.4 Total mean catch per trap per three day haul (CTH_3) (± standard error)—legal and sub-legal lobster combined—for sub-areas in Gloucester Harbor, June-November 1998 and May 1999.

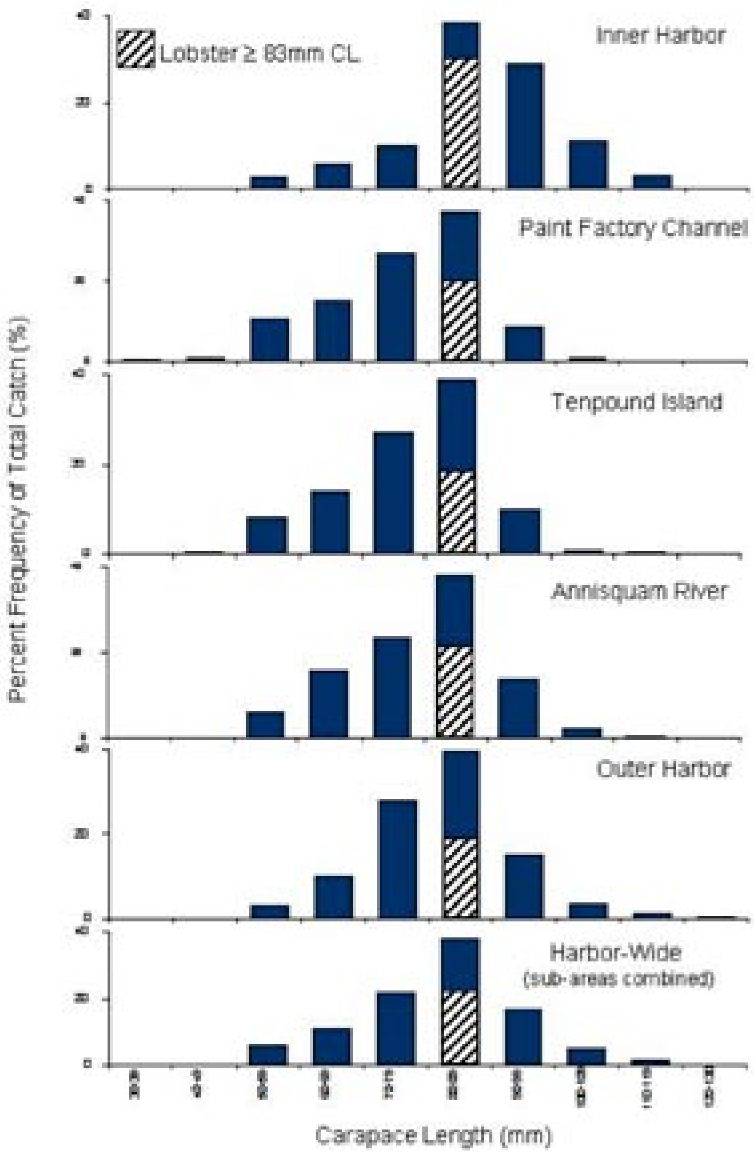


FIGURE 3.5 Length-frequency from sampling during June-November 1998 and May 1999 in Gloucester Harbor and sub-areas. Hatched bar indicates lobster ≥83 mm CL in 80-89 size class.

sub-areas, and AR percentage (12.0%) was notable (Table 3.2). PFC, TI, and OH presented the highest percentage of injured lobster (missing claw), while IH the lowest (Table 3.2).

Discussion

Wheeler and Hughes (1957) [reviewed by Jerome et al. (1969)] described the state waters surrounding Essex County (waters including Gloucester Harbor and Cape Ann) as exemplary fishing grounds. Gloucester Harbor and adjacent waters sustain a substantial portion of Massachusetts coastal lobster population and fishing activity (Estrella and Glenn 1999). This study and systematic statewide resource monitoring (Estrella and Glenn 1999; Pava et al. 1998) illustrate that productive lobster habitat and lobster fishing continues to flourish in Gloucester Harbor.

The index of lobster fishing obtained in this study is the result of one lobsterman. Acknowledging the occurrence of other fishermen and fishing areas in Gloucester Harbor, the pattern of fishing described in this study may underestimate the extent of important fishing grounds. Commercial fishermen, however, are concerned with maximizing harvest of lobster (Lawton et al. 1984b), and this study identifies important fishing grounds in Gloucester Harbor that were not described prior to the study. Clusters of fishing effort were found in specific areas of the harbor, including PFC, TI, and AR, and scattered throughout the OH. The geographic coverage was used as evidence of important fishing grounds.

Estrella and Glenn (1999) present 1998 Massachusetts lobster assessment data, and identify that Cape Ann waters produced slightly higher catch rates of legal-size lobster and similar catches of sub-legal lobster compared to state-wide data. Catch rates during this study indicated comparable or higher harbor-wide catch rates of legal-size lobster and sub-legal lobster (using catch per trap haul – Estrella and Glenn 1999). Legal-size lobster catch rates were heavily influenced from collections in the inner harbor.

The largest catches (interpreted as the period of highest relative abundance) occurred during the summer and early fall. The reduction in catch of sub-legal lobster and subsequent increased catch of legal lobster from October to November 1998 indicated the onset of molting and recruitment of lobster to the fishery. Lobster abundance throughout Gloucester Harbor diminished in November. Resident lobster populations exist in nearshore waters of the Gulf of Maine (Heinig 1998; Watson et al. 1999; Short et al. 2001). However, winter scuba (Malkoski personal communication) and otter trawl (NAI 1999b) surveys confirmed the low abundance of lobster in Gloucester Harbor and were corroborated by the relative lack of commercial fishing during this time period. Seasonal occurrence of lobster during this study support that lobster travel inshore in the spring and return to offshore waters in late autumn (Lawton et al. 1984a; Estrella and Morrisey 1997; Watson et al. 1999).

Spatial variability within Gloucester Harbor was evident, demonstrated by substantially higher catches of legal-size lobster in the inner harbor (IH sub-area) and lower catches in the outer harbor (including the PFC, TI, AR and OH sub-areas). IH catches were considerably higher than harbor-wide, Cape Ann, and statewide data. Difference in catch is partially reflective of abundance, since fishing effort influences catches. Intense trap saturation (i.e., number of traps fishing) decreases catches, and outer harbor waters are heavily fished compared to the inner harbor (which is closed to commercial harvest). The otter trawl and scuba surveys reinforced the trend of higher lobster abundance in the inner harbor. Otter trawl collections and scuba observations at the IH and PFC stations demonstrated concentrated lobster use of the inner harbor.

Harvesting effort and conceivably habitat conditions, including water temperature and organic load in seafloor sediments, influenced inner harbor relative abundance. Studies (e.g., Crossin et al. 1998; Watson et al. 1999) found lobster move to warmer waters to enhance growth. Inner harbor waters were warmer [bottom water temperature average was ~2°C higher than outer harbor stations from June to October 1998 (NAI 1999b)], primarily due to reduced tidal flushing in the inner harbor with deeper harbor and offshore waters, and may present preferable environmental conditions for lobster growth. Fish processing plants directly discharged fish waste to the harbor for decades (Whitman and Howard 1958), and marine sediments continue to present evidence of organic loading (Valente et al. 1999). Adult and juvenile lobster may be attracted to the organic content found in inner harbor sediments.

Commercial lobster gear is an effective method to collect adolescent and adult lobster, and studies using lobster traps demonstrate lobster size equal to / or below the minimum legal size limit (Lawton et al. 1984a; Estrella and Glenn 1999). Harbor-wide length distribution was truncated at the minimum legal size (83 mm CL), but notable differences in size were obvious between the inner and outer harbor waters. Smaller lobster were found and length frequency was truncated at the minimum legal size (i.e., 83 mm CL) in outer harbor sub-areas (i.e., PFC, TI, AR, and OH). The IH length class illustrated a higher proportion of legal-size lobster, resulting in larger average size. Commercial exploitation apparently limits the size range of lobster and is typical of heavily exploited areas.

Male-to-female sex ratio (1.4) identified that more males inhabited Gloucester Harbor than females, and male lobster were larger than female lobster throughout the harbor. Male lobster mature earlier than female lobster, but male lobster must be larger than mates for successful fertilization and to protect females from other males (Aiken and Waddy 1980). The highest male-to-female sex ratios were found in IH and PFC.

The highest percent of ovigerous lobster were found in the IH and the AR sub-area (surrounding the channel connecting the Annisquam River and harbor waters). Higher presence of ovigerous lobster in the IH and AR may indicate female lobster were seeking an optimal water temperature regime to improve egg development (Cooper and Uzmann 1971).

The occurrence of injured lobster in the outer harbor (OH, TI, and PFC) provided evidence of harvesting. Fewer injured lobster were collected in the IH sub-area. Intense fishing effort results in lobster frequently caught and handled which increases chance of being injured.

This study describes seasonal and harbor characteristics of lobster in Gloucester Harbor during 1998-

1999. We assume that commercial fishermen fish in productive areas, and the distribution of lobstering effort demonstrated important fishing grounds in Gloucester waters. Although Gloucester Harbor is a traditional urban harbor, influenced by centuries of human perturbations, harbor waters support a productive lobster population and fishery. The influence of harvesting was apparent during the study.

The inner harbor is closed to lobster fishing, and the lack of fishing effort affects the catch and population characteristics of lobster. It is impossible to evaluate the influence of the inner harbor closed area to the lobster population, and this study did not examine lobster movement throughout the study area (i.e., inner harbor immigration and emigration). Results suggest that inner harbor waters provide refuge from fishing pressure and may assist in supporting a heavily exploited outer harbor. Targeted research to examine the function of closed areas on lobster populations is required to confirm study observations.

Closed areas, also known as marine protected areas or marine refugia, are gaining popularity as means to conserve marine biological diversity and improve fishery productivity (e.g., Johnson et al. 1999; Murawski et al. 2000). The situation in Gloucester Harbor is unique to closed area approaches. Areas closed for protection of marine resources are normally "pristine" environments. The inner harbor is not pristine but relatively degraded (MCZM 2001). Factors contributing to the elevated catches and larger size in the inner harbor include reduced fishing pressure, productive lobster habitat quality, and/or a combination of these reasons.

The identification of fishing areas in coastal waters is required to improve resource management decisions, and the utility of closed areas for marine conservation and fishery enhancement warrants targeted research. The influence of urbanization and environmental degradation to marine and fisheries resources is largely unknown. This study found that lobster are tolerant to degraded conditions. It is important, however, to understand the ecological effects of human perturbations to lobster populations, harvesting practices, and environmental integrity to completely understand the implications of pollution input and coastal alteration projects.

ACKNOWLEDGMENTS

This study was a component of the Massachusetts Dredged Material Management Plan, supported by the Massachusetts Seaport Bond, and the Gloucester Harbor Characterization (CZM grant). Fieldwork was completed by Normandeau Associates Incorporated (Paul Geoghegan, project manager), commercial lobsterman (Jay Gustafarro), and DMF staff (Vin Malkoski and Bob Glenn). Additional financial and editorial support was received from Massachusetts Office of Coastal Zone Management (Deerin Babb-Brott, Anne Donovan, and Christian Krahforst).

LITERATURE CITED

Aiken, D.E. and S.L. Waddy. 1980. Reproductive Biology. In, J.S. Cobb and B.F. Phillips (eds.), The Biology and Management of Lobsters, Volume I. Academic Press, NY. 215-268pp.

Cooper, R.A. and J.R. Uzmann. 1971. Migrations and growth of deep-sea lobsters, *Homarus americanus*. Science 171:288-290.

Crossin, G., S.H. Jury, and W.H. Watson III. 1998. Behavioral thermoregulation in the American lobster, *Homarus americanus*. Journal of Experimental Biology 201:365-374.

Estrella, B.T. and R.P. Glenn. 1999. Massachusetts Coastal Commercial Lobster Trap Sampling Program May - November, 1998. Massachusetts Division of Marine Fisheries, Boston, MA. 20pp.

Estrella, B.T. and T.D. Morrissey. 1997. Seasonal movement of offshore American lobster, *Homarus americanus*, tagged along the eastern shore of Cape Cod, Massachusetts. Fishery Bulletin 95: 466-476.

Factor, J.R. 1995. Chapter 1. Introduction, Anatomy, and Life History. In, J.R. Factor (ed.), Biology of the Lobster *Homarus americanus*. Academic Press, NY. 111-137pp.

Heinig, C.S. 1998. Survey of American lobsters, Homarus americanus, in the Fore River, Portland Harbor, Maine. Prepared for the Portland Harbor Dredge Committee, Portland, ME. Prepared by MER Assessment Corporation, Brunswick, ME.

Jerome, W.C., A.P. Chesmore, and C.O. Anderson. 1969. A study of the marine resources of the Annisquam River – Gloucester Harbor Coastal Ecosystem. Monograph Series Number 8. Massachusetts Department of Natural Resources. Division of Marine Fisheries, Boston, MA. 62pp.

Johnson, D.R., N.A. Funicelli, and J.A. Bohnsack. 1999. Effectiveness of an existing estuarine no-take fish sanctuary within the Kennedy Space Center, Florida. North American Journal of Fisheries Management 19:436-453.

Lawton, R.P., P. Brady, C. Sheehan, W. Sides, E. Kouloheras, M. Borgatti, and V. Malkoski. 1984a. Growth and movement of tagged lobsters released in western Cape Cod Bay, 1970-1977. In, J.D. Davis and D. Merriman (eds.), Lecture Notes on Coastal and Estuarine Studies: Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts. Springer-Verlag, NY. 119-129pp.

Lawton, R.P., G. Luders, M. Kaplan, P. Brady, C. Sheehan, W. Sides, E. Kouloheras, M. Borgatti, and V. Malkoski. 1984b. The commercial lobster pot-catch fishery in the Plymouth vicinity, western Cape Cod Bay. In, J.D. Davis and D. Merriman (eds.), Lecture Notes on Coastal and Estuarine Studies: Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts. Springer-Verlag, NY. 131-150pp.

Malkoski, V.J. 1999. Dredged Material Management Plan – soft-bottom suction sampling pilot program. Massachusetts Division of Marine Fisheries, Pocasset, MA. 11pp.

Massachusetts Office of Coastal Zone Management (MCZM). 2001. Dredged Material Management Plan (DMMP) EOEA No. 11543. Draft Environmental Impact Report (DEIR) for Gloucester, Massachusetts. Prepared for Massachusetts Office of Coastal Zone Management and City of Gloucester, MA. Prepared by Maguire Group, Foxborough, MA.

Murawski, S.A., R. Brown, H.L. Lai, P.J. Rago, and L. Hendrickson. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experience. Bulletin of Marine Science 66:775-798.

Normandeau Associates Incorporated (NAI). 1999a. Early benthic phase lobster survey for Gloucester. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 9pp.

Normandeau Associates Incorporated (NAI). 1999b. Dredged Material Management Plan fisheries resources survey for Gloucester. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 28pp.+append.

Pava, J.A., T.B. Hoopes, and K. Kruger. 1998. 1998 Massachusetts Lobster Fishery Statistics. Massachusetts Division of Marine Fisheries, Gloucester, MA. Technical Series 33. 22pp.

Phillips, B.F., J.S. Cobb, and R.W. George. 1980. General Biology. In, J.S. Cobb and B.F. Phillips (eds.), The Biology and Management of Lobsters, Volume I. Academic Press, NY. 1-82pp.

Science Applications International Corporation (SAIC). 2001. Results of the March 2001 Subbottom profiling and sediment profile imaging survey of the outer Gloucester Harbor. Prepared by SAIC. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Short, F.T., K. Matso, H.M. Hoven, J. Whitten, D.M. Burdick, and C.A. Short. 2001. Lobster use of eelgrass habitat in the Piscataqua River on the New Hampshire / Maine border, USA. Estuaries 24(2):277-284.

United States Geological Survey (USGS). 2000. A Marine GIS Library for Massachusetts Bay: Focusing on disposal sites, contaminated sediments, and seafloor mapping. B. Butman and J. Lindsay (eds.). USGS Open-File Report 99-439.

Valente, R.M., M.C. Swanson, and C.L. Seidel. 1999. Dredged Material Management Plan: Habitat characterization of the DMMP candidate aquatic disposal sites. Prepared by Science Applications International Corporation, Newport, RI. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Watson III, W.H., A. Vetrovs, and W.H. Howell. 1999. Lobster movements in an estuary. Marine Biology 134:65-75.

Wheeler, C.L. and J.T. Hughes. 1957. The lobster fishery in Massachusetts. Massachusetts Department of Natural Resources. Division of Marine Fisheries. 31pp.

Whitman and Howard. 1958. Report on the Existing Sewerage System and Improvements Thereto: City of Gloucester, MA. Gloucester, Massachusetts.

Personal Communication

Malkoski, V.J. Personal Communication. Dredged Material Management Plan – Investigating Gloucester Harbor for wintering lobster. Massachusetts Division of Marine Fisheries, Pocasset, MA.

APPENDIX Gloucester Harbor lobster survey results (catch per trap per three set over days [CTH_3]) for each sampling date (NAI 1999b).

Region	6/12 1998	6/25 1998	7/9 1998	7/23 1998	8/6 1998	8/20 1998	9/3 1998	9/17 1998	10/8 1998	10/22 1998	11/5 1998	11/19 1998	5/13 1999	5/27 1999	Annual Mean (CTH3)	Standard Error (±)
Inner																
Legal	3.2	3.8	3.0	3.6	4.2	3.3	4.0	4.0	1.6	2.8	2.6	1.5	1.4	1.8	2.9	0.3
Sub-legal	1.8	1.1	1.9	1.4	1.3	0.7	1.3	1.5	1.2	0.5	1.0	0.4	0.3	0.5	1.1	0.1
Total	5.0	4.9	4.9	5.0	5.5	4.0	5.4	5.6	2.7	3.4	3.6	1.9	1.7	2.3	4.0	0.4
Outer																
Legal	0.5	0.7	0.8	0.2	0.4	0.5	0.5	0.7	0.4	0.4	0.5	0.6	0.4	0.3	0.5	0.04
Sub-legal	1.3	1.8	1.4	1.0	1.7	1.3	1.4	2.0	1.0	0.6	0.5	0.5	0.7	0.4	1.1	0.1
Total	1.8	2.5	2.3	1.2	2.1	1.8	1.9	2.7	1.4	1.0	1.0	1.1	1.1	0.7	1.6	0.2
Harbor-wide																
Legal	0.9	1.2	1.2	0.8	1.0	1.0	1.1	1.3	0.6	0.8	0.8	0.8	0.6	0.7	0.9	0.1
Sub-legal	1.4	1.7	1.5	1.1	1.6	1.2	1.4	1.9	1.0	0.6	0.6	0.5	0.6	0.4	1.1	0.1
Total	2.3	2.9	2.7	1.8	2.6	2.1	2.4	3.2	1.6	1.4	1.4	1.3	1.2	1.1	2.0	0.2

CHAPTER FOUR

The Relative Abundance, Distribution, Composition, and Life History Characteristics of Fishes in Gloucester Harbor

Anthony R. Wilbur
Massachusetts Office of Coastal Zone Management, Boston, MA

Abstract

This study described the fish community structure in Gloucester Harbor and detailed seasonal and spatial characteristics of relative abundance, community composition, and life history traits. Four otter trawl stations and four seine stations were sampled monthly from June 1998 to May 1999. This study was the first effort to assess the Gloucester Harbor fish community in more than 30 years. A total of 1,786 fish (trawl, N = 1,165; seine, N = 621) were collected, comprised of 29 fish species. Skates, winter flounder, and Atlantic cod were the most abundant (by number), totaling 71.5% of the total otter trawl catch. Resident and transient species exhibited seasonal variation in presence and relative abundance with the highest relative abundance (total fish CPUE) in spring and fall. Juvenile fishes dominated catches. The presence of resident species, including commercially exploited species (winter flounder and windowpane) and non-target species (cunner, lumpfish, and rock gunnel), and the seasonal recruitment of marine young-of-year fishes (Atlantic cod, pollock, red hake, and shorthorn sculpin) demonstrated the use of Gloucester Harbor as nursery habitat. Skates dominated the demersal fish biomass. This study demonstrated the importance of nearshore waters, including urban embayments, in Massachusetts to the development of a relatively diverse fish assemblage.

Introduction

Gulf of Maine demersal fishes historically sustained and continue to support productive fisheries in the Northeast United States and the Canadian Maritimes (NMFS 1998). Fishes of the Gulf of Maine are well described (Bigelow and Schroeder 1953; Collette and Klein-MacPhee 2002), and studies describe spatial and temporal features of the demersal fish assemblage found in Northwestern Atlantic offshore waters (Colvocoresses and Musick 1984; Gabriel 1992). Federal and state monitoring programs assess stock status of commercially and recreationally important species throughout the Gulf of Maine and Massachusetts waters (NMFS 1998; Howe et al. 2000a).

Studies examining intraannual variation of fish fauna composition and relative abundance in nearshore Gulf of Maine waters are rare (Lazzari et al. 1999). Massachusetts fishery resources are assessed biannually through stock assessment surveys (Howe et al. 2000a), but nearshore systems (<9m water depth) are not routinely investigated (Howe et al. 2000b). Gloucester Harbor was initially investigated in 1966-1967 to characterize harbor fishery resources (Jerome et al. 1969). The Jerome et al. (1969) study provided valuable information on fishery resources and demonstrated the importance of coastal waters to a relatively diverse fish assemblage.

Recent studies of nearshore systems focused on specific habitats (e.g., Heck et al. 1989) or species (Howe et al. 2000b). Few published studies, however, examine fish distribution, abundance, community characteristics, and habitat use in Gulf of Maine coastal waters (Ayvazian et al. 1992; Lazzari et al. 1999; Chase et al. 2002; Buchsbaum et al. 2003). Coastal, shallow water environments are ecologically important to many marine fish species, especially

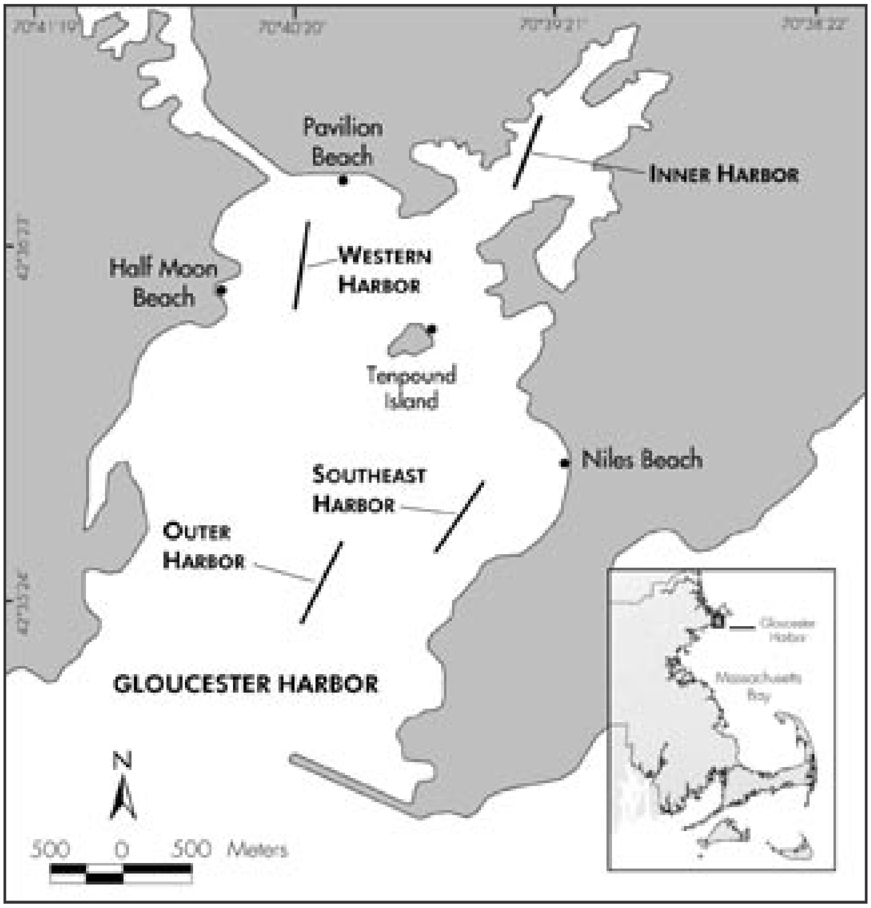


FIGURE 4.1 Study area map. Location of otter trawl and beach seine sampling stations in Gloucester Harbor during June 1998 to May 1999. Lines represent average location of Southeast Harbor (SEH), Outer Harbor (OH), Western Harbor (WH), and Inner Harbor (IH) otter trawl stations. Dots represent beach seine locations.

throughout early ontogenetic development (e.g., Hoss and Thayer 1993; Able and Fahay 1998; Meng and Powell 1999; Howe et al. 2000b). The 1966-1967 study illustrated that juvenile fish inhabit Gloucester Harbor waters (Jerome et al. 1969). Early juvenile fishes require specific habitat conditions that mediate survivorship and growth, and these habitats are often located in nearshore waters. The understanding of early life history requirements of fishes is a critical source of information that is needed to improve the management of coastal waters.

Nearshore marine habitats are diverse and highly susceptible to natural and human perturbations. Embayments were frequently developed to support urban centers, maritime industries, and recreational boating. Harbor development dramatically altered environmental resources and conditions. Anthropogenic influences, including historic and current inputs, affect environmental quality and ecological function of these harbors. Urban embayments present varying degrees of degradation, but contain environmental features that support early life history stages of fishes (Able et al. 1998; Able et al. 1999).

This study documents the results of a twelve-month fish survey in Gloucester Harbor. The objective of the study was to describe fish community structure of Gloucester Harbor and investigate seasonal and spatial characteristics of the fish community, from June 1998 to May 1999. Seasons were defined by examining water temperature and fish assemblage features to facilitate data analyses and description. Total relative abundance (species combined), species

TABLE 4.1 Intertidal seine and subtidal otter trawl sampling stations in Gloucester Harbor, June 1998 to May 1999. Means (SE) included where relevant.

Station	Location[a]		Mean Depth (m)	Substrate	Observations
Seine Sites					
Pavilion Beach	42.6093°N, 70.6680°W			sand	shallow slope
Tenpound Island	42.6023°N, 70.6637°W			sand, gravel, shells	steep slope
Half Moon Beach	42.6045°N, 70.6768°W			sand	moderate slope, ledge on either side
Niles Beach	42.5923°N, 70.6548°W			sand	moderate slope eelgrass offshore
Trawl Sites	*Start*	*End*			
Southeast Harbor	42.6029°N, 70.6675°W	42.5982°N, 70.6730°W	9.9 (0.3)	sand-silt	*Laminaria*, *Agarum*, *Ulva* present
Outer Harbor	42.5985°N, 70.6724°W	42.5929°N, 70.6751°W	11.3 (0.3)	silt-shells	small amounts of macroalgae
Western Harbor	42.6119°N, 70.6744°W	42.6060°N, 70.6758°W	8.0 (0.3)	silt-mud	no macroalgae
Inner Harbor	42.6154°N, 70.6645°W	42.6202°N, 70.6607°W	8.0 (0.2)	soft mud	frequent snags

[a]Average latitude and longitude

composition, and species richness were compared by season and trawl station. Relative abundance and length frequency were documented for common species. Habitat use and the ecological function of harbor waters are discussed for Gloucester Harbor.

MATERIALS AND METHODS

Biological resources were examined in Gloucester Harbor during the development of the Massachusetts Dredged Material Management Plan (MCZM 2001). Fish community characteristics were studied to assess the environmental suitability of in-water dredged material disposal options and evaluate potential impacts.

Study Area

Gloucester Harbor is an urban port in northwestern Massachusetts Bay, Massachusetts (Figure 4.1). The inner harbor supports shoreline and navigation infrastructure, including piers, rip-rap, navigation channels, and mooring areas. The outer harbor shoreline ranges from undeveloped rocky shore and sandy beach to residential property. Seafloor sediments throughout the study area are predominately unconsolidated, soft sediments with areas of ledge and rock (NAI 1999a; Valente et al. 1999; USGS 2000; SAIC 2001; Malkoski personal observation) and patchy distribution of kelp and drift algae (personal observation). Seafloor habitat in the inner harbor is degraded, including chemical contamination and anoxic sediments (Valente et al. 1999; MCZM 2001). Environmental quality improves along a gradient from the inner to outer harbor (Valente et al. 1999; SAIC 2001). Outer harbor sediments generally show negligible evidence of human perturbation (SAIC 2001).

Sampling Techniques

Fishes were sampled in Gloucester Harbor from June 1998 to May 1999. Otter trawl and beach seine sampling was conducted twice per month from June through October 1998 and May 1999 and once per month from November 1998 through April 1999 (18 sample periods; NAI 1999b). Sampling gear and methods used in this project were developed in consultation with Massachusetts Division of Marine Fisheries (DMF). Otter trawl and seine stations were located to represent harbor environs (Table 4.1) and for consistency with previous studies (Jerome et al. 1969; Chase et al. 2002; DMF personal communica-

Beach seine (left), processing a trawl catch (right)

tion). Fixed otter trawl stations were located in the Southeast Harbor (SEH), Outer Harbor (OH), Western Harbor (WH), and Inner Harbor (IH) (72 total trawls). Four seine stations (Pavilion Beach [PB], Tenpound Island [TI], Half Moon Beach [HM], and Niles Beach [NB]) were identified in accessible and haulable waters (i.e., beaches that were capable of being seined) (71 total hauls) (Figure 4.1). Otter trawl and beach seine stations are identified by capital letters throughout the study.

Otter trawl stations were located in waters subjected to a range of human influences. Degradation, including diminished water quality (Kooken et al. 2000) and sediment quality (MCZM 2001), was most prevalent at the IH trawl station. Outer harbor stations (i.e., WH, SEH, and OH) had similar water quality and sediment type, with comparatively less evidence of human influences (SAIC 2001). The PB seine station was a sandy beach adjacent to the inner harbor; TI was located on an island with a mix of sand, gravel, and shells; HM was a sandy beach between a rocky shoreline on the western side of the outer harbor; and NB was located along a sandy beach on the eastern shore (Table 4.1).

A 50-foot seine (15.2 m length; 1.2 m depth; 1.2 x 1.8 m bag; 4.8 mm delta mesh) was used to sample shallow water fishes (intertidal habitat sampling). A 30-foot otter trawl (9.1 m sweep; 8.2 m headrope) sampled fishes in deeper water (subtidal habitat sampling). The otter trawl had 2-inch stretch mesh (5.08 cm) in the body and 1.5-inch stretch mesh (3.81 cm) in the cod end with a 1/4 inch liner (0.64 cm). The cod end liner retained smaller fishes.

The beginning and end coordinates of each trawl sample were recorded, and trawl distance measured with differential Global Positioning System (GPS). The trawl started when trawl doors rested on the seafloor. The trawl ended at 400 m (measured by GPS) and was quickly retrieved to the boat. Tow distance was verified by plotting beginning and end coordinates using Geographic Information System (GIS) software. Otter trawl tow length occasionally varied, so the catch per unit effort (CPUE; number and weight) was standardized to a 400 m tow length (#/400 m). Shallow water habitat (i.e., intertidal) was sampled by positioning the seine parallel to shore in approximately one meter of water and hauled directly to shore, covering a rectangular area. The area sampled (i.e., length of haul and volume of water) for each seine sample was relatively equal, and CPUE was calculated as catch per haul (#/haul).

For each seine and trawl sample, all fishes were identified to species, counted, measured for total length (TL; mm), and weighed (g; aggregate weight by species). Skates (*Leucoraja* spp.) were identified to genus and included little skate (*Leucoraja erinacea*) and winter skate (*Leucoraja ocellata*).

Water Temperature Assessment and Season Identification

Bottom water temperature was recorded with a YSI 600XL water quality meter for each seine and trawl sample (total samples = 128). Instrument failure prohibited water temperature collection on 18 September and 11 November 1998. Trawl and seine stations were separately analyzed to demonstrate difference between shallow and deep waters, and data were described by mean and standard error to show the yearly range of temperature. Trawl water temperature data were compared with the one-way analysis of variance (ANOVA; $p<0.05$) to investigate spatial (station) variability. Season delineation was determined by investigating general trends of bottom water temperature (i.e., increasing, decreasing, or stable) and trawl catches (i.e., variation in CPUE and species assemblage characteristics). These factors provided a rationale for grouping the data by season.

Fish Community and Trawl Station Characterization

Trawl and seine catches were individually analyzed, but the discrete sampling methods collectively provided a description of the harbor fish community. Species composition (% of total CPUE), richness (# of fish species), and total fish relative abundance (species combined, mean CPUE ± standard error; SE) were the parameters used to describe the fish community. Trawl stations and sample periods were combined to describe the overall fish community of the harbor. The temporal characterization of the fish community included analyses by season and month (justification for grouping data by four seasons is presented below). Spatial features were compared by investigating individual trawl stations. Analyses by season and station included relative abundance (mean CPUE ± SE), species richness (mean richness ± SE), and composition (% total CPUE). Relative abundance (total fish monthly mean CPUE ± SE) was analyzed for the seine data to describe temporal characteristics of shallow water fishes. The species list and monthly presence were described by combining otter trawl and beach seine data.

This study examined the hypothesis that temporal and spatial variation in fish assemblage structure existed in Gloucester Harbor. Comparison of seasonal species richness was made with ANOVA, and the Tukey Test examined difference between seasons ($p<0.05$). Parametric assumptions were not always met for variables based on otter trawl samples; therefore, nonparametric methods compared assemblage features. Seasonal CPUE, station CPUE, and station species richness were compared with Kruskal-Wallis Test (non-parametric ANOVA for multiple groups, $p<0.05$). If significant differences were detected with the Kruskal-Wallis statistic, the Mann-Whitney Rank Sum Test (non-parametric statistical equivalent to T-Test for two groups) was used to evaluate two samples (e.g., spring and winter CPUE). The Bonferroni correction adjusted the Mann-Whitney statistic significance value ($p<0.0125$) to reduce the potential of type I error (i.e., rejection of true null hypothesis) for each comparison (Sokal and Rohlf 1995).

Relative Abundance and Length Frequency

Seasonal variation in relative abundance and length-frequency distributions was examined for common species. Relative abundance analysis focused on the top nine species (by number). Length-frequency distributions were described for Atlantic cod (*Gadus morhua*), winter flounder (*Pseudopleuronectes americanus*), and skates (*Leucoraja* spp.).

RESULTS

Season Delineation

Four seasons were identified by comparing water temperature and fish data. Water temperature fluctuation generally corresponded to total relative abundance (Figure 4.2). Seasonal characteristics are summarized in Table 4.2. Spring (April-June; 5 sample periods) was characterized by increasing water temperature and relatively high abundance and richness of fishes; summer (July-September; 6 sample periods) had warm water and relatively stable abundance and moderate richness of fishes; fall (October-December; 4 sample periods) illustrated dramatic water temperature decline, a slight increase and subsequent decrease in relative abundance, and comparatively high species richness; winter (January-March; 3 sample periods) was characterized by stable low water temperatures and low abundance and richness of fishes.

This study used assemblage composition and species richness to assist in determining seasons (Table 4.2; detailed examination of fish data provided below). Characteristics, such as the presence of juvenile Atlantic cod and shorthorn sculpin, overlapped between late winter (March) and early spring (April). The substantially larger catches (total CPUE by number) of Atlantic cod and shorthorn sculpin, occurrence of juvenile pollock, and higher species richness (total number of fish species) in April was used as an ecological indicator of the winter-spring transition. These defined seasons were used for additional analyses of the fish community throughout the study.

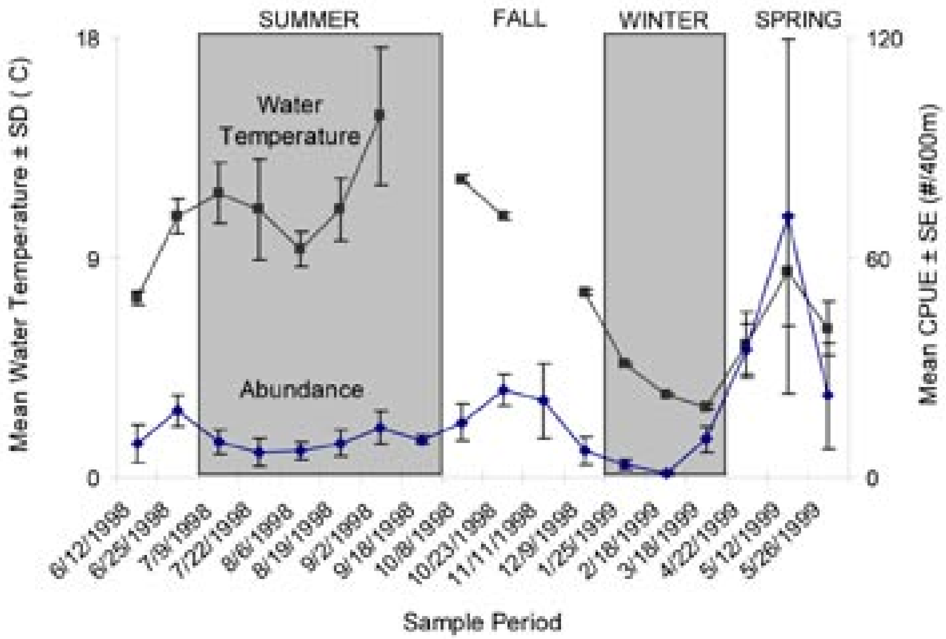


FIGURE 4.2 Seasonal illustration of sample period mean and variation in bottom water temperature and relative abundance of fishes (water temperature and total CPUE for otter trawl data). Water temperature not collected on 18 September and 11 November 1998.

TABLE 4.2 Seasonal water temperature, relative abundance of fishes (total fish catch of combined otter trawl stations) and species richness (total number of fish species per sample period). Mean (SE) included where relevant.

Season	Months[a]	Water Temperature (°C)	CPUE	Species Richness
Spring	April-June (5)	7.6 (0.5)	31.0 (10.4)	11.0 (1.6)
Summer	July-September (6)	11.5 (0.6)	9.4 (1.3)	7.3 (0.8)
Fall	October-December (4)	10.2 (0.6)	16.6 (3.3)	10.5 (1.0)
Winter	January-March (3)	3.6 (0.2)	4.8 (1.6)	3.3 (1.3)

[a]Number of sample periods are given in parentheses.

Water Temperature

Water temperature (mean water temperature ± SE) at trawl stations ranged from 2.9 ± 0.1°C (18 March 1999) to 14.8 ± 2.8°C (2 September 1998). Temperature from the seine stations ranged from 3.3 ± 0.1°C (18 February 1999) to 19.0 ± 0.7°C (22 July 1998). Water temperature at seine stations was higher compared to the trawl stations during June and July 1998 and May 1999 and comparable among seine and trawl stations from end of August 1998 to March 1999 (Figure 4.3).

Bottom water temperatures at trawl stations were not significantly different (ANOVA, $p>0.05$; Table 4.3). IH (9.2 ± 1.0°C) and OH (7.8 ± 0.7°C) had the highest and lowest mean temperature, respectively. Variability observed in bottom water temperature suggested that IH water temperature was notably higher than outer harbor stations (SEH, WH, and OH) during July, August, and September.

Fish Community Characteristics

Twenty-nine fish species were collected in Gloucester Harbor, including the trawl (22 fishes) and seine (20 fishes; Table 4.4). A total of 1,786 fish (trawl, N = 1,165; seine, N = 621) were collected during the study (Appendix 4.1-4.4d). Community characteristics differed between trawl and seine samples.

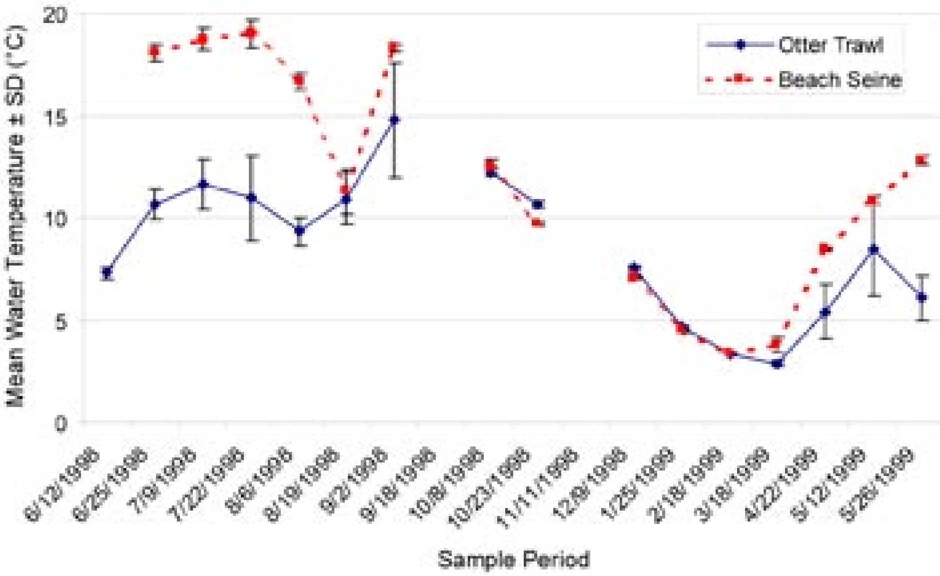


FIGURE 4.3 Bottom water temperature (mean ± SD) at seine and trawl stations for each sample period, June 1998 to May 1999. Water temperature not collected on 18 September and 11 November 1998.

TABLE 4.3 Seasonal mean bottom water temperatures (SE) at otter trawl stations. Total represents study mean.

Station	Spring	Summer	Fall	Winter	Total
Southeast Harbor	7.4 (1.3)	11.0 (0.6)	10.1 (1.4)	3.6 (0.5)	8.3 (0.8)
Outer Harbor	6.6 (0.9)	10.2 (0.7)	10.3 (1.4)	3.6 (0.5)	7.8 (0.7)
Western Harbor	7.8 (1.1)	12.0 (1.2)	10.1 (1.3)	3.7 (0.5)	8.8 (0.9)
Inner Harbor	8.4 (0.7)	12.9 (1.5)	10.1 (1.4)	3.6 (0.6)	9.2 (1.0)

Trawl collections were comprised of skates (24.9%), winter flounder (24.1%), Atlantic cod (22.5%), and other demersal fishes (e.g., rock gunnel [3.4%], shorthorn sculpin [3.3%], red hake [3.1%], and pollock [3.1%]) (Figure 4.4). Skates dominated overall harbor biomass (80.0% of total biomass). Fish composition varied between the seasons (Figure 4.5). Juvenile recruitment of Atlantic cod (35.2%) and pollock (5.8%) to nearshore waters was observed in spring. Spring samples contained 19 total species, including skates (19.9%), winter flounder (19.8%), and shorthorn sculpin (5.0%). Skates (45.6%) and winter flounder (24.3%) constituted the majority of the summer composition (15 total species). Fifteen species were collected during fall. These samples were dominated by winter flounder and skates (32.2% and 24.0%, respectively), with Atlantic cod (8.6%), cunner (5.6%), red hake (5.2%), and lumpfish (4.6%) constituting a substantial portion. The winter fish assemblage (7 species) was comprised of winter flounder (31.6%), Atlantic cod (31.6%), rock gunnel (15.8%), shorthorn sculpin (8.8%), cunner (5.3%), and grubby (5.3%).

The number of fishes (species richness) varied through the study (Figure 4.6). The greatest fish species richness was observed during late summer, early fall, and spring. Fifteen species were found in October 1998, and April and May 1999. The lowest richness was during the winter (January [2 species]-March [6 species]). Species richness differed by season (Table 4.2; ANOVA, $p<0.05$), with spring (mean total # of species per sample period ± SE; 11.0 ± 1.6; Tukey, $p<0.05$) and fall (10.5 ± 1.0; Tukey, $p<0.05$) greater than winter (3.3 ± 1.3).

TABLE 4.4 Common and scientific names of fishes encountered in the June 1998 to May 1999 otter trawl and beach seine survey, seasonal presence[a] and method of collection.

Common Name	Scientific Name	Seasonal Presence[a]	Collection Method
American sand lance	*Ammodytes americanus*	October (1)	seine
Atlantic cod	*Gadus morhua*	June; August; October-November March-May (7)	trawl
Atlantic menhaden	*Brevoortia tyrannus*	September-October (2)	seine
Atlantic silverside	*Menidia menidia*	August-December; February-May (9)	seine & trawl
Bay anchovy	*Anchoa mitchilli*	July-August (2)	seine
Blueback herring	*Alosa aestivalis*	June-August (3)	seine & trawl
Bluefish	*Pomatomus saltatrix*	September (1)	seine
Butterfish	*Peprilus triacanthus*	September (1)	trawl
Cunner	*Tautogolabrus adspersus*	June-July; September-November; February-May (9)	seine & trawl
Grubby	*Myoxocephalus aenaeus*	June-October; December-January; April (8)	seine & trawl
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	September-December; May (5)	trawl
Lumpfish	*Cyclopterus lumpus*	June; August-December (6)	seine & trawl
Mummichog	*Fundulus heteroclitus*	August; October-November (3)	seine
Northern pipefish	*Syngnathus fuscus*	June-July; September-November; April (6)	seine & trawl
Northern puffer	*Sphoeroides maculatus*	September (1)	seine
Ocean pout	*Macrozoarces americanus*	April-May (2)	trawl
Pollock	*Pollachius virens*	April-May (2)	seine & trawl
Radiated shanny	*Ulvaria subbifurcata*	June; April (2)	trawl
Rainbow smelt	*Osmerus mordax*	July; September-December; April (6)	seine & trawl
Red hake	*Urophycis chuss*	June-November; April-May (8)	seine & trawl
Rock gunnel	*Pholis gunnellus*	June-July; September-December; February-May (10)	seine & trawl
Sea raven	*Hemitripterus americanus*	June; October; May (3)	trawl
Seasnail spp.	*Liparis spp.*	August; April-May (3)	trawl
Shorthorn sculpin	*Myoxocephalus scorpius*	June; October-November; March-May (6)	seine & trawl
Skates[b]	*Leucoraja spp.*	June-December; April-May (9)	trawl
Threespine stickleback	*Gasterosteus aculeatus*	June; May (2)	seine
White hake	*Urophycis tenuis*	June; April (2)	trawl
Windowpane	*Scophthalmus aquosus*	June-December; March; May (9)	seine & trawl
Winter flounder	*Pseudopleuronectes americanus*	June-January; March-May (11)	seine & trawl

[a]Total number of months present are given in parenthesis.

[b]Skates are mix of little skate *(Leucoraja erinacea)* and winter skate *(Leucoraja ocellata)*

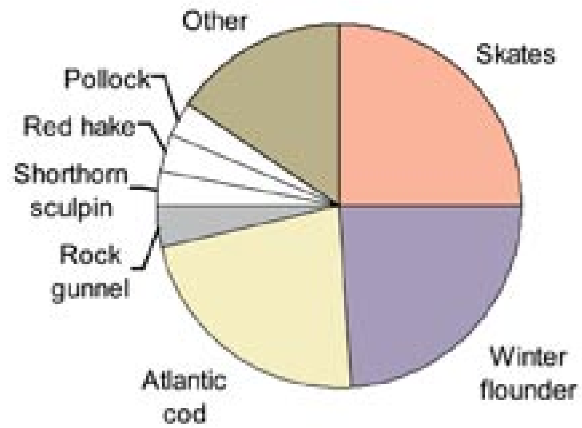


FIGURE 4.4 Fish composition (%) of otter trawl stations (otter trawl stations combined; total CPUE by number) in Gloucester Harbor, June 1998 to May 1999.

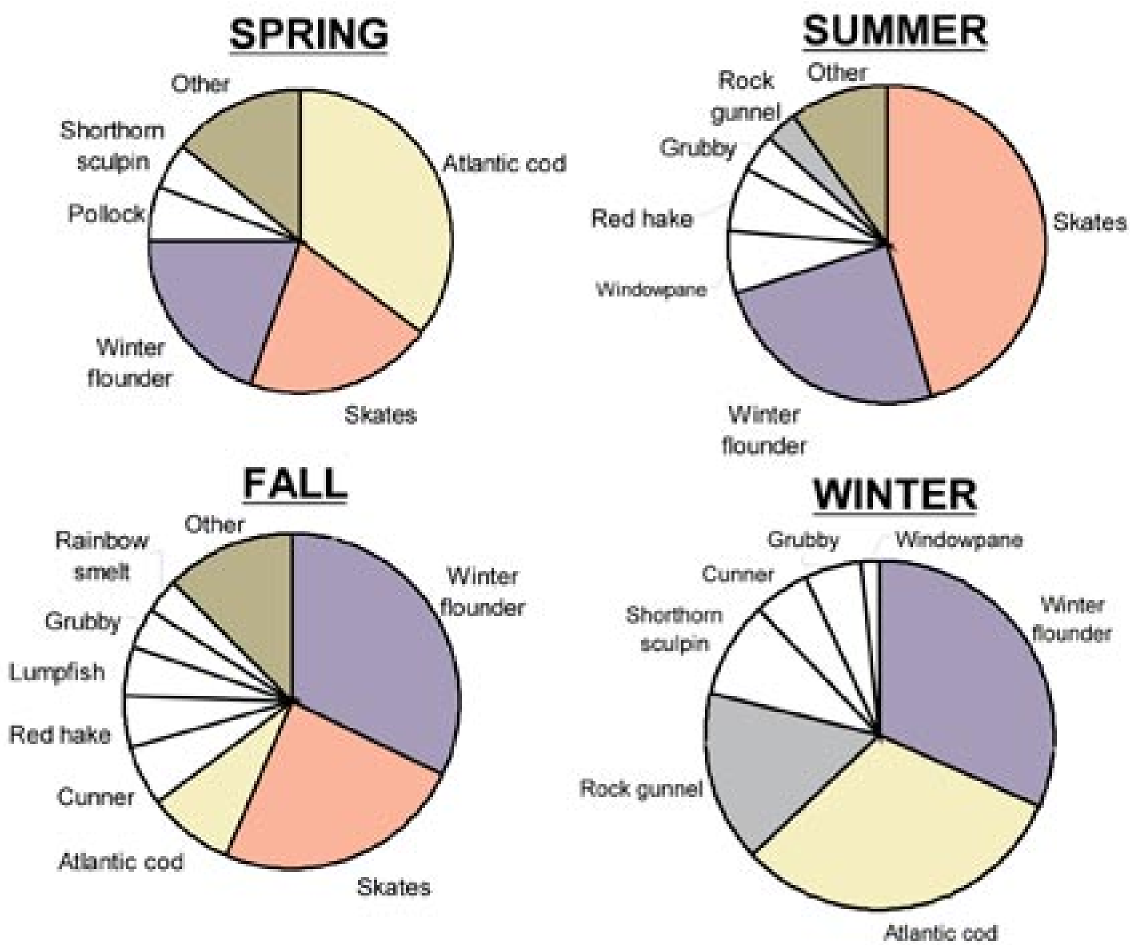


FIGURE 4.5 Seasonal percent composition (%) of fishes (otter trawl stations combined; CPUE by number).

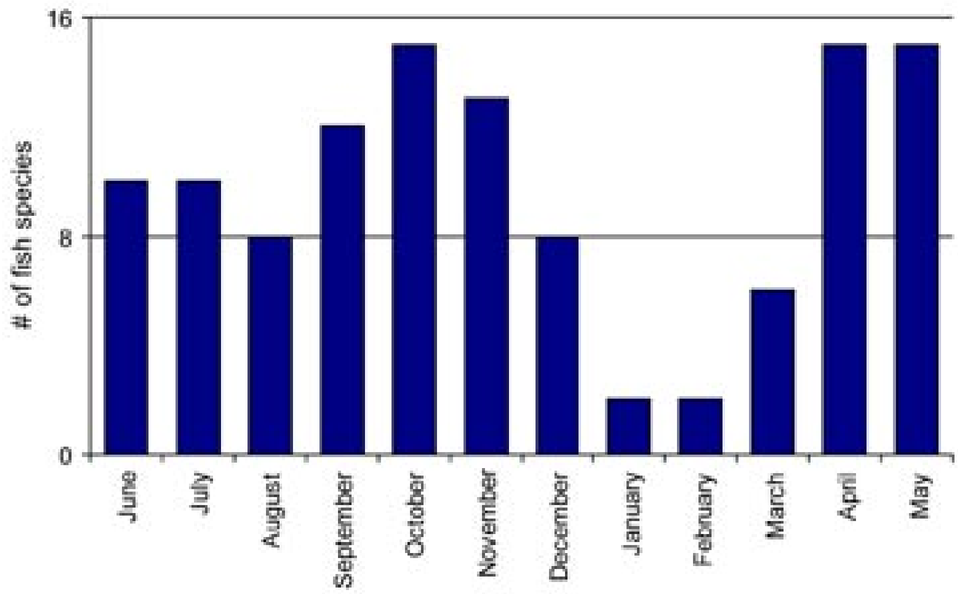


FIGURE 4.6 Monthly total fish species richness (# of species) in Gloucester Harbor from June 1998 to May 1999 (trawl stations combined).

There was significant seasonal variability in the total relative abundance of fishes (Kruskal-Wallis, $p<0.001$). Spring collections (mean CPUE ± SE; 31.0 ± 10.4 CPUE) were greater than summer (9.4 ± 1.3 CPUE; Mann-Whitney, $p<0.0125$) and winter (4.8 ± 1.6 CPUE; Mann-Whitney, $p<0.001$) but not different than fall (16.6 ± 3.3 CPUE; Mann-Whitney, $p=0.3$). The greatest variance (based on SE) of CPUE was observed during spring. Summer catches did not differ from winter (Mann-Whitney, $p=0.02$), but fall CPUE was greater than winter (Mann-Whitney, $p<0.0125$).

There were notable monthly fluctuations in relative abundance, and seasonal relative abundance was often influenced by large catches within a particular month (Appendix 4.1-4.2d). April (34.8 ± 6.8 CPUE) and May (46.5 ± 25.1 CPUE) presented the highest monthly catches, contributing to the spring relative abundance. Winter had low relative abundance with the lowest catches in January (3.2 ± 1.4 CPUE) and February (0.8 ± 1.4 CPUE). Fall abundance was influenced by October (19.3 ± 3.5 CPUE) and November (20.8 ± 10.2 CPUE) samples.

The seine collections were dominated by relatively large catches of Atlantic silverside in September (total catch by number = 162) and early October (301). Atlantic silverside contributed 77% of total seine catch by number. A relatively large catch of lumpfish occurred in early September (37 fish at HM). The lumpfish were associated with beach wrack (personal observation). Seine catches (# of fish/haul) were consistently low throughout the study (Appendix 4.3-4.4d). Low catches ranged from 1.3 to 3.4 fish per haul (June-August 1998) and 0 to 1 fish per haul (November 1998-May 1999), and catches peaked in September (26.8 ± 12.7 fish/haul) and October (41.2 ± 35.7 fish/haul). American sand lance, Atlantic menhaden, bay anchovy, bluefish, mummichog, northern puffer, and threespine stickleback were species collected by the seine and not trawl sampling (Table 4.4).

Temporal frequency (# of months present) was determined using trawl and seine data (Table 4.4). Atlantic silverside, cunner, grubby, rock gunnel, skates, windowpane, and winter flounder were collected at a minimum of one station during 75% (or greater) of the months. Atlantic cod, lumpfish, northern pipefish, rainbow smelt, red hake, and shorthorn sculpin were found during 50% (or greater) of the months. Other demersal fishes (e.g., longhorn sculpin, sea raven, and ocean pout) and several schooling (e.g., Atlantic menhaden) and anadromous fishes, such as rainbow smelt and blueback herring, were infrequently collected but were important seasonal components of the fish assemblage.

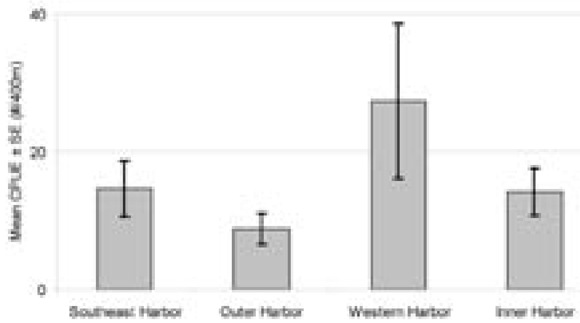


FIGURE 4.7 Otter trawl station total (species combined) annual CPUE (SE) mean (#/400m).

Station Community Assessment

Relative abundance, species richness, and composition were variable between otter trawl stations. The greatest total mean CPUE was found at WH (27.3 ± 11.2 CPUE), but was not significantly higher than SEH (14.7 ± 4.1 CPUE), IH (14.1 ± 3.4 CPUE), and OH (8.8 ± 2.2 CPUE) (Kruskal-Wallis; p=0.05) (Figure 4.7). Station total mean CPUE was frequently affected by relatively large individual catches (Appendix 4.2a-4.2d). The WH mean was particularly influenced by a large catch of young-of-year (YOY) Atlantic cod (151.0 CPUE) on 12 May 1999.

Seasonal characteristics of relative abundance varied among trawl stations (Figure 4.8; Appendix 4.2a-4.2d). Seasonal relative abundance was greatest in spring at SEH (31.9 ± 11.7 CPUE) and WH (60.5 ± 38.7 CPUE). Large catches of YOY Atlantic cod affected the spring CPUE at WH and SEH. OH (16.2 ± 6.9 CPUE) and IH (23.7 ± 10.2 CPUE) illustrated highest relative abundance during the fall. The IH collections in the fall were predominantly comprised of winter flounder (48.0% of fall CPUE). Summer and winter collections did not substantially vary among stations.

Species richness (total # of species per sample period) did not differ among otter trawl stations (Kruskal-Wallis; p>0.05). Species richness (mean richness ± SE) was 4.9 ± 0.6 species at WH, 4.1 ± 0.6 species at SEH, 4.1 ± 0.7 species at IH, and 3.4 ± 0.5 species at OH.

Skates, winter flounder, and Atlantic cod were dominant components of catch composition at each trawl station but composition varied (Figure 4.9). SEH

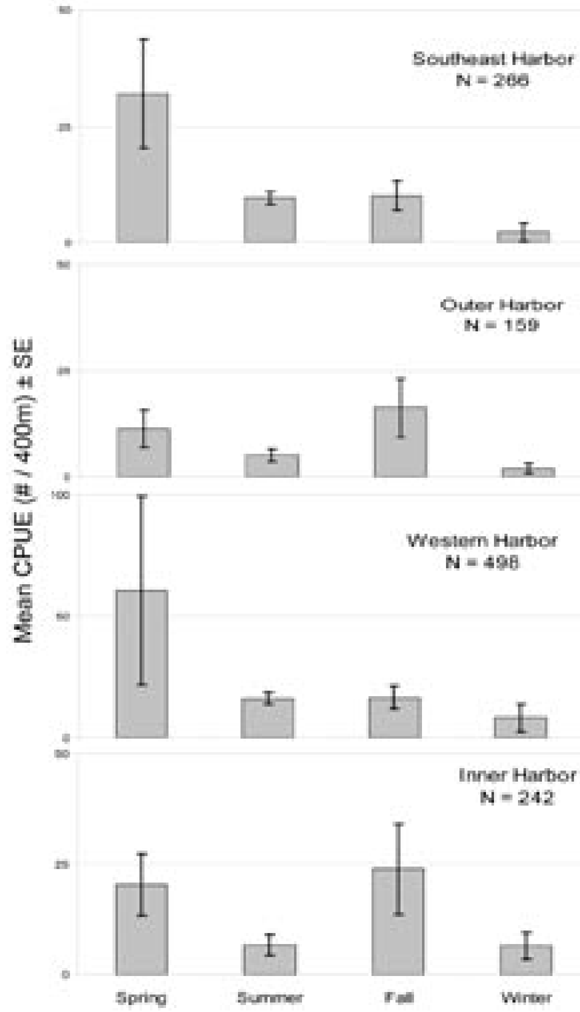


FIGURE 4.8 Seasonal abundance of fishes (CPUE mean ± SE) at otter trawl stations. N=total number of fishes collected. Note different scale at Western Harbor.

total catch was comprised of winter flounder (22.5%), skate species (21.4%), and less common species, including Atlantic cod (15.2%), rock gunnel (9.8%), and pollock (9.5%). Winter flounder accounted for 35.7% of the OH total catch with notable catches of Atlantic cod (19.5%), skate species (10.1%), cunner (8.2%), and longhorn sculpin (3.2%). WH community consisted of Atlantic cod (35.2%), skates (32.4%), and winter flounder (16.4%). Winter flounder (33.4%) and skates (23.1%) dominated IH composition, and Atlantic cod (7.3%), grubby (5.4%), shorthorn sculpin (4.4%), windowpane (4.1%), and rainbow smelt (4.1%) contributed smaller portions to the catch.

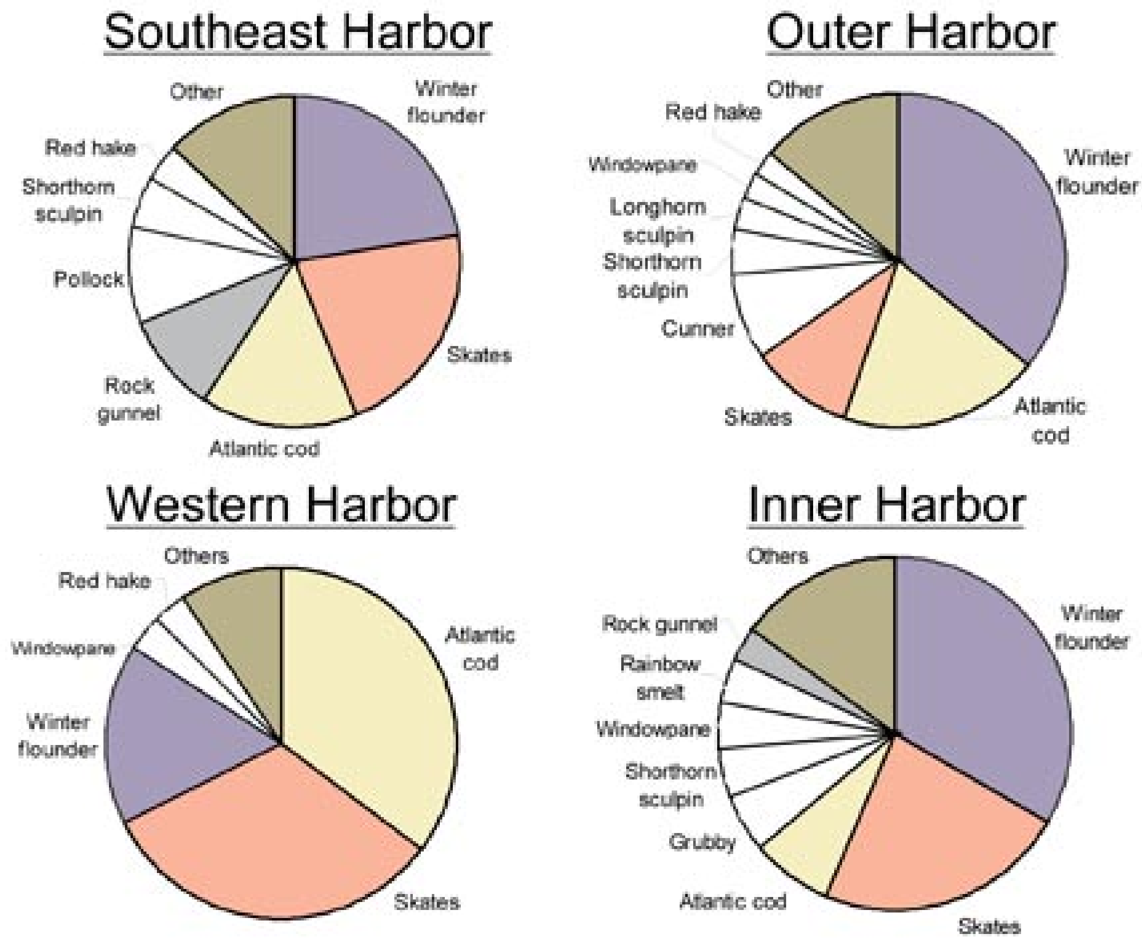


FIGURE 4.9 Trawl station fish composition (% of total CPUE; by number) in Gloucester Harbor, June 1998 to May 1999.

Seasonal Abundance of Common Species

Seasonal occurrence and relative abundance of common fishes was illustrated by total CPUE per sample period (Figure 4.10). Skates were abundant in the spring, summer, and fall, and were absent in the winter. Winter flounder were abundant throughout the year, peaking in October-November 1998 and April and early-May 1999. Windowpane presented two peaks in abundance (9 July 1998 and 12 May 1999). Pollock were collected in spring 1999 (April and May). Atlantic cod were found in summer (25 June and 19 August) and fall (October and November) of 1998 and at a substantially higher relative abundance from March-May 1999. Rock gunnel were encountered during most of the study, with two peak periods of abundance from September-November 1998 and March-May 1999. Shorthorn sculpin were relatively abundant during spring 1999 (March-May 1999). Red hake were present throughout the study, except during the winter (January-March 1999), peaking in June-July and October-November 1998. Cunner were abundant during October-November 1999 and 12 May 1999.

Atlantic Cod, Winter Flounder, and Skate Species Length Distribution

Atlantic cod collected were YOY, ranging from 24 mm TL to 125 mm TL (Figure 4.11). The 1998 YOY cod were collected in June, August, October, and November 1998. The 1999 year class recruited to the harbor in March 1999 and remained through May 1999. Analysis of length illustrated that cod recruited to the harbor around the period of settlement (~25-50 mm TL; Fahay et al. 1999), and modal progression of length provided evidence of growth (Figure 4.12). Cod size distribution and mean size

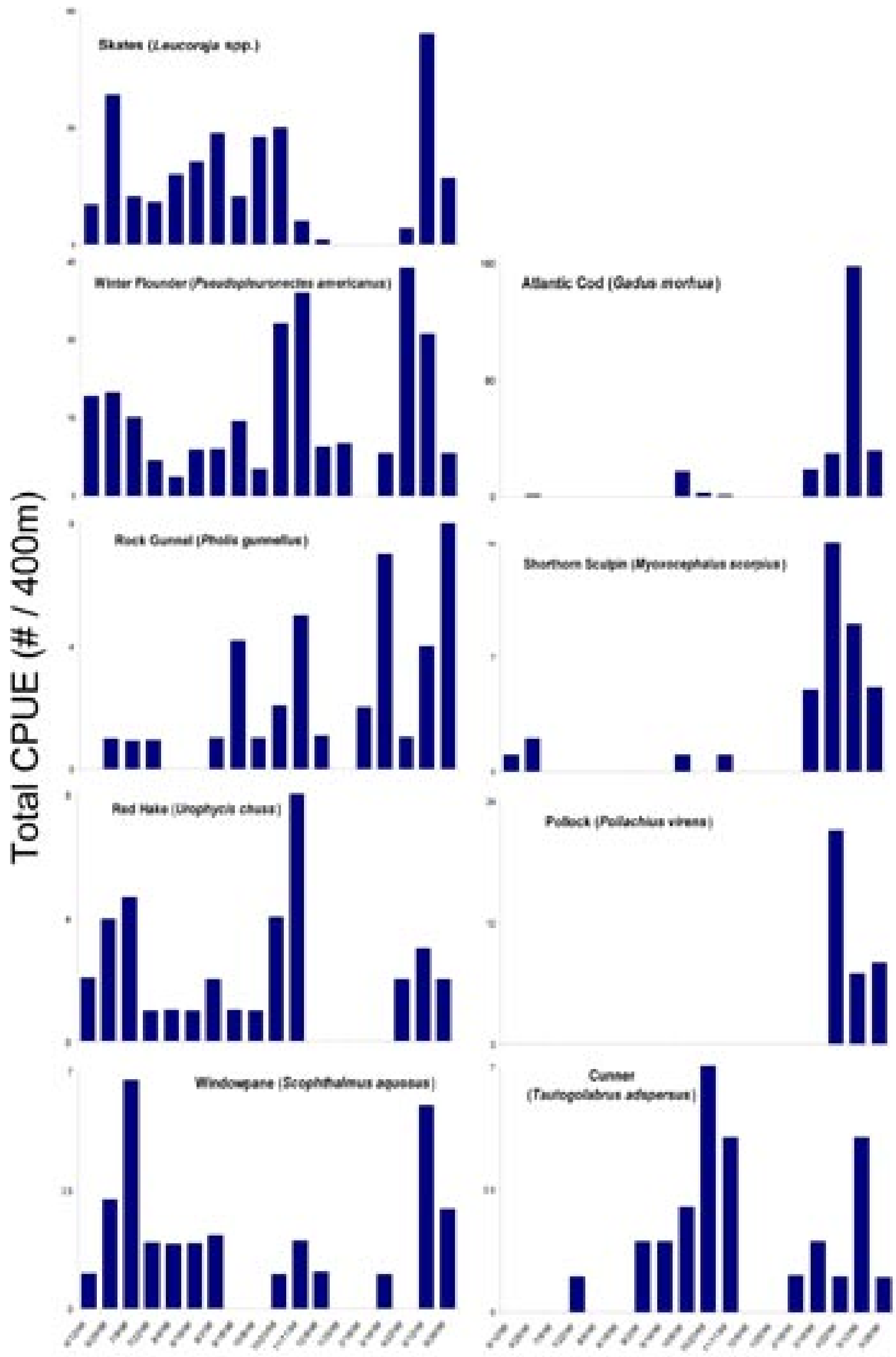


FIGURE 4.10 Total catch per unit effort (sum CPUE - #/400m) for Gloucester Harbor otter trawl stations combined of common fish species, June 1998 to May 1999. Note different scales.

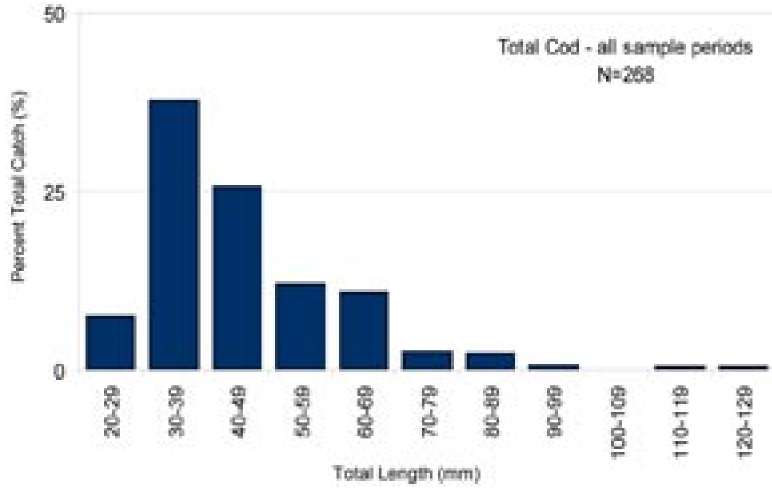


FIGURE 4.11 Composite length frequency of total collection of Atlantic cod (*Gadus morhua*) in Gloucester Harbor. N=total number of cod.

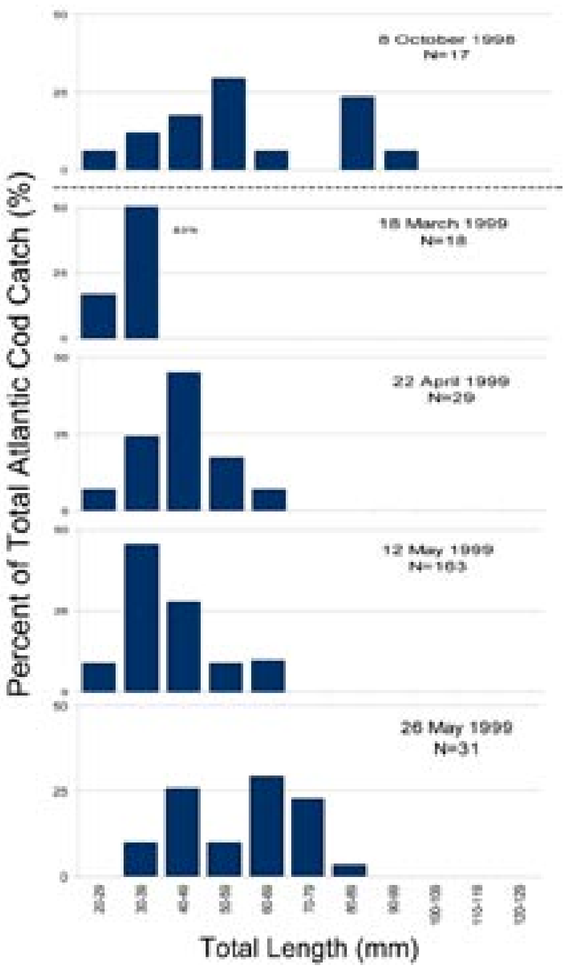


FIGURE 4.12 Sample period length frequency of Atlantic cod, 8 October 1998 and 18 March to 26 May 1999. N=number of cod collected. Cod were collected at low numbers (<5) in June, August, 23 October, and November 1998 (data not shown).

TABLE 4.5 Date and mean (SE) total length (TL) of Atlantic cod collected in Gloucester Harbor in 8 October 1998 and March to May 1999. Length data not shown for small catches in June, August, 23 October, and November 1998.

	Total Length		
Date	Mean	Minimum	Maximum
8-Oct	59.1 (5.2)	25	90
18-Mar	32.5 (0.7)	24	36
22-Apr	42.8 (1.8)	24	66
12-May	40.7 (0.8)	24	67
26-May	57.6 (2.6)	36	80

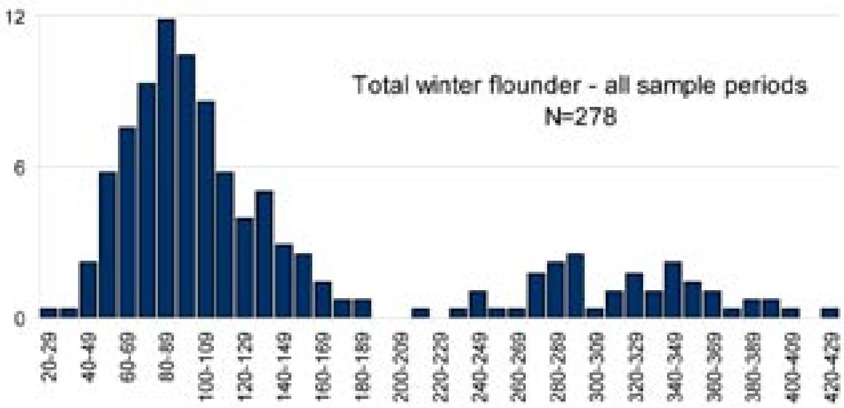


FIGURE 4.13 Composite length frequency of total winter flounder (*Pseudopleuronectes americanus*) in Gloucester Harbor; trawl samples. N=total number of winter flounder collected during the study.

increased from March to May 1999 (Table 4.5). Mean length observed in October 1998 and 26 May 1999 were similar.

YOY, age 1 (yearling), and older winter flounder were found in the harbor, and there was considerable overlap in age class (Howe personal communication; Able and Fahay 1998) (Figure 4.13). YOY and age 1 fish (25 mm to ~ 160 mm TL) were present throughout the study. Multiple year classes, including age two fish and older (220 mm to 425 mm TL; age 2 to 5), age 1 fish (1997 year class; 60 mm to ~140 mm TL), and YOY (1998 year class; < 50 mm TL) were collected from June 1998 to October 1998 and May 1999 (Appendix 4.5). YOY winter flounder were first collected in August 1998 (25 mm to 50 mm TL) and apparently remained in the harbor. During June to November 1998, yearlings (1997 year class; 60 mm to ~180 mm TL) were mostly collected. Relatively low abundance was seen in December 1998-March 1999. Winter flounder collected during this period appeared to be a mix of YOY and age 1 fish (43 mm to 129 mm TL; average length = 79.1 mm TL). Catches increased during April to May 1999 and were mainly 1998 YOY. Larger individuals were also collected in May 1999.

Skate length ranged from 115 mm TL to 595 mm TL (mean TL ± SE = 437.9 ± 5.1). Chase et al. (2002) identified a subset of skates (*Leucoraja* spp.) collected in Salem Sound to species and indicated the majority of skates were little skate (*Leucoraja erinacea*). Based on the Chase et al. (2002) study, similarity in embayments with respect to geographic location and

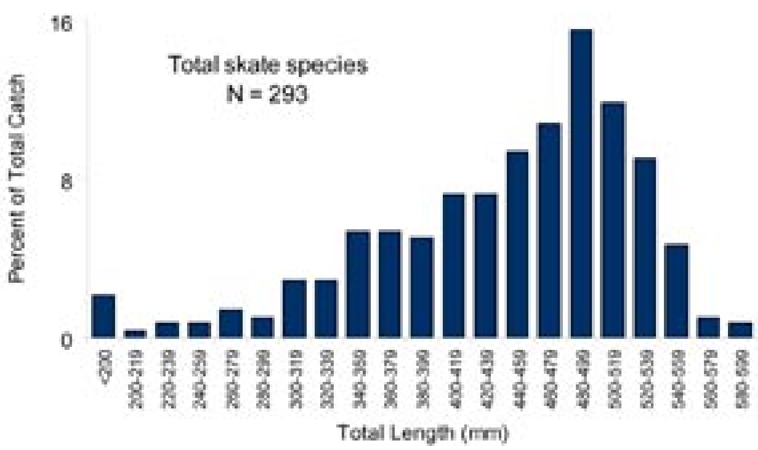


FIGURE 4.14 Composite length frequency of total skates (*Leucoraja* spp.) collected in Gloucester Harbor. N=total number of skates collected during the study.

TABLE 4.6 Fishes collected at Southeast Harbor and Outer Harbor trawl stations during 1966 - 1967[a] (Jerome et al. 1969) and 1998 - 1999 surveys.

Common Name	Scientific Name	1966-1967[a]	1998-1999
Atlantic cod	*Gadus morhua*	X	X
Atlantic tomcod	*Microgadus tomcod*	X	
Blueback herring	*Alosa aestivalis*		X
Cunner	*Tautogolabrus adspersus*	X	X
Grubby	*Myoxocephalus aenaeus*		X
Longhorn sculpin	*Myoxocephalus octodecemspinosus*		X
Lumpfish	*Cyclopterus lumpus*	X	X
Northern pipefish	*Syngnathus fuscus*		X
Ocean pout	*Macrozoarces americanus*		X
Pollock	*Pollachius virens*	X	X
Rainbow smelt	*Osmerus mordax*	X	X
Red hake	*Urophycis chuss*		X
Rock gunnel	*Pholis gunnelus*		X
Sea raven	*Hemitripterus americanus*	X	X
Seasnail	*Liparis spp.*	X	X
Shorthorn sculpin	*Myoxocephalus scorpius*		X
Skates	*Leucoraja spp.*		X
White hake	*Urophycis tenuis*		X
Windowpane	*Scophthalmus aquosus*		X
Winter flounder	*Pseudopleuronectes americanus*	X	X
Yellowtail flounder	*Limanda ferruginea*	X	
	Total Species =	10	19

[a]Stations identified as Niles Beach and Southeast Harbor in 1966 - 1967 were approximately located at the 1998 - 1999 Southeast Harbor and Outer Harbor stations, respectively.

habitat, and life history reviews (Packer et al. 2000a; Packer et al. 2000b), skates collected during this survey were presumably little skate. Little skate life history information was used for the skate length results and discussion.

The majority of skates collected were juvenile (sexually immature; < 500 mm TL) (Figure 4.14). Skates were largely found in the range of 340 mm TL to 540 mm TL with a few smaller (YOY and 1 year skates < 200 mm TL) and larger (> 540 mm TL; age 5 and older). Skates were substantially larger, demonstrated by length and biomass, than other fishes collected during the survey.

Discussion

This study described the fish community in Gloucester Harbor during 1998-1999, and was the first assessment of fishes since 1966-1967 (Jerome et al. 1969). Environmental conditions and quality, fish populations and human influences changed during the past 30 years. This study cannot directly evaluate the effect of these changes on coastal fishes, and comparison of the 1998-1999 and 1966-1967 studies are qualitative (Table 4.6). The 1998-1999 study updated findings from 1966-1967 (Jerome et al. 1969) and provided baseline data for future studies and monitoring.

Water Temperature & Seasonal Classification

Large-scale oceanographic attributes, including water temperature, salinity, and depth, influence the relative abundance, distribution, and composition of fishes (e.g., Oviatt and Nixon 1973; Colvocoresses and Musick 1984; Gabriel 1992). These attributes and processes seasonally fluctuate and demonstrate interannual and intraannual variation. Resource management strategies, such as seasonal restrictions applied to coastal alteration projects, and monitoring programs (e.g., environmental assessment) frequently attempt to predict the variation in environmental attributes to achieve and optimize program objectives. Data used to inform management and monitoring decisions are often aged or absent and require validation. This study investigated approaches to identify ecologically appropriate and distinct seasons based on the combination of biotic and water temperature characteristics in Gloucester Harbor to characterize and explain—in part—the temporal variation of fish assemblages from June 1998 to May 1999.

Water temperature showed a typical seasonal cycle with peak temperature in late summer to lowest temperature in winter. Higher spring and summer water temperatures at beach seine sites compared to deep water trawl stations were predictable given the capacity of shallow water to warming. Water temperature did not differ between trawl stations, but data suggested episodic occurrence of warmer temperature at IH and WH during summer and early fall. Reduced tidal flushing in the inner harbor, occurring from meteorological events (e.g., southwest winds) and the semi-enclosed geography and manmade structures that limit tidal exchange, can affect water temperature. WH temperature was potentially influenced by daily tidal activities and water flow from the Annisquam River. Outer harbor water temperature, including SEH and OH stations, may be dominated by tidal flushing with waters outside of Gloucester Harbor (i.e., Massachusetts Bay).

Water temperature generally affected fish community structure, and periods of the warmest (summer) and coolest (winter) water temperature presented relatively stable water temperature and fish assemblage characteristics (Figure 4.2). Fall and spring were more complex, showing prominent temperature and fish assemblage change. The winter-spring transition was clouded because of similar features (water temperature and fish assemblage) observed in March and April, but fish community attributes, including the presence and relative abundance of juvenile fishes (i.e., Atlantic cod, pollock, and shorthorn sculpin) and species richness, facilitated the spring designation. This transition may be an ecologically important period. The seasons were effectively used to group data, investigate temporal variation, and describe fish community structure, and they corresponded to other Gulf of Maine studies (Ayvazian et al. 1992; Lazzari et al. 1999). Multiple-year surveys are needed to rigorously assess temporal trends, including interannual and intraannual variation; therefore, season identification and discussion were limited in this study by the lack of interannual comparisons.

Understanding long- and short-term seasonal variability is tantamount to effective resource management and monitoring. For example, this study showed the change in the relative abundance and size of juvenile cod species through one year, suggesting that nearshore Gulf of Maine waters are especially important for juvenile cods in late winter to early spring. Increased frequency of fish sampling from early March to June may further characterize the importance of nearshore environments to the survivorship and growth of Atlantic cod and pollock. Targeted experiments and long-term monitoring may improve the understanding of seasonal fluctuation of biotic and abiotic qualities, and provide data to support, justify and improve seasonal management strategies (i.e., environmental windows).

Fish Community

The composition of fishes in Gloucester Harbor consisted of a high proportion of resident species and seasonal peaks in relative abundance of transient species, which is characteristic of boreal fish community structure (Ayvazian et al. 1992). Resident species were found at varying relative abundance throughout the study. Transients included marine and anadromous fishes and largely contributed to the total catch. Catches were principally comprised of demersal juvenile fishes that are effectively collected with the otter trawl used in this study (i.e., small otter trawls potentially underestimate larger, older individuals and pelagic species that avoid the sample gear). Skates, winter flounder, and Atlantic cod were dominant taxa in each season. These species were also the three most abundant species in a recent Salem Sound study (Chase et al. 2002). Relative abundance (CPUE) and species richness were highest in the spring and fall. This observation differs from Salem Sound findings of the highest relative abundance and richness in warmer summer and fall months (Chase et al. 2002). The variability between Salem Sound and Gloucester was probably the result of interannual variation or unidentified differences in habitat condition.

Jerome et al. (1969) studied fishes of the Annisquam River and Gloucester Harbor, and sampling stations included salt marsh and harbor habitats. The current study exclusively focused on harbor waters. The SEH and OH trawl stations were sampled during both studies (or were approximately located in similar areas of the harbor). These stations allowed qualitative comparison between fish community attributes described in 1966-1967 and 1998-1999 (Table 4.6; Jerome et al. 1969).

Total species richness and species presence showed notable differences between the two studies, with more fish species collected in 1998-1999 (19 species) than in 1966-1967 (10 species). Winter flounder and Atlantic cod represented major parts of the catch during the 1966-1967 and 1998-1999. Skates were not collected at the analogous trawl stations during 1966-1967, but skates were a dominant component (i.e., relative abundance and biomass) in 1998-1999. Skates were a minor contributor to collections at a 1966-1967 trawl station located south of the harbor (outside Dog Bar Breakwater). No yellowtail flounder were collected in 1998-1999 and were the third most abundant (by number) species in 1966-1967. Commercially exploited species, including ocean pout, red hake, white hake, and windowpane, and species not targeted for harvest (i.e., grubby, longhorn sculpin, northern pipefish, rock gunnel, and shorthorn sculpin) were present in 1998-1999 but not 1966-1967 (Table 4.6).

Species richness and presence observed in this study and recent Massachusetts Bay surveys (Chase et al. 2002; Buchsbaum et al. 2003) differed from historic studies (e.g., Jerome et al. 1969), which suggests a shift in the demersal fish community structure from the 1960s to the late 1990s. Changes have been reported in other New England estuaries (i.e., diminished flounder distribution and abundance and an increased proportion of pelagic species in the fish community; Jeffries and Terceiro 1985; Meng and Powell 1999; Hughes et al. 2002b; Wyda et al. 2002), and oceanic systems (i.e., replacement of cod and flounder species by dogfish sharks and skates; Fogarty and Murawski 1998). Differences between recent and historic studies may be due to different survey methodology, natural population fluctuation, or anthropogenic perturbation (e.g., commercial exploitation, indirect effects of fishing and habitat degradation), but repeated results provide strong indication of a change in the fish community. The cause for faunal change is not known. Large-scale environmental variation, such as water temperature, will influence catches (Jeffries and Terceiro 1985) and the seasonal distribution and presence of species. Discussion of possible shifts in relative abundance and composition of fishes warrants attention, and detailed examination of long-term datasets and continued monitoring of coastal fishes in the Gulf of Maine are necessary for elucidating status and trends.

Recent studies offered an opportunity to discuss fish community attributes observed in other Gulf of Maine nearshore systems. Chase et al. (2002) found 43 species, counting otter trawl (35 species) and seine (23 species) samples, in Salem Sound, Massachusetts. Discrete habitats were surveyed in Salem that were not investigated in Gloucester (i.e., eelgrass and tidal riverine habitats). Thirty-three species were found in Plum Island Sound, Massachusetts (Buchsbaum et al. 2003). Plum Island Sound contains extensive salt marsh habitats, and fishes were sampled using a beach seine and otter trawl. Kennebec and Wells Harbor, Maine, studies collected 27 and 24 fish species, respectively (Lazzari et al. 1999; Ayvazian et al. 1992). The Kennebec study used a fyke net to sample salt pond habitat and a beach seine to sample sandy beach habitat. Beach seine and otter trawls were used to collect fishes in intertidal and subtidal habitats (e.g., salt marsh, mudflat, and sandy beach) in Wells Harbor.

Twenty-nine fishes were collected in Gloucester Harbor, sharing species with the other boreal embayments of the Gulf of Maine (Ayvazian et al. 1992; Lazzari et al. 1999; Chase et al. 2002; Buchsbaum et al. 2003), a boreal-temperate mixed estuary of Cape Cod (Heck et al. 1989), and southern New England systems, such as Buzzards Bay (Wyda et al. 2002) and Narragansett Bay (Oviatt and Nixon 1973; Meng and Powell 1999). Similar species observed in southern New England waters and Gloucester Harbor were fishes with broad geographic range that overlap temperate and boreal environments, such as Atlantic silverside, cunner, mummichog, northern pipefish, red hake, threespine stickleback, and winter flounder, and fishes (e.g., sculpin species and lumpfish) that range from the northern portion of the Virginian zoogeographic province (i.e., New Jersey) northward through the Gulf of Maine (Bigelow and Schroeder 1953; Murdy et al. 1997).

Taxa were more similar among Gulf of Maine embayments that contained similar habitat features. Mummichog, Atlantic silverside, and stickleback species were dominant from samples in or near salt marsh habitat (Ayvazian et al. 1992; Lazzari et al. 1999; Buchsbaum et al. 2003). Winter flounder, skates, and Atlantic cod were the three most abundant species in Salem Sound (Chase et al. 2002) and Gloucester Harbor. Trawl stations sampled within Salem Sound and Gloucester Harbor were characterized by an unconsolidated soft sediment benthic environment, and the shoreline includes highly developed coast, sandy beaches, and exposed, rocky coast. Gloucester Harbor and Salem Sound are marine systems with areas of deep water and relatively little freshwater input; while systems with salt marsh habitat are generally located in regions with shallow water and comparably more freshwater flow.

This does not suggest that the urban qualities of Salem Sound and Gloucester Harbor are more or less productive than salt marsh systems, but does suggest that habitat features and functions in these areas are substantially different and support different species assemblages than the identified Gulf of Maine environments (Ayvazian et al. 1992; Lazzari et al. 1999; Buchsbaum et al. 2003). Species richness should be cautiously evaluated between studies because of the confounding factors, including methodology (e.g., sample periods, gear efficiency, and catch stability) and habitat type, extent, and condition, which influence fish species presence. The Gulf of Maine studies, in combination, elucidated the regional diversity of fishes inhabiting nearshore environments.

Nursery Habitat

A relatively diverse assemblage of early life stages of fishes were collected during this study and supported Jerome et al. (1969) observations of juvenile fish presence. Environmental requirements of early juvenile phases of fish and the relative importance of nearshore and offshore habitat conditions to early ontogenetic development is an important aspect of Gulf of Maine fish ecology. Processes that mediate survivorship and growth are especially important to fishes during their first year (Able and Fahay 1998). The understanding of environmental conditions necessary before and after settlement to the seafloor is well developed for tropical and temperate fishes (reviewed by Able and Fahay 1998), and the value of coastal waters to juvenile development is generally accepted (Hoss and Thayer 1993). This concept is not thoroughly described for Gulf of Maine waters.

Gloucester Harbor has experienced extensive urbanization and shoreline development along the inner harbor and development within the watershed during the past three centuries. Harbor waters were traditionally used for waste disposal (industrial and sewage), areas of the inner harbor contain contaminated seafloor sediments, navigation channels support active maritime industries, and contemporary inputs (e.g., urban and residential run-off) influence environmental quality. Despite the magnitude and extent of change to the natural environment, Gloucester Harbor contains nursery habitat. The persistence of important nursery habitats supported findings from other urban harbors, including Salem Sound (Chase et al. 2002), New Bedford Harbor (Wilbur et al. 1999; Geoghegan and Wilbur 2003), Providence River (Meng et al. 2002), and New York Harbor (Able et al. 1998 and 1999). The presence of resident species, including commercially exploited winter flounder and windowpane and non-target species (e.g., cunner, lumpfish, and rock gunnel), and the seasonal recruitment of marine YOY fishes (e.g., Atlantic cod, pollock, red hake and shorthorn sculpin) demonstrated the use of Gloucester Harbor as nursery habitat.

Habitat Relationships of Atlantic Cod, Winter Flounder, and Skate Species

Coastal waters, containing eelgrass beds and rocky bottom, and offshore shoal areas (e.g., northeast peak of Georges Bank) are important to Atlantic cod during their first year (Bigelow and Schroeder 1953; Fahay et al. 1999; Collette and Klein-MacPhee 2002). However, habitat requirements for recently settled cod are relatively unknown (Fahay et al. 1999). Howe et al. (2000b) described the importance of Massachusetts Bay coastal waters to YOY and age 1 cod, but the study did not include sampling within nearshore embayments and harbors. All Atlantic cod collected in this study were YOY, and many were newly settled juveniles (i.e., ~25-50 mm TL). Early life history stages tend not to migrate far from spawning locations (Fahay et al. 1999), suggesting Gloucester was in close proximity to spawning areas of the western Gulf of Maine. This study supported observations of high densities of juvenile cod inhabiting Massachusetts Bay and off Cape Ann (Fahay et al. 1999; Howe et al. 2000b). The modal progression of monthly length frequency from March to May 1999 provided evidence of growth and indicated the importance of harbor waters to early ontogeny. An interesting observation was the co-occurrence of YOY pollock with samples containing cod in April and May 1999.

Atlantic cod were collected within a range of unconsolidated soft mud to sand sediments (NAI 1999a; Valente et al. 1999; USGS 2000; SAIC 2001) and water temperature from 2.9°C (mid-March) to 12.5°C (early October 1998). The largest catches occurred from 4.6°C to 9.3°C (May 1999). The observation of YOY cod in October 1998 and spring 1999 indicated an extended spawning period through the summer or two distinct spawning episodes during the study, and supported and improved the Howe et al. (2000b) description of the value of shallow Gulf of Maine waters, including harbors, to juvenile cod.

Coastal waters are used by all life stages of winter flounder and are particularly valuable to spawning and early life history development (see review by Periera et al. 1998). Winter flounder collected were predominately YOY and age 1. Winter flounder were found all year (except February) at stations with unconsolidated mud and sand. Water temperatures ranged from 2.8°C (March 1999) to 16.5°C (early-September 1998), with peak abundance in late-October (10.5°C) to November (no temperature recorded) 1998 and April (4.7°C) to early-May (8.5°C) 1999. The highest catches were composed of young fish. The presence of YOY winter flounder and the non-dispersive behavior of eggs and larvae (Pereira et al. 1998) indicated that Gloucester Harbor was in the vicinity of spawning grounds and provided suitable nursery habitat. Larger winter flounder (>1 year) were seen in June-August 1998 and May 1999. Winter flounder remain common residents of nearshore waters despite diminished population levels (NMFS 1998).

Skates dominated the biomass of bottom-dwelling fishes and were the largest fish collected (i.e., >200 mm TL) throughout the study. Skates were observed at temperatures ranging from 4.6°C (26 May 1999) to 17.8°C (2 September 1998) and at stations with a range of unconsolidated soft mud and sand. Skate abundance (number and biomass) was relatively consistent from June to October 1998 and May 1999, with peak abundance in late-June 1998 (11.3°C) and mid-May 1999 (9.3°C). Skates apparently migrated offshore during winter. The abundance, size, and feeding habitats of skates (Packer et al. 2000a) suggested the skate complex could influence overall composition of the demersal fish and benthic community. Skates are carnivorous and feed on a range of benthic creatures, including fishes (review by Packer et al. 2000a). Direct predation or resource competition (e.g., competition for prey and habitat) may influence the composition and relative abundance of other demersal fishes. Effects of the proliferation of skate populations to other demersal fishes are unknown. Research is needed to determine the impact of skates to the seafloor community (including demersal fishes), predator-prey dynamics, niche overlap, and resource partitioning in coastal embayments.

Summary

Gloucester Harbor supported a relatively diverse fish assemblage, including economically and ecologically valuable species, and the occurrence and abundance of early life history stages of fishes indicated the presence of nursery habitat. The difference in species richness, species presence and relative abundance of common species between recent (Chase et al. 2002; Carey and Haley 2002; Buchsbaum et al. 2003) and historic studies (e.g., Jerome et al. 1969) suggested a shift in the demersal fish community of Massachusetts waters during the past several decades. This study cannot determine the cause of the shift. Long-term, systematic surveys and directed monitoring efforts are required to understand temporal and spatial trends of fish population or community fluctuation and results of human-induced perturbation to fishes and environmental functions. Offshore populations of commercially and recreationally important fish and crab species are evaluated by long-term stock assessments (NMFS 1998; Howe et al. 2000a), but human influences in these survey areas are mainly attributed to harvest (e.g., direct removal of species or physical habitat impact). Nearshore systems, including Gloucester Harbor, are influenced by many sources of natural and anthropogenic stress that potentially affect fish communities. It is unknown, given two targeted, short-term studies of fishes in Gloucester Harbor during the past 30 years, if or how environmental quality influences the productivity of fishes in Gloucester Harbor.

This study is the first characterization of the Gloucester Harbor fish community in more than 30 years; identifies seasonal and spatial features of relative abundance, composition, species richness, and life history characteristics of fishes for 1998-1999; indicates the importance of urban harbors to early life history stages of fishes; and improves the understanding of the nearshore fish community in Massachusetts waters. This study provides a basis for future research and monitoring questions regarding conditions that attract juvenile fishes to Gloucester Harbor; variation in environmental conditions among Massachusetts harbors, embayments, and offshore waters; and causal links between environmental quality and the growth and survivorship of fishes.

Acknowledgments

This study was a component of the Massachusetts Dredged Material Management Plan, supported by the Massachusetts Seaport Bond and the CZM Grant. Field work was completed by Normandeau Associates Incorporated (Paul Geoghegan, project manager), CZM, and DMF staff. DMF (Leigh Bridges and Vin Malkoski) and CZM (Deerin Babb-Brott, Anne Donovan, and Christian Krahforst) contributed to the study and reviewed early drafts of the manuscript. Robert Buchsbaum (Massachusetts Audubon Society), Brad Chase (DMF), and Michele Dionne (Wells National Estuarine Research Reserve) provided reviews that greatly improved the manuscript.

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, New Jersey.

Able, K.W., J.P. Manderson, and A.L. Studholme. 1998. The distribution of shallow water juvenile fishes in an urban estuary: The effects of manmade structures in the lower Hudson River. Estuaries 21(4B):731-744.

Able, K.W., J.P. Manderson, and A.L. Studholme. 1999. Habitat quality for shallow water fishes in an urban estuary: the effects of man-made structures on growth. Marine Ecology Progress Series 187:227-235.

Ayvazian, S.G., L.A. Deegan, and J.T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian zoogeographic provinces. Estuaries 15(3):368-383.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. First Ed., Fishery Bulletin of the Fish and Wildlife Service. Washington, DC.

Buchsbaum, R., T. Puriton, and B. Magnuson. 2003. The marine resources of the Parker River-Plum Island Sound Estuary: An update after 30 years. Published by Massachusetts Office of Coastal Zone Management. Boston, MA.

Carey, D.A. and N. Haley. 2002. Buzzards Bay Disposal Site Report: Massachusetts Division of Marine Fisheries Trawl Data Analysis. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Chase, B.C, J.H. Plouff, and W.M. Castonguay. 2002. The marine resources of Salem Sound, 1997. Massachusetts Division of Marine Fisheries Technical Report TR-6. Collette, B.B. and G. Klein-MacPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine, Third Edition. Smithsonian Institute Press. Washington, DC.

Colvocoresses, J.A. and J.A. Musick. 1984. Species associations and community composition of Middle Atlantic Bight continental shelf demersal fishes. Fishery Bulletin 82(2):295-313.

Deegan, L.A., J.T. Finn, S.G. Ayvazian, C.A. Ryder-Kieffer, and J. Buonaccorsi. 1997. Development and validation of an estuarine biotic integrity index. Estuaries 20(3):601-617.

Elliot, E.M. and D. Jimenez. 1981. Laboratory

Manual for the Identification of Ichthyoplankton from the Beverly-Salem Harbor Area. Massachusetts Division of Marine Fisheries.

Fahay, M.P. 1983. Guide to the early stages of marine fishes occurring in the western North Atlantic Ocean, Cape Hatteras to the southern Scotian Shelf. Journal of Northwest Atlantic Fishery Science 4:1-423.

Fahay, M, P.L. Berrien, D.L. Johnson, and W.W. Morse. 1999. Essential Fish Habitat Source Document: Atlantic cod, Gadus morhua, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-124.

Fogarty, M.J. and S.A. Murawski. 1998. Large-scale disturbance and structure of marine systems: Fishery impacts on Georges Bank. Ecological Applications 8(1) Supplement: S6-S22.

Gabriel, W.L. 1992. Persistence of demersal fish assemblages between Cape Hatteras and Nova Scotia, Northwest Atlantic. Journal of Northwest Atlantic Fishery Science 14:29-46.

Geoghegan, P. and A.R. Wilbur. 2003. Recruitment habitat, growth, and mortality of young-of-the-year scup (Stenotomus chrysops) in a Massachusetts urban estuary. New England Estuarine Research Society and Southern New England Chapter of American Fisheries Society Meeting, Fairhaven, Massachusetts. 8-10 May 2003.

Hardy, J.D. Jr. 1978. Development of Fishes of the Mid-Atlantic Bight. An Atlas of Egg, Larval and Juvenile Stages. Vol. II. Anguillidae through Syngnathidae. USFWS Biol. Serv. Program FWS/OBS-78/2. 458pp.

Heck, K.L., K.W. Able, M.P. Fahay, and C.T. Roman. 1989. Fishes and decapod crustaceans of Cape Cod eelgrass meadows: species composition, seasonal abundance patterns and comparison with unvegetated substrates. Estuaries 12(2):59-65.

Hoss, D.E. and G.W. Thayer. 1993. The importance of habitat to the early life history of estuarine dependent fishes. In Water Quality and the Early Life Stages of Fishes (L.A. Fuiman, ed.). American Fisheries Symposium 14:147-158.

Howe, A.B., T.P. Currier, S.J. Correia, and J.R. King. 2000a. Massachusetts Division of Marine Fisheries Resource Assessment Annual Report. 11 pp. + tables and figures.

Howe, A.B., S.J. Correia, T.P. Currier, J. King and R. Johnston. 2000b. Unpublished MS – Spatial distribution of age 0 and 1 Atlantic cod (Gadus morhua) of eastern Massachusetts coast, 1978-1999, relative to ‘Habitat Area of Particular Concern’. Massachusetts Division of Marine Fisheries, Pocasset, MA. 25 pp. + tables and figures.

Hughes, J.E., L.A. Deegan, M.J. Weaver, and J. Costa. 2002a. Regional application of an index of estuarine biotic integrity based on fish communities. Estuaries 25(2):250-263.

Hughes, J.E., L.A. Deegan, J.C. Wyda, M.J. Weaver, and A. Wright. 2002b. The effects of eelgrass habitat loss on estuarine fish communities of southern New England. Estuaries 25(2): 235-249.

Jeffries, H.P. and M. Terceiro. 1985. Cycle of changing abundances in the fishes of the Narragansett Bay area. Marine Ecology Progress Series 25: 239-244.

Jerome, W.C., A.P. Chesmore, and C.O. Anderson Jr. 1969. A study of the marine resources of the Annisquam River – Gloucester Harbor coastal system. Monograph Series Number 8. Division of Marine Fisheries, Boston, MA. 62 pp.

Johnson, D.L., W.W. Morse, P.L. Berrien, and J. Vitaliano. 1998. Essential Fish Habitat Source Document: Yellowtail flounder, Limanda ferruginea (Storer 1839), life history and habitat characteristics. National Marine Fisheries Service, Highlands, NJ. 28pp.

Kooken, V., C. Dunn, C. DelPapa, and R. Buchsbaum. 2000. Water Quality Assessment: Gloucester Harbor, North River, Salem/Peabody, Saugus River, Smallpox Brook, Salisbury. Prepared for Massachusetts Executive Office of Environmental Affairs, Boston, MA. 55pp.

Lazzari, M.A., S. Sherman, C.S. Brown, J. King, B.J. Joule, S.B. Chenoweth, and R.W. Langton. 1999. Seasonal and annual variations in abundance and species composition of two nearshore fish communities in Maine. Estuaries 22(3A):636-647.

Massachusetts Office of Coastal Zone Management (MCZM). 2001. Dredged Material Management Plan (DMMP) EOEA No. 11543. Draft Environmental Impact Report (DEIR) for Gloucester, Massachusetts. Prepared for Massachusetts Office of Coastal Zone Management and City of Gloucester, MA. Prepared by Maguire Group, Foxborough, MA.

Meng, L. and J.C. Powell. 1999. Linking juvenile fish and their habitats: An example from Narragansett Bay, Rhode Island. Estuaries 22(4): 905-916.

Meng, L., C.D. Orphanides, and J.C. Powell. 2002. Use of a fish index to assess habitat quality in Narragansett Bay, Rhode Island. Transactions of the American Fisheries Society 131:731-742.

Murdy, E.O., R.S. Birdsong, and J.A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press. Washington, DC.

National Marine Fisheries Service (NMFS). 1998. Status of Fishery Resources off the Northeastern United States for 1998. NOAA Technical Memorandum NMFS-NE-115. 149pp.

Normandeau Associates Incorporated (NAI). 1999a. Early benthic phase lobster survey for Gloucester. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 9pp.

Normandeau Associates Incorporated (NAI). 1999b. Dredged Material Management Plan fisheries resources survey for Gloucester. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 28pp.+append.

Normandeau Associates Incorporated (NAI). 1999c. Dredged Material Management Plan – Fisheries resources survey for New Bedford. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 28pp. + append.

Oviatt, C.A. and S.W. Nixon. 1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution and abundance. Estuarine and Coastal Marine Science 1:361-378.

Packer, D.B., C.A. Zetlin, and J.J. Vitaliano. 2000a. Essential Fish Habitat Source Documents: Little skate, Leucoraja erinacea, life history and habitat characteristics. National Marine Fisheries Service, Highlands, NJ.

Packer, D.B., C.A. Zetlin, and J.J. Vitaliano. 2000b. Essential Fish Habitat Source Documents: Winter skate, Leucoraja ocellata, life history and habitat characteristics. National Marine Fisheries Service, Highlands, NJ.

Pereira, J.J., R. Goldberg, and J.J. Ziskowski. 1998. Essential Fish Habitat Source Document: Winter flounder, Pseudopleuronectes americanus (Walbaum), life history and habitat characteristics. National Marine Fisheries Service, Milford CT.

Science Applications International Corporation (SAIC). 2001. Results of the March 2001 Subbottom profiling and sediment profile imaging survey of the outer Gloucester Harbor. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Sokal, R.R. and F.J. Rohlf. 1995 Biometry: The Principles and Practice of Statistics in Biological Research. Third Edition. W.H. Freeman and Company. New York, NY. 887pp.

United States Geological Survey (USGS). 2000. A Marine GIS Library for Massachusetts Bay: Focusing on disposal sites, contaminated sediments, and seafloor mapping. B. Butman and J. Lindsay (eds.). USGS Open-File Report 99-439.

Valente, R.M., M.C. Swanson, and C.L. Seidel. 1999. Dredged Material Management Plan: Habitat characterization of the DMMP candidate aquatic disposal sites. Prepared by Science Applications International Corporation, Newport, RI. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Wilbur, A.R., V.J. Malkoski, P. Geoghegan, and D. Babb-Brott. 1999. Distribution of juvenile fishes in New Bedford Harbor, Massachusetts: Human influences on benthic habitat characteristics. 15th Biennial International Conference, Estuarine Research Federation '99. New Orleans, Louisiana. September 25-30, 1999.

Wyda, J.C., L.A. Deegan, J.E. Hughes, and M.J. Weaver. 2002. The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the Mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay. Estuaries 25(1): 86-100.

Personal Communication

Malkoski, V.J. Personal Communication. Dredged Material Management Plan – Investigating Gloucester Harbor for wintering lobster. Massachusetts Division of Marine Fisheries, Pocasset, MA.

APPENDIX 4.1 Total fish CPUE (number/400m) for otter trawl stations combined (72 trawls) in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Skate spp.	10.1	38.3	12.2	10.8	17.8	21.2	28.4	12.1	27.5	29.8	6.0	1.0				4.1	54.0	17.0	290.1
Winter flounder	19.1	20.8	12.3	6.7	3.6	8.8	9.0	14.2	5.0	33.1	39.0	9.3	10.0		8.0	43.7	31.0	8.0	281.6
Atlantic cod		1.0				3.0			17.0	5.0	1.0				18.0	29.1	157.0	31.4	262.3
Red hake	2.0	4.0	4.7	3.8	1.0	1.0	2.0	2.0	2.0	4.0	8.0					2.0	3.0	2.0	41.4
Rock gunnel		1.0	0.9	0.9			1.0	4.2	1.0	2.1	5.0	1.1		2.0	7.0	1.0	4.0	8.0	39.1
Shorthorn sculpin	1.0	2.0							1.0		1.0				5.0	14.0	9.0	5.1	38.2
Pollock																21.1	7.0	8.0	36.1
Windowpane	1.0	3.2	6.7	2.0	1.9	1.9	2.2			1.0	2.0	1.1			1.0		6.0	2.9	32.9
Cunner				1.0			2.0	2.0	3.0	7.1	5.0			1.1	2.0	1.0	5.0	1.0	30.1
Grubby	2.1			1.9	1.8		1.1	4.2		5.1		5.3	3.0			1.0			25.4
Lumpfish							2.0	1.1		5.1	3.0	4.2							15.3
Rainbow smelt			0.9							1.0	4.0	4.3				4.0			14.3
Seasnail spp.						1.0										9.1	3.0	1.0	14.0
Longhorn sculpin							3.0	1.0	1.0		4.0	2.0					2.0		13.0
Northern pipefish							1.0		1.0	2.0	4.0					1.0			9.0
Sea raven		1.0							1.0								2.0	3.0	6.9
Radiated shanny		1.0														4.0			5.0
Ocean pout																2.9		1.0	3.9
Blueback herring					2.6														2.6
Butterfish							2.2												2.2
Atlantic silverside											1.0						1.0		2.0
White hake	1.0															1.0			2.0
Total	36.2	72.2	37.7	27.0	28.6	36.8	53.8	40.7	59.4	95.2	83.0	28.3	13.0	3.1	41.0	139.1	284.0	88.3	1167.3

APPENDIX 4.2a Total fish CPUE (number/400m) for Southeast Harbor (SEH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Winter flounder	2.1	5.9	4.9	0.9	1.7	2.9	6.0	5.0	4.0	5.0	2.0					8.0	4.0	7.0	59.4
Skate spp.	2.1	9.8	4.9		0.9	5.9	4.0	3.0	6.0	9.0	1.0						1.0	9.0	56.4
Atlantic cod																15.0		25.0	40.0
Rock gunnel		1.0		0.9			1.0		1.0		5.0			1.0	4.0		4.0	8.0	25.9
Pollock																17.0		8.0	25.0
Shorthorn sculpin									1.0							6.0	2.0	4.0	13.0
Red hake	1.0	2.0	1.0			1.0	1.0			1.0							1.0	2.0	9.9
Cunner									1.0		1.0				2.0	1.0			5.0
Grubby	2.1			1.9															3.9
Longhorn sculpin							2.0	1.0											3.0
Radiated shanny																3.0			3.0
Blueback herring					2.6														2.6
Windowpane	1.0					1.0													2.0
Sea raven		1.0																1.0	2.0
Lumpfish												1.0							1.0
Northern pipefish											1.0								1.0
Ocean pout																		1.0	1.0
Seasnail spp.																1.0			1.0
White Hake																1.0			1.0
Total	8.2	19.5	10.7	6.5	5.2	10.7	14.0	10.0	14.0	15.0	10.0	1.0	0.0	1.0	6.0	55.0	12.0	65.0	263.9

APPENDIX 4.2b Total fish CPUE (number/400m) for Outer Harbor (OH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Winter flounder	1.0	3.2	3.8	0.9	1.0	4.0	1.0	4.0		16.0		3.0				16.6	2.0		56.5
Atlantic cod						2.0			16.0	5.0					1.0	2.9	1.0	2.9	30.9
Skate spp.	1.0		1.0			1.0	1.0	4.0	1.0	6.0		1.0							16.0
Cunner							1.0	1.0	1.0	1.0	3.0						5.0	1.0	13.0
Shorthorn sculpin		1.1													2.0	2.0	2.0		7.0
Longhorn sculpin									1.0			2.0					2.0		5.0
Windowpane		1.1	1.9							1.0									4.0
Red hake			1.0							1.0	1.0						1.0		4.0
Grubby												1.0	2.0						3.0
Lumpfish							1.0			2.0									3.0
Seasnail spp.																	3.0		3.0
Sea raven									1.0									2.0	3.0
Ocean pout																2.9			2.9
Northern pipefish										2.0									2.0
Pollock																	2.0		2.0
Rock gunnel								1.0							1.0				2.0
Rainbow smelt																1.0			1.0
Total	2.0	5.4	7.6	0.9	1.0	7.0	4.0	10.0	20.0	34.0	4.0	7.0	2.0	0.0	4.0	25.4	18.0	5.9	158.1

APPENDIX 4.2c Total fish CPUE (number/400m) for Western Harbor (WH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic cod		1.0				1.0			1.0						15.0	4.0	151.0		172.9
Skate spp.	7.0	8.6	6.4	9.8	8.9	13.3	18.0	3.0	20.5	10.7	5.0					2.0	39.0	6.8	159.0
Winter flounder	16.0	8.6	3.6	4.9	0.9	1.9	2.0	1.0	1.0	4.9	3.0	2.0	5.0			14.0	11.0	1.0	80.7
Windowpane			2.7	2.0	0.9	1.0					1.0				1.0		5.0	2.9	16.4
Red hake		1.0	2.7	1.0			1.0	1.0	1.0	1.0	4.0					2.0	1.0		15.6
Shorthorn sculpin		1.0													1.0	3.0	2.0		7.0
Pollock																1.0	5.0		6.0
Cunner							1.0	1.0		2.0	1.0								5.0
Grubby					1.8			1.0		1.0			1.0						4.8
Northern pipefish							1.0		1.0		2.0								4.0
Lumpfish							1.0				1.0	1.0							3.0
Seasnail spp.																3.0			3.0
Rainbow smelt			0.9													2.0			2.9
Rock gunnel			0.9												2.0				2.9
Atlantic silverside											1.0						1.0		2.0
Longhorn sculpin							1.0				1.0								2.0
White Hake	1.0																		1.0
Radiated shanny		1.0																	1.0
Total	24.0	21.0	17.3	17.6	12.4	18.1	25.0	7.0	24.4	19.5	19.0	3.0	6.0	0.0	19.0	31.0	215.0	11.7	490.9

APPENDIX 4.2d Total fish CPUE (number/400m) for Inner Harbor (IH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Winter flounder		3.2						4.2		7.2	34.0	4.3	5.0		8.0	5.1	14.0		85.0
Skate spp.		20.0		1.0	8.0	1.0	5.4	2.1		4.1						2.1	14.0	1.1	58.8
Atlantic cod											1.0				2.0	7.2	5.0	3.4	18.6
Grubby							1.1	3.2		4.1		4.3				1.0			13.7
Shorthorn sculpin	1.0										1.0				2.0	3.1	3.0	1.1	11.2
Windowpane		2.1	2.1		1.0		2.2				1.0	1.1					1.0		10.5
Rainbow smelt										1.0	4.0	4.3				1.0			10.4
Rock gunnel								3.2		2.1		1.1		1.1		1.0			8.4
Lumpfish								1.1		3.1	2.0	2.2							8.3
Cunner				1.0					1.0	4.1				1.1					7.2
Red hake	1.0	1.1			1.0					1.0	3.0								7.1
Pollock																3.1			3.1
Longhorn sculpin											3.0								3.0
Butterfish							2.2												2.2
Seasnail spp.																2.1			2.1
Northern pipefish											1.0					1.0			2.0
Sea raven																	2.0		2.0
Radiated shanny																1.0			1.0
Total	2.0	26.3	2.1	2.0	10.0	1.0	10.8	13.7	1.0	26.7	50.0	17.3	5.0	2.1	12.0	27.7	39.0	5.7	254.4

APPENDIX 4.3 Sample period fish catch by number in Gloucester Harbor seine stations; all stations combined (71 hauls).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside					2.0	5.0	81.0	81.0	301.0			1.0		1.0	1.0	4.0		2.0	479.0
Lumpfish		1.0				1.0	37.0												39.0
Blueback herring		4.0	21.0																25.0
Atlantic menhaden							1.0		9.0	2.0									12.0
Grubby	9.0	1.0								1.0									11.0
Winter flounder		1.0					5.0	1.0	1.0	1.0		1.0					1.0		11.0
Northern pipefish		1.0	1.0					1.0	1.0	4.0									8.0
Mummichog					1.0				3.0		3.0								7.0
Red Hake	2.0	1.0	1.0				2.0		1.0										7.0
Rainbow smelt								2.0	3.0										5.0
Windowpane	1.0	2.0						1.0											4.0
Sand lance									2.0										2.0
Bay anchovy			1.0			1.0													2.0
Cunner	2.0																		2.0
3-spine stickleback	1.0																	1.0	2.0
Bluefish								1.0											1.0
Northern puffer							1.0												1.0
Pollock																	1.0		1.0
Rock gunnel	1.0																		1.0
Shorthorn sculpin																	1.0		1.0
Total	16.0	11.0	24.0	0.0	3.0	7.0	127.0	87.0	321.0	8.0	3.0	2.0	0.0	1.0	1.0	4.0	3.0	3.0	621.0

APPENDIX 4.4a Total fish catch (#/haul) for Pavilion Beach (PB) in Gloucester Harbor (17 hauls; no sample on 11 November 1998).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside							52.0		22.0			1.0				4.0		1.0	80.0
Windowpane	1.0	2.0						1.0											4.0
Mummichog									3.0										3.0
Red hake	2.0								1.0										3.0
Northern Pipefish								1.0	1.0										2.0
Winter flounder		1.0										1.0							2.0
Rainbow smelt									1.0										1.0
3-spine stickleback	1.0																		1.0
Total	**4.0**	**3.0**					**52.0**	**2.0**	**28.0**			**2.0**				**4.0**		**1.0**	**96.0**

APPENDIX 4.4b Total fish catch (#/haul) for Tenpound Island (TI) in Gloucester Harbor (18 hauls).

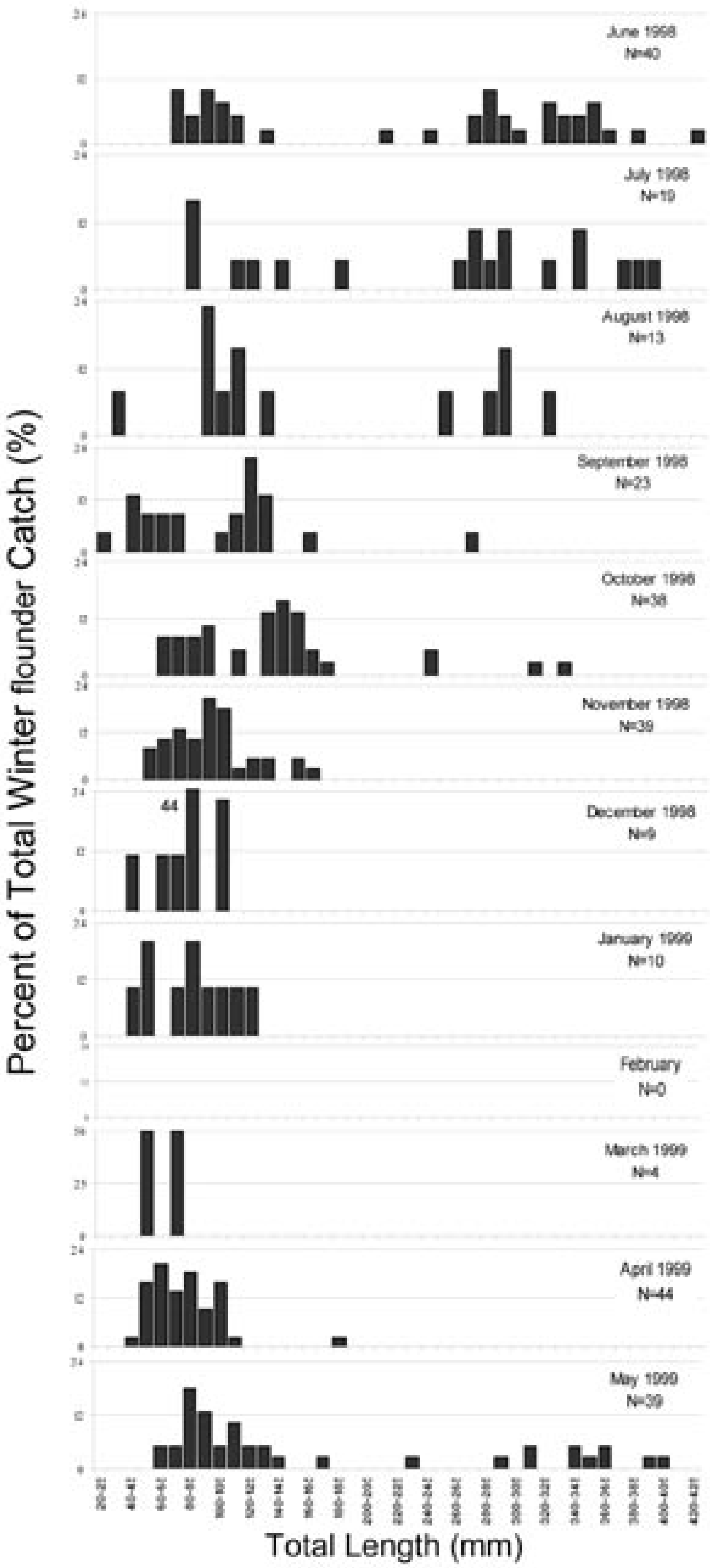
Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Blueback herring		4.0																	4.0
Atlantic silverside							3.0												3.0
Cunner	2.0																		2.0
Grubby	1.0	1.0																	2.0
Northern pipefish										2.0									2.0
Atlantic menhaden							1.0												1.0
Red hake		1.0																	1.0
Rock gunnel	1.0																		1.0
Shorthorn sculpin																	1.0		1.0
Total	**4.0**	**6.0**					**4.0**			**2.0**							**1.0**		**17.0**

APPENDIX 4.4c Total fish catch (#/haul) for Half Moon Beach (HM) in Gloucester Harbor (18 hauls).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside						5.0	25.0	81.0	276.0										387.0
Lumpfish		1.0				1.0	37.0												39.0
Blueback herring			21.0																21.0
Atlantic menhaden									9.0										9.0
Winter flounder							5.0	1.0	1.0								1.0		8.0
Grubby	4.0									1.0									5.0
Mummichog					1.0						3.0								4.0
Rainbow smelt								2.0	2.0										4.0
Red hake			1.0				2.0												3.0
Sand lance									2.0										2.0
Bay anchovy			1.0			1.0													2.0
Northern pipefish		1.0	1.0																2.0
Bluefish								1.0											1.0
Pollock																	1.0		1.0
3-spine stickleback																		1.0	1.0
Total	4.0	2.0	24.0		1.0	7.0	69.0	85.0	290.0	1.0	3.0						2.0	1.0	489.0

APPENDIX 4.4d Total fish catch (#/haul) for Niles Beach (NB) in Gloucester Harbor (18 hauls).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside					2.0		1.0		3.0					1.0	1.0			1.0	9.0
Grubby	4.0																		4.0
Atlantic menhaden										2.0									2.0
Northern pipefish										2.0									2.0
Northern puffer							1.0												1.0
Winter flounder										1.0									1.0
Total	4.0				2.0		2.0		3.0	5.0				1.0	1.0			1.0	19.0



APPENDIX 4.5 Winter flounder length frequency in Gloucester Harbor, June 1998 to May 1999; trawl samples. N=total number of winter flounder collected per month.

CHAPTER FIVE

Identification of the Type and Quality of Gloucester Harbor Coastal and Seafloor Habitats: Synthesis of Harbor and Regional Studies

Anthony R. Wilbur
Massachusetts Office of Coastal Zone Management, Boston, MA

Abstract

This study synthesized the results of statewide coastal habitat and seagrass mapping, regional seafloor habitat mapping and harbor-specific seafloor habitat assessments for Gloucester Harbor. Five coastal habitats, several eelgrass beds and four seafloor habitats with variable features were found within Gloucester Harbor. Human-induced disturbance was apparent along a gradient from degraded seafloor conditions in the Inner Harbor to non-degraded, higher seafloor quality in the Outer Harbor. The study used sediment profile imaging, a multibeam seafloor mapping system and diving observation to identify, describe and map seafloor habitats. The utility of each method was discussed. The different methodologies and data collected emphasized the importance of using multiple techniques to thoroughly assess seafloor habitat conditions. The integration of results provided the first assessment of Gloucester Harbor coastal and seafloor resources. The study discusses the value of marine habitat mapping and monitoring.

Introduction

Comprehensive coastal and seafloor habitat maps are fundamental to understanding and appropriately managing marine habitat and life. The Massachusetts Department of Environmental Protection (DEP) produced maps showing the statewide distribution of coastal habitats, such as salt marsh, rocky intertidal, and tidal flats, and seagrass. The DEP maps provide essential information that increase the understanding of statewide coastal and seagrass resources and improve management of these resources. No single program systematically examines or maps seafloor habitats in Massachusetts.

The lack of seafloor habitat characterization and maps hinders resource management efforts. Seafloor habitat conditions influence the presence, absence, and productivity of demersal creatures, including exploited and non-target species. Seafloor environments, including benthic habitats and inhabitants, found in coastal Massachusetts support a relatively diverse assemblage of species and life history stages. Threats to seafloor and coastal habitat occur from a range of human activities, including fishing, pollution, dredging and dredged material disposal, aquaculture, construction of structures, and shipping. Impacts from threats are frequently ignored and difficult to quantify without habitat mapping and monitoring. Mapping and monitoring of coastal and seafloor habitats are required to detect long-term change in habitat quality, benthic community structure, and ecological processes (e.g., trophic dynamics).

Gloucester Harbor (Figure 5.1) was investigated by a series of surveys to characterize fisheries resources and benthic habitats (MCZM 2001). The surveys were not intended to comprehensively describe seafloor habitat; however, substantial geographic areas of the seafloor environment were investigated, analyzed, and described. Existing statewide and regional assessments provided baseline conditions and complimentary information on coastal habitats, sea-

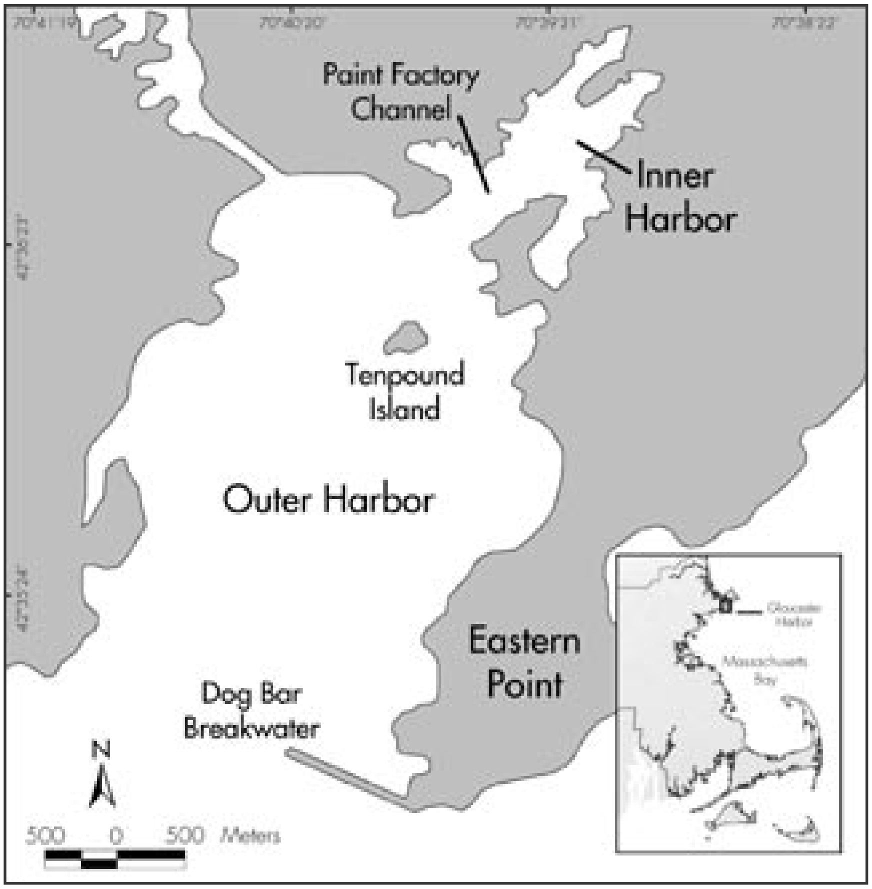


FIGURE 5.1 Landmarks and geographic features in Gloucester Harbor.

grass, and seafloor resources. This study synthesizes harbor-specific and regional research to identify and describe coastal and seafloor habitat types and conditions in Gloucester Harbor. The study discusses the significance and management application of mapping and monitoring seafloor habitat.

Coastal Habitats

Methods

The Massachusetts DEP mapped the statewide distribution of wetlands and streams, including coastal habitats. Habitats were interpreted from stereo, 1:12000 scale, color-infrared photography and 1:5000 black and white ortho-rectified digital aerial photography (MassGIS 2002). Remotely sensed maps were extensively field verified, and maps were generated at 1:5000 scale. The DEP maps identify coastal and terrestrial features. This study presents the distribution of coastal habitats in Gloucester Harbor.

Results and Discussion

Coastal beach, sea cliff (bank bluff), salt marsh, rocky intertidal, and tidal flats line the outer harbor of Gloucester (Figure 5.2). The western shore is more exposed to the open ocean, characterized by rocky intertidal and sea cliffs. There are limited areas of salt marsh and pockets of coastal beach throughout the outer harbor. The outer harbor coastline was altered by the construction of Dog Bar breakwater, but the majority of the coastal habitats persisted through the development of Gloucester. The inner harbor was drastically changed through the development of the harbor. The inner harbor was extensively filled (e.g., harbor waters were filled to and around Fivepound Island to create the State Pier) and was heavily armored with man-made structures. Patches of sea cliff, coastal beach, tidal flats and salt marsh remain in the inner harbor (Figure 5.2).

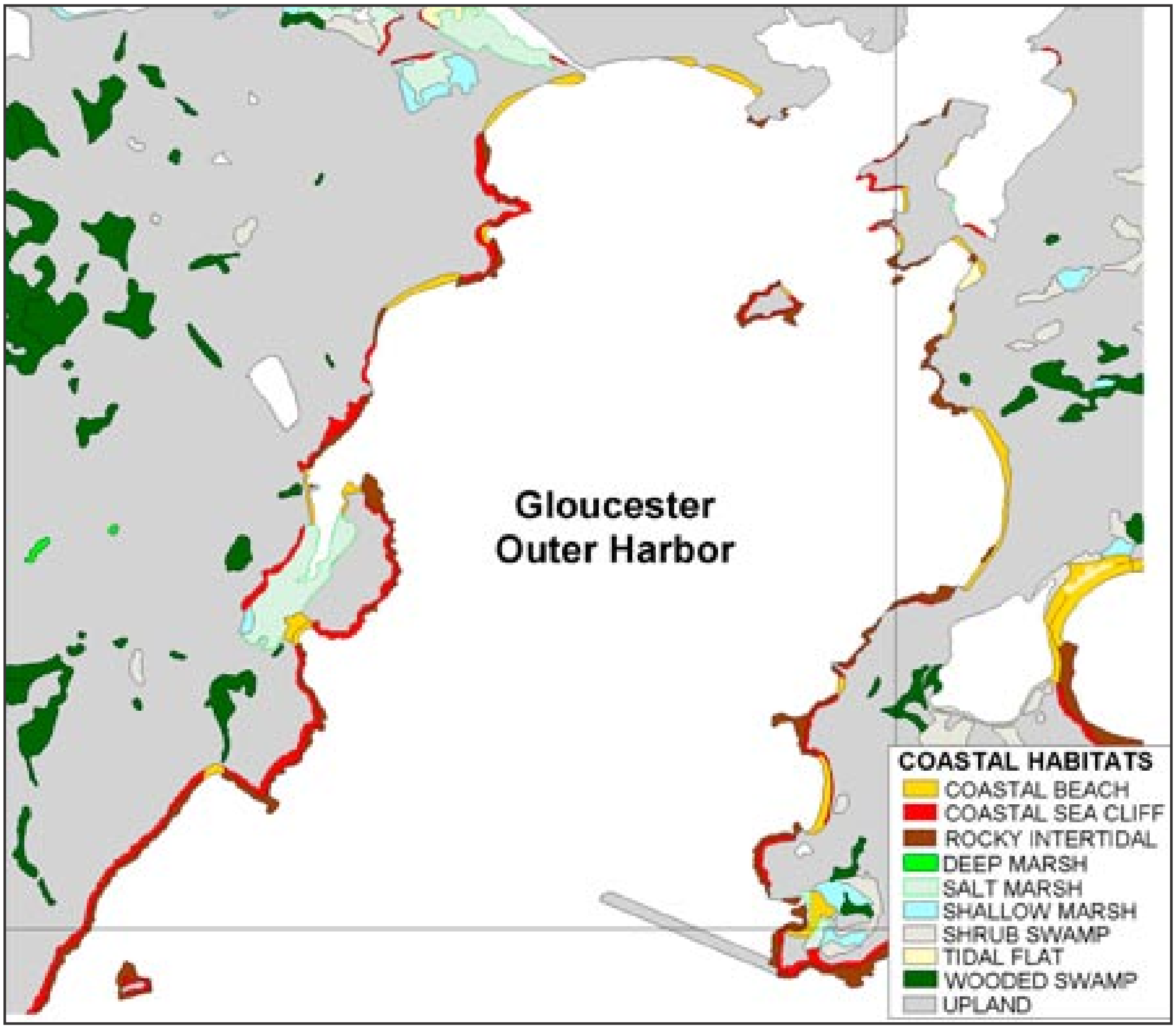


FIGURE 5.2 Coastal habitats in Gloucester Harbor (MassGIS 2002).

Submerged Vegetation

Methods

Eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) are two species of submerged rooted vegetation (SRV) found in Massachusetts marine and estuarine waters. Eelgrass is the dominant species in Massachusetts. DEP (Costello personal communication) mapped the statewide distribution of seagrass through aerial photography (at a scale of 1: 20000), photographic interpretation, and extensive field verification. Data presented in this study are from the 1995 assessment.

Results and Discussion

Eelgrass is a productive nearshore marine habitat that supports diverse floral and faunal assemblages, absorbs nutrients, stabilizes sediments, and provides detrital biomass for lower trophic levels (see Stephan and Bigford 1997 and Fonseca et al. 1998 for review). Wasting disease (*Labyrinthula* spp.) decimated North Atlantic eelgrass populations during the early 1930s, including populations in Gloucester Harbor. The loss of eelgrass substantially affected wildlife resources (e.g., avifauna foraging habitat) (Addy and Aylward 1944; Dexter 1985). Eelgrass populations recovered in Gloucester Harbor and Cape Ann waters (Addy and Aylward 1944; Dexter 1985), and distribution has remained stable (Buchsbaum personal communication). The 1995 DEP survey showed that Gloucester Harbor contained five discrete eelgrass beds in the outer harbor (Figure 5.3).

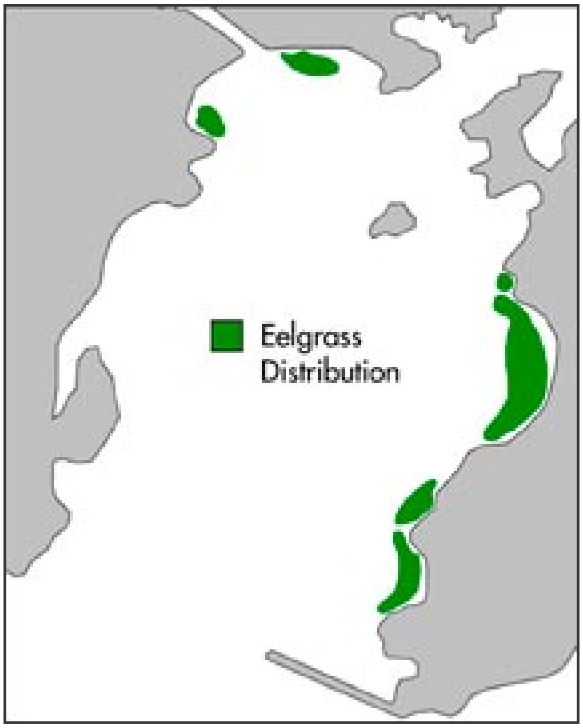


FIGURE 5.3 Distribution of eelgrass (*Zostera marina*) in Gloucester Harbor (eelgrass map produced from 1995 aerial photography and field verification; C. Costello personal communication; www.state.ma.us/mgis/massgis.htm).

These results are based on one sample but indicate suitable environmental conditions to support eelgrass habitat in Gloucester Harbor. The distribution and quality of eelgrass is temporally and spatially variable, and there is no long-term record of seagrass distribution in Gloucester Harbor. Trends of seagrass distribution and quality cannot be determined with the existing information. Previous studies (1930-1984) demonstrated the variability of eelgrass distribution around Cape Ann (Dexter 1985), but sampling within Gloucester Harbor during this period was limited (Addy and Aylward 1944). Eelgrass distribution is influenced by a combination of natural and anthropogenic factors, including proliferation of epiphytic growth and disease, pollution, direct disturbance, physical alteration to the watershed, and natural cycles (NOAA 1997). Relationships between seagrass quality and human-influences are not fully understood (e.g., Lent et al. 1998). It is assumed that harbor water quality improved with the movement of the wastewater outfall from the outer harbor to south of the Dog Bar Breakwater. Excessive nutrients were not observed in the outer harbor (Michael and Fleming 2000), and nitrogen loading does not appear to reduce eelgrass quality in Gloucester Harbor (Chandler et al. 1996; Lent et al. 1998). Recent aerial photography (2001) provided a complimentary dataset that indicated no loss of eelgrass coverage in Gloucester Harbor from 1995 to 2001 (Costello personal communication).

Seafloor Habitat

Methods

Science Applications International Corporation (SAIC) collected and analyzed sediment surface and sediment profile images to describe benthic habitat type and quality (Valente et al. 1999; SAIC 2001). Rhoads and Germano (1982; 1986) describe sediment profile imagery methodology and analyses. Photographs of the sediment surface were obtained with a downward-looking camera; the resultant surface images show a 40 cm by 60 cm area of the seafloor. The surface images provide an undisturbed record of seafloor features (i.e., sediment type, topography, and biogenic structures). Sediment profile images (SPI) were collected with a specialized camera that penetrates into the seafloor and obtains a vertical cross-section photograph (profile) of the upper 15 to 20 cm of the seafloor, including the sediment-water interface. The seafloor was photographed with the Benthos Model 3731 Camera (Benthos Inc, Falmouth, MA). Underwater color photographs were digitized, and an image analysis system was employed to analyze SPI (Valente et al. 1999).

Features identified by SPI include sediment type, grain size, camera penetration, apparent redox potential discontinuity (RPD) depth, biogenic structure (worm tubes) and activity (burrows and feeding voids), and benthic habitat type (Rhoads and Germano 1982, 1986; Nilsson and Rosenberg 1997). The Wentworth classification scheme was used to describe sediment grain size in this study (see Table 5.1 for equivalent metric units). Seafloor rigidity (i.e., surface sediment hardness or bearing strength) was measured by camera penetration. RPD depth is an estimate (apparent) of oxidation of surficial sediments. The RPD depth estimate is the distance between high-reflectance surface sediment (oxic sediments) and low-reflectance sediment (anoxic sediment).

TABLE 5.1 Sediment profile imaging data, including grain size major mode frequency, camera penetration, apparent RPD depth, and habitat type, from 1998 and 2001 (Valente et al. 1999; SAIC 2001). NA represents SPI samples that did not penetrate the seafloor (hard bottom). Means (SD) included where relevant.

Substrate	All 1998	Inner Harbor 1998	Paint Factory Channel 1998	Tenpound Island 1998	Tenpound Island 2001	Outer Harbor 2001	All 2001
Frequency of Grain Size (phi) Mode[a]							
>4	90.9	94.1	66.7	100.0	100.0	73.1	76.6
4 to 3	6.1	5.9	16.7			23.9	20.8
<-1	3.0		16.7				
NA						3.0	2.6
Camera Penetration (cm) Mean	14.0 (4.8)	13.6 (4.6)	12.5 (7.5)	15.4 (2.9)	15.5 (3.1)	10.7 (5.0)	11.3 (5.0)
Apparent RPD Depth (cm) Mean	4.9 (2.6)	3.5 (2.4)	5.8 (2.7)	6.9 (1.3)	10.8 (4.1)	6.0 (4.0)	6.6 (4.3)
Habitat Type	mix	soft mud (silt)	soft mud (silt); hard bottom	soft mud (silt)	soft mud (silt)	soft mud (silt); sand; hard bottom	mix

[a]**Grain Size:** >4 phi = <0.0625 mm; 4 to 3 phi = 0.625 - 0.125 mm; 3 to 2 phi = 0.125 - 0.250 mm; 2 to 1 phi = 0.250 - 0.50 mm; 1 to 0 phi = 0.50 - 1.00mm; 0 to -1 phi = 1.00 - 2.00 mm; <-1 phi = >2.00 mm

Sediment profile images were collected throughout Gloucester Harbor in 1998 and 2001 (Valente et al. 1999; SAIC 2001). Sediment surface images were concurrently collected with the 1998 SPI. The benthos from the inner harbor to Tenpound Island were sampled in 1998 and included 33 SPI and 22 surface images. Seventy-seven SPI were collected from Tenpound Island to Dog Bar Breakwater in 2001. Tenpound Island stations were sampled in 1998 and 2001. Four of the 2001 stations targeted the historic location of the wastewater outfall (located in the outer harbor).

This paper incorporated an existing regional study (USGS 1998) and site-specific surveys (NAI 1999; Malkoski personal communication). USGS employed a multibeam seafloor mapping system that used sound to measure water depth (i.e., bathymetry) and surficial sediment characteristics (USGS 1998). The mapping system also included the collection of sidescan sonar data. The survey provided a highly detailed map (scale of 1:25000) of seafloor topography and substrate type for portions of Gloucester Harbor, Massachusetts Bay, Jeffreys Ledge, and Stellwagen Bank.

Diving surveys, during October 1999 and January 2001, targeted areas in the inner and outer harbor (Figure 5.4; NAI 1999; Malkoski personal communication). NAI (1999) assessed 10 metered transects of varying length from the inner harbor to Tenpound Island, totaling 3450 linear meters (NAI 1999). The winter survey contained four 200 meter transects (Malkoski personal communication). Divers swam the length of each transect and recorded substrate type, number of lobster, and presence of additional biogenic features (e.g., fish, invertebrates, and vegetation), providing a qualitative and quantitative assessment of seafloor features. Underwater video was collected along the length of each transect and complemented the diver survey.

Results

Unconsolidated, soft mud (silt-clay; >4 phi) to fine sand (4 to 3 phi) was predominantly found throughout Gloucester Harbor (Figure 5.5A; USGS 1998; NAI 1999; Valente et al. 1999; SAIC 2001; Malkoski personal communication). Surface sediments showed little topography (e.g., ripples), suggesting low seafloor energy that is not subject to substantial sediment transport (SAIC 2001). Seafloor sediments

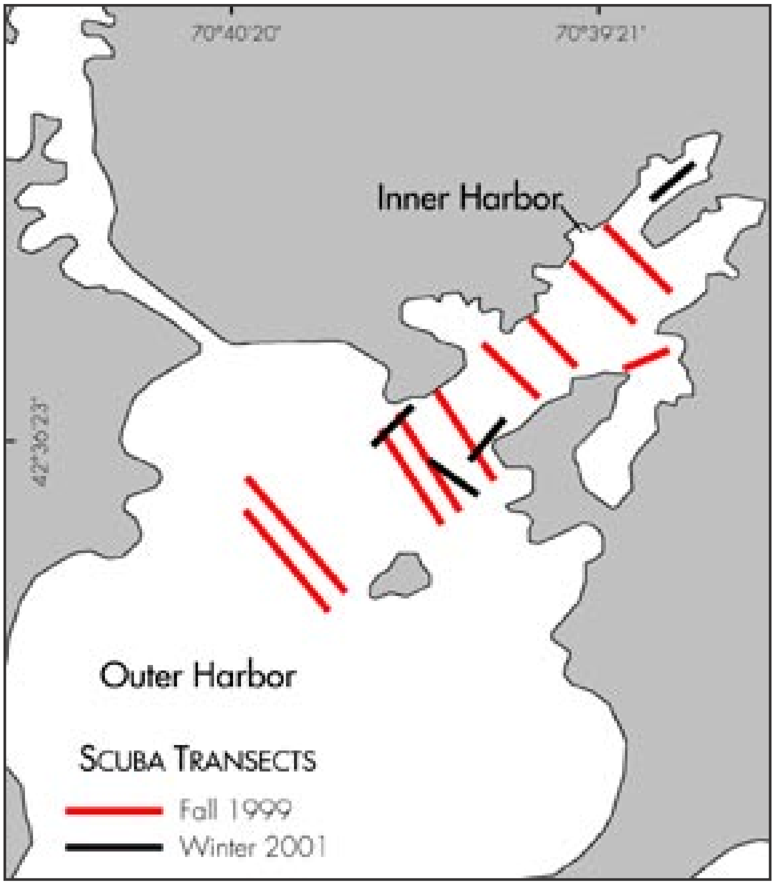


FIGURE 5.4 Location of diving transects in Gloucester Harbor in October 1999 (fall; solid line) and January 2001 (winter; dotted line) (NAI 1999; Malkoski personal communication). Video was collected along the length of each transect.

had relatively low substrate rigidity (i.e., deep camera penetration) and variable RPD depth (Table 5.1; Valente et al. 1999; SAIC 2001).

RPD variance was related to harbor location and grain size. Inner harbor benthos were characterized by soft mud, shallow RPD depth, and sedentary organisms living on the seafloor surface (e.g., epifauna; worms) (Figure 5.6). The navigational channel adjacent to the Paint Factory was a soft mud/fine sand mix and showed comparable camera penetration and RPD depth relative to the outer harbor. Stations around Tenpound Island had unconsolidated soft mud, deep camera penetration, relatively deep RPD, and evidence of infauna feeding at depth (Figure 5.7).

Outer harbor grain size was more variable, with camera penetration and RPD depth associated to grain size. Soft mud sediments in the outer harbor were comparable to samples surrounding Tenpound Island, characterized by deep camera penetration, oxidized surfical sediments (i.e., deep RPD depth), and infauna presence (Figure 5.8). RPD depth was slightly lower in the southeast corner of the outer harbor (i.e., located adjacent to Dog Bar Breakwater). Western outer harbor samples were coarser grained (i.e., medium sand; 3 to 2 phi) and more rigid, limiting the vertical profile of the image and ability to measure RPD depth (Figure 5.9). Samples northeast of Dog Bar Breakwater (near the harbor mouth) were interpreted as hard bottom (consolidated sediment) because of no camera penetration. Western outer harbor is more exposed to Massachusetts Bay and subjected to higher bottom energy and winnowing of fine-grain sediments, resulting in higher sand content and harder bottom.

Areas of coarser-grained sediment (sand) and relatively high surficial relief were observed south and west of Tenpound Island (Figure 5.10; USGS 1998; NAI 1999). The area south of Tenpound Island was generally smooth, soft mud (USGS 1998); local fishermen refer to the area as the "Pancake." The multibeam survey clearly showed the corridor of the new wastewater outfall, stretching from the old wastewater outfall to south of Dog Bar Breakwater (USGS 1998). Inner harbor and Tenpound Island had relatively smooth, homogeneous mud bottom. Abandoned gear (a.k.a., ghost gear) was extensively found on the seafloor surrounding Tenpound Island and within the inner harbor (NAI 1999). Green crabs, hermit crabs, American lobster, and shellfish species (e.g., blue mussels) were observed throughout the diving survey area (Figure 5.4). Estimates of juvenile and adult lobster relative abundance ranged from 0.06 lobster/m 0.20 lobster/m, indicative of good lobster habitat. The multibeam study area extended well-beyond Gloucester Harbor and showed harder substrate, including coarser-grain sand and cobble,

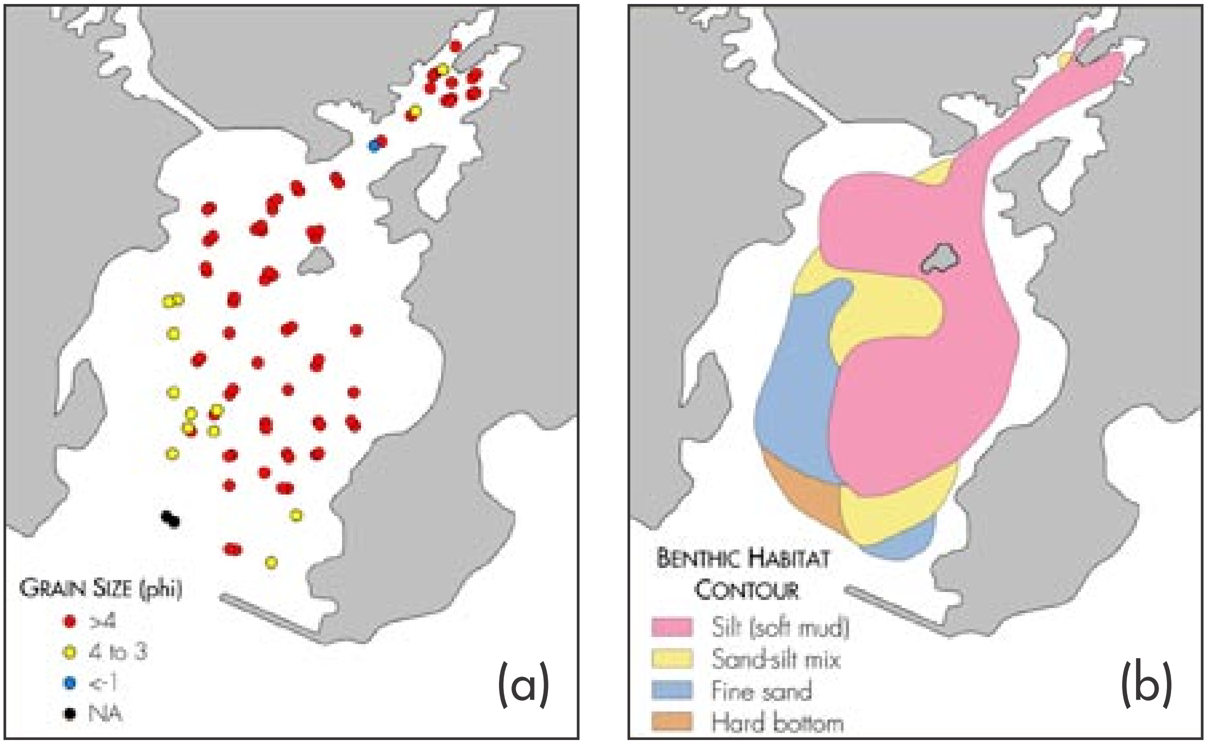


FIGURE 5.5 The 1998 and 2001 sediment profile and surface imaging sample locations, showing (A) major mode grain size from sediment profile imagery; and (B) benthic habitat classification contoured from sediment and surface imagery (Valente et al. 1999; SAIC 2001). Sample station used for hard bottom benthic habitat shown as NA (not analyzed).

outside Dog Bar Breakwater and Eastern Point. Substrate character bordering Eastern Point generally reflects the sedimentary environment of the adjacent shoreline. The diving and multibeam surveys complimented the SPI assessment of seafloor habitat (Figure 5.5b).

Discussion

The inclusion of biotic and abiotic features is essential to identify and describe seafloor habitat. This study presented several surveys, varying in scales and objectives, and the results collectively improved the description of seafloor habitat type and condition in Gloucester Harbor. The multibeam survey predominately showed one sediment type, represented by blue (mud), and provided detailed bathymetry (seamless spatial coverage) throughout the harbor (Figure 5.10). SPI refined the multibeam assessment, finding a range of sediment types from mud to sand (Figure 5.5), and improved the description of habitat quality. Diving supplemented the seafloor description by locating areas of hard bottom and describing biota. Microhabitat features, including small-scale (<1 m) bedforms and biogenic structure, were identified using SPI and diving. The unique contribution of diver surveys was the snapshot evaluation (direct observation) of mobile demersal creatures within the study area. The multibeam, diving, and SPI studies demonstrated the utility of each sampling technique for examining seafloor habitat. A thorough evaluation of habitat quality requires assessments of diverse seafloor resources at varying scales, necessitating the use of multiple techniques.

The sediment profile imaging identified seafloor habitat type and quality. Images presented quantifiable information on sediment features (sediment type, rigidity, and oxic/anoxic conditions) and biological characteristics (presence of benthic epifauna and infauna, burrows, feeding voids, biogenic tubes, and reworked sediments). These characteristics can be associated with the ecological function of the seafloor environment (Nilsson and Rosenberg 1997). Aggregations of polychaetes and no apparent RPD at the seafloor surface are indicative of stressed benthos (e.g., organically enriched and/or recently dis-

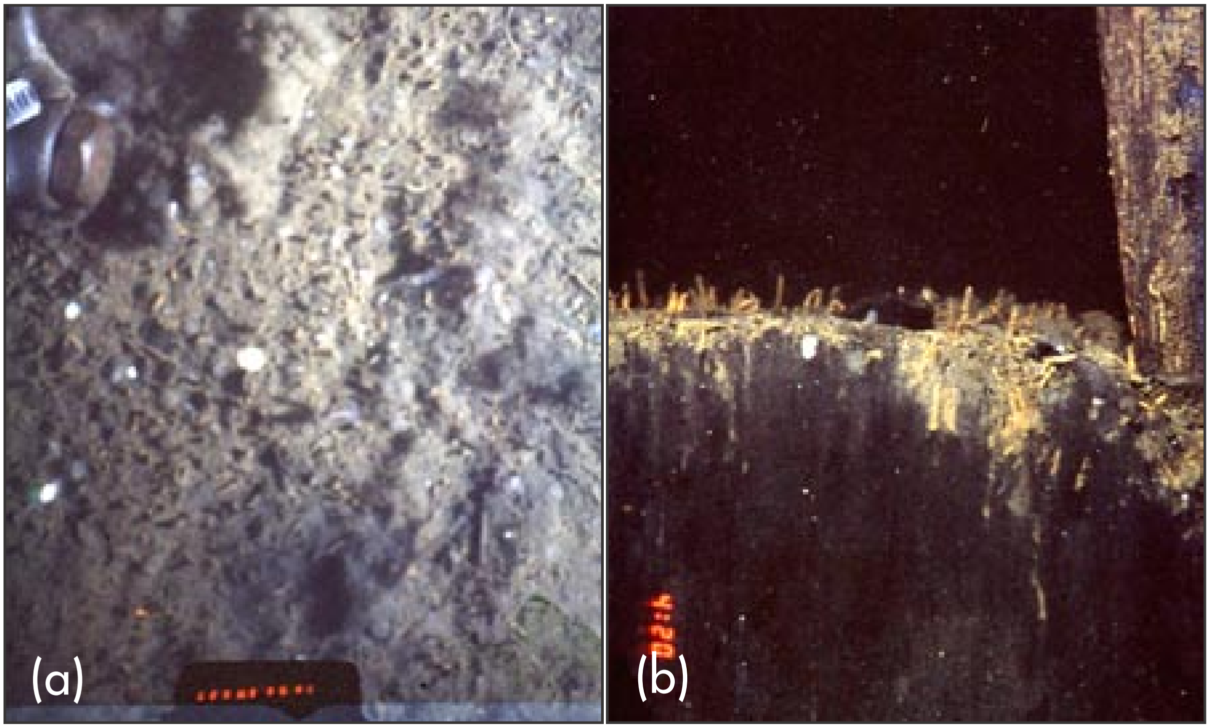


FIGURE 5.6 Representative surface and sediment profile images from the inner harbor. (A) Surface image showing soft mud and worm tubes; (B) Sediment profile image showing soft mud (silt-clay; >4 phi), relatively abundant worm tubes, marine debris (piling), and low apparent surficial sediment oxidation; mean RPD depth is 1.22 cm. Images from Valente et al. 1999.

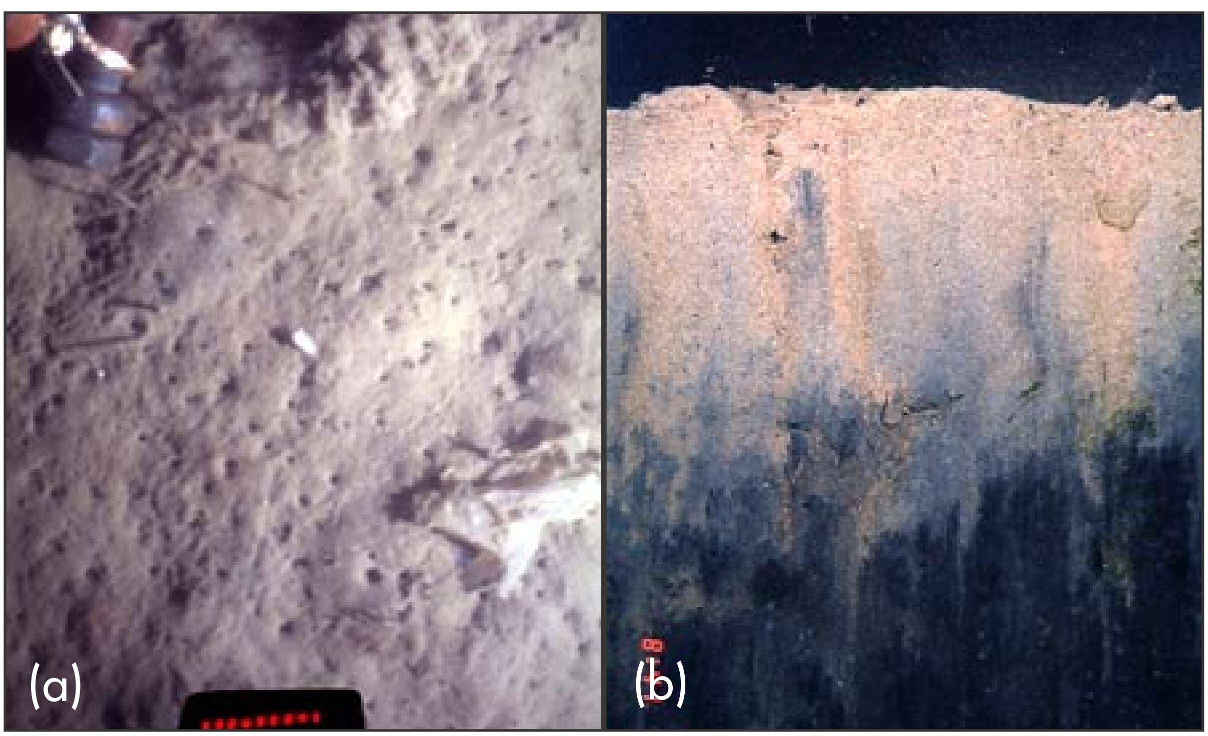


FIGURE 5.7 Representative surface and sediment profile images from benthos adjacent to Tenpound Island. (A) Surface image showing soft mud, abundant burrows, and debris (plastic bag); (B) Sediment profile image showing soft mud (silt-clay; >4 phi), worm tubes, feeding voids, and relatively high surficial sediment oxidation; mean RPD depth is 4.56 cm. Images from Valente et al. 1999.

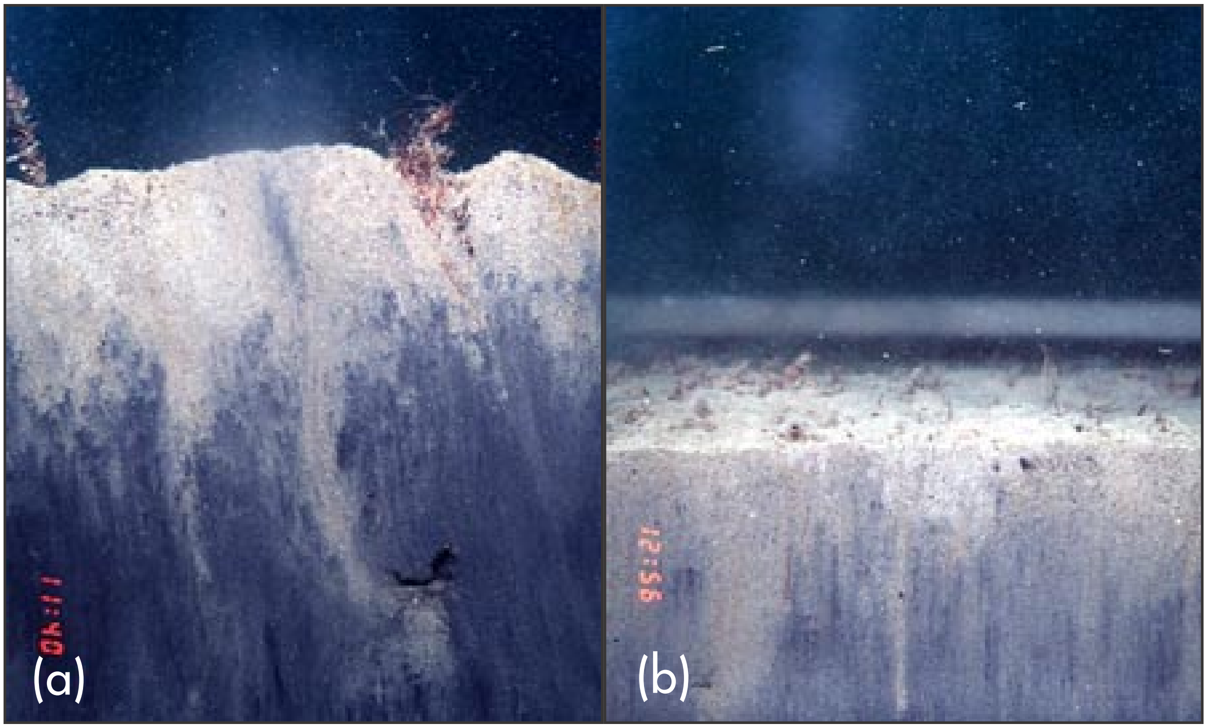


FIGURE 5.8 Representative sediment profile images from soft mud in the outer harbor. (A) Sediment profile image showing soft mud (silt-clay; >4 phi), feeding voids, red algae, relatively high surficial relief, and well-developed apparent sediment oxidation; mean RPD depth is 4.12 cm; (B) Sediment profile image showing soft mud (silt-clay; >4 phi), relatively lower camera penetration, worm tubes, and moderate surficial sediment oxidation; mean RPD is 2.09 cm. Images from SAIC 2001.

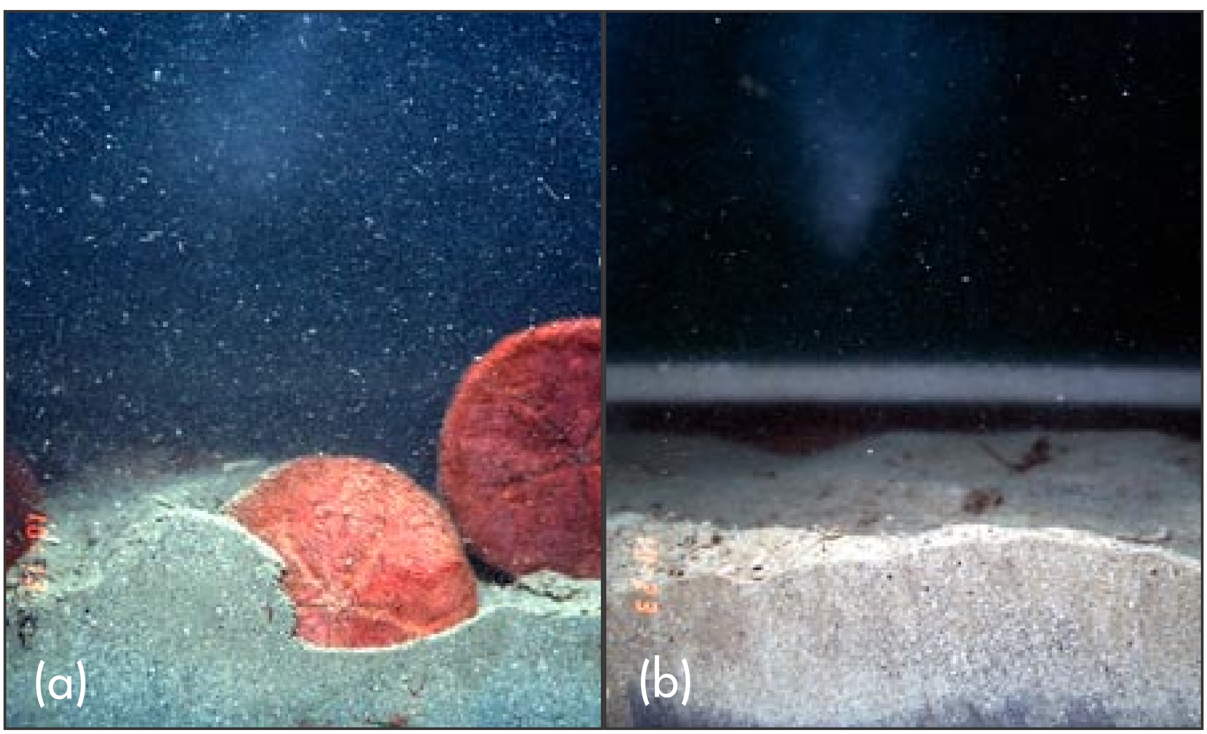


FIGURE 5.9 Representative sediment profile images from sand in the outer harbor. (A) Sediment profile image showing fine sand (4 to 3 phi), sand dollars, low camera penetration, and relatively high surficial relief; (B) Sediment profile image showing fine sand (4 to 3 phi), low camera penetration, and relatively high surficial relief. RPD is not measured because of low camera penetration. Images from SAIC 2001.

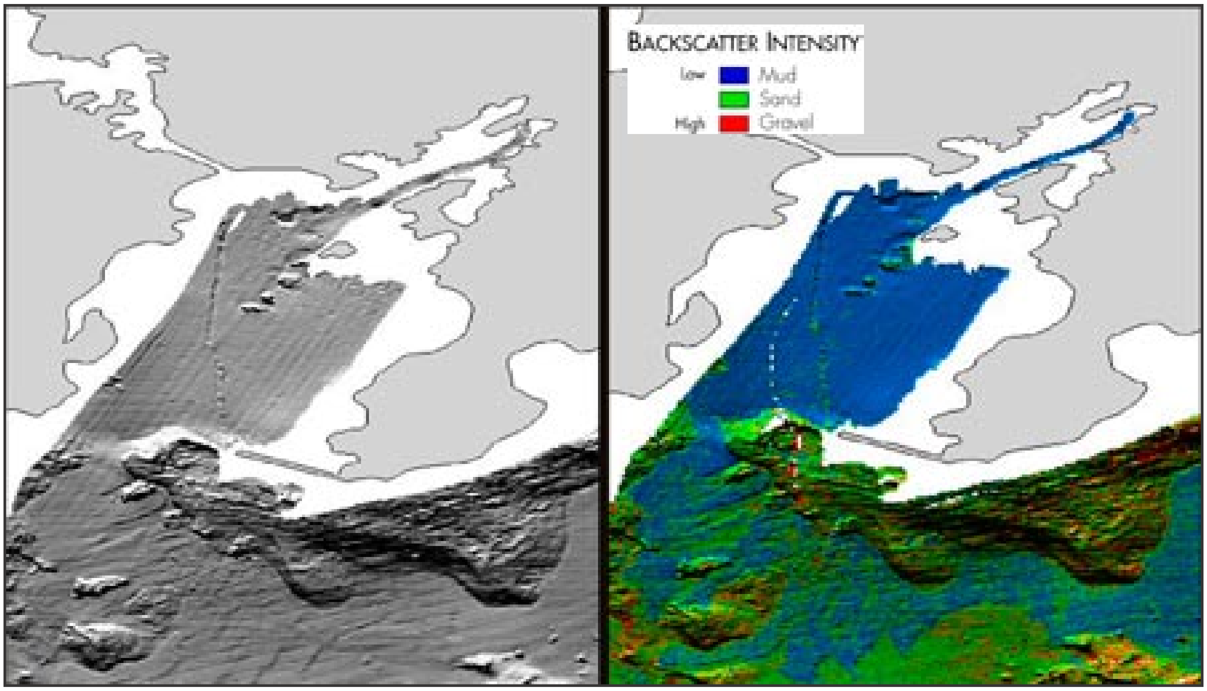


FIGURE 5.10 (A) Sidescan sonar image showing sun-illuminated topography; (B) Sun-illuminated topography with multibeam backscatter intensity for Gloucester Harbor. Red indicates high backscatter material including coarse sand, gravel and rock; green indicates sand; blue indicates mud. The topography is vertically exaggerated to demonstrate small-scale variability (USGS 1998; 2000).

turbed) (Pearson and Rosenberg 1978; Rhoads and Germano 1982, 1986). These features were found in the inner harbor and suggest a high inventory and/or continued input of organic matter. Shallow RPD depths were observed in other nearshore Massachusetts Bay environments (i.e., Boston and Salem Harbor) that are heavily influenced by anthropogenic inputs (Shea et al. 1991; Valente et al. 1999; Arnofsky et al. 2001).

Benthic habitat in the outer portion of the inner harbor, areas adjacent to Tenpound Island, and outer harbor exhibited higher habitat quality and were characterized by well-oxidized seafloor sediments and evidence of infauna (e.g., presence of mollusks or feeding voids). The blackness of sediments underlying the oxygenated sediments at some outer harbor stations indicated a substantial reservoir of organic matter, but the well-developed RPD layer showed benthic organisms may be processing the inputs and maintaining sediment oxidation (SAIC 2001). The relatively lower RPD found behind Dog Bar Breakwater suggested higher rates of organic matter deposition or increased rates of sedimentation relative to erosion—possibly a result of reduced tidal circulation in this area (SAIC 2001).

Stations in the vicinity of the former wastewater outfall were comparable to outer harbor samples. Black, reduced sediment found at one station indicated continued elevated levels of organic matter (SAIC 2001), but prolonged effects from the previous outfall seem spatially limited.

There were notable differences between the 1998 and 2001 SPI surveys in boundary roughness (measure of highest and lowest surficial feature from SPI) and apparent RPD. There was higher boundary roughness and deeper RPD depth in 2001. These features represent higher biological activity and probably reflect seasonal differences (i.e., March 2001 supported higher biological activity compared to November 1998).

The presence of coarse-grained sediment influenced the effectiveness of the SPI technique in areas of the outer harbor because of limited camera penetration. Surface images were not collected in 2001. Surface images enable the characterization of surficial sediment type and biogenic structure, but sub-surface attributes (e.g., oxic/anoxic conditions) are not available. Study areas potentially containing consolidated, coarse-grain sediment should be sampled with surface and sediment profile images to improve habitat description.

Habitat type and quality were described by combining the 1998 and 2001 SPI results, and descriptions were improved using multibeam (USGS 1998) and diving observations (NAI 1999; Malkoski personal communication). Four habitat categories, based primarily on substrate character, were identified in Gloucester Harbor. Sediments were predominantly soft mud and fine sand, transitioning to coarser material toward the western shoreline and mouth of the harbor. Physical, chemical, and biological properties varied among and within habitat types.

The surveys demonstrated a gradient from degraded seafloor habitat quality in the inner harbor to increasingly higher seafloor habitat quality (non-degraded) around Tenpound Island and throughout the outer harbor. Reduced tidal flushing, increased anthropogenic inputs, and physical disturbance apparently influenced seafloor habitat quality in the inner harbor. The reduced habitat quality, however, supported an abundant American lobster population (NAI 1999; Wilbur and Glenn 2002). The inner harbor is closed to commercial lobster fishing, and the lack of fishing effort influences the presence and abundance of lobster. Nevertheless, the presence of lobster suggested that despite the magnitude of degradation in the inner harbor, the system continues to provide habitat to this commercially and ecologically valuable species (Wilbur and Glenn 2002).

Describing habitat requires focused examination of the biological communities, including invertebrate, vertebrate, and plant species, which vary through space and time. Biological sampling to describe the benthic community was not conducted during this study, but benthic infauna were collected at locations in the outer harbor as part of the wastewater outfall monitoring (Michael and Fleming 2000). Monitoring results provided an indication of species presence and relative abundance at a limited spatial scale (Michael and Fleming 2000). Substrate type generally dictates benthic community structure in the Gulf of Maine (e.g., Langton and Uzmann 1989), but small-scale variability in physical structure and topography contributes to variability in biotic assemblages (e.g., Zajac et al. 2000). Habitat categories in this study were primarily founded on substrate type, acknowledging the heterogeneity within habitat classes and along gradients of disturbance. The different methodologies and data collected emphasized the value of individually and mutually using multiple techniques to identify and describe seafloor habitat.

Summary

This study provided a useful overview of existing coastal habitats and eelgrass distribution and presented novel detail on the type and quality of seafloor habitats in Gloucester Harbor. Coastal habitats in Gloucester Harbor were certainly changed through the development of the inner harbor, but outer harbor characteristics remained relatively unaltered. Spatial and temporal trends of eelgrass distribution are unknown. Continued mapping and monitoring of eelgrass in Gloucester (and statewide) increases the understanding of eelgrass and enables resource managers to advance the management of this productive marine habitat. The seafloor habitat studies yielded a tremendous amount of information and should be used, in conjunction with existing coastal and eelgrass maps, for preliminary decision making of coastal activities that potentially affect the marine environment. This synthesis can also be used to design marine monitoring and research intended for examining long-term spatial and temporal trends of seafloor habitat quality.

Gloucester Harbor seafloor habitat quality changed through the development of the economically productive port and alteration of land use in the watershed. Seafloor habitat is not an environmental attribute that is regularly monitored in Massachusetts. Habitat quality, and subsequent ecological function, changes along gradients of human disturbance (e.g., Rhoads and Germano 1986; Valente et al. 1992; Hargrave et al. 1997; Nilsson and Rosenberg 1997). The consequences of seafloor habitat degradation, such as organic loading, oxygen depletion, and physical disturbance, can transfer through trophic levels (e.g., from benthic macrofauna to demersal fishes) (Nilsson and Rosenberg 1997). Seafloor habitat mapping and subsequent systematic monitoring and targeted research are required to detect long-term trends in habitat quality, examine ecological value and function, and determine effects of anthropogenic perturbation. This type of information is necessary to develop effective management strategies to maintain and conserve the integrity of marine habitat and life.

Acknowledgments

This study was a component of the Massachusetts Dredged Material Management Plan, supported by the Massachusetts Seaport Bond and the CZM grant. Gloucester Harbor-specific fieldwork was completed by Science Applications International Corporation (Peggy Myre and Ray Valente), Normandeau Associates Incorporated (Paul Geoghegan, project manager), and Massachusetts Division of Marine Fisheries staff (Vin Malkoski and Bob Glenn). Deerin Babb-Brott, Anne Donovan, Christian Krahforst, and Megan Tyrrell (CZM), Robert Buchsbaum (Mass Audubon), Brad Chase (DMF), and Ray Valente (SAIC) reviewed an earlier version of the manuscript.

Literature Cited

Addy, C.E. and D.A. Aylward. 1944. Status of eelgrass in Massachusetts during 1943. The Journal of Wildlife Management 8(4):269-275.

Arnofsky, P., A. Wilbur, S. Wolf, and T. Fredette. 2001. Post-construction benthic analyses of CAD cells in inner Boston Harbor. Is this a successful successional project? New England Estuarine Research Society Spring Meeting. Salem, Massachusetts. 31 May – 2 June 2001.

Chandler, M., P. Colarusso, and R. Buchsbaum. 1996. A study of eelgrass beds in Boston Harbor and northern Massachusetts Bay. Submitted to US Environmental Protection Agency, Narragansett, RI. 50pp.+tables and figures.

Dexter, R.W. 1985. Changes in the standing crop of eelgrass, *Zostera marina* L., at Cape Ann, Massachusetts, since the epidemic of 1932. Rhodora 87:357-366.

Factor, J.R. 1995. Chapter 1. Introduction, Anatomy, and Life History. In, J.R. Factor (ed.), Biology of the Lobster *Homarus americanus*. Academic Press, NY. 111-137pp.

Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Ocean Program Decision Analysis Series No. 12. National Oceanic and Atmospheric Administration Coastal Ocean Office, Silver Spring, MD. 222pp.

Hargrave, B.T., G.A. Phillips, L.I. Doucette, M.J. White, T.G. Milligan, D.J. Wildish, and R.E. Cranston. 1997. Assessing benthic impacts of organic enrichment from marine aquaculture. Water, Air and Soil Pollution 99:641-650.

Jerome, W.C., A.P. Chesmore, and C.O. Anderson. 1969. A study of the marine resources of the Annisquam River – Gloucester Harbor Coastal Ecosystem. Monograph Series Number 8. Massachusetts Department of Natural Resources. Division of Marine Fisheries, Boston, MA. 62pp.

Langton, R.W. and J.R. Uzmann. 1989. A photographic survey of the megafauna of the central and eastern Gulf of Maine. Fishery Bulletin 87(4): 945-954.

Lent, E., M. Chandler, P. Colarusso, and R. Buchsbaum. 1998. A study of the relationship between water quality, coastal geomorphology and eelgrass (*Zostera marina* L.) meadows in Massachusetts Bay. Submitted to US EPA, Region 1, Boston, MA. 41pp.+tables and figures.

Malkoski, V.J. 1999. Dredged Material Management Plan – soft-bottom suction sampling pilot program. Massachusetts Division of Marine Fisheries, Pocasset, MA. 11pp.

Massachusetts Geographic Information Systems (MassGIS). 2002. www.state.ma.us/mgis/massgis.htm.

Massachusetts Office of Coastal Zone Management (MCZM). 2001. Dredged Material Management Plan (DMMP) EOEA No. 11543. Draft Environmental Impact Report (DEIR) for Gloucester, Massachusetts. Prepared for Massachusetts Office of Coastal Zone Management and City of Gloucester, MA. Prepared by Maguire Group, Foxborough, MA.

Michael, A.D. and S. Fleming. 2000. Gloucester 301(b) monitoring program 1999 annual report. Submitted to Gloucester Department of Public Works, Gloucester, MA. 84pp.+tables and figures.

National Oceanic Atmospheric Administration (NOAA). 1997. NOAA's estuarine eutrophication survey. Volume 3: North Atlantic Region. NOAA Office of Ocean Resources Conservation and Assessment, Silver Spring, MD.

Nilsson, H.C. and R. Rosenberg. 1997. Benthic habitat quality assessment of an oxygen stressed fjord by surface and sediment profile images. Journal of Marine Science 11:249-264.

Normandeau Associates Incorporated (NAI). 1999. Early benthic phase lobster survey for Gloucester. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 9pp.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanographic Marine Biological Annual Review 16:229-311.

Rhoads, D.C. and J.D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: an efficient method of remote ecological monitoring of the seafloor (REMOTS System). Marine Ecological Progress Series 8:115-128.

Rhoads, D.C. and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: a new protocol. Hydrobiologia 142:291-308.

Science Applications International Corporation (SAIC). 2001. Results of the March 2001 Subbottom profiling and sediment profile imaging survey of the outer Gloucester Harbor. Prepared by Science Applications International Corporation, Newport, RI. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Shea, D., D.A. Lewis, B.E. Buxton, D.C. Rhoads, and J.A. Blake. 1991. The sedimentary environment of Massachusetts Bay: Physical, chemical and biological characteristics. Massachusetts Water Resources Authority, Environmental Quality Department Technical Report No. 91-6. Boston, MA.

Stephan, C.D. and T.E. Bigford. 1997. Atlantic coastal submerged aquatic vegetation: A review of its ecological role, anthropogenic impacts, state regulation and value to Atlantic coastal fisheries. Atlantic States Marine Fisheries Commission Habitat Management Series #1. Washington DC.

United State Geological Survey (USGS). 1998. Mapping the sea floor and biological habitats of the Stellwagen Bank National Marine Sanctuary Region. USGS Fact Sheet 078-98.

United State Geological Survey (USGS). 2000. A Marine GIS Library for Massachusetts Bay: Focusing on disposal sites, contaminated sediments, and seafloor mapping. B. Butman and J. Lindsay (eds.). USGS Open-File report 99-439.

Valente, R.M., D.C. Rhoads, J.D. Germano and V.J. Cabelli. 1992. Mapping of benthic enrichment patterns in Narragansett Bay, RI. Estuaries 15:1-17.

Valente , R.M., M.C. Swanson, and C.L. Seidel. 1999. Dredged Material Management Plan: Habitat characterization of the DMMP candidate aquatic disposal sites. Prepared by Science Applications International Corporation, Newport, RI. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.

Wahle, R.A. & R.S. Steneck. 1991. Recruitment habitats and nursery grounds of American lobster (*Homarus americanus* Milne Edwards): a demographic bottleneck? Mar. Ecol. Prog. Ser. 69: 231-243.

Wilbur, A.R. and R.P. Glenn. 2002. Lobstering in Gloucester Harbor: distribution, relative abundance and population characteristics of American lobster (*Homarus americanus*). Massachusetts Marine Monitoring Technical Series 02-04. Boston, MA.

Zajac, R.M., R.S. Lewis, L.J. Poppe, D.C. Twichell, J. Vozarik, and M.L. DiGiacomo-Cohen. 2000. Relationships among sea-floor structure and benthic communities in Long Island Sound at regional and benthoscape scales. Journal of Coastal Research 16(3):627-640.

Personal Communication

Buchsbaum, R. Personal Communication. Massachusetts Audubon Society, Wenham, MA.

Costello, C. Personal Communication. Massachusetts Department of Environmental Protection. Boston, MA.

Malkoski, V.J. Personal Communication. Dredged Material Management Plan – Investigating Gloucester Harbor for wintering lobster. Massachusetts Division of Marine Fisheries, Pocasset, MA.