Site Suitability Analysis for Shellfish Spawning Sanctuaries in Wellfleet Harbor, Massachusetts

Master's Project Paper
by

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Submitted to

University of Massachusetts Boston
Graduate School of Mathematics and Science
Department of Earth, Environmental and Oceanographic Science

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2007

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Acknowledgements

I would like to give thanks to all contributors during my graduate career and all the individuals that contributed to this project.

Special thanks to the Cape Cod Extension in Barnstable County: Bill Walton, Diane Murphy and William Burt.

In Wellfleet special thanks to Andy Koch, shellfish constable, Andy Petty and Hillary Green from the Wellfleet Health and Conservation Department and Krista Lee of the Cape Cod National Seashore.

In the Massachusetts Division of Marine Fisheries, Jerry Moles, David Whittaker and Neil Churchill

In the Cape Cod Commission, Steven Tucker.

Most importantly thank you to my advising professors Anamarija Frankic and Juanita Urban-Rich, as well as Alan Gontz for consultation with the project. Also my course professors: Juanita Urban-Rich, David Terkla, Mary Davis, Bob Bowen, Eugene Gallagher, David Merwin, Bernie Gardner, and John Duff. In addition, Harlyn Halvorsen, for initial consultation.

Thanks to the professors for whom I was a teaching assistant: Willliam Hagar, Steven Rudnick and Robert Beattie.

Special thanks to graduate student Juliang Li for GIS consultation.

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ABSTRACT

Wellfleet Harbor has been well known for its oyster and quahog harvests and abundant shellfish resources. Like many developed coastal areas, Wellfleet Harbor has been experiencing increased population, landuse conversions, and tourism development, while at the same time the abundance of its shellfish species has been declining. This is mainly due to fishing pressure, habitat loss and alteration, water quality degradation and shellfish diseases. However, Wellfleet continues to support a very active historical, cultural and economically important shellfishing community. This project addresses how to restore sustainable shellfishing and aquaculture development using coastal ecosystem based management. Properly sited and established shellfish spawning sanctuaries represent restorative and precautionary measures in fortifying the current spawning population and increasing natural shellfish abundance. Using GIS and existing environmental data, land use maps, and coastal and marine use zones, the site suitably and use conflict analysis were performed (Frankic, 2003). Identified areas for potential spawning sanctuaries were evaluated based on both environmental and socio-economical suitability analysis. Provided management recommendations have capacity to forecast conflicts in a system that is evolving under both anthropogenic and climatic forces.

Background

The world is a different place than it was even one century ago. One primary factor in this difference is the exponential growth in global population and the increasing impact mankind is having on the natural environment. Marine and coastal ecosystems are not excluded from this. As described in the United Nations Environmental Program (UNEP) 2006 publication, "coastal and marine ecosystems are among the most productive, yet threatened, ecosystems in the world." Coastal and marine ecosystems are recognized for providing a variety of services that fall under the following broad categories: provisioning services, regulating services, cultural services and supporting services (UNEP 2006). Given the popularity of such coastal areas and the enjoyment of the services they provide, they are coming under increasing pressure as populations in these areas increase disproportionately from the rest of the world, and our demands from them are increasing.

It was estimated that in 2001, approximately one third of the world population lived within 100 km of the ocean and 44% within 150 km (U.N. Ocean Atlas). In the United States, 153 million people, or 53% of the population, live in the coastal counties that constitute only 17% of the land area in the contiguous U.S. and Hawaii (Crossett et al 2004). While population growth rates in these counties are not drastically higher than in the rest of the U.S. counties, their smaller area and higher population density have made this a more prominent problem than in other parts of the country (Crossett et al 2004). People's presence in the coastal areas has become the most important driving force of change in coastal and marine systems that now ecosystems can not be overseen properly without considering social and human components of the environment (Hughes et al 2005; Folke 2006).

It is crucial to work towards ensuring a more sustainable relationship between man and marine systems that management takes into consideration not only how man affects the natural environment, but also how reliant the world is on healthy and properly functioning coastal and marine ecosystems. The outcomes of the increasing presence of human kind in the coastal areas are munificent. Increased presence has lead to increased development and changes in landuse. Such changes have lead to nutrient and sediment loading and eutrophication, as well as water quality degradation (UNEP 2006). Some development has decreased critical coastal fixtures such as salt marshes and other wetlands, barrier beaches and productive tidal or seagrass flats (UNEP 2006). Excessive demand on extractive resources such as seafood products leads to overfished systems and degraded habitats (UNEP 2006; Jackson et al 2001). In addition to these immediate problems, the time delayed pressures of a human induced climate change will also come to bear on these dynamic coastal ecosystems (UNEP 2006).

At the same time that humans continue to exert these pressures on coastal ecosystems, they continue to demand increasingly the services these systems provide. Demand for seafood products is high. Not only do many people from food poor countries rely on seafood for a cheap protein source, but people from developed countries have changed their preferences for a more seafood rich diet. It is also thought that shifting demographics and population growth in the U.S. and other countries, is causing the increase in sea food demand and faces a large seafood deficit of about $8 billion annually (Goudey, et al, 2006; http://www.fas.usda.gov/ffpd/Fish-

Circular/Market_News/IATR_Seafood_Imports.pdf). Over fished systems suffering from habitat loss and degraded water quality are not able to provide the quantity of seafood required by the market. Coastal tourism is also a booming industry. The recreational benefits of coastal systems rely on their healthy condition. Recreational fishing, boating, swimming, site seeing and the desire to visit these areas is all dependent upon a coastal system that can provide these services. Coastal livelihoods also rely upon the healthy condition of these systems, as do cultural tradition and spiritual rites.

The present study explores the town of Wellfleet, Massachusetts. The harbor and the wild shellfish resource in this town have come under pressure from the human element in the ecosystem. Following an ecosystem based approach, a proposed action in regards to the shellfish resource and harbor functionality, shellfish spawning sanctuaries, is examined.

Goal: This study will examine the need for shellfish spawning sanctuaries, given the current condition of the harbor. It will also analyze existing data to determine where there are suitable sites for shellfish spawning sanctuaries in Wellfleet Harbor. While achieving the overall goal of suitability analysis, the project's aim is also to demonstrate the importance of scientific data and the application of GIS in site suitability analysis for spawning sanctuaries and for coastal decision making.

Objectives:

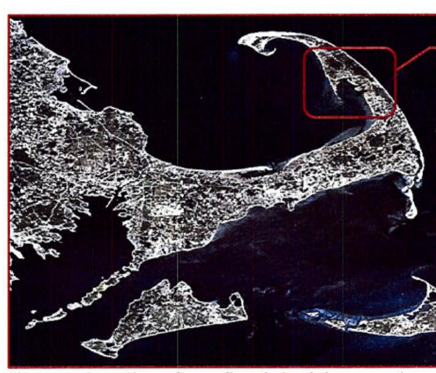
- Assess the need for spawning sanctuaries and identify siting criteria
- Use existing data in GIS format to analyze sites and provide a recommendation as to their suitability
- Demonstrate that current GIS applications in site suitability analysis can be expanded and applied to site analysis for spawning sanctuaries

Section 1: Introduction

Wellfleet is a thriving community located on the outer part of Cape Cod, Massachusetts. Central to the heritage, character and economy of the town is Wellfleet Harbor. The natural beauty of the town and harbor, its tranquility and the recreational value it affords have drawn many people to the area, including life long residents, tourists and retirees. While the same attributes of this area that drew many people to Cape Cod and Wellfleet continue to do so, they are also coming under increasing pressure from the increase in their popularity in the larger population. People love the Cape Cod region for its natural beauty, recreational opportunities, savory seafood, spectacular beaches and its seemly quaint seafaring traditions. However, the pressures that Cape Cod visitors and residents exert on this fragile coastal ecosystem threaten the functionality of the underlying ecosystem.

Figure 1.1 Location of Wellfleet

Source:
http://www.1uptravel.com/worldmaps/n-america2.html



(Source: http://terrafly.cs.fiu.edu/aerial_posters/template.asp?item=1041)

The problems in Wellfleet are not unique. They are occurring in the backdrop of global marine systems being over harvested of their fish/shellfish stocks as well as critical components such as spawning grounds and habitat being stressed and degraded (Folke et al 1998). There are many cases of both anthropogenic changes of land use, overexploitation of marine resources, particularly shellfish, and habitat alteration causing decline in the abundance and health of such stocks, as well as the social systems built on top of them: Chesapeake Bay, the south shore of Long Island, James River, Delaware Bay as well as other Cape Cod areas such as Pleasant Bay are a few examples (Woods et al 2005; Mackenzie 1996; PBRMA 1998).

Physical history of Cape Cod

During the later half of the 20th century Cape Cod has undergone extensive change. Many Massachusetts residents will remark that the "Cape" (as it is endearingly termed) is not what it used to be. That is has become too commercialized, too crowded and too hectic in the summer months. Along with population increase and commercialization of the area have, come more subtle changes in the environment, often not perceived by the unwary traveler seeking a bit of relief from an exhaustive job.

Cape Cod as it was first encountered by the pioneering wave of European explorers of New England waters in the 16-17th centuries was a place of abundant resources. From which the namesake derives, the waters off of Cape Cod were replete with the infamous Cod fish and so the arm of land was named. It is reported in several accounts that the fish were so thick that one could drop down a basket and catch them

(Kurlansky 1998). While the history of Cape Cod as we know it could be considered to start with that first wave of settlers, much occurred before the colonization.

The actual beginning of history for the area could be more conveniently considered as the last ice age. This period started about 25,000 years ago and with it the northeastern section of the current U.S. was covered by the Laurentide ice sheet that extended out past the current land area of the continent and into the Atlantic Ocean (http://pubs.usgs.gov/gip/capecod/glacial.html). The evidence suggests that the ice sheet extended as far south as today's Martha's Vineyard and Nantucket Island. As the Ice Age passed and the ice sheet began to retreat, the islands and arm of Cape Cod were fashioned through the movement and melting of the ice sheet. Most of Cape Cod as it is known today is the remnant of glacial outwash. Wellfleet's origin was as a glacial outwash plane and it is speckled with more telling artifacts such as kettle ponds and large boulders (http://pubs.usgs.gov/gip/capecod/glacial.html).

In more recent times the barren plains left after the glacial retreat have been transformed. Wind blown sediments and the arrival of seeds have brought Cape Cod from barren to fertile (http://pubs.usgs.gov/gip/capecod/glacial.html). The area displays a classic upland of pine barrens. Underlying sediment is largely the porous sand deposits and therefore fluids easily flow below ground. Coastal lying areas are patchworks of dunes and beaches, salt marshes and freshwater wetlands. These features have endowed the Cape with a beauty some say is unrivaled on the east coast of the U.S. In addition the area is endowed with rich marine resources.

The emergence of tourism and the population boom

As noted previously the settlement of the Wellfleet area was precipitated by the abundant marine resources. As the economy of Wellfleet expanded and matured, and new technologies reached the Cape area, however, the base of the economy started to change. When whaling declined in the 1700s it was replaced with shellfishing and finfishing in the 1800s. As fish stocks declined, shellfishing remained a vital resource. And in the 1900s as wild shellfishing waned with lower natural abundances, aquaculture stepped in to fill the hole. Tourism to the rather pristine Cape Cod also established its place in the late 1800s and throughout the 1900s. While a scattered few Bostonians were said to have summer houses in Wellfleet after the arrival of the railroad, tourism development was jumpstarted by the construction of an inn and yacht club that began in 1885 (WLCP). Tourism has become the sector of primary importance for the Cape's and Wellfleet's economy and demographics, not eliminating but most certainly surpassing the shellfish resource in value.

The population of Wellfleet during its fledgling years was relatively stable at just over one thousand residents, but fluctuated in response to the status of finfishing, whaling or shellfishing. This was the situation until around 1950 when a boom in regional population and tourism changed the demographics of the area. The population in Barnstable County (encompassing all of Cape Cod minus the islands) nearly tripled in the period from 1950 to 2000 (see Figure 1.2). Wellfleet had a similar trend, doubling in the same period (see Figure 1.3).

Figure 1.2a: Population of Barnstable County, 1930-2001 (Source: CCC bulletin)

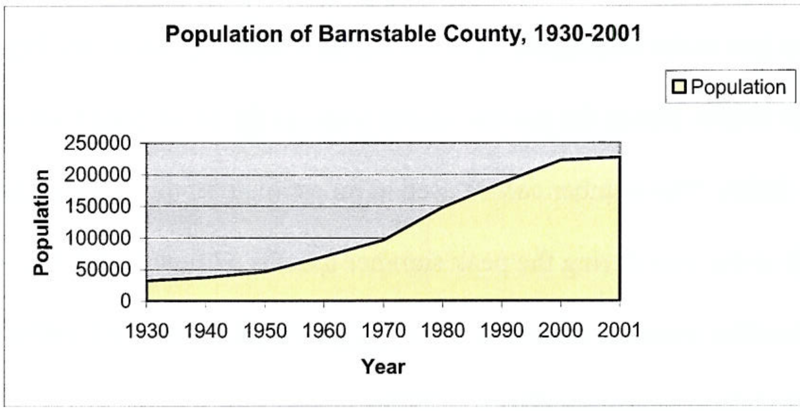
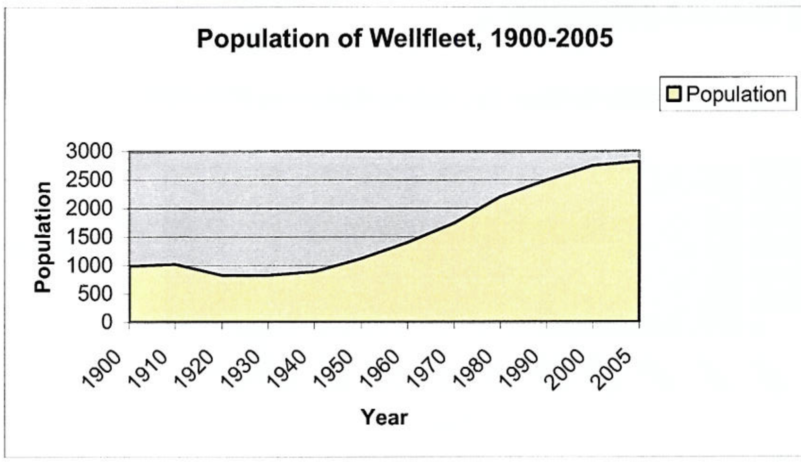


Figure 1.2b: Population of Wellfleet, 1900-2005 (Source: WLCP; U.S. Census Bureau

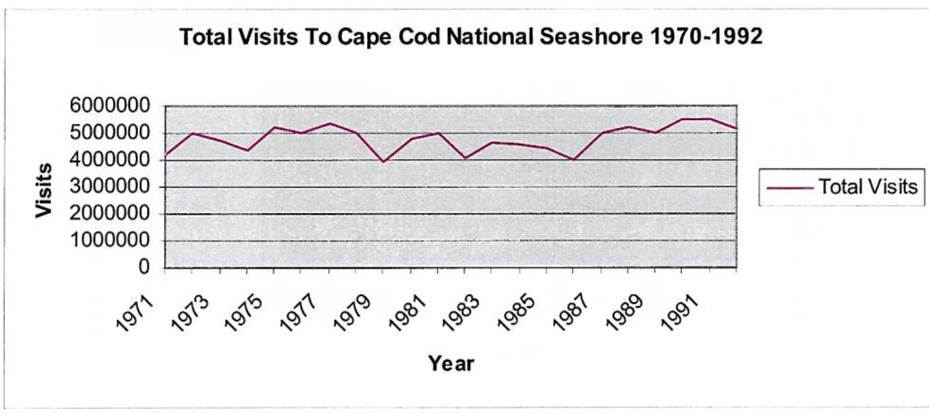


Tourism has been for quite a while now, and still remains the number one driver for the Wellfleet economy. Wellfleet has broken from the days when it depended nearly solely on extraction of marine resources and had a stable year round population. While Wellfleet today still is defined by its coastal areas and marine resources, its population responds strongly to a seasonal tourism boom that occurs during the summer months of June, July and August and a late spring and fall shoulder season.

While there is no official count of tourists to Wellfleet or the Cape region, the town uses the Cape Cod National Seashore visitor center in Wellfleet as its source for tourism statistics. The center has logged the number of visitors since the National

Seashore's inception in 1961. While this count has wavered since 1961, on the whole it has wavered from just under 4 million to about 5.5 million to the present, see Figure 1.3 (WLCP). Another source places the present annual average for all of Cape Cod at 6 million (Barrow 2001). This number can be used as an estimate of the total number of tourists that flock to the area during the peak summer months of June-August and the late spring and fall shoulder seasons. In a state whose population is just over 6 million, this number of tourist visits is enormous (Barrow 2001).

Figure 1.3: Number of Annual Tourist Visits Registered at the Cape Cod National Seashore Visitors Center in Wellfleet, 1971-1992 (Source: WLCP)



As tourism became a leading industry on the Cape, the area became increasingly known for its natural beauty, scenic views, relaxed pace of life and good seafood. For the aging population that did not mind the cold New England winters, these characteristics made the Cape attractive as a retirement destination. This trend has continued to the present. The demographic profile of the Cape is again changing to show not only a growing population, but one that has a higher percentage of elderly people, and constantly decreasing primary school aged children and young adults (Age). The Cape Cod Commission reports that the average percentage of population in the 65 plus category in Barnstable County was 23.1% in 2000 (Age). This drastically exceeds the statewide average of 13.5%. In fact, out of 351 total towns in state, Cape towns capture ranks 1-7 and also close trailing ranks of 10,11 and 17 for the oldest towns in the commonwealth. Wellfleet is the eleventh oldest town in Massachusetts (Age).

The trend of retirees migrating to the Cape is a driver for further development in this region. Tourism has already given way to many second homes or vacation homes on the Cape. The retiree trend is turning some of these vacation houses into year round residences. The conversion of summer "cottages" or remodeling of existing houses is a significant portion of construction business on the Cape. An end result of the residence conversion is a lot more people staying on the Cape year round, exerting further stress on the area's fragile resources. In addition to tourists and retirees, the Cape has also seen an increase in residents that either live in the area already or come to the area to live, but commute off Cape to work.

Another socioeconomic trend on the Cape is the lack of a robust economical base that provides year round employment. While increased demand for property from vacationers and residential and commercial expansion has driven up real estate values, the economy base has not offered similar growth or opportunity in the employment field (Barrow 2001). Year round, livable wage employment on the Cape is at a premium, since the economy base is primarily seasonal catering to tourism in the warmer months. So while there is an increase in population there is an erosion of the economic base that keeps young people in the picture.

Emerging Problems: The result of increasing population and development on the fragile Cape Peninsula

The synthesis of these demographic changes occurring on the Cape Cod is increased pressure on the natural environment and increased demand of natural resources.

The increase in population alone has exerted phenomenal pressure on the area. More people and more visitors have lead to land use changes. Vegetated areas have been converted into residential zones as well as commercial and urban uses. Salt marshes have been diked off, and fragile coastal areas such as sand dunes have been encroached upon by large vacation homes. Wellfleet, in the later part of the 20th century lost considerable forested land as well as freshwater wetlands to development (see Figure 1.4). Residential zones increased in area as well as commercial zones (see Figure 1.4).

Figure 1.4 Wellfleet Landuse Changes

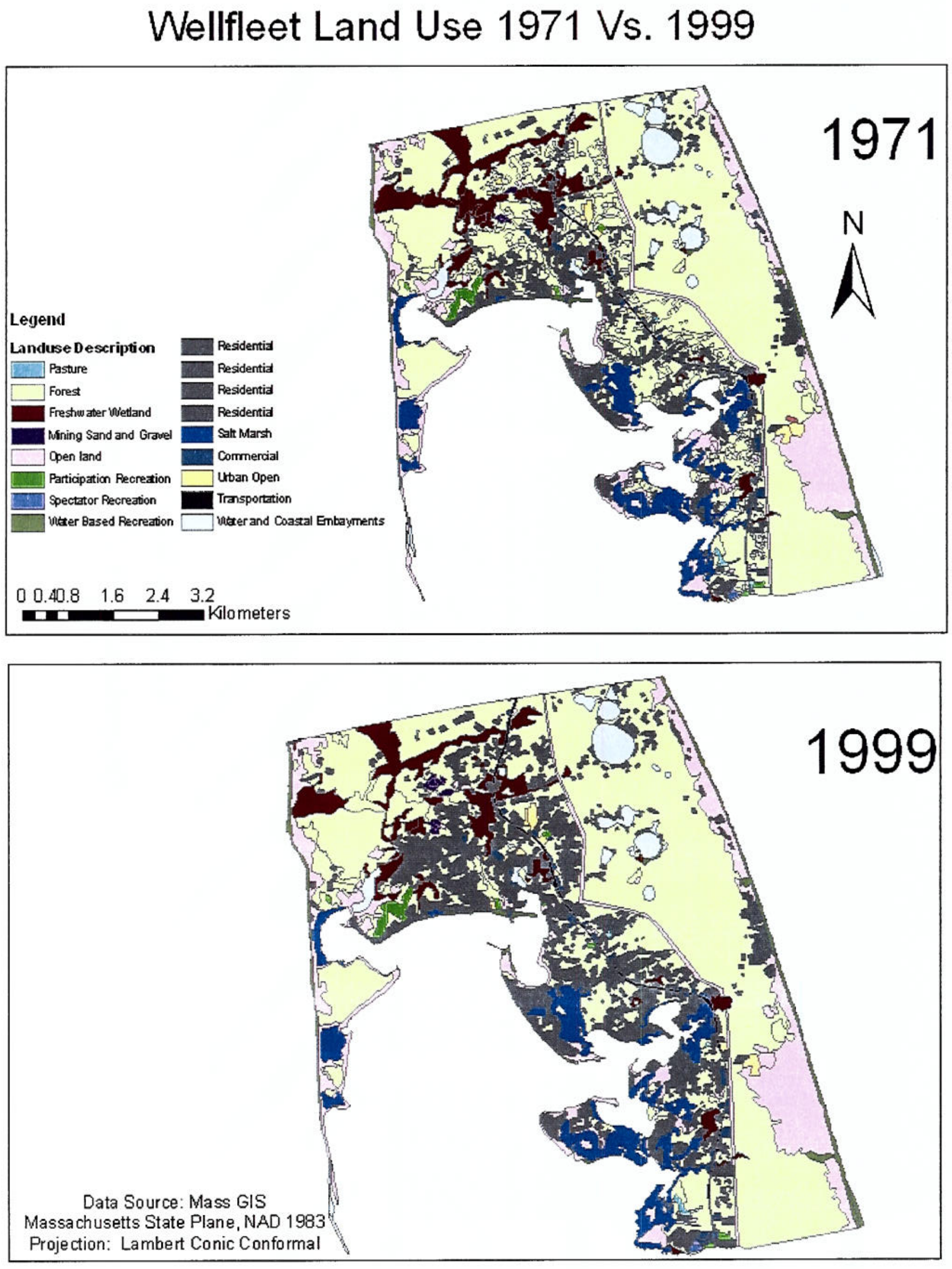


Figure 1.5 Wellfleet Landuse Comparison

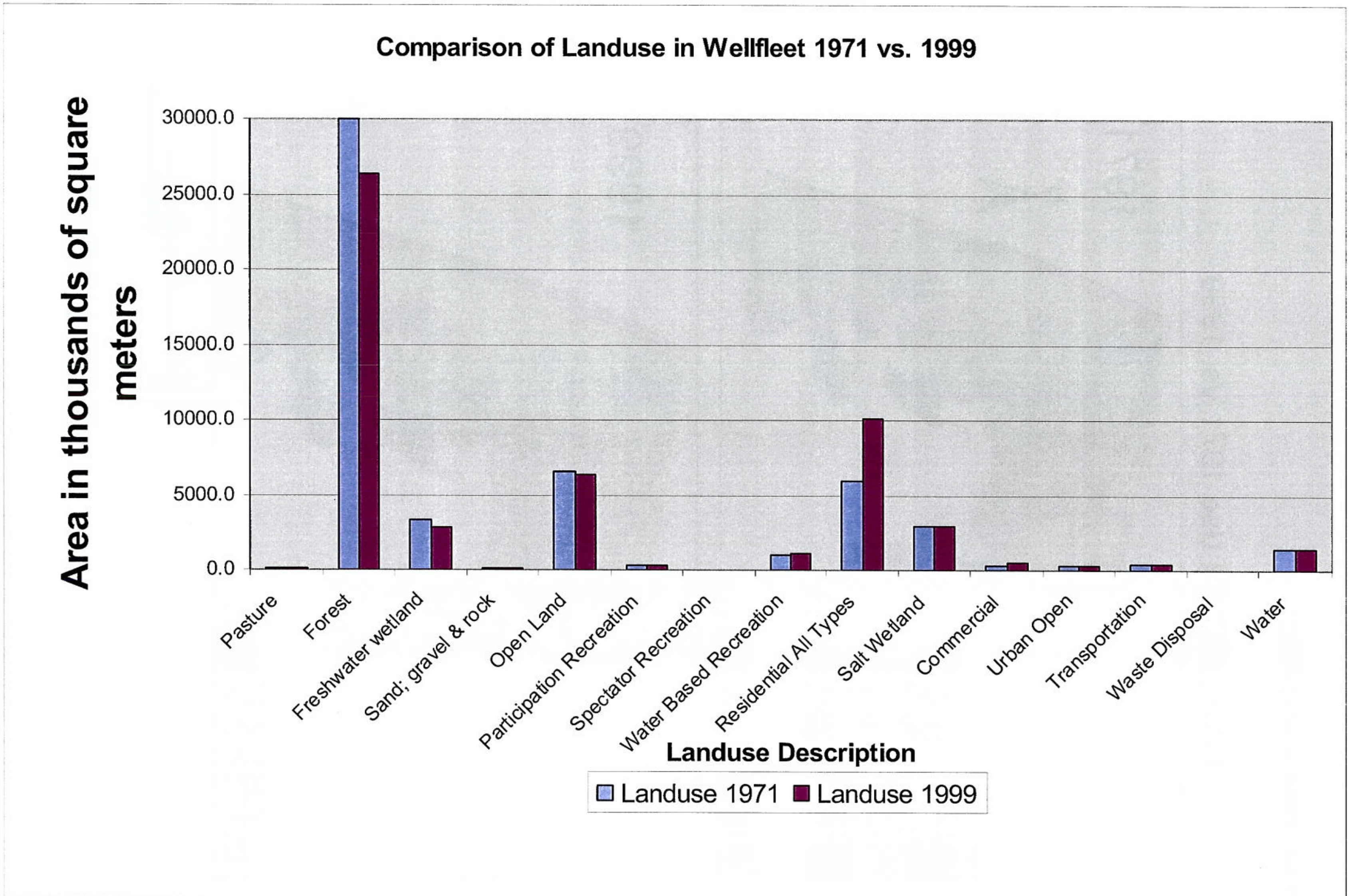
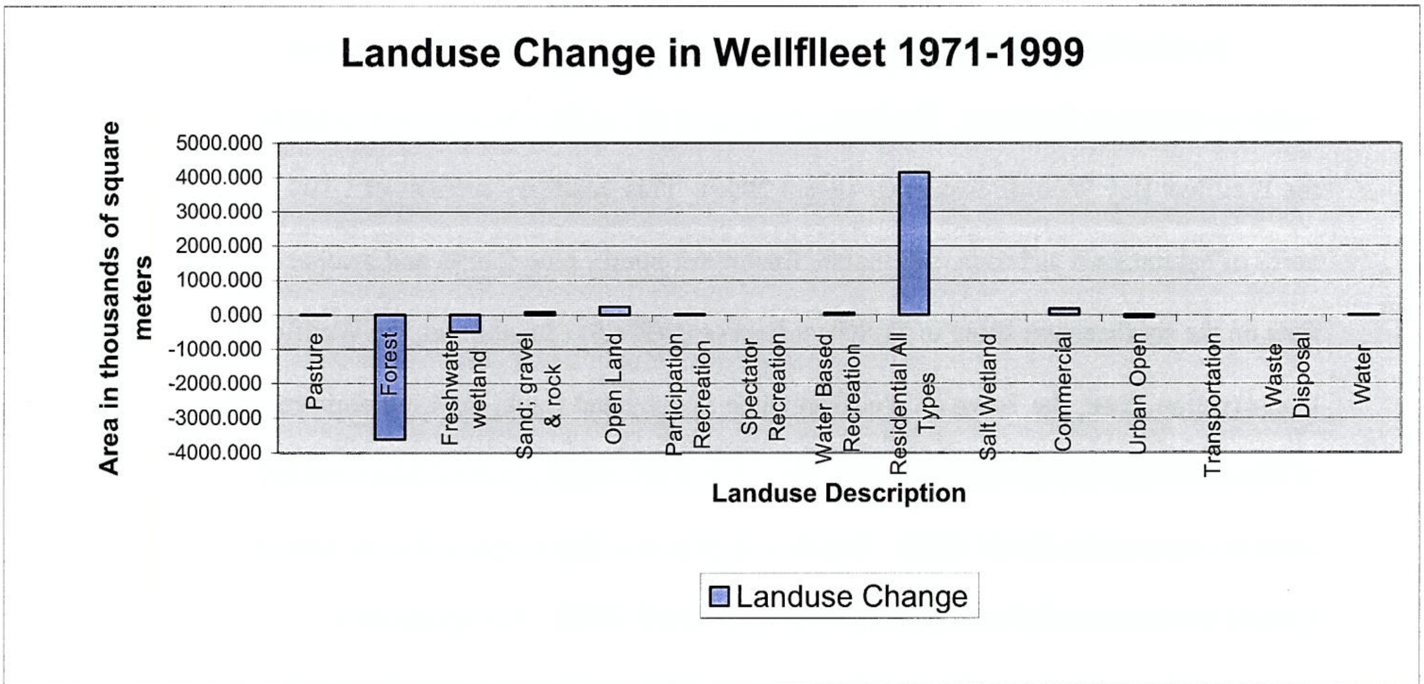


Figure 1.6 Wellfleet Area Changes in Landuse



While Wellfleet has been experiencing this pattern of growth and subsequent pressure on its natural environment, it may not be as hard off as other Cape communities. Wellfleet has the benefit of being protected to varying degrees by several designations. The first and likely the most important was the designation of the Cape Cod National Seashore (CCNSS) in 1961 (Riehl 2006). This designation, whose spatial extent included several outer Cape towns, placed 61% of Wellfleet land area under protection to "provide recreational access, cultural preservation and continuity of traditional ways of life" (Riehl 2006). The result of the CCNSS for Wellfleet was limitation of developed areas, and a concentration of commercial and residential development to a narrow band of land on the eastern and northern shore of the harbor.

Most Cape towns are not fortunate enough to have such a high percentage of their land protected from the usual development pressures.

Besides the CCNSS, there are a couple other organizations that have put land under protection in Wellfleet. The Massachusetts Audubon Society owns and operates the Wellfleet Bay Wildlife Sanctuary (Riehl 2006). This sanctuary consists of 1,100 acres of habitat such as beach, salt marsh, freshwater ponds, pine forests and heather flats on the southeastern shore of Wellfleet Harbor (WBWS). In addition, the Wellfleet Conservation Trust, the Town of Wellfleet Open Space/Land Bank, the Commonwealth of Massachusetts and the South Wellfleet Conservation Trust together hold around 400 acres in conservation (Riehl 2006). Wellfleet Harbor was also designated as an Area of Critical Environmental Concern (ACEC) in 1989 (Riehl 2006). This designation recognizes the ecological and cultural importance of the harbor and marks the area as one that is critical to protect due to the importance of the ecological features it has. Such a designation puts in place a framework for agencies of the Executive office of Environmental Affairs to corroborate to the purpose of scientific monitoring of the area, preservation/restoration of local resources and minimizing the effects of activities in the ACEC on the natural environment and culturally important features (ACEC Program Overview). It is unclear what actions have been taken under this designation.

Social Assessment

While Wellfleet is considered a lovely place to live and visit, it does not provide many opportunities for employment. Tourism is the primary source of economic gain. While many people are employed in the services industry that is tourism, the employment is largely seasonal. Another major source of employment in the area is construction. The population growth, and home conversion/ remodeling trends have vitalized the construction and building sector. Shellfishing, like in times past, remains a critical economic sector that provides employment, food and recreation to many.

Section 2: Shellfishing and Aquaculture: Two important activities in Wellfleet Harbor

The harbor's endowment of natural resources has given way to active shellfishing throughout the area's history and continues today. In Wellfleet, the shellfishing industry is comprised of both wild catch and aquaculture operations. Both wild shellfishing and aquaculture are traditional uses of the harbor that are remnants of the town's heritage, dating back to pre-colonial times (Riehl 2006). The industry is a source of year round employment for people in the area and was a $3.5 million business in 2005 (Riehl 2006). The industry also supports a full time shellfish department and generates funds for the town through the purchase of shellfish harvest permits (Riehl 2006). Recreational shellfishing is also an important opportunity that the shellfish resource provides.

The Social and Economic Importance of Shellfish

Historical role

Members of the Nauset Native American tribe are thought to have inhabited the modern day Wellfleet area starting around 6,000-4,500 B.C. (WLCP 1994). There is evidence that the early residents of the area were largely marine dependent, utilizing the shellfish, finfish and marine mammals that were present in the harbor. Later Native Americans were thought to live with a heavier winter time dependence on the marine fauna and a shift towards agricultural dependence in the warmer months (WLCP 1994).

Scattered shellfish waste dumps, indicate a historic abundance of shellfish and the subsequent importance of them for Native American settlements (WLCP 1994).

While the first European settlers in the Wellfleet area were attracted by the abundant shellfish and fish resources that garnered names such as Oyster Bay and Billingsgate (after the famous London fish market), they also adopted the Native American lifestyle of seasonal agriculture and fishing. These first settlements were established around mid 17th century and their growth was fed by the abundance of various marine resources. The 1700s marked a great whaling period for the settlements in the Wellfleet area (WLCP 1994). What began as a shore based hunt transitioned into a wider hunt into Cape Cod Bay and eventually a Wellfleet whaling fleet of 20-30 ships and over 400 men that hunted whales as far a field as Africa (WLCP 1994). Whaling declined during the last quarter of the century due to a British war ship blockade during the American Revolutionary War that destroyed the whaling fleet (WLCP 1994).

At the same time, shellfish harvesting of oysters and quahogs and finfishing continued to be vital to Wellfleet. A crash of the oyster population in the 1770s was precipitated by overharvest and excessive substrate removal suitable for oyster spat settlement. Like the decline of the whaling industry, the oyster crash hit the town hard. The 1800s, however, saw the heyday of finfishing and salt making. The fishing fleet's main target was mackerel. This industry, however, also peaked during the century with 95 fishing vessels, and subsequently declined as the 20th century approached (WLCP 1994). The importation of oyster spawning stock, primarily from Chesapeake Bay, eventually revitalized the oyster industry and the town economy during the 1800s. Transportation of seafood and other products to market was facilitated during this century through a shipping route between Wellfleet and Boston, and later on a railroad that connected to Fall River and ports beyond (WLCP 1994).

There are four commercially important species currently being harvested in town whose importance has fluctuated throughout history. In decreasing value of catch the species are the northern quahaug *Mercenaria mercenaria*, the Eastern Oyster *Crassostrea virginica*, the Bay Scallop *Agropecten irradians*, and the soft shell clam or steamer *Mya arenaria* (SMP 2002*)*. While all four species can be encountered in Wellfleet Harbor, the town has come to be known for its tasty oysters and large quahaug landings. The trends of culture and wild harvest of these species in Wellfleet is similar to that of national trends. While culturing of the Eastern Oyster and the northern quahog have increased, the wild harvest of both species has conversely declined, see Figures 2.1 a-d.

Figure 2.1a U.S. Trends in *Crassostrea virginica* aquaculture production, 1950-2004

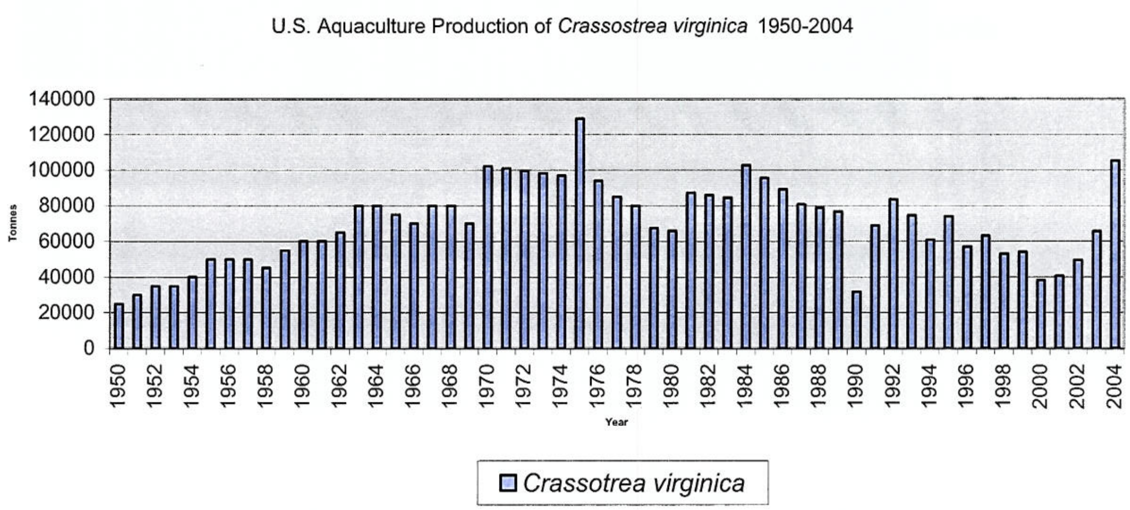


Figure 2.1b U.S. trends in *Mercenaria mercenaria* aquaculture production 1950-2004

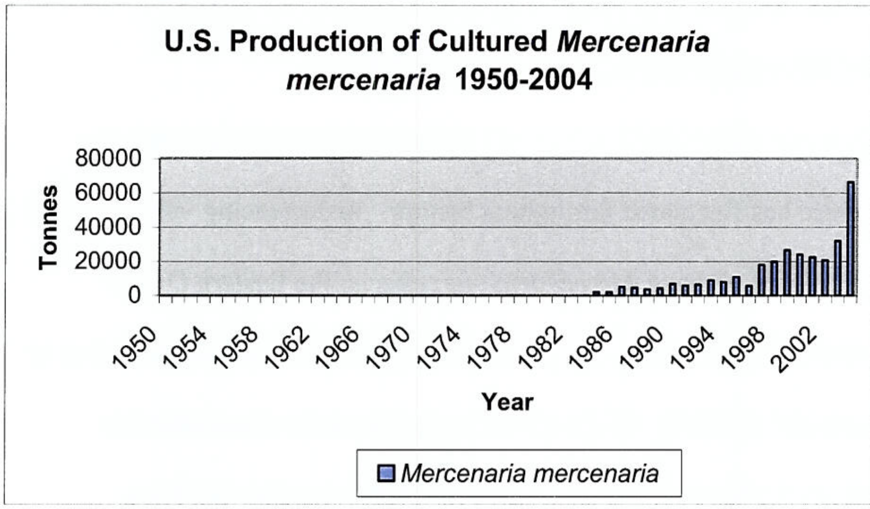


Figure 2.1c U.S. National trends in Crassostrea wild harvest 1950-2005

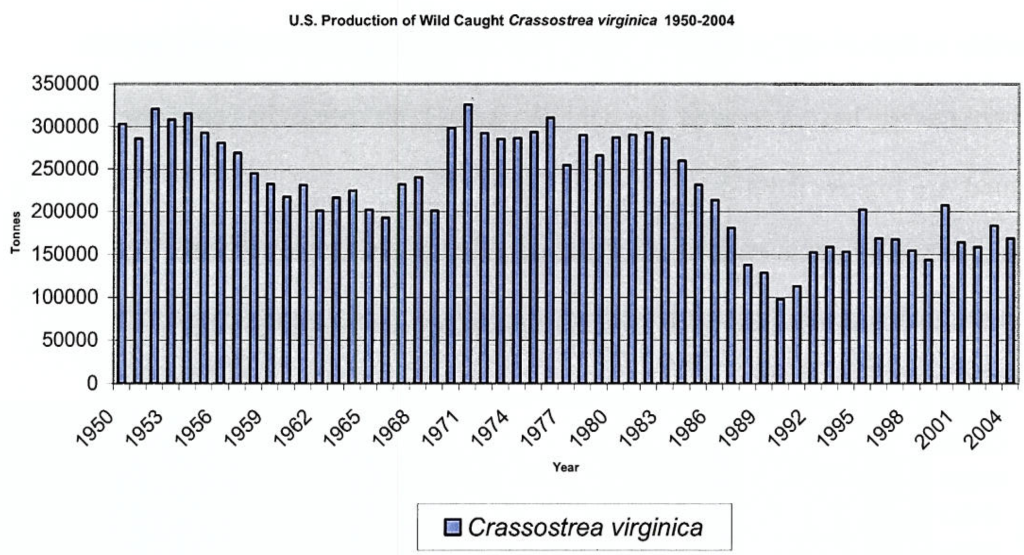
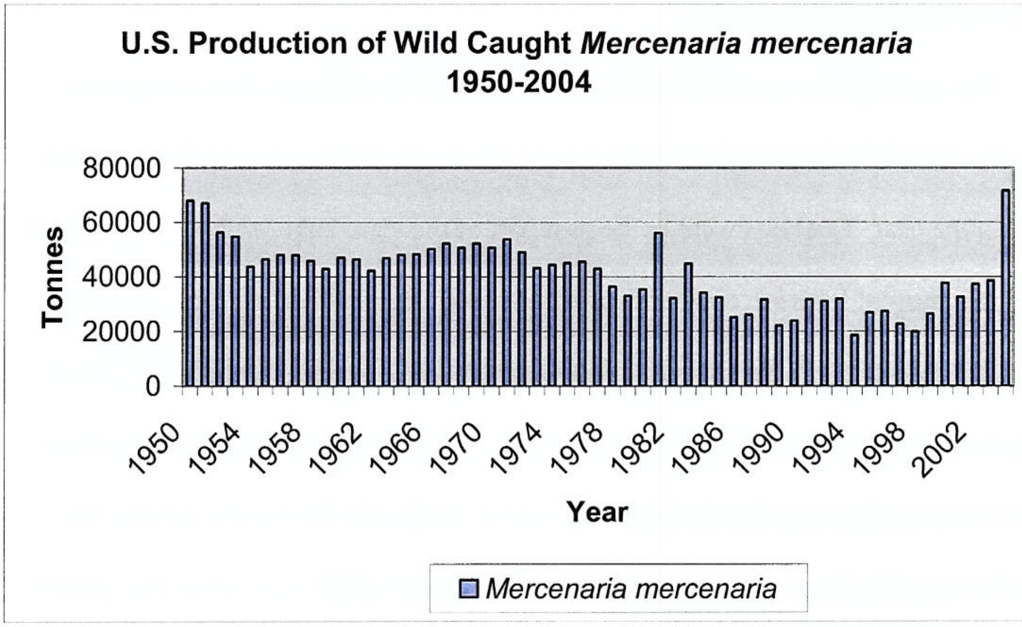


Figure 2.1d U.S. trends in wild Mercenaria mercenaria production 1950-2004



Furthermore each of these commercial species has played a role in the cultural history of the region. In particular, the quahog or hard clam (*Mercenaria mercenaria)* has been pivotal in both the Native American and post colonial histories; the chronicles of these cultures would not be complete without the discussion of the quahog.
It can be said that the influence of the quahog has reached far beyond its most traditional contribution as a source of income and employment.

One of the most well known contributions of the quahog is its shell. The quahog shell in the northern part of its US east coast range has been used by native tribes to make the prized wampum. Wampum was the polished purple pieces of the quahog shell. It was used for trading within and amongst tribes. It was appreciated for its decorative properties and used in various jewelry and adorning applications. It was traded with other tribes for furs. It was even briefly used as currency by Europeans after their arrival. While this tradition has faded, wampum is still appreciated for its beauty and used to make jewelry.

The quahog also spawned a New England tradition that lasts into the present. While the clam bake is not quite what it used to be it continues to be a tradition rooted deeply in the past. Quahogs were in the past part of the clam bake, which comprised of a large steaming of lobsters, clams, mussels and corn often held on the beach. Clam bakes helped draw many people to the coastal areas and to propagate the popularity of locally harvested seafood. They were also large communal events that drew members of local communities together to share the area's local foods. Today the quahog has been eliminated in favor of the more tender and juicy soft shell clam, but it was pivotal in the development of this tradition. Clam bakes continue to be widely popular today. While the origin of the clambake as either a native American tradition or a post colonial invention, it is an important cultural institution handed down to us from history. The other commercially harvested species, such as the soft shell clam, bay scallop or razor clam, may also have been included in the clam bake menu, although specific mention of them is made in the literature (Neustadt 1992).

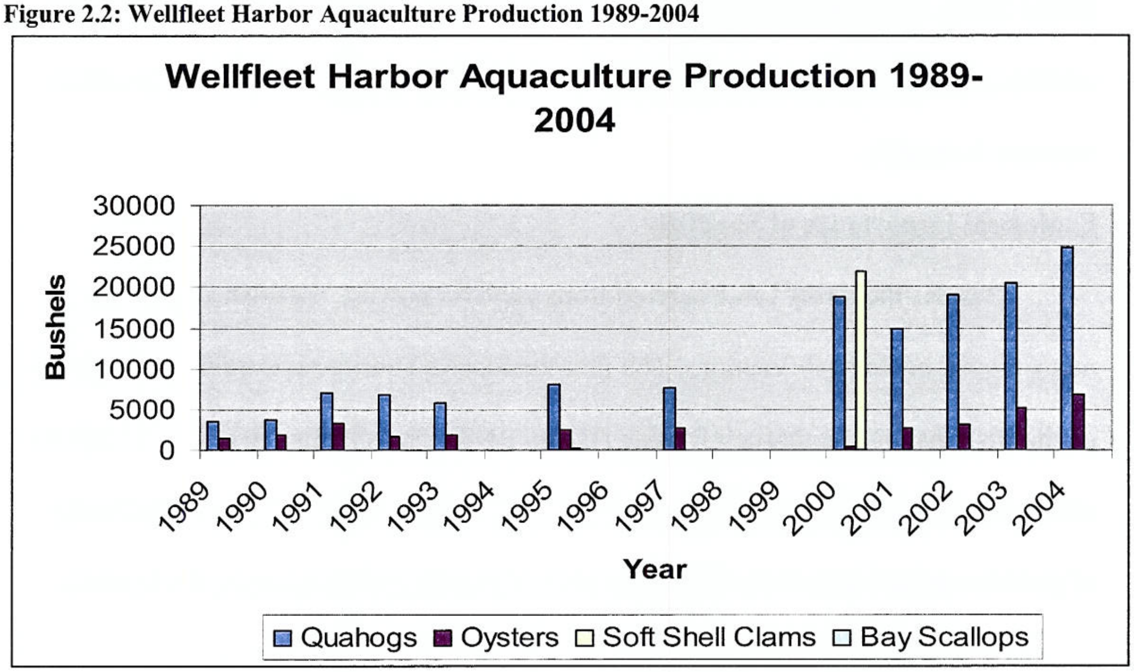
The Eastern oyster *(Crassostrea virginica)* was a more popular raw food. They were often included on appetizer menus in pubs and bars as oysters on the half shell. While its shell was not used for adornments or as currency in native American tribes as was the quahog, it was alternatively used to make lime during the post colonial era.

<u>Present role</u>

Wellfleet Harbor presently has a total surface area of 6,094 acres at mean high water and 3,815 acres at mean low water (Wellfleet Harbor Project). The area of public shellfishing grounds utilized for wild harvest is 2,500 acres (Riehl 2006). This is a significant proportion of the harbor's total area. There are currently around 200 acres of intertidal land being leased for aquaculture (Wellfleet Harbor Mapping Project, 2002). While aquaculture is present and in terms of production, more important, it is clear that the wild harvest uses more of the harbor's area and that it is sensitive to resource depletion and degradation.

A large number of people are involved in Wellfleet's shellfish industry. In 2005, there were 73 aquaculture grant holders and an estimated 200 people working on the aquaculture sites. A GIS map generated in the Wellfleet Harbor Mapping Project in 2002 shows 131 aquaculture grants being leased by a total of 71 lessees with an average lease size of 1.5 acres. The approximate total area of grants in that same year was 197 acres, a mere 3% of the harbor's total area at mean high water. The area leased out in aquaculture grants has been increasing as well has been the production of these aquaculture grants (see fig.2.1).

Figure 2.2: Wellfleet Harbor Aquaculture Production 1989-2004



A total of 1328 shellfishing licenses for wild harvest were issued in Wellfleet in 2005 (Riehl 2006). Approximately 283 of these permits were commercial, while the remaining 1048 were recreational held by both town residents and non-residents/visitors alike (Riehl 2006). The distribution of permits illustrates that shellfishing is not only a commercial endeavor in town, but also a recreational one for Wellfleet's year round residents, seasonal residents and visitors.

A 1994 survey of tourists in Wellfleet revealed that 23% participated in recreational shellfishing on their trips (WHRC 1994). It also showed that 71-86% of tourists enjoyed viewing commercial fishing/shellfishing activities occurring in the harbor. The same survey given to residents of Wellfleet showed that the average resident had taken slightly over 8 shellfishing trips in the past twelve months, and that 14% had worked in shellfishing or fishing in the past or were currently employed in the industry (WHRC 1994). It is clear then, that in a town whose year round population is around 3,056 and seasonal population is 21,000, that shellfishing is not a minor player (Riehl 2006). With the harbor's wild shellfishing industry and recreational shellfishing central to the identity and economics of the town, investing in the conservation of this resource is crucial.

Ecological Importance of Shellfish

Besides the direct value derived from shellfish harvest, shellfish also serve many crucial ecological functions. The first function to consider is the filtering capacity of shellfish that occurs through feeding (Dame 1998). The shellfish in question feed on microscopic suspended particles carried in water currents. The diet consists primarily of particles greater than 3um. Phytoplankton is the principal component, but bacteria, detritus, nanozooplankton, inorganic particles and dissolved organic matter are also consumed (Dame 1998). The filtration action of shellfish clears large volumes of water of suspended particles and functions to maintain water clarity. The overall good water quality in Wellfleet is one reason for its popularity with tourists.

Another function of shellfish is their place in the food web. Shellfish are a link between microscopic plankton and particles to higher trophic levels. Shellfish are preyed upon by fish, birds, crabs, worms and other marine invertebrates. It is clear that healthy shellfish populations are important to other marine organisms and human uses of the water body. Shellfish also take part in material cycling.

Maintaining a healthy population of shellfish in Wellfleet Harbor equates to maintaining the critical ecosystem functions indigenous shellfish populations perform. The maintenance of these functions supports the ecosystem in all facets. As coastal areas such as Wellfleet come under increasing stress, all ecosystem functions are crucial. The resilience of ecosystems to stressful conditions is dependent upon ecosystem function.

Wellfleet Harbor Management Plan

In 2006 Wellfleet wrote a Harbor Management Plan that embodies a holistic vision for the harbor and town, very similar to an ecosystem based approach. Foremost it spearheaded the idea that the area is rich in natural resources and aesthetic value, such as shellfish, and that the town must work towards adequate protection of these resources. Common goals included:

1. Maintain good water quality
2. Ensure multiple, traditional uses of harbor with local employment opportunities
3. Maintain biological diversity of the harbor

4. Take a longer term perspective with policies and actions

In addition, a Shellfish Management Plan Draft was written in 2001. This plan, synthesized and gathered information about shellfishing and aquaculture in Wellfleet and proposed several changes in the management scheme in order to see a more fruitful and sustainable shellfishery, both wild and cultured.

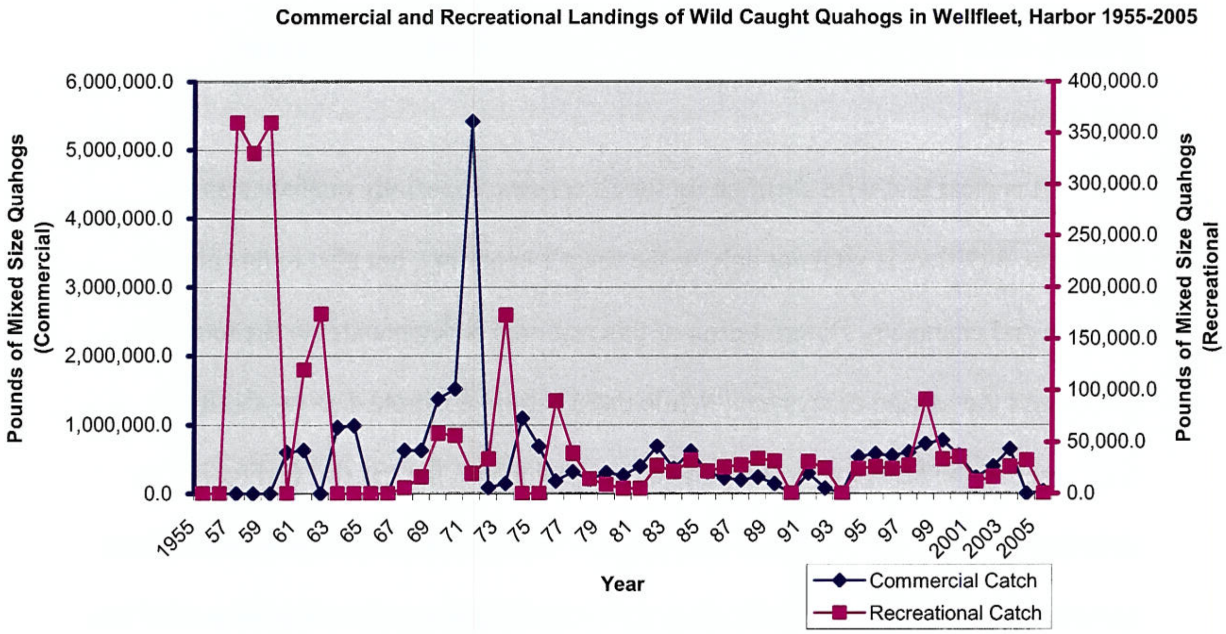
Marine resources, particularly shellfish, being so central to Wellfleet, should be carefully considered as the town looks forward. While the town has a vision of longer term perspective in regards to its harbor and resource base, revisions of current practices may be necessary. Any management action in Wellfleet in regards to preserving the wild shellfish stocks should strive to be instep with the aforementioned goals.

Management of Wild Shellfishing

Management of shellfish stocks in Massachusetts is carried out through home rule. That is each town or municipality has the responsibility for managing its own shellfish stocks, both to maintain the stocks and enhance production. This process is overseen by a natural resources department or shellfish department and is carried out by a shellfish constable with guidance from the Massachusetts Division of Marine Fisheries (DMF). Typical management techniques involve size limits, catch limits, rotation of closed and open areas, and enhancement through planted nursery seed. Wellfleet employs a number of techniques. These include planting of seed in recreational harvest areas, size limits for each species, catch limits, no dredge areas and seasonal closures of certain areas in the harbor. In addition the DMF must carry out a program that protects public health, by monitoring the waters where shellfish are grown for consumption. This federal program is the National Shellfish Sanitation Program (NSSP), which certifies shellfish beds as having safe levels of bacteria and contaminants.

It is clear that wild shellfishing for all species, especially quahaugs and oysters,in Wellfleet is vital not only to the town's economy, but also to its cultural heritage and character. Deterioration of this resource is detrimental to the town, its people and the marine ecosystem. While there is little concrete data on shellfish abundance in the harbor over the past century and a half, the general feeling is that abundance is lower than it has been in the past. Catches of all species are down from historic highs (SMP 2002). A Division of Marine Fisheries publication from 1907 has a record of 145 shellfishermen in Wellfleet with the annual quahog only landing at 30,000 bushels, during a time when the fishery was reported to be declining (Belding 2004). This figure does not include the catches for other species such as oysters, soft shell clams and bay scallops. The highest landing recorded of the annual wild harvest of all species in recent times has been approximately 25,000 bushels in the early 1980s, while most years the total is much less than 20,000 bushels (SMP 2002). The two statistics are comparable as the same number of acres is being harvested and similar restrictions are in place.

Figure 2.3: Wild Harvest of Quahogs 1955-2005



The town was not immune from fisheries decline before the presently perceived decline of the 20th and 21st centuries. In the 1770s there was a drastic decline in oyster catch due to the removal hard substrate such as shells from the harbor that oysters rely on. The problem was gradually alleviated through continual introduction of oysters from other eastern seaboard towns (Riehl 2006). Again in the 1870s the oysters declined drastically. That time over fishing was suspected to be the cause (Riehl 2006).

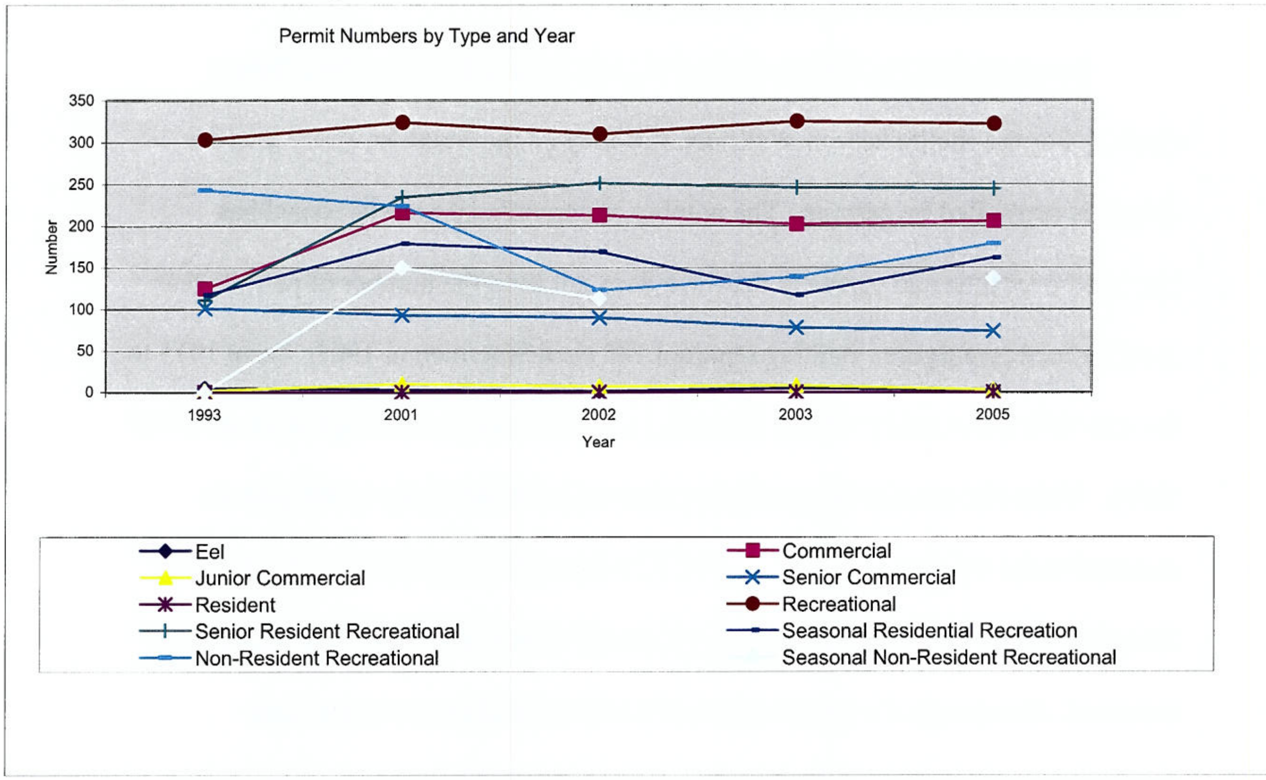
Issues Facing the Shellfish Populations and Shellfishing Industry

There is no singular cause of the present decline of the wild shellfishery, but rather several possible reasons that can be considered. They are related to increase of fishing effort since colonial times, localized decline in water quality and subsequent loss of habitat. Increased and sustained fishing effort is likely the main contributor.

Shellfish Harvest and its Effect on Abundance

Increased fishing effort is often cited as the principle reason for a fishery decline. For the shellfishery in Wellfleet, this may be the situation. Entry into the fishery is controlled by permits. The number of commercial permits issued has increased over time and currently the town does not limit the number of permits that can be issued (see figure. Belding reported 145 shellfishermen in 1907. From 1915 to the mid 1920s, the number of commercial permits hovered in the range of 10-60 (SMP 2002). While this number has gradually increased, a drastic jump to 250 permits occurred in the 1970s and since the late 1990s the number has held steady just under 300 (SMP 2002). The number of permits issued for recreational purposes has also increased. Also people dedicated only to recreational fishing are increasingly purchasing commercial permits that allow them access to many more of the town's shellfishing areas than do the restricted recreational permits (Andy Koch, personal communication). The end result is a larger number of people utilizing the shellfish resource and increasing pressure on a finite resource.

Figure 2.4: Shellfishing Permits Issued 1993-2005



There is a general resistance for tougher restriction on shellfish resources. Given the biology of commercial shellfish it is hard for some to comprehend the possibility that the resource can indeed be depleted (Peterson 2002). The Shellfish Management Plan of 2002 states that a general misconception in Wellfleet about the shellfish resource is that "two oysters could repopulate the harbor (SMP 2002)." Fecundity of bivalve shellfish is particularly high, as is with most invertebrates (Kraeuter 2005; Gosling 2003). This high fecundity is often compensated for by high mortality rates in the planktonic stage and after settlement. Causes of mortality are predation, larval abnormalities, and environmental conditions such as: salinity and temperature conditions, food supply, pollutants and weather conditions during the planktonic stage and lack of suitable substrate (Gosling 2003). Although the planktonic life stages of bivalves are in part responsible for their high mortality rates at these early stages, they also endow the populations with certain advantages. These include: the potential for broad dispersion, population resilience after die offs from the colonizing ability of the larvae, high reproductive potential given optimal environmental conditions, and increased range in dispersion range because of small egg size (Gosling 2003). This high fecundity also perpetuates the misconception that stocks are invincible.

The same reasons that give some advantage in the reproduction of bivalves also serve as pretenses to disregard any concept of spawner-recruit relationship in most traditional shellfish management schemes (Peterson 2002; Kraueter et al 2005). The general perception is that shellfish populations are extremely resilient, therefore there is little need to manage for recruitment or that recruitment in bivalves is density dependent (Peterson 2002). Interpretation of this concept precludes that harvesting the standing stock intensely will promote good recruitment through compensatory processes of spawning adults and settlement (Peterson 2002).

There is, however, emerging evidence of a spawner recruit relationship in highly fecund bivalve species (Peterson 2002; Kraeuter et al 2005). Long term data sets for a *Mercenaria mercenaria* fishery in central North Carolina and Great South Bay, NY were analyzed. Results suggest in the NY study that at low densities, approximately 1 individual m^{-2} and below, there is a strong spawner recruit relationship in which recruitment is limited by adult spawning stock (Kraueter 2005) and the North Carolina study revealed a 65-72% decrease in recruitment in the past two decades (Peterson 2002).

In addition to lower catches, invertebrate populations experience natural boom and bust cycles. In Wellfleet, the bust side is intensified through thorough harvest of adult stock in the preceding boom year (SMP 2002). This in essence is an intensive removal of broodstock. The town also relies on outside purchase of seed quahaug that is reared in town beds and placed in the recreational public fishing grounds (SMP 2002). The full potential of harvest is not being realized and this goes against the town's goal of maintaining stable gainful employment in the shellfishing sector, maintaining traditional uses of the harbor, and having a longer term perspective of actions taken in the harbor. Lower catches and deterioration of the shellfishery is harmful not only because year round employment is scarce, but also because it is part of the town's cultural heritage and because healthy shellfish populations serve important ecological functions in the harbor.

Another aspect, the market for shellfish, is also at play in the present decline. The situation for the quahog and the oyster are quite distinct. The quahog used to be marketed in three main size classes, the smaller being the most valuable and the largest being the least valuable. The smallest was the littleneck at 25.4-36.4 mm, 25.4 mm (1 inch) being the smallest legally harvestable size. The middle size quahog was the cherrystone measuring between 36.5-41.3 mm. Any quahogs greater than 41.3 mm were considered to be chowders (Kraeuter et al 2005). In the past twenty years, this classification scheme has shifted to expand the smaller size classes of quahogs, dividing the littleneck into three "neck" categories and shifting the cherrystone and chowder classification to slightly larger clams than before (Slaughter, personal communication).

Because of clam meat characteristics and manner of consumption, the smaller quahogs are more valuable. Necks, the smaller quahog size classes, while capable of bringing in substantial money to the harvester, are less valuable than an oyster. Prices for neck classes had been in the low to mid twenty cents range until about five years ago when they dropped drastically to around 12-15 cents (Andy Koch, personal communication). Logically, harvesters prefer to land smaller size classes and receive more money for their work and the result has been a shift in favor of harvesting the smaller size classes of quahog. This pattern is reinforced through daily catch limits imposed on harvesters, as the harvester prefers to bring in his 5 bushel limit loaded with a higher per unit value item. Oysters from Wellfleet are generally sold for consumption on the half shell, rather than as shucked meats. The average price per oyster is $.50 (personal communication Tom Slaughter).

Shellfish aquaculture, although often presented as an environmentally and socially beneficial activity in the coastal zone, can have and has had significant negative economic impact on wild shellfisheries. The average wild harvester these days must work doubly hard as he did in the 1990s, i.e. go out for both low tides, to earn the same amount of money. If he isn't working with double the effort, he likely is earning less money than the last decade (Tom Slaughter, personal communication). This can primarily be attributed to the increase in aquaculture product, as well as other factors.

Though no population studies have examined this issue, the current bias towards harvesting the smaller size classes of quahogs has many potential implications for the quahog abundance in Wellfleet Harbor. As a quahog increases in size, so does the number of eggs or sperm released from the individual (MacKenzie et al 2001; Gosling 2003). Therefore, larger cherrystone and chowder quahogs contribute more eggs than the smaller neck classes. Given the fact that the bias in harvesting is towards the necks and cherrystone classes a couple of processes may be occurring. On the one hand, high catch grading may lead to larger individuals being left behind in favor of smaller ones. The shellfish constable of Wellfleet, however, has indicated that fishers will go to areas where smaller quahogs are known to be present and larger individuals caught along with them will not be sent back (Andy Koch personal communication). On the other hand a completely opposite process could be occurring. One, intense harvest of smaller clams is leaving a lower number of clams to grow larger. Two, since fewer clams are making it past the cherrystone stage to the chowder stage, the contribution of the harvested quahogs to the annual set is lower than if there had been larger quahogs that produced more eggs every year. Three, the wild stock of quahogs is yielding fewer eggs for a set that will not be as substantial as when there was a higher standing stock of larger adults. This process has been termed recruitment overfishing by some and is not often considered in shellfish management schemes because of the debatable perception that shellfish recruitment is density dependent (Peterson 2002).

<u>Waterquality in Wellfleet Harbor</u>

"Water quality is the theme that ties together all of Wellfleet Harbor. Shellfishing, beach-going, boating, water sports, natural resources…all depend on the excellence of water quality in the harbor." Wellfleet Harbor Management Plan

Considering the larger ecosystem of Wellfleet, large changes in the terrestrial environment may be causing a decline in water quality that has potential effects for the shellfish resource. From 1960 – 2002 the population increased from 1,400 to 3,056

(Riehl 2006, WHRC 2005). Summer population has gone from 16,000 in 1990 to 21,000 in 2004 (Riehl 2006). More year round and seasonal residents have increased the expanse of residential areas, commercial areas and infrastructure. In Wellfleet, development is driving degradation in water quality, as it has for all of Cape Cod. Shellfish in general, however, require relatively good water quality and this causes a conflict between increased growth in the town and the traditionally and economically important use of the harbor for shellfish harvesting.

Increased development in residential areas and commercial areas came with higher population, both year round and seasonal. More people and activity mean and increase in everything that comes along with commerce and people, such as human wastes. In 2003, Wellfleet had approximately 3,300 individual onsite septic systems or cesspools for residences and commercial buildings and no municipal treatment center (Wright-Pierce 2004). In addition there was one existing Department of Environmental Protection (DEP) groundwater discharge permit for a satellite plant in a trailer park with a maximum daily discharge of 21,600 gallons; this system however, had not yet been constructed (Wright-Pierce 2004).

Wastewater treatment systems are considered to be a large source of nutrient input to both ground water, inland freshwater and coastal embayments such as Wellfleet Harbor (Wright-Pierce 2004). The current estimate for wastewater generation on the Cape is 12 billion gallons annually, which reduces to an average of 32 million gallons/day. Looking at just the summer season flow is estimated to be 53 million gallons/day (Wright-Pierce 2004). On Cape Cod there are only 5 central wastewater plants, about 40 satellite plants permitted to discharge ≥10,000 gallons/day, and 13 cluster systems that process waste for grouped house parcels (Wright-Pierce 2004). The remainder of the systems are individual onsite septic systems. It is approximated that 85% of wastewater Cape wide is passed through these traditional septic systems, therefore nearly all of the wastewater on the Cape undergoes minimal nitrogen removal (Wright-Pierce 2004). More urgently approximately 10 billion gallons of this wastewater recharges ground water annually, which also flows to inland freshwater bodies and more applicably to this discussion, coastal embayments (Wright-Pierce 2004).

As part of a Cape wide mobilization towards better management of waste water, many towns are moving towards regulations that are "more-stringent-than-Title-5". Title 5 is the current state sanitary code for all systems that are not permitted by the DEP ground and surface water discharge permits (Wright-Pierce 2004). Such stringent systems are termed Innovative/Alternative (I/A) systems that provide enhanced treatment through biological technology to remove nutrients, while traditional septic systems only settle out solids (Wright-Pierce 2004; Riehl 2006). While systems in compliance with title 5 are assumed to have discharge with a nitrogen concentration of 35-42 mg/l, the I/A systems are assumed to have a discharge concentration of 19 mgl/l nitrogen or less and can also incorporate phosphorus removal (Wright-Pierce 2004; Riehl 2006).

Wellfleet, while it has only 60 I/A individual onsite septic systems, has a relatively high percentage considering all other Cape towns (Wright-Pierce 2004). Only one town, Mashpee, exceeds Wellfleet's enhanced treatment rate at 2.4%. This is likely the case because Waquoit Bay in Mashpee has an urgent water quality problem that is being addressed (Riehl 2006). Just under 2% of Wellfleet's individual treatment systems are enhanced treatment, compared to a Cape average of .5% (Wright-Pierce 2004). Wellfleet is actually considered to be relatively proactive through recent local public health bylaws. If a new waste water system is being constructed or an older system is being upgraded within a 100 foot buffer from "marine resource areas" or wells it must employ a new I/A system (Riehl 2006).

In addition to septic systems, Wellfleet also recognizes other significant sources of nitrogen and nutrient input to its harbor. While septic systems are considered the largest potential source of nutrient input, road run-off, atmospheric deposition, fertilizers pet feces and recreational boat discharge are also regarded as potential problems.

Despite Wellfleet's slightly proactive approach to water pollution, several recent studies (Minibays 1998, Mass Estuaries Program and Cape Cod National Seashore with the Audubon Society) in general show good water quality with evidence of localized declines in several water quality parameters that are troubling (Riehl 2006). The high tidal exchange, approximately 2/3 of the harbor volume, is cited as highly beneficial for water quality maintenance (Riehl 2006). In addition 66% of the terrestrial area in Wellfleet is protected to some degree through the Cape Cod National Seashore and other conservation bodies. Water quality impact in certain locations is as follows:

- Duck Creek: high nitrogen and chlorophyll A, loss of biological diversity in bottom sediments and system
- Black Fish Creek: high nitrogen and chlorophyll A, loss of biological diversity in bottom sediments and system
- Herring River: high nitrogen
- Mayo Beach: high nitrogen and chlorophyll A

- Chipman's Cove: macro and micro algal blooms

Interruption of suitable environmental conditions for shellfish, which can be induced by water quality changes, may lead to decline in wild stocks. Increased nitrogen can initiate blooms of macro and micro algae, increases in turbidity and decreases in dissolved oxygen. There is also anecdotal evidence through fishermen reports that there has been a recent increase in amount of macro algae in the harbor. Macro algae mats create a nuisance in the harbor. Besides blocking passage of light through the water column, they may also provide more habitats for harmful parasites that infect shellfish and can also wash up on shellfish beds in the intertidal area and overheat them during low tide. All of these occurrences are related to changes in water quality and can threaten shellfish stocks.

Results of the Division of Marine Fisheries shellfishing area bacterial monitoring is also another issue of concern. While the monitoring for coliform has not shown evidence for human wastes entering the harbor from faulty septic systems, it has shown that tidal restrictions and some areas of the harbor with less flushing and more road run off are more susceptible to high levels of coliform. These areas are: upper Herring River, sometimes lower Herring River, Duck Creek above Uncle Tim's Bridge and Hatches Creek. Higher levels of coliform in the aforementioned areas have lead to increased size of permanent and conditional shellfishing area closures (Riehl 2006). Shellfishing ground closures results in less harvestable area for shellfishermen and a more thorough harvest of open areas.

<u>Shellfish Diseases</u>

Another challenge for all commercial shellfish species in Wellfleet, both cultured and wild, is disease. Oysters have been affected by multiple diseases for many years, those being MSX (*Haplosporidium nelsoni*), Dermo (*Perkinsus marinus*) and juvenile oyster disease. The nature of the diseases does not make them a looming threat in Wellfleet, but rather a minor problem that will infect a few oysters here or there (personal communication Andy Koch). Quahogs in particular face an emerging challenge in the form of a parasitic infection named quahog parasite unknown, or QPX. QPX has been shown to be more prevalent in both hatchery or nursery reared batches of individuals as well as in cultured quahogs from seed brought in from outside of the local area (Ford et al 2002). High density plantings, such as are common in aquaculture plots, also have shown a positive correlation with QPX infection and mortality (Ford et al 2002). Wellfleet experienced a brief outbreak of QPX in 2004 whose potentially devastating outcomes were averted by a quick removal of the infected clams from the harbor.

While aquaculture is going strong in Wellfleet, changes in the wild shellfishing sector and social structure of Wellfleet may have lead to declines not only in quahaug abundances, but all wild shellfish from historic levels. It appears that there is increasing effort in the wild shellfishery, heavy removal of adult broodstock and because of intense harvest of smaller quahogs, lower numbers of larger adult quahogs. Increases in population on land along with accompanying infrastructure development are contributing to localized decreases in water quality and this can potentially lead to loss of suitable habitat for all shellfish. An increasing prevalence of disease, especially being introduced in aquaculture plots, is another risk present for the wild shellfishery. Given the importance of a healthy population of all shellfish species for Wellfleet, especially quahos and oysters, it is important to not only safeguard against future depletion, but also to restore current populations to higher abundances.

Section 3: Spawning Sanctuaries: An approach towards improving the shellfish population

Shellfish spawning sanctuaries: Looking towards improved resource management using the ecosystem based approach

When we explore more deeply the reasons for why spawning sanctuaries may be good for Wellfleet Harbor, the considerations go far beyond the actual fishery. The paradigm shift in environmental management towards the ecosystem based approach rather than the regulations of single species or singular actions has potential for improving the sustainability of future management approaches. The ecosystem based approach looks at whole systems and considers all activities occurring there as well as human beings.

The ecosystem based approach supplants the previous paradigm of sectoral management (McLeod et al 2005). While a widely accepted definition of ecosystem based management continues to evolve, there are many aspects of this approach that are generally accepted as constituents of the approach. A consensus statement proposed by a large group of natural and social scientists states:

> Ecosystem-based management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need…it considers the cumulative impact of different sectors. Specifically, ecosystem-based management emphasizes protection of ecosystem structure, functioning and key processes; is place based; explicitly accounts for the interconnectedness within systems…and among systems; integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependencies. (McLeod et al 2005)

In this approach, the ecosystem must be defined. While they come in various sizes, an ecosystem consists of flora, fauna, biotic and abiotic processes, the physical environment, and in this definition, humans (McLeod et al 2005).

Marine protected areas (MPAs) have emerged in the past few decades as a prominent approach to marine conservation (Allison et al 1998). MPAs are commonly defined as "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved b law or other effective means to protect part or all of the enclosed environment (Allison et al 1998)." While MPAs can be implemented for the achievement of many goals, common goals may be biodiversity conservation, species protection or habitat protection (Allison et al 1998).

The use of spawning sanctuaries, one type of MPA, to address wild stock declines and future sustainability of the wild shellfishery in Wellfleet Harbor was suggested in the 2002 Shellfish Management Plan Draft, but they have never been adopted (SMP 2002). The establishment of sanctuaries, along with several other management measures such as fishing ground rotation and seasonal closures were recommended as a new approach to shellfish management in the town (SMP 2002). Sanctuaries that are properly sited (considering environmental and socio-economic suitability indicators) can be effective tools in an integrated approach to resource management (Airame et al 1998, Allison et al 1998).

The IUCN (The World Conservation Union) has recommended that no take zones, such as the ones being investigated in the present study, be increased from their current extent by 2012 in order to do a better job in conserving fish stocks and protecting marine biodiversity. World wide these no take zones presently occupy a mere 0.04% of the global marine area, while the recommended expansion would cover 20-30% of the marine area (Jones 2006). The expansion is seen as potentially beneficial, but also highly problematic (Jones 2006).

Spawning sanctuaries are cited as an effective strategy when wild stocks face pressure from excessive fishing and recruitment limitation, both possible reasons for the decline in shellfish stocks over time in Wellfleet (Brumbaugh et al 2005). They are also cited as effective supplements to more traditional fishery management practices such as size restrictions and catch limits (Airame et al 1998). The concept behind spawning sanctuaries is the creation of a protected area for individuals of the target species. The population of shellfish in general is dependent on the "set" of larvae (Belding 2004). By setting aside a protected area where moderately dense aggregation of adults can release eggs and sperm into the water column, there is the potential for an increased set and therefore a subsequent population increase over time. Reigning water currents would act to advect recruits to areas adjacent to the reserves in effect supplementing and potentially increasing abundance outside of the reserve boundaries. Spawning sanctuaries are increasingly used because of the multitude of potential benefits. Some of them are:

- Maintain or improve water quality
- A consistent year to year supply of larvae and potential set
- Reduce reliance on outside seed planting
- Increase annual set, bust years that are not as intense
- Help fishery move towards sustainability
- Additional protection against population crashes
- Contribution to disease resistant stock development
- Restoration of the ecological function of bivalves

Another potential benefit of a no take sanctuary is the measure of precaution it would bring to existing management schemes (Allison et al 1998; Peterson 2002). Failures and inaccuracy in standard population projections as well as unaccounted for variation have lead to the realization that accounting for uncertainty may be a critical part of fishery management (Lauck et al 1998). No take sanctuaries can be seen as cushions that mitigate unplanned and unforeseeable events or variations. In ecosystems we must plan for the unplanned for occurrence, or in other words account for uncertainty. Also while fisheries science is largely developed on predictions and towns in Massachusetts may be well steeped into their management regimes, we may not be sure of how well management schemes may jive with *in situ* conditions. In effect a precautionary move for sanctuaries serves as protection against human error in management schemes and may make up for our lack of being able to predict all variation that could affect a commercial population (Allison et al 1998). It is further proposed that these sanctuaries could be sources of recovery for otherwise devastated populations (Allison et al 1998). If and future abundance studies show that the population is relatively healthy, it could also be considered good that action was taken before any long term decline took place.

The public can derive additional benefit from no take sanctuaries in the form of educational opportunity and research potential (Airame et al 1998). This would provide an optimal chance to research an area that is fished with an area that is not fished. Such analysis could bring about deeper understanding of the ecosystem in an undisturbed state. Several universities in Massachusetts have very active departments conducting marine research as well as there are many other active research organizations such as Sea Grant of the CCNSS. Such reserves would provide prime research opportunities.

The Nature Conservancy is a vocal and active proponent of spawning sanctuaries. They have been able to even lease submerged lands of bays that are in serious decline in the shellfish sector (Beck et al 2004).

Spawning sanctuaries are currently being used across the U.S. Some of the places employing these sanctuaries are Indian River Lagoon, Florida, Great South Bay, Long Island, NY, Pamlico Sound, North Carolina, Peconic Estuary, Long Island, NY and Chesapeake Bay (Arnold 2001; The Nature Conservancy; Beck et al. 2004). This strategy is being employed not only for population restoration, but also for recuperation and maintenance of critical ecological functions, such as filtering water of suspended matter and the grazing of microscopic phytoplankton.

Considering the emerging environmental management paradigm shift towards an ecosystem based approach, spawning sanctuaries fit in quite nicely; In addition spawning sanctuaries may help to achieve some of the goals set forth in the 2006 Harbor Management Plan. There are four main components to management under the ecosystem based approach that any actions adhering to it should follow: integration, sustainability, precaution and adaptability (Boesh 2005).

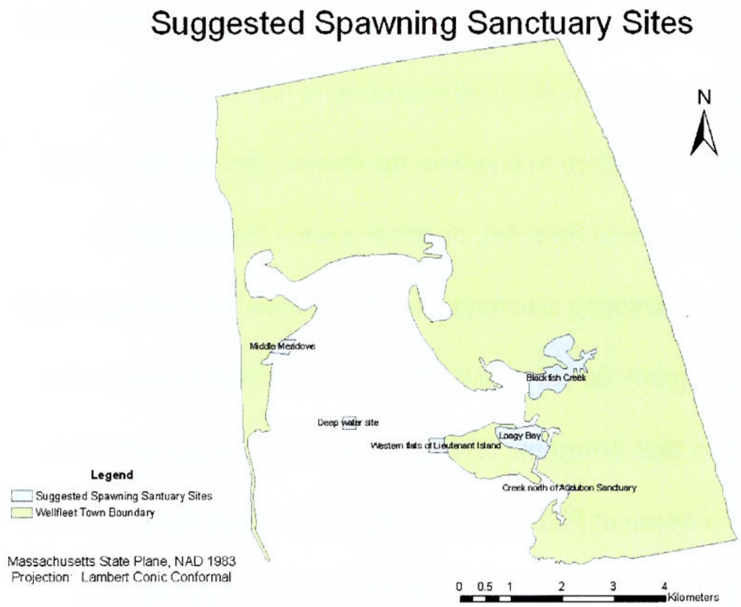
Considering the health of the quahog and oyster populations is an integrated action because these species serve many functions in the ecosystem. These shellfish are an important food source to many marine organisms, their filtering action helps maintain good water quality in the harbor, and socio-economically, their healthy population supports wild shellfishing. Establishing protected areas for spawning shellfish may also contribute to sustainability of the ecosystem and any activity using these shellfish species. The protected areas would also serve the purpose of precaution. Although the harbor ecosystem is in relatively good condition at present, and the harvests sufficient, actions should be taken to maintain the current state of the system against current trends that have not been detected, or future events that can not be predicted. The establishment of spawning sanctuaries can be adapted according to their effectiveness. A monitoring program should be put into place that would monitor for changes occurring in parameters that determine effectiveness of such protected areas.

The 2002 Shellfish Management Plan Draft, in addition to suggesting the use of spawning sanctuaries, also suggested six potential sites where sanctuaries could be located and are illustrated in Figure 3.1. These sites are:

1. West side of Middle Meadows
2. Blackfish Creek
3. Loagy Bay
4. Western flats of Lieutenant's Island
5. Creek north of Audubon Sanctuary
6. A deep water site (specific location not specified)

These were designated as potential sites because in 2002 they were lightly fished areas and because their locations were perceived to be conducive of dispersion of larval shellfish to fishable areas (personal communication, Bill Walton).

Figure 3.1: Suggested Spawning Sanctuary Sites



While MPAs and spawning sanctuaries are being widely employed, it is imperative that they are properly planned and that they are located in suitable areas. As there are no formal standards or criteria for the spawning sanctuary siting process, a set appropriate to the local conditions of Wellfleet Harbor will be proposed and applied. Since we are considering living organisms, first and foremost biological factors must be considered. Quahogs and oysters, as all mollusks, have a certain range of environmental conditions where they are able to live and thrive. The suitable site must meet these requirements. In addition, the fate of larval shellfish that are formed at this site must be considered. Besides considering biology, it must also be taken into account that Wellfleet Harbor is a highly prized area and there are multiple uses occupying a small area. Other uses must also be considered to determine sanctuary compatibility with other existing or future uses. Therefore before establishment of spawning sanctuaries, it is appropriate to conduct assessments to determine not only if the site is suitable environmentally, but also if the site would work considering any use conflicts.

There is not much literature that exists on the relationship between area of spawning population or abundance of spawning population to the recruitment outcome for commercial shellfish species. In addition the effective size, distribution and number of sanctuaries remains a little researched field (Allison et al 1998). Despite this fact, it remains an important question to determine what an optimal size for each spawning sanctuary would be as well as how many there should be. Size should ultimately depend on the goals articulated for the sanctuary (Airame et al 1998). In the context of fisheries, size will be a sensitive issue in that the size must be large enough to achieve an improvement in abundance, while at the same time not subtracting substantially from the income potential of resource extractors in the first few years of reserve implementation (Airame et al 1998). Size and number, then, are important factors when we consider what the goal of the spawning sanctuaries would be.

A recent study by Kraeuter et al 2005 shows evidence of a spawner/recruit relationship (SRR) for quahogs. Below a certain density then, the stock becomes recruitment limited. This, however, leaves unanswered question that are not addressed in published literature. The consideration then is what would be an optimal density for successful spawning, fertilization and recruitment outside of sanctuary borders? In addition what is an effectual expanse of this spawning aggregation?

As briefly noted, planning and design is crucial for the success of an MPA. One of the first steps to guide this planning is the articulation of clear and achievable goals

(Airame et al 1998; Helvey 2004). If we do not clearly define what it is we are hoping to achieve with the spawning sanctuaries, there is no basis for proper design or planning. Also there is no basis for evaluating the outcomes and successes/failures of the sanctuary if there are no initial goals.

Airame et 1998 and Helvey 2004 suggest the following goal categories that were used in the planning of the California Channel Islands Marine Reserve: ecosystem biodiversity, sustainable fisheries, social and economic, natural and cultural heritage, and educational. Given the previous discussion of the importance of the shellfishery for Wellfleet, it is clear here that protection of this industry is the crux of our goal. The vision is that the sanctuaries would promote a sustainable shellfishery in Wellfleet Harbor. The sanctuaries will act as a restorative force for standing stocks through recruitment spill over beyond their borders and as a precautionary tool against uncertainty both in the face of environmental variability and change and inherent management inaccuracy. Additionally, the goal is to maintain resilience of the ecosystem, maintain an aspect of the area's natural and cultural heritage, and provide educational opportunity. By improving abundance and resiliency of the stocks, the profession of shellfishing may become more secure and the potential for increased yields could spur additional economic opportunity. Finally, but not unimportantly is the protection of ecosystem biodiversity. Wellfleet Harbor, while feeling pressure from development and other human activity, remains relatively in good ecological condition. However, by setting aside sanctuaries, crucial ecological function of shellfish and other associated flora and fauna may be protected in the sanctuaries.

While setting aside an MPA as a form of spawning sanctuary may sound appealing and fulfilling of our biological, ecological and socio-economic goals, the criticisms of these "fishing refugia" must be acknowledged. While there is some evidence that protected areas create spillover to adjacent areas, other studies have been unable to demonstrate the usefulness of sanctuaries as a source of recruits for adjoining areas (Allison et al 1998; Jones 2006). No take zones trying to be implemented under the main premise that they can enhance abundance in adjacent zones will likely be scientifically challenged (Jones 2006). In addition no take spawning sanctuaries will only protect the area and contained biota from fishing pressures and not other causes of variation or mortality (Allison et al 1998).

Resistance to formation of sanctuaries by members of the community is not unexpected (Jones 2006). Designation areas as no take sanctuaries will lead to an initial decrease in area of fishing grounds, albeit small relative to total harvest area. Such a decrease in harvesting area may also lead to a short term small drop in catch. In addition, a dichotomy exists between people who are focused on environmental thought and those who are involved in the fishing industry. Fishermen respond to market price and demand and in this case often argue that supply is sufficient and sometimes too great. The other side of this, the environmental scientists, is the presumption that markets can be expanded. It is also the goal of the U.S. to increase their seafood production (Nash 2005). Taking into consideration the future then, the potential for increased production is optimal. So while potential outcomes of sanctuaries can be highly beneficial, they are not yet widely accepted as effectual, nor do they encompass a full spectrum of protection. In addition, discussion of these sanctuaries may inspire resistance from those individuals involved in the fishing industry.

Taking into consideration the situation in Wellfleet, the potential benefits of spawning sanctuaries as well as potential negative effects, goals of these sanctuaries must be established. They are as follows.

- Find areas where quahogs and oysters can be protected from fishing in order to carryout their adult lives and spawn.
- It is the goal that these dense spawning aggregations will contribute to greater abundance outside of the protected areas.
- Protect undisturbed areas where the full array of benthic assemblages can persist with the mollusks.
- Create areas where education and research opportunities can take place.
- Minimize the effect of loss of harvesting ground for the fishing community.

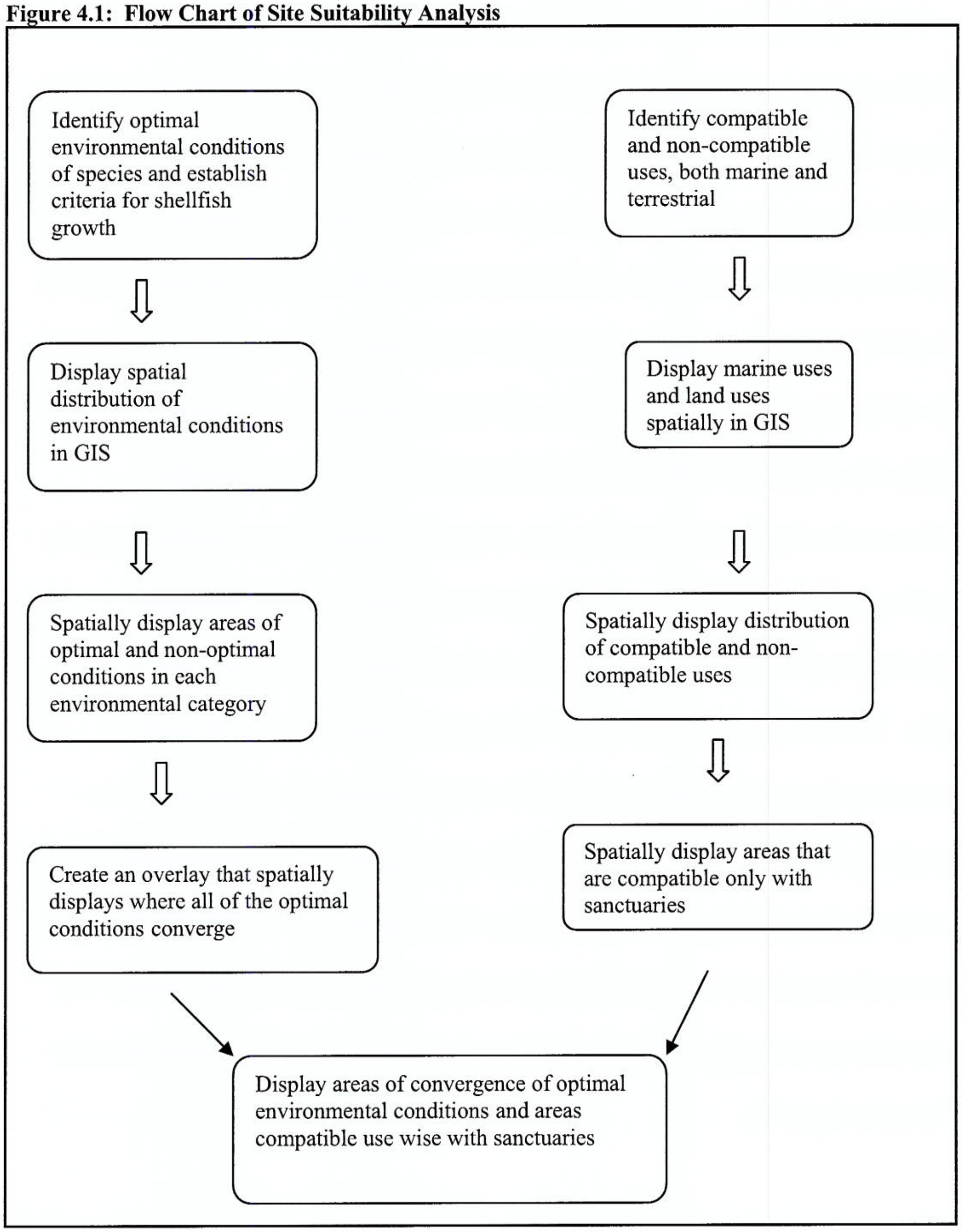
Section 4: Suitability Analysis: Investigation of locations for spawning sanctuaries

Analysis and Methods

Having established that planning and design is critical in achieving the goals of an MPA and operating under the principle that the environment sets the limit for sustainable development, in this case spawning sanctuaries, the rest of this section will set out to investigate suitable and optimal areas for siting the sanctuaries. Knowing now what the goals are, indicators must be selected that will show that the goals are achievable. Frankic 2003 sets forth a multi phase process for analyzing site suitability for certain activities occurring in the coastal zone, and the methodology here will follow that process adapted for spawning sanctuaries.

Considering that the sanctuaries must be areas that quahogs and oysters will be able to live and spawn successfully without major stress, looking for such areas will be necessary. The **first phase**, then is determining the environmental conditions that dictate the success of quahog and oyster survival, growth and reproduction. From these conditions, environmental criteria for sanctuaries can be developed. The **second phase** is the creation of maps that display the spatial distribution of environmental conditions in the study area. In addition an analysis of all maps according to the criteria established in phase one will produce a final map depicting areas of suitable environmental conditions in the study area. The **third phase** is a use conflict analysis. This phase will show that even if some areas are environmentally suitable for sanctuaries, they may not have compatible uses occurring in the same area or in the vicinity. The **fourth phase** incorporates management issues imposed on both environmentally suitable and use compatible sites by the presence of certain socio-economic variables. The **fifth phase** is the development of potential action plans to help with decision making for the proposed activity taking into consideration the results of the initial four phases (Frankic 2003). For the purposes of this project, phases 1-3 were performed and explained below, while phase 4 is incorporated in the discussion (see Section 5, pp 54).

Figure 4.1: Flow Chart of Site Suitability Analysis



Phase One: Determination of Environmental Conditions

To effectively manage an organism, the life history of the organism must be known. Management must be able to take into consideration the habitats and conditions in the marine environment that the target organisms require. In the present study, we are most concerned with the environmental requirements for adult spawning stock. Large spawning adults are known to produce more eggs and sperm than younger and smaller individuals in both species (Gosling 2003). Therefore areas that have environmental conditions that are favorable for growth and spawning are required. Through literature review, environmental requirements and physical, chemical and biological indicators that should ideally be considered for this stage of quahog and oyster growth have been identified. They are proposed as environmental siting criteria for quahog spawning sanctuaries.

Quahogs and oysters have similar life histories. Mature male and female individuals are often triggered to spawn through temperature thresholds. The male often releases the sperm first and females will release their eggs shortly after. Therefore temperature plays an important role in the spawning process.

Salinity and temperature are cited as being primary in determination of quahog and oyster distribution and abundance (Menzel 1989; Gosling 2003). Both species are considered euryhaline and tolerate a wide range of salinity values that are common in estuaries. They are also very tolerant of wide temperature ranges and can survive below freezing during the cold winters through dormancy. There is, however, an ideal temperature range for growth and spawning during the growing season. Given the historic abundance in Wellfleet Harbor, it is clear that in general the salinity and temperature range are ideal for oysters and quahogs. However, the salinities of certain areas such as tidal creeks and the mouths of these creeks and rivers may be more suitable to one species over another. Burrowing depth also leads to a difference of temperature tolerance in the two species. Oysters are epifaunal and are more exposed to winter ice, whereas quahogs burrow several inches and are more protected from colder temperatures.

Substrate is another aspect critical in shellfish life history. Both adults and settling larvae prefer different textures in substrate. Quahogs have been shown to prefer coarse substrates such as sand, gravel, and a sand/mud mix (Gosling 2003). They will also settle into vegetated areas such as marsh grass and sea grass beds. Oysters are different than quahogs in that they require a hard substrate like shell or rock (Gosling 2003). They often settle on other oysters and these aggregations can result in oyster reefs.

Dissolved oxygen (DO) is another requirement of aerobic marine organisms such as quahogs and oysters (Whetstone et al 2005). Low levels of DO can cause stress on organisms that will affect their growth as well as it can lead to enhanced mortality (Gosling 2003). Current speed and/or tidal flushing is another factor shown to be influential in the success and growth rate of shellfish (Brumbaugh et al 2005). The role of water currents is that they carry food past the suspension feeding bivalves as well as clean the surrounding area. Currents are also related to dissolved oxygen concentration in that they bring in oxygenated waters. Tidal flushing can play the same role as currents. Availability of food, for the most phytoplankton, is another major limiting factor in quahog growth (Menzel 1989). Chlorophyll A concentration can be used as a proxy for food concentration.

When considering harvest of shellfish, fecal coliform monitoring is also a crucial factor. They can also be considered in sanctuary siting. Another factor is bathymetry. Bathymetry also affects distribution and survival as the organisms prefer a certain depth range and have different growth rates in different depths. The presence of predators should also be taken into consideration. Most shellfish species, including quahogs and oysters, experience extreme mortality in the larval stages and post settlement stages (Hunt and Mullineaux 2002). While adults have a much lower mortality rate from predation, fish and birds can still feed on adult shellfish. In addition to all of these factors, many more can be considered such as presence of contaminants in the sediment and water column, and a circulation pattern that will elucidate the hydrography that controls larval dispersion, transport and fate.

Waters in Massachusetts must be state certified as shellfish growing waters through a bacterial monitoring program. Shellfish bound for consumption can not be harvested when the coliform indicator level is exceeded. While the analysis parameters above include an acceptable coliform indicator level ($\leq$ 14 CPU) in accordance with Massachusetts Division of Marine Fisheries standards, it can be considered that shellfish in the spawning sanctuaries will not be harvested and consumed. This presents a possibility of employing areas that are closed for shellfishing as spawning sanctuaries (Peterson 2002). In fact the Nature Conservancy suggests using such areas as *de facto* reserves that will minimize potential conflict with acceptability (Brumbaugh et al 2005). The benefit of this idea is that prime fishing grounds will not be taken from the fishing industry and given over to conservation.

While the idea may be good, potential of this being applied in Wellfleet may be limited considering the present extent of state certified shellfishing waters and proposed changes in the harbor. At present, closed areas in Wellfleet comprise upper Herring River and upper Duck Creek. A tidal restriction in the Herring River combined with high bird populations inland of the restriction are the cited reasons for high bacterial counts in the area. A process for the implementation of a removal plan for the tidal restriction, however, is in place and ideally within a couple of years the restriction will be either altered for improved flushing or removed (Portnoy and Allen 2006). In the case of Duck Creek, the water quality parameters such as dissolved oxygen and salinity may not be optimal for quahog or oyster growth.

Table 4.1: Review of ideal suitability indicators and existing data
(Brumbaugh et al 2005; Frankic 2003; Dame 1996; FIGIS)

Environmental Suitability Indicator	No Data or Insufficient Data Available
Salinity (psu)	
Temperature (°C)	
Substrate type	X
Current speed and direction	X
Dissolved Oxygen (ppm)	
Coliform (Cfu/100ml)	
State Shellfishing Approval	
Heavy Metals	X
Suspeded Matter (mg/l)	
Benthic condition	X
Phytoplankton counts	
Bathymetry/tidal range	
Water body circulation	X
Presence of predators	X

Given that not all of this data exists and that some of it may be strictly descriptive and non spatial or quantitative, only certain limiting environmental factors can be considered. Reviewing the environmental tolerances of the two species and available data, criteria for the present analysis of phase two are established. The criteria are presented in Figures 4.2 and 4.3.

Figure 4.2: Environmental Suitability Criteria for Quahogs

Environmental Factors for Quahogs	Not Suitable	Suitable	Optimal
Salinity (PSU)	<12, >35	12 - 20	20-35
Annual Temperature Range (°C)	<-6, ≥36	-6 – 35	N/A
Spawning Temperature (°C)	N/A	N/A	20-31
Depth (meters)	>15	intertidal	1-15
Dissolved Oxygen (ppm)	>1	1-4	>4
Fecal coliform (# of times exceeding 14 CFU/100ml)	N/A	0-1 times	>2 times

(Dame 1996; Gosling 2003; Lorio and Malone 1994; Sellers and Stanley 1984)

Figure 4.3: Environmental Suitability Criteria for Oysters

Environmental Factors for Oysters	Not Suitable	Suitable	Optimal
Salinity (PSU)	0- 7.5, >40	7.5-14, 28-40	14-28
Annual Temperature Range (°C)	<-2, >35	> -2 - < 35	N/A
Spawning Temperature (°C)	<16, >34	16-20, 31-34	20-30
Depth (meters)	>30	intertidal	1-30
Dissolved Oxygen (ppm)	<1	1-4	>4
Fecal coliform (# of times exceeding 14 CFU/100ml)	N/A	0-1	>2

(Dame 1996; Gosling 2003; Menzel, 1989; Stanley and Dewitt 1983; Whetstone et al 2005)

<u>Phase Two: Creation of GIS maps and Environmental Site Suitability Analysis</u>

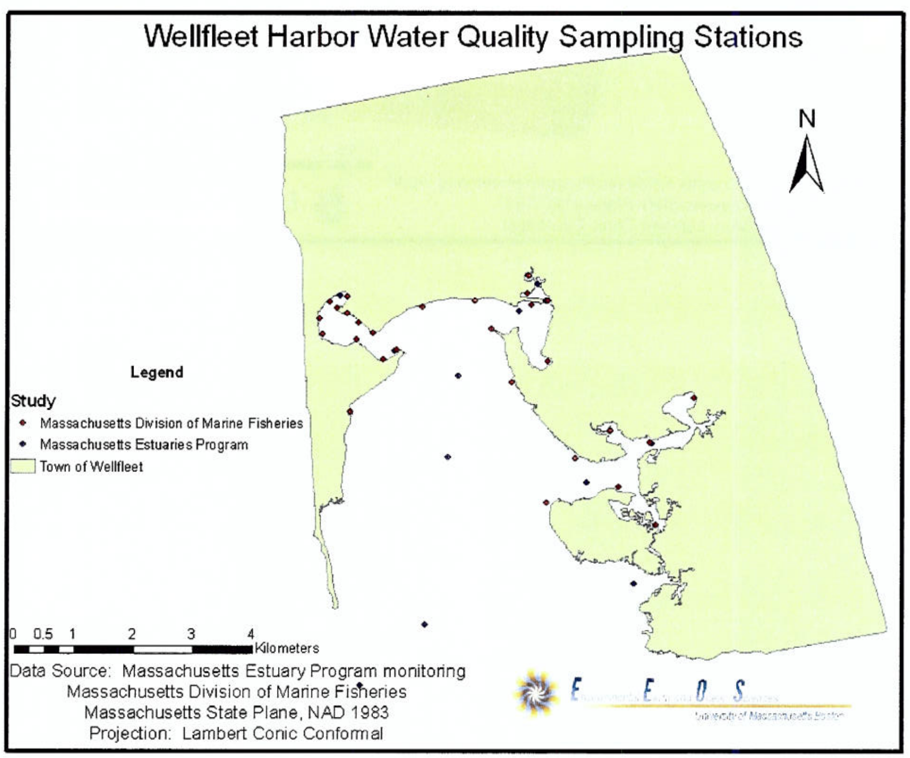
Key to examining these two categories of indicators, life history and use compatibility, is spatial variability. A tool that can analyze the spatial distribution of indicators is necessary. GIS (geographic information systems) is an extremely useful tool in the decision making process. It provides us with the ability to depict the variation of data on a spatial scale. Suitable conditions can be displayed on a georeferenced map. Considering the distribution of the criteria given in Tables, optimal, suitable and non suitable ranges can be selected and overlaid. Such an overlay will reveal environmentally suitable areas for spawning sanctuaries. GIS has been used previously in aquaculture applications. Site suitability analysis for locating aquaculture areas is frequently performed using GIS (Frankic 2003; Arnold 2001). It is also widely employed in planning marine reserve design and siting (Airame et al 2003; Helvey 2004; Villa et al 2002). Organisms in spawning sanctuaries, like cultured organisms, also have certain environmental, physical and space needs.

GIS analysis has been successfully used in aquaculture site suitability analysis as well as keeping inventory of coastal and aquaculture infrastructure (Frankic 2003, Arnold et al 2000; Carswell et al 2005). The present analysis will be carried out in a similar method as past aquaculture site suitability analysis as demonstrated in Frankic 2003 and Arnold et al 2000. All data will be integrated into a GIS using ESRI's Arc GIS 9.1. This integration will occur in two parts, the environmental suitability analysis and the use conflict analysis. Some data is available in GIS format and some is not. Data that is not in GIS format must be digitized.

The first step will be conducting the environment suitability analysis. Multiple criteria analysis (MCA) is an appropriate approach to use when trying to find areas with convergence of selected variables (Villa et al 2002). It employs Boolean overlay to determine convergence (Price 2006). GIS layers will be created for each environmental indicator in the harbor.

Data for the environmental analysis has been borrowed from the Massachusetts Division of Marine Fisheries coliform monitoring program and from the Massachusetts Estuary Program Monitoring in Wellfleet Harbor. Data was collected from various sampling stations (see figure 4.4). In GIS, sampling stations represent point data. In order to carry out a MCA, this point data needs to be converted into continuous data. Point data will be converted from vector format to raster layers using the IDW (inverse distance weighted) method in ESRI's ARCGIS 9.1. Environmental suitability analysis will then be performed according to the multiple criteria set forth in Figures 4.2 and 4.3 (Frankic 2003).

Figure 4.4: Sampling Stations for Water Quality Data



The following maps, Figures 4.5 – 4.10, were created from the aforementioned data acquired at the sampling stations displayed in figure 4.4. These layers were used in environmental site suitability analysis.

Figure 4.5: Wellfleet Harbor Salinity

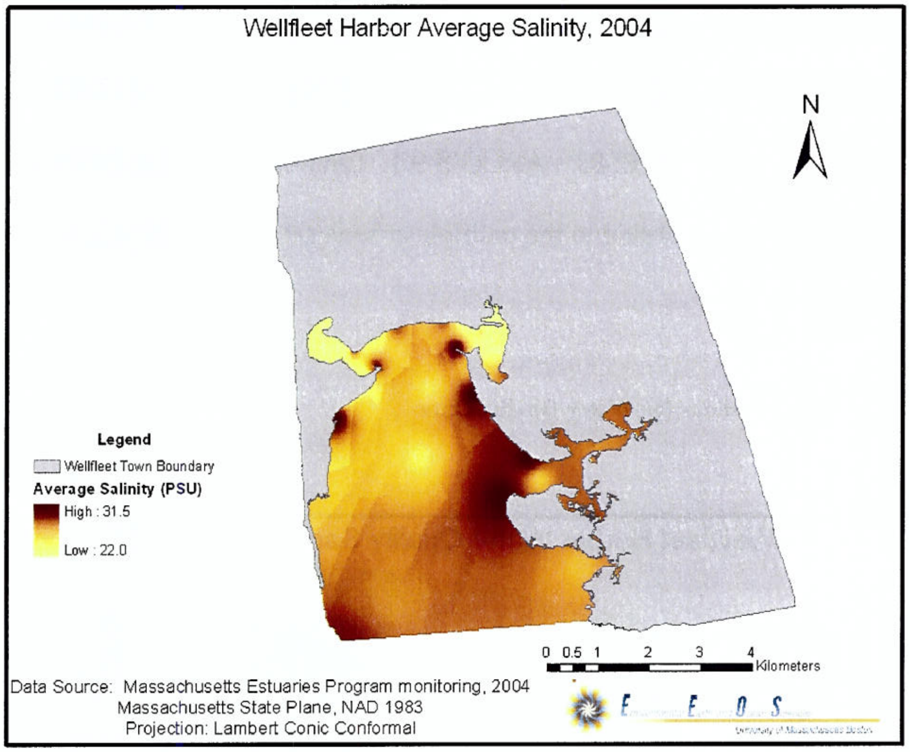


Figure 4.6a: Wellfleet Harbor Temperature Maximum

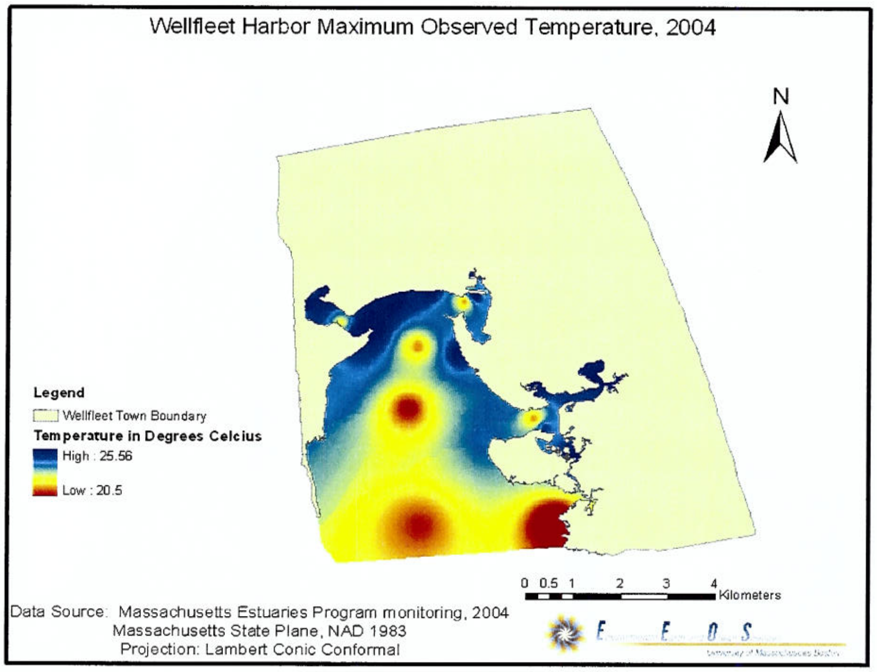


Figure 4.6b: Wellfleet Harbor Temperature Minimum

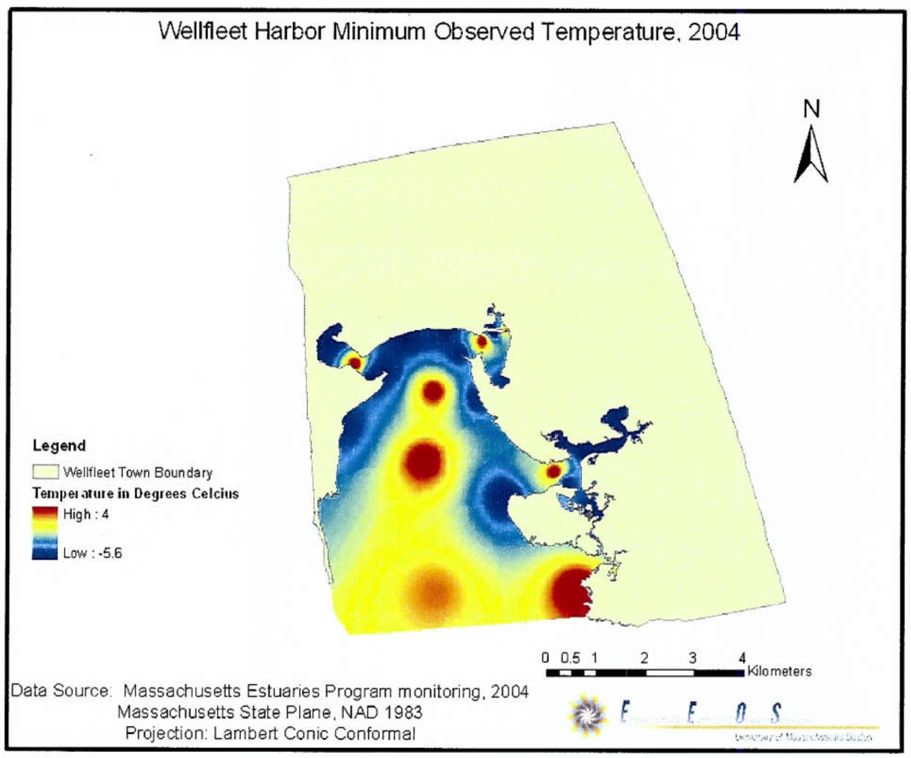


Figure 4.7: Wellfleet Harbor Bathymetry

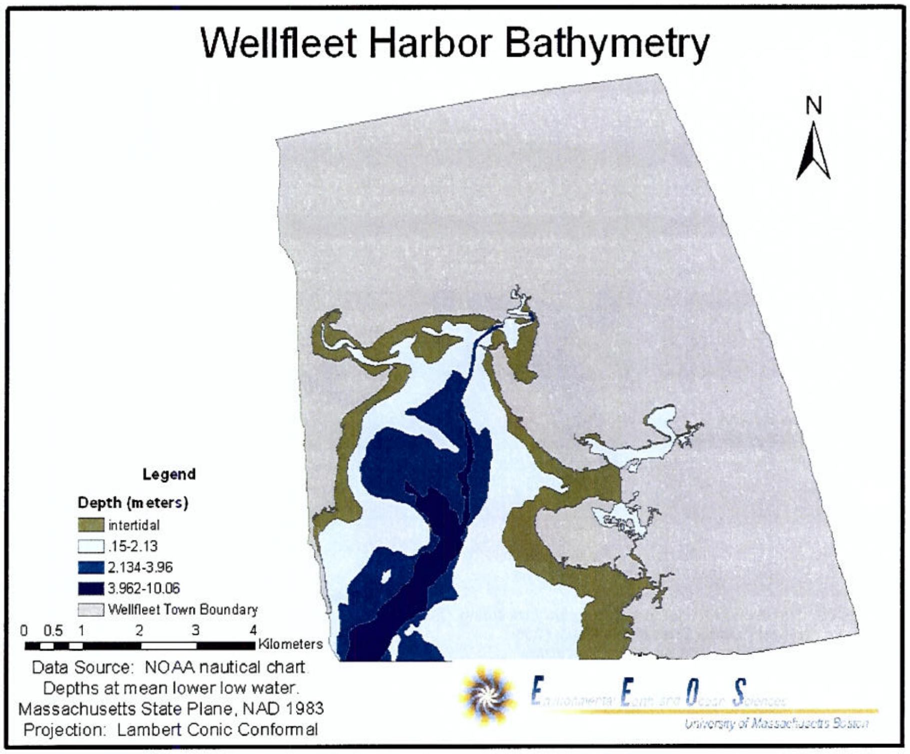


Figure 4.8: Wellfleet Harbor Dissolved Oxygen Concentration Maximum

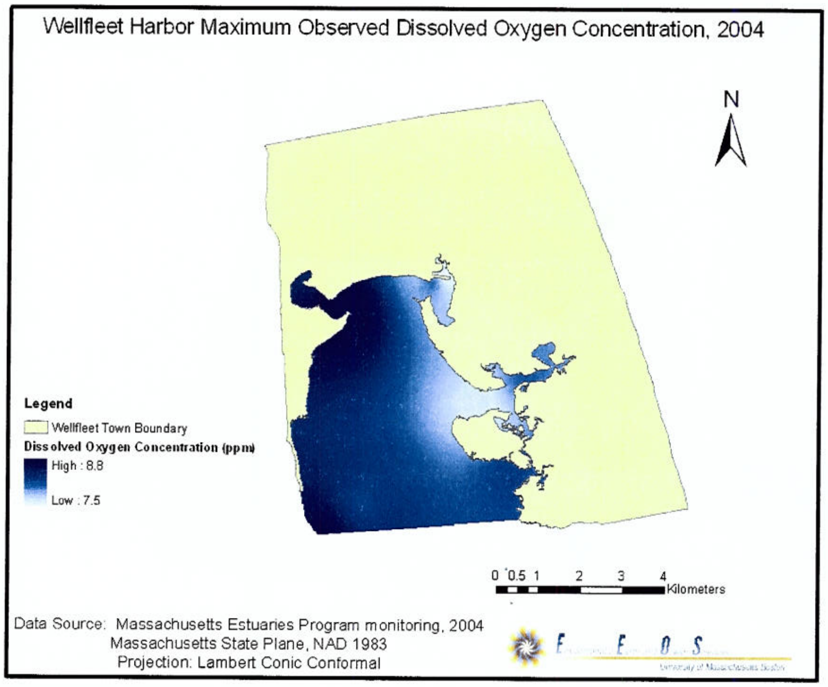


Figure 4.9: Wellfleet Harbor Dissolved Oxygen Concentration Minimum

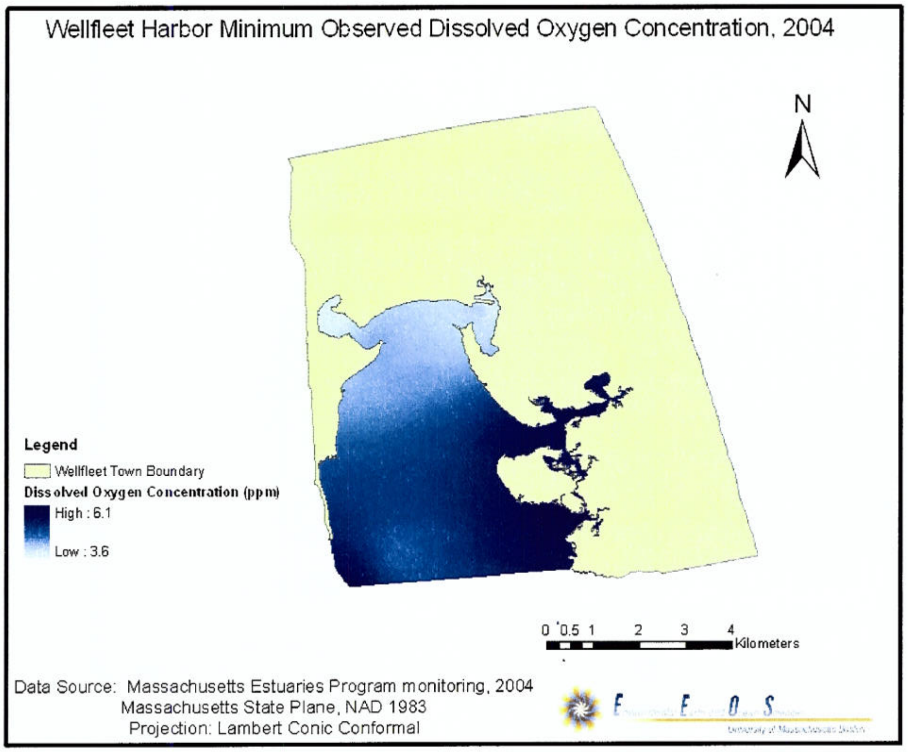
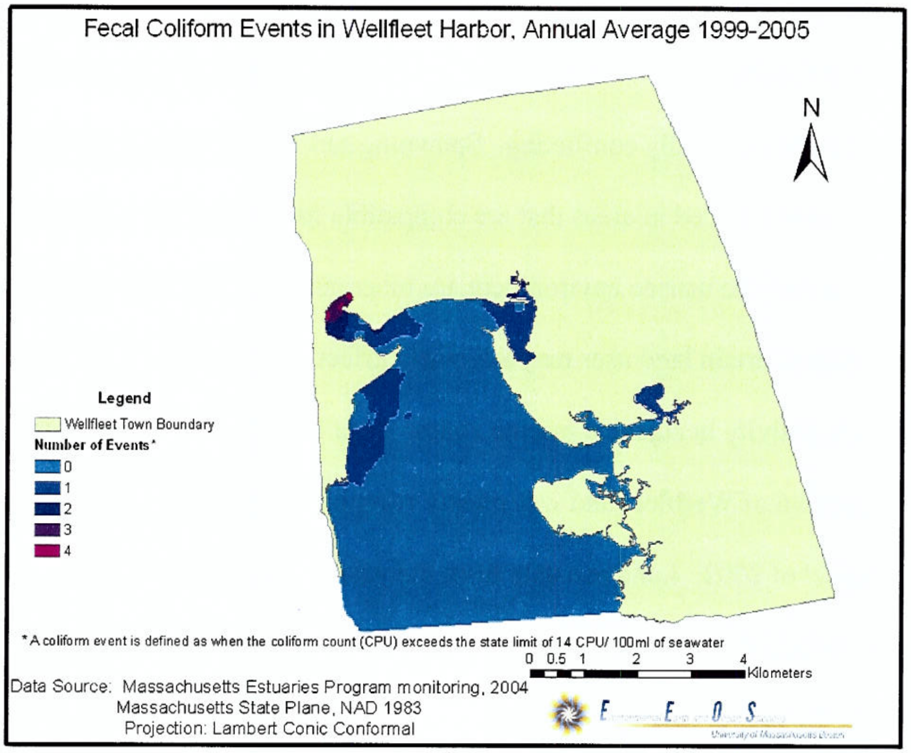


Figure 4.10: Wellfleet Harbor Fecal Coliform Closures



Phase Three: Use Conflict Analysis

The second part of the GIS assessment is the use conflict analysis. It must be considered that Wellfleet is a harbor of multiple uses and various human activities that can in some cases be spatially conflicting. Spawning sanctuaries must not add to spatial conflict and must be placed in areas that are compatible for conservation of shellfish beds. Many uses of the marine environment are inherently not compatible with each other. In addition certain land uses may adversely affect the marine environment or precede certain activity in adjacent marine zones. Data displaying the uses of the harbor is held by the town of Wellfleet and was mostly compiled in the Wellfleet Harbor Mapping Project of 2002. Land use data from the year 1999 and earlier is available from Massachusetts GIS. Once all data is collected a conflict analysis will be performed. While sites in the harbor may be environmentally suitable, there may be a conflicting use present rendering the area not suitable for sanctuaries. This analysis will determine if placing sanctuaries in environmentally suitable sites will conflict with current or planned uses. This part of the analysis can also show if sanctuaries are feasible or if the site is more suited to another use (Frankic 2003).

The first step in this phase is to determine the relevant current and planned uses of the harbor. As stated previously, Wellfleet Harbor is a bustling water body that is used by many people in many different ways. Reviewing the best information available current uses of Wellfleet Harbor have been identified in Table 4.2. In consideration of future uses, there are not many. Dredging of the channel and marina will continue into the foreseeable future. The number of aquaculture grants has also been essentially capped and there is no currently planned future expansion of this industry (personal communication, Andy Koch). The only other foreseeable change is the renovation of the Herring River tidal restriction that will restore a certain percentage of natural tidal flow into the river's marsh section (Portnoy and Allen 2006).

Table 4.2: Current Uses of Wellfleet Harbor

Shellfish aquaculture	Sub aquatic vegetation
Wild shellfish harvest	Beaches
Marina	Marina and channel dredging
Boating	Vessel mooring

Physical conflict is the most straight forward use conflict present in this analysis. Several items from Table 4.2 fall in this category and can simply be designated as areas that are not compatible for spawning sanctuaries. Important harbor uses can be seen in Figure 4.11. Aquaculture is physically a problem for sanctuaries. The aquaculture sites are being leased by individuals from the state for private enterprises, and more importantly are employing the benthic area. The presence of the marina and recreational boating in the harbor presents another physical conflict for sanctuaries. Because of strong tidal forcing, the harbor is considered to be accumulating sediment and therefore creating a sediment problem for the harbor's navigational channel (Riehl 2006). Since boating, both for recreational and commercial purposes, is so important for Wellfleet, dredging is employed to maintain the deep water channel and marina. The process of dredging removes bottom sediment and inherently would cause a conflict with shellfish beds. Related to boating is vessel mooring areas. These mooring areas are where vessels can have a permanent mooring as well as use anchors. Dropping heavy moorings or anchors into the bottom sediment may cause increased mortality of shellfish. The areas of physical conflict are displayed in Figure 4.12.

Sub aquatic vegetation, though currently not protected by any Massachusetts law, is recognized by the state's coastal zone management as a critical habitat that is important in coastal ecosystems (Wilbur 2004). SAV beds are however given consideration under the Clean Water Act, Rivers and Harbor Act and Massachusetts Wetlands Protection Act when a permit for coastal development is submitted (Wilbur 2004). Statewide mapping of the resource for monitoring purposes started in the 1990s. According to the statewide maps of SAV beds completed in 2001, Wellfleet has large seagrass meadows outside of its harbor and only several small patches of *Ruppia maritima* or Widgeon grass in the mouth of Herring River (Mass GIS). The area of these beds, both inside and outside of the harbor, has decreased since the mapping done in 1995. 2006-2007 marks a new round of mapping, and considering the trend from 1995-2001, the monitoring may reveal that even the small patches of SAV inside the harbor have disappeared.

Given the recognized importance of SAV as habitat and provider of ecosystem services, it would ideally be protected under Massachusetts law (Wilbur). Considering the present study of suitable areas for spawning sanctuaries, the objectives are mutual. SAV beds provide habitat for shellfish. By merging the interests of protecting SAV beds and the establishment of no take spawning sanctuaries, such SAV beds present in Wellfleet Harbor can be considered optimal sites for these sanctuaries.

Table 4.3: GIS layers to be utilized in the use conflict analysis

- Location of marina, channel and mooring fields
- Aquaculture lease areas
- SAV beds

Figure 4.11: Wellfleet Harbor Spatial Uses

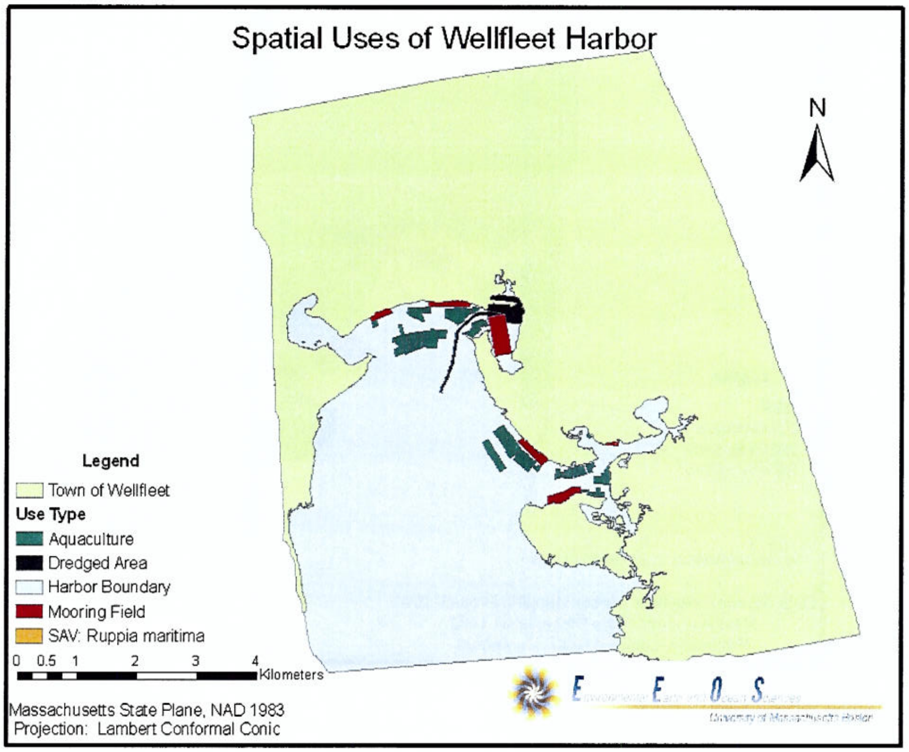
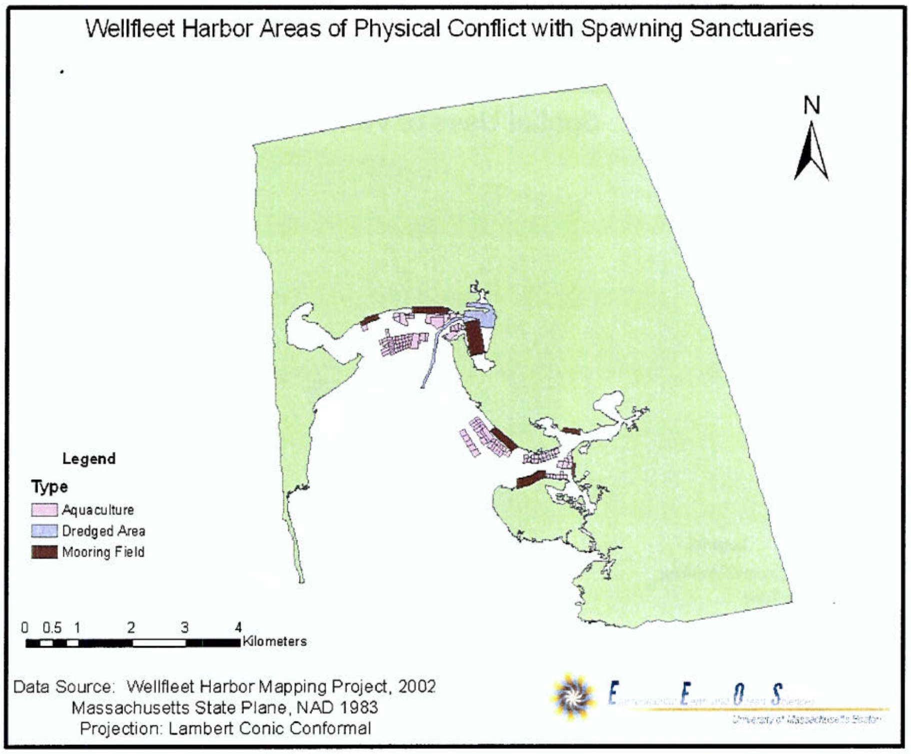


Figure 4.12: Areas of Physical Conflict with Spawning Sanctuaries in Wellfleet Harbor



Section 5: Discussion and Results

Starting out with the principle that the environment sets the limit for possibilities, this project has set out to be useful in the decision making of shellfish and harbor management decisions in Wellfleet. The analysis of the harbor has answered the question: Where are there suitable sites for mixed quahog and oyster spawning sanctuaries? Development of site suitability criteria for *Mercenaria mercenaria* and *Crassotrea virginica* spawning sanctuaries, GIS maps displaying environmental indicators in the harbor, GIS maps illustrating harbor uses, as well as output maps that illustrate the areas that are suitable and management issues and options for the sites are the major outcomes of this project. This case study has also shown the usefulness of readily available, quality scientific data for resource managers. This project will help the town decide if these are suitable areas for the spawning sanctuaries and if it is a good decision to implement them. While no management actions will come from the project, it will use scientific data to aid in the decision making process. The expected result before the analysis was that most of the harbor would prove to be environmentally suitable, but that the use conflict analysis would reveal non-compatibility in many areas of the harbor.

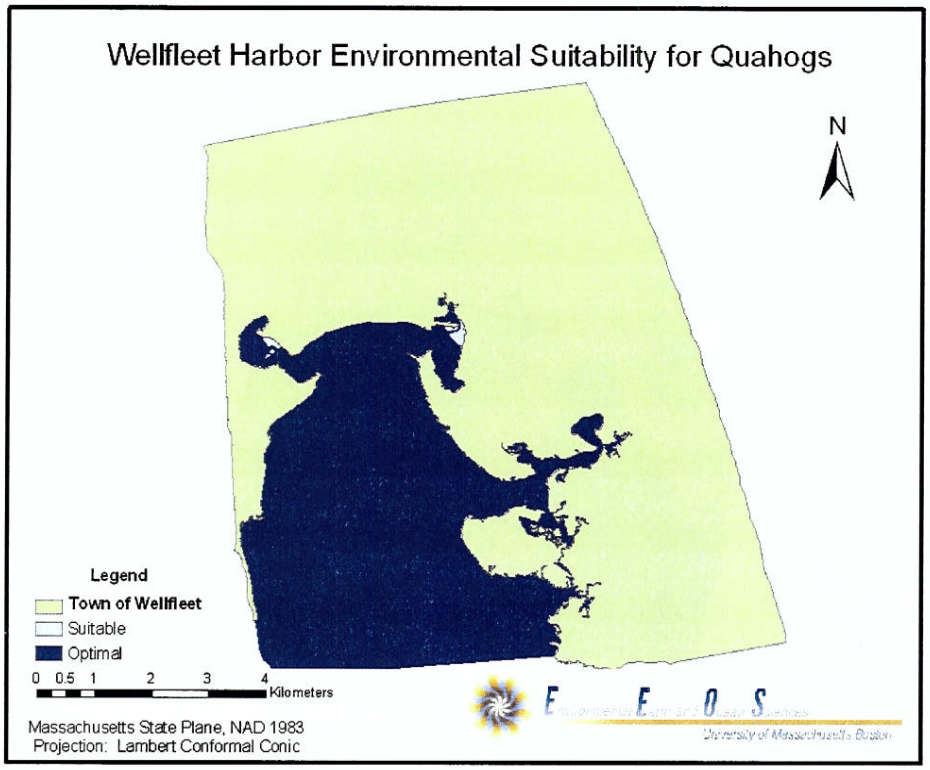
Spawning sanctuaries have been promoted in many estuary restoration projects, and may be a good approach towards stewardship of the natural and social resource base in Wellfleet. While this is the case, improperly sited sanctuaries will not contribute positively towards this stewardship. Site suitability analysis is an efficient and useful exercise to put existing data to work towards effective management decisions.

Phase 2: Environmental Site Suitability Analysis

Given the historic and present abundance of all shellfish species in Wellfleet Harbor, it is known that environmental conditions in the harbor are generally hospitable for the proliferation of commercially important species. Considering the spatial scale of the harbor and the proposal that there be 6-10 designated several acre spawning sanctuaries, the goal is to find where the best place for these sanctuaries would be in the harbor. Environmental conditions do vary within the confines of the harbor and accordingly there are areas that will provide better conditions for shellfish growth and survival. The environmental site suitability analysis was therefore employed to answer this question.

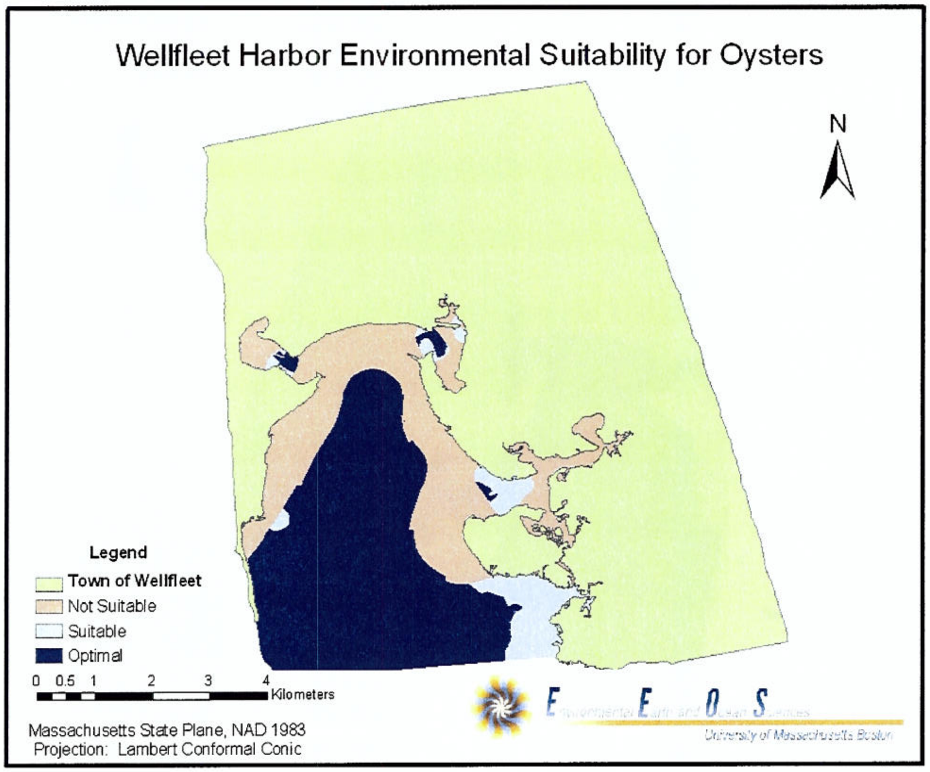
The results of the environmental site suitability analysis according to the criteria set forth in figures 4.2 and 4.3 are revealing. The outcome for the quahog analysis shows that most of the harbor falls into an optimal classification. There are small areas classified as suitable due to low oxygen levels, intertidal depth, and lower salinity. According to the same analysis, there are no areas considered not suitable for quahog growth.

Figure 5.1: Results of Environmental Site Suitability for Quahogs



Similarly, the results for the oyster analysis are also interesting. The primary difference between the analysis for quahogs and oysters is the presence of not suitable areas for oysters. This oyster species is different in that it can't tolerate temperatures as low as those that quahogs can tolerate. In addition oysters are epifaunal as opposed to infaunal, which makes them more susceptible to ice that may form in intertidal areas or ice that comes down from the shore. The presence of not suitable areas for oysters in the harbor is a product of low temperature predictions. Like the quahog analysis, it is also shown that there are areas that are suitable as well as optimal. The optimal areas for quahogs and oysters are largely shared in the center or deep water area of the harbor.

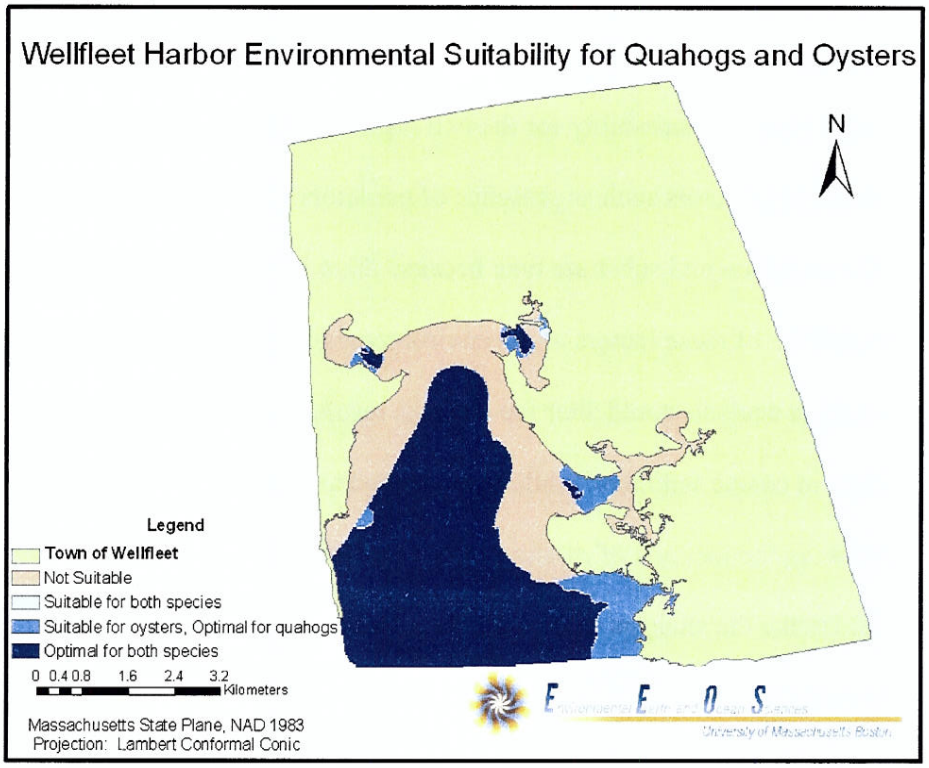
Figure 5.2: Results of Environmental Site Suitability for Oysters



The outcome layers for the two species evaluated in environmental site suitability analysis can not be considered individually. The spawning sanctuary proposal was for mixed species, i.e. quahogs and oysters, therefore these two layers must be combined. The result of this combination shows the harbor classified as follows: not suitable for sanctuaries, suitable for both species, suitable for oysters but optimal for quahogs, optimal for oysters but suitable for quahogs and optimal for both species.

This environmental site suitability analysis confirms the beginning hypothesis that most areas of the harbor would be suitable for spawning sanctuaries. It becomes clear that, given the available data, there is environmental non-suitability, suitability and optimality for quahog and oyster spawning sanctuaries. This outcome is consistent with anecdotal description of high density of quahogs in deep water areas of the harbor and the higher stress endured by organisms located in the intertidal area (personal communication, Andy Koch). While cultured oysters are brought out of the water during the winter, many aquaculturists who raise quahogs in the intertidal suffer loss during the winter due to ice that may form and scrape or crush the quahogs.

Figure 5.3: Wellfleet Harbor Environmental Suitability for mixed (quahog and oyster) spawning sanctuaries



While this spatial environmental analysis is being employed to answer the question in this project, it has not been tested in the field. One source of uncertainty in this analysis is the prediction surfaces created from water monitoring stations. The data in the analysis that shows the nearshore/intertidal area is not suitable for oysters, is low winter time temperatures. By stating that much of the nearshore/intertidal area in the harbor is not suitable for oysters, we are assuming the minimum temperature reached in these areas is as shown by the prediction surface. The monitoring stations used to create this prediction surface, however, were all located in the intertidal area. The distribution of these points, may therefore skew the temperature prediction surface and yield a slightly inaccurate representation.

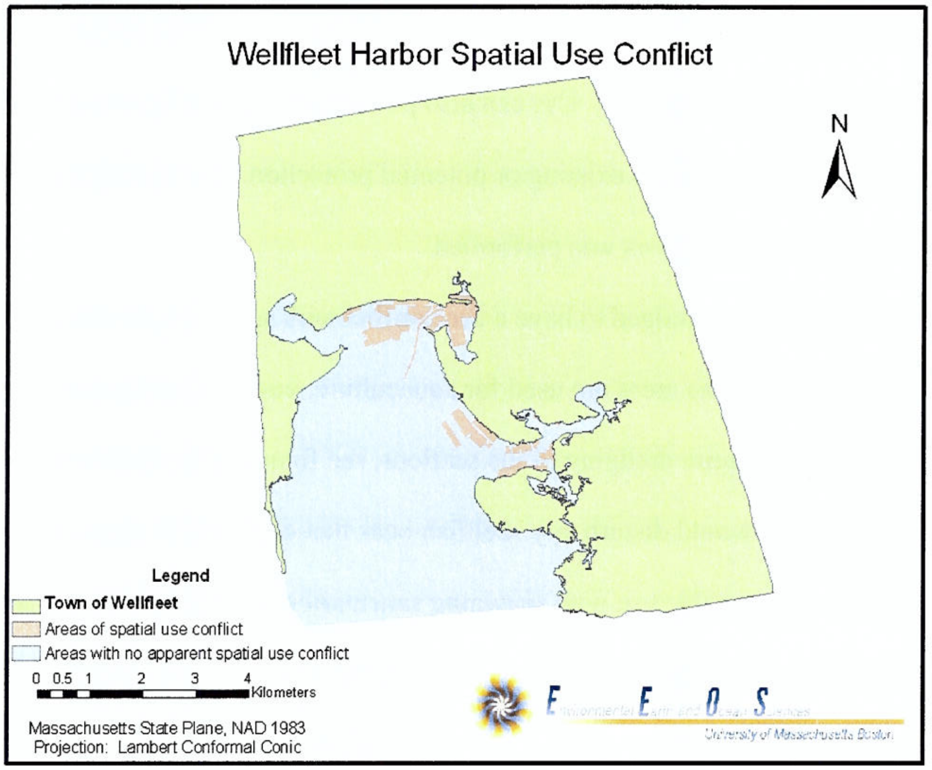
In addition, all the environmental factors that should ideally be considered to do carry out a more accurate analysis, are simply not available. This is another source of inaccuracy or uncertainty. In Table 4.1, ideal environmental factors to consider in determining environmental suitability for the two organisms are listed. It also shows that the analysis is missing factors such as presence of predators, harbor circulation, current speeds, benthic condition and substrate type because there is no existing data for these factors. The addition of these factors to the environmental selection criteria employed in the multiple criteria analysis could alter the analysis results. For example, quahogs like to settle and live in coarse sediment, while oysters need to cement themselves onto a hard substrate. Knowing the location of existing oyster reefs that are underlain with coarse sediment would make the analysis more accurate. Another example is the presence of predators. In certain areas of the harbor, due to prevailing environmental conditions, predators of the juvenile and adult shellfish will be more abundant than in other areas. Adding this data to the analysis would better show areas of predicted success for the survival of both adult spawning organisms and the offspring of these broodstock as they are broadcast in the currents around the harbor.

Phase 3: Use Conflict Analysis

It has been made clear at this point that man has a major presence in this coastal area. The human presence in Wellfleet Harbor has lead to many uses of the harbor system. These uses may prove to limit site suitability for spawning sanctuaries or to promote the suitability of the sites. The mechanism of this process that would limit site suitability would be spatial conflict. Use can also promote the suitability of an area by having a compatible use, such as existing or potential protection. By identifying uses of the harbor, a use conflict analysis was performed.

The areas that were judged to have a use conflict with spawning sanctuaries are displayed in figure 5.4. The areas are used for aquaculture, vessel mooring areas and marina activities that require dredging of the seafloor, see figure 4.12. Both vessel mooring and dredging would disturb any shellfish beds that occur in the same area and are therefore not a compatible use with spawning sanctuaries. Aquaculture lease areas are public lands that are contracted over to private owners for the purpose of rearing shellfish. Besides the existing use of these submersed areas by aquaculture that is guaranteed in lease contracts, aquaculture is a highly important economic activity for Wellfleet that should not be compromised. Therefore aquaculture sites are not compatible with spawning sanctuaries.

Figure 5.4: Areas of Spatial Use Conflict for Spawning Sanctuaries in Wellfleet Harbor



Compatible sites with spawning sanctuaries are areas that are currently protected, are being considered for protection or have the potential to be protected in the near future. This would include any areas of sub aquatic vegetation (SAV). As revealed by the latest aerial survey of the harbor in 2001, there was a small patch of ruppia maritima in the mouth of the Herring River (MassGIS). Considering the ecosystem services of SAV beds and their dwindling benthic coverage, they should ideally be protected (Wilbur). This mutual ideal of protection, then, is considered optimal in the present study for location of spawning sanctuaries.

The combination of the use conflict analysis and environmental analysis is displayed in figure 5.5. The results are not drastically different than the environmental analysis (figure 5.3), as much of the incompatible uses occurring in the harbor are located in areas that are not environmentally suitable for the mixed oyster and quahog spawning sanctuaries.

Figure 5.5: Wellfleet Harbor Site Suitability for Spawning Sanctuaries

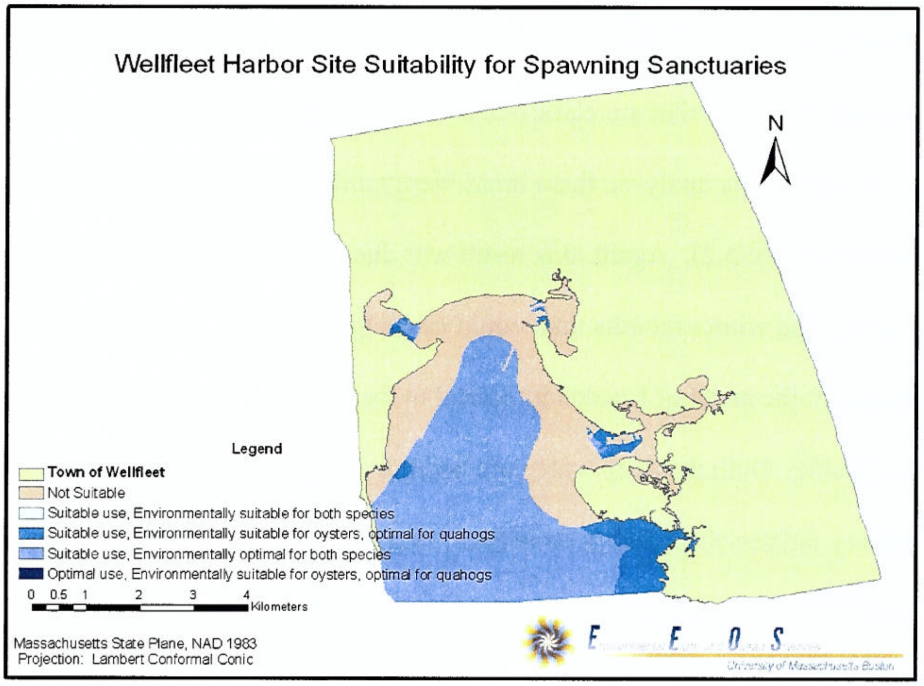
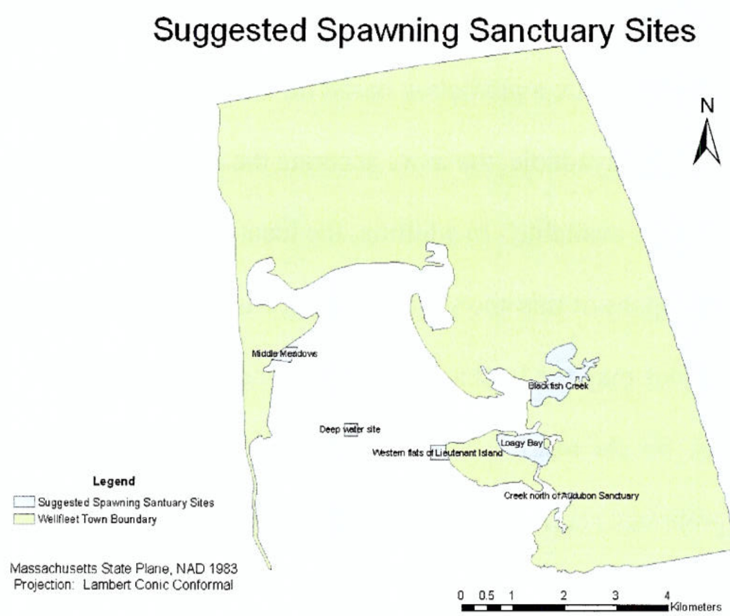


Figure 5.6: Initial Suggested Spawning Sanctuary Sites



Comparing the results of the site suitability analysis displayed in figure 5.5 with the initial six suggested spawning sanctuary sites, figure 5.6, we are able to make suggestions as to which of the suggested sites are predicted to be suitable for spawning sanctuaries. It is clear that the Middle Meadows, Blackfish Creek, Lieutenant Island and Loagy Bay sites fall into areas that are classified as not suitable. Recalling the initial environmental site suitability analysis, these areas were rendered not suitable in the analysis for oysters (figure 5.2). Again, this result was due to lower temperatures reached in these areas during the winter months that would cause high mortality in oysters. There is however, an area to the north of Lieutenant Island in the mouth of Blackfish Creek that is classified as suitable. Both the deep water site and the creek to the north of the Audubon Sanctuary fall are classified as environmentally optimal with no use conflict. Although four of the six suggested sites are not shown to be suitable for spawning sanctuaries, there is a large part of the harbor that is.

While the results revealed in the analysis are a starting point for locating sanctuaries, they should not be taken as an unshakeable truth. The results of the analysis, the environmental analysis in particular, are a prediction based on the best available data. As stated before, the more data that is available, the more accurate the analysis and it is clear that not all of the ideal data was available. In addition, the location of sampling sites was not designed with the purpose of this site suitability analysis in mind. Therefore the distribution of the sampling sites may not lend itself to the best representation of actual environmental conditions. So, the results of the site suitability analysis should be considered as a good starting point that should reflected upon more thoroughly by members of the local community, local scientists and that should be considered with other factors not included in the environmental and use conflict analysis.

Phase 4: Other Factors to Consider in Management Decisions

There are other issues to consider that may not have been directly included in phase 2 (environmental site suitability analysis) and phase 3 (use conflict analysis). These include issues that have no explicit spatial distribution that can be included in the analysis or other factors that should be considered but can not enter the analysis as a black and white (suitable or not suitable) classification. Combined with the spatially explicit outcomes of phase 2 and 3 they can lead to better informed harbor management decisions.

One of these issues that could lead to physical conflict for spawning sanctuaries would be the wild harvest of shellfish. While the intention of these sanctuaries is to help protect this industry, they will ultimately lead to a slight decrease in available fishing grounds. The intention, then, is to minimize this. The issue should be given extra attention, not only for the economic well being of the wild shellfishing industry, but also for the social acceptance of spawning sanctuaries amongst Wellfleet's fishermen and other concerned citizens.

The harbor's shellfishing beds are divided into several areas (see figure 5.7) with a complex set of rules for the time of year the area can be fished, the type of harvesting allowed, and the numbers of bushels allowed (see Table 5.1). Given the considerable popularity of seasonal shellfishing (June-September) and its restricted spatial extent, the areas used for this type of shellfishing should not be considered for spawning sanctuaries. Harvesting methods employed differ around the harbor. Locating a sanctuary in the middle of a dredging ground would not be logical because the difficulty of locating such a designated area and the physical difficulty of a dredge and then re-deploying it outside of the protected area. This difficulty would likely either lead to rejection of the sanctuary site by fishermen or non-compliance if the site were designated protected. If the method of harvest, however, were hand picking or raking, the physical difficulty in locating the protected area and disengaging from harvest would not be great and would therefore likely have a higher chance of both acceptance and compliance amongst the fishing community. Table 5.1 lists the fishing areas, their open season, the allowed method of harvest and management considerations in regards to the possibility of locating a spawning sanctuary within that fishing area.

Figure 5.7: Wellfleet Harbor Wild Shellfish Harvest Regulation Areas

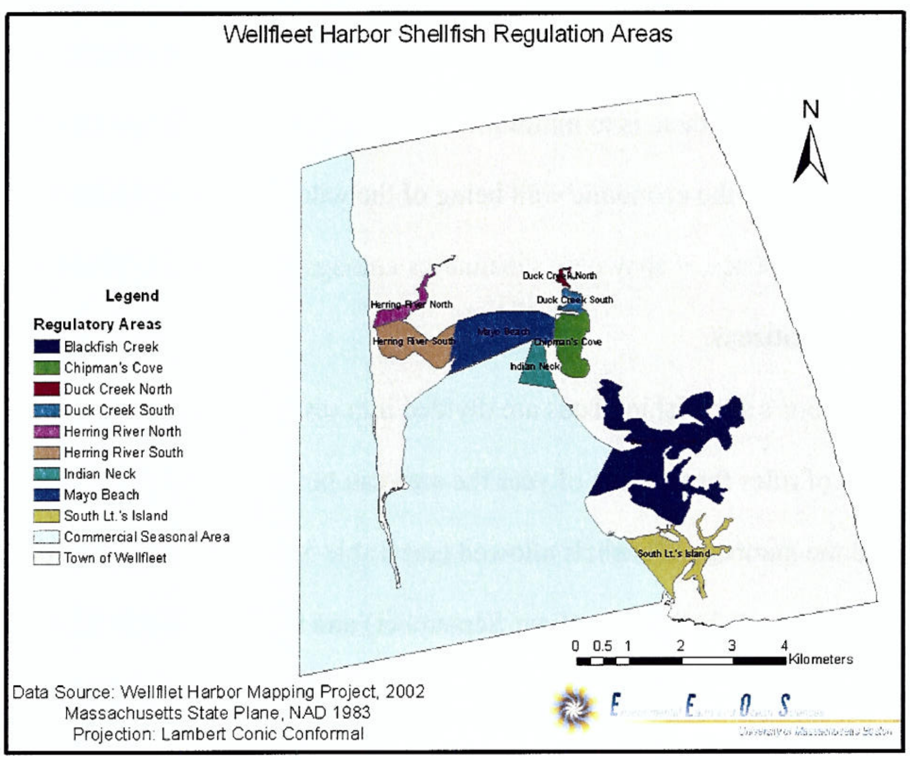


Table 5.1: Wild Shellfish Harvest Regulation and Management Considerations

Areas	Sub Area	Open for Harvest	Harvest Method
AREA 1: Commercial Only			
	Duck Creek	Year Round	Hand Raking
	Herring River	Year Round	Hand Raking
	Mayo Beach	Year Round	Hand Raking
AREA 2: Non-Commercial Only			
	Indian Neck	June1-Sept.30 (Sunday and Wednesday) Oct1-May31 (7 days a week)	Hand Raking
AREA 3: Commercial and Non-Commercial			
	Main Harbor (Non-Commercial)	Oct1-May31 (7 days a week)	Hand Raking
	Main Harbor (Commercial)	Oct1-May31 (7 days a week)	Hand Raking and Dredge/Drag
	Chipman's Cove (Non-Commercial)	Oct1-May31 (7 days a week)	Hand Raking
	Chipman's Cove (Commercial)	Oct1-May31 (7 days a week)	Hand Raking

Note: Total commercial harvest limit is 5 bushels daily
Note: Total non-commercial harvest limit is 10 quarts weekly

Shellfish Regulatory Area	Restrictions	Management Considerations
Indian Neck Recreational	Open to recreational raking only Year round	Mode of harvest makes it easier to have designated protected areas. However, this is the only area open to recreational harvest during the busy summer season and the importance of this activity does allow the elimination of the harvesting area. This area should either not be considered or another recreational area would have to be designated
Chipman's Cove	Open to commercial and recreational raking fall-winter	Mode of harvest makes it easier to have designated protected areas. Also the area is only seasonally open to harvest leading to less use conflict with fishermen.
Mayo Beach/Herring River	Open to commercial raking year round	Mode of harvest makes it easier to have designated protected areas.
Duck Creek	Open to commercial raking year round	Mode of harvest makes it easier to have designated protected areas.
Seasonal Area	Open to commercial and recreational raking and dredging October 1- May 31	The area is a seasonal harvest area, which is beneficial for use conflict. However, the use of dredging for shellfish harvest may make it difficult to designate protected areas that are easily avoidable by fishermen towing dredges.

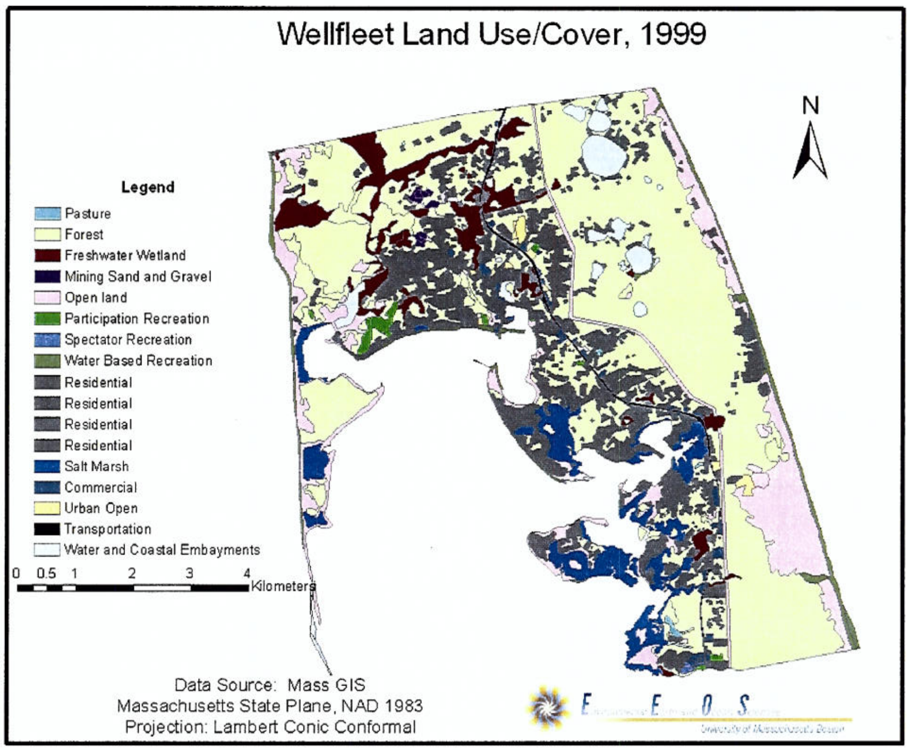
While it would be ideal to locate a spawning sanctuary outside of fishing areas, nearly the whole harbor is open to fishing or is leased for aquaculture. Areas that are either closed to fishing or closed frequently during the year because of high coliform concentrations would be better for locating spawning sanctuaries. The number of times fishing areas are closed to shellfish harvest because of high coliform concentrations was captured in the environmental site suitability analysis (see figure 4.10). Areas that were closed more frequently (mostly Herring River and Upper Duck Creek), however, were for the most part environmentally not suitable for mixed spawning sanctuaries, except for a small section in the middle of Herring River. In addition, the small SAV bed is located in this same area of Herring River (see figure 5.5). This site in Herring River (see figure 5.5) should be further considered for a spawning sanctuary.

Another factor to consider in regards to wild shellfish harvest is the relative abundance of shellfish around the harbor. In other words, where do fishermen harvest the most? For example it would lead to a severe use conflict to restrict harvest and establish a spawning sanctuary in the middle of the most abundant fishing area of the harbor. Amongst the fishermen of Wellfleet there is anecdotal evidence of high quahog abundance in the channel and deep water areas of the harbor (personal communication, Andy Koch). There is, however, no recent or thorough survey of shellfish abundance that could be considered. If such a survey were conducted, or a more spatially explicit description could be provided by fishermen, this data could be worked into the analysis to avoid restricting harvest in better fishing areas.

Landuse and land cover is another factor that can be considered in a site suitability analysis. What happens on the land directly affects the nearby aquatic environment. In addition, in Massachusetts, private owners of property on the waterfront may also own the adjacent tidal lands out to the mean low water line. Residential ownership of the intertidal land, could therefore present an obstacle to the establishment of spawning sanctuaries in this area.

While nearly 2/3 of Wellfleet is fortunate enough to be protected under the National Park Service as the Cape Cod National Seashore that leaves a third of the town subject to normal commercial and residential development and related activities (Riehl 2006). Most of these residential and commercial uses are concentrated around the harbor, upland from the potential spawning sanctuary sites. The most recent land use map from 1999 is displayed below in figure 5.8.

Figure 5.8: Wellfleet Land use



Most of the areas shown in the analysis to be suitable for spawning sanctuaries are in the deep water area of the harbor (Figure 5.5). This means that there will not be a direct problem with adjacent land use. However, there are some areas shown to be suitable for sanctuaries that are adjacent to land. Additionally, future decision makers may find reason to locate a sanctuary adjacent to the land despite the outcome of the site suitability analysis.

Wellfleet is not a large urban area, nor does it have any intense agriculture or other sources of contaminants and runoff. Any problems encountered with upland land use should not be major. The following table takes each land use listed for Wellfleet in 1999 and briefly discusses any applicable issues to be taken into consideration before establishing a spawning sanctuary.

Table 5.2: Management Considerations of Land use

Land use		**Management Considerations**
Pasture		Compatible land use unless there is excessive runoff or waste from grazing animals
Forest		Compatible land use. Preferential adjacent use.
Freshwater wetland		Compatible land use. Preferential adjacent use.
Mining sand/gravel		Due to potential contaminant and sediment runoff, sanctuary establishment directly adjacent to such areas should be avoided. Consider a buffer between the mining area and sanctuary.
Open Land		Compatible land use unless there is excessive runoff.
Participation Recreation		Compatible land use. Runoff from treated turf may be an issue.
Spectator Recreation		Compatible land use. Runoff from treated turf may be an issue.
Water Based Recreation		Compatible as long as the recreational activity does not excessively stir up the sediments. Water based recreation could also provide easy access to the tourist/visitor to the sanctuary and may compromise it. Establishment of a sanctuary here also presents the potential for public outreach and ecological education.
Residential		Residential areas may present ownership problems in the intertidal area. Also contaminants from lawn runoff may pose a small problem. Make sure ownership of the intertidal area is explicit and consider a small buffer between the areas.
Salt Marsh		Compatible adjacent land use. Preferential adjacent area.
Commercial		Due to runoff with sediment, contaminants and trash, sanctuaries directly adjacent to such areas should be avoided. Consider a large buffer between commercial areas and sanctuaries.

Urban Open		Due to runoff with sediment, contaminants and trash, sanctuaries directly adjacent to such areas should be avoided. Consider a large buffer between urban open areas and sanctuaries. Also easy access for tourists here could compromise the sanctuary.
Transportation		Due to runoff from roads that may contain sediment and contaminants, location of a sanctuary directly adjacent to these areas should be avoided. Consider a buffer between a transportation area and a sanctuary. Also tourists with easy access to the water could compromise the sanctuary.
Water and Coastal Embayments		Compatible use.

Future Work

If spawning sanctuaries are designated, more data collection and future work is warranted. While many spawning sanctuaries have been designated across the country, there has not been much work in monitoring the effectiveness of the sanctuaries in achieving the goals with which they are set forth. Therefore future work in regards to sanctuaries is that a monitoring program should be implemented along with spawning sanctuaries to measure their effect on quahaug populations and water quality. In keeping with an ecosystem based approach, monitoring is key for adaptive management. Regarding spawning sanctuaries, there must be a before and after. Monitoring must be capable of detecting change in the system that may precipitate because of implemented management decisions. Having the goal of the sanctuaries clearly stated allows us to match the monitoring approach to be able to evaluate progress and adapt the method of management according to the results of monitoring.

Another useful project to conduct for the harbor, considering the wild and culturing shellfish industry, would be a carrying capacity assessment. This assessment would address, likely through modeling, what the biomass of shellfish is that the harbor can sustain without being degraded. Such an assessment is crucial in the long term for the wild shellfishery and aquaculture industry, as well as it is important in consideration of all the other uses of the harbor. While establishing sanctuaries could be beneficial, if the harbor's carrying capacity is exceeded by the combination of activities, no benefit would come from their establishment. In addition human activities, in that they require a certain degree of pristine environments and exploitable resources, ideally require a carrying capacity assessment. Rees and Wackernagel define this concept of the human carrying capacity as "the maximum rate of resource consumption and waste discharge that can be sustained indefinitely without progressively impairing the functional integrity and productivity of ecosystems" (quoted in Folke et al 1998). In essence the question deals with how many humans can live there, how much human disturbance on land and in turn Wellfleet Harbor is absorbed by the system and how much resource extraction can occur without permanent damage to the harbor?

A harbor wide biological inventory was published in 1972 by the Division of Marine Fisheries, commonly called the Curley Report. It took an inventory of the flora and fauna species present in the harbor as well as estimating their abundance. Such an inventory was repeated in the early 1990s. Ideally a more thorough inventory should occur every few years to monitor the changes taking place in the harbor. In addition to an environmental inventory including biological, chemical and physical data, a socio-economic inventory should also be conducted. Having these inventories will better aid in analyzing outcomes of resource management options in the coastal zone (Frankic 2003). In regards to implementing spawning sanctuaries, a harbor inventory would be a useful tool for comparing the before and after changes in terms of abundance of shellfish and other associated biological communities if sanctuaries were established.

Referring back to Table 4.1, it is apparent that there is some environmental data that is either not available or insufficient for decision making. A prominent missing element is substrate type. While pieces of anecdotal information on the benthic substrate exist on old nautical charts and an incomplete town map, the information is not adequate for inventory purposes. In regards to shellfish, it is a crucial piece of information. Shellfish species settle out of their planktonic larval stage when they are ready and when they encounter their preferred substrate type. As explained previously, oysters settle onto hard substrate, quahogs prefer sand and gravel, scallops prefer SAV and soft shell clams prefer soft mud and sand (Dame 1996).

Another piece of missing data is the prevailing physical circulation pattern and currents in the harbor. Currents are particularly useful when dealing with suspension or filter feeding organisms such as shellfish. Water currents carry food particles past the organisms and on the opposite end flush pollutants and continuously bring in fresh water (Dame 1996). In relation to this examination of Belding's data from Wellfleet harbor shows a strong positive correlation between strength of water currents and growth rate of quahogs (Belding 2004).

In consideration of spawning sanctuaries, the hope is that new settling recruits will not be advected out of the harbor with the current, but rather retained (Brumbaugh et al 2005). The circulation and current largely will determine this pattern and are, along with benthic substrate, indispensable for examinations in siting sanctuaries. Circulation also largely governs transport of all other substances or materials carried in the water. In the case of a large chemical contamination in the harbor, the circulation pattern will reveal transport patterns of the substance.

The next steps than should be the establishment of an action plan for spawning sanctuaries. The outcome of the site suitability analysis together with the additional management considerations and additional insight of local citizens of Wellfleet should be reviewed town decision makers. They will need to ask the following questions: Is the town already adequately protecting the shellfish resource and habitat? Do they want to protect and potentially restore their shellfish resource? Are they willing to try spawning sanctuaries? Given the analysis and additional considerations, where will the sanctuaries be most effective and acceptable?

In conclusion, it is clear that a thorough discussion and consideration of all factors, both environmental and socio-economic, will lead to better management decisions for the resources of Wellfleet Harbor. In regards to the mixed species spawning sanctuaries considered in the present study, the analysis has been revealing. Although some parts of the harbor may be environmentally suitable for oysters and quahogs, this suitability may be limited through human use of the harbor. In addition it is clear that other issues may affect suitability, as discussed here, the wild shellfishing industry and land use. The environment ultimately determines the success of a biological community, however, the environment must now be considered projected within human social systems. Both environmental factors and social factors are shown here to affect the site suitability for shellfish spawning sanctuaries.

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