Site Suitability Analysis for Offshore Sea Scallop (*Plactopecten magellanicus)* Aquaculture Martha's Vineyard, Massachusetts

Master's Project Paper

by

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ABSTRACT

Global catch data reveals that harvests from the world's wild fisheries are approaching exhaustion. Expansion within the field of aquaculture would give promise to an increase in seafood. Aquaculture projects offer a plan that could result in providing an additional source of fish, while stimulating employment opportunities for fishing communities that have been left stagnant from diminishing fisheries. As coastal areas become more populated, suitable near shore sites for aquaculture are scarce. As a result, a focus on offshore sites that might accommodate both spatial and environmental requirements is sensible. This project, aimed at determining the suitability of sites for a sea scallop aquaculture venture offshore the island of Martha's Vineyard, Massachusetts, was undertaken with the hope of giving assistance to the rejuvenation of the island's fishing heritage. Through the use of Geographic Information System (GIS) software, areas offshore the island were mapped according to the environmental requirements for sea scallops and the potential conflicting uses within the area. The overlapping areas resulting from these analyses display many promising sites for a sea scallop aquaculture project. Though a lack of available spatially defined offshore data limits a definitive examination of suitable sites, and the eventual incorporation of more information involving socioeconomic data and current fishing effort is needed before the optimum site for sea scallop aquaculture can finally be selected, reliable advances were made in determining the general suitability of an aquaculture venture off the island's shores.

PROJECT DESCRIPTION

With an understanding of the hardships encountered by New England fishermen, the present study examines the feasibility of the development of offshore aquaculture for the fishing village of Menemsha, located on the island of Martha's Vineyard, Massachusetts. Through an analysis of existing data, this project aims to determine suitable offshore sites for sea scallop aquaculture around the island of Martha's Vineyard. Sites have been determined based upon a consideration of the environmental conditions necessary for sea scallop survival and an assessment of offshore uses and potential conflicts within the area. All available offshore environmental data and uses of the area have been mapped using Geographic Information System (GIS) software with the purpose of spatially displaying both suitable and unsuitable sea scallop aquaculture sites. Based upon the sites available and an economic analysis of a past sea scallop aquaculture endeavor, the goal of this project is to analyze the beneficial viability of such aquaculture sites for the fishing community of Menemsha. The goal of this venture is to analyze both the feasibility of aquaculture sites and their eventual viability within the fishing community of Menemsha on the island of Martha's Vineyard, while considering a careful examination of available sites and the economic trials of a preexisting sea scallop aquaculture endeavor.

The methodology used to perform this analysis is based on Frankic (2003) and includes the following five phases:

PHASE 1: Environmental Analysis (A): Determine the environmental conditions necessary for sea scallops.

PHASE 2: Environmental Analysis (B): Develop maps using GIS (Geographic Information Systems) to spatially display the environmental conditions gathered in Phase 1 for the area under investigation.

PHASE 3: Conflict Analysis: Identify and map all existing and potential uses of the area under investigation and produce maps indicating suitable and unsuitable aquaculture sites based on environmental and conflict analysis.

PHASE 4: Identify management issues within the suitable area through the incorporation of socioeconomic issues.

PHASE 5: Create action plans for the aquaculture project within the areas deemed most suitable.

Following this process, Phase 1 engages in an extensive literature review to determine the environmental requirements for sea scallops. Based on exiting information the collected data describing the environmental conditions of the project area is presented. In order to spatially display this information, it is essential that all of the data be geographically referenced. This allows the data to be translated into maps using GIS software. Extensive research indicates that the available offshore data for the project's region is still lacking. Only substrate and bathymetry data are found to exist in the area under investigation. As a result, a parallel project was constructed to acquire subsurface temperature data. Although this data cannot be integrated into GIS software, it provides further information on the offshore area.

After acquiring and mapping all available environmental data for the area, it was then important to perform a conflict analysis, which is Phase 3 in the methodology. This step allows for areas with conflicting activities to be eliminated from the suitable sites. Similar to the environmental data, it was important for the other uses of the area to be in a spatially defined format. Following the Environmental and Conflict Analyses, maps were generated to indicate the sites that offer suitable environmental conditions for sea scallops without disrupting the other uses and infrastructures within the same vicinity.

The potential management issues addressed within Phase 4 of this project involves deficient fishing effort data, site security problems, and the protection of permissible fixed gear within the aquaculture site. Phase 5 is not addressed within this project.

BACKGROUND

Give a man a fish and he will have food for a day.
Teach a man how to grow fish and he can feed the world.

-Modified by R.R. Stickney from a Chinese proverb

Currently, the world consumes an estimated 107 million metric tons of seafood[1] each year, and it is projected that by 2030 an additional 40 million metric tons of seafood products will be needed in order to meet the current per capita consumption of the world's growing population (FAO (1) 2006). Although our technology and general ingenuity has facilitated our "successfully" harvesting all we can from the ocean's wild fisheries, we are now in the midst of a calamity. Trends in capture fishery supply show that we have reached a plateau (Figure 1.1), a fact, which is compounded when statistics show that 75% of the world's capture fisheries, are deemed fully exploited, overexploited, or depleted (FAO (2) 2006). With the demand for seafood continuing to rise, the emergence of aquaculture as a means of both sustaining and augmenting the world's seafood supply is ineluctable.

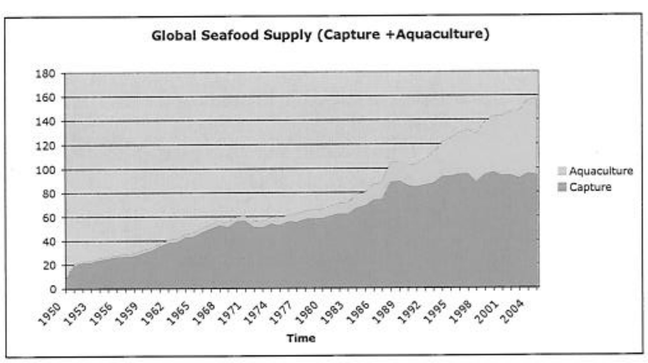

Figure1.1. World seafood supply/production (FAO (2) 2007).

[1] This figure includes seafood from capture fisheries and aquaculture sources.

WORLD AQUACULTURE

According to the United Nations Food and Agriculture Association (FAO), aquaculture is defined as "the farming of aquatic organisms, including fish, mollusks, crustaceans, and aquatic plants," with farming implying "some form of intervention in the rearing process to enhance production as well as ownership of the stock being cultivated" (FAO 2000). While growth in seafood supply from capture fisheries remains stagnant, worldwide aquaculture industries have grown at an average rate of 8.8% per year since 1950 (FAO (1) 2006). Not only is the growth rate of aquaculture higher than capture fisheries, which are barely growing at 1.2% per year, but it also surpasses the growth of terrestrial farmed meat industries (2.8%), making it the fastest-developing food production sector in the world (FAO (2) 2006). In 2005, global aquaculture production was estimated to be 47.8 million metric tons, accounting for approximately 34% of the total supply of seafood (including human consumption and non-food uses) (FAO (2) 2006).

Overall, the expansion and growth of aquaculture production has occurred predominantly in developing countries, with Asian countries producing over 90% of global aquaculture in 2004 (Marine Aquaculture Task Force (MATF 2007). Of these countries, China leads the world in aquaculture, supplying about 70% of the total quantity and 51% of the total global aquaculture production value (FAO (2) 2006). In general, Asian aquaculture chiefly involves the cultivation of carp and seaweed for domestic uses, and shrimp and mollusks for export purposes (MATF 2007).

UNITED STATES AQUACULTURE

In the United States, both freshwater and marine species are cultivated using a variety of aquaculture techniques. Freshwater species are generally grown using natural and man-made pond and tank systems. These freshwater species include catfish, crawfish, trout, tilapia, baitfish, and striped bass (MAFT 2007). Catfish production is considered to be the top aquaculture industry in the United States, supplying over 71% of the total aquaculture production in 2003 (MATF 2007). Catfish production occurs principally in Mississippi, Arkansas, and Alabama (MATF 2007).

Even though freshwater species make up the majority of aquaculture production and value in the United States, there are also a substantial number of marine aquaculture farms. The primary marine species produced in the United States include Atlantic salmon, oysters, clams, mussels, and saltwater shrimp (MATF 2007). Within the cultured marine species, Atlantic salmon dominate production with the largest facilities operating in Maine and Washington (MATF 2007). Marine species are grown in coastal waters, using a wide variety of species dependent methods. Such methods include "ponds, raceways, silos, circular pools, closed systems, cage and net pens, sea ranches, rafts, and long-lines" (Cicin-Sain et al. 2001).

Though the United States produces less than 2% of the total world aquaculture seafood supply, the industry has shown rapid growth since the 1980s (FAO (2) 2006). Despite this growth, however, the United States is still ranked 10th in terms of global aquaculture production, amounting to a $1billion annual industry, in comparison to the $70 billion world aquaculture industry (MATF 2007). Required expansion within the United States aquaculture industry becomes more apparent when learning that the United

States is recognized as the third largest consumer of seafood in the world (NMFS 2007), importing 80% of its seafood supply, with approximately 40% of the seafood imports being farmed (MATF 2007). This has created a United States seafood trade deficit estimated to be $8 billion dollars annually (MATF 2007). In the meantime, the demand for seafood continues to escalate, spurred by both the rising population and a correlating increase in seafood consumption. All of these factors, together with the collapse of the capture fisheries, have resulted in the United States being in a serious dilemma. In an attempt to rectify the situation, the United States Department of Commerce has called for a national expansion of the aquaculture industry to reach $5 billion by 2025 (MATF 2007).

However, as near-shore areas become more developed, the areas suitable for coastal aquaculture are diminishing (MATF 2007). Escalating development of coastal areas tends to heighten user conflicts and decrease water quality, both of which are factors found to constrain aquaculture endeavors. Of added importance, with near-shore and land-based aquaculture facilities, a cap remains on the number of species that can be raised without producing multiple conflicts and causing environmental degradation. With these factors in mind, the concept of offshore aquaculture, or the propagation of marine species in federal waters[2] is seen as a possible solution.

[2] Federal waters are defined as "those waters from the seaward limit of state jurisdiction to the seaward limit of federal jurisdiction, generally 3-200 miles from the coast" (Cincin-Sain et al. 2005). This area includes the Exclusive Economic Zone (EEZ) which encompasses both the Territorial Sea (usually 3-12 nautical miles) and the Contiguous Zone (12-24 nautical miles), and then extends out to 200 nautical miles (Kalo et al. 2007).

This movement offshore is thought to increase the number of suitable aquaculture sites because offshore areas are not as conflict-prone as inshore regions, which must balance the demands of recreational, real estate, and commercial uses (Naylor (1) 2006). Unlike near-shore areas, stronger currents offshore offer a natural way of flushing excess waste and feed from aquaculture facilities (Naylor (1) 2006). Furthermore, due to the large expanse of the United States Exclusive Economic Zone (11,351,000 km^2), offshore aquaculture is believed to have the potential to expand aquaculture production in order to meet the projected seafood demands of the future (Cicin-Sain et al. 2001).

OFFSHORE AQUACULTURE CONCERNS

While offshore aquaculture has the potential to meet the population's rising nutritional demands, expand jobs in coastal communities, alleviate pressure on depleting wild species, and restore species through stock enhancement, the possibility of adverse effects are real (MATF 2007). As aquaculture technology has grown, allowing for the formation of larger-scaled projects, impacts on the environment have become more of a concern. Such issues include water pollution, genetic effects from farmed species on wild populations, spread of non-native species, and the utilization of wild fish as feed for aquaculture species (MAFT 2007). With some of these problems being illustrated with United States Atlantic salmon and shrimp culture, many are wary of the expansion of aquaculture into offshore waters, viewing it as another exploit that could critically alter our oceans.

Added to these concerns, the lack of a policy that permits and directs such projects in federal waters has further stalled the expansion of offshore aquaculture operations. Although the National Offshore Aquaculture Act of 2007 is currently up for governmental review, no policy has currently been accepted. With the awareness that this aquaculture policy will determine if the movement of aquaculture offshore will result in its being a positive force or yet another cause of harm, leaders have been cautious in both the formation and acceptance of the Act. While there are no current projects occurring in federal waters, knowledge acquired from aquaculture projects occurring in offshore-like environments in state waters of the United States is being used to assist the development of future projects and policies in offshore waters. Presently, there are three commercial "offshore" endeavors involving the cultivation of shellfish and finfish, which are located in Hawaii, New Hampshire, and Puerto Rico.

As the prospect of offshore aquaculture increases, the need to designate appropriate offshore sites becomes essential. New England is believed to be especially suited for the expansion of offshore aquaculture, possessing suitable waters and harboring the infrastructure and skill within its many fishing communities to operate offshore aquaculture equipment (Kite-Powell et al. 2003). Furthermore, the imminent collapse of the ground-fishing industry and the heightening of regulations have made it harder to make a living from the ocean, forcing small-scale fishermen to sell their permits to large fleet owners and search for work elsewhere. These changes are glaringly evident in the once burgeoning fishing communities of Massachusetts.

MASSACHUSETTS COMMERCIAL FISHERY

The commercial fishing history of Massachusetts stems back to the great whaling years of the 18^{th} century, a time when harpoons reigned and large numbers of Right whales "haunted" the coasts (Robotti 1962). Around this same time, the cod fishery began to build, bringing more wealth to Massachusetts. While Massachusetts still harbors a strong commercial fishing industry, it has drastically changed since the legendary years of whales and cod. Throughout the time of World War II, inventions, consisting of high-powered boats, dragging nets, and the concept of fish freezing, have spurred the fishing industry forward. These changes expanded fishing farther offshore, increased catch quantities, and diversified harvests (Kurlansky 1998), eventually leading to the great exploit of the groundfishery,[3] a category of fish that encompassed the majority of the commercially valuable marine fish species (Playfair 2003). Ultimately, such large landings perpetuated the belief that this resource was inexhaustible, resulting in increased over-fishing and the eventual depletion of many groundfish stocks. In the 1960s, sharp declines in haddock catches caused, first, a shift in fishing concentration to yellowtail flounder stocks and then to cod (Doeringer et al. 1986). As with haddock stocks, yellowtail flounder and cod fisheries began to suffer from over-fishing.

In attempt to assist stock recovery, a variety of regulatory measures were developed. Due to great fishing pressures from foreign fleets, a regulatory act was created to forbid foreigners from fishing areas within 200 miles of the coast of the United States (Doeringer et al. 1986). This act, passed in 1976, was entitled the Fishery Conservation and Management Act and is known today as the Magnuson-Stevens Fishery Conservation and Management Act. In addition to closing off United States waters to foreign fishing, the Act formed eight fishery management councils to regulate both the commercial and recreational marine fishing industries. While this Act did result in initial stock recovery, the boom was fleeting. Increased landings enticed even more boats to join the fishing industry, heightening fishing pressures (Doeringer et al. 1986). As stocks fell and quotas

[3] Groundfish include 12 different species, some of which are cod, halibut, flounder species, sole, plaice, pollock, hake, and haddock (NEFMC (2) 2005).

were enforced, competition increased with newer, faster boats holding the advantage. In the end, over-fishing still took place, signaling difficulties in the implementation of the new regulation.

Since the initial introduction of the Magnuson-Stevens Act, many amendments and provisions have been added, shifting the focus to the conservation and restoration of fish stocks and the ecosystems upon which they rely. Although fishing today is still highly regulated, wild fish stocks continue to provide over 57% of the world's supply of seafood (FAO (1) 2006). In Massachusetts today the most economically valuable commercial fishery is the sea scallop, bringing in a value of $234,794,913 in 2006 (Figure 1.2). Following the value of the sea scallop are the American lobster ($52,388,213), goosefish/monkfish ($17,711,827), Atlantic cod ($16,075,499), and Atlantic mackerel ($10,202,013) (NMFS 2006).

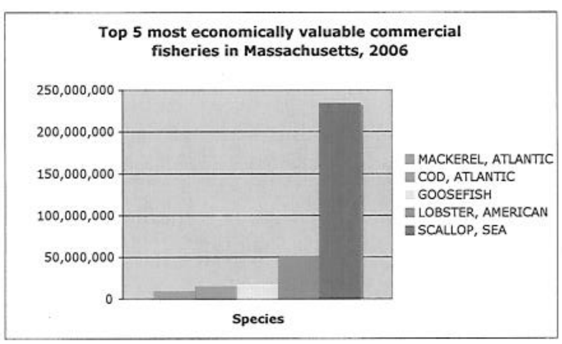

Figure 1.2. Top 5 most economically valuable commercial fisheries in Massachusetts, 2006 (NMFS 2006).

While the sea scallop industry in Massachusetts brought in the highest revenue of all its fisheries, looking at the evidence from the groundfish industry, this highly profitable fishery "could all be lost quite suddenly" (Smolowitz et al. 1998). With this concept in mind, and with an eye on the future, an investigation of sea scallop aquaculture as a means of complementing wild harvest holds interest. Studies have found sea scallop aquaculture to be especially enticing for various reasons. Scallops are filter feeders, allowing them to be cultivated without adding any extra nutrients from feed sources into the ocean environment (Smolowitz et al. 1998). Although over-fishing is currently not an issue within the sea scallop fishery, the commercial harvest of this species is believed to result in a number of potentially adverse effects. Such effects include bottom impacts from scallop gear, which are thought to decrease the productivity of scallops along with other species. There are also non-catch mortalities from scallop gear and bycatch issues as well. Added to these effects, the United States imports about 27,000 metric tons of scallops per year, worth $238 million in 2006 (NMFS 2007). With these factors in mind and with the sea scallop infrastructure and market already established, sea scallop aquaculture could be a feasible mode of increasing the resource supply while decreasing the country's seafood deficit.

CHAPTER I: MARTHA'S VINEYARD

Approximately 3.5 miles off the coast of mainland Massachusetts lies the 100-square mile island of Martha's Vineyard (Figure 1.3). While only a thousand years ago this island was the home of nearly 3,000 Wampanoag Native Americans, today it is a popular summer destination harboring over 75,000 occupants[4] on a typical summer day (Railton 2006). Nevertheless, this population blast is a seasonal trend, with the year-round population of the island estimated to be about 15,582 in 2004 (Martha's Vineyard Commission (2) 2006; U.S. Census Bureau 2004). This number includes year-round residents in all of the six island towns, which include Aquinnah, Chilmark (including Menemsha and Nomans Land), Edgartown, West Tisbury, Tisbury (also known as Vineyard Haven), and Oak Bluffs. These towns, along with the Elizabeth Islands, are a part of Dukes County.

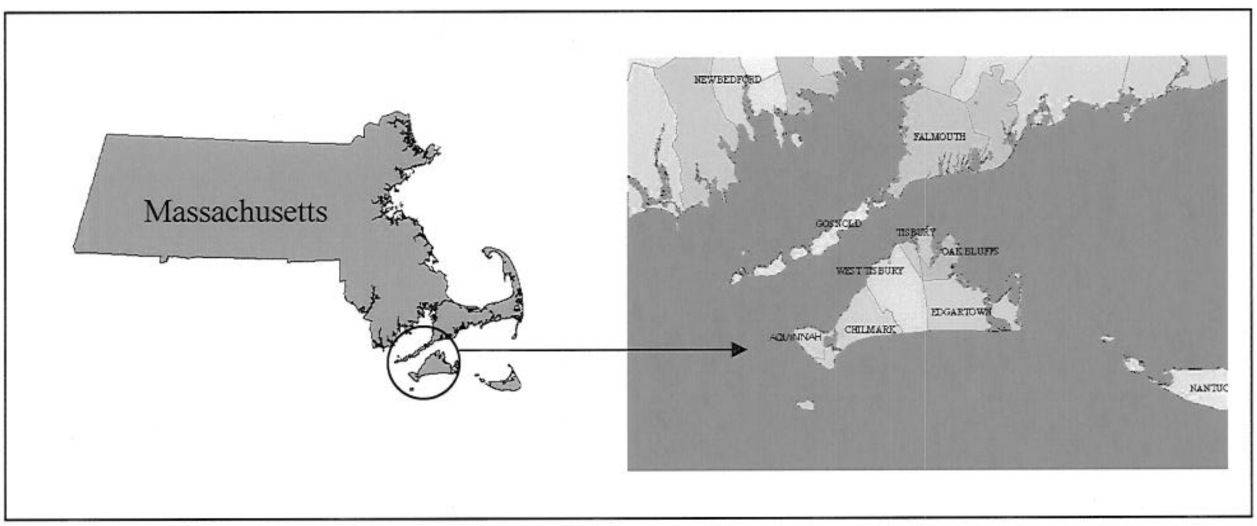

Figure 1.3. Location of Martha's Vineyard, MA.

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[4] Occupants include year-round residents, seasonal homeowners, guests, transients, day-trippers, and cruise passengers (MV Commission (2) 2006).

Using references common to a metropolis, the island towns of Martha's Vineyard are generalized into "up-island" and "down-island" groupings. Up-island towns consist of West Tisbury, Chilmark, and Aquinnah, while the down-island towns include Vineyard Haven, Oak Bluffs, and Edgartown. The down-island towns are more populated, with each town holding approximately 25% of the island's total population (MV Commission (2) 2006) (Figure 1.4). Moreover, the majority of island jobs and businesses are located in the down-island towns, with Vineyard Haven being the primary year-round port of the island.

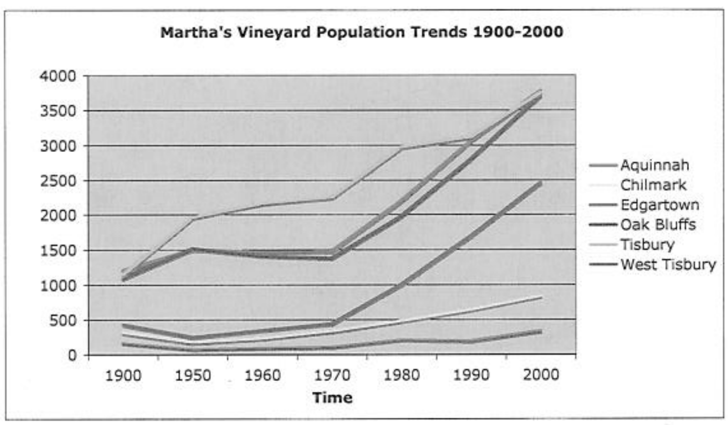


Figure 1.4. Population trends of Martha's Vineyard's six towns from 1990-2000 (most recent U.S. Census) (MV Commission (2) 2006).

ENVIRONMENT

Pitch pine, scrub oak, and sand-plain habitats dominate the island's natural environment, providing homes for many rare plant and animal species. Approximately 41,136 acres of the Vineyard and an additional 11,731.3 acres offshore the island have been designated as Priority Habitat[5] according to the Natural Heritage and Endangered Species Program (Martha's Vineyard Commission (2) 2005). This designated habitat represents about 70% of the total acreage of the island and is host to such rare species as the piping plover, beach tiger beetle, Nantucket shadbush, Northern harrier, and fritillary butterfly, to mention only a few. Currently, 39% of the island consists of protected open space, 40% of the island is regarded as developed, and the remaining 21% of the island is unprotected developable land (MV Commission (3) 2007) (Figure 1.5).

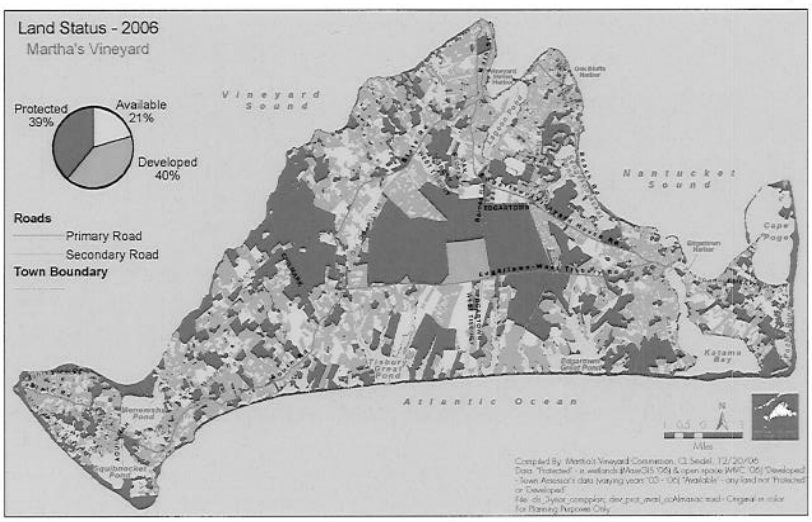


Figure 1.5. Description of the land status of Martha's Vineyard in 2006 (MV Commission (3) 2007).

The island holds within its frame 98 fresh and coastal ponds, covering approximately 9,000 acres (MV Commission (2) 2005). These ponds provide breeding grounds for herring and winter flounder, and supply habitats for shellfish, including bay scallops, oysters, and quahogs. Recreational and commercial shellfishing is particularly important on the Vineyard, both economically and culturally (Table 1.1). The harvesting

[5] According to the Massachusetts Endangered Species Act (MESA), Priority Habitats are "the geographic extent of Habitat for state-listed species" (MESA 2005).

of shellfish offers another viable means of income as well as the opportunity for island residents to harvest seafood directly, contributing to the simplicity and self-sufficiency of the community (MV Commission (1) 2005).

2007 Shellfish Landings from Martha's Vineyard Waters

COMMON NAME	POUNDS*
CLAM, NORTHERN QUAHOG	44,267
CLAM, SOFT	44,208
CRAB, HORSESHOE	30,062
OYSTER, EASTERN	198,021
SCALLOP, BAY	198,405
SCALLOP, SEA	6,881
WHELK, CHANNELED	224,779

**pounds of whole animal (shell-on)*

Table 1.1. 2007 shellfish landings from Martha's Vineyard waters (MDMF (1) 2007).

EMPLOYMENT

Overall, the employment and revenue of the Martha's Vineyard is dominated by its seasonal visitor-based economy with approximately 44% of employment stemming from tourist-related jobs (retail, food, arts, entertainment, and accommodations) (MV Commission (1) 2006). Second to the tourism industry is employment within educational and public administration areas, supplying 15% of the island employment and, finally, the construction industry, which accounts for 8% of the island's jobs (Figure 1.6).

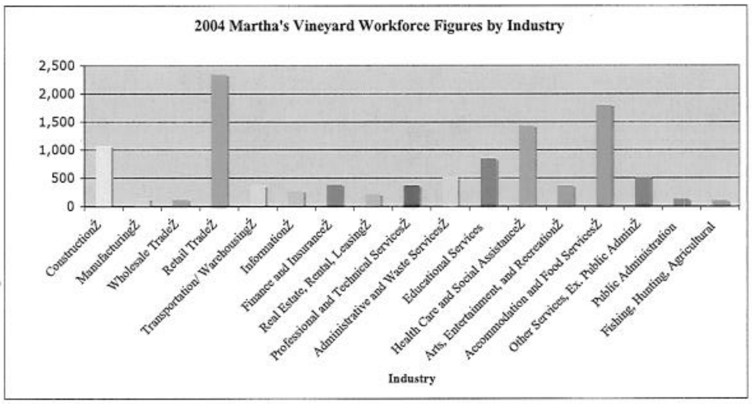


Figure 1.6. Workforce figures by industry for 2004 (MV Commission (1) 2006).

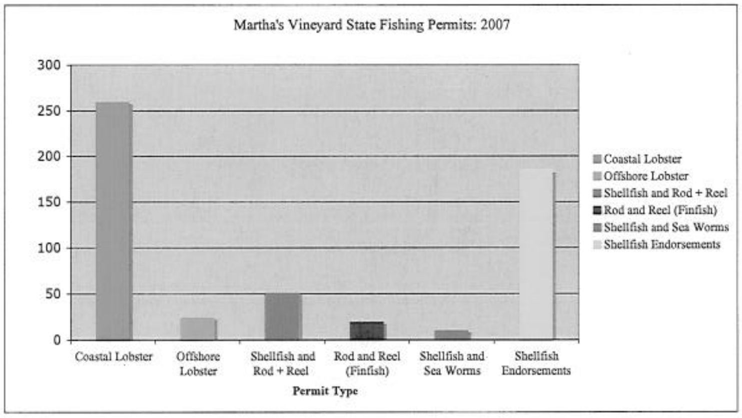
While tourism and construction combine to provide over half of the employment on the island, these occupations have imbedded issues. The island tourist season is limited, primarily, to the warm summer months, dropping off drastically as the weather gets colder and summer vacations come to an end. The employment market mimics this pattern, allowing for plenty of seasonal job opportunities but far fewer year-round positions. As a result, unemployment rates are found to triple from 2% in the summer to more than 7% in the off-season winter months (MV Commission (3) 2006).

Limited year-round employment opportunities on Martha's Vineyard, where the cost of living has been found to be as much as 57% higher than other surveyed areas in the United States and 12% higher than Boston (MV Commission (1) 2007), is a grave issue. High housing costs, gas prices, automobile service rates, and grocery prices, all of which are impacted by an island's dependency on the importation of goods, contribute greatly to the higher living costs experienced on the Vineyard (MV Commission (1) 2007). The need for more viable year-round positions for the local residents of the Vineyard is incontrovertible.

While a large percentage of island jobs are provided by construction, this industry has an inevitable ceiling, which will almost certainly be reached as available and designated open spaces and lots are developed. For islands such as Martha's Vineyard, which consists of water-defined, smaller areas, this issue will arrive sooner. Since the peaking of the construction boom on Martha's Vineyard in the 1980s, building permits have decreased; though approximately 200 residential permits per year are still issued (MV Commission (3) 2006). Understanding the potential repercussions of an over-built island and that the Vineyard's "natural setting, environmental purity, rural small-town character, and recreational access to ponds and beaches" are its core assets; initiatives to protect the island's land have materialized. These plans involve preserving land for agricultural and fishing uses, and continuing to protect critical habitats and open spaces (MV Commission (2) 2007). Additionally, fishing and farming are recognized as activities that add to the scenic interests of the island and are also viewed as ways of building a more local economy that is less dependent on the mainland (MV Commission (2) 2007).

Situated on the western tip of the island, within the town of Chilmark, is the village of Menemsha, which still functions as the heart of the fishing community on the island, though the level and type of fishing has changed dramatically. Less than 30 years ago, Menemsha's fishing fleet was bringing in an abundance of swordfish, groundfish, lobster, and scallops. As regulations have increased and stocks have declined, it has become impossible for locals to make a living in the same way. Scallop boats, which once brought in 1,000 bushels per trip and employed 30 islanders, can no longer operate due to catch limits (Crowe and Osmers 2008). Fluke and summer flounder boats are experiencing declining profits as a result of regulations, as well. As described by one Menemsha fisherman, "The first year of the plan, [Magnuson-Stevens Act] we fished one hundred ten days [before Menemsha fishermen fished 150 days of the year]. The second year was one hundred days. The third year was one hundred-one days. The fourth year was fifty-six days. The fifth year was fifty-two, and this year…it was reduced to thirty days" (Playfair 2003). The concurrence of diminished stock and increased regulations has, necessarily, caused many to abandon fishing. Yet, while the number of local fishermen and the levels of fishing are significantly smaller than that of previous generations, fishing is still vital to the traditions and heart of the island and, most essentially, of Menemsha.

The island residents hold a variety of permits that are regulated at both State and Federal levels, depending on the waters and species being fished (Figure 1.7). In 2005, there were 93 individual incomes generated from the fishing industry on the island (United States Census Bureau 2005). The protection and expansion of the fishing economy on the island is considered important in increasing the island's year-round job possibilities, while adding to its traditional character and beauty. But, as evidenced in the preceding statistics, an expansion of the fishing industry would necessarily rely upon alternative ventures and ideas such as aquaculture.



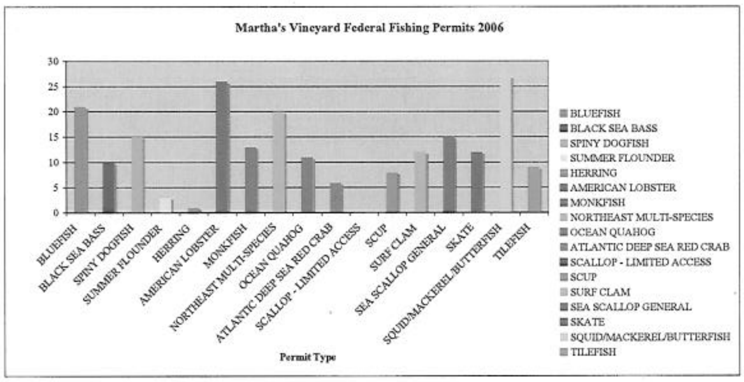


Figure 1.7. State (2007) and federal (2006) fishing permits possessed by residents on Martha's Vineyard, MA (MDMF 2007) (NOAA 2006).

AQUACULTURE ON MARTHA'S VINEYARD

The movement toward aquaculture on Martha's Vineyard began over 30 years ago with the development of the Martha's Vineyard Shellfish Group, Inc. and the construction of a solar-assisted shellfish hatchery. In 1980, the MV Shellfish Group began a non-profit corporation, with a Board of Directors comprised of the Shellfish Constables and a selectman from each of the island's towns (Karney 1988). With the understanding of the economic importance of shellfish harvests on the island, the hatchery was charged with the duty of expanding and stabilizing local shellfish populations. Therefore, most projects have concentrated on the cultivation of the more economically important shellfish species on the island, which include quahogs, oysters, and bay scallops. However, in 1995 and 1996 the hatchery, along with the Fishing

Industry Grants (FIG), sponsored extensive training sessions in aquaculture techniques for a number of fishermen with the hope of expanding aquaculture skills and projects within the local fishing community.

Today the shellfish hatchery produces shellfish seed from oysters, quahogs, bay scallops, and soft shell clams. Once the seed reaches a certain stage, they are transferred to a nursery located on Chappaquiddick Island. Ultimately, the shellfish are moved to a field nursery system for one season of "protected" growth. Afterward, the shellfish are seeded throughout the island's ponds. Additionally, the MV Shellfish Group, Inc. monitors the status of the oyster diseases, Dermo and Juvenile Oyster Disease (JOD), on the island. With the hope of recovering decimated oyster populations, the Shellfish Group is working in partnership with Rutgers University and the Woods Hole Marine Biological Laboratory on experiments testing oyster strains that appear to be resistant to these diseases.

Another project currently being investigated by the Shellfish Group and local fishermen involves offshore mussel cultivation. This project employs the use of a rope culture methodology, which has had successful results in the offshore waters of New Hampshire. By involving four local fishermen, this project is seen as a possible method of sustaining the local fishing village of Menemsha. Initial experiments have found temperatures to be conducive to mussel growth, and not to the presence of pea crabs (a crab species that inhabits mussels, decreasing their market value). (MV Shellfish Group, Inc 2008)

While the Martha's Vineyard Shellfish Group, Inc. has helped enhance and stabilize shellfish harvests on the Vineyard, the need for additional aquaculture projects is still critical. With the deficiency of year-round jobs, escalating island population, and the necessity to preserve the island's traditional fishing community, the proposition of more aquaculture projects is promising. The development of more aquaculture projects offers not only a mode of alleviating issues the island and its residents face, but also the more expansive issues of wild stock depletions and national seafood deficits. Understanding these needs, the community of Martha's Vineyard has set goals designed to foster the development of aquaculture projects and create guidelines for successful expansion. With the community in mind, this paper investigates the potential for a sea scallop aquaculture project with the hope of sustaining the traditional commercial fishing industry on the island.

In order to achieve this objective, it is important to understand how the current commercial sea scallop fishery operates. As it is the aim of this project to complement wild harvests, an understanding of the important commercial scallop grounds, prime harvest seasons, regulatory restrictions, and possible issues within this commercial fishery would be essential to the avoidance of potentially conflicting competition. Keeping this in mind, the following chapter will consist of a thorough review of the commercial sea scallop fishery.

CHAPTER II. REVIEW OF THE SEA SCALLOP COMMERCIAL FISHERY

The harvesting of sea scallops began over 120 years ago along the inshore waters of New England. Before the 1920s, most landings occurred from scallop beds off the coast of Maine, making Maine's ports the first distributors of sea scallops (Naidu and Robert 2006). Although sea scallop fisheries originated in inshore waters, the industry did not experience significant expansion until more abundant offshore beds were discovered. With the findings of scallop beds off Long Island in the 1920s and then Georges Bank in the 1930s, significant scallop quantities began to be harvested, changing the scallop fishery into a booming industry (Serchuk et al. 1981). In 1965, the New England scallop fleet landed 5,600 metric tons of scallops, with 95% of the harvest coming into New Bedford, Massachusetts (Doeringer et al. 1986). However, after 1965 scallops stocks on George's Bank began to show signs of depletion, shifting fishing efforts to the more productive beds off the Mid-Atlantic States (Doeringer et al. 1986). Soon these grounds were also depleted, with landings dropping to approximately 1,800 metric tons in 1973. With time and the discovery of new grounds off Chatham, scallop landings began to increase.

Today the sea scallop is the only significant wild scallop industry in the world, supplying 27,000 metric tons of scallop meats, worth $386 million dollars in the United States in 2006 (NMFS 2006) (Figure 2.1). The task of maintaining the sea scallop fishery, however, has not been an easy one; there is a continual need to make adjustments to its management regime in order to comply with the demands of the industry. Although the objective of this project is to assess the feasibility of sea scallop aquaculture, it is essential to begin with an examination of the current status of this commercial fishery in order to gain an understanding of how such a valuable resource is managed.

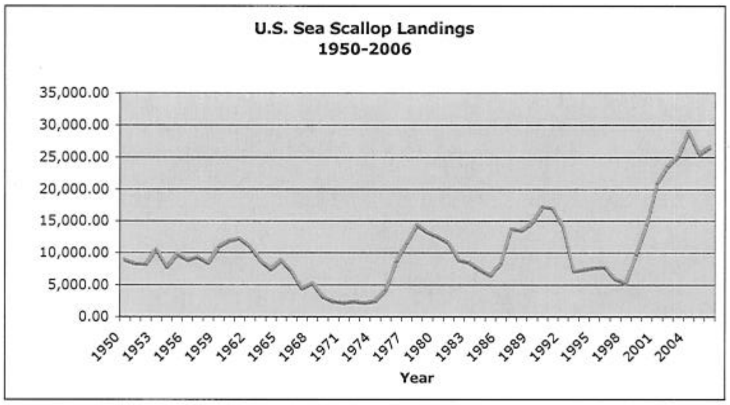


Figure 2.1. Trends in sea scallop landings in the United States from 1950-2006 (NMFS 2006).

With the passage of the Magnuson-Stevens Fishery Conservation and Management Act in 1976, the National Marine Fishery Service (NMFS) was granted the task of regulating the fisheries of the United States from 3 miles to 200 miles offshore (Kalo et al. 2007). Additionally, this act formed eight regional fishery management councils, which are responsible for regulating the U.S. fishery resources. Together, in 1982, the New England and Mid-Atlantic councils developed the Atlantic Sea Scallop Fisheries Management Plan (FMP), designed to regulate the sea scallop fishery as a single stock throughout its distribution in the U.S. (Maine to Cape Hatteras, North Carolina) from the shoreline to the Exclusive Economic Zone (EEZ) boundary (EPA 2006). Since this first FMP, additional amendments and framework adjustments have been added as needed to address and modify regulations with the overall purpose being "to prevent over-fishing and improve yield-per-recruit from the fishery" (NEFMC (1) 2007).

Originally, the main mode of regulation was the enforcement of a minimum average meat weight (number of scallops meats/unit of weight). However, with the introduction of Amendment 4 in 1994, the management strategy shifted to regulating fishing effort rather than meat weight (NEFSC 2007). Currently, within this year-round fishery, effort control involves a combination of management practices, which are directed to regulate the two types of scallop permits: limited access, and general category. Depending on the permit type and category, regulations can include open Days at Sea (DAS) allocations, crew limits, access area trip, possession limits, harvest restrictions, and impact regulations (NEFMC (2) 2007).

LIMITED ACCESS PERMITS

Nearly all sea scallop landings are harvested by vessels operating under limited access permits (NEFMC (2) 2007). In 2006, there were 351 vessels with limited access permits spanning from the Gulf of Maine to North Carolina, landing about 18,000 metric tons of scallops. From 2004-2006 limited access vessels brought in an average of $1.0 million dollars in total revenue per vessel (NEFMC (2) 2007). The limited access permit was created in 1994 with the formation of Amendment 4 to the FMP. In order to originally qualify for a limited access permit, vessels had to have participated in the scallop fishery between 1988-1990 (NEFMC 2003). All limited access vessels have to renew their permits each year or they will lose their fishing eligibility within the limited access fishery (NOAA (1) 2007). Limited access permits are divided into 3 main categories: fulltime, part-time, and occasional. Distribution of these permit categories was also decided by the activity of the fishing vessel between 1985-1990 (NEFMC 2003). Those with higher fishing activities were granted more access to the sea scallop fishery. Attached to each permit category are a number of regulations to control fishing effort.

Open Days at Sea Allocation

At the start of each fishing year, limited access permit category vessels are given a set number of open DAS and access area trip allotments. Open DAS allow permitted scallop vessels to fish in all areas within Federal waters, not including scalloped closed areas, habitat closed areas, and scallop access areas (NOAA (1) 2007). The number of DAS granted is dependent on the permit category. In 2007, full-time permits were allowed 51 open DAS, part-time vessels 20, and occasional permits 4 (NEFMC (1) 2007).

Although possession limits are not imposed on open DAS, limits on crew numbers are applied. One main job of crewmembers on board limited access vessels is to shuck the scallops. Due to both the short tolerance of scallops out of water and the long trips limited access vessels make, scallops are shucked at sea. Because scallops can be caught faster than they can be shucked, vessels tend to halt fishing in order to allow the shucking process to catch up with the haul, delaying the draw of another load. Larger crews mean faster shucking rates and, subsequently, more time to actively fish, which can result in higher fishing efforts and catches. For this reason, on all open DAS, a crew limit of 7 was established in order to restrict the "processing power" of all limited access scallop vessels. This limit is applied to all limited access permit categories and gears except those in the Small Dredge Program, which are limited to a crew size of five. (NEFSC 2007)

Access Area Trip Allocations

In addition to open DAS, limited access vessels are also allocated trips within specific geographic areas called access areas. The practice of rotational area management is used to control fishing effort and scallop stocks within these areas. The concept behind this type of management is that grounds possessing smaller scallops are closed to prevent fishing mortalities and then re-opened when the scallops are larger, resulting in higher harvest yields. Therefore, open and closed access areas are rotated on the basis of current sea scallop stock assessments. Presently, there are a total of six areas classified as scallop access areas. These areas include the following: Closed Area I (CAI), Closed Area II (CAII), Nantucket Lightship Access Area (NLCA), Hudson Canyon Access Area (HCAA), the Elephant Trunk Access Area (ETAA), and Delmarva Access Area (DAA) (Figure 2.2). In 2007, only three access areas were opened to scallop vessels and included the Nantucket Lightship Closed Area, Closed Area I, and the Elephant Trunk Access Area (NOAA (2) 2007). Full-time limited access vessels were allowed one trip in both the NLCA and CAI, and three trips in the ETAA. Part-time vessels were allowed up to one trip in both the NLCA and CAI, and up to two trips in the ETAA; the total number of trips made in all three categories cannot exceed two trips (NOAA (2) 2007). Occasional vessels had the option of choosing only one trip in any of the three open access areas. While crew limits are not imposed on access areas, possession limits are applied to each limited access category. In 2007, full-time and part-time vessels were permitted to land 18,000 pounds (8.6 metric tons) of scallop meats per access area trip, while occasional vessels could land 7,500 pounds (3.4 metric tons) (NOAA (2) 2007).

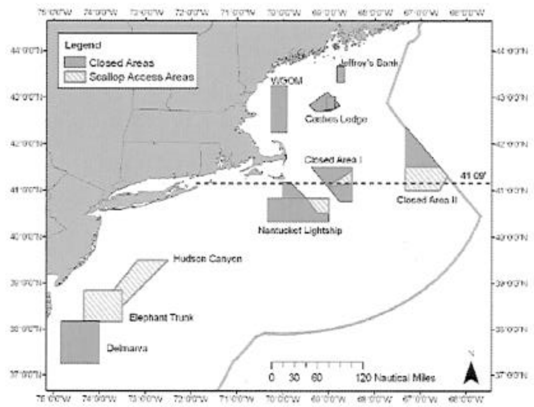


Figure 2.2. Sea scallop fishing access areas (NOAA (2) 2007).

Both full-time and part-time limited access vessels are required to have Vessel Monitoring Systems (VMS) installed on board. These systems send out geographic position signals at least once every 30 minutes to the National Marine Fishery Science department. Before leaving port for a trip, the captain must declare the intent of the fishing trip and then wait until the trip is cleared by NOAA Fisheries before departing. This system helps in regulating both DAS and access area locations and trips. (NOAA (2) 2007).

GENERAL CATEGORY PERMITS

In addition to limited access permits, vessels can also harvest sea scallops under general category permits. These vessels are typically smaller (less than 50 feet and fish from beds closer to shore). In New England, most general category permit holders also have groundfish and lobster permits (NEFMC (2) 2007). Instead of being regulated by DAS, general category fishing effort is managed by a possession limit, which is dependent on the type of general category permit. Category 1A permits are allowed to harvest up to 40 pounds (0.02 metric tons) of shucked scallops, or 5 bushels of in-shell scallops per day. These permit holders are not required to have a vessel monitoring system (VMS). On the other hand, Category 1B scallop permits are required to install a VMS on their vessels, but they are permitted to harvest up to of 400 pounds (0.18 metric tons) of scallop meats or 50 U.S. bushels of in-shell scallops per day (NOAA (3) 2007).

Both general permit categories are only allowed to harvest scallops in state exemption areas or open access areas unless the vessel is a part of a state waters exemption program. General category vessels not enrolled in an exemption program are only permitted to fish in exemption areas. There are five scallop exemption areas: the Gulf of Maine, the Great South Channel, Southern New England, the Mid-Atlantic, and open access areas (Figure 2. 3). Exemption areas help regulate where fishery vessels can harvest scallops, with the purpose of minimizing any negative impacts. Each exemption area has specific gear requirements and landing restrictions. If enrolled in an exemption program, the vessel is not restricted to Federal gear regulations and scallop possession limits. However, other FMP restrictions do apply and all state regulations are applicable.

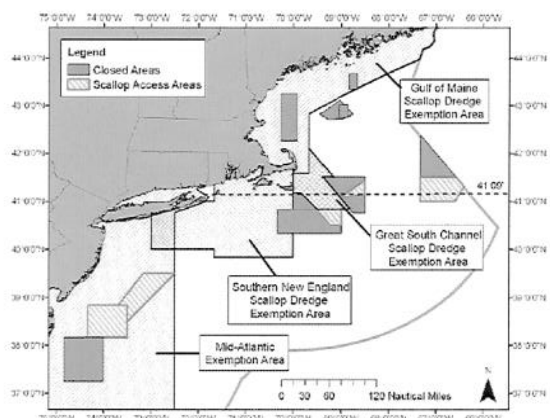


Figure 2.3. Sea scallop exemption areas. (NMFS 2006)

Similar to the limited access permit category, general access permits are also allowed to fish in open access areas but must follow different requirements than limited access vessels. In 2007, the general category vessel fleet had unlimited access to the Hudson Canyon Access Area (HCAA) but limited trips for Closed Area I (216), Nantucket Lightship Closed Area (394), and the Elephant Trunk Access Area (865). Once the fleet has used up all the allotted trips within an access area, the area is closed, ceasing harvest from general category permits. While fishing in the access areas, general category vessels are only allowed to harvest scallops. Additionally, they are not allowed to use trawl gear, and all dredges cannot have a combined width greater than 10.5 feet (NOAA (4) 2007).

Increases in scallop landings and higher scallop prices have resulted in an expansion in the desire for general category permits. Permit numbers have risen from 1,992 in 1994 to 2,501 in 2006 (NEFMC (2) 2007). Although the actual active general scallop permits (defined as vessels that have landed >1pound scallop meats) are much lower; over the years the number of trips and the amount of scallop meats landed has increased. While there were 2,501 actual general category permits in 2006, only 535 of these vessels were listed as active, bringing in a total of 4,420,917 pounds (2,005 metric tons) of scallop meats (NEFMC (2) 2007). This increased fishing effort from the general category is believed to be a contributing factor to high fishing mortality rates[6]. With this in mind, the New England Fishery Management Council prepared a section within Amendment 11 to the Sea Scallop Fishery Management Plan to address this issue. This

[6] Fishing mortality rates or the rates at which a species is harvested, assist in determining if a fishery is considered overfished. If the rate of fishing mortality compromises the ability of the fishery to produce the maximum sustainable yield (MSY) ("the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions"), the fishery is considered overfished (Kalo et al. 2007).

amendment proposes that general category permits be issued under a limited entry program, granting a set amount of permits to only qualified vessels.

HARVESTING RESTRICTIONS AND IMPACTS

Towed fishing gear has been used for hundreds of years; concern over its impact on species and bottom ocean environments has been omnipresent. In 1376, a quote to the King of England displays the apprehension

> "that the great and long iron of the wondyrchoun [beam trawl] runs so heavily and hardly over the ground when fishing that it destroys the flowers of the land below the water and also the spat of Oysters, Mussels and other fish upon which the great fish are nourished" (Shepard and Auster 1991).

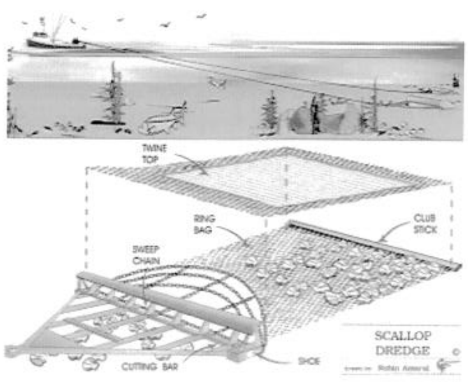
With ongoing concern for such consequences, fishing gear has undergone constant modifications in an effort to achieve greater efficiency, reductions in by-catch, and impact on protected species.

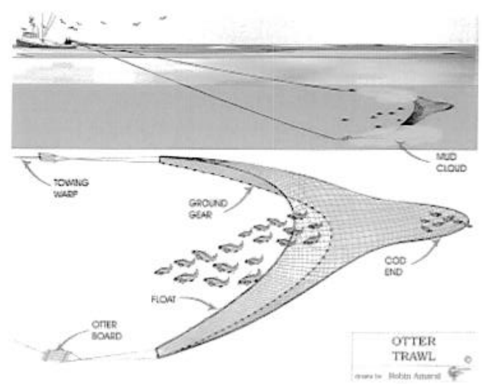
Within the sea scallop fishing industry there are different gear restrictions for each permit type. Limited access vessels must hold specific gear permits allowing the use of dredges, trawl nets, or any gear type (NEFMC (2) 2007). With dredge gear permits, vessels can use scallop dredges or be a part of the Small Dredge Program. Scallop dredges cannot exceed a combined width of more than 31 feet. They are additionally required to be made of bags of iron rings no smaller than four inches and possess a twine top made from ten inch square or diamond mesh (Figure 2.4). A ring size of four inches allows smaller finfish and invertebrates to escape, while being more efficient at catching larger scallops and decreasing overall fishing time (NEFMC 2003). Twine tops with 10-

inch squares are also intended to allow finfish escapement and reduce bycatch levels. Vessels in the Small Dredge program may only use one dredge up to 10.5 feet in width. Most vessels tend to use New Bedford-style scallop dredges, but some vessels in the Mid-Atlantic use otter trawls (Figure 2.5).

Trawl gear is restricted by maximum sweep, minimum mesh, and gear obstruction regulations. The maximum sweep of a trawl net cannot exceed 144 feet, and it must not be made of mesh smaller than 5.5.inches (NOAA (5) 2007). Furthermore, trawls cannot place anything on top of net that could restrict the mesh size in any way. All vessels are required to stow all gear types when crossing through a closed area or an access area that is not being utilized as a trip.

Within the general category permit group, all gear types are allowed, including nets, traps, clam dredges, scallop dredges, and bottom trawl gear (NEFMC (1) 2005). However, specific gear regulations are applied depending on the area being fished. Most vessels within this permit category fish with scallop dredges or trawls, but scallop dredges tend to bring in over 65% of all general permit scallop (NEFMC (2) 2007).





Figures 2.4 and 2.5. Illustrations of gear parts and uses within the sea scallop fishery (Smolowitz 1998).

Bycatch regulations

Even with strict gear regulations, limited DAS, and focused fishing within controlled access areas, bycatch continues to occur in the scallop fishery. Groundfish species are especially vulnerable because, like scallops, they inhabit the ocean floor. The most common bycatch species in the scallop fishery are monkfish, little skate, yellowtail flounder, fourspot flounder, summer flounder, winter flounder, sand-dab flounder, winter skate, cod, clearnose skate, smooth skate, and thorny skate (NEFMC 2003). The level and species type of bycatch fluctuates depending on the season and location. In New England, many of the groundfish species such as cod, yellowtail, thorny skate, winter skate and monkfish, are classified as over-fished[7] (NEFSC 2006). As a result of the delicate state of the groundfish fishery and how it overlaps with the successful scallop industry, managing these resources is extremely challenging.

In an attempt to decrease bycatch levels while still permitting the sea scallop fishery to continue, bycatch levels are set each year for the entire sea scallop fishing fleet in both open area DAS and access area trips. Scallop vessels are allowed to harvest specific levels of other species if possessing a New England multi-species permit. This type of permit allows landings of these 15 different species: Atlantic cod, haddock, pollock, yellowtail flounder, witch flounder, winter flounder, windowpane flounder, American plaice, Atlantic halibut, redfish, ocean pout, white hake, silver hake (whiting), red hake, and offshore hake (NEFMC (3) 2007). In open area DAS, vessels holding a multi-species permit may possess up to a maximum of 300 pounds (0.14 metric tons) of

[7] "Over-fished" is defined by the Magnuson-Stevens Act to be "a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield…" (Kalo et al. 2007).

all New England multi-species combined, per trip. By governing the amount of bycatch that can be landed on board a vessel and by not closing an area to fishing once limits are caught, high levels of regulatory discards can occur through this type of regulation (NEFMC 2003).

As an alternative to bycatch possession limits, open access areas trips use Total Allowable Catch (TAC) limits, which distribute a bycatch percentage for the entire scallop fleet. Once the limit is met, the access area closes to all fishing. Within access areas, yellowtail flounder bycatch levels are carefully monitored. The sea scallop fishing fleet was permitted to have a yellowtail bycatch TAC of 9.8 % of the annual TAC of yellowtail flounder for 2007. This equated to be 21.3 meters in the Nantucket Lightship Closed Area, and 88.2 meters in Closed Area I.

Impacts on Protected Species

In addition to groundfish species, scallop gear can also injure other species. In 2006 NMFS conducted a Biological Opinion to determine which threatened and endangered species are the least and most likely to be affected by the scallop fishery. The Opinion concluded that the shortnose sturgeon; the Gulf of Maine's Atlantic salmon; the Hawksbill sea turtle populations; and the North Atlantic Right, Humpback, Fin, Sei, and Sperm whales were all not affected by the scallop fishery. They also found that there was no impact on the critical habitat areas of the Right whale (NEFMC (2) 2007).

There are, however, other species that have been negatively affected by the scallop fishery, including endangered species such as the Loggerhead, Leatherback, Kemp's Ridley, and Green sea turtles. The distributions of all of these sea turtle species overlap to some degree with the sea scallop fishery; they have been observed to be captured in both dredge and trawl gear. Between 1996 and 2005, 64 sea turtles, (Loggerheads, Kemp's Ridley, or Green turtles) were observed to be captured in scallop dredges (NEFMC (2) 2007). From 2004-2005 trawl gear was estimated to catch anywhere from 81 to 191 sea turtles in the Mid-Atlantic. As a result of such impacts on sea turtles, seasonal gear restrictions and closures were enacted to decrease turtle captures. Such gear restrictions include modified chain mats on scallop dredge gear from May-November in certain Mid-Atlantic waters and turtle excluder devices (TEDs) on trawl gear (NEFMC (2) 2007).

Damage can also be done to smaller scallops due to impacts from dredges and trawls. Such injury can result from chipped and separated shells. The degree of damage has been found to differ with substrate and with harder substrates such as gravel-cobble, which show significantly higher damage to scallops than sandy substrates (Shepard and Auster 1991). Furthermore, studies have found predators to be lured to the paths trawls and dredges make, being attracted by the disturbed and injured scallops (Shepard and Auster 1991). Even slightly damaged scallops were found to be more susceptible to starfish predation.

The sea scallop fishery is attached to a multitude of regulations, which are intended to deter overfishing of both the sea scallop and the non-target species that encompass the fishery's bycatch. Current closures and regulations, however, are heavily dependent upon correct stock estimates and the honor of the scallop fleet. While it is essential to place regulations on the ways in which this natural resource is harvested and by whom, there is a fine line between successful management and over-management. With the understanding of the importance of the sea scallop fishery and the possible negative impacts associated with the wild harvest of this species, it is useful to assess possible offshore aquaculture sites, with the intent of increasing local projects and providing a more sustainable mode of contribution to the supply of sea scallops. Furthermore, it is also essential to review the history of sea scallop aquaculture, noting culture techniques and outlining current and past projects. This basic knowledge can prevent avoidable errors both in siting a culture area and growing the species.

CHAPTER III. REVIEW OF SEA SCALLOP AQUACULTURE

Of the 400 scallop species existing throughout the world, only 33 species are harvested at commercial levels, with three-quarters of the total global production accomplished through aquaculture (Spencer 2002)(Figure 3.1). Japan and China dominate the production of cultured scallops, primarily through the farming of the Japanese scallop (*Patinopecten yessoensis*), grown in both Japan and China, and the bay scallop (*Argopecten irradians*, an exotic), and Farrer's scallop (*Chlamys farreri*), which is grown in China. Although 19 other countries cultivate scallops, only Japan, China, and Chile have been able to generate quantities sufficient for commercial production. This is believed to be a result of the various biological, economic, and legal constraints linked to this industry, problems that, in the future, may have to be addressed more comprehensively in order to meet the projected demand of seafood. With this in mind, this chapter is comprised of a review of sea scallop aquaculture techniques and associated projects.

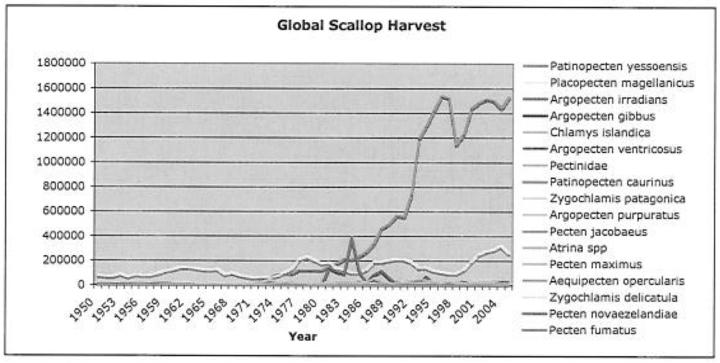


Figure 3.1. World scallop (all species) harvest trends of wild and aquaculture sources, with top harvests coming from the Japanese scallop in red (*Plactopecten yessoensis*) and the sea scallop in yellow (*Plactopecten magellanicus*). The Calico scallop (*Argopecten gibbus*) shown in purple exhibited a harvest peak in 1985, but quantities have since dropped (FAO (2) 2007).

The origin of scallop aquaculture

Scallop aquaculture began in the 1930s in Japan, but it wasn't until the 1960s, when Japanese wild scallop production dropped, that an emphasis on the refinement of aquaculture techniques occurred (Spencer 2002). As a result, scallop production increased from 10,000 metric tons in 1965 to 110,000 metric tons in 1975. In 2005, Japan produced 491,000 metric tons of scallops, with approximately 41% of the production coming from aquaculture (FAO (1) 2007). The primary species cultivated in Japan is *Patinopecten yessoensis*, the Japanese scallop, which is a native species inhabiting the northwest Pacific Ocean. Production time is influenced by method and area and can take anywhere between 1½ to 3½ years to reach a marketable size of 10 cm. Japan's ingenuity and successful culturing of scallop species prompted other countries to develop comparable culturing methods and apply them to their native species.

Sea Scallop Aquaculture Techniques

Although there are variations in culturing procedures that are dependent upon the species and site, the basic steps involved are the same. These steps involve the following:

1) Collection of scallop spat, 2) intermediate culture, 3) and final grow-out (Parsons and Robinson 2006).

Step 1: Collection of scallop spat

The method used to procure scallop spat, or larvae, depends on the abundance of wild scallop spat in the area. If large quantities of wild spat are absent or inconsistent, it may be necessary to culture scallop seed through hatchery technology. Otherwise, spat can be collected from the wild using a technique developed in Japan.

HATCHERY SPAT COLLECTION

Cultivation of sea scallop spat through hatchery techniques involves inducing adult scallops to spawn in the laboratory. This entails a combination or solo use of three methods: altering water temperatures, increasing water circulation, and the injection of serotonin (Parsons and Robinson 2006). By increasing or decreasing water temperatures a few degrees, researchers have been successful in stimulating scallops to spawn. This has been proven by Culliney (1974) who induced scallops to spawn by increasing water temperature from 3-5°C, and Fournier and Marsot (1986) who accomplished spawning by decreasing water temperatures from 10-4°C (Parson and Robinson 2006). Additionally, increasing water circulation to 20 l/min has also been found to stimulate scallop spawning within only one hour (Parson and Robinson 2006). An injection of 0.5 ml of 2mM serotonin, a neurotransmitter, into the adductor muscle results in spawning within a half hour of injection (Parson and Robinson 2006). After spawning, the eggs incubate at 12-16°C for 2- 4 days. After this time, the larvae are considered to be "D" larvae or shelled larvae. They are fed a mixed algal diet consisting of 2.0-6.4 μm/day. Generally, between 35 to 45 days after fertilization, the scallop larvae begin to settle.

Substrate, such as small pebbles and shell pieces, are placed in the culture tanks to encourage spat settlement (Parson and Robinson 2006).

WILD SPAT COLLECTION

Sea scallops usually spawn every year between July and October. Therefore, spat collectors, which are typically onion bags (80 x 37 cm) filled with monofilament (100g) (Spencer 2002), are suspended in the water column during or soon after spawning has occurred. The bags are hung on long-lines below the surface; depending on the project, there can be several thousands of spat collectors per long-line system (Spencer 2002). These systems are usually positioned in locations where scallop populations are known to exist (Parsons and Robinson 2006).

Scallop larvae are planktonic for one month, after which they begin to settle. Work in Japan found that scallop spat has the propensity to settle onto monofilament, which accounts for bags filled with monofilament. Scallop larvae enter into the onion bag and attach to the monofilament where they stay for 9 to 11 months (Parson and Robinson 2006). After this time, the spat is too large to fall through the mesh of the onion bags, therefore remaining in the bags until the collectors are harvested. However, the work does not end here. The collected material must then be sorted, removing any other invertebrates that settled with the scallops (Parson and Robinson 2006). At this point, scallops are approximately 10 mm and are ready for the intermediate culture phase (Parson and Robinson 2006).

Step 2: Intermediate culture

After the harvested or spawned scallop spat is 10mm, it is still too small for other methods, such as bottom seeding and ear hanging. Use of any of these methods at this size can result in extremely high predation rates and shell damage, respectively (Parsons and Robinson 2006). Therefore, an intermediate culture phase is necessary in order to safely grow the scallop to a larger size. This is achieved by transferring the scallop spat into pearl nets during the coolest part of the day. Pearl nets are pyramid shaped (20 x 35 x 35 cm) and made of synthetic netting; usually about 7 to 10 nets are hung per line (Spencer 2002). Because high densities negatively impact growth, it is generally recommended that scallop densities not exceed one-third of the cage floor. This is thought to be a result of food depletion rather than an effect of limited space (Côté et al. 1994).

Step 3: Final Grow-out

Once scallops are 40 to 60 mm they are ready for the final grow-out phase (Parson and Robinson 2006). At this point the scallops are between 16 to 26 months old. There are two main methods employed for the final grow-out phase: suspension culture and bottom culture. There are different modes of performing each of these methods, depending on the culture site and project scale.

SUSPENSION CULTURE

Suspension culture involves the use of cages or "ear hanging" techniques to position scallops in the water column. These methods usually take 0.5 to 2 years after the intermediate culture phase and produce 90 mm market-sized scallops (Parson and Robinson 2006). Lantern nets are most commonly made of a 10-layered net system 200 cm long x 50 cm wide (Spencer 2002). Like the pearl net, they are suspended from long lines below the water surface. Again, depending on project design and site characteristics, the number and depth of these nets fluctuate.

Sometimes, as a result of close confinement, the lantern net method can result in misshaped scallops due to biting between them. To avoid these issues, some growers opt to use pocket nets rather than the lantern net system. Pocket nets are made of polyethylene netting that is supported by a wire frame. However, this method has been found to produce scallops with two convex shells. There is no available information on how or if this abnormality affects scallop meat or sale price (Spencer 2002).

Ear hanging involves actually hanging scallops by their "ears" or auricles, which is achieved by drilling a hole and threading nylon monofilament through the ear of the scallop and then attaching it to a braided rope, or dropper line (Parson and Robinson 2006). Scallops are hung 15 cm apart, and up to 120 scallops can be hung on each dropper line, with a 100m-long long-line system (with dropper lines spaced 25-30 cm apart) capable of holding up to 45,000 scallops (Spencer 2002). However, this method is only successful in shallow waters ($\leq$ 10m), which are protected from strong waves and winds (Spencer 2002).

BOTTOM CULTURE

Bottom culture consists of growing scallops on the ocean floor in either bottom cages or by seeding directly on the ocean floor. For this operation to be successful, it is necessary that the selected site of seeding possess the necessary biological and physical requirements for scallop growth. Unlike suspension culture, scallops grown through bottom culture are vulnerable to predation (Parsons and Robinson 2006). Studies have found predation rates to significantly drop with increasing scallop size (Barbeau et al. 1996). For this reason, survival rates have been found to be higher in bottom culture projects seeding with scallops greater than 25mm (Barbeau et al. (1) 1994).

However, there are some problematic issues in regard to bottom culture. It is possible for scallops that are not kept in cages to "escape" from culture areas, resulting in production loss (Parson and Robinson 2006). Furthermore, some studies show that growth rates are slower in bottom-cultured scallops, which is believed to be a result of decreased food availability at depths (Cote et al. 1993). However, it is important to note that other investigations have found bottom culture growth rates to be comparable to suspended culture rates (Kleinman et al. 1996). Although bottom culture is associated with a number of challenging factors, it involves a much lower capital cost than suspension culture and can still produce a profitable quantity of marketable scallops (Kite-Powell et al. 2003). After approximately three years, cultivated scallops are 90 mm and can be harvested in the fall and brought to market (Parson and Robinson 2006).

Sea Scallop Aquaculture Projects

Although Japan began culturing the Japanese scallop in the 1930s, it wasn't until the 1970s that researchers in Newfoundland began to investigate sea scallop culture techniques (Parsons and Robinson 2006). Similar to Japan, Newfoundland was also stimulated to study aquaculture by a decline in wild scallop production. This drop in natural scallop populations was also felt in waters off Québec and Nova Scotia. Initial efforts in these areas have concentrated on methods for restocking and enhancing the wild populations but have evolved into the establishment of a commercial scale hatchery and projects investigating intermediate and final grow-out culture techniques in Newfoundland (Parson and Robinson 2006). These projects, which were created in the 1990s, helped fuel the formation of two other large-scale scallop culture projects in Canada, OPEN (Ocean Productivity and Enhancement Network) and REPERE (Research on sea scallop culture for stock enhancement) (Parson and Robinson 2006). Together, these projects were the foundation and motivation for the formation of other operations in Newfoundland, Prince Edward Island, New Brunswick, Nova Scotia, and Québec (Parsons and Robinson 2006). Today there are only small to medium-sized commercial culture operations occurring in Nova Scotia and Québec and only one large-sized enhancement endeavor taking place in Québec (Parsons and Robinson 2006). Together, in 2005, these projects produced a total of 11 metric tons of cultured sea scallops, valued at $97,000 (Canada Ministry of Fisheries and Oceans 2007).

United States Sea Scallop Aquaculture Projects: New Hampshire

In the United States, suspended and bottom culture techniques have been examined in projects in New Hampshire and Massachusetts. In 2001, the University of New Hampshire investigated the potential for sea scallop aquaculture in the northeast. The scallop spat for this project was obtained by Stonington Fishermen's Alliance, which collected spat through collectors placed in Penobscot Bay. The spat was then divided and placed into pearl nets for deployment offshore in June 2001, using a long-line system with 5 to 7 nets per string.

Some of the issues that were experienced in this project were heavy fouling of pearl nets, high labor costs, and elevated scallop mortalities. Within three weeks after deployment, hydroids and mussels covered the pearl nets. This caused the long-line system to weigh down, requiring additional buoys to maintain suspension in the water column. The fouling also resulted in a reduction in food availability for the scallops. Additionally, mussel seed within the pearl nets caused the scallops to be clumped together and become attached to the nets, requiring intensive labor when thinning, which increased scallop mortalities. However, once scallops reached a shell height of 35mm, mortalities dropped to < 2%. Even so, heightened labor levels resulted in a switch to bottom culture after scallops reached 50 mm. During the spring of 2003, scallops were harvested and an economic study was performed on the project. Although the scallop meat yield and quality proved to be excellent, the project was not found to be economically viable due to the extensive labor costs associated with biofouling (Richard Langan, personal communication, 2007).

Massachusetts

Another project instigated by a drop in wild production was a large-scale project in U.S. federal waters off the island of Martha's Vineyard, Massachusetts. This endeavor, known as the Seastead project, was a partnership between scientists and local fishermen that attempted to demonstrate environmentally sound and economically successful sea scallop culture methods. This project began in 1995 and examined various grow-out techniques and then performed an economic analysis on each method. However, the project was stalled while waiting for site approval from the New England Fishery Management Council, the Army Corps of Engineers, and Martha's Vineyard fishermen (Smolowitz et a1. 1998). After conflict issues were resolved, which took over 30 months, the project was given exclusive use of an offshore area 9 miles^2 into Rhode Island Sound, 15 km south of Martha's Vineyard to begin the study (Smolowitz et al. 1998). Originally, the project had planned to acquire juvenile sea scallops from the Martha's Vineyard Shellfish Hatchery, but because of permitting delays, the hatchery was forced to seed the cultured scallops at another site off Cape Cod. Instead, intermediate sized, wild-caught scallops (40-60 mm) were collected in order to begin testing culture techniques in the offshore site (Smolowitz et al. 1998).

In 1997, various bottom and suspension culture techniques were tested at the site in order to determine which method had the most potential for both scallop production and economic investment. One method involved seeding scallops directly on the ocean bottom. For this technique, 38,000 scallops were seeded onto the site in May 1997 and left undisturbed for 9 months. However, difficulties occurred in finding the seeded site after the 9 month time period. Therefore, a second experiment was performed in June 1998. This time 150,000 scallops were seeded in the site area, and the location was constantly monitored throughout the grow-out time through sampling and video observation (Smolowitz et al. 1998).

Another bottom culture method examined in this project involved the use of bottom cages. For this experiment, 48 bottom cages, made out of vinyl-coated steel wire by the Riverdale Mills Company, were deployed on the site in the late summer of 1997. The cages had two shelves and were stocked with scallops ranging from 40 to 120 mm in size at various densities. Mortalities were observed in the bottom cages, due to complications during the harvesting and transporting (harvested from commercial tows, transported a long distance, experienced high temperatures) of the scallops used to stock the cages. However, few predators were found in the cages and only limited biofouling had occurred. During a visit to the site in March 1999, all high flyers marking the cages were missing. This was thought to be a result of a very windy winter season. In June, one missing cage trawl was located, exhibiting strong evidence of damage by either a clam or scallop dredge. Additionally, signs that the cages had been vandalized were evident from three cages, which had been cut open and emptied of all scallops. However, the rest of the scallops that were retrieved from this line had grown an average of 21 mm in 236 days, a rate that is considered good (Smolowitz et al. 1998).

The final method investigated in this project was designed to test a suspension culture technique involving a 20-unit Japanese lantern cage long-line system. The net system was deployed in October. However, soon after deployment, it was reported that the long-line system was tangled by, what was speculated to be, strong winds and currents at the site. After the report, efforts were made to retrieve and detangle the system, but it could not be found. In the end, the only method that showed both sufficient growth rates and potential profit was the bottom seeding grow-out method (Smolowitz et al. 1998).

Economic Assessment of Seastead Project

Another aspect crucial to the success of a sea scallop aquaculture project is its economic viability, a component addressed in the Seastead project by Kite-Powell et al. (2003). While there have been past investigations on the demand for sea scallops in the New England market, this study is the only one (known by the author) to examine the economic practicality of various offshore sea scallop aquaculture techniques. As explained above, the Seastead project experimented with different sea scallop culture techniques in offshore waters. These methods of cultivation included direct bottom seeding and three different types of cage culture (lantern cages, bottom cage trawls, and bottom cage clusters). After a thorough examination of these modes, bottom seeding was determined to be the only potentially profitable method. Although bottom culture resulted in slower growth rates and higher losses (predation, movement), the costs associated with deployment, maintenance, and gear were much lower. With this understanding, this section will provide a review of the bottom seeding economic analysis performed within the Seastead project. This review will assist in determining whether or not there appear to be sufficient areas within the offshore sites that are deemed suitable after the site suitability analysis has been performed.

Within the economic analysis performed by Kite-Powell et al. (2003), some basic assumptions were made. They estimated all capital costs and operating costs over a period of 20 years. The farm operation was scaled to produce 100,000 pounds (45.4 metric tons) of scallop meats every 2 years, assuming that it would take 2 years for juvenile scallops to reach a harvestable size. Additionally, the following baseline assumptions were applied to evaluate the economic potential of a bottom culture operation (Table 3.1).

BASELINE ASSUMPTIONS	**REQUIREMENTS**
Operations	
Harvesting	5 acres/hour
Boat expenses	$2,000/day
Biology	
Seeding Density	40,000 juveniles/acre
Loss rate (over 2 yrs)	50%
Average size @ harvest	25 count (meats/lb)
Gear	
Cage costs	n/a
Mooring costs	n/a
Other	
Lease of shore facility	n/a
Distance from port (by boat)	2 hours
Length of working days	12 hours
Market price	$7/lb
Onshore expenses: Administrative, marketing, management expenses	$20,000/yr

Table 3.1.Baseline assumptions used within the economic assessment performed by Kite-Powell et al. (2003).

Using these assumptions, the results of the economic model indicate that in order for a sea scallop bottom culture project to produce a profitable amount, which was determined to be 100,000 pounds (45.4 metric tons) of scallop meats/cycle (2 years), an initial investment of $400,000 is required. To produce this amount of scallop meat, a lease area of approximately 150 acres is needed. Assuming the seeded scallops were sold at $7.00/pound of meat, with a 50% loss rate (Kite-Powell et al. 2003), an estimate of an average annual net revenue of $179,000 is plausible. This method of culture was found to be profitable with loss rates as high as 50%, while prices were only $4/pound. Furthermore, losses of 70% with a market price of $6/pound were predicted to still bring in a profit. Additional baseline expenses and requirements were also outlined in this analysis and are listed in (Table 3.2). Unlike, the commercial fishery, when cultured sea scallops reach a harvestable size, there is flexibility in terms of harvest time. Kite-Powell et al. (2003) recommends waiting to sell until commercial scallop landings are the lowest, which is usually January and November. Bringing scallops to market at this time might avoid potential price conflicts with wild harvests as well (i.e. depressing market prices due to an increase in landings).

Baseline Results from Kite-Powell et al. (2003) Economic Analysis	**Requirements**
Performance	
Net Present Value @ 10% real discount rate	$1,354,000
Average annual revenue	$350,000
Average annual costs	$171,000
Average net revenue/yr	$179,000
Scale	
Acreage	143
Gear	n/a
# of marker buoys	14
Capital Investment	$42,000
Vessel Time	
Collecting and deployment	142 days/cycle
Harvesting	3 days/cycle
Mooring and buoy maintenance	5 days/year
Cost Breakdown	
Gear	$4,000
Gear maintenance	$2,000
Collect/deployment	$142,000
Harvesting	$3,000 (2%)

Table 3.2 Baseline economic results of a sea scallop bottom culture project (Kite-Powell et al. 2003).

CHAPTER IV. SITE SUITABILITY ANALYSIS

In completion of the reviews of the sea scallop commercial fishery and aquaculture history and techniques, it is now possible to begin the analysis phase of this project. The process of determining whether a location is suitable for an aquaculture project involves a consideration of both the environmental requirements of the species desired to be cultured and the other uses of the area. This process, developed by Frankic (2003), will serve as the framework for this analysis. The steps required to achieve this outcome are outlined in five phases:

PHASE 1: Environmental Analysis (A): Determine the environmental conditions necessary for sea scallops.

PHASE 2: Environmental Analysis (B): Develop maps using GIS (geographic information systems) to spatially display the environmental conditions gathered in Phase 1 for the area under investigation.

PHASE 3: Conflict Analysis: Identify and map all existing and potential uses of the area under investigation and produce maps indicating suitable and unsuitable aquaculture sites based on environmental and conflict analysis.

PHASE 4: Identify management issues within the suitable area through the incorporation of socioeconomic issues.

PHASE 5: Create action plans for the aquaculture project within the areas deemed most suitable.

The outcome of this method will generate maps indicating sites that offer suitable environmental conditions for sea scallops without disrupting the other uses and infrastructures within the same vicinity.

Phase 1: Environmental Analysis (A) of the Sea Scallop

Before a sea scallop aquaculture endeavor can be initiated, it is critical to hold a solid understanding of the biological and environmental requirements of the organism. This information will be compiled and used to assess whether the offshore areas of Martha's Vineyard display suitable environmental requirements for sea scallops. This section entails a full review of the life history and environmental requirements of the sea scallop, an essential first step in determining whether a location is suitable for a sea scallop aquaculture project.

The sea scallop (*Plactopecten magellanicus*) of the Family Pectinidae, is characterized as being a large, fast-growing, very fecund and valuable bivalve species. On average, sea scallops grow to be between 10-15 cm in size, with the largest recorded shell height reaching 23 cm (Naidu and Robert 2006). They can live for more than 20 years, growing rapidly between the ages of 3-5 years, where shell height has been found to increase from 50-80% and meat weight, the harvested part of the scallop, can quadruple (Hart 2006). Although reaching sexual maturity at approximately age 2, scallops younger than 4 years of age minimally contribute to the total egg production (Hart 2006). By age 4, female sea scallops are estimated to produce approximately 2 million eggs per spawning season (Hart and Chute 2004).

Life Cycle

The sea scallop life cycle begins once the eggs are externally fertilized in the water column. Once this occurs, the fertilized eggs sink to the sea floor until they reach their first larval stage of development, called the trochophore stage. At this stage and the second, or veliger stage, sea scallop larvae or spat are pelagic, and remain planktonic for 4 to 7 weeks

(Hart and Chute 2004). Because scallop larvae are planktonic during these phases, their transport is governed by the flow of water currents around spawning locations. For this reason, the Georges Bank gyre is believed to retain the larvae spawned in the region, thereby creating a self-sustaining population of sea scallops on the bank (Hart and Chute 2004).

After the veliger stage, sea scallop larvae enter into the pediveliger stage, at which point the larvae are no longer pelagic. A foot and byssus gland develops, allowing the larvae to secrete threads for attachment purposes. At this time the larvae, with approximately 0.25mm in shell height, settle to the ocean floor, a period known as spatfall. On Georges Bank this phase occurs around the middle of December (Hart and Chute 2004). This stage is followed by changes in diet, morphology, and movement; survival is greatly influenced by the surfaces the spat settles on. For this reason, harder surfaces are thought to enhance survival, providing a stationary surface for attachment.

When sea scallops are between 2-3cm they are considered juveniles (Couturier et al. 1995). At this stage they lose their byssal attachments and develop the ability to swim (Hart and Chute 2004). This function assists with escaping predation and other disturbances. Juvenile sea scallops have similar appearances to adults. However, they tend to "exhibit a prismatic structure in the thin right valve" and an off-centered adductor muscle (NEFMC 2003). Scallops reach commercial size at about 4 to 5 years old.

Distribution

Sea scallops have a geographic distribution within the Northwest Atlantic Ocean that spans from the Strait of Belle Isle, Newfoundland, to Cape Hatteras, North Carolina (Hart and Chute 2004), with the largest population densities extending from the Virginia Capes to Port au Port Bay, Newfoundland. In this range, the principle sea scallop U.S.

commercial fisheries occur on grounds in the Mid-Atlantic (Virginia to Long Island, NY) and Georges Bank, a bank 100 kilometers (62 miles) offshore between Cape Cod, Massachusetts, and Cape Sable Island, Nova Scotia (Figure 4.1). Of these areas, Georges Bank is the most productive grounds with an area larger than 31, 000 km^2 (Naidu and Robert 2006).

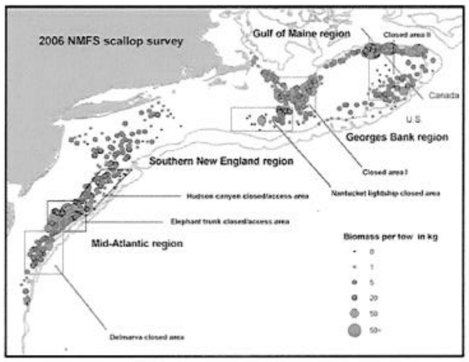


Figure 4.1. Sea scallop distribution and stock assessments based on NEFSC 2006 scallop surveys (NEFSC 2007).

Within this distribution, environmental factors, which include temperature, depth, substrate type, food concentrations, turbidity, oxygen levels, water currents, and salinity, are thought to influence scallop survival and determine spatial distribution (Brand 2006). Additionally, ecological interactions between predators play a role in determining suitable sea scallop habitats (Brand 2006). The following subsections explain the importance of each of these factors in more detail. However, it is important to note that many of these facets of study are interrelated, making it difficult to study any in isolation of the others.

Temperature and Bathymetry

Plactopecten magellanicus is considered a cold-water species, with an optimal growth temperature of 10°C (Brand 2006). Although able to tolerate temperatures above 10°C, temperatures between 20-24°C, are considered lethal to sea scallops; sea scallop larvae have proved to be adversely affected by temperatures above 19°C. Furthermore, growth rates have been found to decrease by 5% at 8°C and 20% at 12°C (Mullen and Moring, 1986). Overall, temperature is known to have an effect on all life cycles of sea scallops (adult, juvenile, and larvae) and has also been found to influence reproduction (Brand 2006). Due to this sensitivity to temperature, sea scallops are found to occur at different depths throughout their geographic range. North of Cape Cod, sea scallops are found in shallower waters at depths less than 40m, while South of Cape Cod they tend to be found at depths between 25 and 200m (Hart 2006).

Substrate

Suitable substrates for sea scallops depend on the life stage of the scallop. Unlike other pectinid species, post-larval (spat) settlement onto a particular substrate is not observed (Thouzeau et al. 1991). Instead, post-larval scallops are typically found to attach themselves to a variety of material/substrate including shells and shell fragments, bryozoans, hydrozoans, amphipod tubes, and sand grains (Thouzeau et al. 1991). Because of its delicate nature amid constant shifting, scallop spat has a difficult time surviving on sandy substrates (Mullen and Moring 1986; Hart and Chute 2004).

Juvenile scallops (2-3cm) are found on gravel, rocks, shells, and silt. They have also been known to attach to bryozoans, hydroids, or algae (Stokesbury and Himmelman 1995; Hart and Chute 2004). Studies show that juvenile scallops tend to select more heterogeneous sediments such as gravel or pebble substrates rather than homogeneous sediments such as sand or flat, hard bottom substrates (Wong et al. 2006). Adult sea scallops are found on a variety of sediments including gravel, firm sand, shells, and rocks (Hart and Chute 2004), but are more commonly found on gravel, sand, or a combination of the two (Wong et al. 2006; Hart 2006).

Although, *P. magellanicus* is able to tolerate some silt or mud, occupation of this substrate is not where areas of high population or the fastest growth rates are observed (Brand 2006). Fine, suspended sediments inhibit food availability and feeding mechanisms of sea scallops and are therefore considered unsuitable for scallop inhabitation (NEFMC 2003). Additionally, sediment type can also have an effect on predator-related mortalities. Because sea scallop predators (see Predator section) prefer different substrates, certain sediment types may increase or decrease predation rates (Wong et al 2006). Furthermore, different substrates also offer various levels of protection and refuge from potential predators (Wong et al 2006). For these reasons, sediment type is critical for both feeding conditions and basic survival.

Food Habits and Requirements

Sea scallops are suspension filter feeders, feeding primarily on phytoplankton and microzooplankton. However, during episodes of low phytoplankton concentrations, sea scallops have been found to ingest particles of detritus. Scallop diet varies with geographic location; populations living in bays and coastal areas feed more on detritus from seaweed and sea-grass, while offshore populations rely on phytoplankton and resuspended organic material as their main food source (Hart and Chute 2004). Scallop diet changes in both near shore and offshore populations, depending on the seasonal fluctuations of the food sources (Hart and Chute 2004).

Suspension feeding is performed through the use of cilia, or hair-like structures, located on the gills. By creating small currents with the cilia, scallops are able to direct water toward them to be filtered for food (Hart and Chute 2004). Bacon et al. (1998) found that juvenile sea scallops ingest up to 7mg of food per liter of water filtered, although feeding rates or clearance rates (volume of water cleared of particles/unit of time) have been found to decline when food concentrations increase between 1 and 14 mg/l (Bacon et al. 1998). Conversely, other studies have found clearance rates to be void of influence from particle concentration (MacDonald et al. 2006). Either way, it is not debated that excessive levels of inorganic suspended material and clay particles can inhibit sea scallop feeding (Cranford and Gordon 1992). Sea scallops, however, are able to reject poorer quality particles based on the concentration of chlorophyll-a and organic composition (MacDonald et al. 2006).

In laboratory experiments Cranford and Gordon (1992) found that diets consisting of only detritus or resuspended sediments are not sufficient to support the growth of adult sea scallops (MacDonald et al. 2006). Instead they found that only plankton diets, such as *Isochrysis galbana* and *Chaetoceros gracilis*, were able to maintain scallop growth (MacDonald et al. 2006). On Georges Bank, plankton biomass or chlorophyll-a concentrations have been found to decrease with depth (Thouzeau et al. 1991).

Turbidity

As noted previously, scallops are sensitive to turbid waters or those clouded with suspended material. Increases in turbidity can result from disturbances on the ocean floor following actions such as dredging and bottom trawling. In shallower waters, storms and run-off can also have an affect on turbidity (Marsden and Bull 2006). Because scallops are benthic creatures, they are naturally exposed to resuspended particles from normal bottom turbulence, and therefore have adopted strategies to tolerate turbid waters for short periods of time (Parson and Robinson 2006). Some strategies include reducing their clearance rates and increasing the amount of pseudofaeces produced. In this way, they are able to select higher quality food particles and reject those that are poorer in quality (MacDonald et al. 2006). However, if inorganic suspended particles become greater than 2mg/m^3, growth rates become reduced (Parson and Robinson 2006). This has been exhibited in studies on a type of scallop found in the North Irish Sea, *Pecten maximus,* where growth rates significantly decreased with increasing levels of mud (MacDonald et al. 2006). This reduction in growth is believed to be a result of feeding restraints from heavy particulate matter, which triggers excessive food sorting and the production of pseudofaeces (Parson and Robinson 2006). Not only does heavy turbidity inhibit feeding rates, but it can also deplete dissolved oxygen in the water (Orensanz et al. 2006).

Oxygen concentrations

Although there appears to be no specific information on the oxygen requirements for sea scallops, the general dissolved oxygen (DO) level required for most aquatic organisms is 5 mg/l (Stickney 2005). As long as DO levels remain at or above this level, aquatic animals with gills, which include scallops, will not be stressed. Hypoxic conditions begin to occur when the DO level is less than 2.0 mg/l (Stickney 2005). At this point, the oxygen levels are so low mortalities begin to occur. Even though some species are able to tolerate lower DO levels, scallops have been found to be intolerant of anoxic conditions (McDonald et al. 2006). The three main factors that influence DO levels are temperature, salinity, and depth (Stickney 2005). As these factors increase, the amount of oxygen that can be held in water is reduced, resulting in a lowering of DO levels. Low oxygen levels and high turbidity are commonly coupled with fine-grain, silty sediments, therefore further explaining the low survival rates of scallops inhabiting soft, muddy substrates (MacDonald et al. 2006). Oxygen consumption ($VO_2 = ml\ O_2h^{-1}$) also known as the metabolic rate of bivalves, is influenced by many factors including the following: temperature, salinity, body size, food concentrations, oxygen tension, reproductive state, physical condition, and degree of activity (MacDonald et al. 2006). The normal rate of oxygen consumption for *P.magellanicus* is estimated to be 0.244 ml O_2/hour/gram of dry tissue weight (MacDonald et al. 2006). Active scallops have been found to consume 2.4 times more oxygen than those resting.

This aspect is especially essential to understand in terms of transporting live scallops out of their water environment (i.e. movement from hatchery to offshore grow-out areas). Because scallops are not capable of remaining tightly closed for long periods of time, they are quickly susceptible to desiccation when exposed to air (MacDonald et al. 2006). Some believe that survival during transportation could be increased by packaging scallops tightly together to prevent shell gaping and by packaging with pure oxygen (MacDonald et al. 2006).

Water Currents

Water currents can influence both larval distribution and scallop feeding activity. Features such as gyres retain scallop larvae, resulting in relatively persistent aggregations of scallops within the same area of the spawning. This is believed to occur on Georges Bank where years with tight gyres have been correlated with strong scallop production; loose gyres are associated with low production. Although sea scallops have the ability to swim, there is no proof that mass migrations occur. Once scallop beds or clusters form, they tend to remain in the same area (Hart and Chute 2004).

Current velocities can also affect the feeding activity of both juvenile and adult scallops. Feeding rates of juvenile scallops are inhibited in current velocities greater than

10cm/sec (Wildish and Saulnier 1992; Chute and Hart 2004), while adult scallops are inhibited by velocities greater than 25 cm/sec (Chute and Hart 2004). Water movement, however, is necessary for growth, feeding, oxygen uptake, and waste removal (Hart and Chute 2004; Wildish and Saulnier 1992). Studies have found that current velocities of 10 cm/sec are optimal for scallop growth (Hart and Chute 2004; Wildish and Saulnier 1992).

Salinity

Sea scallops inhabit ocean waters, which have an average salinity of 35 ppt. Studies have found that scallop larvae exposed to salinities as low as 10.5 ppt for duration of 42 hours exhibited initial shock but eventually recovered (Culliney 1974). Juveniles have also been found to tolerate changes in salinity, reacting normally to salinities of 21 ppt. Based on these studies, it is thought that sea scallops larvae could be euryhaline (Mullen and Moring 1986). Salinities lower than 16.5 ppt are considered lethal to adult sea scallops (Hart and Chute 2004).

Predators and Parasites

Known predators of adult and juvenile sea scallops include the following species: rock crab (*Cancer irroratus*), American lobster (*Homarus americanus*), starfish (*Asterias vulgaris, Crossaster papposus*), moonsnail (*Lunatia heros*), burrowing anemones (*Ceriantheopsis americanus*), Atlantic cod (*Gauds morhua*), American plaice (*Hippoglossoides platessoides*), and Atlantic wolffish (*Anarhicas lupus*) (Mullen and Moring 1986). Additionally, larval sea scallops are preyed upon by a large variety of planktivores (Mullen and Moring 1986).

Unlike most bivalves, sea scallops are capable of "swimming" by jet propulsion. This is achieved by clapping their valves, forcing water that has entered between their valves to be pushed out, therefore propelling the scallops forward. According to studies by Dadswell and Weihs (1990) and Carson et al. (1996), scallops with shell heights 11-80mm are able to swim upward approximately 0.5-3 meters. On the other hand, larger scallops (shell height >100mm) are hindered by their heavier shells and can only move small distances across the sea floor (Dadswell and Weihs 1990). As a result of being mobile, scallops have the ability to escape predators and change locations.

Even with the ability to swim, increasing temperatures can result in a decrease in scallop escape response, causing predation rates to increase. Studies have found a significantly higher chance of predation by sea stars at 15°C than at 4° and 8°C (Barbeau and Scheibling 1994). Although, predation by faster, more mobile predators, such as the rock crab, *Cancer irroratus*, appears to be temperature independent and tends to be more active at warmer temperatures, as well (Barbeau and Scheibling 1994).

Substrate can also have an impact on predation rates of sea scallops. Experimental studies have found that predation rates by sea stars on juvenile scallops 11-15mm are reduced when the scallops are distributed on textured substrates such as pebbles and shells (Wong and Barbeau 2003). It is thought that predators could play an influential role in, not only the survival, but also the dispersal of sea scallops (Barbeau and Scheibling 1994).

Sea scallop parasites are considered rare but can include *Hexamita sp*., a flagellate that has been found many other mollusks and in laboratory scallops, and *Trichodina sp*., a ciliate (NEFMC 2003).

Phase 2: Environmental Analysis (B): Mapping Environmental Indicators

Following an extensive review of sea scallop biology and environmental requirements, it was important to determine what information is available for the offshore waters of Martha's Vineyard. In order to spatially display these requirements, it was necessary that the data be in a format compatible for use with GIS (Geographic Information System) software. GIS allows information to be viewed over space and time, making it an invaluable analytical tool. The data available for the region of the project is listed in the table below (Table 4.1).

Environmental Suitability Indicators	**Data available for project area**
Temperature (°C)	
Bathymetry (m)	√
Bottom substrate type	√
Chlorophyll a (μg/l)	
Turbidity (mg/l)	
Dissolved Oxygen (mg/l)	
Current velocity (cm/s)	
Salinity (ppt)	
Presence of predators	

Table 4.1. Key environmental suitability indicators for sea scallops and a summary of available data for offshore areas around Martha's Vineyard, MA. (Brand 2006; Frankic 2003; Spencer 2002).

As indicated by the lack of check marks in the table, most of the ideal environmental suitability indicator data for sea scallops was not present in the offshore areas around Martha's Vineyard. In response to this deficiency, a plan to organize the collection of bottom temperature data in the coastal waters off of Martha's Vineyard was implemented. This project is detailed in the following section.

ACQUISITION OF TEMPERATURE DATA

In order to create a more accurate assessment of the area, additional information was essential. Because of timescale and funding limitations, it was not possible to acquire all of the needed information. However, one important and essential indicator to determine the suitability of an offshore site, that of temperature, was attainable within the constraints of both time and money.

Temperature can greatly influence the survival and distribution of any species, determining whether or not an area is optimal for the cultivation of the species and what predators might be present. At the time the project was undertaken, only surface temperature data existed for this site. Given that temperature can differ vastly between the surface, water column, and ocean floor, and considering, as well, that sea scallop aquaculture techniques utilize either the water column or ocean floor, subsurface temperature data was needed. Temperature at the sea surface, or the mixed layer, is generally controlled by solar radiation and wind mixing, spanning an average depth of 300 meters (Libes 1992). Beneath the mixed layer is the thermocline, a region where temperature begins to decrease with depth. After 1000m, classified as the deep zone, water temperatures are constant with depth (Libes 1992). Furthermore, because sea scallop culture techniques can involve the water column and the ocean floor, it was of interest to obtain a temperature profile of the offshore area under investigation.

As stated earlier, sea scallops inhabit the ocean floor from depths usually ranging from 25 to 200 meters (Brand 2006). The lethal temperature ranges for adult sea scallops have been found to be from 20 to 24°C, and a sudden increase in water temperature can result in mass mortality of scallop beds. If the investigated area exhibited these temperatures, the potential for an aquaculture project would be greatly reduced.

Temperature Data Collection Methodology

Temperature data was acquired through the assistance of a local, commercial lobster boat, F/V Martha Elizabeth, for both transportation and use of lobsterpot lines for the attachment of the temperature sensors. On August 30, 2007, eight Tidbit v2 (3.0 x 4.1 x 1.7 cm) temperature sensors were attached to five different lobster pot lines (Figure 4.2).

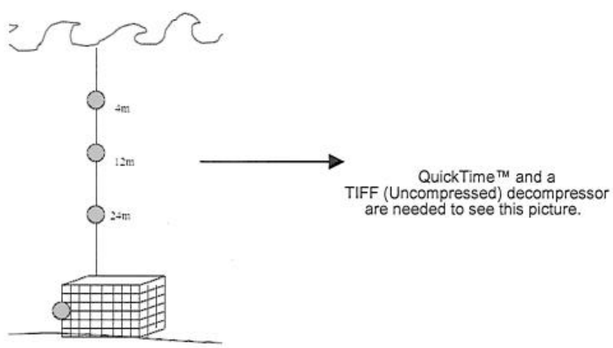


Figure 4.2. Project design and Tidbit v2 temperature sensor (Onset 2007).

On one lobster line, sensors were placed at depths of 4, 12, 24 and 34 meters (pot). Four other sensors were attached to four additional lobster pots. All sensors were attached to the pot and lines using nylon lobster line and were programmed to collect temperature data every three hours. All pots used in this study were located offshore Martha's Vineyard in federal waters (Figure 4.3). On November 5, 2005, all temperature sensors were retrieved and brought into shore. At this time, one sensor was damaged (Line 1, 12m), while another sensor was missing (Line 1, 34m). Daily averages were calculated for the rest of the sensors and graphed.

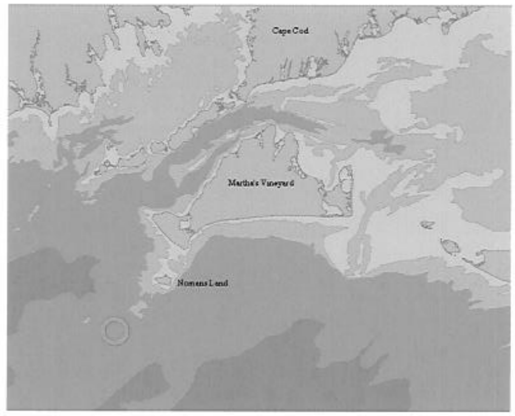


Figure 4.3. Map of temperature project site.

Environmental Indicator Maps

After acquiring all available environmental data for the area, the next step of Phase 2 of the analysis involved mapping the data (Table 4.2). Only maps of bathymetry (Figure 4.4) and sediment data (Figure 4.5) were legitimate due to the limited amount of available data for the offshore areas of this project. While temperature data was collected, because of the limited size of the collection area, the points cannot be accurately expanded to display temperature data for the entire area investigated. As a result, the temperature averages for the depths collected served only as an initial guideline and description of the offshore waters of Martha's Vineyard.

Name	Description	Source	Format
Bathymetry	Based on USGS contour maps that were gridded and contoured at 5 meter intervals by Signell et al. (1999).	CZM Moris Project, 2002;USGS, 1999	Shapefile (polygon); Vector
Sediment	Derived from the USGS Sediment Texture database.	CZM Moris Project, 2002;USGS, 1999	Shapefile (polygon); Vector

Table 4.2. Descriptions and sources of data used within the environmental analysis phase.

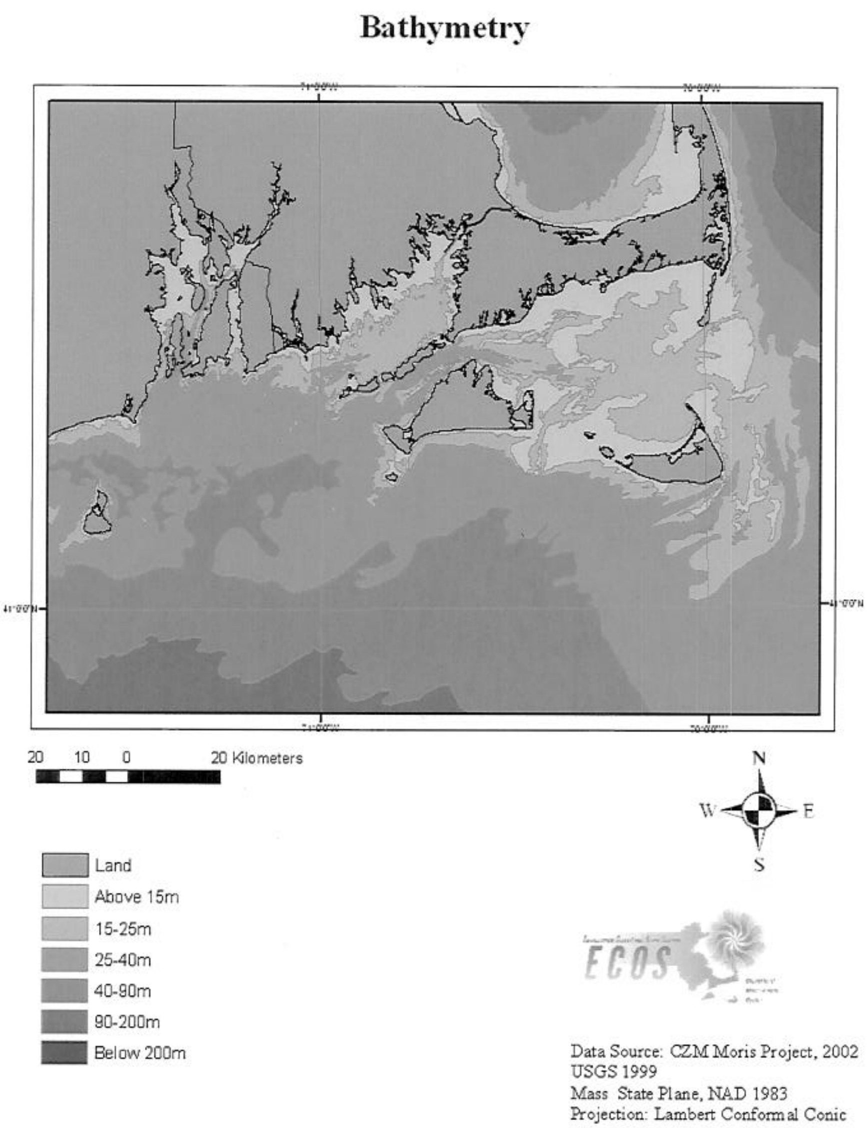


Figure 4.4. Bathymetry data of the offshore waters of Martha's Vineyard.

Sediment Types

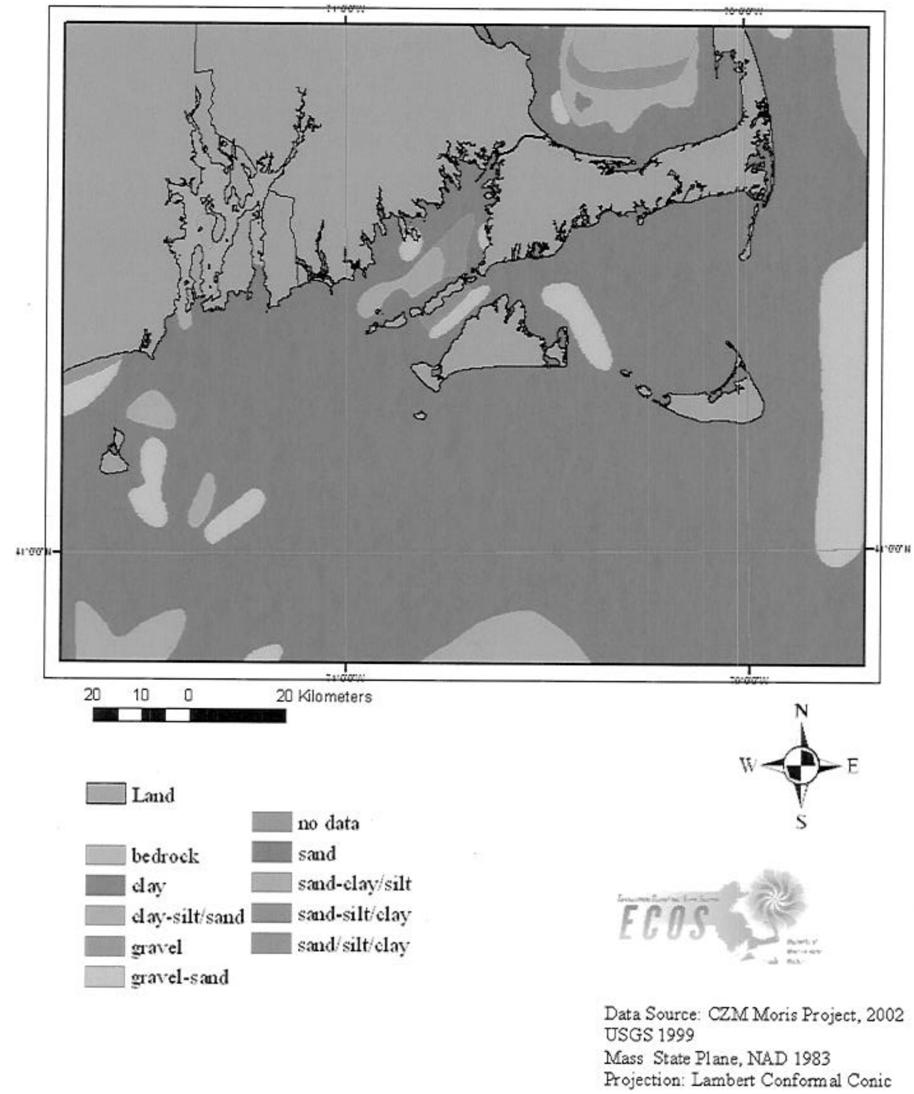


Figure 4.5. Sediment types for the offshore waters around Martha's Vineyard.

Using the existing environmental information, conditions were ranked as suitable or unsuitable, according to the requirements for sea scallop survival (Table 4.3). These criteria were then used to produce a map displaying the environmental conditions within the offshore areas of the study that are suitable and unsuitable for sea scallops.

Using the analysis technique of Boolean map overlay, within the GIS program the intersecting suitable areas of both the bathymetry and sediment type layers were combined. Boolean grids are grids that contain only two values, ones or zeros. The ones represent a true result, while zeros represent a false result. In this case, the ones corresponded with the suitable areas and the zeros corresponded with the unsuitable areas. When the grids were overlaid and the values multiplied, areas that had a one in both maps yielded a one (1x1), while areas that had a 0 (1x0; 0x0) yielded a 0. In this way the intersecting suitable conditions in both maps could be combined to produce a final map showing potential sea scallop habitats according to bathymetry and sediment types for the offshore waters of Martha's Vineyard.

Environmental Indicator	**Suitable**	**Unsuitable**
Bathymetry (m)	25-200	>200[8]
Bottom substrate Type	gravel, sand, or combination	clay, silt, mud, boulder
Temperature (°C)	>0; <20	>20; <0

Table 4.3. Ranked environmental conditions according to the available requirements for sea scallop habitats.

[8] Sea scallops have been found to occupy depths as deep as 384 meters (Brand 2006). For the purposes of this project, depths greater than 200 meters will be considered unsuitable.

Phase 3: Conflict Analysis

After completing the environmental analysis, it was important to perform a conflict analysis. While some areas appeared to be suitable for a sea scallop aquaculture project based on the environmental analysis, given the other uses of the area, this may not be the case. Additionally, the inclusion of the possible conflicts into the site suitability analysis and selection could allow for greater support and acceptance of the project by both the island community and the other users of the area. The first step of this analysis process required the description of all current and potential uses of the area. Similar to the environmental requirements, only existing available data for the area were used in the analysis.

In order to set a limit to the broad word "offshore," a focus area of 3-20 nautical miles from the Vineyard was set. This limit started at the 3 nautical mile state boundary line and extended offshore 20 nautical miles in all directions. The 3 nautical-mile starting point was chosen because the goal of this project was to examine the suitability of offshore sites. In the context of this project, they have been defined as federal waters, or waters that generally span from 3 to 200 nautical miles. As with one of the benefits of offshore aquaculture, projects sited past the 3 nautical miles state boundary line assisted in the elimination of potential conflicts associated with the near-shore waters. While federal waters extend seaward to 200 nautical miles, this project examined waters only out to 20 nautical miles from the coastline of Martha's Vineyard. This limit was defined with the intention of keeping boat fuel expenses down and allowing day trips to the potential site(s) to be feasible. Such distance would take a vessel leaving from Menemsha and traveling at an average speed of 8 knots approximately 2 to 2.5 hours to arrive at the full extent of the investigated area.

Even though this project focused on sites within 3-20 nautical miles offshore, data for the areas outside this region was also included. This addition provides a depiction of the possible suitable areas bordering the defined focus region. Due to the current lack of regulatory structure in offshore waters, the inclusion of areas outside the focus region could reveal possible suitable areas within state waters. The islands of Martha's Vineyard, Nomans Land, and Nantucket bring the state boundary line farther offshore. As a result, some of these areas could exhibit offshore-like qualities, while remaining in state waters. Projects in these areas could potentially be permitted through the Massachusetts's Division of Marine Fisheries.

USES OF WATERS AROUND MARTHA'S VINEYARD

The waters near and around Martha's Vineyard are used and zoned for a variety of purposes displayed in Table 4.4.

Use Category	**Current/potential uses of waters around Martha's Vineyard**
Navigational	Ferry routes, shipping lanes, boat traffic
Nautical Zones	Prohibited areas, anchorage areas, unexploded ordinance area, explosives dump, area to be avoided, net hazards
Underwater Infrastructure	Cable lines/areas
Fishing	Commercial and Recreational
Endangered/ Threatened Species	<u>Whales:</u> Northern Right, Fin, Blue, Sei, Sperm, Humpback <u>Sea Turtles:</u> Loggerhead, Leatherback, Kemp's Ridley, Hawksbill, Green

Table 4.4. Uses of Offshore Waters around Martha's Vineyard

Although all of these uses/zones occur in the waters surrounding Martha's Vineyard, not all pose as conflicts to a potential sea scallop aquaculture project. Conflicts could involve both physical and regulatory issues or a combination of the two. In order to determine which uses could be considered conflicts to this project, a detailed description of each use is necessary.

Navigational Uses

With ferries being one of the main modes of transportation to Martha's Vineyard, areas where their routes occur had to be avoided within this analysis. Not only are these areas subject to constant boat traffic, but also under law[9], navigable waterways cannot be impeded. With this in mind, areas that are used for ferry routes and shipping lanes were considered unsuitable and conflicting for an aquaculture endeavor and are displayed in Figure 4.8.

Nautical Zones and Underwater Infrastructures

Through an examination of GIS data derived from nautical charts, there appeared to be a number of nautical zones and infrastructures around the waters of Martha's Vineyard. Potential zoning conflicts included anchorage areas, prohibited areas, areas to be avoided, unexploded ordinance areas, and explosives dump areas. Anchorage areas are zones set designated as a suitable place for boats to anchor, taking into account boat traffic, depth, and ocean bottom (NOAA 1997). Constant anchoring over an area seeded with sea scallops can result in damage to the shells of the scallops; therefore anchorage areas were eliminated from the suitable areas. No authorized entry is allowed with a prohibited area, therefore all these areas are conflicting and were not included within the

[9] The Rivers and Harbors Act of 1899 prohibits the obstruction of navigable waters of the United States, unless approved by Congress (Kalo et al. 2007).

suitable available areas. Likewise, areas to be avoided also present hazards to navigation and were considered unsuitable. Other sites offshore Martha's Vineyard have been listed by NOAA as being locations of unexploded ordinances, or areas where explosive weapons did not detonate. There is also a site that has been designated by the Navy as an explosives dump. Explosive dumps are generally used for the disposal of ammunition, unexploded weapons, and chemicals (NOAA 1997). These areas could present issues if the materials are entangled in mobile fishing gear, which would impact bottom-seeding operations that are also harvested in this manner. Additionally, because some scallop aquaculture methods require the use of the ocean floor (bottom-seeding and cages), being near or around dangerous material could be considered a conflict in terms of the health of the cultured scallops. Furthermore, some bottom areas possess boulders and shipwrecks, items that may result in harvesting complications and gear damages. Therefore these areas were deemed to be areas of conflicted suitability.

Additionally, specific locations of the ocean floor around Martha's Vineyard are occupied by underwater infrastructure, usually involving cable lines. In order to supply Martha's Vineyard with electricity and phone service, multiple underwater cable lines are present. Because the presence of cable lines within a bottom culture area could present hazardous issues when lines are in need of service, these areas also fell within those considered to be of conflicting uses and were listed as unsuitable areas. All of these conflicts are picture in Figure 4.9.

Commercial and Recreational Fishing

While both commercial and recreational fishing are recognized as other uses of the offshore waters, these activities would only present conflicting uses to an aquaculture operation if they were disturbing the site and/or the species being cultivated. Therefore, an understanding of the gear employed in the harvest techniques is essential in deciphering whether the fishery would be considered a conflict. The majority of recreational fishing involves catching fish species by way of angling, or fishing with a rod or handline in state waters. However, recreational permits also allow the harvest of lobsters. Commercial fisheries can either occur in federal or state waters depending on the species and license. Furthermore, commercial permits involve both fixed and mobile gear depending on the species and harvest regulations. Within commercial fishing permits, fixed gear can include lobster traps, sink gillnets, and bottom long-lines.

FIXED GEAR

Lobsters are harvested from traps/pots that sit on the ocean floor. The traps are connected to a line that is attached to a buoy, which includes the permit number and unique color combinations of the permit holder. Lobster traps are considered a type of fixed gear, as they remain in the same location for a period of time (usually from 2 days to 1 week). Fixed gear would have the potential to be conflicting within an aquaculture project that also utilized fixed gear (lantern cages, bottom cages). Competition for space would be the main issue associated between these different utilizations of the same area. However, lobster trapping could occur with the adherence to buffers placed around the suspended aquaculture gear. On the other hand, if only a bottom culture method were being employed, all types of fixed gear would not represent any physical conflict. If anything, they would assist in protecting the site from vessels utilizing mobile gear.

Fishermen from both the island and the mainland harvest the offshore waters around Martha's Vineyard for lobster. During the Seastead scallop aquaculture investigation, lobster fishing was designated as a "controlled activity," meaning that lobster gear was allowed for those fishermen who applied for permission. Applications are required in order to inform the users when their gear needs to be removed from the site. Other gear types that were allowed through the submission of an application were longlining and handgear fishing. Even though gillnetting was prohibited in the Seastead project, it is also considered a type of fixed gear. Similar to the restrictions the Seastead project placed on longliners, gillnetting can occur within a site area as long as it stays a set distance from any suspended systems utilized. If only a bottom seeding culture operation were being employed, then both gillnetting and longlining could occur anywhere within the site without posing any conflicts.

While fixed gear would present a conflict only when harvesting from the culture site, this type of gear would not represent a threat the majority of the time and could easily be relocated for the short period needed for harvest. Therefore, within this conflict analysis, all types of fixed gear were not considered to be a conflicting use. Such gear types include lobster trapping, longlining, handgear fishing, and gillnetting.

MOBILE GEAR

Mobile gear consists of gear that is towed by a vessel, such as trawls or dredges (Smolowitz 1998). Such gear could entangle suspended, fixed gear within an aquaculture operation, resulting in gear damage and loss. Additionally, because mobile gear would be used to harvest scallops, the presence of vessels possessing this type of gear in the area of a sea scallop aquaculture site would be extremely threatening, and would therefore be considered a conflict.

Endangered/Threatened Species

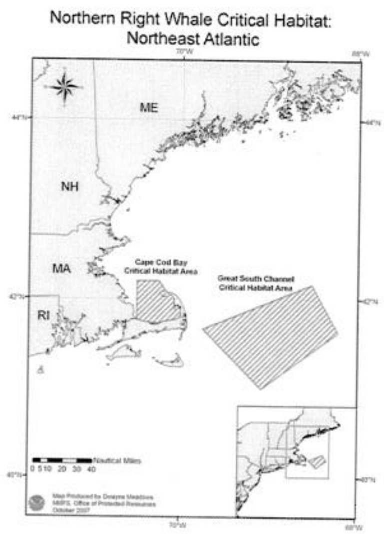
The Endangered Species Act of 1973 (ESA) protects endangered or threatened species and the critical habitats ("to the maximum extent prudent") that they occupy (Kalo et al. 2007). Actions that "change or degrade the habitat of a listed marine species where it actually kills or injures the species by significantly impairing essential behavior patterns, including breeding, spawning, rearing, migrating, feeding and sheltering, will be in violation of the Act" (Kalo et al. 2007). With this in mind, it was important to assess whether or not an offshore scallop aquaculture project would place harm on any of endangered species within the area.

A variety of endangered and threatened whale and sea turtle species have been known to inhabit the offshore waters around Martha's Vineyard. However, these species are not known to aggregate around this area in large concentrations. Whale species include the Northern Right, Fin, Blue, Sei, Sperm, and Humpback. Sea turtle species found within this area are the Loggerhead, Leatherback, Kemp's Ridley, Hawksbill, and Green. While the Right whale's critical habitat does not fall within the boundaries of this project (Figure 4.6), whale sightings do occur around this area (Figure 4.7) (NOAA (7) 2007). These sightings generally occur in the springtime as the whales travel to Cape Cod Bay. Loggerhead, Green, and Kemp's Ridley sea turtles tend to be found in the area from mid-summer to fall when water temperatures are warmer. Their critical habitats occur in the more tropical waters around Puerto Rico and the Virgin Islands (NOAA (6) 2007).

Both whales and sea turtles are known to be at risk of entanglement in lobster pot lines, seines, and fish weirs (NEFMC 1996). With this in mind, similar structures utilized in an aquaculture project, such as lantern and bottom cages, could present entanglement threats. During the Seastead project, which investigated various culture techniques offshore Martha's Vineyard, all suspended gear were determined to have enough tension to make all lines taut. Taut lines are believed to present less of a threat to whales and turtles than loose lines, which can entangle flukes and flippers easily (NEFMC 1996). Furthermore, designs that limited the number of lines to the surface were further encouraged to decrease entanglement risks.

Another potential issue involves harvesting bottom-seeded scallops. Sea scallops cultured in this manner are typically harvested the same way as the commercial sea scallop fishery, using trawls or dredges. As noted in the Chapter II, a Biological Opinion report published by NMFS in 2006 found the commercial sea scallop fishery to have no impacts on Hawksbill sea turtles or Right, Sei, Fin, and Humpback whales. However, species that were impacted by scallop gear involved the Green, Leatherback, Kemp's Ridley, and Loggerhead sea turtles.

While the commercial sea scallop fishery is very different than a sea scallop aquaculture project, if a bottom culture practice was employed, risks to endangered species, especially sea turtles, could be considered less than those imposed by the commercial sea scallop fisheries. Assuming such an aquaculture project would harvest the site every 2 years, the use of mobile gear would be much lower than the commercial fishery, decreasing potential sea turtle mortalities. As a result, all methods of sea scallop aquaculture within the area investigated would not likely result in any adverse effects to either whales or sea turtles, and would therefore not be considered conflicting "uses" of the area investigated. However, it is of importance to note that if suspended culture methods were used, more care would need to be given to ensure that the design, location, and concentration of the gear offered the least adverse affect on these threatened and endangered species.



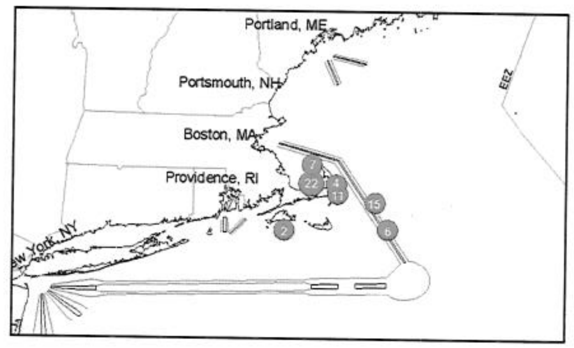


Figure 4.6. (Left) Northern Right Whale critical habitats within the Northeast Atlantic (NOAA (6) 2007).
Figure 4.7. (Right) Right Whale sightings for March 30, 2007 (NOAA 2007).

After a review of the potential uses of the offshore area around Martha's Vineyard, the following uses displayed in Table 4.5 were considered conflicting with regard to a sea scallop aquaculture facility. The conflicts spatially available for incorporation into this phase of the analysis are also listed in Table 4.5. The sources and descriptions of conflict data used with the analysis are listed in Table. 4.6.

Use Category	Conflict with offshore sea scallop aquaculture operation	Data Available
Navigational	Ferry routes, shipping lanes	√
Nautical Zones	Prohibited areas, anchorage areas, unexploded ordinance area, explosives dump, area to be avoided, net hazards	√
Underwater Infrastructure	Cable lines/areas	√
Fishing	Mobile gear: trawls, dredges	Only select fisheries data for 2005 available

Table 4.5. Conflicting uses of the offshore waters around Martha's Vineyard and the status of data availability for each conflict.

Name	Description	Source	Format
Nautical Infrastructure	Based on NOAA nautical charts. Contains 25 offshore infrastructures including cable areas, pipelines, channel boundary lines, safety zones, sewer lines etc.	CZM Moris Project, 2002; MassGIS 1997	Shapefile (linear); Vector
Industrial Uses	Areas currently and historically used for industrial waste, dredged material and munitions disposal.	CZM Moris Project, 2002; USGS 1999	Shapefile (polygon); Vector
Net Hazards	Offshore areas that are considered hazardous to fishing nets.	CZM Moris Project, 2002; USGS 1999	Shapefile (polygon); Vector
Fishing Effort	Selected 2005 Vessel Monitoring System (VMS) data	NEFMC 2005	Shapefile (point); Vector

Table 4.6. Conflict data descriptions and sources.

Within the conflicts utilized in this analysis, fishing effort was defined as being the total Days at Sea believed to represent fishing activity according to speed profiles obtained from Vessel Monitoring System (VMS) data for 2005. The fisheries that utilize mobile gear types within the area, and which also had available VMS data, are listed in

Table 4.9. It is important to consider the length of time these fisheries spent in the areas where they were fishing. Vessels that spent less than 7 days in an area throughout the entire year of 2005 were assumed to be independent of the resources of the particular area. For this reason, only vessels that spent more than 7 days of the year in the area were classified as contributors to conflicting uses (Figure 4.10).

Fishery	Gear Type
Sea Scallop: Limited and General Access	Dredge or trawl
Multispecies	Trawl A or B
Monkfish	Trawl
Herring	Trawl

Table 4.7. Fisheries accounted for within the conflict analysis and the type of gear utilized.

For the purposes of this project, a safety buffer would be applied to all conflicts, ensuring that an aquaculture project would not disrupt the current uses of the offshore areas. Currently, there are no principles established that place buffer zones around nautical infrastructures and zones. According to the Army Corps of Engineers, this is usually performed on a case-by-case basis (O'Donnell 2007, personal communication). Under Article 260 of the United Nations Convention on the Law of the Sea, safety zones are placed around scientific research installations within the EEZ at a distance not exceeding 500 meters (United Nations 1982). While this principle does not address the nautical infrastructures and zones, it was used as a reference point for this project. Because, in this case, the purpose of the buffer would be to ensure that there is enough space between the use and the potential aquaculture site, a buffer of 1000 meters was applied to all conflicts (Figure 4.11). The application of this buffer would help strengthen the suitability of the determined sites. The following maps display each conflict before the application of the 1000-meter buffer. Using the same Boolean overlay process, the potential buffered conflicts were mapped and then overlaid with the environmental data, allowing for the suitable areas for all criteria to be distinguished.

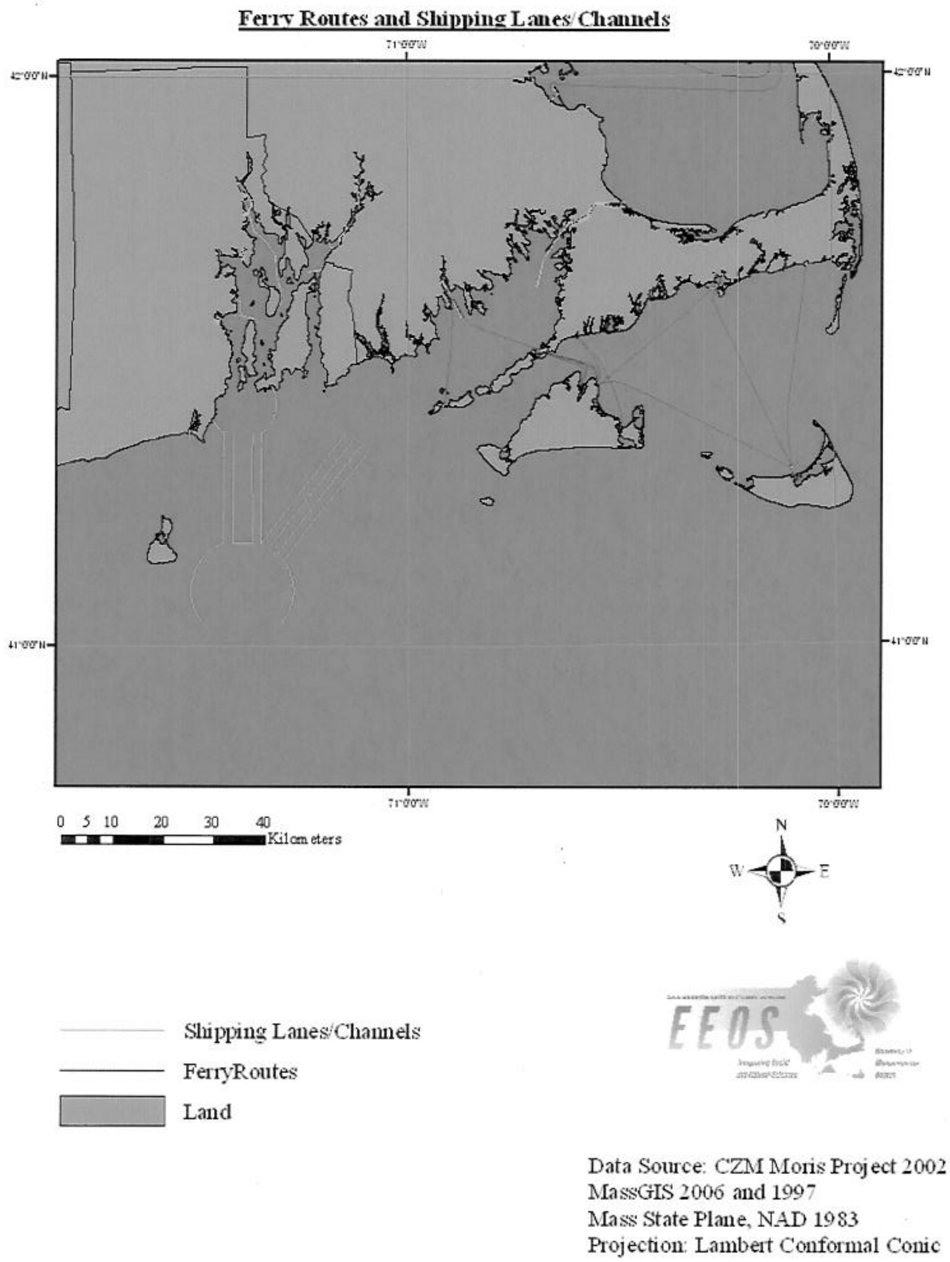


Figure 4.8. Ferry routes and shipping lane/channels.

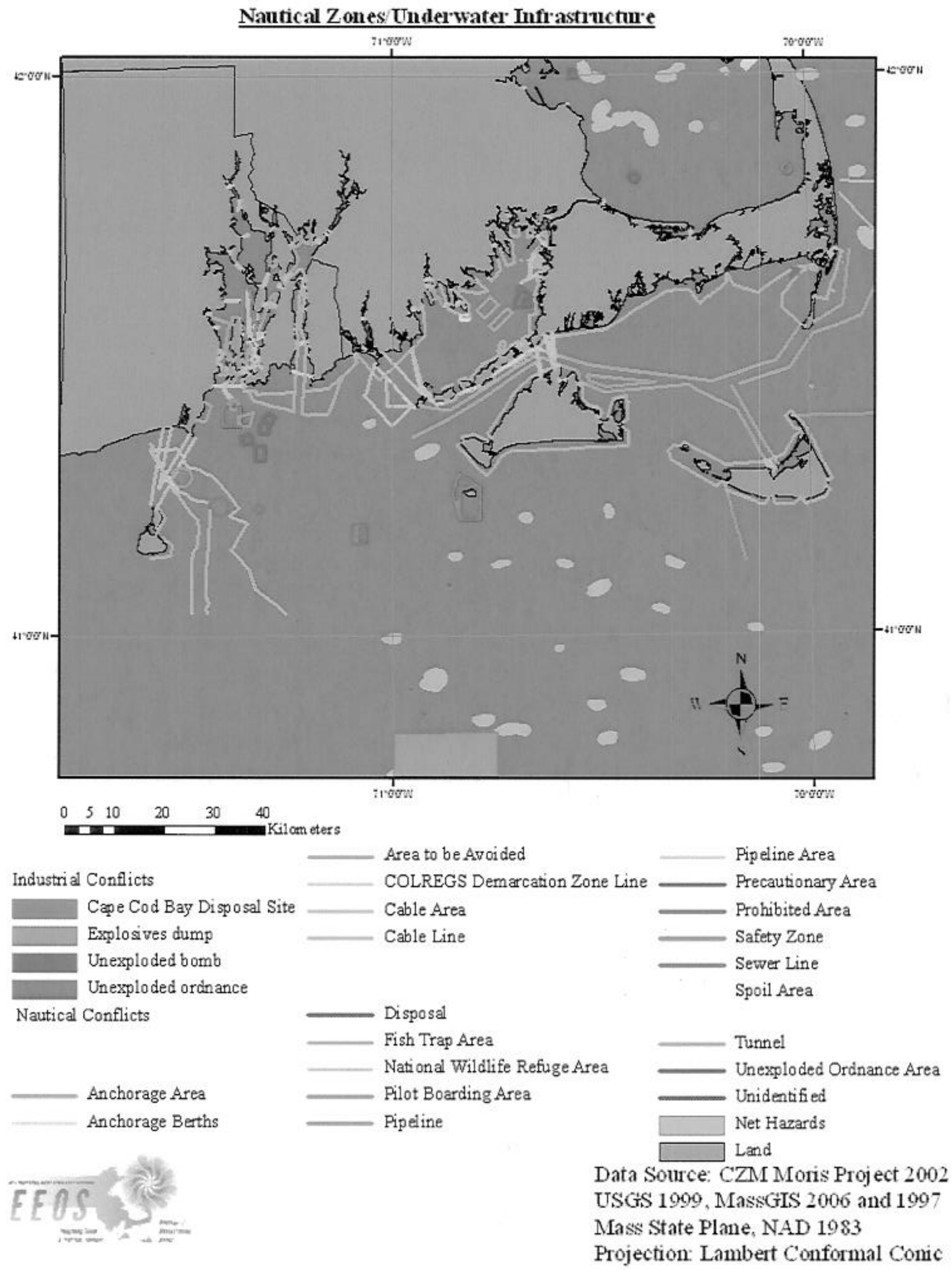


Figure 4.9. Nautical zones and underwater infrastructure.

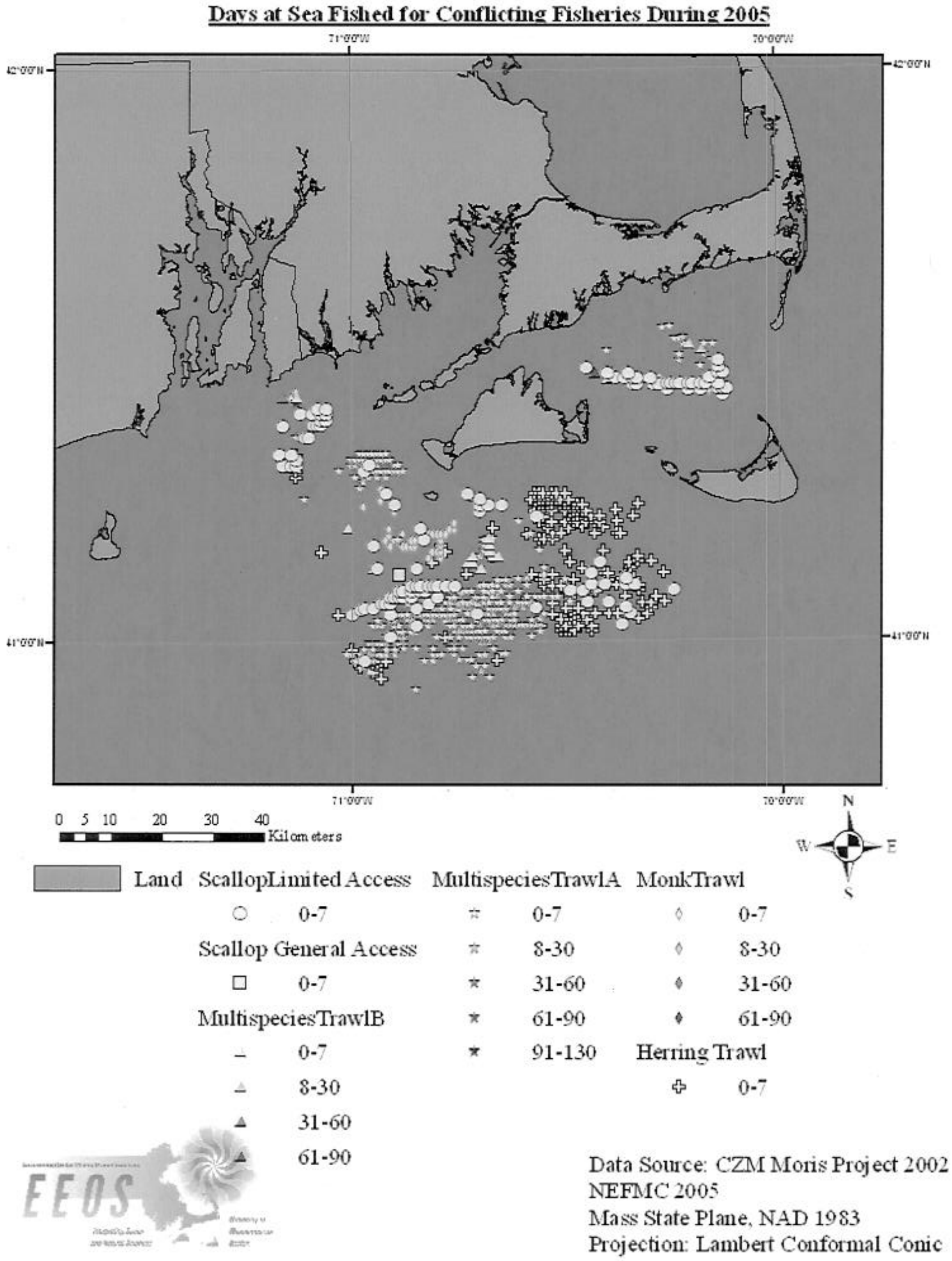
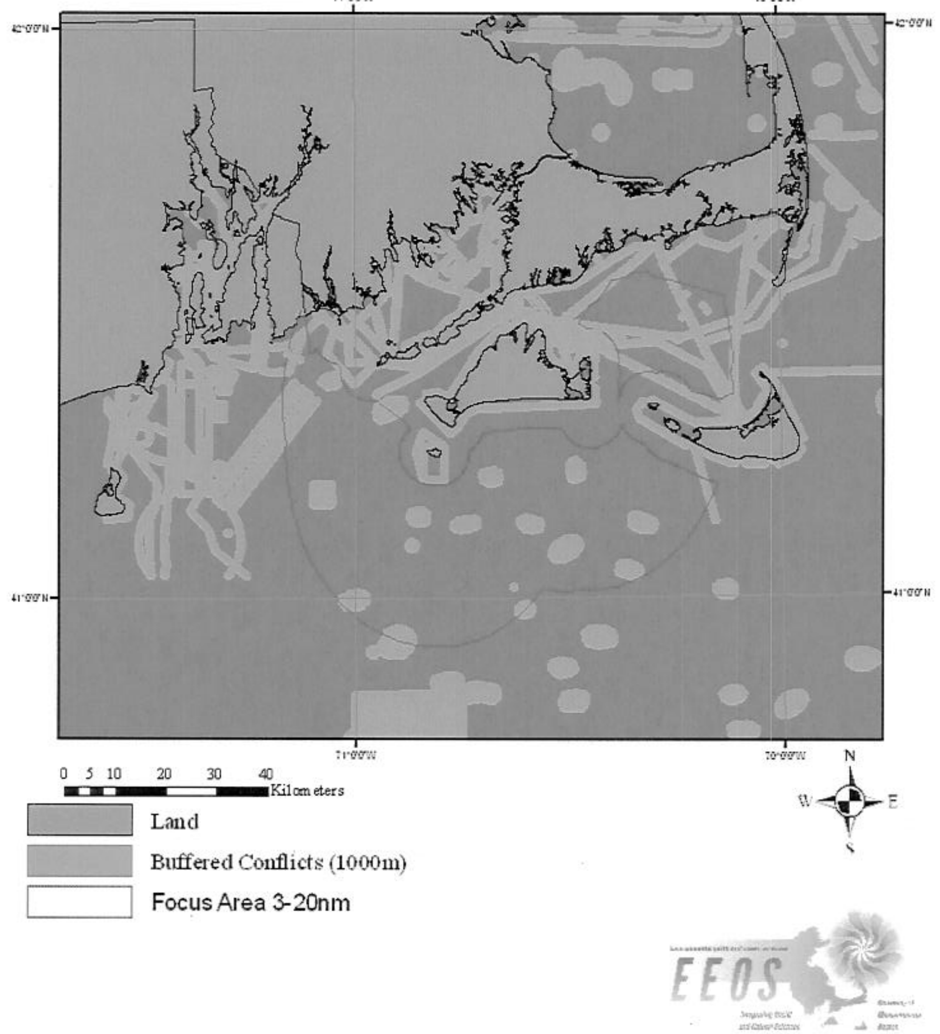


Figure 4.10. Days at Sea fished for conflicting fisheries for the 2005 fishing year.

Conflicting Uses with 1000-meter Buffer



Data Source: CZM Moris Project 2002
USGS 1999, NEFCM 2005, MassGIS 2006 and 1997
Mass State Plane, NAD 1983
Projection: Lambert Conformal Conic

Figure 4.11. Buffered conflicting uses of the offshore waters around Martha's Vineyard.

CHAPTER V. DISCUSSION AND RESULTS

Upholding both an attentiveness to the hardships faced by Massachusetts' fishing communities and a worldwide need to expand seafood supplies, this sea scallop aquaculture project was designed to determine if offshore areas around Martha's Vineyard, Massachusetts are suitable for such a venture. Indeed, as the island of Martha's Vineyard confirms the necessity for job augmentation within its fishing community, an aquaculture site suitability analysis for the island is timely. Such a proposal requires, as well, that offshore aquaculture be rooted in a responsible manner, that the quality of the environment be the primary obligation. Sea scallop aquaculture complies with both the needs of the Vineyard's fishing community and the environmental sensitivity of the island and its surrounding waters. The culture of sea scallops requires no artificial feeding and no application of chemicals or antibiotics; it can be achieved in a manner that does not interfere with the multiple uses of offshore waters. The sea scallop is an appealing species to culture.

In order to designate whether the offshore area around Martha's Vineyard offers suitable sites, this project followed the methodology described by Frankic (2003). This analysis involves a description of the environmental attributes and other uses of the offshore waters through the application of the best available data for the area. Following this procedure, this project was able to determine where suitable sites for sea scallop aquaculture occur in the offshore waters of Martha's Vineyard.

Given that sea scallops are native to the Northwest Atlantic Ocean, many suitable environmental sites are assumed to be present. However, as these offshore areas are also utilized for the harvest of various commercial fisheries, it was presupposed that the number of suitable sites would be greatly reduced with the inclusion of the conflict analysis. With the incorporation of past economic analysis, this study hoped to determine whether the resulting sites from the suitability analysis might offer enough area to maintain an economically viable sea scallop aquaculture operation.

Results of Phase 2: Environmental Suitability Analysis

This stage of the analysis required the compilation of available environmental data with the necessary environmental requirements for sea scallops. Finding that there was limited spatially described data for the Vineyard's offshore area, a supplementary temperature project was formed with the purpose of expanding the description of the area.

Temperature Results

On November 5, 2007, the temperature sensors were retrieved and data downloaded. Daily averages indicate that all sensors, except for the sensor placed at 4 meters, remained in temperatures sufficient for sea scallops (Figure 5.1.). Monthly averages indicate that during September water temperatures at or above 4 meters are not suitable for sea scallops (19.7°C) (Table 5.1.). After September it appears that the water temperature decreases, allowing temperatures at depths of 4 meters to reach suitable levels. While this project provided preliminary information indicating that depths from 24 to 36 meters offshore Martha's Vineyard have sufficient temperatures for sea scallops during the months of September and October, the description of other months, particularly August, is needed to provide a thorough assessment of the bottom water temperatures. Since this temperature data currently does not exist, this project cannot make a definitive conclusion that all depths investigated are suitable for sea scallops.

However, the study does ascertain that depths from 24 meters and below are not at risk of reaching temperatures too high for this species. Since sea scallops generally inhabit areas from 25-200 meters, temperature results indicate that offshore areas at these depths around Martha's Vineyard, in terms of bottom water temperature during September and October, are sufficient for sea scallops.

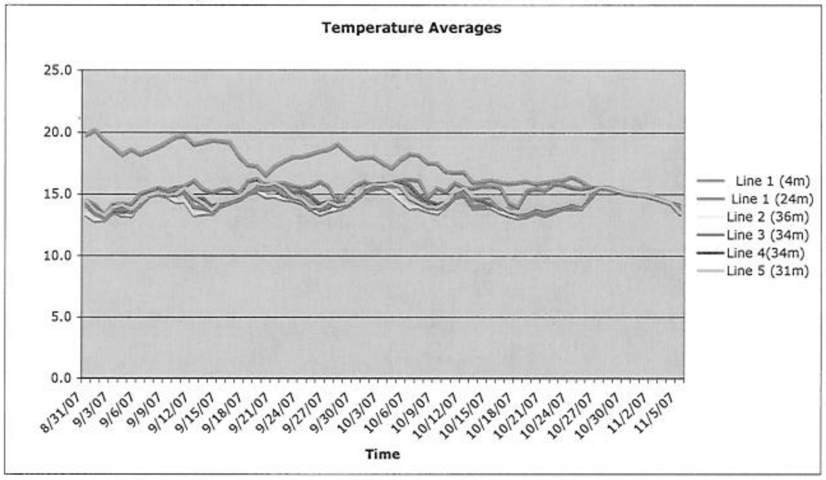


Figure 5.1. Average daily temperatures of five different locations and depths of waters offshore Martha's Vineyard.

Temperature Sensor ID and depth	Average Monthly* Temperature (°C)	
	September	October
Line 1, 4m	19.7	16.3
Line 1, 24m	15.3	15.4
Line 2, 36m	14.2	14.4
Line 3, 34m	14.5	14.6
Line 4, 34m	14.7	14.9
Line 5, 31m	14.6	14.7

Table 5.1. Average monthly temperatures from all locations.

* September's average temperatures include August 30. October's averages include November 1st through November 5th.

Results of the Environmental Analysis: Suitable bathymetry and sediment

As sea scallops are an important commercial species in Massachusetts, it is important that a sea scallop aquaculture project is not placed where large, commercial aggregations of scallops already exist. According to a scallop assessment survey performed by NEFSC in 2006 (Figure 4.1, Chapter 4), and with the knowledge of the sea scallop commercial management areas (Figure 2.2, Chapter 2), the offshore areas within this study do not overlap with any commercial beds.

However, it is also essential that the area(s) are environmentally conducive for successful scallop growth. As noted in Phase 1 of the environmental analysis, there are many conditions that influence the survival of the sea scallop. Such factors include temperature, depth, substrate type, food concentrations, turbidity, oxygen levels, water currents, and salinity. The presence of predators also has an impact on sea scallop survival. Ideally, all of these factors would be addressed in the environmental analysis phase. However, research revealed a lack of spatially referenced offshore data for this area. Therefore, this project was only able to incorporate bathymetry and sediment type data within this phase of the analysis (Figure 5.2). As a result, it must be recognized that there is some degree of uncertainty within the interpretation of this phase of the analysis. Even so, the map displaying the suitable bathymetry and sediment types for sea scallops is able to assist in differentiating between suitable and unsuitable offshore areas. If aquaculture is to expand in the offshore waters, however, it is critical that these areas be further described in a way that can be viewed and geographically referenced.

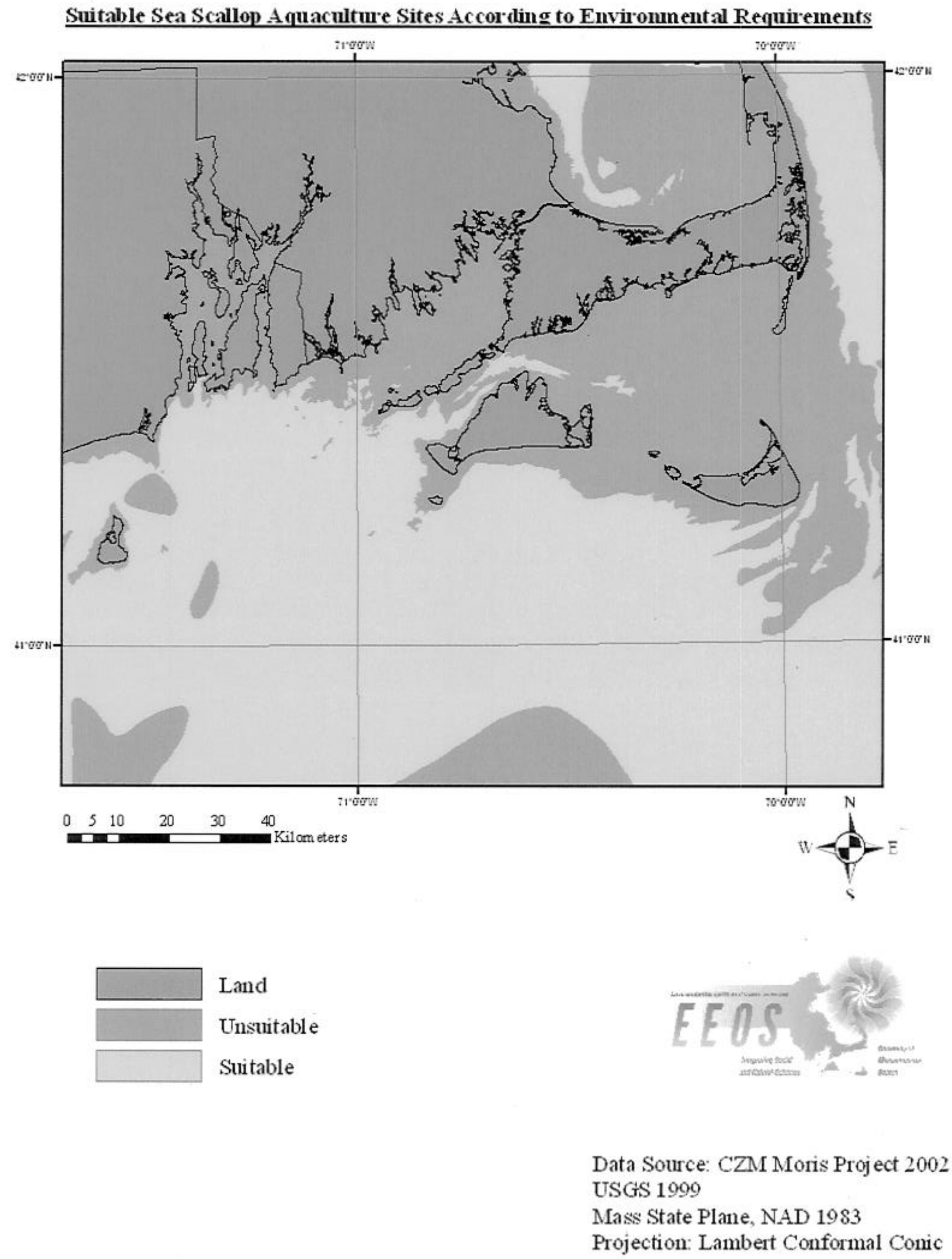


Figure 5.2. Results of Phase 2: Environmental Site Suitability Analysis.

Results of Phase 3: Conflict Analysis

While the resulting map from the environmental analysis phase displays vast areas that offer suitable environmental conditions in terms of bathymetry and sediment type, it is believed that these areas would be significantly reduced with the addition of other uses of the area. After the application of 1000-meter buffers around all the potential conflicting uses of the area and the integration of the environmental requirements, the resulting suitable areas are pictured in Figure 5.4. From this map, it is apparent that for either environmental or use conflicting reasons, many of the near-shore areas around Martha's Vineyard are not sufficient for sea scallop aquaculture. The offshore federal waters to the east of Martha's Vineyard within the 20-mile focus area, in particular, appear to be unsuitable. This is mainly due to the shallow waters present in this area. However, it appears that there are extensive areas south of Martha's Vineyard and farther offshore, which are quite suitable for a sea scallop aquaculture project.

The economic analysis performed by Kite-Powell et al. (2003) concludes that the only economically viable mode of culture for sea scallops offshore appears to be bottom-seeding culture. Strong currents, high wave action, damage and loss from mobile fishing gears, and expense were factors attributed to the failure of multiple suspended culture designs. As the area investigated within this study overlaps with the area of the Seastead project, and therefore the economic analysis, it seems that bottom-seeding might be the most economically feasible mode of culture. For suspended culture options to be a possibility within this offshore environment, it would be necessary to perform another investigation testing various technologies with an approach aimed at keeping expenses down and designing gear that could withstand the harsh offshore conditions.

One aspect that also has an affect on whether a sea scallop aquaculture operation is successful is the market prices of scallop meats. According to Kite-Powell et al. (2003), if scallop prices fall below $4/pound with harvest losses as high as 50%, the project will not be profitable. While market prices vacillate from year to year, an examination of market trends from 1956 to 2006 indicate the last year scallop prices fell below $4/pound was in 2002 (Figure 5.3). As predicted by economic theory, there is an inverse relationship between prices and landings; all else equal, as landings increase, prices decrease. Although the success of such a project is largely dependent upon both the loss rate and market prices, these factors cannot be predicted until an operation is underway. One benefit that an aquaculture operation has over a commercial fishery is that harvesting can be postponed until market prices reach more tolerable levels.

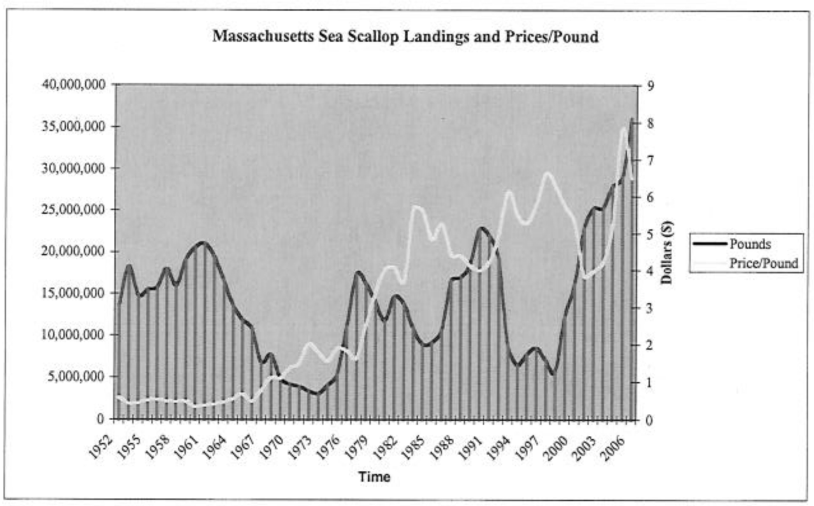


Figure 5.3. Trends in sea scallop landings and market prices 1956-2006 (NMFS 2006).

Another factor addressed in the analysis of Kite-Powell et al. (2003) is the area needed for a successful sea scallop bottom-seeding operation. Their study determines that 150 acres, or approximately 1km^2, would be a sufficient area to produce enough scallops to maintain the operation. With this in mind, numerous sites within the area under investigation (Figure 5.5) are appropriate for such a project. However, it is important to note that not every fishery that utilizes this area was able to be included within the analysis. Currently, not every fishery is required to be equipped with a vessel monitoring system (VMS). In 2007, approximately 5,000 vessels operating within the United States' Exclusive Economic Zone possessed a VMS (NOAA 2008). Furthermore, it is difficult to acquire this information as it displays "hot" fishing areas, which is considered very sensitive material. Other forms required by many fisheries are Vessel Trip Reports (VTR). While these reports are more comprehensive in terms of catch data, the locations reported are not considered to be as accurate as VMS data. Unless the fishery requires reporting of the specific harvest locations, it is very difficult to integrate this information into such an analysis. This deficiency is present in this project; therefore, the areas that appear to be suitable from this analysis may in fact prove to be otherwise. As a result, this map must be interpreted with some uncertainty.

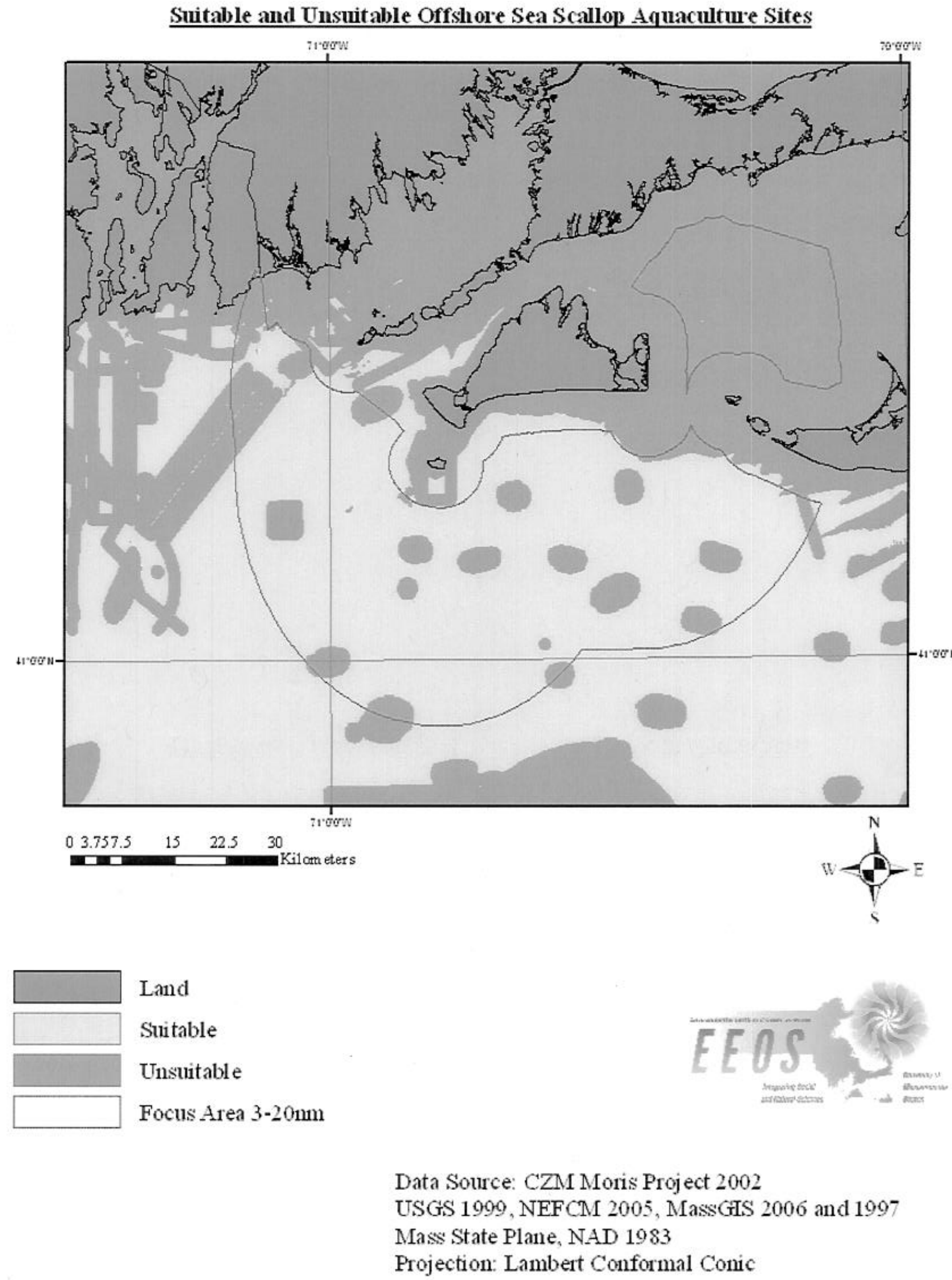


Figure 5.4. Final map displaying suitable and unsuitable areas for sea scallop aquaculture after performing environmental and conflict analyses.

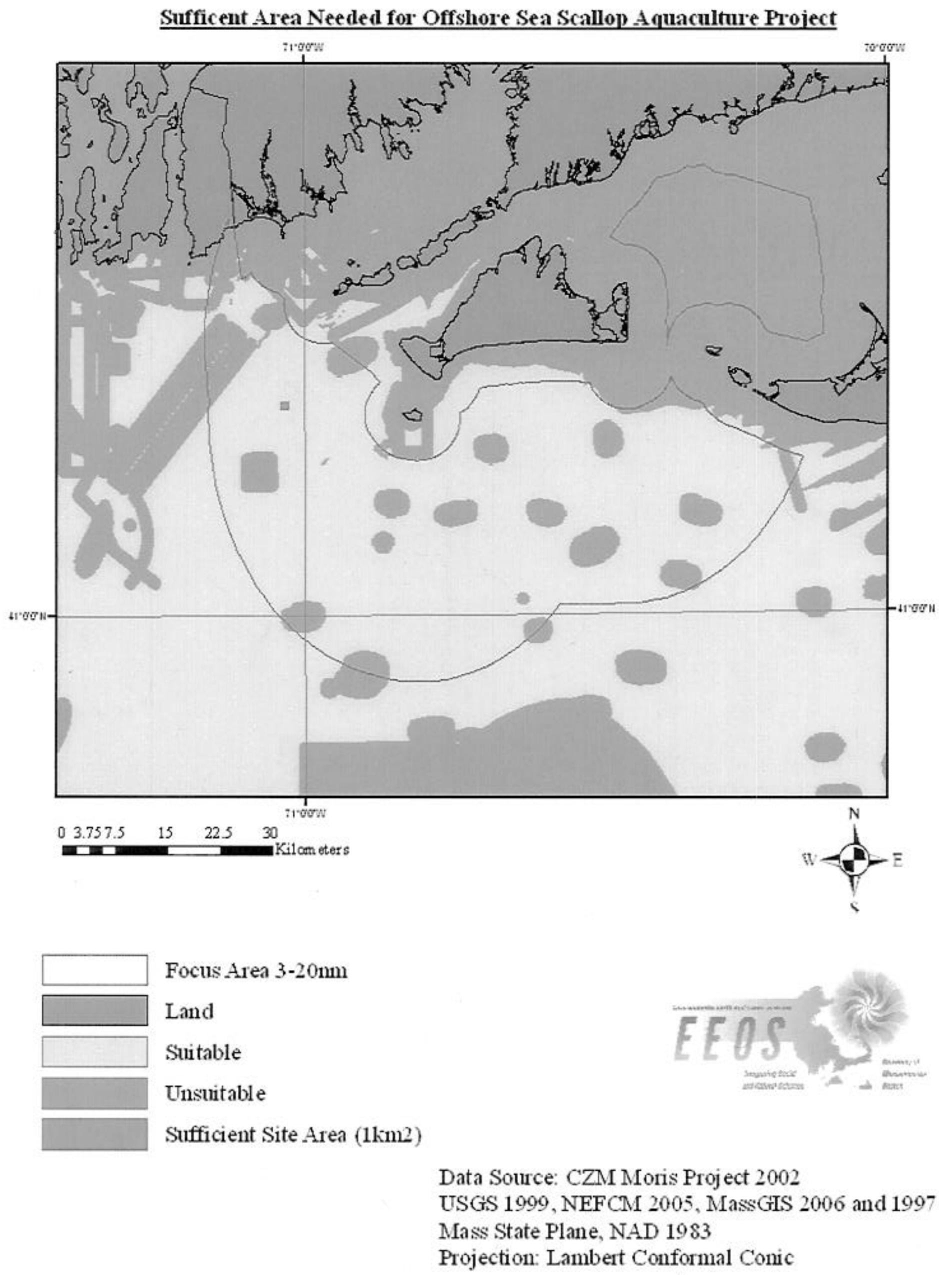


Figure 5.5. Suitable conditions overlaid with sufficient area needed for a successful sea scallop aquaculture operation according to Kite-Powell et al. (2003). The sufficient site area depicted in the map is presented as a visual example of the size of space needed for a sea scallop aquaculture project. It does not represent an actual, proposed site.

Phase 4: Management Issues

If this project to were to operate successfully, the possible socioeconomic issues of an aquaculture operation and the other uses of the area would have to be considered.

Such factors are generally difficult to display spatially, but they would have to be identified and the potential management options would have to be described. Some potential management issues apparent within this study involve a lack of the designation of all fishing effort, site security problems, and the protection of permissible fixed gear within the aquaculture site.

Fishing Effort

Although fishing effort for available fisheries in 2005 was able to be included in this analysis, this data does not represent a complete profile of the fishing uses for the area. As stated above, it is difficult to obtain spatially defined information that accurately displays fishing effort. While the presence of a sea scallop aquaculture site would represent a conflict only to mobile gear vessels that would be prohibited within the area, it would be important to accurately determine the offshore areas actively utilized by these fisheries. With this in mind, one possible mode of including additional fishing effort for the area would be to directly discuss and compare maps with the local fishermen. Through an examination of map areas deemed suitable from the application of available environmental and use data, to actual fished areas designated from fishermen's maps, further conflicting areas could be made apparent.

Site Security

Another issue that would have to be controlled is the security of the site. This would entail a management strategy to prohibit the passage of vessels that pose potential threats to the aquaculture operation. Within the conflict analysis, such vessels were defined as those possessing mobile gear such as dredges or trawls. If these vessels were permitted to traverse the designated site area, it would be difficult to make certain that they were not simply harvesting scallops from the culture area.

In the Northeast, over 2,000 fishing vessels are required to possess VMS devices. Such fisheries include sea scallops, multispecies, red crab, monkfish, and herring. Generally, the larger vessels that hold higher catch quantities are required to have VMS devices; yet, some of the smaller vessels permitted under different restrictions are not. For example, within the sea scallop fishery general category permit 1A, vessels are not required to have VMS devices on board. Even though vessels under this permit category are only allowed to harvest 40 pounds of scallop meats, continual harvest of the cultured area could have an affect on the production of the aquaculture site. However, the only way to completely eliminate this risk would be to require all fisheries to possess VMS devices, a movement that could be met with significant opposition from fishermen. In order to protect the aquaculture site from all vessels that present a threat to the cultured area, some method would need to be established entailing a sufficient penalty if caught. Such an effort would need to be thoroughly reviewed and established by NMFS.

Protection of Fixed Gear

While all types of fixed gear are deemed to be non-conflicting uses within a sea scallop aquaculture culture area, there are potential issues to consider in terms of the protection of the fixed gear within the site. Even without the presence of an aquaculture project, issues between fisheries that utilize mobile gear and those that use fixed gear frequently arise. Such conflicts generally occur when there is an overlap in the productive areas of the species within these fisheries; an overlap usually results in the damage or loss of fixed gear. One such issue that surfaced within the Seastead investigation involved the concern that sea scallops within the cultured site may "spill out" into neighboring areas not within the designated protected site. With the possibility that these sea scallops would bring more mobile gear fishermen into the area, lobstermen voiced concerned about the safety of their gear and the lobsters within the area. In this case, the issue was resolved by moving the proposed site to an area that posed less of a threat to the inshore lobster fishery.

Another way of managing such an issue would be to create a buffer around the project site. Such a buffer could help protect the lobster gear within the area while decreasing the harvest losses felt by the aquaculture endeavor. While there are currently no regulations placing buffer zones around offshore aquaculture projects, a similar sized buffer as used within the conflict analysis could be a good starting point. Therefore, adding a 1000-meter buffer around a $1km^2$ (150 acres) seeded site could assist in protecting the fixed gear within the area. With this in mind, combining the area needed for an aquaculture site with a 1000-meter buffer would promote the requirement of a leased area of $3km^2$ (Figure 5.6). However, in order to ensure that this buffered distance offers the needed protection, this distance would need to be established in concordance with lobster fishermen.

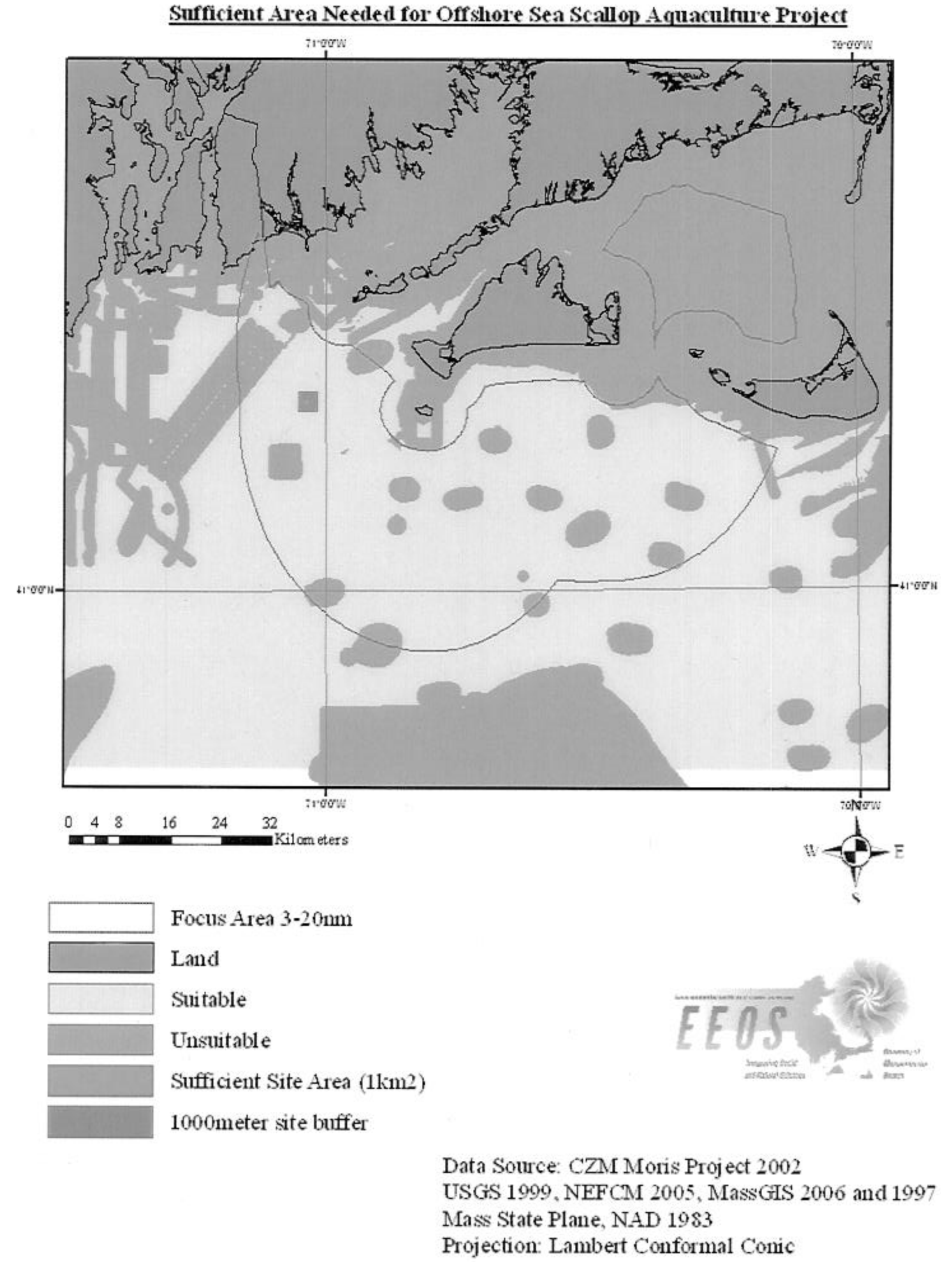


Figure 5.6. Example of site area required with the addition of a 1000-meter buffer.

Future Work and Recommendations

As this study has helped assist in the siting of an offshore sea scallop aquaculture project, there are still plenty of questions left to answer before such an endeavor can be executed. This project underscores the need for further development of spatially explicit data describing the offshore areas of the proposed region as well as *all* offshore waters of the United States. The existence of this data is a stipulation for the accurate site potentiality of offshore aquaculture endeavors. Such data should include both environmental attributes and other uses of the waters. With this in mind, it is also essential for regulators to provide access to fishing effort data whenever available. Currently, it is difficult to obtain recent fishing effort data, which obscures accurate analysis of potential aquaculture sites. While this barrier is designed to protect fishermen, open access to current fishing effort data would help eliminate conflicting areas, thereby helping fishermen.

Another subject of study that needs focus is the retrieval rate of seeded scallops. This facet is not described within the Seastead scallop aquaculture project, but it could have profound effects on the success of a bottom-seeding sea scallop venture. While issues faced by the Seastead project indicate that scallop beds tend to move, no information was gathered indicating the amount of scallops harvested within the study. After losing track of the first batch of seeded scallops, the Seastead researchers devised an underwater video sled that was frequently deployed to monitor the locations of the seeded beds (Smolowitz et al. 1998). Under natural conditions (excluding vandalism from other fishing vessels), sea scallop loss can be a result of movement or predation. If these factors make it impossible to harvest at least 50% of the amount of scallops seeded, then another technique must be investigated. Therefore, before a full-scale offshore sea scallop project can begin, it is essential to further investigate and document the retrieval rates of other bottom-seeding operations.

Additional research is required in determining how sea scallops can be acquired at a size suitable for bottom seeding (>25mm). While the Seastead project obtained special permits to harvest undersized wild scallops, this method could impact commercial sea scallop beds and catches. Because the intent of this project is to enhance scallop harvests without competing or harvesting from the wild fishery, raising scallop seed through aquaculture methods is seen as the best technique. However, in order to raise enough scallop seed to the desired 25mm size, near-shore hatchery infrastructure will be necessary. Kite-Powell et al. (2003) determined that an offshore area needed to be seeded with 40,000 scallops/acre for harvests to be successful. If 150 acres are essential to produce harvest quantities needed to make this project successful, then the production and seeding of 6 million, 25mm scallops would be necessary. Understanding this issue, further work must investigate whether there are suitable near-shore areas available for such a production. This would entail the initial use of a hatchery and then a type of cage system within near-shore waters for scallops to grow to 25mm. This process may present issues within the near-shore waters around Martha's Vineyard in terms of both high water temperatures during the summer months, and conflicts with the variety of uses within these waters.

For this reason it is also important to research current sea scallop hatcheries. If it is possible for such hatcheries to cultivate the desired amount of sea scallops, this option may prove to be more plausible than growing scallops locally. However, with this option it is important to account for and recognize the high possibility of mortalities due to transportation factors.

Another area in need of further research is to ascertain the actual number of employees such a project would require and the relative hours/per year needed by each employee. Kite-Powell et al. (2003) predicts that a bottom seeding operation would require 150 days of "vessel time," divided into collection and deployment, harvesting, and mooring and buoy maintenance. Within the baseline assumptions, workdays are considered 12/hour days, but there is no mention of how many people would be required to make such a project operate successfully. Without this information, it is hard to make a definitive determination of the number of jobs this project could provide to the community of Martha's Vineyard.

In the end, this study provides a foundation to assist in the development of offshore sea scallop aquaculture for the island of Martha's Vineyard. Although the United States currently lacks a regulatory framework to permit aquaculture projects within federal waters, maps from this analysis indicate that there are suitable sites within state waters. As the movement toward offshore aquaculture will be stalled until a regulatory process is accepted, the utilization of these offshore-like, state waters may be the only choice for such a venture to occur. Whether or not this is the case, the suitability maps produced from this study can be discussed with the other users to create a more accurate description of the offshore waters around Martha's Vineyard. This process can potentially lead to the designation of an agreeable and suitable site for a sea scallop aquaculture project. If research indicates that retrieval rates of bottom-seeded scallops are sufficient and that an ample supply of 25mm scallops is accessible, this project could prove to be not only profitable, but an additional mode of augmenting the world's seafood supply. The Chinese proverb that is the banner of this paper, an ancient precursor of the essential struggle we face today to establish a sustainable seafood supply, heralds the purpose of this study. The establishment of aquaculture ventures is not a luxury of thought but a requisite plan for the survival of fish as a source of food and, in my opinion, the survival of fish as a source of exquisite beauty.

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