Final
M/V *World Prodigy* Oil Spill
Restoration Plan and Environmental Assessment
Narragansett Bay, Rhode Island

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Final Environmental Assessment and Restoration Plan

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EXECUTIVE SUMMARY

In June, 1989 the Greek tanker *World Prodigy* ran aground in Narragansett Bay, Rhode Island releasing approximately 290,000 gallons of number 2 fuel oil. Numerous species of marine organisms were adversely affected by the spill. The National Oceanic and Atmospheric Administration (NOAA) assesses and claims damages (compensation) from responsible parties for injuries to natural resources from discharges of oil, and is required to use those funds to restore the injured resources. In 1991, NOAA received $567,299 as a result of a legal settlement between the Federal government and the responsible party. NOAA will use these funds to restore the natural resources injured by the spill.

The Clean Water Act, as amended by the Comprehensive Environmental Response, Cleanup, and Liability Act (CERCLA), requires Federal and State natural resource trustees to restore, rehabilitate, replace, or acquire the equivalent of the natural resources injured by an oil spill. This restoration plan describes the proposed use of the settlement funds received by NOAA. The proposed plan presents a summary of the incident and injuries caused by the spill, identifies categories of restoration that were considered (resource and habitat enhancement, acquisition of equivalent resources, and no action), identifies criteria for project selection, and discusses the proposed alternatives.

NOAA's goal is to restore the resources injured by the *World Prodigy* oil spill and compensate the public for the lost use of those resources by enhancing habitat value for numerous marine resources, with specific emphasis on lobsters, quahogs (hard clams), and estuarine finfish. To meet this goal, NOAA proposes several actions: (1) enhance lobster habitat by establishing several lobster reefs; (2) transplant quahogs and establish quahog "spawner sanctuaries" to help restock formerly productive areas of the bay and to make more of the resource available to shellfishermen; (3) establish eelgrass beds in multiple sites throughout Narragansett Bay to enhance fisheries habitat; and (4) restore a saltmarsh system on Sachuest Point in Middletown, RI to enhance habitat for estuarine dependent fish and shellfish.

The National Environmental Policy Act (NEPA) requires an assessment of the effects of any Federal action that may impact the environment. This document also serves as an environmental assessment and will comparatively evaluate alternative methods for restoring or replacing the injured resources.

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I. INTRODUCTION: Purpose and Need for Action

The *World Prodigy* Oil Spill and its Impact on Narragansett Bay's Resources

On June 23, 1989, the Greek-registered oil tanker *World Prodigy*, owned by Ballard Shipping Company, en route from Bulgaria to Providence, Rhode Island, grounded on Brenton Reef in Narragansett Bay off Newport, Rhode Island (Figure 1). The impact of the grounding ruptured nine of the vessel's 23 cargo tanks causing the discharge of approximately 290,000 gallons of number 2 fuel oil into the bay. The oil eventually spread over a 123 square mile area of the bay and Rhode Island Sound. A portion of the oil was stranded on intertidal areas of lower Narragansett Bay. The spill adversely affected numerous species of marine organisms including large numbers of adult crustaceans, fish, shellfish and crustacean eggs and larvae, and a variety of benthic organisms in certain heavily oiled locations (Pilson 1989). Additionally, various human uses were adversely affected. The entirety of Narragansett Bay was closed to shellfishing as a precautionary measure for one week leading to a loss of access to shellfishing grounds for commercial and recreational clammers. Many of the state's beaches also were closed for up to two months, in some cases, though most were closed for several days.

Data collected by NOAA's National Marine Fisheries Service and other agencies suggested that the *World Prodigy* spill killed a significant number of planktonic life forms, larval and juvenile fish, and larval shellfish and crustaceans. Species that were adversely affected included significant numbers of early life stages of tautog, cunner, scup, sea robin, and larval lobsters (K. Sherman, National Marine Fisheries Service, pers. corr. 1989). The greatest proportion of NOAA trust resource losses were annually spawned pelagic juveniles. Their deaths represented the loss of a significant portion of the 1989 year class of those species within the impacted area (K. Sherman, NMFS, personal communications). Analysis of the data obtained by the State of Rhode Island, The University of Rhode Island, NOAA, the Food and Drug Administration, the U.S. Environmental Protection Agency and the U.S. Coast Guard demonstrated that the quahog or hard clam (*Mercenaria mercenaria*), American lobster (*Homarus americanus*) and a variety of finfish eggs and larvae were among the most seriously impacted of the NOAA trust resources in Narragansett Bay.

The shores of Conanicut Island were most affected. The Rhode Island Division of Fish and Wildlife conducted shoreline surveys at Mackerel and Hull Coves in Jamestown, RI and collected over 800 dead, small lobsters and crabs in those two locations. The total number may have been considerably greater since it is probable that not all carcasses were washed ashore and many could have been carried away by scavengers (gulls, foxes, skunks, and raccoons) (Pilson, 1989). Though the oil spread throughout a large area in Narragansett Bay and Rhode Island Sound, within days the oil had largely disappeared from the surface waters as a result of evaporation and mixing in the water column (Pilson, 1989). However, data collected for several years following the spill indicated that significant concentrations of oil remained in the beach sand in Hull Cove (Mulhare and Therrien, 1993). Extrapolation of that data suggests that degradation of the oil would slowly continue with significant concentrations remaining for at least five years after the spill (Mulhare and Therrien, 1993).

In addition to the scientific sampling performed by the various Federal and state agencies, and academic institutions, a computer model was run to simulate the effects of the spill on the bay's resources. The Natural Resource Damage Assessment Model for Coastal and Marine Environments ("Type A Model") was used to estimate damages caused by the spill. The model uses a variety of inputs including air and water temperature, current and wind data, type and amount of oil spilled, and resources present in the impact area, to calculate injuries to the affected resources. The modeling results were similar to the data collected, however, the model predicted large numbers of adult fish kills where sampling did not detect any (French, *et al.*, 1990).

Generally, refined petroleum products such as number 2 fuel oil (home heating oil) have greater concentrations of toxic components (i.e., aromatics) than crude oil. Consequently, spills of refined products are likely to have a greater ecological impact (Malins, 1977). The high content of toxic aromatics was one reason for the severity of effects of the 1969 spill from the barge *Florida* in West Falmouth, Massachusetts (Mielke, 1990). That spill released 4,500 barrels of number 2 fuel oil into Buzzards Bay. Number 2 fuel oil, as well as the other light oils, can have long-term impacts on intertidal resources. Although number 2 oil is considered to be moderately volatile, evaporation is not as complete as with a lighter fraction such as gasoline. Number 2 fuel can leave a residue, up to one-third of the spill amount. Porous sediments absorb this fuel oil rapidly; the petroleum moves downward as far as the water table allows. Refractory portions of the oil spilled at West Falmouth still remain in the sediments (Boesch, *et al.*, 1974; Mielke, 1990; Teal *et al.*, 1992).

The impact that no. 2 fuel oil has on an organism depends on environmental and biological factors, as well as oil concentration. Cardwell (1973) found that toxicity of no. 2 fuel oil increases concomitantly with increasing temperature. Heavy oil contamination results in the death of marine and salt marsh animals, particularly benthic animals (Burns and Teal, 1979; Pilson, 1990). In general, sensitivity to oil varies with life stage and species, with eggs being the most sensitive, and adults being the least.

The ability of an organism to avoid a contaminant is a major determinant in its ability to survive an oil spill. Generally, finfish are less at risk due to their motility; they can leave the area of degradation (RPI, 1989). Crustaceans are generally more sensitive than bivalves; since the latter can close their shells for extended periods. The marketability of bivalves, however, can be severely impacted. Even if they survive an oil spill, they still may be unfit for human consumption. Bivalves surviving the initial toxic dosing can accumulate oil in their tissues in the course of normal feeding. Clark (1989) reported that tainting, or becoming oily tasting, can occur at very low levels of contamination (a few parts per million) and remain present even after four weeks of attempted depuration. During harvesting, even a small quantity of oil on harvesting gear or a few organisms can taint the whole catch and render it worthless. Handling and processing quickly spread the tainting substance throughout the catch.

Settlement

A $3.9 million settlement resolving all Federal claims for response, clean up and injuries to natural resources was reached with the responsible party by the U.S. Government in 1991. NOAA received $567,299 to be used for restoration to compensate for injuries to natural resources. The remaining balance went to the Coast Guard and other Federal agencies for reimbursement for response and clean-up costs. The Under Secretary for Oceans and Atmosphere (NOAA Administrator), on behalf of the Secretary of Commerce, acts as a Federal trustee for natural resources under the Comprehensive Environmental Response, Compensation and Liability Act of 1980, the Clean Water Act, the Marine Protection, Research and Sanctuaries Act, and the Oil Pollution Act of 1990. Under these laws, NOAA acts on behalf of the public to assess and claim damages (compensation) for injuries to natural resources from discharges of oil or releases of hazardous substances, and to use the recovered damages to restore, replace, or acquire the equivalent of the injured resources. This proposed restoration plan was drafted to fulfill NOAA's requirements under these authorities.

Proposed Actions

The goal of the proposed restoration efforts is to restore the resources injured by the *World Prodigy* oil spill by enhancing habitat value for numerous marine resources, with specific emphasis on lobsters, quahogs (hard clam), and estuarine finfish. Projects were developed to address these resources because they were the most significantly affected by the oil spill. In order to meet this goal NOAA proposes several actions: (1) enhance lobster habitat by establishing several lobster reefs; (2) transplant quahogs and establish quahog "spawner sanctuaries" to help restock formerly productive areas of the bay and to make more of the resource available to shellfishermen; (3) establish eelgrass beds in multiple sites throughout Narragansett Bay to enhance fisheries habitat; and (4) restore a saltmarsh system on Sachuest Point in Middletown, RI to enhance habitat for estuarine dependent fish and shellfish.

Lobster reefs. To restore the lobster resource injured by the oil spill, NOAA proposes to establish six artificial reefs measuring 10 meters by 20 meters made of various sizes of cobble and boulders in the lower west passage of Narragansett Bay (Figure 1). We propose to place all six reefs in 20-30 feet of water off the Bonnet Shores area. The specific locations within this general area will be chosen in consultation with local fishermen and based on a side-scan sonar survey and current data. A total of 450 m^3 of cobble and boulders will be used covering 1,200 m^2 of bay bottom.

Quahog transplant and spawner sanctuaries. To compensate for the lost use of clam beds and restore the quahog resource injured by the oil spill, NOAA proposes to transfer a portion of the settlement funds to the Rhode Island Department of Environmental Management to be used to fund the transplanting of quahogs from restricted waters to two "spawner sanctuaries" at the mouth of Greenwich Bay and near Gould Island in the Sakonnet River (Figures 2 and 3). Quahogs will be transplanted to these locations and will be off limits to harvesting for two years.

Eelgrass bed restoration. To restore estuarine finfish injured by the oil spill, NOAA proposes to establish eelgrass beds at approximately 10 different locations throughout Narragansett Bay. Sites will be identified following site surveys and consultation with local investigators. Selection will be based on water quality conditions, sediment particle size, historical evidence of presence of eelgrass, degree of exposure to waves and tidal currents, and existing uses.

Salt marsh restoration. To restore estuarine finfish injured by the oil spill, NOAA proposes to restore a salt marsh in the Sachuest Point National Wildlife Refuge in Middletown, RI (Figure 4). This marsh has been degraded by inadequate tidal flow caused by road construction and an inadequately sized culvert. Tidal flow will be restored by replacing the culvert with two larger culverts and clearing the tidal creeks of excess sedimentation. Restoration of tidal flow should restore the marsh's natural vegetation and increase fish access to the marsh thereby enhancing the production of estuarine fish.

II. AFFECTED ENVIRONMENT

This section describes the environment affected by the T/V *World Prodigy* oil spill (the *World Prodigy* site) including a general description of the physical, biological, and cultural environments. All descriptions are non-technical. Citations refer the reader to more detailed information.

In 1989 dollars, Narragansett Bay generated almost $2.5 billion in revenues for the State of Rhode Island based on direct exploitation of the bay's fisheries, tourism, marine-related industry, marine research and education, and U.S. Navy-related activities (NBP, 1992). The major contributing sectors to this annual revenue include fish and shellfish harvesting, marine transportation, national defense, education, scientific research, and recreational activities. Many of these and other economically important activities associated with the bay depend on the productivity and functions of coastal and marine habitats found along the Rhode Island shoreline.

Physical and Biological Environment

Rhode Island is located along the southern coast of the New England region of the United States. The climate of the state is influenced by oceanic processes and is characterized by moderately cold winters and mild summers. Rhode Island contains numerous coastal, estuarine, and oceanic natural resources distributed along its 419 miles of coastline (Seavey, 1975). The most prominent of these features is Narragansett Bay.

Narragansett Bay is considered the state's most valuable natural resource (NBP, 1992). The bay is a 147 square mile glacially carved, drowned river estuary that dominates the physical geography of Rhode Island. The watershed of the bay encompasses 1,657 square miles within Rhode Island and Massachusetts (NBP, 1992). Narragansett Bay is influenced by marine waters via Rhode Island Sound at its southern end, and by freshwater inputs from numerous rivers, streams, ponds, industrial plants, sewerage treatment facilities, precipitation and other sources throughout the watershed. It is estimated that the bay receives 2,400 million gallons of freshwater everyday (Pilson, 1985; Ries, 1989). The salinity of the waters of the bay are distributed across a north-south gradient from the fresher upper bay areas (15‰) to the saline lower reaches of the mouth (33‰) (Bricker, 1993). The average depth of the bay is 27 feet with some areas (East Passage) having an average depth of 50 feet (NBP, 1992). The northern portion of the bay is surrounded by the heavily urbanized area of Providence and contains sediments that reflect the years of human and industrial waste disposal in the bay. The lower portion of the bay is surrounded by less densely populated communities and is generally characterized by less contaminated habitats.

The shoreline and waters of Narragansett Bay contain approximately 4,800 acres of coastal wetlands (RIDOA, 1988). Coastal wetlands in Rhode Island include salt marshes, freshwater the settlement funds to the Rhode Island Department of Environmental Management to be used to fund the transplanting of quahogs from restricted waters to two "spawner sanctuaries" at the mouth of Greenwich Bay and near Gould Island in the Sakonnet River (Figures 2 and 3). Quahogs will be transplanted to these locations and will be off limits to harvesting for two years.

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Narragansett Bay provides important fishery habitat for anadromous species, estuarine and marine finfish, shellfish and numerous other non-commercial but important lower trophic-level species (NBP, 1992). Commercial fisheries harvests in the state had a dockside value of $76 million in 1993 (U.S. DOC, 1994). The quahog (*Mercenaria*) is the most important commercial fishery within the bay (NBP, 1992; Pratt *et al.*, 1992) and supports over 2,000 jobs. Other important commercial stocks harvested from the bay include winter flounder (*Pleuronectes americanus*), lobster (*Homarus americanus*), menhaden (*Brevortia tyrannus*), and butterfish (*Poronotus triacanthus*) (see Olsen and Stevenson, 1975). Recreational fishing is estimated to generate more than $18 million of annual economic activity in Rhode Island (McConnell, *et al.*, 1981). Both commercial and recreational fisheries in Narragansett Bay are imperiled by over-utilization, habitat loss, and various types of pollution (NBP, 1992). These valuable fisheries can be maintained only through efforts to effectively manage fishing pressure, protect critical estuarine habitats, reduce pollution inputs, and initiate watershed-based ecological restoration.

Endangered and Threatened Species

Numerous Federally endangered and threatened species are seasonal or occasional visitors to Narragansett Bay. Several species of sea turtles may be present from June through November as wanderers in the bay. These include the threatened Atlantic loggerhead (*Caretta)*, and the endangered Atlantic leatherback (*Dermochelys coriacea*), Atlantic Kemp's ridley (*Lepidochelys kempi*), and the green sea turtle (Chelonia mydas) (D. Beach, NMFS pers. comm; Gould and Gould, 1992). The loggerhead, Kemp's ridley and green sea turtles are mostly juvenile and subadult individuals foraging in nearshore coastal waters. The Kemp's ridley appears to prefer estuarine areas where green crabs and mussels are found. Loggerheads feed on benthic organisms found in large bay systems and leatherbacks forage in the open waters in search of jellyfish. Several whale species (humpbacks, finback, and right whales) may transit the mouth of Narragansett Bay and Rhode Island Sound but do not typically enter the bay. Threatened or endangered bird species inhabiting the bay include the endangered bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (Falco peregrinus), roseate tern (*Sterna dougallii*), and the threatened piping plover (*Charadrius melodus*) (Gould and Gould, 1992). The bald eagle, which is a rare migrant and winter visitor is most commonly found in salt ponds. Peregrine falcons are uncommon migrants usually seen in nearshore and tidal flat areas. The roseate tern is an uncommon summer breeder which favors rocky shores and islands for breeding. The piping plover is an uncommon migrant and summer breeder preferring sandy beaches for breeding and feeding (Gould and Gould, 1992).

Historic and Cultural Resources

The earliest evidence of human habitation of the Rhode Island coast dates back to 6,500 B.C. (Hale, 1980). Narragansett Bay has been a centerpiece of activities associated with local native American populations, the development of colonial America, the birth of the industrial revolution, the defeat of the Axis forces in World War II, and the origin of scientifically based marshes, forested wetlands, emergent wetlands, scrub-shrub wetlands, seagrasses, and tidal flats (Tiner, 1989). These coastal habitats support populations of wildlife including birds, fish, insects, mammals, and reptiles. Extensive scientific investigations have been conducted within the salt marshes of the bay by scientists at the University of Rhode Island Graduate School of Oceanography (University of Rhode Island, 1972). Salt marshes cover about 2800 acres of land around Narragansett Bay and fringing marshes line some 80 km of the bay shoreline. These intertidal wetlands, located along the bay shore and tributaries, serve as habitat for many important commercial and recreational marine fish species and other organisms that form critical links in the food chain of the bay ecosystem (Nixon and Oviatt, 1973; Nixon, 1982). It is estimated that 15-30% of the fisheries landed in Rhode Island waters are dependent upon estuarine wetlands (Greg Miller, National Marine Fisheries Service, pers. comm.).

Intertidal flats are composed of mud and sand sediments that occur between the limits of low and high tide and encompass some 4400 acres around Narragansett Bay (NBP, 1992). The utilization of tidal flats by numerous species of fish is also determined by water temperature and other factors such as tide level and time of day. Tidal flats are dominated by benthic worms and epibenthic crustaceans (Whitlach, 1982). These areas are believed to have few vertebrate residents, but instead are seen as areas "for the conversion of plant production into animal biomass" and that are interconnected to other coastal habitats (Whitlach, 1982). Tidal flats are also utilized as feeding and resting areas for migrating shorebirds such as sandpipers, and as foraging areas by other birds including herons, gulls, and terns (Whitlach, 1982). Many species of birds and fish alternate feeding between tidal flats and salt marshes in response to the tidal cycle.

The bay also contains eelgrass (*Zostera marina*) beds that function as finfish and shellfish habitat, sediment traps, nitrogen fixers, and wave energy absorption areas (Thayer *et al.*, 1984; Adamowicz, 1994). Seagrass beds were once found throughout some shallow areas of the bay. The decline is believed to have been caused by wasting disease, elevated nutrient loadings, increased turbidity, navigation channel construction and other forms of anthropogenic habitat destruction (Thayer *et al.*, 1984).

Sandy beaches are extremely important to the Rhode Island economy which is heavily dependent upon summer tourism (University of Rhode Island, 1994). Most of the state's sandy beaches are located outside of the bay along the shores of Block Island Sound. However, there are several significant sandy shorelines within the lower reaches of the bay especially at Narragansett Pier, Scarborough Beach, and Newport (Olsen and Grant, 1973). These coastal barriers provide foraging grounds to shore birds and mammals, as well as intertidal habitat for marine crustaceans and molluscs. Barrier beaches provide storm surge protection for coastal development and serve to moderate oceanic influences upon back barrier habitats such as salt ponds and coves. These and other coastal natural areas serve as recreational areas for residents and tourists, and provide habitat for important biological resources.

III. PROPOSED ACTIONS AND ALTERNATIVES

This section describes the actions NOAA considered to restore the resources injured by the *World Prodigy* oil spill. As discussed above, The Clean Water Act, as amended by CERCLA, requires NOAA to use settlement funds recovered from responsible parties to "restore, replace, or acquire the equivalent of the injured natural resources." NOAA considered three categories of activities: habitat restoration/resource enhancement; habitat acquisition; and no action. The environmental consequences of each of the aforementioned categories and alternatives is presented and discussed in this chapter. Monitoring methodologies for each of the preferred alternatives is also discussed.

The goal of the proposed actions is to enhance habitat value for a variety of marine resources with specific emphasis on quahogs (hard clams), lobsters, and estuarine finfish. This goal was developed because the spill adversely affected large numbers of the eggs, larvae and adults of these resources and because the public was prohibited from harvesting some of these resources during a period after the spill. To meet this goal NOAA proposes several actions: (1) enhance lobster habitat by establishing several lobster reefs; (2) transplant quahogs and establish "spawner sanctuaries" to help restock formerly productive areas of the bay and to make more of the resource available to shellfishermen; (3) establish eelgrass beds in multiple sites throughout Narragansett Bay to enhance fisheries habitat; and (4) restore a saltmarsh system on Sachuest Point to enhance habitat for estuarine dependent fish and shellfish.

A monitoring program will be implemented for each effort to evaluate its effectiveness. A requisite to any restoration project is a well designed and cost-effective monitoring effort. Such an effort forms the foundation and is a prerequisite of restoration plans because it is the sole means of providing a measure of the viability, stability and persistence of the restoration and, therefore, an assessment of the effective use of the settlement funds. The monitoring plan will provide the necessary information to establish criteria for and evaluate the need for mid-course corrections, should they be necessary.

Each alternative discussed below was evaluated based on the following criteria: (1) the project must restore resources injured by the spill; (2) the project must be cost effective; and (3) the project should use a proven technique and have a relatively high probability of achieving the restoration goal. Those projects which could not satisfy all of those criteria were eliminated from consideration. Table II at the end of this chapter summarizes the results of the criteria evaluation for each alternative. While there are more projects that can meet the above criteria than there is available funding, NOAA has determined that the proposed actions will be the most effective means to restore the injured resources.

1. Habitat Restoration/Resource Enhancement

In this category, several projects are considered to restore or enhance the resources and services injured by the *World Prodigy* oil spill. Seven alternative projects are considered, four of which are proposed. The proposed projects (letters A-D) are discussed first followed by the rejected proposals (letters E-G). General costs are provided for the proposed actions. Detailed budget information is available from NOAA at the address and phone number listed on the front cover page.

A. Lobster Habitat Enhancement (Preferred Alternative)

Hundreds of adult lobsters and other crustacea and untold numbers of their larvae were killed by the *World Prodigy* oil spill. To address these injuries to the lobster population in Narragansett Bay, NOAA proposes to enhance habitat for lobsters and associated fauna by establishing several rocky reefs in the bay, tagging and seeding the reef with hatchery-reared lobsters, and monitoring the development of the lobster population in this new habitat. A limited number of hatchery-reared lobsters will be tagged and used to seed the reef to monitor their development and to test the efficacy of stocking hatchery reared-lobsters using coded micro-wire tags. NOAA will issue a contract for the purchase and construction of the lobster reef and will issue a grant to the University of Rhode Island to conduct the design and monitoring work.

The enhancement of marine resources, either to enhance harvests or to restore losses, has a long history. Methods to enhance fishery resources include regulating fishing effort to reduce pre-recruit mortality or increase survival of breeding stock, adding hatchery-reared animals, increasing useful habitat, and protecting breeding stock in sanctuaries (Conan, 1986; Addison and Bannister, 1994). When habitat has degraded due to natural or anthropogenic causes, restoration of the habitat is appropriate to allow populations to return to pre-disturbance levels, assuming the cause of the degradation has been removed or is below acceptable levels.

Lobster Life History and Biology

The American lobster, *Homarus americanus*, is one of the largest and most valuable crustaceans in the world. It is found from the intertidal zone to depths of 700 m along the northeast coast of North America from New Jersey to Labrador. Lobsters have been studied scientifically for over one hundred years. A commercial fishery developed in the United States and Canada during the mid- 1800s and currently supports a large and valuable industry in both countries (Fogarty, in press).

The life cycle of the American lobster is reasonably well understood. Females mature at sizes ranging from 60 to 105 mm carapace length (CL) and hatch their eggs into the water column where the larvae remain for between 11 and 54 days (MacKenzie, 1988). The developing larvae and postlarvae are transported considerable distances (e.g., Katz *et al.*, 1993). The postlarva swims at the surface for several days, then makes the transition from pelagic to benthic habitat, settling and remaining for several years in shallow, cobble substrata (Hudon, 1987; Wahle and Steneck, 1991). Early benthic phase lobsters are cryptic and quite restricted in habitat use (Wahle and Steneck, 1991); they probably do not emerge from their shelters until reaching a size of about 25 mm CL (Wahle, 1992; Cobb and Wahle, 1994). Larger, but still sexually immature adolescent phase lobsters are found on a variety of bottom types, usually characterized by an abundance of potential shelters. Inshore, they are found in greatest abundance in rock and boulder areas (Cooper and Uzmann, 1980). There are very few data on the density of lobster populations. Surveys by divers have provided estimates ranging from 70 to 32,500 lobsters per hectare in inshore rocky areas (Cobb and Wang, 1985). In Rhode Island and Connecticut, densities of approximately one lobster per 10 m^2 were reported by Cobb (1971) and Stewart (1970) in rocky habitat. Juvenile lobsters seldom move more than a few kilometers (Wilder, 1963). Once mature, animals may range over 30 km annually and some travel as far as 100 km or more on cross-shelf migrations (Cooper and Uzmann, 1971) or along the coast (Campbell and Stasko, 1985).

Habitat Enhancement Efforts

Previous attempts to increase lobster populations in local areas through habitat enhancement have been successful. A relatively systematic habitat enhancement effort was conducted in Rhode Island waters (Sheehy, 1976). Artificial shelters, made of pumice concrete, were placed on featureless sand substrate in the Point Judith Harbor of Refuge. Lobsters of all sizes, including newly settled lobsters, colonized the shelters quickly, as did other species of crabs and fish. Design of the shelter was important: the triple chamber design was used by a larger number of lobsters than was the single chamber design. Lobsters both used the chambers and burrowed underneath the solid portions of the concrete blocks. Orientation of the shelter was important for hydrodynamic reasons. Currents, particularly during storms would scour around the shelters or flip them over.

An artificial reef made of 8 heaps (1 x 4m) of blocks fabricated from pulverized fuel ash covered an area of 10 m x 30 m in Poole Bay, England. The reef was situated approximately 3 km from hard substrate inhabited by lobsters. Within three weeks after deployment of the reef, lobsters (*H. gammarus*) were found on the reef by divers. Population estimates of lobsters on the reef are in the range of 20-30 animals per 100 m^2. Most of the movement of tagged lobsters seen was between units of the reef, and residence times on the reef were high. Several tagged individuals were resampled several times over a period of more than a year (Jensen *et al.*, 1994.)

A large rock reef (2740 m^2) was built in eastern Canada and the development of the lobster population followed for 7 years. During the first two years, the reef was colonized by lobsters larger than the average size of individuals in nearby natural areas, and the biomass was lower. However, after 5 years, the size distribution of lobsters on the reef was similar to natural ground, and the biomass was higher than neighboring areas (Scarratt, 1968, 1973).

The characteristics of a good artificial reef for lobsters were described by Spanier (1994). These include being a good recruitment substrate for postlarvae and juveniles, and being a refuge from predation for all stages. Adequate shelter and food resources also are important to the maintenance of a population on an artificial reef. Placement of the reef in a location where lobsters of all sizes will recruit to it also is important.

Project Description

Overview

NOAA proposes to establish six artificial reefs made of various sizes of cobble and boulders in the west passage of Narragansett Bay. All six reefs will be placed on sandy bottom in approximately 20-30 feet of water off the Bonnet Shores area (Figure 1), where both lobstering activity and earlier sampling have demonstrated a naturally occurring population. The specific locations within this general area will be chosen in consultation with local fishermen. Areas where quahogging is common, or where draggers frequently work will be avoided.

The proposed reef location in the lower West Passage, off Bonnet Point in Narragansett is reported in the Narragansett Bay Project Habitat Inventory to be "marine sand." Pratt (University of Rhode Island, personal communication) subclassifies the area as "bay mouth wave-washed sand." McMaster (1960) classified the area as "sand" and noted that the clay content was less than 10%. Little sampling for benthic fauna has been done in this area. The surf clam, *Spisula*, is found and occasionally harvested in the vicinity. A few specialized forms of benthic fauna adapted for mobile sands would be expected to inhabit this area. At the mouth of the Sakonnet River, where similar substrate is found, the benthos includes the capitellid *Amastigos caperatus*, two species of the polychaete *Arcia*, the predatory polychaete *Nephtys picta*, Haustoriid amphipods, and beds of the sand dollar *Echinarachnius parma* (S. Pratt, personal communication).

The reefs should become populated by newly settled lobsters and lobsters that migrate in from nearby, natural areas. The development of the population on the reefs will be followed over time. In addition, hatchery-reared lobsters will be released onto the reefs. This may augment the natural population and test the question of whether hatchery releases have an impact on lobster density. The impact of the reefs on the density of lobsters in the area where the reefs are placed will be evaluated using a Before/After-Control/Impact (BACI) design which addresses the needs for replicated sampling in time and in space and the comparisons of control (unaltered) areas to the affected area (Underwood, 1992).

Reefs

A total of six small reefs are proposed. Each of the artificial reefs will be composed of an area of cobble (small rocks 3-10 cm diameter, see Wahle and Steneck, 1991; Wahle, 1992) and an area of larger rocks and boulders (20-40 cm diameter). This range of substrate sizes will provide refuge for the whole span of lobster size (Wahle, personal observation). As a lobster grows, it outgrows the habitat it first selects and must move to new habitat where larger crevices are available (Wahle, 1992; Caddy and Stamotopoulos, 1990.) Each reef will be 10m x 20m. Vertical relief will be on the order of 1/4m in the cobble section and 1/2m in the rock/boulder section. A total of 450 cubic meters of cobble and boulders will be used,