NOAA Technical Memorandum NMFS-NE-181

Characterization of the Fishing Practices and Marine Benthic Ecosystems of the Northeast U.S. Shelf, and an Evaluation of the Potential Effects of Fishing on Essential Fish Habitat

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

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This series represents a secondary level of scientific publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Characterization of the Fishing Practices and Marine Benthic Ecosystems of the Northeast U.S. Shelf, and an Evaluation of the Potential Effects of Fishing on Essential Fish Habitat

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Editorial Notes

Publication Date: This document was both submitted and accepted on January 6, 2004, for issuance in this series. Consequently, the issue number (*i.e.*, 181) and publication date (*i.e.*, January 2004) were assigned at that time. Subsequent to that time, some new information was added and some existing information was revised. These actions explain why some post-January 2004 data, as well as some 2005 literature citations, appear in a document with a January 2004 publication date.

Species Names: The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Nelson *et al.* 2004[a]; Robins *et al.* 1991[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

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Internet Availability: This issue of the *NOAA Technical Memorandum NMFS-NE* series is being copublished, *i.e.*, as both a paper and Web document. The Web document, which will be in HTML (and thus searchable) and PDF formats, can be accessed at: *http://www.nefsc.noaa.gov/nefsc/publications/*.

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Contents

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Acronyms

ASMFC = Atlantic States Marine Fisheries Commission
EEZ = exclusive economic zone
EFH = essential fish habitat
FMP = fishery management plan
FVTR = fishing vessel trip report
GIS = geographical information system
GOM = Gulf of Maine
HF = heavily fished
LF = lightly fished
MAB = Mid-Atlantic Bight
MAFMC = Mid-Atlantic Fishery Management Council
MBW = Maine Bottom Water
MIW = Maine Intermediate Water
MSA = Magnuson-Stevens Fishery Conservation and Management Act
MSW = Maine Surface Water
NEFMC = New England Fishery Management Council
NMFS = (NOAA) National Marine Fisheries Service
NOAA = (U.S. Department of Commerce) National Oceanic and Atmospheric Administration
PSI = pounds per square inch (lb/in^2)
TMS = 10-minute square (of latitude or longitude) (10′ square)
UF = unfished

PREFACE

This document was conceived in 2001 by the Northeast Region Essential Fish Habitat Steering Committee. At that time, committee members were Louis Chiarella and Dianne Stephan (NOAA Fisheries Service's Northeast Regional Office, Gloucester, MA), Tom Hoff (Mid-Atlantic Fishery Management Council, Dover, DE), Robert Reid (Northeast Fisheries Science Center (NEFSC), Highlands, NJ), Michael Pentony (New England Fishery Management Council, Newburyport, MA), and Carrie Selberg (Atlantic States Marine Fisheries Commission). An early draft that included habitat characterization information, the spatial distribution of fishing activity by gear type, and a summary of relevant gear-effects studies, was prepared to assist a panel of academic and fishing industry experts that met in October 2001 to assess the habitat impacts of commercial fishing gear in the region. Following the workshop, these chapters were revised and updated, and new chapters describing fishing gear and practices and assessing the vulnerability of habitats utilized by federally managed fish and invertebrate species to fishing were added.

Seven authors collaborated in the preparation of this document. Louis Chiarella prepared the original gear descriptions, relying partially on information compiled by Michael Pentony. Additional information was later added to this section by David Stevenson. Dianne Stephan prepared the habitat characterization chapter, in collaboration with Robert Reid and David Stevenson. David Stevenson prepared the gear distribution maps and summaries, using data provided by Kurt Wilhelm, and summarized the relevant gear-effects literature. Korie Johnson (NOAA Fisheries Service's Office of Habitat Conservation, Silver Spring, MD) assisted with the literature review. Dianne Stephan, Louis Chiarella, Robert Reid, and David Stevenson collaborated on the habitat vulnerability evaluations. John McCarthy, a contractor at the Howard Laboratory (Highlands, NJ), assisted with text formatting and the preparation of tables and figures. Meredith Lock, also a contractor at the Howard Laboratory, helped with literature review and document assembly. Vince Guida (NEFSC, Highlands, NJ) provided some habitat characterization information. Thomas Noji (NEFSC, Highlands, NJ), David Mountain (NEFSC, Woods Hole, MA), and Peter Colosi (Northeast Regional Office, Gloucester, MA) commented on an early draft. David Packer (NEFSC, Highlands, NJ) and Jon Gibson (NEFSC, Woods Hole, MA) edited the document.

1. INTRODUCTION

This document was developed to provide assistance in meeting the Essential Fish Habitat (EFH) mandates of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) for the NOAA Fisheries Service's Northeast Region (hereafter just "Northeast Region" or "the region") which ranges from Maine to North Carolina. The 1996 amendments to the MSA require that federal fishery management plans (hereafter just "FMPs") minimize, to the extent practicable, adverse effects on EFH caused by fishing [MSA Section 303(a)(7)]. Pursuant to the EFH regulations [50 CFR 610.815(a)(2)], FMPs must include an evaluation of the potential adverse effects of fishing on EFH, including the effects of fishing activities regulated under other federal FMPs. The evaluation should consider the effects of each fishing activity on each type of habitat found within EFH, and provide conclusions as to whether and how each fishing activity adversely affects EFH. FMPs must describe each fishing activity, and must review and discuss all available and relevant information such as information regarding the intensity, extent, and frequency of any adverse effect on EFH, the type of habitat within EFH that may be adversely affected, and the habitat functions that may be disturbed. The evaluation should also consider the cumulative effects of multiple fishing activities on EFH. Additionally, FMPs must identify any fishing activities that are not managed under the MSA that may adversely affect EFH. Such activities may include fishing managed by state agencies or other authorities. However, regional fishery management councils (hereafter just "councils") are not required to take action to minimize adverse effects from non-MSA fishing activities. In completing this evaluation, councils are expected to use the best scientific information available, as well as other appropriate information sources.

This document emphasizes those fishing gears directly managed by the New England Fishery Management Council (NEFMC) and Mid-Atlantic Fishery Management Council (MAFMC). Much of the information included in earlier drafts of this document was incorporated into recent environmental impact statements and amendments to NEFMC FMPs for Atlantic sea scallops, groundfish, and monkfish (goosefish) (NEFMC 2003a,b, 2004), and into an environmental impact statement that evaluated the effects of gears used in the Atlantic herring fishery on EFH (NOAA/NMFS 2005). The information in this document relates strictly to the direct physical and biological effects of fishing on benthic habitat; it does not include resource population effects or ecosystem-level effects that are caused by the removal of targeted species or bycatch.

The information used in this document includes descriptions of benthic habitats and species assemblages (fish and invertebrates) in four subregions of the Northeast U.S. Shelf Ecosystem, descriptions of 37 gear types used in state and federal waters in the region, and the extent and distribution of fishing activity for the major commercial fishing gears used in the region during 1995-2001. In addition, this document summarizes the results of 73 scientific studies that form the basis for understanding the effects of fishing on benthic marine habitats in the region, and evaluates the vulnerability of benthic EFH to fishing for 47 species of federally managed fish and invertebrate species in the region. Conclusions reached by a panel of experts that met in October 2001 for the purpose of evaluating habitat effects in the Northeast Region (NREFHSC 2002) were also incorporated. A preliminary draft of this document was distributed to the workshop panelists to assist them in conducting their evaluation.

2. HABITAT CHARACTERIZATION OF THE NORTHEAST U.S. SHELF ECOSYSTEM

The Northeast U.S. Shelf Ecosystem includes a broad range of habitats with varying physical and biological properties. From the cold waters of the Gulf of Maine (GOM) south to the more tempered climate of the Mid-Atlantic Bight (MAB), oceanographic and biological processes interact to form a network of expansively to narrowly distributed habitat types. This chapter provides a portion of the background information needed to evaluate the effects of fishing on benthic habitats in the region by: 1) reviewing habitat functions and associations; 2) describing four regional systems and their associated physical and benthic biological features; 3) covering the habitat aspects of coastal and estuarine features; and 4) describing benthic invertebrate communities in New England and the MAB, and their distribution in relation to depth and sediment type.

HABITAT FUNCTIONS AND ASSOCIATIONS

From a biological perspective, habitats provide living things with the basic life requirements of nourishment and shelter. Habitats may also provide a broader range of benefits to the ecosystem, such as the way seagrasses physically stabilize the substrate and help recirculate oxygen and nutrients. This section, however, focuses on how benthic marine habitats provide food and shelter for federally managed species in the Northeast Region.

The spatial and temporal variation of prey abundance influences the survival, recruitment, development, and spatial distribution of organisms at every trophic level above primary producers. For example, the abundance and distribution of planktonic organisms greatly influence the growth, survival, and distribution of fish larvae. In addition, the migratory behavior of juvenile and adult fish is directly related to seasonal patterns of prey abundance and changes in environmental conditions, especially water temperature. Prey supply is particularly critical for the starvation-prone, early-life-history stages of fish.

The availability of food for planktivores is highly influenced by oceanographic properties. The seasonal warming of surface waters in temperate latitudes produces vertical stratification of the water column which isolates sunlit surface waters from deeper, nutrient-rich water, leading to reduced primary productivity. In certain areas, upwelling, induced by wind, storms, and tidal mixing, inject nutrients back into the photic zone, stimulating primary production. Changes in primary production from upwelling and other oceanographic processes affect the amount of organic matter available for other organisms higher up in the food web, and thus influence their abundance and distribution. Some of the organic matter produced in the photic zone sinks to the bottom and provides food for benthic organisms. In shallower water, benthic macroalgae and microalgae also contribute to primary production. Recent research on benthic primary productivity indicates that benthic microalgae may contribute more to primary production than has been originally estimated (Cahoon 1999).

Benthic organisms provide an important food source for many fish species. Bottom-dwelling sand lances are eaten by many fish, and benthic invertebrates are the main source of nutrition for many demersal fish. Temporal and spatial variations in benthic community structure affect the distribution and abundance of bottom-feeding fish. Likewise, the abundance and species composition of benthic communities are affected by a number of environmental factors, including temperature, sediment type, and the availability of organic matter.

A number of recent studies have focused on the habitat associations of juvenile demersal fish. In shallow, coastal waters of the Northeast Region, effects of physical habitat factors and prey availability on the abundance and distribution of young-of-the-year flounder (various species) have been investigated in nearshore and estuarine habitats in Connecticut, New Jersey, and North Carolina (Rountree and Able 1992; Howell *et al.* 1999; Walsh *et al.* 1999; Manderson *et al.* 2000; Phelan *et al.* 2001; Stoner *et al.* 2001). There are few comparable studies of more open, continental shelf environments. In the Northeast Region, Steves *et al.* (1999) identified depth, bottom temperature, and time of year as primary factors delineating settlement and nursery habitats for juvenile silver hake and yellowtail flounder in the MAB. Also, in a series of publications, Auster *et al.* (1991, 1995, 1997) correlated the spatial distributions of juvenile benthic fish (*e.g.,* silver hake) with changes in microhabitat type on sand bottom at various open shelf locations in Southern New England.

In addition to providing food sources, another important functional value of benthic habitat is the shelter and refuge from predators provided by structure. Three-dimensional structure is provided by physical features such as boulders, gravel and cobble, sand waves and ripples, and mounts, burrows and depressions created by organisms. Structure is also provided by emergent epifauna such as sponges, bryozoans, anemones, mussels, tunicates, and corals.

The importance of benthic habitat complexity was discussed by Auster (1998) and Auster and Langton (1999). They developed a conceptual model that compared fishing gear effects across a gradient of habitat types. Based on this model, habitat value increases with increased structural complexity, from the lowest value in flat sand and mud to the highest value in piled boulders. The importance of habitat complexity to federally managed species is a key issue in the Northeast Region. Whether, and to what degree, the removal of emergent epifauna from gravel and rocky bottom habitats affects the survival of juvenile Atlantic cod and other species is of particular concern. Field studies (in the northeastern United States and eastern

Canadian waters, and other locations), laboratory experiments, and modeling studies have addressed the issue of removal of emergent epifauna. Because of the importance of this issue in the Northeast Region, this research is summarized below.

The first field study linking survival of juvenile Atlantic cod and haddock to habitat type on Georges Bank was by Lough *et al.* (1989). Using submersibles, they observed that recently settled age-0 juvenile Atlantic cod (and haddock), <10 cm long, were primarily found in pebble-gravel habitat at 70-100 m depths on eastern Georges Bank. They hypothesized that the gravel enhanced survival through predator avoidance; coloration of the fish mimicked that of the substrate, and from the submersible the fish were very difficult to detect against the gravel background. The authors considered increased prey abundance to be another, but less likely, explanation for the concentration of these fish on gravel. Presence of emergent epifauna, and any effects of epifauna on survival of the juveniles, were not noted.

Gregory and Anderson (1997), using submersibles in 18-150 m depths in Placentia Bay, Newfoundland, similarly found that the youngest Atlantic cod observed (age 1, 10-12 cm long) were primarily associated with low-relief gravel substrate; their mottled color appeared to provide camouflage in the gravel. Older juveniles (ages 2-4) were most abundant in higher relief areas with coarser substrate (*e.g.,* submarine cliffs). No selection by juvenile Atlantic cod for substrates with macroalgae cover was seen, and emergent epifauna was not mentioned.

In the first study suggesting an added value of emergent epifauna on Georges Bank gravel, Valentine and Lough (1991) observed from submersibles that attached epifauna was much more abundant in areas of eastern Georges Bank that had not been fished (due to the presence of large boulders). They felt the increased bottom complexity provided by the epifauna might be an important component of fisheries habitat, but both trawled and untrawled gravel habitats were considered important for survival of juvenile Atlantic cod.

Other field studies on the relationship between juvenile Atlantic cod abundance and habitat complexity have been in shallower inshore waters, and results may not be directly applicable to conditions on offshore banks like Georges Bank. In 2-12 m depths off the Newfoundland coast, Keats *et al.* (1987) found [in contrast to Gregory and Anderson (1997), above] juvenile Atlantic cod to be much more abundant in macroalgae beds than in adjacent areas which had been grazed bare by sea urchins. This was true of 1-yr-old fish (7.8-12.5 cm) as well as older, larger (12.6-23.5 cm) juveniles. The larger fish fed on fauna associated with the macroalgae, so enhanced food supply was a probable benefit of the increased complexity. The smallest 1-yr-olds fed on plankton, and it was unlikely their growth was affected by presence of macroalgae.

Tupper and Boutilier (1995a) examined four habitat types (sand, seagrass, cobble, and rock reef) in St. Margaret's Bay, Nova Scotia, and reported that Atlantic cod settlement was equal in all habitats, but survival and juvenile densities were higher in the more complex habitats. Growth rate was highest in seagrass beds, but predator (larger Atlantic cod) efficiency was lowest, and juvenile survival highest, on rock reef and cobble. The authors considered the different habitats to provide a tradeoff between enhanced foraging success and increased predation risk. In another study in St. Margaret's Bay, Tupper and Boutilier (1995b) found that Atlantic cod settling on a rocky reef inhabited crevices in the reef, and defended territories around the crevices. Fish that settled earlier and at larger sizes grew more quickly and had larger territories. Size at settlement and timing of settlement were thus considered important in determining competitive success of individuals.

Habitat associations of juvenile Atlantic cod were also examined by Gotceitas *et al.* (1997) using SCUBA divers in Trinity Bay, and beach seines in Trinity, Notre Dame, and Bonavista Bays, Newfoundland. In both types of surveys, almost all age-0 Atlantic cod were found in eelgrass beds as opposed to less structurally complex areas, and eelgrass was suggested to be an important habitat for these fish. Older juveniles were more abundant on mud, sand, and rocky bottoms than in eelgrass.

A seining study by Linehan *et al.* (2001) in Bonavista Bay, Newfoundland, found age-0 Atlantic cod (<10 cm long) to be more abundant in vegetated (eelgrass) than in unvegetated habitats, both day and night. However, potential predators of juvenile Atlantic cod were also most abundant in eelgrass. Tethering experiments with age-0 Atlantic cod at six sites in 0.7-20 m depths indicated that predation increased with depth, being about three times higher at deeper sites. At shallow sites, predation was generally higher in unvegetated sites than in eelgrass.

Habitat use of age-0 and -1 Atlantic cod in state waters off eastern Massachusetts is discussed by Howe *et al.* (2000), based on analysis of 22 yr (1978-1999) of data from spring and fall trawl surveys by the Massachusetts Division of Marine Fisheries. Results showed the survey area is important for Atlantic cod settlement, with at least two pulses of newly settled fish found in most years. Spatial distribution patterns of young Atlantic cod were clear, stable, and strongly related to depth. In spring, just-settled Atlantic cod were most abundant in depths <27 m; in fall these age-0 Atlantic cod were found in 9-55 m depths, but were concentrated in 27-55 m. Age-1 Atlantic cod were more abundant in deeper waters (18-55 m in spring, 37-55 m in fall). Habitat complexity per se was not the primary focus of this analysis, and some of the most complex (*e.g.,* rocky) habitats could not be sampled by the survey. However, the greater abundance of just-settled fish in shallower waters was thought to be linked to the higher complexity of these habitats. It was postulated that high densities of age-0 fish indicated areas of high productivity and preferred habitat. Given the abundance of juvenile Atlantic cod in these surveys, eastern Massachusetts waters were recommended as a coastal "Habitat Area of Particular Concern" for the GOM Atlantic cod stock.

Kaiser *et al.* (1999) analyzed beam trawl catch data from a number of stations in the English Channel and reported that small gadoid species were present in deeper (>30 m), structurally complex habitats with rocks, soft corals, bryozoans, hydroids, and sponges, and were absent in shallow water habitats which were inhabited by several species of flounder. Most of the structure-forming benthic species that were present in deeper water were also present in shallow water, but at reduced abundances, and the total biomass of sessile epibenthic species was higher in shallow water. These results suggest that depth and the amount of cover provided by certain types of emergent epifauna (*e.g.,* sponges) were the most important factors affecting habitat utilization by gadoid (and flounder) species.

Information on the effects of habitat complexity on juvenile Atlantic cod survival is also available from several laboratory studies. Gotceitas and Brown (1993) compared substrate preferences of juvenile Atlantic cod (6-12 cm) for sand, gravel-pebble, and cobble, before and after introduction of a larger Atlantic cod. Before the predator was introduced, small Atlantic cod preferred sand or gravel-pebble over cobble. In the presence of the predator, they chose cobble if available, and the cobble reduced predation. The experiment did not test effects of emergent epifauna on substrate choices or survival. Gotceitas *et al.* (1995) conducted a similar study, but with 3.5-8 cm Atlantic cod in a tank with one of two combinations of three substrates: 1) sand, gravel, and 30-cm long strips of plastic to simulate kelp (*Laminaria* sp.); or 2) sand, cobble, and "kelp." Based on the authors' earlier study, cobble was considered to provide a "safe" habitat that reduced predation. Responses to introduction of two kinds of larger Atlantic cod were tested: fish that actively attempted to eat the smaller Atlantic cod, versus "passive" predators that showed no interest in the smaller fish. In the presence of passive predators, small Atlantic cod preferred sand substrates and avoided kelp. When exposed to an active predator, they hid in cobble if available or kelp if there was no cobble. Both cobble and kelp significantly reduced predation, and small Atlantic cod appeared able to modify their behavior based on the varying risk presented by different predators.

Fraser *et al.* (1996) tested responses of age-0 (5.2-8.2 cm) and age-1 (10.2-13.5 cm) Atlantic cod to predators (3-yr old Atlantic cod), using the same tanks as Gotceitas *et al.* (1995), but with only two substrate choices: sand versus gravel, and sand versus cobble. With no predator present, age-0 or -1 Atlantic cod by themselves preferred sand to gravel or cobble, but if both age-0 and -1 fish were in the tank, the smaller fish tended to avoid the larger ones and to increase use of gravel/cobble. When a predator was introduced, both age-0 and -1 Atlantic cod hid in cobble if available; in the sand/gravel trials, they attempted to flee from the predator. In the predator's presence, the avoidance of age-1 Atlantic cod by age-0 Atlantic cod disappeared; overall, however, there was some indication of habitat segregation between age-0 and age-1 Atlantic cod.

Gotceitas *et al.* (1997) again used the same experimental system to compare use of sand, gravel, and cobble substrates, as well as three densities of eelgrass, by age-0 Atlantic cod (3.5-10 cm) in the presence and absence of a predator (age-3 Atlantic cod). With no predator, the small Atlantic cod preferred sand and gravel to cobble. When a predator was introduced and cobble was present, age-0 fish hid in the cobble or in dense eelgrass (720 stems/m^2) if present. With no cobble, they hid in all three densities of eelgrass. Age-0 Atlantic cod survival (time to capture and number of fish avoiding capture) was highest in cobble or eelgrass 1000 stems/m^2. In other combinations, time to capture increased with both presence and density of vegetation.

Borg *et al.* (1997) conducted a laboratory study of habitat choice by two size groups of juvenile Atlantic cod (7-13 and 17-28 cm TL) on sandy bottoms with different vegetation types. Four habitats, typical of shallow soft bottom on the west coast of Sweden, were tested in six combinations. During daylight, fish preferred vegetation to bare sand, while at night -- when juvenile Atlantic cod feed in open, sandy areas -- no significant choice was made. Both size classes preferred *Fucus* kelp, the most complex habitat that was tested.

Lindholm *et al.* (1999) tested effects of five habitat types, representing a gradient of complexity, on survival of age-0 Atlantic cod (7-10 cm) in the presence of age-3 conspecifics. Substrates were sand, cobble, sparse short sponge, dense short sponge, and tall sponge. Sponge presence significantly reduced predation compared to that on sand, with density of sponges being more important than sponge height. Increasing habitat complexity reduced the distance from which a predator could react to the prey. The authors concluded that alteration of seafloor habitat by fishing could lower survival of juvenile Atlantic cod. (There was no significant increase in survival in epifauna compared to bare cobble, however.)

In a mesocosm experiment, Isakkson *et al.* (1994) compared the foraging efficiency of Atlantic cod on three different prey species on bare sand and eel grass with varying percent cover of filamentous algae. Foraging efficiency of Atlantic cod on sand shrimp (*Crangon crangon*) and green crabs was greatest in unvegetated substrate. Survival of these two prey species was significantly enhanced by the addition of moderate amounts of algal cover to sand substrates. Shore shrimp (*Palaemon adspersus*) were equally susceptible to predation in all habitat types.

The effects of habitat complexity on post-settlement survival of juvenile Atlantic cod have been examined via modeling (Lindholm *et al.* 2001). Data from the Lindholm *et al.* (1999) laboratory study described above were used to assign maximum values for juvenile mortality in the least complex habitats, and in the most complex habitats. Twelve runs of a dynamic monthly model were made, with the first run (month) representing settlement of the Atlantic cod. Results indicated that reduction of habitat complexity by fishing had significant negative effects on survival of juvenile Atlantic cod, and that preservation of complexity through use of marine protected areas could reduce these negative effects.

Elsewhere and for other species, Charton and Ruzafa (1998) correlated increased habitat complexity (numbers of rocky boulders) in the Mediterranean with higher numbers and abundances of reef fish. There is evidence provided by laboratory experiments that habitat complexity can benefit fish that inhabit open, sandy habitats by providing refuge from bottom currents in the troughs between sand ripples (Gerstner 1998; Gerstner and Webb 1998).

In some situations, other habitat characteristics may be equally or more important than complexity. As discussed above, Lough *et al.* (1989) hypothesized that gravel substrate enhanced survival of juvenile Atlantic cod because the coloration of these juveniles mimicked the substrate. In a similar example, American plaice adults are thought to use gravel-sand sediments as a coloration refuge (Scott 1982). It is apparent that in identifying habitat value, a broad range of characteristics associated with habitat structure and function, which may vary by species and life stage, must be considered. Evaluations cannot be limited to individual aspects such as substrate type. Unfortunately, the amount of information available for individual parameters is limited, especially quantitative information necessary for multivariate analyses. Further development of multivariate relationships between biological, chemical, and physical habitat features will increase our understanding of the marine environment and advance the evidence of direct links between habitat conditions and fishery productivity.

REGIONAL SYSTEMS

The Northeast U.S. Shelf Ecosystem (Figure 2.1) has been described as including the area from the GOM south to Cape Hatteras, extending from the coast seaward to the edge of the continental shelf, including the slope sea offshore to the Gulf Stream (Sherman *et al.* 1996). The continental slope includes the area east of the shelf, out to a depth of 2000 m. Four distinct subregions comprise the Northeast Region: the GOM, Georges Bank, the MAB, and the continental slope. Occasionally, another subregion, Southern New England, is described; however, we incorporated discussions of any distinctive features of this area into the sections describing Georges Bank and the MAB.

The GOM is an enclosed coastal sea, characterized by relatively cold waters and deep basins, with a patchwork of various sediment types. Georges Bank is a relatively shallow coastal plateau that slopes gently from north to south and has steep submarine canyons on its eastern and southeastern edge. It is characterized by highly productive, well-mixed waters and strong currents. The MAB is comprised of the sandy, relatively flat, gently sloping continental shelf from Southern New England to Cape Hatteras, NC. The continental slope begins at the continental shelf break and continues eastward with increasing depth until it becomes the continental rise. It is fairly homogenous, with exceptions at the shelf break, some of the canyons, the Hudson Shelf Valley, and in areas of glacially rafted hard bottom.

Pertinent physical and biological characteristics of each of these subregions are described subsequently in this section. The first portion of each description summarizes oceanographic and geologic features, and the second portion summarizes biological features. Source references used to describe the general physical features of these subregions are not cited in the following text, but include Backus 1987; Schmitz *et al*. 1987; Tucholke 1987; Wiebe *et al*. 1987; Cook 1988; Reid and Steimle 1988; Stumpf and Biggs 1988; Abernathy 1989; Townsend 1992; Mountain *et al*. 1994; Beardsley *et al*. 1996; Brooks 1996; Sherman *et al*. 1996; Dorsey 1998; Kelley 1998; NEFMC 1998; and Steimle *et al*. 1999b. In some cases, recent or specific research results are cited in the text. References used in the biological summaries are also cited in the text.

Gulf of Maine

Physical Features

Although not obvious in appearance, the GOM is actually an enclosed coastal sea, bounded on the east by Browns Bank, on the north by the Nova Scotian (Scotian) Shelf, on the west by the New England states, and on the south by Cape Cod and Georges Bank (Figure 2.2). The GOM was glacially derived, and is characterized by a system of deep basins, moraines, and rocky protrusions with limited access to the open ocean. This geomorphology influences complex oceanographic processes that result in a rich biological community.

The GOM is topographically unlike any other part of the continental border along the U.S. Atlantic coast. The GOM's geologic features, when coupled with the vertical variation in water properties, result in a great diversity of habitat types. It contains 21 distinct basins separated by ridges, banks, and swells. The three largest basins are Wilkinson, Georges, and Jordan (Figure 2.2). Depths in the basins exceed 250 m, with a maximum depth of 350 m in Georges Basin, just north of Georges Bank. The Northeast Channel between Georges Bank and Browns Bank leads into Georges Basin, and is one of the primary avenues for exchange of water between the GOM and the North Atlantic Ocean.

High points within the Gulf include irregular ridges such as Cashes Ledge which peaks at 9 m below the surface, as well as lower flat-topped banks and gentle swells. Some of these rises are remnants of the continental shelf that was left after most of it was removed by the glaciers. Other rises are glacial moraines, and a few such as Cashes Ledge are outcroppings of bedrock. Very fine sediment particles created and eroded by the glaciers have collected in thick deposits over much of the GOM, particularly in its deep basins (Figure 2.3). These mud deposits blanket and obscure the irregularities of the underlying bedrock, forming topographically smooth terrains. Some shallower basins are covered with mud as well, including some in coastal waters. In the rises between the basins, other materials are usually at the surface. Unsorted glacial till covers some morainal areas, as on Sewell Ridge to the north of Georges Basin and on Truxton Swell to the south of Jordan Basin. Sand predominates on some high areas, and gravel, sometimes with boulders, predominates on others.

Coastal sediments exhibit a high degree of smallscale variability. Bedrock is the predominant substrate along the western edge of the GOM north of Cape Cod in a narrow band out to a depth of about 60 m. Rocky areas become less common with increasing depth, but some rock outcrops poke through the mud covering the deeper seafloor. Mud is the second-most common substrate on the inner continental shelf. Mud predominates in coastal valleys and basins that often abruptly border rocky substrates. Many of these basins extend without interruption into deeper water. Gravel, often mixed with shell, is common adjacent to bedrock outcrops and in fractures in the rock. Large expanses of gravel are not common, but do occur near reworked glacial moraines and in areas where the seafloor has been scoured by bottom currents. Gravel is most abundant at depths of 20-40 m, except in eastern Maine where a gravel-covered plain exists to depths of at least 100 m. Bottom currents are stronger in eastern Maine where the mean tidal range exceeds 5 m. Sandy areas are relatively rare along the inner shelf of the western GOM, but are more common south of Casco Bay, especially offshore of sandy beaches.

An intense seasonal cycle of winter cooling and turnover, springtime freshwater runoff, and summer warming influences oceanographic and biologic processes in the GOM. The Gulf has a general counterclockwise nontidal surface current that flows around its coastal margin (Figure 2.4). This current is primarily driven by fresh, cold Scotian Shelf water that enters over the Scotian Shelf and through the Northeast Channel, and freshwater river runoff, which is particularly important in the spring. Dense, relatively warm, and saline slope water entering through the bottom of the Northeast Channel from the continental slope also influences gyre formation. Counter-clockwise gyres generally form in Jordan, Wilkinson, and Georges Basins, and in the Northeast Channel as well. These surface gyres are more pronounced in spring and summer; with winter, they weaken and become more influenced by the wind.

Stratification of surface waters during spring and summer seals off a mid-depth layer of water that preserves winter salinity and temperatures. This cold layer of water is called "Maine Intermediate Water" (MIW), and is located between the more saline Maine Bottom Water (MBW) and the warmer, stratified Maine Surface Water (MSW). The stratified MSW is most pronounced in the deep portions of the western GOM. Tidal mixing of shallow areas prevents thermal stratification and results in thermal fronts between the stratified areas and cooler mixed areas. Typically, mixed areas include Georges Bank, the southwest Scotian Shelf, eastern Maine coastal waters, and the narrow coastal band surrounding the remainder of the Gulf.

The Northeast Channel provides an exit for cold MIW and outgoing MSW, while it allows warmer, more saline slope water to move in along the bottom and spill into the deeper basins. The influx of water occurs in pulses, and appears to be seasonal, with lower flow in late winter and a maximum in early summer.

GOM circulation and water properties can vary significantly from year to year. Notable episodic events include shelf-slope interactions such as the entrainment of shelf water by Gulf Stream rings (see the "Continental Slope/Physical Features" section), and strong winds that can create currents as high as 1.1 m/s over Georges Bank. Warm-core Gulf Stream rings can also influence upwelling and nutrient exchange on the Scotian Shelf, and affect the water masses entering the GOM. Annual and seasonal inflow variations also affect water circulation.

Internal waves are episodic and can greatly affect the biological properties of certain habitats. Internal waves can shift water layers vertically, so that habitats normally surrounded by cold MIW are temporarily bathed in warm, organic-rich surface water. On Cashes Ledge, it is thought that deeper nutrient rich water is driven into the photic zone, providing for increased productivity. Localized areas of upwelling interaction occur in numerous places throughout the Gulf.

Benthic Biological Features

Based on 303 benthic grab samples collected in the GOM during 1956-1965, Theroux and Wigley (1998) reported that, in terms of numbers, the most common groups of benthic invertebrates in the GOM were annelid worms (35%), bivalve mollusks (33%), and amphipod crustaceans (14%). Biomass was dominated by bivalve mollusks (24%), sea cucumbers (22%), sand dollars (18%), annelids (12%), and sea anemones (9%). Watling (1998) used numerical classification techniques to separate benthic invertebrate samples into seven bottom assemblages. Distribution was determined from both quantitative soft-bottom sampling and qualitative hard-bottom sampling. These assemblages are identified in Table 2.1, and their distribution is indicated in Figure 2.5. This classification system considers predominant taxa, substrate types, and seawater properties. (See the last section of this chapter for more information on benthic invertebrate communities in New England.)

An in-depth review of GOM habitat types has been prepared by Brown (1993). Although still preliminary, this classification system is a promising approach. It builds on a number of other schemes, including Cowardin *et al.* (1979), and tailors them to Maine's marine and estuarine environments. A significant factor that is included in this system, but has been neglected in others, is the amount of "energy" in a habitat. Energy could be a reflection of wind, waves, or currents present. This is a particularly important consideration in a review of fishing gear effects since it indicates the natural disturbance regime of a habitat. The amount and type of natural disturbance are in turn an indication of the habitat's resistance to, and recoverability from, disturbance by fishing gear. Although this work appears to be complete in its description of habitat types, unfortunately, the distributions of many of the habitats are unknown.

Demersal fish assemblages for the GOM and Georges Bank were part of broadscale geographic investigations conducted by Gabriel (1992) and Mahon *et al.* (1998). Both of these studies and a more limited study by Overholtz and Tyler (1985) found assemblages that were consistent over space and time in this region. In her analysis, Gabriel (1992) found that the most persistent feature over time in assemblage structure from Nova Scotia to Cape Hatteras was the boundary separating assemblages between the GOM and Georges Bank, which occurred at approximately the 100-m isobath on northern Georges Bank. Overholtz and Tyler (1985) identified five assemblages for this region (Table 2.2). The GOM deep assemblage included a number of species found in other assemblages, with the exception of American plaice and witch flounder, which were unique to this assemblage. Gabriel's approach did not allow species to co-occur in assemblages, and classified these two species as unique to the deepwater GOM - Georges Bank assemblage. Results of these two studies are compared in Table 2.2. Auster *et al.* (2001) went a step further and related species clusters on Stellwagen Bank to different substrate types in an attempt to use fish distribution as a proxy for seafloor habitat distribution. They found significant associations for 12 of 20 species, including American plaice (fine substrate) and haddock (coarse substrate). Species clusters and associated substrate types are given in Table 2.3.

Georges Bank

Physical Features

Georges Bank is a shallow (3-150 m depth), elongate (161-km wide by 322-km long) extension of the continental shelf that was formed by the Wisconsinian glacial episode. It is characterized by a steep slope on its northern edge and a broad, flat, gently sloping southern flank. The Great South Channel lies to the west. Natural processes continue to erode and rework the sediments on Georges Bank. It is anticipated that erosion and reworking of sediments will reduce the amount of sand available to the sand sheets, and cause an overall coarsening of the bottom sediments (Valentine and Lough 1991).

Glacial retreat during the late Pleistocene deposited the bottom sediments currently observed on the eastern section of Georges Bank, and the sediments have been continuously reworked and redistributed by the action of rising sea level, and by tidal, storm, and other currents (Figure 2.6). The strong, erosive currents affect the character of the biological community. Bottom topography on eastern Georges Bank is characterized by linear ridges in the western shoal areas; a relatively smooth, gently dipping seafloor on the deeper, easternmost part; a highly energetic peak in the north with sand ridges up to 30 m high and extensive gravel pavement; and steeper and smoother topography incised by submarine canyons on the southeastern margin (see the "Continental Slope" section for more on canyons). The interaction of several environmental factors, including availability and type of sediment, current speed and direction, and bottom topography, has formed seven sedimentary provinces on eastern Georges Bank (Valentine and Lough 1991) which are described in Table 2.4 and depicted in Figure 2.6. The gravel-sand mixture is usually a transition zone between coarse gravel and finer sediments.

The central region of the bank is shallow, and the bottom is characterized by shoals and troughs, with sand dunes superimposed upon them. The two most prominent elevations on the ridge and trough area are Cultivator and Georges Shoals. This shoal and trough area is a region of strong currents. The dunes migrate at variable rates, and the ridges may also move. In an area that lies between the central part and Northeast Peak, Almeida *et al.* (2000) identified high-energy areas between 35 and 65 m deep where sand is transported on a daily basis by tidal currents, and a low-energy area >65 m deep that is affected only by storm currents.

The area west of the Great South Channel, known as Nantucket Shoals (Figure 2.2), is similar in nature to the central region of the bank. Currents in these areas are strongest where water depth is shallower than 50 m. This type of traveling dune-and-swale morphology is also found in the MAB, and further described in that section of this document. The Great South Channel separates the main part of Georges Bank from Nantucket Shoals. Sediments in this region include gravel pavement and mounds, some scattered boulders, sand with storm generated ripples, and scattered shell and mussel beds. Tidal and storm currents range from moderate to strong, depending upon location and storm activity (pers. comm.; Page C. Valentine, U.S. Geological Survey, Woods Hole, MA).

Oceanographic frontal systems separate water masses of the GOM and Georges Bank from oceanic waters south of the bank. These water masses differ in temperature, salinity, nutrient concentration, and planktonic communities, which influence productivity and may influence fish abundance and distribution. Currents on Georges Bank include a weak, persistent clockwise gyre around the bank, a strong semidiurnal tidal flow predominantly northwest and southeast, and very strong, intermittent storm-induced currents, which all can occur simultaneously (Figure 2.4). Tidal currents over the shallow top of Georges Bank can be very strong, and keep the waters over the bank well mixed vertically. This results in a tidal front that separates the cool waters of the well-mixed shallows of the central bank from the warmer, seasonally stratified shelf waters on the seaward and shoreward sides of the bank. The clockwise gyre is instrumental in distribution of the planktonic community, including larval fish. For example, Lough and Potter (1993) describe passive drift of Atlantic cod and haddock eggs and larvae in a southwest residual pattern around Georges Bank. Larval concentrations are found at varying depths along the southern edge between 60 and 100m.

Benthic Biological Features

Amphipod crustaceans (49%) and annelid worms (28%) numerically dominated the contents of 211 sediment samples collected on Georges Bank during 1956-1965 (Theroux and Wigley 1998). Biomass was dominated by sand dollars (50%) and bivalve mollusks (33%). Theroux and Grosslein (1987) utilized the same database to identify four invertebrate assemblages: Western Basin, Northeast Peak, central Georges Bank, and southern Georges Bank. (See the last section of this chapter for more information on benthic invertebrate communities in New England.) They noted that it is impossible to define discrete boundaries between assemblages because of the considerable intergrading that occurs between adjacent assemblages; however, the assemblages are distinguishable. Their assemblages are associated with those identified by Valentine and Lough (1991) in Table 2.4.

The Western Basin assemblage (Theroux and Grosslein 1987) is found in the upper Great South Channel region at the northwestern corner of the bank, in comparatively deep water (150-200 m) with relatively slow currents and fine bottom sediments of silt, clay, and muddy sand. The fauna is comprised mainly of small burrowing detritivores and deposit feeders, and carnivorous scavengers. Representative organisms include bivalve mollusks (*Thyasira flexuosa, [En]ucula tenuis,* and *Musculus discors*), annelids (*Nephtys incisa, Paramphinome pulchella, Onuphis opalina,* and *Sternaspis scutata*), the brittle star *Ophiura sarsi*, the amphipod *Haploops tubicola*, and the red deepsea crab (*[Chaceon] quinquedens*). Valentine and Lough (1991) did not identify a comparable assemblage; however, this assemblage is geographically located adjacent to Assemblage 5 as described by Watling (1998) (Table 2.1; Figure 2.5)

The Northeast Peak assemblage is found along the Northern Edge and Northeast Peak, which varies in depth and current strength, and includes coarse sediment consisting mainly of gravel and coarse sand with interspersed boulders, cobbles, and pebbles. The fauna tends to be sessile (coelenterates, brachiopods, barnacles, and tubiferous annelids) or free-living (brittle stars, crustaceans, and polychaetes), with a characteristic absence of burrowing forms. Representative organisms include amphipods (*Acanthonotozoma serratum* and *Tiron spiniferum*), the isopod *Rocinela americana*, the barnacle *Balanus hameri*, annelids (*Harmothoe imbricata, Eunice pennata, Nothria conchylega,* and *Glycera capitata*), the sea scallop *Placopecten magellanicus*, brittle stars (*Ophiacantha bidentata* and *Ophiopholis aculeata*), and soft corals (*Primnoa resedaeformis* and *Paragorgia arborea*).

The Central Georges Bank assemblage occupies the greatest area, including the central and northern portions of the bank in depths <100 m. Medium-grained shifting sands predominate this dynamic area of strong currents. Organisms tend to be small to moderately large with burrowing or motile habits. Sand dollars (*Echinarachnius parma*) are most characteristic of this assemblage. Other representative species include mysids (*Neomysis americana* and *Mysidopsis bigelowi*), the isopod *Chiridotea tuftsi*, the cumacean *Leptocuma minor*, the amphipod *Protohaustorius wigleyi*, annelids (*Sthenelais limicola, Goniadella gracilis,* and *Scalibregma inflatum*), gastropods (*[Euspira] heros* and *Nassarius trivittatus*), the starfish *Asterias vulgaris*, the shrimp *Crangon septemspinosa*, and the crab *Cancer irroratus*.

The Southern Georges Bank assemblage is found on the southern and southwestern flanks at depths from 80 to 200 m, where fine-grained sands and moderate currents predominate. Many southern species exist here at the northern limits of their range. The dominant fauna includes amphipods, copepods, euphausiids, and the starfish genus *Astropecten*. Representative organisms include amphipods (*Ampelisca compressa, Erichthonius rubricornis,* and *Synchelidium americanum*), the cumacean *Diastylis quadrispinosa,* annelids (*Aglaophamus circinata, Nephtys squamosa,* and *Apistobranchus tullbergi*), crabs (*Euprognatha rastellifera* and *Catapagurus sharreri*) and the shrimp *Munida iris*.

Along with high levels of primary productivity, Georges Bank has been historically characterized by high levels of fish production. Several studies have attempted to identify demersal fish assemblages over large spatial scales. Overholtz and Tyler (1985) found five depth-related demersal fish assemblages for Georges Bank and the GOM that were persistent temporally and spatially (Table 2.2). Depth and salinity were identified as major physical influences explaining assemblage structure. Gabriel (1992) identified six assemblages which are compared with the results of Overholtz and Tyler (1985) in Table 2.2. Mahon *et al.* (1998) found similar results.

Mid-Atlantic Bight

Physical Features

The MAB includes the shelf and slope waters from Georges Bank south to Cape Hatteras, and east to the Gulf Stream (Figure 2.1). Like the rest of the continental shelf, the topography of the MAB was shaped largely by sea - level fluctuations caused by past ice ages. The shelf's basic morphology and sediments derive from the retreat of the last ice sheet, and the subsequent rise in sea level. Since that time, currents and waves have modified this basic structure.

Shelf and slope waters of the MAB have a slow southwestward flow that is occasionally interrupted by warm-core rings or meanders from the Gulf Stream. On average, shelf water moves parallel to bathymetry isobars at speeds of 5-10 cm/s at the surface and 2 cm/s or less at the bottom. Storm events can cause much more energetic variations in flow. Tidal currents on the inner shelf have a higher flow rate of 20 cm/s that increases to 100 cm/s near inlets.

Slope water tends to be warmer than shelf water because of its proximity to the Gulf Stream, and tends to be more saline. The abrupt gradient where these two water masses meet is called the shelf-slope front. This front is usually located at the edge of the shelf and touches bottom at about 75-100 m depth of water, and then slopes up to the east toward the surface. It reaches surface waters approximately 25-55 km further offshore. The position of the front is highly variable, and can be influenced by many physical factors. Vertical structure of temperature and salinity within the front can develop complex patterns because of the interleaving of shelf and slope waters; *e.g.,* cold shelf waters can protrude offshore, or warmer slope water can intrude up onto the shelf.

The seasonal effects of warming and cooling increase in shallower, nearshore waters. Stratification of the water column occurs over the shelf and the top layer of slope water during the spring-summer and is usually established by early June. Fall mixing results in homogenous shelf and upper slope waters by October in most years. A permanent thermocline exists in slope waters from 200 to 600 m deep. Temperatures decrease at the rate of about 0.02°C/m, and remain relatively constant except for occasional incursions of Gulf Stream eddies or meanders. Below 600 m, temperature declines, and usually averages about 2.2°C at 4000 m. A warm, mixed layer approximately 40-m thick resides above the permanent thermocline.

The "cold pool" is an annual phenomenon particularly important to the MAB. It stretches from the GOM along the outer edge of Georges Bank and then southwest to Cape Hatteras. It becomes identifiable with the onset of thermal stratification in the spring and lasts into early fall until normal seasonal mixing occurs. It usually exists along the bottom between the 40- and 100-m isobaths, and extends up into the water column for about 35 m, and to the bottom of the seasonal thermocline. The cold pool usually represents about 30% of the volume of shelf water. Minimum temperatures for the cold pool occur in early spring and summer, and range from 1.1 to 4.7°C.

The shelf slopes gently from shore out to between 100 and 200 km offshore where it transforms to the slope (100-200 m of water depth) at the shelf break. In both the Mid-Atlantic and on Georges Bank, numerous canyons incise the slope, and some cut up onto the shelf itself (see the subsequent "Continental Slope" section). The primary morphological features of the shelf include shelf valleys and channels, shoal massifs, scarps, and sand ridges and swales (Figures 2.7 and 2.8).

Most of these structures are relic except for some sand ridges and smaller sand-formed features. Shelf valleys and slope canyons were formed by rivers of glacier outwash that deposited sediments on the outer shelf edge as they entered the ocean. Most valleys cut about 10 m into the shelf, with the exception of the Hudson Shelf Valley that is about 35 m deep. The valleys were partially filled as the glacier melted and retreated across the shelf. The glacier also left behind a lengthy scarp near the shelf break from Chesapeake Bay north to the eastern end of Long Island (Figures 2.7 and 2.8). Shoal retreat massifs were produced by extensive deposition at a cape or estuary mouth. Massifs were also formed as estuaries retreated across the shelf.

The sediment type covering most of the shelf in the MAB is sand, with some relatively small, localized areas of sand-shell and sand-gravel. On the slope, silty sand, silt, and clay predominate.

Some sand ridges (Figure 2.7) are more modern in origin than the shelf's glaciated morphology. Their formation is not well understood; however, they appear to develop from the sediments that erode from the shore face. They maintain their shape, so it is assumed that they are in equilibrium with modern current and storm regimes. They are usually grouped, with heights of about 10 m, lengths of 10-50 km, and spacing of about 2 km. Ridges are usually oriented at a slight angle towards shore, running in length from northeast to southwest. The seaward face usually has the steepest slope. Sand ridges are often covered with smaller similar forms such as sand waves, megaripples, and ripples. Swales occur between sand ridges. Since ridges are higher than the adjacent swales, they are exposed to more energy from water currents, and experience more sediment mobility than swales. Ridges tend to contain less fine sand, silt, and clay, while relatively sheltered swales contain more of the finer particles. Swales have greater benthic macrofaunal density, species richness, and biomass due, in part, to the increased abundance of detrital food and the physically less rigorous conditions.

Sand waves are usually found in patches of 5-10 with heights of about 2 m, lengths of about 50-100 m, and spacing of about 1-2 km. Sand waves are primarily found on the inner shelf, and often observed on sides of sand ridges. Sand waves may remain intact over several seasons. Megaripples occur on sand waves or separately on the inner or central shelf. During the winter storm season, these megaripples may cover as much as 15% of the inner shelf. They tend to form in large patches and usually have lengths of about 3-5 m with heights of about 0.5-1 m. Megaripples tend to survive for less than a season. They can form during a storm and reshape the upper 50-100 cm of the sediments within a few hours. Ripples are also found everywhere on the shelf, and appear or disappear within hours or days, depending upon storms and currents. Ripples usually have lengths of about 1-150 cm and heights of a few centimeters.

Sediments are uniformly distributed over the shelf in this region (see Figure 2.3). A sheet of sand and gravel varying in thickness from 0 to10 m covers most of the shelf. The mean bottom flow from the constant southwesterly current is not fast enough to move sand, so sediment transport must be episodic. Net sediment movement is in the same southwesterly direction as the current. The sands are mostly medium-to-coarse grains, with finer sand in the Hudson Shelf Valley and on the outer shelf. Mud is rare over most of the shelf, but is common in the Hudson Shelf Valley. Occasionally, relic estuarine mud deposits are re-exposed in the swales between sand ridges. Fine sediment content increases rapidly at the shelf break, which is sometimes called the "mud line," and sediments are 70-100% fines on the slope.

The northern portion of the MAB is sometimes referred to as Southern New England. Most of this area was discussed under Georges Bank; however, one other formation of this region deserves note. The "Mud Patch" is located just southwest of Nantucket Shoals and southeast of Long Island and Rhode Island (Figure 2.3). Tidal currents in this area slow significantly, which allows silts and clays to settle out. The mud is mixed with sand, and is occasionally resuspended by large storms. This habitat is an anomaly of the outer continental shelf.

Artificial reefs are another significant Mid-Atlantic habitat, formed much more recently on the geologic time scale than other regional habitat types. These localized areas of hard structure have been formed by shipwrecks, lost cargoes, disposed solid materials, shoreline jetties and groins, submerged pipelines, cables, and other materials (Steimle and Zetlin 2000). While some of materials have been deposited specifically for use as fish habitat, most have an alternative primary purpose; however, they have all become an integral part of the coastal and shelf ecosystem. It is expected that the increase in these materials has had an effect on living marine resources and fisheries, but these effects are not well known. In general, reefs are important for attachment sites, shelter, and food for many species, and fish predators such as tunas may be attracted by prey aggregations, or may be behaviorally attracted to the reef structure. The overview by Steimle and Zetlin (2000) used NOAA hydrographic surveys to plot rocks, wrecks, obstructions, and artificial reefs, which together were considered a fairly complete list of nonbiogenic reef habitat in the Mid-Atlantic estuarine and coastal areas (Figure 2.9).

Benthic Biological Features

Wigley and Theroux (1981) reported on the faunal composition of 563 bottom grab samples collected in the MAB during 1956-1965. Amphipod crustaceans and bivalve mollusks accounted for most of the individuals (41% and 22%, respectively), whereas mollusks dominated the biomass (70%). Three broad faunal zones related to water depth and sediment type were identified by Pratt (1973). The "sand fauna" zone was defined for sandy sediments (1% or less silt) that are at least occasionally disturbed by waves, from shore out to the 50-m depth (Figure 2.10). The "silty sand fauna" zone occurred immediately offshore from the sand fauna zone, in stable sands containing a small amount of silt and organic material. Silts and clays become predominant at the shelf break, line the Hudson Shelf Valley, and support the "silt-clay fauna." (See the "Regional Benthic Invertebrate Communities/Mid-Atlantic Bight" section of this chapter for more information on benthic invertebrate communities in the MAB and their relation to depth and sediment type).

Building on Pratt's work, the Mid-Atlantic shelf was further divided by Boesch (1979) into seven bathymetric/ morphologic subdivisions based on faunal assemblages (Table 2.5). Sediments in the region studied (Hudson Shelf Valley south to Chesapeake Bay) were dominated by sand with little finer materials. Ridges and swales are important morphological features in this area. Sediments are coarser on the ridges, and the swales have greater benthic macrofaunal density, species richness, and biomass. Faunal species composition differed between these features, and Boesch (1979) incorporated this variation in his subdivisions (Table 2.5). Much overlap of species distributions was found between depth zones, so the faunal assemblages represented more of a continuum than distinct zones.

Demersal fish assemblages were described at a broad geographic scale for the continental shelf and slope from Cape Chidley, Labrador, to Cape Hatteras, North Carolina (Mahon *et al.* 1998), and from Nova Scotia to Cape Hatteras (Gabriel 1992). Factors influencing species distribution included latitude and depth. Results of these studies were similar to an earlier study confined to the MAB continental shelf (Colvocoresses and Musick 1984). In this latter study, there were clear variations in species abundances, yet the authors demonstrated consistent patterns of community composition and distribution among demersal fishes of the Mid-Atlantic shelf. This is especially true for five strongly recurring species associations that varied slightly from spring to fall (Table 2.6). The boundaries between fish assemblages generally followed isotherms and isobaths. The assemblages were largely similar between the spring and fall collections, with the most notable change being a northward and shoreward shift in the temperate group in the spring.

Steimle and Zetlin (2000) described representative epibenthic/epibiotic, motile epibenthic, and fish species associated with sparsely scattered reef habitats that consist mainly of manmade structures (Table 2.7).

Continental Slope

Physical Features

The continental slope extends from the continental shelf break, at depths between 60-200 m, eastward to a depth of 2000 m. The width of the slope varies from 10-50 km, with an average gradient of 3-6°; however, local gradients can be nearly vertical. The base of the slope is defined by a marked decrease in seafloor gradient where the continental rise begins.

The morphology of the present continental slope appears largely to be a result of sedimentary processes that occurred during the Pleistocene, including, 1) slope upbuilding and progradation by deltaic sedimentation principally during sea-level low stands; 2) canyon cutting by sediment mass movements during and following sea-level low stands; and 3) sediment slumping.

The slope is cut by at least 70 large canyons between Georges Bank and Cape Hatteras (Figure 2.11), and by numerous smaller canyons and gullies, many of which may feed into the larger canyon systems. The New England Seamount Chain, including Bear, Mytilus, and Balanus Seamounts, occurs on the slope southeast of Georges Bank. A smaller chain (Caryn, Knauss, etc.) occurs in the vicinity in deeper water.

A "mud line" occurs on the slope at a depth of 250-300 m, below which fine silt and clay-size particles predominate (Figure 2.3). Localized coarse sediments and rock outcrops are found in and near canyon walls, and occasional boulders occur on the slope because of glacial rafting. Sand pockets may also be formed because of downslope movements.

Gravity-induced, downslope movement is the dominant sedimentary process on the slope, and includes slumps, slides, debris flows, and turbidity currents, in the order from thick cohesive movement to relatively nonviscous flow. Slumps may involve localized, short, downslope movements by blocks of sediment. However, turbidity currents can transport sediments thousands of kilometers.

Submarine canyons are not spaced evenly along the slope, but tend to decrease in areas of increasing slope gradient. Canyons are typically "v" shaped in cross section, and often have steep walls and outcroppings of bedrock and clay. The canyons are continuous from the canyon heads to the base of the continental slope. Some canyons end at the base of the slope, but others continue as channels onto the continental rise. Larger and more deeply incised canyons are generally significantly older than smaller ones, and there is evidence that some older canyons have experienced several episodes of filling and re-excavation. Many, if not all, submarine canyons may first form by mass-wasting processes on the continental slope, although there is evidence that some canyons were formed because of fluvial drainage (*e.g.,* Hudson Canyon).

Canyons can alter the physical processes in the surrounding slope waters. Fluctuations in the velocities of the surface and internal tides can be large near the heads of the canyons, leading to enhanced mixing and sediment transport in the area. Shepard *et al.* (1979) concluded that the strong turbidity currents initiated in study canyons were responsible for enough sediment erosion and transport to maintain and modify those canyons. Since surface and internal tides are ubiquitous over the continental shelf and slope, it can be anticipated that these fluctuations are important for sedimentation processes in other canyons as well. In Lydonia Canyon, Butman *et al.* (1982) found that the dominant source of low-frequency current variability was related to passage of warm-core Gulf Stream rings rather than the atmospheric events that predominate on the shelf.

The water masses of the Atlantic continental slope and rise are essentially the same as those of the North American Basin [defined in Wright and Worthington (1970)]. Worthington (1976) divided the water column of the slope into three vertical layers: deepwater (colder than 4°C), the thermocline (4-17°C), and surface water (warmer than 17°C). In the North American Basin, deepwater accounts for two-thirds of all water, the thermocline for about one-quarter, and surface water the remainder. In the slope water north of Cape Hatteras, the only warm water occurs in the Gulf Stream and in seasonally influenced summer waters.

The principal cold water mass in the region is the North Atlantic Deep Water. North Atlantic Deep Water is comprised of a mixture of five sources: Antarctic Bottom Water, Labrador Sea Water, Mediterranean Water, Denmark Strait Overflow Water, and Iceland-Scotland Overflow Water. The thermocline represents a straightforward water mass compared with either the deepwater or the surface water. Nearly 90% of all thermocline water comes from the water mass called the Western North Atlantic Water. This water mass is slightly less saline northeast of Cape Hatteras due to the influx of southward flowing Labrador Coastal Water. Seasonal variability in slope waters occurs only in the upper 200 m of the water column.

In the winter months, cold temperatures and storm activity create a well-mixed layer down to about 100-150 m, but summer warming creates a seasonal thermocline overlain by a surface layer of low-density water. The seasonal thermocline, in combination with reduced storm activity in the summer, inhibits vertical mixing and reduces the upward transfer of nutrients into the photic zone.

Two currents found on the slope, the Gulf Stream and Western Boundary Undercurrent, together represent one of the strongest low-frequency horizontal flow systems in the world. Both currents have an important influence on slope waters. Warm- and cold-core rings that spin off the Gulf Stream are a persistent and ubiquitous feature of the Northwest Atlantic Ocean. The Western Boundary Undercurrent flows to the southwest along the lower slope and continental rise in a stream about 50 km wide. This boundary current is associated with the spread of North Atlantic Deep Water, and forms part of the generally westward flow found in slope water. North of Cape Hatteras, it crosses under the Gulf Stream in a manner not yet completely understood.

Shelf and slope waters of the Northeast Region are intermittently affected by the Gulf Stream. The Gulf Stream begins in the Gulf of Mexico and flows northeastward at an approximate rate of 1 m/s (2 knots), transporting warm waters north along the eastern coast of the United States, and then east towards the British Isles. Conditions and flow of the Gulf Stream are highly variable on time scales ranging from days to seasons. Intrusions from the Gulf Stream constitute the principal source of variability in slope waters off the Northeast Continental Shelf.

The location of the Gulf Stream's shoreward, western boundary is variable because of meanders and eddies. Gulf Stream eddies are formed when extended meanders enclose a parcel of seawater and pinch off. These eddies can be cyclonic, meaning they rotate counterclockwise and have a cold core formed by enclosed slope water (cold-core ring), or anticyclonic, meaning they rotate clockwise and have a warm core of Sargasso Sea water (warm-core ring). The rings are shaped like a funnel, wider at the top and narrower at the bottom, and can have depths of over 2000 m. They range in approximate size from 150 to 230 km in diameter. There are 35% more rings and meanders near Georges Bank than in the Mid-Atlantic region. A net transfer of water on and off the shelf may result from the interaction of rings and shelf waters. These warm- or cold-core rings maintain their identity for several months until they are reabsorbed by the Gulf Stream. The rings and the Gulf Stream itself have a great influence over oceanographic conditions all along the continental shelf.

Benthic Biological Features

Polychaete annelids represent the most important slope faunal group in terms of numbers of individuals and species (Wiebe *et al.* 1987). Ophiuroids (brittle stars) are considered to be among the most abundant slope organisms, but this group is comprised of relatively few species. The taxonomic group with the highest species diversity is the peracarid crustaceans (which include amphipods, cumaceans, and isopods). Some species of the slope are widely distributed, while others appear to be restricted to particular ocean basins. The ophiuroids and bivalve mollusks appear to have the broadest distributions, while the peracarid crustaceans appear to be highly restricted because they brood their young, and lack a planktonic stage of development. In general, gastropods do not appear to be very abundant; however, past studies are inconclusive since they have not collected enough individuals for largescale community and population studies. (See the "Regional Benthic Invertebrate Communities" section of this chapter for more information on benthic invertebrate communities on the continental slope.)

In general, slope-inhabiting benthic organisms are strongly zoned by depth and/or water temperature, although these patterns are modified by the presence of topography, including canyons, channels, and current zonations (Hecker 1990). Moreover, at depths of <800 m, the fauna is extremely variable and the relationships between faunal distribution and substrate, depth, and geography are less obvious (Wiebe *et al.* 1987). The fauna occupying hard surface sediments is not as dense as in comparable shallow water habitats (Wiebe *et al.* 1987), but there is an increase in species diversity from the shelf to the intermediate depths of the slope. Diversity then declines again in the deeper waters of the continental rise and plain. Hecker (1990) identified four megafaunal zones on the slope of Georges Bank and Southern New England (Table 2.8).

One group of organisms of interest because of the additional structure they can provide for habitat and their potential long life span are the alcyonarian soft corals. Soft corals can be bush or treelike in shape; species found in this form attach to hard substrates such as rock outcrops or gravel. These species can range in size from a few millimeters to several meters, and the trunk diameter of large specimens can exceed 10 cm. Other alcyonarians found in this region include sea pens and sea pansies (Order Pennatulacea), which are found in a wider range of substrate types. In their survey of Northeast U.S. Continental Shelf macrobenthic invertebrates, Theroux and Wigley (1998) found alcyonarians (including the soft corals *Alcyonium* sp., *Acanella* sp., *Paragorgia arborea,* and *Primnoa reseda*, and the sea pens) in limited numbers in waters deeper than 50 m, and mostly at depths from 200 to 500 m. Alcyonarians were present in each of the geographic areas identified in the study (Nova Scotia, GOM, Southern New England Shelf, Georges Slope, and Southern New England Slope) except Georges Bank. However, *Paragorgia* and *Primnoa* have been reported in the Northeast Peak region of Georges Bank (Theroux and Grosslein 1987). Alcyonarians were most abundant by weight in the GOM, and by number on the Southern New England Slope (Theroux and Wigley 1998). In this study, alcyonarians other than sea pens were collected only from gravel and rocky outcrops. Theroux and Wigley (1998) also found stony corals (*Astrangia danae* and *Flabellum* sp.) in the Northeast Region, but they were uncommon. In similar work on the Mid-Atlantic shelf, the only alcyonarians encountered were sea pens (Wigley and Theroux 1981). The stony coral *Astrangia danae* was also found, but its distribution and abundance were not discussed, and are assumed to be minimal.

As opposed to most slope environments, canyons may develop a lush epifauna. Hecker *et al.* (1983) found faunal differences between the canyons and slope environments. Hecker and Blechschmidt (1979) suggested that faunal differences were due at least in part to increased environmental heterogeneity in the canyons, including greater substrate variability and nutrient enrichment. Hecker *et al.* (1983) found highly patchy faunal assemblages in the canyons, and also found additional faunal groups located in the canyons, particularly on hard substrates, that do not appear to occur in other slope environments. Canyons are also thought to serve as nursery areas for a number of species (Cooper *et al.* 1987; Hecker 2001). The canyon habitats in Table 2.9 were classified by Cooper *et al.* (1987).

Most finfish identified as slope inhabitants on a broad spatial scale (Colvocoresses and Musick 1984; Overholtz and Tyler 1985; Gabriel 1992) (Tables 2.2 and 2.6) are associated with canyon features as well (Cooper *et al.* 1987) (Table 2.9). Finfish identified by broad studies that were not included in Cooper *et al.* (1987) include offshore hake, fawn cusk-eel, longfin hake, witch flounder, and armored searobin. Canyon species (Cooper *et al.* 1987) that were not discussed in the broadscale studies include squirrel hake, conger eel, and tilefish. Cusk and ocean pout were identified by Cooper *et al.* (1987) as canyon species, but classified in other habitats by the broadscale studies.

Coastal and Estuarine Features

Coastal and estuarine features such as salt marshes, mud flats, rocky intertidal zones, sand beaches, and submerged aquatic vegetation are critical to inshore and offshore habitats and fishery resources of the Northeast. For example, coastal areas and estuaries are important for nutrient recycling and primary production, and certain features serve as nursery areas for juvenile stages of economically important species. Salt marshes are found extensively throughout the region. Tidal and subtidal mud and sand flats are general saltmarsh features and also occur in other estuarine areas. Salt marshes provide nursery and spawning habitat for many fish and invertebrate species. Saltmarsh vegetation can also be a large source of organic material that is important to the biological and chemical processes of the estuarine and marine environment.

Rocky intertidal zones are high-energy, periodically submerged environments found in the northern portion of the Northeast system. Sessile invertebrates and some fish inhabit rocky intertidal zones. A variety of algae, kelp, and rockweed are also important habitat features of rocky shores. Fishery resources may depend on particular habitat features of the rocky intertidal zone that provide important levels of refuge and food.

Sandy beaches are most extensive along the Northeast coast. Different zones of the beach present suitable habitat conditions for a variety of marine and terrestrial organisms. For example, the intertidal zone presents suitable habitat conditions for many invertebrates, and transient fish find suitable conditions for foraging during high tide. Several invertebrate and fish species are adapted for living in the high-energy subtidal zone adjacent to sandy beaches.

REGIONAL BENTHIC INVERTEBRATE COMMUNITIES

New England

Theroux and Wigley (1998) reported the results of an extensive, 10-yr benthic sampling program in New England. A total of 1,076 bottom grab samples were collected during spring, summer, and fall during 1956-1965 on the continental shelf and slope in Southern New England, Georges Bank, and the GOM. Twenty-eight percent of the samples (303) were collected in the GOM, 20% (211) on Georges Bank, 32% (344) in Southern New England, and 12% (133) on the slope in Southern New England and on Georges Bank. Results were summarized according to major taxonomic groups, principal species, depth ranges, sediment types, ranges of bottom water temperatures, and the sediment organic carbon content. Results presented here are for major taxa by depth range and sediment type. Detailed information for the individual subregions is not presented in this document. Distribution and abundance information for the Mid-Atlantic region is compiled in an earlier publication (Wigley and Theroux 1981) and is summarized in the next section of this chapter.

The density and biomass of all taxa exhibited similar patterns (Figure 2.12). Both were generally higher in coastal GOM waters, on the southern and eastern areas of Georges Bank (including the Northeast Peak), on most of the Southern New England shelf, and south of Long Island. Density and biomass were lower in deeper water of the GOM, on the north-central part of Georges Bank, on the western side of the Great South Channel, on the continental slope and rise, and in portions of Southern New England. Very high biomass was reported in Rhode Island coastal waters, in Cape Cod Bay, and at the southern end of the Great South Channel. Total biomass (mean wet weight per square meter) was about twice as high on the Southern New England shelf and on Georges Bank as in the GOM and over 10 times higher than on the continental slope. Echinoderms and mollusks dominated the biomass in the GOM, on Georges Bank, and in Southern New England. Crustaceans and annelids dominated the density in Southern New England and on Georges Bank; annelids and mollusks dominated in the GOM.

Depth Influence

Analysis of faunal composition by major taxonomic groups in eight different depth ranges reveals a pronounced decline in density at the shelf break, particularly between 100-200 m (Figure 2.13). Density declined very little between 25 and 100 m, and by 60% between 100 and 200 m. Density continued to decline at successively greater depths, but very slowly per meter increase in depth. The relative changes in biomass on the shelf were more pronounced (Figure 2.14). Biomass declined by 50% between 25-100 m and by 55% between 100-200 m.

On the shelf (down to 100 m), crustaceans (mostly amphipods) were numerically the most abundant taxon, with annelids accounting for 20-29% of the organisms; in just the 0-24 m depth range, mollusks accounted for 23%. Bivalve mollusks made up over half the biomass in the 0-24 and 50-99 m depth ranges, and 33% in the 25-49 m range. Echinoderms (sand dollars and sea urchins) dominated the biomass in the intermediate depth range (25-49 m) on the shelf. Between 100 and 499 m, annelids were the most numerous taxon, but echinoderms dominated the biomass. Mollusks accounted for 36-46%, and annelids for 12-39%, of the organisms in deeper water (500-4000 m), with a diminishing proportion of annelids and an increasing proportion of "other" organisms. Biomass on the shelf rise was composed of a variety of taxa.

Sediment Influence

Theroux and Wigley (1998) classified sediments sampled in the New England region into six categories: gravel, glacial till, shell, sand, sand-silt, and silt-clay. Four of these sediment types were well sampled (148-455 samples); shell and till sediments were poorly sampled (6-22 samples) and will not be included in the discussion that follows, even though the data are included in Figure 2.15. Total numbers and biomass were highest in sand and lowest in silt-clay, with intermediate values in gravel and sand-silt. Amphipods dominated numerically in gravel (42%) and sand (56%), but annelids were also numerous (25-33%). Annelids, crustaceans, and mollusks made up nearly equal proportions, by number, of the sand-silt samples, and mollusks and annelids dominated, by number, the silt-clay samples. Mollusks accounted for 50% of the biomass in gravel; the remainder was composed primarily of annelids, crustaceans (mostly barnacles and crabs), sea anemones, sponges, and tunicates. Bivalve mollusks accounted for about half (48%) of the biomass in sand, but echinoids were also important (33%). Bivalve mollusks were also the dominant taxon in biomass in sand-silt (42%), but less so in silt-clay (20%) where 50% of the biomass was composed of echinoderms, mostly sea cucumbers. Annelids made up 15% and 19% of the biomass in sand-silt and silt-clay sediments, respectively.

Important Fauna

Theroux and Wigley (1998) described the geographic distribution of 24 genera and species of benthic invertebrates in New England that were selected because of their common occurrence, regional ubiquity, or distinctive distribution patterns. Information summarizing the importance of these genera and species as prey for fish and their sediment associations is given in Table 2.10.

Mid-Atlantic Bight

Wigley and Theroux (1981) reported the results of an extensive 10-yr benthic sampling program in the MAB, an area extending from Cape Cod to Cape Hatteras and including Southern New England (which was also included in the more recent report by Theroux and Wigley (1998) for New England). A total of 667 bottom grab samples were collected during spring, summer, and fall, primarily between 1962 and 1965, on the continental shelf, slope, and rise. A nearly equal number of samples were collected in each of three subregions: Southern New England (Cape Cod to Montauk Point, Long Island), the New York Bight (Montauk Point to Cape May, New Jersey), and the Chesapeake Bight (Cape May to Cape Hatteras). Results were summarized according to major taxonomic groups, depth ranges, sediment types, ranges of bottom water temperatures, and the sediment organic carbon content. Results presented here are for major taxa by depth range and sediment type. Detailed information for the individual subregions is not presented in this document.

Over the entire MAB, arthropods (mostly amphipods) numerically made up 46% of the benthic fauna, followed by mollusks (25%, mostly bivalves) and annelids (21%). Biomass was dominated by mollusks (71%).

Among subregions, there was some variation in the densities of the major taxa; the proportion of amphipods diminished from north to south, while the proportion of mollusks increased. There was no variation in biomass, though; mollusks dominated the biomass in all three subregions.

From a geographic perspective, total density generally declined from shallow inshore areas to deeper areas on the slope, and from north to south. There were some small areas of low and high density on the mid-shelf in the southern half of the region, and there was a large area of high density in Southern New England and south of Long Island (Figure 2.16). Biomass (mostly mollusks) was more variable, with areas of high and low biomass scattered throughout the region (Figure 2.17).

Depth Influence

Total density was about the same in the shallowest depth interval (0-24 m) as it was at 50-99 m, and then declined by 61% between 50 and 200 m, and continued to decline, although not as rapidly (per unit change in depth) in deeper water (Figure 2.18). Mollusks (mostly bivalves) were numerically more abundant in the shallowest depth range (0-24 m), and amphipods in the next two deeper shelf depth ranges (25-49 and 50-99 m). The density of amphipods declined dramatically in the deeper water (100-199 m), as did annelids but less so, while the density of mollusks remained the same and that of echinoderms (brittle stars) increased. On a percentage basis, annelids, mollusks, and echinoderms made up nearly equal proportions, by number, of the benthic fauna between 100 and 200 m. Annelids were the most numerous taxon between 200 and 500 m, as were mollusks in deeper water.

Total biomass (mean grams per square meter) was lower in all depth ranges in the MAB than in New England, and declined by about 78% between shallow water (0-24 m) and the 100-199 m depth interval (Figure 2.18). The rate of decline generally diminished in deeper water. The high biomass in the 0-24 m depth range was due to the prevalence of bivalve mollusks, which were not nearly as abundant in deeper shelf waters, but still accounted for 58-65% of the biomass in depths <100 m. A variety of echinoderms (sand dollars, sea cucumbers, brittle stars, and starfish) accounted for 45% of the biomass between 100 and 200 m, where bivalve mollusks still made up 21% and sea anemones 19%. Sand dollars, sea cucumbers, and brittle stars (with annelids) still dominated the biomass between 200 and 500 m, and annelids were the taxon which accounted for most of the biomass between 500 and 1000 m. Echinoderms and echiurid worms dominated the biomass of the sparse fauna of the continental rise.

Sediment Influence

Sediments in the MAB were classified into eight categories: gravel, sand-gravel, shell, sand-shell, sand, silty sand, silt, and clay. Figure 2.19 was derived for this document from data given in Wigley and Theroux (1981), and excludes the results for two poorly sampled sediment types: gravel and shell. Sample sizes for the other six groups ranged from 18 (sand-gravel) to 285 (sand). Total density was highest in sand-gravel and sand-shell, moderately high in sand and silty sand, and low in silt and clay. Total biomass was highest in silty sand, moderate in sand-gravel and sand, and low in sand-shell, silt, and clay.

Amphipods dominated the sand-gravel and sand sediment types numerically, while mollusks were the most numerous taxon in the other four substrates. Almost all of the mollusks in sand-gravel, sand-shell, and sand were bivalves, but gastropods were also important in silty sand. Annelids, hydroids, and bryozoans were numerically important components of the sand-gravel fauna. Annelids were also common in sand, silty sand, sand-gravel, silt, and clay substrates. Bivalve mollusks dominated the biomass in all six substrates. Other taxa with abundant biomass were barnacles in sand-gravel, and sand dollars in sand-shell and sand.

Important Fauna

Wigley and Theroux (1981) described the geographic distribution of 24 genera and species of benthic invertebrates in the MAB that were selected because of their common occurrence or distinctive distribution patterns. Ten of them were also described in the New England region (see earlier): they are the annelids *Sternaspis scutata* and *Scalibregma inflatum,* the mollusks *Arctica islandica, Cerastoderma pinnulatum,* and *Cyclocardia borealis,* the arthropods *Leptocheirus pinguis, Cirolana* spp., *Crangon septemspinosa,* and *Pagurus* spp., and the echinoderm *Echinarachnius parma*. Information summarizing the habitat associations of the other 14 genera and species is given in Table 2.11.

Table 2.1. Gulf of Maine benthic assemblages as identified by Watling (1998). (Geographical distribution of assemblages is shown in Figure 2.4.)

Benthic Assemblage	**Benthic Community Description**
1	Comprises all sandy offshore banks, most prominently Jeffreys Ledge, Fippennies Ledge, and Platts Bank; depth on top of banks ~70 m; substrate usually coarse sand with some gravel; fauna characteristically sand dwellers with an abundant interstitial component
2	Comprises the rocky offshore ledges, such as Cashes Ledge, Sigsbee Ridge, and Three Dory Ridge; substrate either rock ridge outcrop or very large boulders, often with covering of very fine sediment; fauna predominantly sponges, tunicates, bryozoans, hydroids, and other hard-bottom dwellers; overlying water usually cold MIW
3	Probably extends all along coast of GOM in water depths <60 m; bottom waters warm in summer and cold in winter; fauna rich and diverse, primarily polychaetes and crustaceans, probably consists of several (sub-) assemblages due to heterogeneity of substrate and water conditions near shore and at mouths of bays
4	Extends over soft bottom at depths of 60-140 m, well within the cold MIW; bottom sediments primarily fine muds; fauna dominated by polychaetes, shrimp, and cerianthid anemones
5	Mixed assemblage comprising elements from the coldwater fauna as well as a few deeper water species with broader temperature tolerances; overlying water often a mixture of MIW and MBW, but generally colder than 7°C most of year; fauna sparse, diversity low, dominated by a few polychaetes, with brittle stars, sea pens, shrimp, and cerianthids also present
6	Comprises fauna of deep basins; bottom sediments generally very fine muds, but may have a gravel component in offshore morainal regions; overlying water usually 7-8°C, with little variation; fauna shows some bathyal affinities but densities are not high, dominated by brittle stars and sea pens, and sporadically by a tube-making amphipod
7	True upper slope fauna that extends into the Northeast Channel; water temperatures are always >8°C and salinities are at least 35 ppt; sediments may be either fine muds or a mixture of mud and gravel

Table 2.2. Comparison of two studies of demersal fish assemblages of Georges Bank and Gulf of Maine. (Species associated with the comparable habitats of both studies are listed opposite each other in bold type.)

Overholtz and Tyler (1985)		**Gabriel (1992)**	
Assemblage	**Species**	**Species**	**Assemblage**
Slope and Canyon	**Offshore hake** **Blackbelly rosefish** **Gulf Stream flounder** Fourspot flounder, goosefish, silver hake, white hake, red hake	**Offshore hake** **Blackbelly rosefish** **Gulf Stream flounder** Fawn cusk-eel, longfin hake, armored sea robin	Deepwater
Intermediate	**Silver hake** **Red hake** **Goosefish** Atlantic cod, haddock, ocean pout, yellowtail flounder, winter skate, little skate, sea raven, longhorn sculpin	**Silver hake** **Red hake** **Goosefish** Northern shortfin squid, spiny dogfish, cusk	Combination of Deepwater Gulf of Maine - Georges Bank and Gulf of Maine - Georges Bank Transition
Shallow	**Atlantic cod** **Haddock** **Pollock** Silver hake White hake Red hake Goosefish Ocean pout	**Atlantic cod** **Haddock** **Pollock**	Gulf of Maine - Georges Bank Transition Zone (*see below also*)
	Yellowtail flounder **Windowpane** **Winter flounder** **Winter skate** **Little skate** **Longhorn sculpin** Summer flounder Sea raven, sand lance	**Yellowtail flounder** **Windowpane** **Winter flounder** **Winter skate** **Little skate** **Longhorn sculpin**	Shallow Water Georges Bank-Southern New England
Gulf of Maine-Deep	**White hake** **American plaice** **Witch flounder** **Thorny skate** Silver hake, Atlantic cod, haddock, cusk, Atlantic wolffish	**White hake** **American plaice** **Witch flounder** **Thorny skate** Redfish	Deepwater Gulf of Maine - Georges Bank
Northeast Peak	**Atlantic cod** **Haddock** **Pollock** Ocean pout, winter flounder, white hake, thorny skate, longhorn sculpin	**Atlantic cod** **Haddock** **Pollock**	Gulf of Maine - Georges Bank Transition Zone (*see above also*)

Table 2.3. Substrate associations with five finfish aggregations on Stellwagen Bank, Gulf of Maine. (Numerical data are mean number of fish per research vessel survey tow for 10 dominant species in each aggregation (Auster et al 2001).)

SUBSTRATE TYPE					
Coarse		**Wide Range**		**Fine**	
Species	**Mean**	**Species**	**Mean**	**Species**	**Mean**
Northern sand lance	1172.0	American plaice	63.3	American plaice	152.0
Atlantic herring	72.2	Northern sand lance	53.0	Acadian redfish	31.3
Spiny dogfish	38.4	Atlantic herring	28.5	Silver hake	29.5
Atlantic cod	37.4	Silver hake	22.4	Atlantic herring	28.0
Longhorn sculpin	29.7	Acadian redfish	16.0	Red hake	26.1
American plaice	28.0	Atlantic cod	14.0	Witch flounder	23.8
Haddock	25.7	Longhorn sculpin	9.5	Atlantic cod	13.1
Yellowtail flounder	20.2	Haddock	9.1	Haddock	12.7
Silver hake	7.5	Pollock	7.9	Longhorn sculpin	12.5
Ocean pout	9.0	Red hake	6.2	Daubed shanney	11.4
No. tows = 83		**No. tows = 159**		**No. tows = 66**	
Haddock	13.1			Silver hake	275.0
Atlantic cod	7.3			American plaice	97.1
American plaice	5.3			Atlantic mackerel	42.0
Silver hake	3.3			Pollock	41.1
Longhorn sculpin	2.0			Alewife	37.2
Yellowtail flounder	1.9			Atlantic herring	32.0
Spiny dogfish	1.6			Atlantic cod	18.1
Acadian redfish	1.6			Longhorn sculpin	16.8
Ocean pout	1.3			Red hake	15.2
Alewife	1.1			Haddock	13.2
No. tows = 60				**No. tows = 20**	

Table 2.4. Sedimentary provinces and associated benthic landscapes of Georges Bank. (Provinces as defined by Valentine *et al.* (1993) and Valentine and Lough (1991) with additional information from Page C. Valentine (pers. comm., U.S. Geological Survey, Woods Hole, MA). Benthic assemblages as assigned by Theroux and Grosslein (1987). See text for further discussion on benthic assemblages.)

Sedimentary Province (province no.)	**Depth Range (m)**	**Description**	**Benthic Assemblage**
Northern Edge / Northeast Peak (1)	40-200	Dominated by gravel with portions of sand, common boulder areas, and tightly packed pebbles; bryozoa, hydrozoa, anemones, and calcareous worm tubes are abundant in areas of boulders; strong tidal and storm currents	Northeast Peak
Northern Slope and Northeast Channel (2)	200-240	Variable sediment type (gravel, gravel-sand, and sand) and scattered bedforms; this is a transition zone between the northern edge and southern slope; strong tidal and storm currents	Northeast Peak
North /Central Shelf (3)	60-120	Highly variable sediment types (ranging from gravel to sand) with rippled sand, large bedforms, and patchy gravel lag deposits; minimal epifauna on gravel due to sand movement; epifauna in sand areas includes amphipods, sand dollars, and burrowing anemones	Central Georges
Central and Southwestern Shelf - shoal ridges (4)	10-80	Dominated by sand (fine and medium grain) with large sand ridges, dunes, waves, and ripples; small bedforms in southern part; minimal epifauna on gravel due to sand movement; epifauna in sand areas includes amphipods, sand dollars, and burrowing anemones	Central Georges
Central and Southwestern Shelf - shoal troughs (5)	40-60	Gravel (including gravel lag) and gravel-sand between large sand ridges; patchy large bedforms, strong currents; minimal epifauna on gravel due to sand movement; epifauna in sand areas includes amphipods, sand dollars, and burrowing anemones	Central Georges
Southeastern Shelf (6)	80-200	Rippled gravel-sand (medium- and fine-grained sand) with patchy large bedforms and gravel lag; weaker currents; ripples are formed by intermittent storm currents; epifauna includes sponges attached to shell fragments and amphipods	Southern Georges
Southeastern Slope (7)	400-2000	Dominated by silt and clay with portions of sand (medium and fine), with rippled sand on shallow slopes and smooth silt-sand deeper	None

Table 2.5. Mid-Atlantic habitat types (as described by Pratt (1973) and Boesch (1979)), with characteristic macrofauna (as identified in Boesch (1979))

Habitat Type [after Boesch (1979)]	**Description**		
	Depth (m)	**Characterization (Pratt (1973) faunal zone)**	**Characteristic Benthic Macrofauna**
Inner shelf	0-30	Coarse sands with finer sands off MD and VA (sand zone)	Polychaetes: *Polygordius, Goniadella,* and *Spiophanes*
Central shelf	30-50	(sand zone)	Polychaetes: *Spiophanes* and *Goniadella* Amphipod: *Pseudunciola*
Central and inner shelf swales	0-50	Occurs in swales between sand ridges (sand zone)	Polychaetes: *Spiophanes, Lumbrineris,* and *Polygordius*
Outer shelf	50-100	(silty sand zone)	Amphipods: *Ampelisca vadorum* and *Erichthonius* Polychaetes: *Spiophanes*
Outer shelf swales	50-100	Occurs in swales between sand ridges (silty sand zone)	Amphipods: *Ampelisca agassizi, Unciola,* and *Erichthonius*
Shelf break	100-200	(silt-clay zone)	Not given
Continental slope	>200	(none)	Not given

Table 2.6. Major recurrent demersal finfish assemblages of the Mid-Atlantic Bight during spring and fall (as determined by Colvocoresses and Musick (1984))

Season	**Species Assemblage**				
	Boreal	**Warm Temperate**	**Inner Shelf**	**Outer Shelf**	**Slope**
Spring	Atlantic cod Little skate Sea raven Goosefish Winter flounder Longhorn sculpin Ocean pout Silver hake Red hake White hake Spiny dogfish	Black sea bass Summer flounder Butterfish Scup Spotted hake Northern searobin	Windowpane	Fourspot flounder	Shortnose greeneye Offshore hake Blackbelly rosefish White hake
Fall	White hake Silver hake Red hake Goosefish Longhorn sculpin Winter flounder Yellowtail flounder Witch flounder Little skate Spiny dogfish	Black sea bass Summer flounder Butterfish Scup Spotted hake Northern searobin Smooth dogfish	Windowpane	Fourspot flounder Fawn cusk eel Gulf Stream flounder	Shortnose greeneye Offshore hake Blackbelly rosefish White hake Witch flounder

Table 2.7. Mid-Atlantic reef types, location, and representative flora and fauna (as described in Steimle and Zetlin (2000))

Location (Type)	**Representative Flora and Fauna**		
	Epibenthic/Epibiotic	**Motile Epibenthic Invertebrates**	**Fish**
Estuarine (oyster reefs, blue mussel beds, other hard surfaces, semi-hard clay, and *Spartina* peat reefs)	Eastern oyster, barnacles, ribbed mussel, blue mussel, algae, sponges, tube worms, anemones, hydroids, bryozoans, common Atlantic slipper snail, jingleshell (*Anomia* sp.), northern stone coral, sea whips, tunicates, caprellid amphipods, and wood borers	Xanthid crabs, blue crab, Atlantic rock crabs, portly spider crab, juvenile American lobster, and sea stars	Gobies, spot, striped bass, black sea bass, white perch, oyster toadfish, scup, black drum, Atlantic croaker, spot, sheepshead porgy, pinfish, juvenile and adult tautog, pinfish, northern puffer, cunner, sculpins, juvenile and adult Atlantic cod, rock gunnel, conger eel, American eel, red hake, ocean pout, white hake, and juvenile pollock
Coastal (exposed rock/soft marl, harder rock, wrecks and artificial reefs, kelp, and other materials)	Boring mollusks (piddocks), red algae, sponges, anemones, hydroids, northern stone coral, soft coral, sea whips, barnacles, blue mussel, northern horse mussel, bryozoans, skeleton and tubiculous amphipods, polychaetes, jingle shell, and sea stars	American lobster, Jonah crab, Atlantic rock crab, portly spider crab, sea stars, urchins, and squid egg clusters	Black sea bass, pinfish, scup, cunner, red hake, gray triggerfish, black grouper, smooth dogfish, summer flounder, scad, bluefish, amberjack, Atlantic cod, tautog, ocean pout, conger eel, sea raven, rock gunnel, and radiated shanny
Shelf (rocks and boulders, wrecks and artificial reefs, and other solid substrates)	Boring mollusks (piddocks), red algae, sponges, anemones, hydroids, stone coral, soft coral, sea whips, barnacles, blue mussel, northern horse mussel, bryozoans, amphipods, and polychaetes	American lobster, Jonah crabs, Atlantic rock crab, portly spider crabs, sea stars, urchins, and squid egg clusters (with addition of some deepwater taxa at shelf edge)	Black sea bass, scup, tautog, cunner, gag, sheepshead, porgy, round herring, sardines, amberjack, Atlantic spadefish, gray triggerfish, mackerels, small tunas, spottail pinfish, tautog, Atlantic cod, ocean pout, red hake, conger eel, cunner, sea raven, rock gunnel, pollock, and white hake
Outer shelf (reefs and clay burrows including “pueblo village community”)			Tilefish, white hake, and conger eel

Table 2.8. Faunal zones of the continental slope of Georges Bank and Southern New England (from Hecker (1990))

Zone	**Approximate Depth (m)**	**Gradient**	**Current**	**Fauna**
Upper slope	300-700	Low	Strong	Dense filter feeders: Scleratinians (*Dasmosmilia lymani, Flabellum alabastrum*), and quill worm (*Hyalinoecia* sp.)
Upper middle slope	500-1300	High	Moderate	Sparse scavengers: red deepsea crab (*Chaceon quinqueidens*), northern cutthroat eel, common grenadier (*Nezumia*), alcyonarians (*Acanella arbuscula* and *Eunephthya florida*) in areas of hard substrate
Lower middle slope/transition	1200-1700	High	Moderate	Sparse suspension feeders: cerianthids and sea pen (*Distichoptilum gracile*)
Lower slope	>1600	Low	Strong	Dense suspension and deposit feeders: ophiurid (*Ophiomusium lymani*), cerianthids, and sea pens

Table 2.9. Habitat types for the canyons of Georges Bank, including characteristic fauna. (Faunal characterization is from Cooper *et al.* (1987) and is for depths <230 m only.)

Habitat Type	**Geologic Description**	**Canyon Locations**	**Most Commonly Observed Fauna**
I	Sand or semiconsolidated silt substrate (claylike consistency) with <5% overlay of gravel. Relatively featureless except for conical sediment mounds	Walls and axis	Cerianthid, pandalid shrimp, white colonial anemone, Jonah crab, starfishes, portunid crab, greeneye, brittle stars, mosaic worm, red hake, fourspot flounder, shellless hermit crab, silver hake, and Gulf Stream flounder
II	Sand or semiconsolidated silt substrate (claylike consistency) with >5% overlay of gravel. Relatively featureless	Walls	Cerianthids, galatheid crab, squirrel hake, white colonial anemone, Jonah crab, silver hake, sea stars, ocean pout, brittle stars, shell-less hermit crab, and greeneye
III	Sand or semiconsolidated silt (claylike consistency) overlain by siltstone outcrops and talus up to boulder size. Featured bottom with erosion by animals and scouring	Walls	White colonial anemone, pandalid shrimp, cleaner shrimp, rock anemone, white hake, sea stars, ocean pout, conger eel, brittle stars, Jonah crab, American lobster, blackbelly rosefish, galatheid crab, mosaic worm, and tilefish
IV	Consolidated silt substrate, heavily burrowed/excavated. Slope generally >5° and <50°. Termed “pueblo village” habitat	Walls	Sea stars, blackbelly rosefish, Jonah crab, American lobster, white hake, cusk, ocean pout, cleaner shrimp, conger eel, tilefish, galatheid crab, and shell-less hermit crab
V	Sand dune substrate	Axis	Sea stars, white hake, Jonah crab, and goosefish

Table 2.10 Habitat associations, and importance as prey for fish, of 24 select genera and species of benthic invertebrates in New England. (Source: Theroux and Wigley (1998).)

Phylum	Genus/Species	Description
Annelida	*Aphrodita hastata*	Polychaete often found in Atlantic cod, haddock, and red hake stomachs; commonly inhabits mud bottoms, or mixed bottoms with high mud content
	Scalibregma inflatum	Polychaete that is an important food source for many demersal fish; inhabits silty sand substrates
	Sternaspis scutata	Burrowing polychaete eaten by winter flounder; commonly inhabits silty sediments
Mollusca	*Arctica islandica* (ocean quahog)	Small- to medium-sized individuals preyed upon by Atlantic cod; usually inhabits muddy sand bottoms, very abundant in some localities on the continental shelf such as the southern part of Georges Bank
	Astarte undata (wavy astarte)	Most abundant at mid-shelf depths (50-99 m) in sand and till substrates; not a major prey item of demersal fishes
	Cerastoderma pinnulatum (northern dwarf cockle)	Infrequently found in fish stomachs; prefers sandy substrates, but is also found in other types of substrate
	Cyclocardia borealis (northern cyclocardia)	Broadly distributed throughout the region, prefers sand and till substrates; not common in fish diets
	Modiolus modiolus (northern horsemussel)	Largest and most common mussel offshore of New England, prefers sand and sand-shell substrates
	Placopecten magellanicus (sea scallop)	Most abundant on coarse sandy bottoms; juveniles eaten by some demersal fishes, principally haddock and ocean pout
	Buccinum spp.	Four species of whelk of which *B. undatum* (waved whelk) is by far the most common, typically found at mid- to lower shelf depths in sand and coarser-grained sediments
	Neptunea [lyrata] decemcostata (wrinkle whelk)	Typically inhabits hard bottoms ranging from coarse sand to gravels at mid- to lower shelf depths
Arthropoda	*Ampelisca agassizi*	Tube-dwelling amphipod, the most abundant species of amphipod in the southwestern half of the region, preferring a sandy substratum; a common prey item in the diet of many demersal fish
	Leptocheirus pinguis	Another tube-dwelling amphipod abundant on sandy shelf substrates; very important prey species for demersal fish
	Unciola irrorata	Another tube-dwelling amphipod important in sands of Georges Bank; an important prey species for demersal fish
	Crangon septemspinosa (sevenspine bay shrimp)	Found in sandy sediments in inshore and shelf waters, very abundant in certain localities; an important prey item for nearly all demersal fishes
	Homarus americanus (American lobster)	Widely distributed from inshore bays to offshore canyons, inhabits a variety of substrates
	Hyas coarctatus (Arctic lyre crab)	Common throughout the region on muddy and pebbly bottoms
	Pagurus spp. (hermit crabs)	Seven species ubiquitous throughout the region in nearly all substrate types; preyed upon by demersal fishes
	Cirolana spp. (isopods)	At least three species, common on muddy and sandy bottoms in the GOM and on Georges Bank
Echinodermata	*Asterias vulgaris* (northern or purple starfish)	One of the most common species of starfish in the region, normally found on sandy bottoms; juveniles occasionally found in fish stomachs
	Leptasterias spp.	Several species of starfish that are common inhabitants on sandy bottoms, very abundant in certain locations; small specimens occasionally preyed upon by some species of demersal fish
	Echinarachnius parma (northern sand dollar)	Most abundant member of the urchin family in the New England region, especially in some locations on Georges Bank, lives on sand; a common prey item for flounders, haddock, and Atlantic cod
	Strongylocentrus droebachiensis (green sea urchin)	Another ubiquitous echinoid, a hard-bottom dweller; preyed upon by haddock and American plaice
	Ophiura spp. (brittle stars)	At least three species, widely distributed and occur in most sediment types; common in diets of haddock and American plaice

Table 2.11 Habitat associations of 14 of 24 (see Table 2.10 for information on the other 10) select genera and species of benthic invertebrates in the Mid-Atlantic Bight. (Source: Wigley and Theroux (1981).)

Phylum	**Genus/Species**	**Description**
Annelida	*Hyalinoecia tubicola*	Tube-dwelling polychaete that inhabits the shelf break at depths >200 m
Pogonophora	*Siboglinum ekmani*	Tube-dwelling species found in deep water on the continental slope and rise
Mollusca	*Thyasira* spp. (cleftclams)	Five species of small bivalves most commonly found in offshore waters and in fine-grained bottom sediments
	Lucinoma blakean[um] (Blake lucine)	Bivalve most common in outer continental shelf waters
	Ensis directus (razor clam)	Sand-dwelling species found in shallow inshore waters and on the continental shelf
	Polinices spp. (moon snails)	Two species found on sandy sediments on the continental shelf
	Alvania spp. (alvanias)	At least two species of small gastropods usually associated with silt-clay bottom sediments, found on the continental shelf and slope in Southern New England and on the slope further south
Arthropoda	*Ampelisca* spp.	Six species of tube-dwelling amphipods found inshore and on the shelf, very abundant in some localities
	Phoxocephalus holbolli	Amphipod that characteristically inhabits fine sand sediments on the continental shelf
	Trichophoxus epistomus	Widely distributed burrowing amphipod that inhabits sand and silty sand sediments on the shelf
	Cancer spp. (rock crabs)	Two species that inhabit a variety of bottom sediments throughout the Mid-Atlantic shelf
Echinodermata	*Echinocardium cordatum* (sea potato)	Burrowing heart urchin that usually inhabits sand sediments in moderately shallow water, found only in the southern part of the region
	Astropecten spp.	Two species of burrowing sea stars that are common in silty sand bottom sediments on the northern half of the Mid-Atlantic shelf
	Amphilimna olivacea	Brittle star that inhabits moderately deep water in Southern New England along the outer continental shelf and upper slope

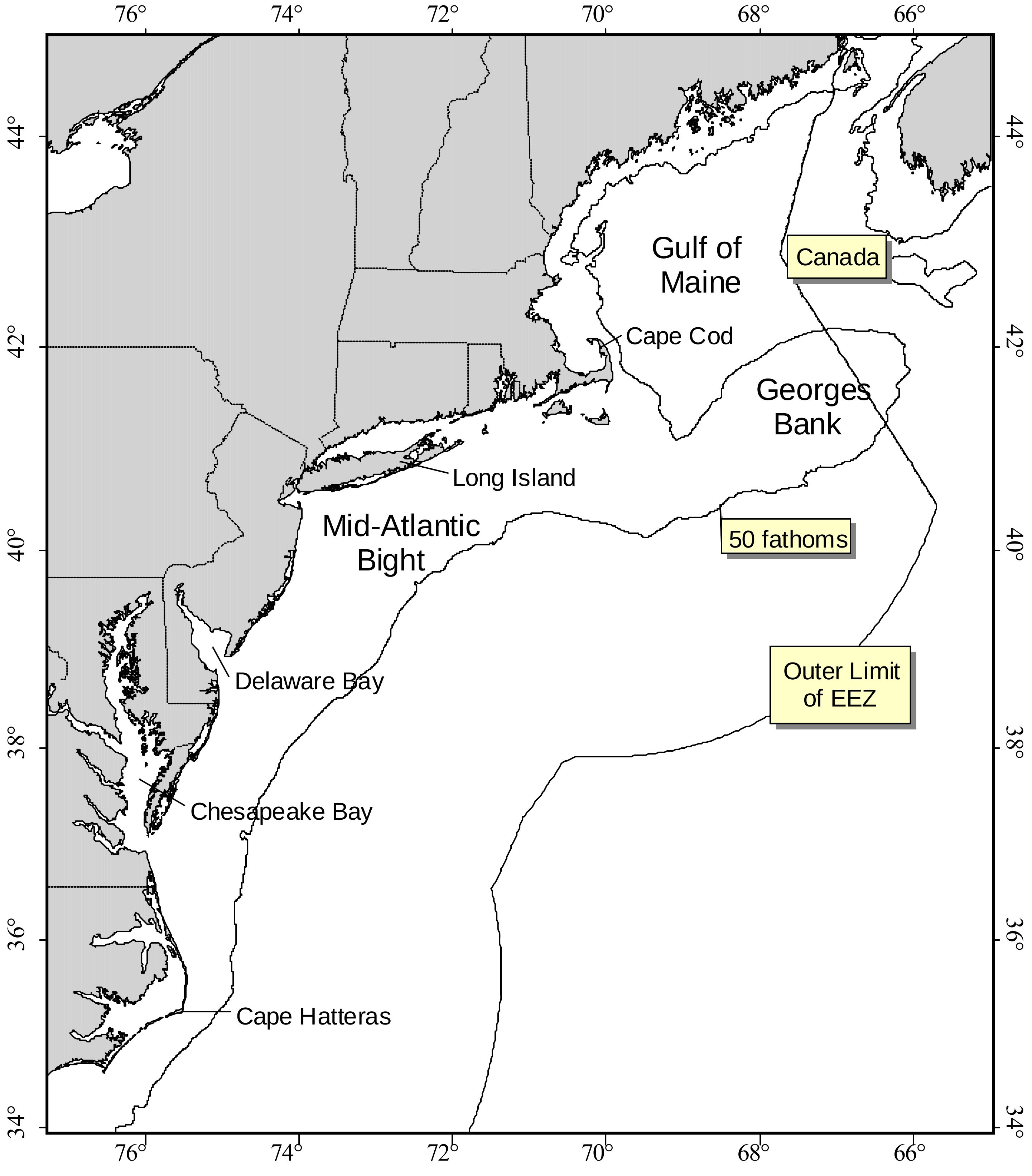


Figure 2.1. Northeast U.S. Shelf Ecosystem, showing the boundaries of the continental shelf (50-fathom line), the EEZ (200-mi limit), and the three principal systems (Gulf of Maine, Georges Bank, and Mid-Atlantic Bight).

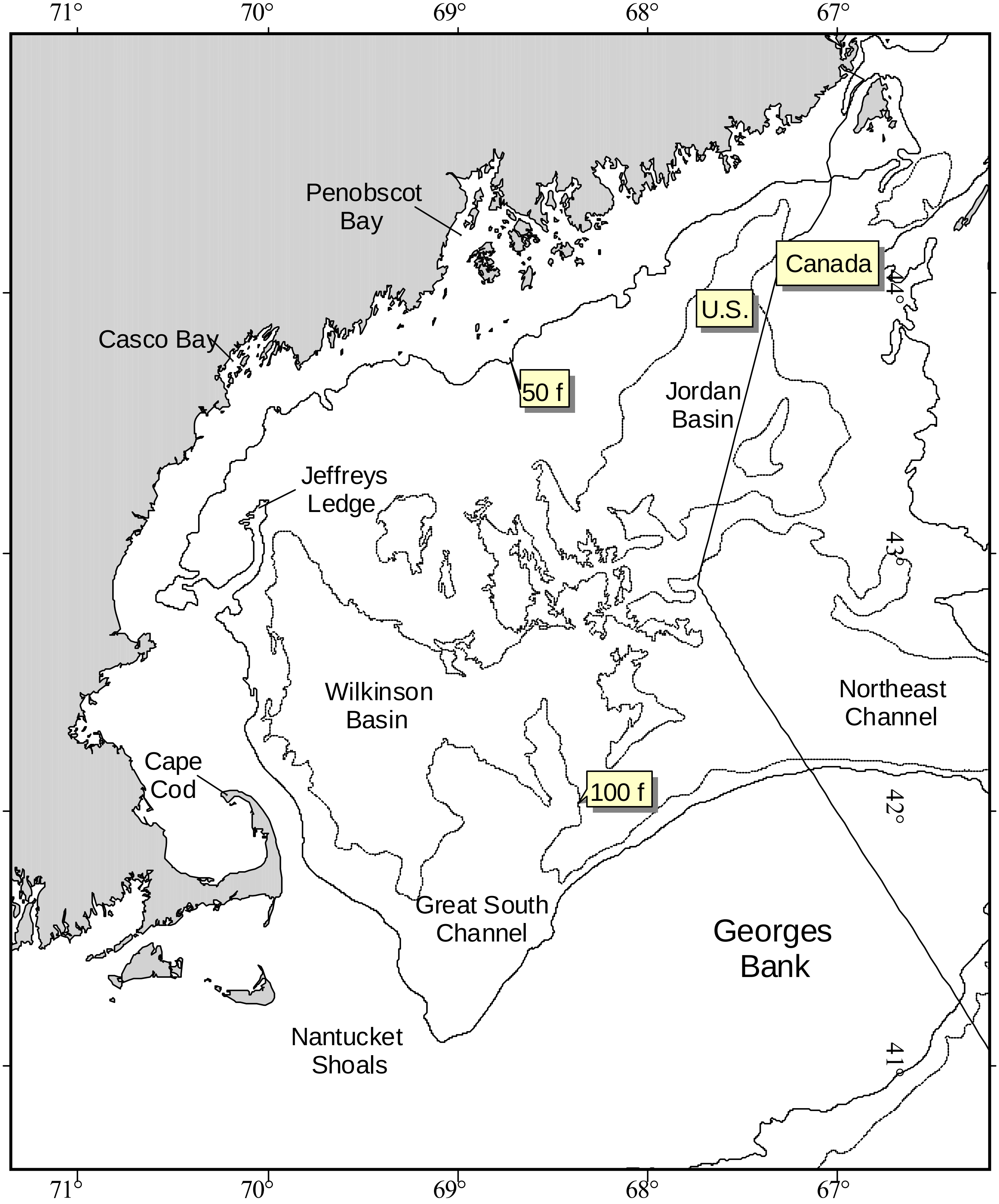


Figure 2.2. Gulf of Maine, showing the 50-fathom and 100-fathom lines of the continental shelf, the boundary between the U.S. Canadian EEZs, and the principal physiographic features.

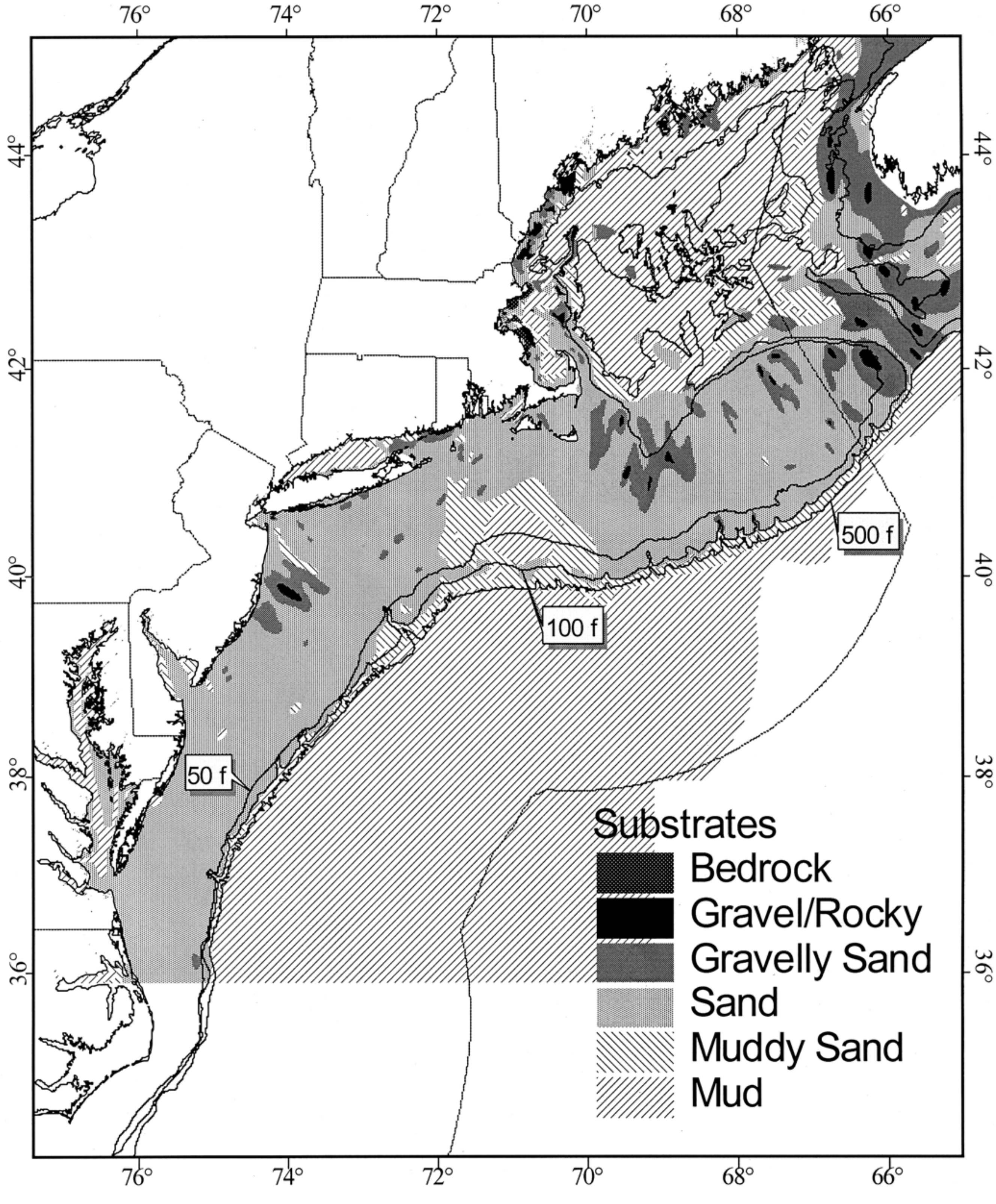


Figure 2.3. Northeast Region sediments. (Modified from Poppe, Schlee, Butman, *et al.* (1989), and Poppe, Schlee, and Knebel (1989).)

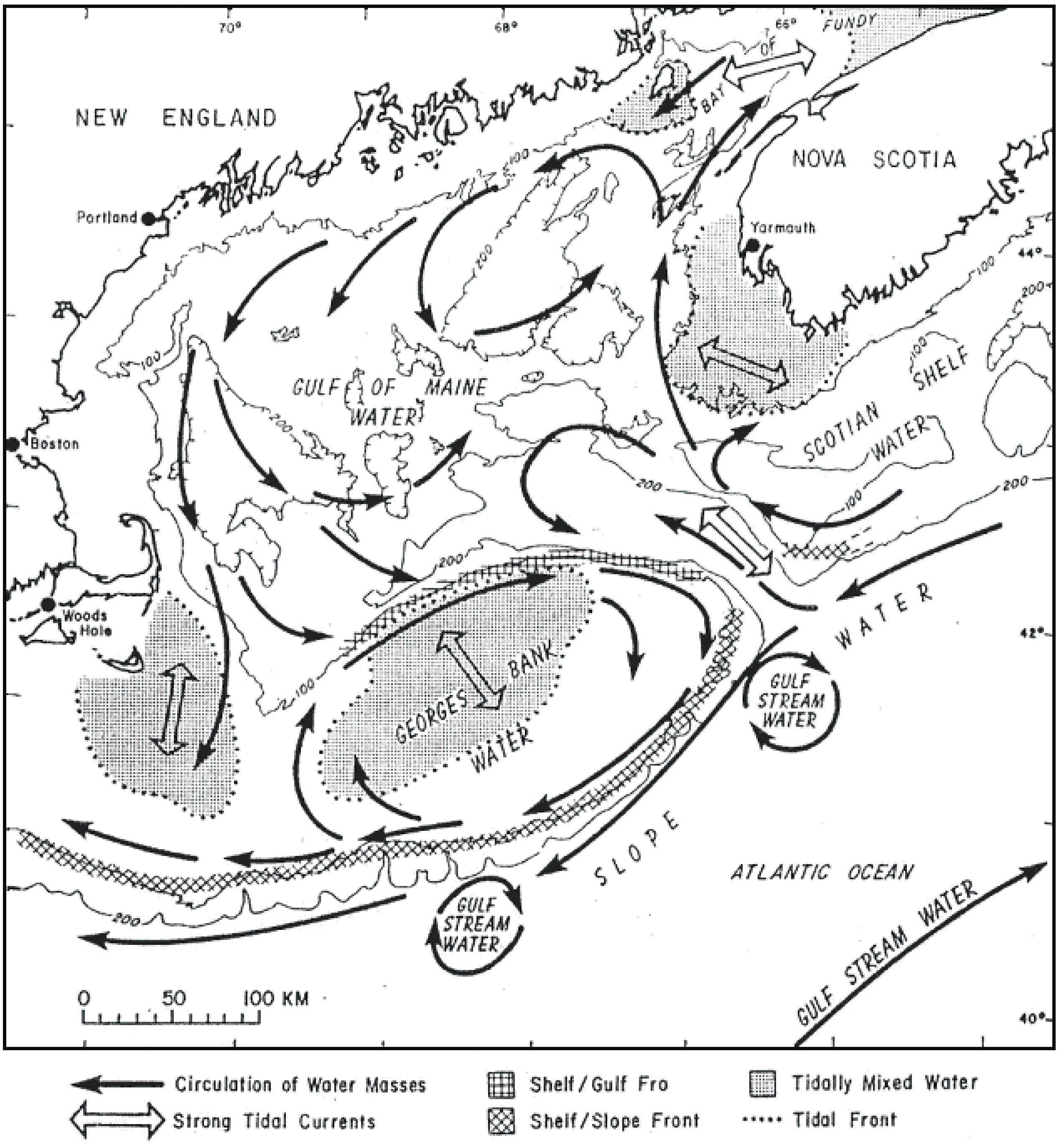


Figure 2.4. Water mass circulation patterns in the Georges Bank - Gulf of Maine region. (Depth in meters. Source: Valentine and Lough (1991).)

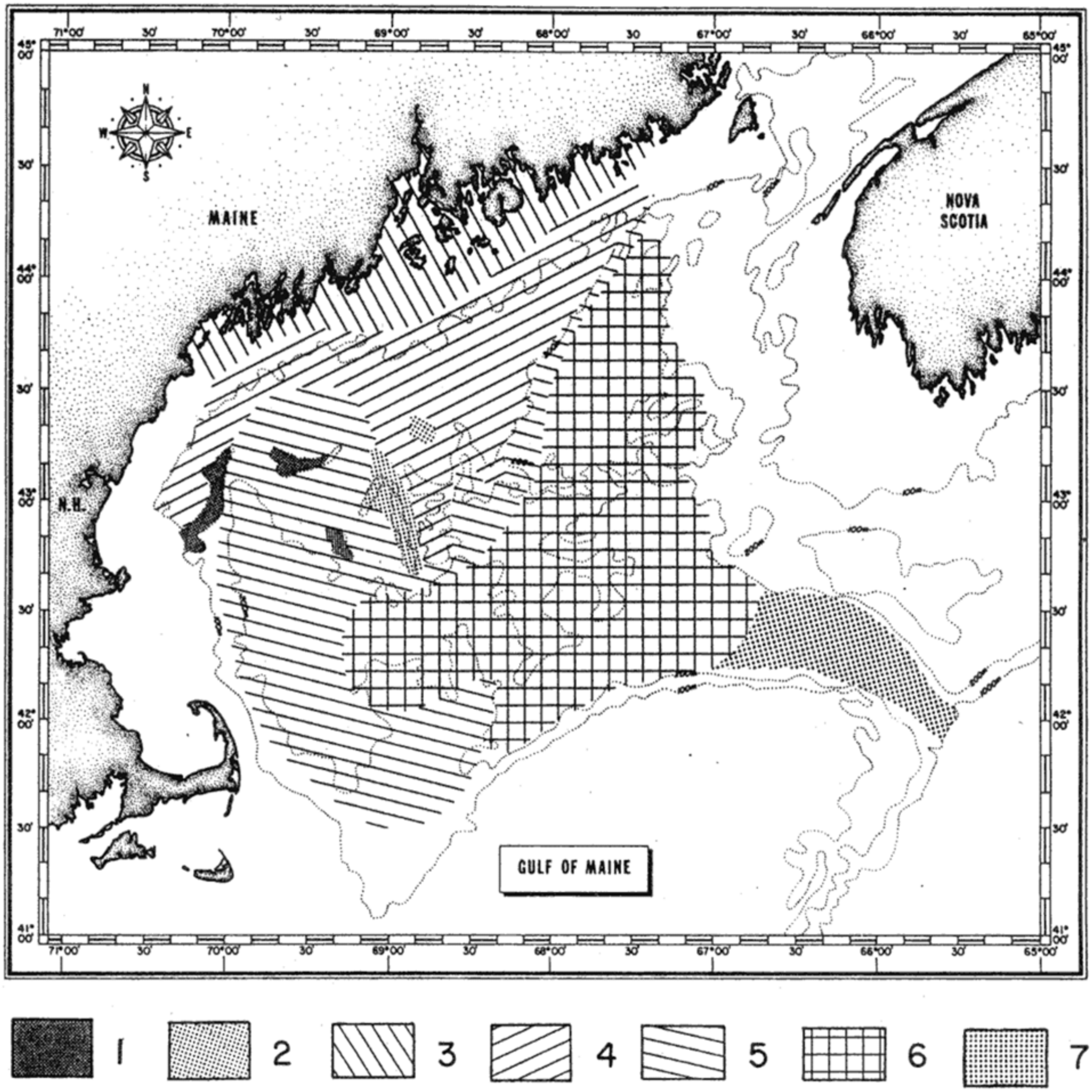


Figure 2.5. Distribution of the seven major benthic assemblages in the Gulf of Maine. (1 = sandy offshore banks; 2 = rocky offshore ledges; 3 = shallow (<50 m) temperate bottoms with mixed substrate; 4 = boreal muddy bottom, overlain by Maine Intermediate Water, 50-160 m (approximate); 5 = cold deep water, species with broad tolerances, muddy bottom; 6 = deep basin warm water, muddy bottom; and 7 = upper slope water, mixed sediment. Source: Watling (1998).)

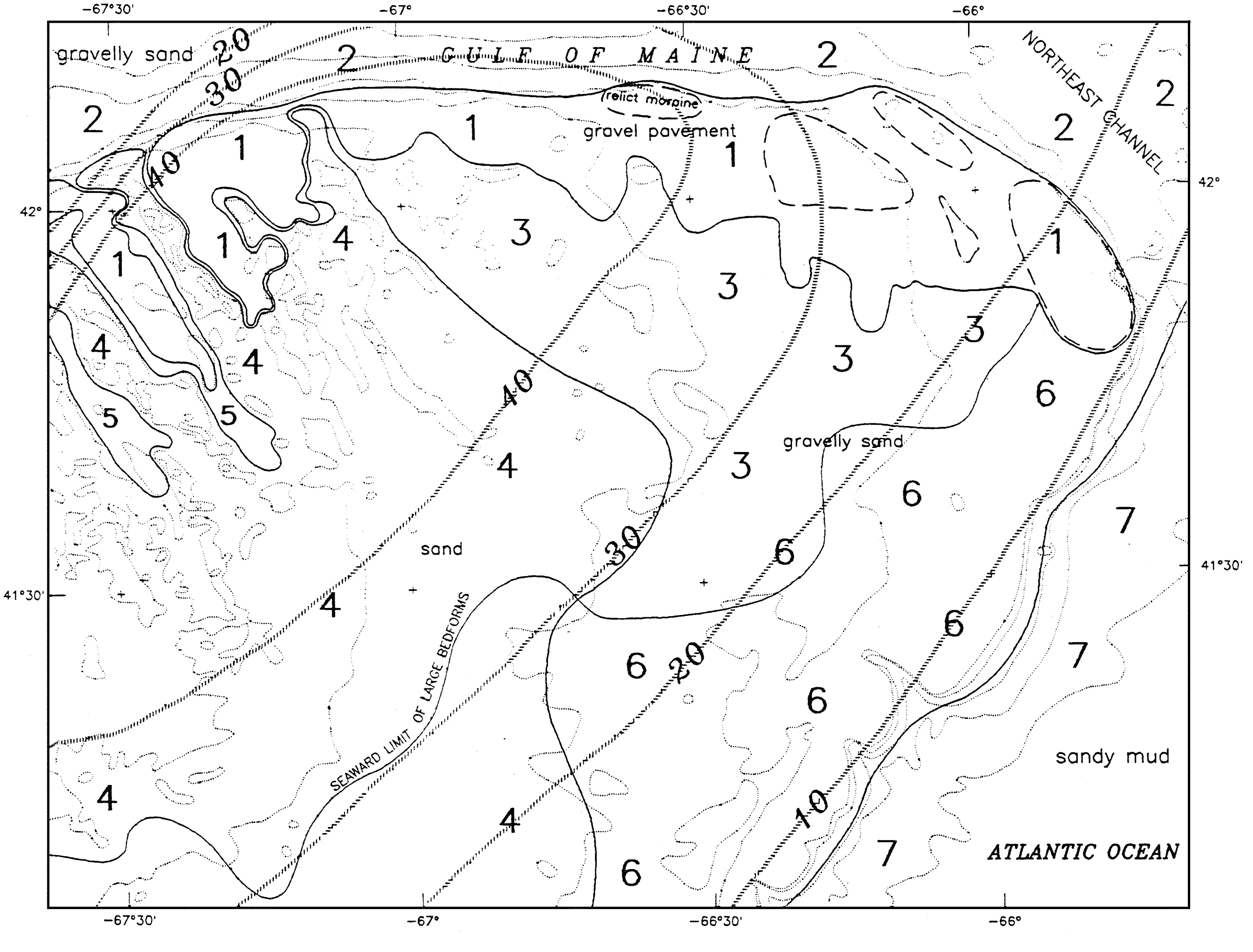
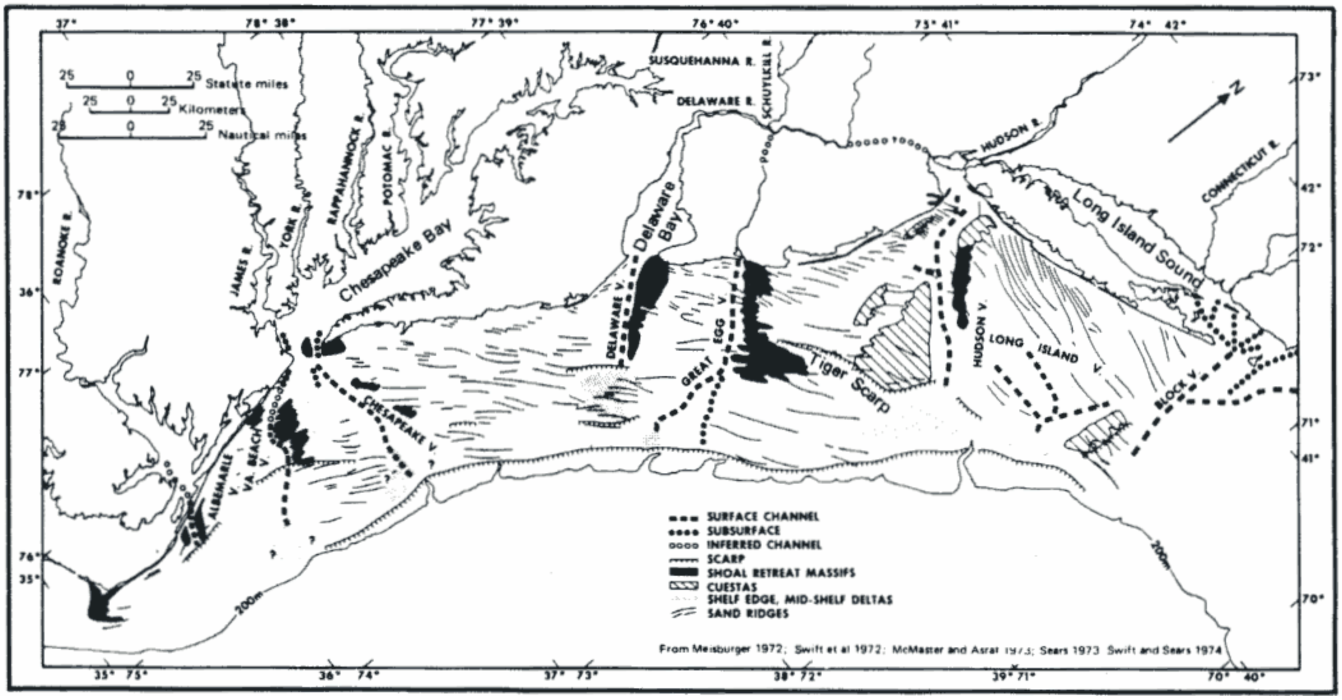
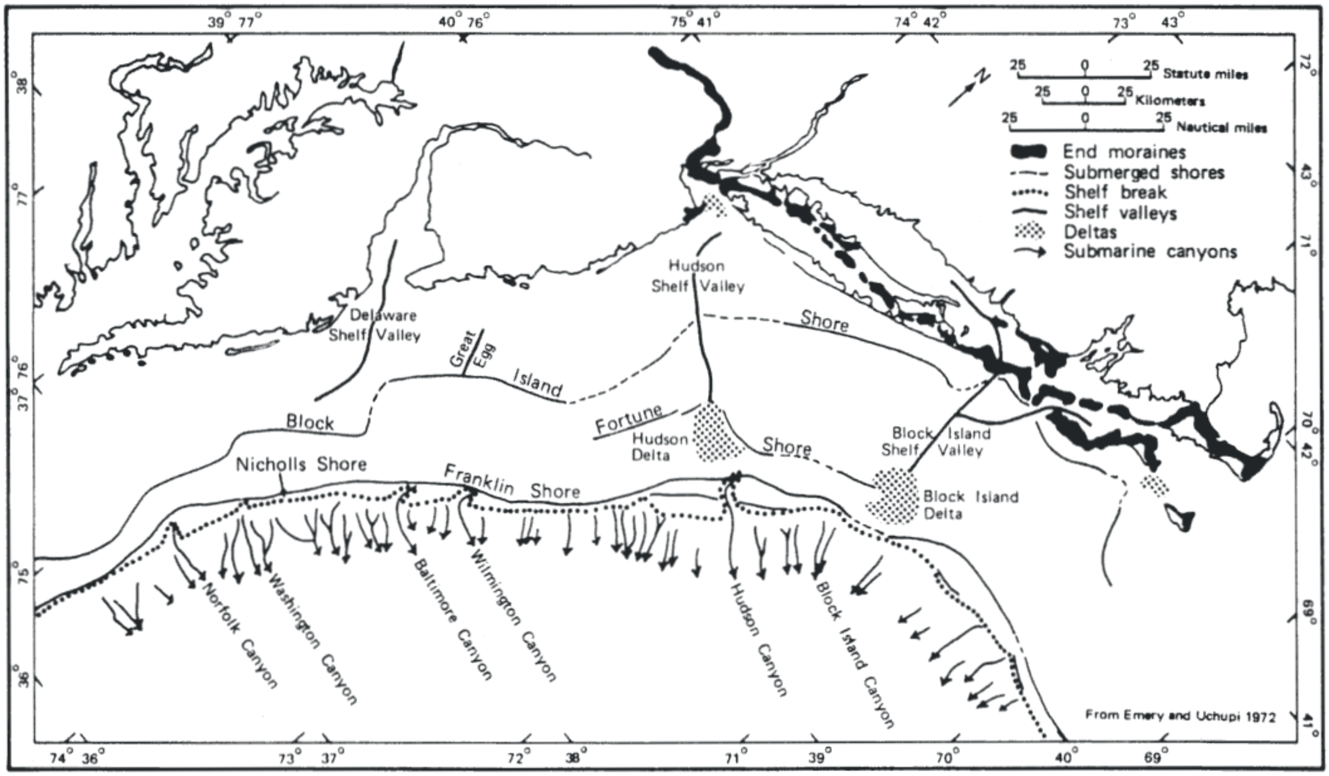


Figure 2.6. Sedimentary provinces of eastern Georges Bank. (Numbered 1-7. Based on criteria of seafloor morphology, texture, sediment movement and bedforms, and mean tidal bottom current speed (shown as hatched-line contours ranging between 10 and 40 cm/s). Relict moraines (bouldery seafloor) are enclosed by dashed lines. See Table 2.4 for descriptions of provinces. Source: Valentine and Lough (1991).)



From Meisburger 1972; Swift et al 1972; McMaster and Asrat 1973; Sears 1973 Swift and Sears 1974

Figure 2.7. Mid-Atlantic Bight submarine morphology. (Source: Stumpf and Biggs (1988).)



From Emery and Uchupi 1972

Figure 2.8. Major features of the Mid-Atlantic and Southern New England continental shelf. (Source: Stumpf and Biggs (1988).)

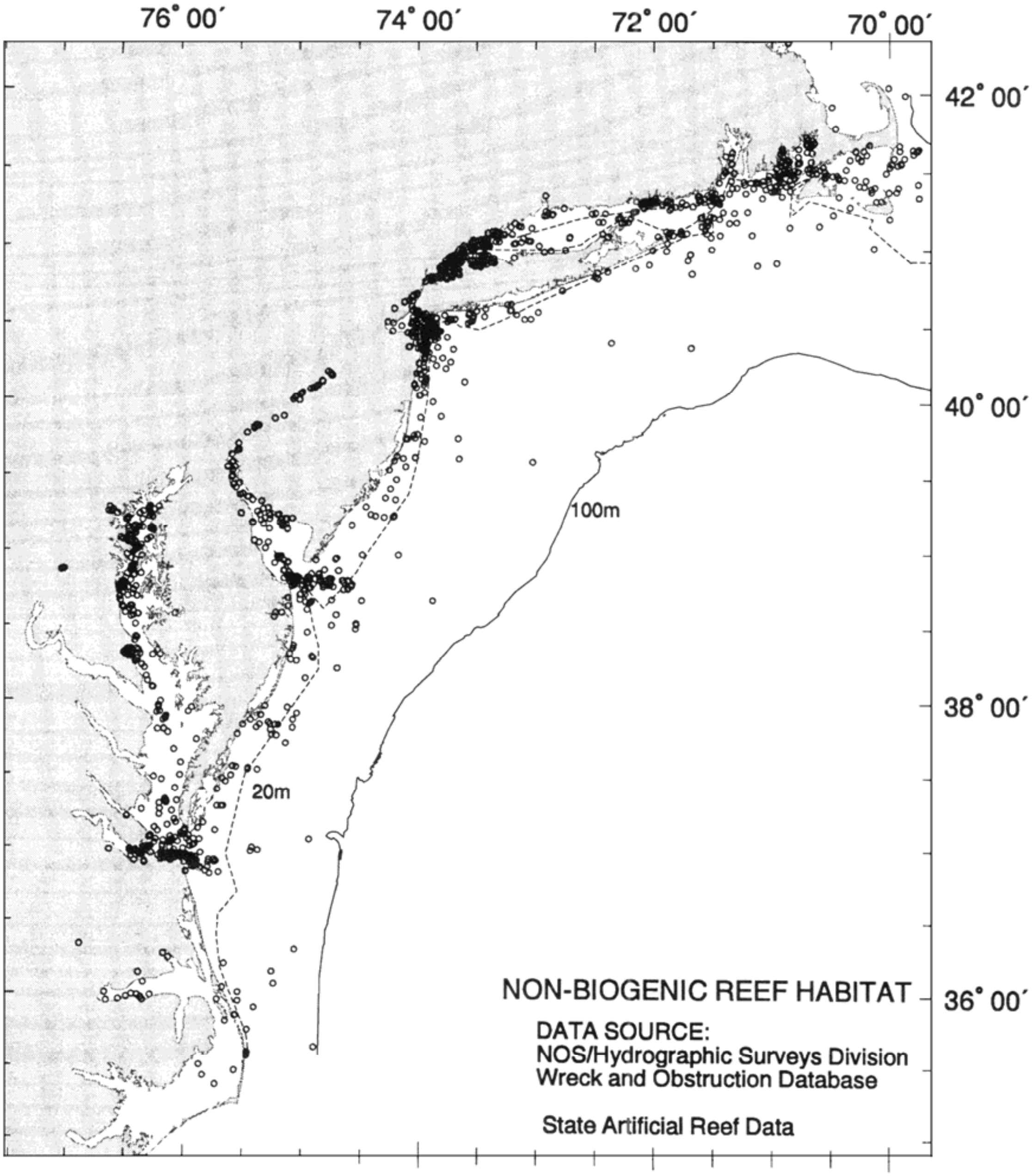


Figure 2.9. Summary of all reef habitats (except biogenic, such as mussel or oyster beds) in the Mid-Atlantic Bight. (Source: Steimle and Zetlin (2000).)

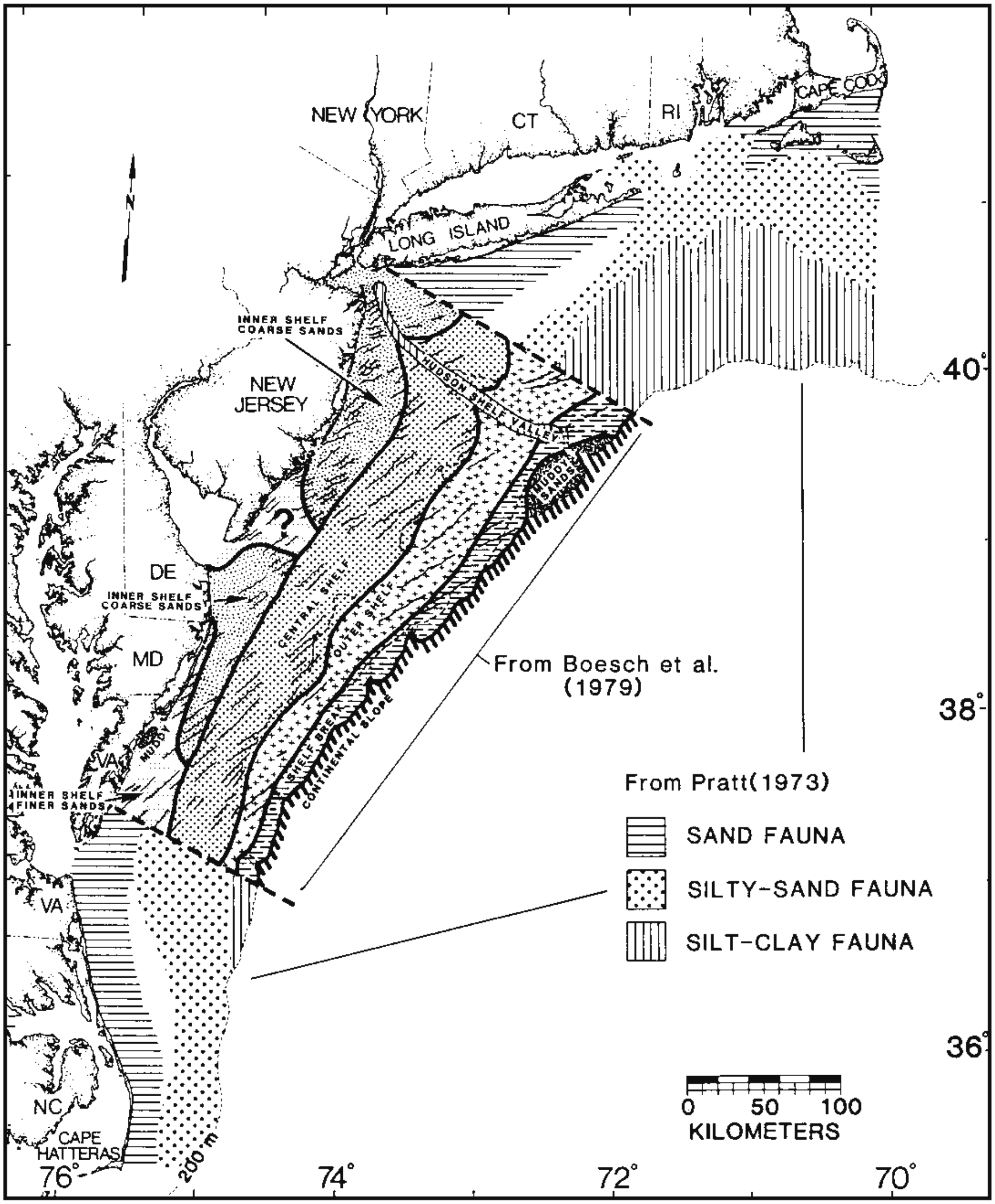


Figure 2.10. Schematic representation of major macrofaunal zones on the Mid-Atlantic shelf. (Approximate location of ridge fields indicated. Source: Reid and Steimle (1988).)

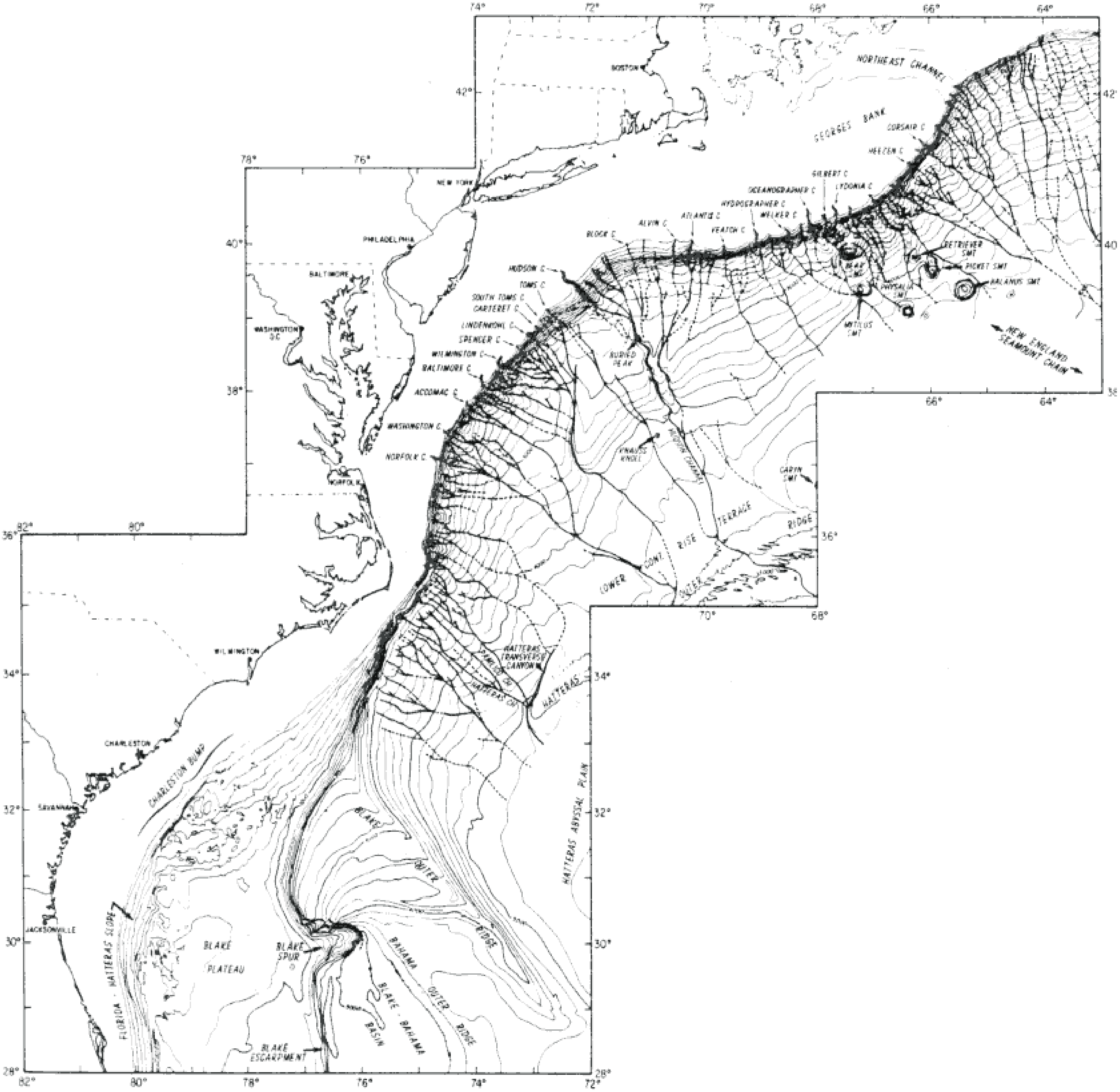
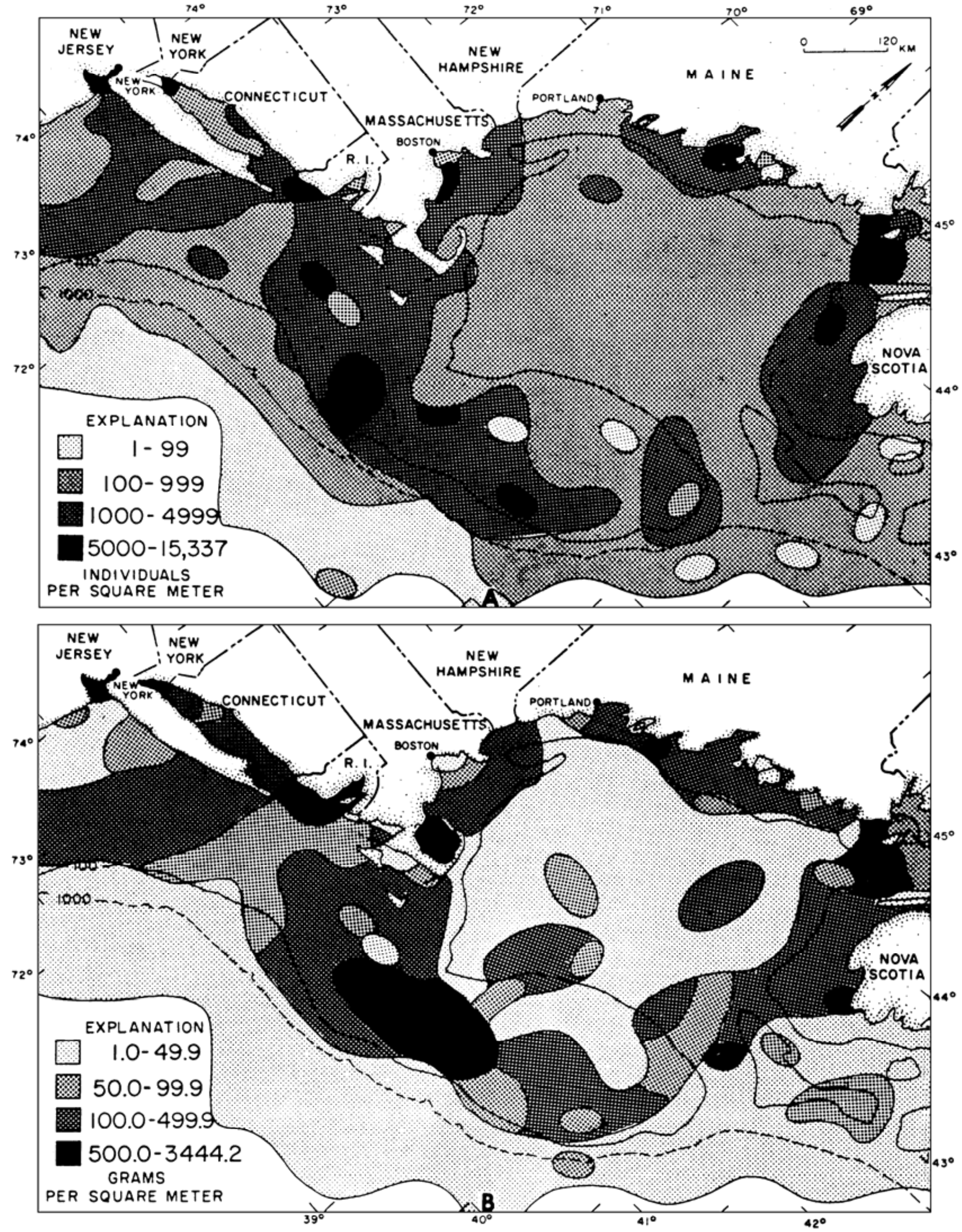


Figure 2.11. Bathymetry of the U.S. Atlantic continental margin. (Contour interval is 200 m below 1000 m of water depth, and 100 m above 1000 m of water depth. Axes of principal canyons and channels are shown by solid lines (dashed where uncertain or approximate). Source: Tucholke (1987).)



ALL TAXA COMBINED

Figure 2.12. Geographic distribution of the density (top) and biomass (bottom) of all taxonomic groups of benthic invertebrates in the New England region, 1956-1965. (Source: Theroux and Wigley (1998).)

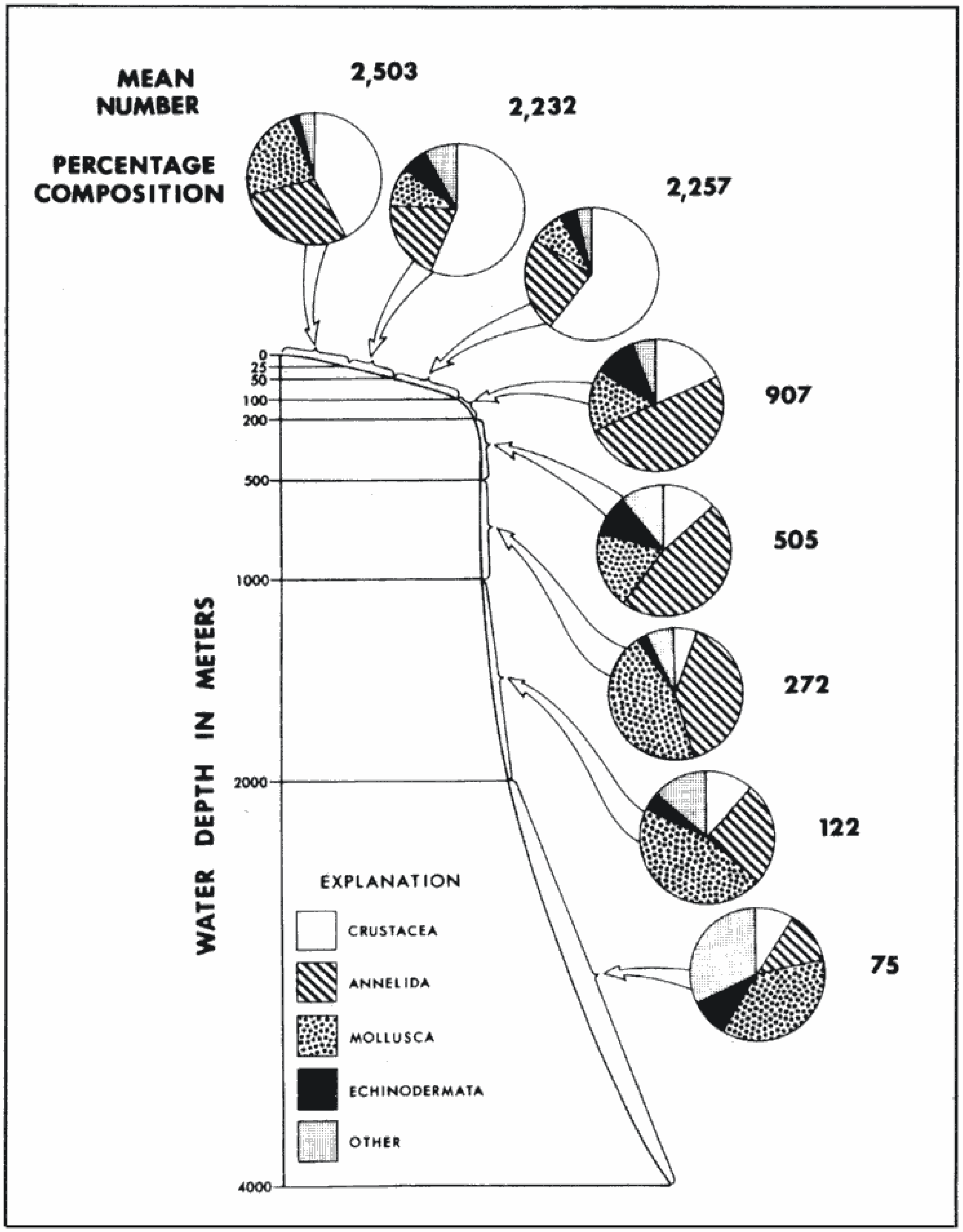


Figure 2.13. Percentage composition (by number of individuals) and density (as mean number of individuals per square meter of bottom area) of the major taxonomic groups of New England benthic invertebrate fauna in relation to water depth. (Source: Theroux and Wigley (1998).)

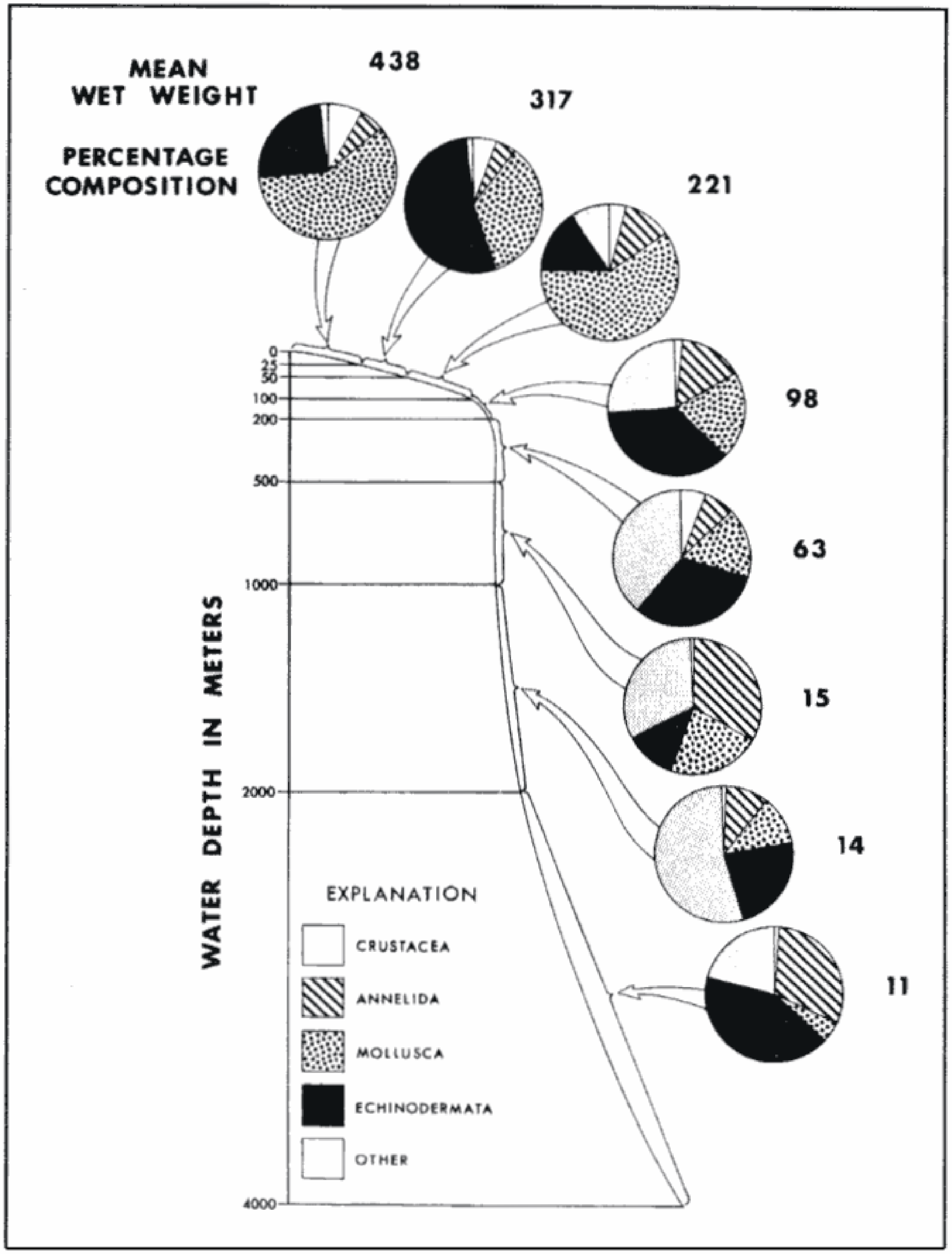


Figure 2.14. Percentage composition (by wet weight) and biomass (as mean wet weight in grams of individuals per square meter of bottom area) of the major taxonomic groups of New England benthic invertebrate fauna in relation to water depth. (Source: Theroux and Wigley (1998).)

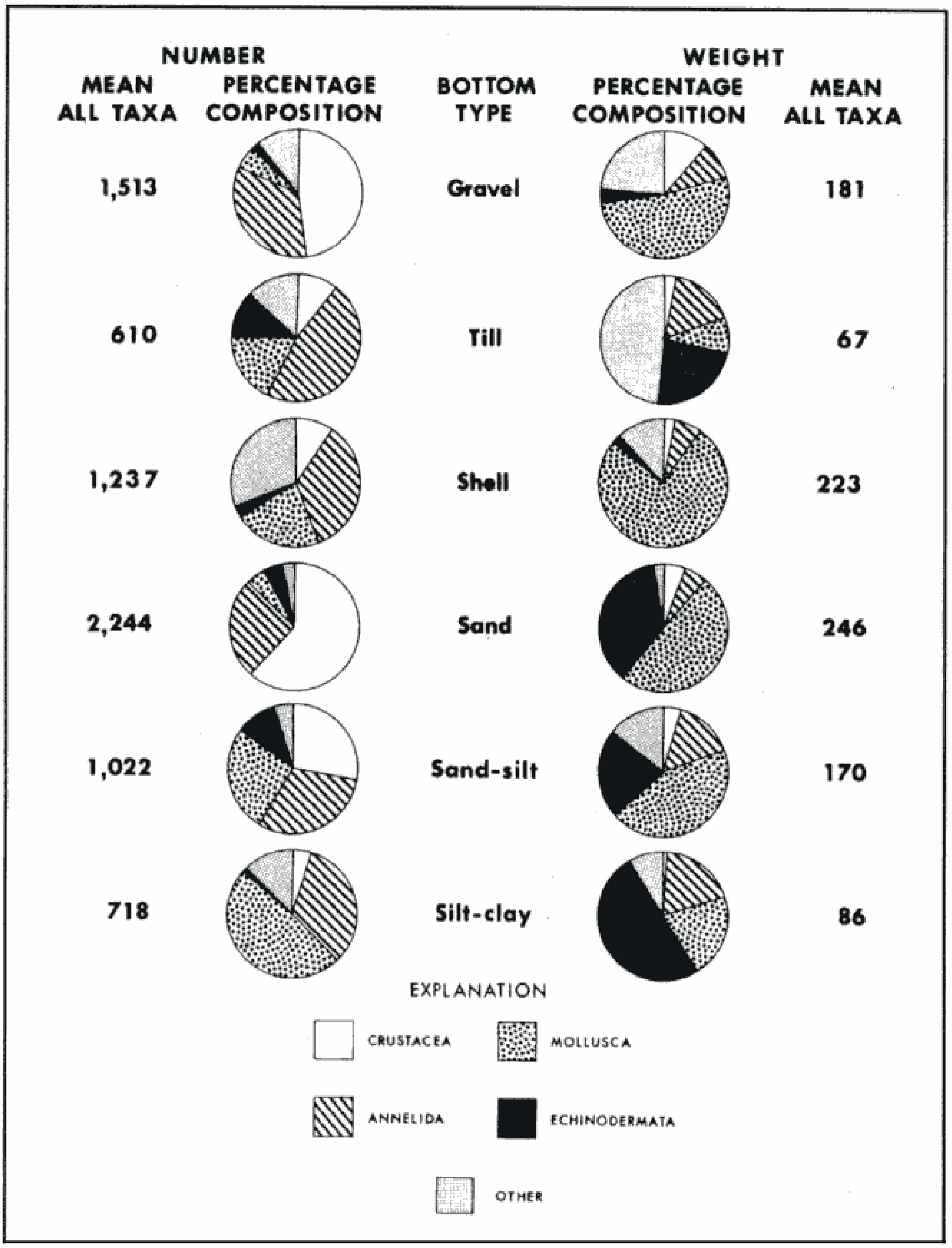


Figure 2.15. Percentage composition (by number of individuals and by wet weight) and density and biomass (as mean number and wet weight (in grams), respectively, of individuals per square meter of bottom area) of the major taxonomic groups of New England benthic invertebrate fauna in relation to bottom type. (Source: Theroux and Wigley (1998).)

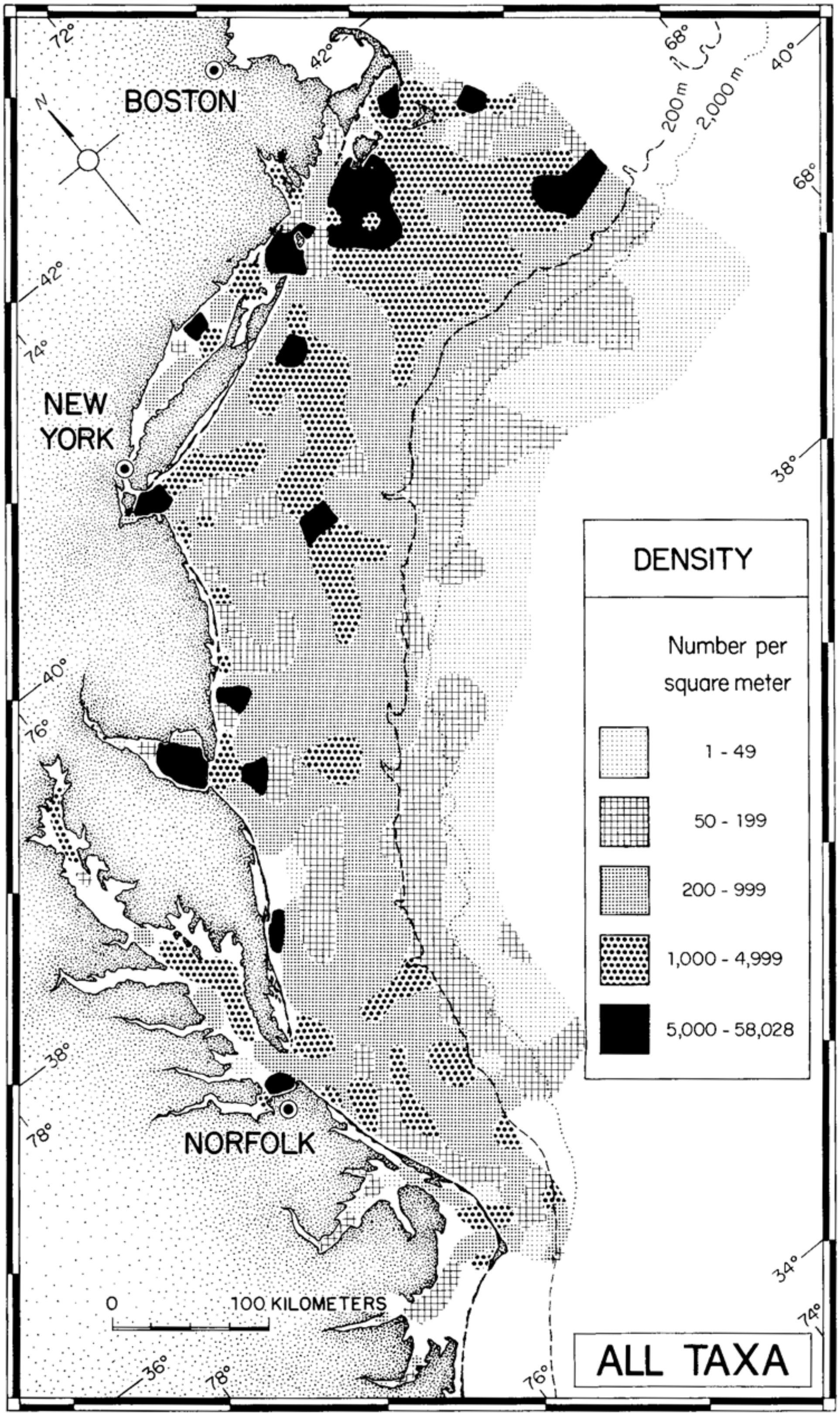


Figure 2.16. Geographic distribution of the density (as mean number of individuals per square meter) of all taxonomic groups of benthic invertebrates in the Mid-Atlantic region, 1956-1965. (Source: Wigley and Theroux (1981).)

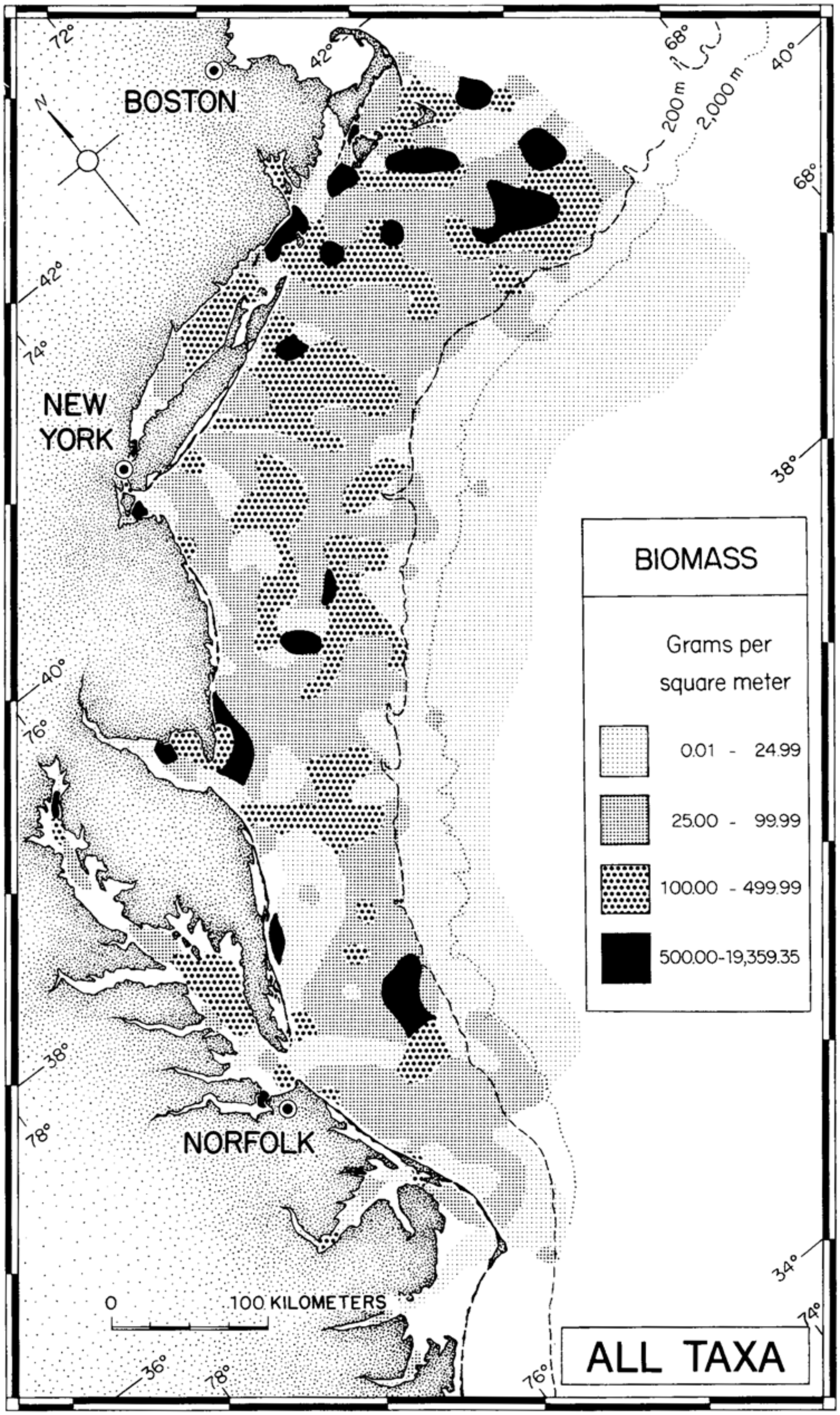


Figure 2.17. Geographic distribution of the biomass (as mean wet weight in grams per square meter) of all taxonomic groups of benthic invertebrates in the Mid-Atlantic region, 1956-1965. (Source: Wigley and Theroux (1981).)

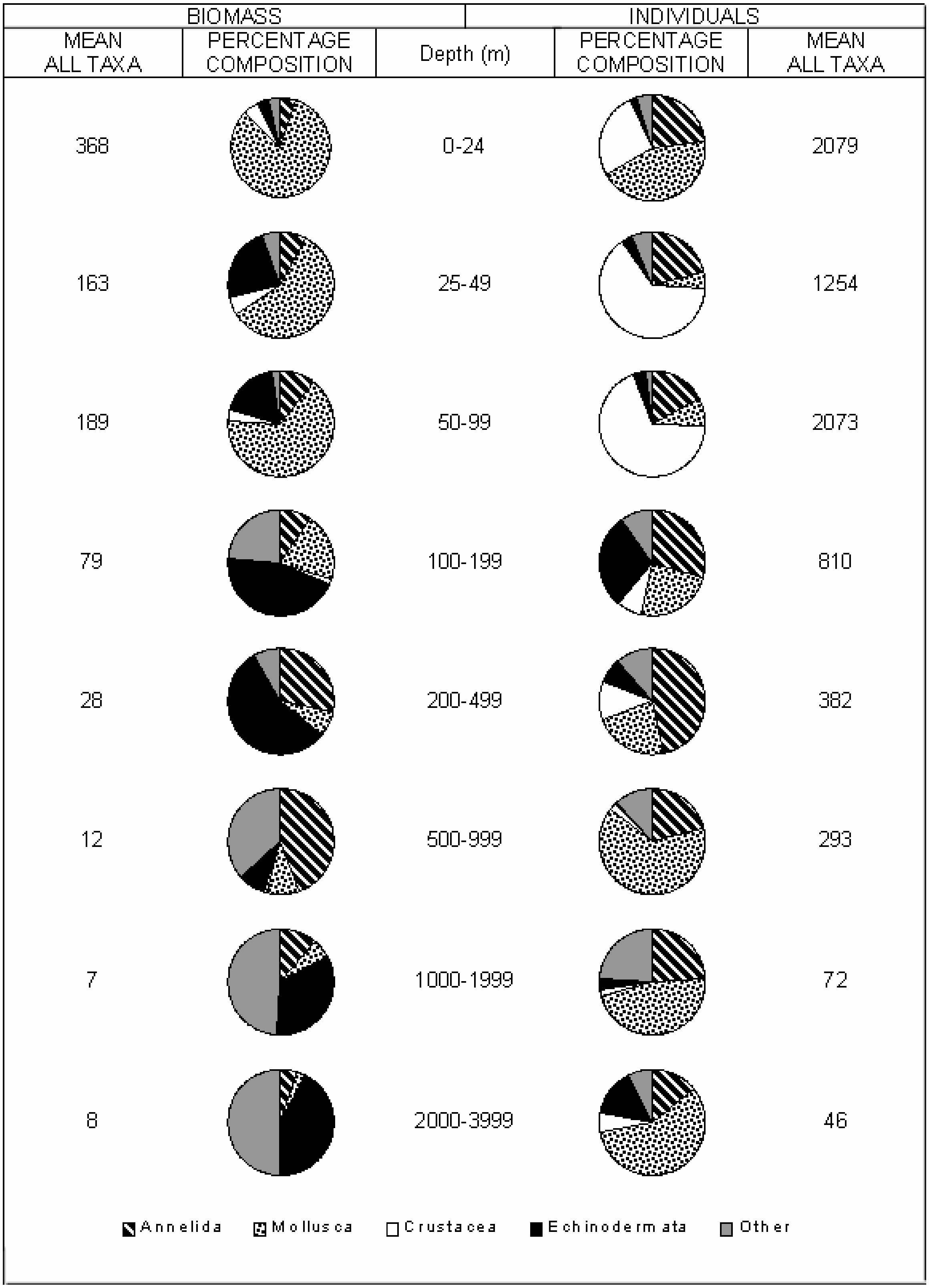


Figure 2.18. Percentage composition (by number of individuals and by wet weight) and density and biomass (as mean number and wet weight (in grams), respectively, of individuals per square meter of bottom area) of the major taxonomic groups of Mid-Atlantic benthic invertebrate fauna in relation to water depth. (Source: Wigley and Theroux (1981).)

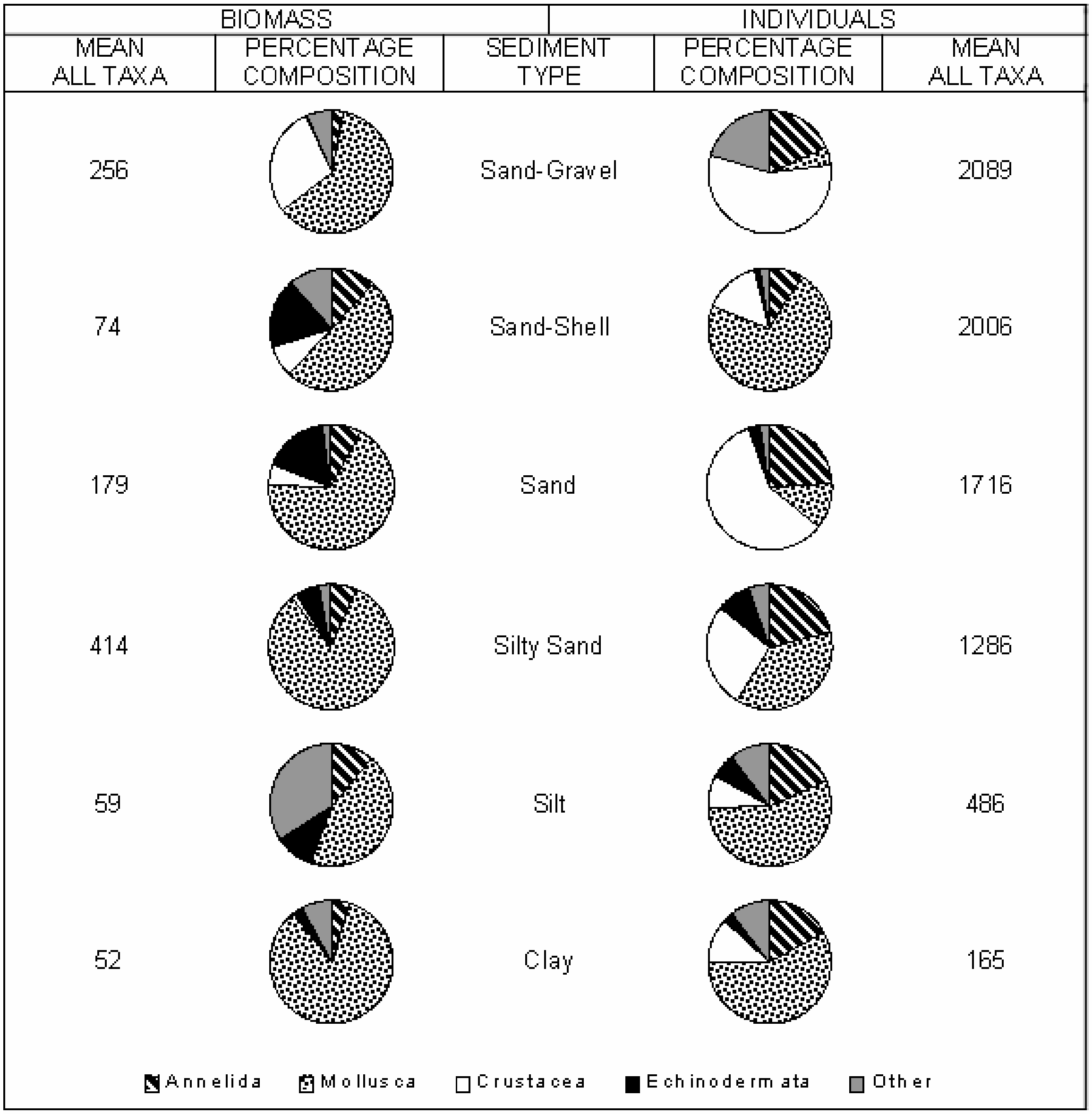


Figure 2.19. Percentage composition (by number of individuals and by wet weight) and density and biomass (as mean number and wet weight (in grams), respectively, of individuals per square meter of bottom area) of the major taxonomic groups of Mid-Atlantic benthic invertebrate fauna in relation to bottom type. (Source: Wigley and Theroux (1981).)

3. FISHING GEAR AND PRACTICES USED IN THE NORTHEAST REGION

The geographical area of responsibility of the Northeast Region also falls variously within the jurisdiction of the New England Fishery Management Council (NEFMC) and Mid-Atlantic Fishery Management Council (MAFMC), as well as the individual states from Maine to North Carolina which are represented by the Atlantic States Marine Fisheries Commission (ASMFC). These organizations are responsible for the management of many different fisheries, extending from the upper reaches of rivers and estuaries to the outer limit of the Exclusive Economic Zone, located 200 mi offshore, well beyond the edge of the continental shelf (Figure 2.1). In addition, some federally managed species that are found at certain times of year in the Northeast Region are managed by the South Atlantic Fisheries Management Council.

Fishing gear types used to land 1% or more of any species managed by either the NEFMC or MAFMC are listed in Table 3.1, and gear types that contributed 1% or more of any individual state's total landings for federally and state-managed species are listed in Table 3.2. Although certain gear types used in state waters are not managed by the federal government, they may adversely impact EFH that is designated in nearshore, estuarine, and riverine areas. Consequently, Table 3.3 lists all fishing gear types and harvesting techniques that are identified in Tables 3.1 and 3.2, and indicates whether they are used in estuaries, coastal waters (0-3 mi), or offshore waters (3-200 mi). Since the seafloor is the location of the habitat types most susceptible to gear disturbances, Table 3.3 also indicates which gear types and harvesting techniques contact the bottom, and which ones are regulated under a federal fishery management plan (FMP). This document considers a gear to be regulated under a federal FMP if it is typically utilized to harvest fish under a federal vessel or operators permit. Most of the gear types listed in Table 3.3 are described in this chapter of the document.

Unless otherwise noted by reference in the following descriptions, the information used to describe gear types and fishing practices in the Northeast Region was obtained from four primary sources: Sainsbury (1996), DeAlteris (1998), Everhart and Youngs (1981), and the report of a panel of science and fishing industry representatives on the effects of fishing gear on marine habitats in the region (NREFHSC 2002). Information regarding the use of fishing gears in state waters within the region was extracted from Stephan *et al*. (2000). The gear descriptions in this document are based on information that was available to the authors and, in some cases, are incomplete.

BOTTOM-TENDING MOBILE GEAR

Bottom Trawls

Trawls are classified by their function, bag construction, or method of maintaining the mouth opening. Function, in turn, may be defined by the part of the water column where the trawl operates (*e.g.*, bottom) or by the species that it targets (Hayes 1983). Bottom trawls are designed to be towed along the seafloor and to catch a variety of demersal fish and invertebrate species. Mid-water trawls are designed to catch pelagic species in the water column, and do not normally contact the bottom. They are described under "Pelagic Gear" later in this chapter. Three general types of bottom trawl, are used in the Northeast Region, but one of them, the bottom otter trawl, accounts for nearly all commercial bottom trawling activity.

Otter Trawls

There is a wide range of otter trawl types used in the Northeast Region because of the diversity of fisheries prosecuted and bottom types encountered in the region. The specific gear design is often a result of the target species (*e.g.*, whether they are found on or off the bottom) as well as the composition of the bottom (*i.e.*, smooth versus rough and soft versus hard). Bottom otter trawls are used to catch a variety of species throughout the region and account for a higher proportion of the catch of federally managed species than any other gear type in the region (Tables 3.1 and 3.2).

There are three components of the otter trawl that come in contact with the seafloor: the doors, the ground cables and bridles which attach the doors to the wings of the net, and the sweep which runs along the bottom of the net mouth. The footrope of the net is attached to the sweep. Bottom trawls are towed at a variety of speeds, but average about 5.6 km/hr (3 knots).

Use of this gear in the region is managed under several federal FMPs. Bottom trawling is also subject to a variety of state regulations throughout the region.

Doors

The traditional otter board or door is a flat, rectangular wood structure with steel fittings and a steel "shoe" along the leading and bottom edges that prevents damage and wear of the door as it drags over the bottom. Wooden trawl doors are still in use in the Northeast Region, but they have been largely replaced by heavier, more efficient, steel doors. Two types of steel doors commonly used in the region are the V-shaped "Thyboron" door and the cambered (or curved) "Bison" door (pers. comm.; Alan Blott, National Marine Fisheries Service, North Kingstown, RI). Either type of door can be slotted to allow some water to flow through the door, further increasing its efficiency. Steel "shoes" can be added at the bottom of the door to aid in keeping it upright and take the wear from bottom contact. The sizes and weights of trawl doors used in the Northeast Region vary according to the size and type of trawl, and the size and horsepower of the vessel. Large steel doors (4-5 m^2) weigh between 700 kg and 1 mt.

It is the location on each door at which the towing cable, or "warp," is attached that creates the towing angle, which in turn creates the hydrodynamic forces needed to push the door outward and downward, thus spreading the wings of the net. The nontraditional designs increase the spreading force of the door by increasing direct pressure on the face of the door and/or by creating more suction on the back of the door. On fine-grained sediments, the doors also function to create a silt cloud that aids in herding fish into the mouth of the net. On rocky or more irregular bottom, trawl doors impact rocks in a jarring manner and can jump distances of 1-2 m (Carr and Milliken 1998).

Ground Cables and Bridles

Steel cables are used to attach the doors to the wings of the net. A ground cable runs along the bottom from each door to two other cables (*i.e.*, the upper and lower "bridles") that diverge to attach to the top and bottom of the net wing. The lower bridle also contacts the bottom. In New England, fixed rubber disks ("cookies") or rollers are attached to the ground cables and lower bridles to assist the passage of the trawl over the bottom. For bottom trawling, in very general terms, bridles vary in length from 9 to 73 m (30 to 240 ft), while ground cables vary from 0 to 73 m (0 to 240 ft), depending upon bottom conditions, towing speed, and fish behavior.

Sweeps

Two types of sweep are used on smooth bottom in New England (Mirarchi 1998). In the traditional chain sweep, loops of chain are suspended from a steel cable, with only 2-3 links of the chain touching bottom. Contact of the chain with the bottom reduces the buoyancy of the trawl so that it skims just a few inches above the bottom to catch species such as squid and scup that swim slightly above the bottom. The other type of New England smooth-bottom sweep is used to catch flounder. Instead of a cable, it uses a heavy chain with rubber cookies stamped from automobile tires. This latter type of sweep is always in contact with the bottom. The cookies vary in diameter from 10 to 41 cm (4 to 16 in) and do not rotate (Carr and Milliken 1998).

On rough bottoms, roller and rockhopper sweeps are used (Carr and Milliken 1998). In the roller sweeps, vertical rubber rollers as large as 91 cm (36 in) in diameter are placed at intervals along the sweep. In fact, however, only the "rollers" that are located at or near the center of the sweep actually "roll" over the bottom; because the sweep is shaped in a curve, the others are oriented at increasing angles to the direction of the tow and do not rotate freely as they are dragged over the bottom (pers. comm.; Alan Blott, National Marine Fisheries Service, North Kingstown, RI). In New England, roller sweeps have been largely replaced with "rockhopper" sweeps that use larger fixed rollers, and are designed to "hop" over rocks as large as 1 m in diameter. Small rubber "spacer" disks are placed between the larger rubber disks in both types of sweep. Rockhopper gear is no longer used exclusively on hard-bottom habitats, but is actually quite versatile and is used in a variety of habitat types (Carr and Milliken 1998). The range of footrope/headrope lengths for bottom trawls used in the New England inshore day-boat fleet is 18/12 m (60/40 ft) for smaller (12-m or 40-ft) vessels, and increases up to 42/36 m (140/120 ft) for larger vessels (21 m/70 ft or larger) (pers. comm.; Alan Blott, National Marine Fisheries Service, North Kingstown, RI).

Factors Affecting Area Swept by Bottom Otter Trawls

The area of bottom that is contacted by a bottom otter trawl during a tow is a function of the linear distance covered (a product of the speed of the net over the bottom and the duration of the tow) and the width of the tow path. The width of the tow path is the distance between the doors (*i.e.*, across the mouth of the net) and varies according to the force exerted on the doors, the ground cables, the sweep, and the net as it is towed over the bottom. Nets towed at higher speeds, or that offer more resistance to being towed through the water and over the bottom, are swept back in a more pronounced parabolic shape than nets towed at slower speeds, or nets that offer less resistance. Mirarchi (1998) has estimated that on smooth bottom and at a towing speed of 5.6 km/hr (3 knots), the linear distance between the doors is equal to roughly one-third of the total length of the ground cables, the bridles, and the sweep. Thus, a bottom trawl with a 30-m (100-ft) sweep and 75-m (250-ft) bridles and ground cables on either side of the net would sweep an area 60 m (200 ft) wide.

Some Specific Types of Otter Trawl Used in the Region

A number of different types of bottom otter trawl used in the Northeast Region are specifically designed to catch certain species of fish, on specific bottom types, and at particular times of year. Some of the major differences in bottom trawl design are described here, but these descriptions are not very specific because there are many variations of each basic trawl type, and because detailed information on all the different types of bottom trawl used in the region are lacking. Furthermore, the performance of any bottom trawl (*i.e.*, how it "behaves" as it is towed over the bottom), and the degree to which it contacts and disturbs the bottom during any tow, are affected by a number of factors such as how much trawl wire is set out (relative to the depth), the bottom type and topography, the amount of bottom current, etc.

Flatfish trawls, described by Mirarchi (1998), are designed with a low net opening between the headrope and the footrope and more ground rigging (i.e, rubber cookies and chain) on the sweep. This type of trawl is designed so that the sweep will follow the contours in the bottom, and to get fish like flounders -- that lie in contact with the seafloor -- up off the bottom and into the net. It is used on smooth mud and sand bottoms. A high-rise or fly net with larger mesh has a wide net opening and is used to catch demersal fish that rise higher off the bottom than flatfish (NREFHSC 2002).

Bottom otter trawls used to catch species like scup and squid that swim over the bottom are rigged very lightly, with loops of chain suspended from the sweep (Mirarchi 1998). This gear is designed to skim along the seafloor with only two or three links of each loop of chain touching the bottom (details are described above). This type of trawl is also used on smooth bottoms.

Bottom otter trawls that are used on "hard" bottom (*i.e.*, gravel or rocky bottom), or mud or sand bottom with occasional boulders, are rigged with rockhopper gear. The purpose of the "ground gear" in this case is to get the sweep over irregularities in the bottom without damaging the net. The purpose of the sweep in trawls rigged for fishing on smooth bottoms is to herd fish into the path of the net (Mirarchi 1998).

Small-mesh trawls are used in the Northeast Region to capture northern and southern shrimp, silver hake (whiting), butterfish, and squid. Bottom trawls used to catch northern shrimp in the GOM are smaller than most fish trawls. Footropes range in length from 12 m to over 30 m (40-100 ft), but most are 15-27 m (50-90 ft). Regulations require that northern shrimp trawls may not be used with ground cables, and that the "legs" of the bridles not exceed 27 m (90 ft). These regulations were implemented in order to reduce the amount of area swept during a tow, thus reducing the bycatch of groundfish species. Northern shrimp trawls are also required to have Nordmore grates in the funnel of the net which reduce the retention of groundfish that enter the net. There has been a trend in recent years towards the use of heavier, larger roller and/or rockhopper gear in this fishery (ASMFC 2004).

The raised-footrope trawl was designed especially for fishing for silver hake, red hake, and dogfish. It was designed to provide vessels with a means of continuing to fish for small mesh species without catching groundfish. Raised-footrope trawls can be rigged with or without a chain sweep. If no sweep is used, drop chains must be hung at defined intervals along the footrope. In trawls with a sweep, chains connect the sweep to the footrope. Both configurations are designed to make the trawl fish about 0.45-0.6 m (1.5-2 ft) above the bottom (Carr and Milliken 1998). Although the doors of the trawl still ride on the bottom, underwater video and observations in flume tanks have confirmed that the sweep in the raised-footrope trawl has much less contact with the seafloor than does the traditional cookie sweep that it replaces (Carr and Milliken 1998).

An important consideration in understanding the relative effects of different otter trawl configurations is their weight in water relative to their weight in air. Rockhopper gear is not the heaviest type of ground gear used in this region since it loses 80% of its weight in water (*i.e.*, a rockhopper sweep that weighs 1000 lb on land may only weigh 200 lb in water). Plastic-based gear has the smallest weight-in-water to weight-in-air ratio (approximately 5%). For the same reasons, steel doors are much heavier in water than wooden doors.

Pair Trawls

Bottom pair trawls are towed over the bottom by two vessels, each towing one warp of the net. The mouth of the net is kept open by the outward pull provided by the two boats, so that no otter boards are required. By utilizing the combined towing power of the two vessels, and as no otter boards are needed, a larger net may be worked than would be possible by a single vessel. Alternatively, two vessels of low horsepower can combine to use this method efficiently. Bottom pair trawls are effective at catching demersal species such as cod and flatfish as well as small pelagic species.

This gear is rigged more simply than an otter trawl, with the warps being connected directly to the bridles from each wing of the net. Normally, a greater warp length/water depth ratio than for otter trawling is required because there are no doors to increase the drag of the gear in the water. The additional "scope" allows the warps to tend the bottom for some distance ahead of the bridles, creating a mud cloud that herds fish into the opening of the net. In some operations, ground cables may be rigged ahead of the bridles with weights placed at the connection to the warps.

Pair trawling for groundfish species managed by the NEFMC is currently prohibited.

Danish and Scottish Seines

Danish or long seining, or "anchor dragging," was developed in the 1850s prior to the advent of otter trawling. The Danish seine is a bag net with long wings that includes long warps set out on the seafloor enclosing a defined area. As the warps are retrieved, the enclosed triangular area reduces in size. The warps dragging along the bottom herd the fish into a smaller area, and eventually into the net mouth. The gear is deployed by setting out one warp, then the net, and finally the other warp. On retrieval of the gear, the vessel is anchored. This technique of fishing is aimed at specific schools of fish located on smooth bottom.

In contrast to Danish seining, if the vessel tows ahead while retrieving the gear, then this is referred to as Scottish seining or "fly-dragging." This method of fishing is considered more appropriate for working small areas of smooth bottom, surrounded by rough bottom.

Scottish and Danish seines have been used experimentally in U.S. demersal fisheries. Space conflicts with other mobile and fixed gears have precluded the further development of this gear in the United States, as compared to northern Europe.

This activity is managed under federal FMPs.

Hydraulic Clam Dredges

Atlantic Surfclam and Ocean Quahog Fishery

Hydraulic clam dredges have been used in the Atlantic surfclam fishery for over five decades, and in the ocean quahog fishery since its inception in the early 1970s. The typical dredge is 3.7 m (12 ft) wide and about 6.7 m (22 ft) long, and uses pressurized water jets to wash clams out of the seafloor. Towing speed at the start of the tow is about 4.6 km/hr (2.5 knots), and declines as the dredge accumulates clams. The dredge is retrieved once the vessel speed drops below about 2.8 km/hr (1.5 knots), which can be only a few minutes in very dense beds. However, a typical tow lasts about 15 min. The water jets penetrate the sediment in front of the dredge to a depth of about 20-25 cm (8-10 in) and help to "drive" the dredge forward.The water pressure that is required to fluidize the sediment varies from 50 lb/in^2 (psi) in coarse sand to 110 psi in finer sediments. The objective is to use as little pressure as possible since too much pressure will blow sediment into the clams and reduce product quality. The "knife" (or "cutting bar") on the leading bottom edge of the dredge opening is 14 cm (5.5 in) deep for surfclams and 9 cm (3.5 in) for ocean quahogs. The knife "picks up" clams that have been separated from the sediment and guides them into the body of the dredge ("the cage").

Hydraulic clam dredges can be operated in areas of large-grain sand, fine sand, sand with small-grain gravel, sand with small amounts of mud, and sand with very small amounts of clay. Most tows are made in large-grain sand. Surfclam/quahog dredges are not fished in clay, mud, pebbles, rocks, coral, large gravel >0.5 in, or seagrass beds.

Use of this gear in the region is managed under federal FMPs, and is also regulated in state waters in the Mid-Atlantic region, especially in shallow waters where submerged aquatic vegetation grows.

Softshell Clam Fishery

Hydraulic dredges are also used in the softshell (*Mya arenaria*) fishery in state waters of Maryland and Virginia. In this fishery, the dredge manifold and blade are located just forward of an escalator, or conveyor belt, that carries the clams to the deck of the vessel. Escalator dredges are typically operated from 15-m (49-ft) vessels in water depths of 2-6 m (7-20 ft). This gear cannot be operated in water depths less than one-half the length of the escalator.

Use of the escalator dredge is not managed under federal FMPs. This gear is subject to many of the same state laws and regulations that apply to surfclam and ocean quahog dredges in state waters.

Sea Scallop Dredges

The New Bedford-style scallop dredge is the primary gear used in the Georges Bank and Mid-Atlantic sea scallop fishery, and is very different than dredges utilized in Europe and the Pacific because it has no teeth on its leading edge.

The forward edge of the New Bedford-style dredge includes a cutting bar which rides above the surface of the substrate, creating turbulence that stirs up the substrate and kicks objects (including sea scallops) up from the surface of the substrate into the bag. Shoes on the cutting bar ride along the substrate surface. A sweep chain is attached to each shoe and to the bottom of the ring bag (Smolowitz 1998). The bag, which is made of metal rings with chafing gear on the bottom and of twine mesh on the top, drags on the substrate when fished. Tickler chains run from side to side between the frame and the ring bag, and, in hard-bottom scalloping, a series of rock chains run from front to back to prevent large rocks from getting into the bag. New Bedford-style dredges are typically 4.3 m (14 ft) wide; one or two of them are towed by single vessels at speeds of 4-5 knots (7.4-9.3 km/hr). New Bedford-style dredges used along the Maine coast are smaller. Dredges used on hard bottoms are heavier and stronger than dredges used on sand. Towing times are highly variable, depending on the density of marketable-sized sea scallops at any given location. Tows can be as short as 10 min or as long as 1 hr (pers. comm.; Ron Smolowitz, industry advisor to NEFMC Habitat Committee, Falmouth, MA).

In the Northeast Region, scallop dredges are used in high- and low-energy sand environments, and high-energy gravel environments. Although gravel exists in low-energy environments of deepwater banks and ridges in the GOM, the fishery is not prosecuted there.

The leading edge of scallop dredges used in Europe, Australia, and New Zealand to catch other species of scallop that "dig" into the bottom have teeth that dig into the substrate. A very limited amount of scallop dredging with toothed dredges takes place along the U.S. and Canadian coast of the GOM. These toothed dredges are used by smaller vessels that are not able to tow a New Bedford-style dredge fast enough (4-5 knots) to effectively catch scallops.

The use of scallop dredges in federal waters of the Northeast Region is managed under federal FMPs.

Other Nonhydraulic Dredges

Quahog Dredges

Mahogany quahogs (a colloquial name for ocean quahogs in New England) are harvested in eastern Maine coastal waters using a dredge that is essentially a large metal cage on skis, with 15-cm (6-in) long teeth projecting at an angle off the leading bottom edge (pers. comm.; Pete Thayer, Maine Department of Marine Resources, West Boothbay Harbor, ME). The teeth rake the bottom and lift the quahogs into the cage.

This fishery takes place in small areas of sand and sandy mud found among bedrock outcroppings in depths of 9-76 m (30-250 ft) in state and federal coastal waters north of 43°20' N latitude. These dredges are used on small boats (approximately 9-12 m (30-40 ft) long). Because water pressure is not used to dislodge the clams from the seafloor, all the power required to pull these dredges forward is provided by the boat's engine.

This dredging activity is managed under a federal FMP. Maine state regulations limit the length of the cutter bar to 91 cm (36 in).

Oyster, Crab, Mussel, and Whelk Dredges

The oyster dredge is a toothed dredge consisting of a steel frame 0.5-2.0 m (2-7 ft) wide, a tow chain or wire attached to the frame, and a bag to collect the catch. The teeth are 5-10 cm (2-4 in) in length. The bag is constructed of rings and chain links on the bottom to reduce the abrasive effects of the seafloor, and of twine or webbing on top. In the Northeast Region, oyster dredges are used in state waters from Connecticut to North Carolina to harvest the eastern oyster (*Crassostrea virginica*).

Blue crabs (*Callinectes sapidus*) are harvested with dredges (or "scrapes") similar to oyster dredges in state waters in New York, New Jersey, Delaware, Virginia, and North Carolina. Stern-rig dredge boats (approximately 15 m (49 ft) long) tow two dredges in tandem from a single chain warp. The dredges are equipped with 10-cm (4-in) long teeth that rake the crabs out of the bottom.

Dredges are also used to harvest blue mussels (*Mytilus edulis*) in state waters of Maine and Massachusetts, and to harvest channeled and knobbed whelks (*Busycon canaliculatus* and *B. carica*, respectively) in New York, Delaware, and Virginia.

These dredging activities are not managed under federal FMPs. The design and use of crab and shellfish dredges are subject to various restrictions in state waters.

Bay Scallop Dredges

The bay scallop (*Argopecten irradians*) dredge may be 1.0-1.5 m (3.3-4.9 ft) wide and about twice as long. The simplest bay scallop dredge can be just a mesh bag attached to a metal frame that is pulled along the bottom. For bay scallops that are located on sand and pebble bottom, a small set of raking teeth is set on a steel frame, and skids are used to align the teeth and the bag. Bay scallop dredges are used in state waters of Massachusetts, Rhode Island, New York, and North Carolina.

This dredging activity is not managed under federal FMPs.

Sea Urchin Dredges

Similar to a simple bay scallop dredge, the sea urchin dredge is designed to avoid damaging the catch. It has an upturned, sled-like shape at the front that includes several automobile leaf springs tied together with a steel bar. A tow bail is welded to one of the springs and a chain mat is rigged behind the mouth box frame. The frame is fitted with skids or wheels. The springs act as runners, enabling the sled to move over rocks without hanging up. The chain mat scrapes up the urchins. The bag is fitted with a cod-end for ease of emptying. This gear is generally used in depths up to 27.5 m (90 ft). Sea urchin dredges are used in state waters in the GOM to harvest green sea urchins (*Strongylocentrotus drobachiensis*).

This dredging activity is not managed under federal FMPs.

Seines

Beach Haul Seines

The beach seine resembles a wall of netting of sufficient depth to fish from the sea surface to the seafloor, with mesh small enough that the fish do not become "gilled." A floatline runs along the top to provide floatation, and a leadline with a large number of attached weights runs along the bottom to ensure that the net maintains good contact with the bottom. Tow lines are fitted to both ends.

The use of a beach seine generally starts with the net on the beach. One end is pulled away from the beach, usually with a small skiff or dory, and is taken out and around and finally back to shore. Each end of the net is then pulled in towards the beach, concentrating the fish in the middle of the net. The middle of the net is eventually brought onshore as well, and the fish are removed. This gear is generally used in relatively shallow inshore areas.

This activity is not managed under federal FMPs.

Long Haul Seines

The long haul seine is set and hauled in shallow estuarine and coastal areas by one or two boats. The net is a single wall of small-mesh netting (*i.e.*, <5 cm (2 in) as stretched mesh) that is usually >400 m (1310 ft) long and about 3 m (10 ft) deep. In a single-boat operation, one end of the net is attached to a pole driven into the bottom, and the net is set in a circle. After closing the circle, the net is hauled into the boat, reducing the size of the circle, and concentrating the fish. Finally, the live fish are brailed or dipnetted out of the net. In two-boat operations, the net is set as the boats travel in opposite directions, in a circle, from the same starting point. When the net is all out, the boats turn on the same course and pull the seine for some distance before they come together to close the net.

This activity is not managed under federal FMPs.

Stop Seines

The stop-seine fishery evolved from the traditional weir fishery for Atlantic herring in Maine (see "Trap Nets" later in this chapter) and involves the setting of nets across a cove with a narrow entrance after the herring enter, thus blocking their escape. Once the fish are "shut off," the fishermen wait until the fish enter a small "pocket" in the net. Once they enter the pocket, they are removed with a small purse seine and transferred to boats called "carriers" which bring the catch ashore (NOAA/NMFS 2005). This gear is not used much any more (ASMFC 1999a).

This activity is not managed under federal FMPs.

BOTTOM-TENDING STATIC GEAR

Pots

Pots are small, portable, rigid traps that fish and invertebrates enter through small openings, with or without enticement by bait, but can only leave with difficulty. They are used to capture lobsters, crabs, black sea bass, eels, and other bottom-dwelling species seeking food or shelter. Pot fishing can be divided into two general classifications: 1) inshore potting in estuaries, lagoons, inlets, and bays in depths up to about 75 m (250 ft); and 2) offshore potting using larger and heavier vessels and gear in depths up to 730 m (2400 ft) or more.

Lobster Pots

Originally, pots used to harvest American lobster (*Homarus americanus*) were constructed of wooden laths with single, and later, double, funnel entrances made from net twine. Today, almost all of the pots are made from coated wire mesh. They are rectangular and are divided into two sections, the "kitchen" and the "parlor." The kitchen has an entrance on both sides of the pot and is baited. Lobsters enter either chamber then move to the parlor through a long, sloping tunnel to the parlor. Escape vents are installed in both areas of the pot to minimize the retention of sublegal-sized lobsters. Rock crabs (*Cancer* spp.) are also harvested in lobster pots.

Lobster pots are fished as either a single pot per buoy, two or three pots per buoy, or strung together in "trawls" of up to 100 pots. Single pots are often used in rough, hard-bottom areas where lines connecting pots in a trawl line tend to foul on bottom structure. They are fished in trawls on flatter types of bottom. The area of bottom that comes in contact with a single trap during the setting and hauling process is small, but the cumulative effect of several million pots being set and hauled several times a week may be significant (Smolowitz 1998). The total number of traps used in the lobster fishery increased from just over one million in 1970 to over four million in 1998 (ASMFC 2000). According to NREFHSC (2002), important features of lobster pots and their use are the following:

- About 95% of lobster pots are made of plastic-coated wire.
- Pots in trawls are connected by "mainlines" which either float off the bottom, or, in areas where they are likely to become entangled with marine mammals, sink to the bottom.
- Soak time depends on season and location — usually 1-3 days in inshore waters in warm weather, but up to several weeks in colder waters.
- Offshore pots are larger (>1.2 m (4 ft) long) and heavier [~45 kg (100 lb)] than inshore pots, with an average of about 40 pots per trawl. They are usually deployed for 1 wk at a time.

Although the offshore component of the fishery is regulated under federal rules, American lobster is not managed under a federal FMP.

Fish Pots

Fish pots used to catch black sea bass, ocean pout, and scup (Table 3.1) are similar in design to lobster pots, and are usually fished singly or in trawls of up to 25 pots and in shallower waters than offshore lobster pots or red deepsea crab pots. Pots may be set and retrieved 3-4 times per day when fishing for scup.

Atlantic hagfish (*Myxine glutinosa*) pots are 55-gal plastic barrels with 3-6 entrance funnels and several rows of approximately 1-cm (3/8-in) escape holes. They are set 45-63 m (150-210 ft) apart to depths of 90-282 m (300-930 ft). Small boats fish 20-40 traps in a string, hauling several times per trip, and larger vessels fish 80-200 traps in a string, hauling 1-2 times per day. Soak time varies from 6 to 24 hr. The captain of a 26-m (85-ft) hagfish boat reported that he sets and hauls 1,000 traps (five sets of 200 traps) on each 5-day trip (NEFSC 2004).

Cylindrical pots are typically used for capturing American eels (*Anguilla rostrata*) in rivers and estuaries; however, half-round and rectangular pots are also used. They are hauled and set in a manner similar to that of lobster pots.

The use of fish pots in the black sea bass, scup, and ocean pout fisheries is managed under federal FMPs. Atlantic hagfish and American eel fishing activities in the region are not managed under federal FMPs.

Crab Pots

Crab pots are used in inshore coastal and estuarine waters in the Mid-Atlantic states to catch blue crabs (*Callinectes sapidus*). These pots typically consist of wire mesh. A horizontal wire partition divides the pot into an upper and lower chamber. The lower chamber is entered from all four sides through small wire tunnels. The partition bulges upward in a fold about 20 cm (8 in) high for about one-third of its width. In the top of the fold are two small openings that give access to the upper chamber. These crab pots are always fished as singles, and are hauled by hand in small boats, or by a pot hauler in larger boats. They are generally fished after an overnight soak, except early and late in the season. These pots are also effective for American eels. This activity is not managed under a federal FMP.

For red deepsea crabs (*Chaceon quinquedens*), the traditional-style pots are wood and wire traps that are 1.2 m long, 0.75 m wide, and 0.5 m high (48 x 30 x 20 in) with a top entry. A second style of pot used in this fishery is conical in shape, 1.3 m (4 ft) in diameter, and 0.45 m (22 in) high with a top-entry funnel. According to information provided in the 2002 red crab FMP (NEFMC 2002), vessels use an average of 560 pots that are deployed in trawls of 75-180 pots per trawl along the continental slope at depths of 400-800 m (1300-2600 ft). The pots are transported to and from the fishing grounds during each trip and are generally hauled daily. The vessels are large, typically measuring 27-46 m (90-150 ft) long. There are six vessels engaged in this fishery, which is managed by the NEFMC.

Whelk Pots

Wood and wire pots are used in southern Massachusetts waters to catch whelks, primarily the channeled whelk (pers. comm.; Frank Germano, Massachusetts Division of Marine Fisheries, New Bedford, MA). The pots are fished singly or in trawls with as many as 40 pots to a trawl in depths of 1.5-27 m (5-90 ft). They are set mostly on sandy bottom, often in or near seagrass beds. They are open at the top and baited, mostly with horseshoe crabs. Whelk pots are also used in coastal waters off New Jersey, Delaware, Maryland, and Virginia.

This activity is not managed under federal FMPs.

Trap Nets

A trap net is generally a largescale device that uses the seabed and sea surface as boundaries for the vertical dimension. The gear is installed at a fixed location for a season, and is passive, as the animals voluntarily enter the gear. Trap nets are used in nearshore areas through which fish regularly move or congregate. They are of varying size and configuration and rely for their effectiveness on preventing fish from leaving the trap once they have entered it. They are made of a leader or fence that directs fish into the trap, and a heart, or parlor, that leads fish via a funnel into the bay or trap section where the fish are held until they are harvested by the fishermen. Four specific types of trap net are described in this document.

Fish Pound Nets

Pound nets are constructed of netting that is attached to piles or stakes driven into the seafloor. Pound nets have three sections: the leader, the heart, and the pound. The leader (there may be more than one) may be as long as 400 m (1300 ft), and is used to direct fish into the heart(s) of the net. One or more hearts are used to further funnel fish into the pound and prevent escapement. The pound, which may be as large as a 15-m (49-ft) square, holds the fish until the net is emptied. The pocket usually has a netting floor; the fish are concentrated for “brailing” (a “brailer” is a very large dip net) by gradually bringing the sidewalls and bottom netting into boats working inside the pocket. These nets are generally fished in waters <50 m (160 ft) deep. A number of federally managed species are harvested in pound nets (Table 3.1).

This activity is not managed under a federal FMP.

Fyke Nets

Constructed of a series of wood or metal hoops covered with netting, fyke nets are 2.5-5.0 m (8.2-16.4 ft) long. There are usually two wings of netting at the entrance which are attached to upright stakes and give the overall net a "Y-shape." (Fyke nets that don't have wings are also called hoop nets). There are one or more funnels inside the net that direct fish to the rear of the net (the "car") where they become trapped. Occasionally, a long leader is used to direct fish to the entrance. Fish are removed by lifting the car out of the water and loosening a rope securing the rear of the car. These nets are generally fished in shallow water and used in river fisheries.

Fyke net fishing activity is not managed under a federal FMP.

Weirs

A weir is a simple maze that intercepts species that migrate along the shoreline. Weirs are used in the juvenile Atlantic herring fishery in eastern Maine and New Brunswick (Bay of Fundy) where the tides are extreme. At low tide, closely spaced wooden stakes are driven into the bottom. In the traditional style of weir, brush is interwoven between the stakes to form a barrier. Traps formed of netting have largely replaced the wooden weirs. The fish encounter the lead that they follow to deeper water, finally passing into an enclosure or "pound." Once they are concentrated in the "pocket," the fish are removed with a small purse seine. There are very few weirs currently in use in Maine (ASMFC 1999a).

This activity is not managed under a federal FMP.

Floating Traps

In New England, much of the shoreline and shallow subtidal environment is rocky, and stakes cannot be driven into the bottom. Therefore, a floating trap can be designed to fish from top to bottom, and be built to suit the individual location. The webbing of such traps is supported at the sea surface with floats, and held in place on the seafloor with large anchors. The net is usually somewhat "T-shaped," with the long portion of the net (*i.e.*, the leader) designed to direct fish into a box of net at the top of the T. The leader is often made fast to a ring bolt ashore. The catch, design elements, and scale of these floating traps are similar to pound nets.

This activity is not managed under a federal FMP.

Bottom Gill Nets

A gill net is a large wall of netting which may be set at or below the surface, on the seafloor, or at any depth between. They are equipped with floats at the top and lead weights along the bottom. Bottom gill nets are anchored or staked in position. Fish are caught as they try to pass through the net meshes. Gill nets are highly selective because the species and sizes of fish caught are highly dependant on the mesh size of the net. They are used to catch a wide range of species, including many federally managed species (Table 3.1).

Sink/Anchor Gill Nets

Gill nets have three components: leadline, netting, and floatline. Leadlines used in New England are 30 kg (65 lb) per net; leadlines used in the Mid-Atlantic are slightly heavier. The netting is monofilament nylon, and the mesh size varies depending on the target species. Nets are anchored at each end, using materials such as pieces of railroad track, sash weights, or Danforth anchors. Anchors and leadlines have the most contact with the bottom. Individual gill nets are typically 91 m (300 feet) long and 3.6 m (12 ft) high. Strings of nets may be set out in straight lines, often across the current, or in various other configurations (*e.g.*, circles), depending upon bottom and current conditions. Bottom gillnet fishing occurs in the Northeast Region in nearshore coastal and estuarine waters as well as offshore on the continental shelf.

In New England, bottom gill nets are fished in strings of 5-20 nets attached end to end. They are fished in two different ways, as "standup" and "tiedown" nets (Williamson 1998). Standup nets are used to catch Atlantis,c cod, haddock, pollock, and hake and are soaked for 12-24 hr. Tiedown nets are set with the floatline tied to the leadline at 1.8-m (6-ft) intervals, so that the floatline is close to the bottom, and the net forms a limp bag between each tie. They are left in the water for 3-4 days, and are used to catch flounders and goosefish (monkfish). Bottom gill nets in New England are set in relation to changes in bottom topography or bottom type where fish are expected to congregate. Other species caught in bottom gill nets in New England are spiny dogfish, and skates (Table 3.1).

In the Mid-Atlantic, sink gill nets are fished singly or in strings of just 3-4 nets (pers. comm.; Glenn Salvador, National Marine Fisheries Service, Lewes, DE). The Mid-Atlantic fishery is more of a "strike" type fishery in which nets are set on schools of fish or around distinct bottom features and retrieved the same day, sometimes more than once. They catch species such as bluefish, Atlantic croaker, striped bass, spot, mullet, spiny and smooth dogfish and skates.

The use of sink gill nets in federal waters is managed under federal FMPs. The use of gill nets is restricted or prohibited in some state waters in the region.

Stake Gill Nets

Generally, stake gill nets are used inshore. A small boat is used to set the net across a tidal flow, and to lift it at slack tide for removing fish. Wooden or metal stakes run from the surface of the water into the sediment and are placed every few meters along the net to hold it in place. When the net is lifted, the stakes remain in place. Stake gill nets are used in the Mid-Atlantic states to catch red drum, bluefish, king mackerel, and Spanish mackerel (Table 3.1).

These activities are not managed under federal FMPs.

Run-Around Gill Nets

The run-around gill net is used in shallow, nearshore areas to encircle schools of fish. They are set rapidly from the stern of small, fast boats. The leadline contacts the bottom, thus preventing the fish from escaping. Run-around gill nets are used in the Northeast Region to catch red drum (Table 3.1).

Use of this type of gill net is not managed under federal FMPs.

Bottom Longlines

A longline is a long length of line, often several miles long, to which short lengths of line ("gangions") carrying baited hooks are attached. Longlining for bottom species on continental shelf areas and offshore banks is undertaken for a wide range of species. The two primary federally managed species caught with this gear in 2004 in the Northeast Region were golden tilefish and redfish (Table 3.1). Bottom longlines are also referred to as "trot" lines and are used in the Mid-Atlantic states to harvest blue crabs.

Bottom longline fishing in the Northeast Region is conducted with hand-baited gear that is stored in tubs ("tub trawls") before the vessel goes fishing, and with vessels equipped with automated "snap-on" or "racking" systems. The gangions are 38 cm (15 in) long and 0.9-1.8 m (3-6 ft) apart. The mainline, hooks, and gangions all contact the bottom. In the Cape Cod (Massachusetts) longline fishery, up to six individual longlines are strung together, for a total length of about 460 m (1500 ft), and are deployed with 9-11 kg (20-24 lb) anchors. Each set consists of 600-1200 hooks. In tub trawls, the mainline is parachute cord; stainless steel wire and monofilament nylon gangions are used in snap-on systems (Leach 1998). The gangions are snapped to the mainline as it pays off a drum, and removed and rebaited when the wire is hauled. In New England, longlines are usually set for only a few hours at a time in areas with attached benthic epifauna. Longlines used for tilefish are deployed in deep water, may be up to 40 km (25 mi) long, are stainless steel or galvanized wire, and are set in a zigzag fashion .

These activities are managed under federal FMPs.

PELAGIC GEAR

Mid-Water Trawls

Mid-water trawls are used to capture pelagic species throughout the water column. For nets used on single boats, the net is spread horizontally with two large metal doors positioned in front of the net. A common type of type of mid-water trawls used in the Atlantic herring and Atlantic mackerel fisheries is the "rope" trawl. The forward portion of these nets is constructed of a series of ropes that extend back to very large meshes in the forward portion of the net that become progressively smaller toward the rear of the net. In the second type of net, instead of ropes, the large meshes begin immediately in the forward portion of the net. The large opening of the net functions to "herd" schooling fish toward the rear of the net (see *www.gma.org*, the website of the Gulf of Maine Research Institute). Once the net is deployed, changes in its position in the water column (height above the bottom) are made by increasing or decreasing the speed of the vessel or by bringing in or letting out trawl wire (NOAA/NMFS 2005). An electronic sonar system mounted in the mouth of the net allows the fisherman to continually monitor the size of the net opening and the height of the net above the bottom during each tow. In most cases, two heavy weights (*e.g.*, "balls"of heavy chain each weighing 1000-5000 pounds) are attached forward of the net to cables that extend from the net opening to the trawl doors. This is done while fishing in deep water to get the net closer to the bottom without using as much trawl wire. Schools of fish are located by means of directional sonar systems. Mid-water trawls may occasionally contact the bottom if the target species remain near the bottom (NOAA/NMFS 2005).

Tows typically last for several hours and catches are large. The fish are usually removed from the net while it remains in the water alongside the vessel by means of a suction pump. In some cases, the fish are removed from the net by repeatedly lifting the cod end aboard the vessel until the entire catch is in the hold.

The use of mid-water trawls is managed under federal FMPs.

Paired Mid-Water Trawls

Mid-water trawls that are towed by two vessels are called "pair" trawls. Pair trawls used in the Atlantic herring fishery are designed identically as single boat mid-water trawls, but do not have doors, since the net is spread by the two vessels. Pair trawls are also used to catch Atlantic mackerel (Table 3.1). The nets can be towed more efficiently by two vessels because of their combined towing power and because there are no doors. Pelagic pair trawling has proved particularly successful in catching fish schooling near the surface or in shallower areas where noise from the two vessels herds fish into the path of the net. Noise produced by a single vessel as it passes over a school of fish (especially herring, which are very sensitive to underwater sound) often causes fish to escape capture. Pelagic pair trawls may occasionally contact the bottom (NOAA/NMFS 2005).

Pelagic pair trawling is managed under federal FMPs.

Purse Seines

The purse seine is a deep, nylon-mesh net with floats on the top and lead weights on the bottom. Rings are fastened at intervals to the leadline, and a purseline runs completely around the net through the rings. A school of fish is encircled with the net, then the net is pursed by drawing in a cable that runs through all the rings until the fish are forced to the surface and into a small enough pocket in the net that they can be transferred to the vessel. Purse seines vary in size according to the species fished, the mesh size, the size of the vessel, and the depth to be fished. Purse seines are currently used in the Northeast Region to catch Atlantic herring, Atlantic menhaden, and several species of tuna.

In the herring fishery, one end of the net remains in the vessel and the other end is attached to a power skiff that is deployed from the stern of the vessel and remains in place while the vessel encircles a school of fish with the net. Most purse seines used in the New England herring fishery range from 30 to 50 m deep (NOAA/NMFS 2005). If the depth of the net exceeds the depth of the water where it is set, the leadline can contact the bottom when the nets are first set out, before they are "pursed." Purse seining is a year-round pursuit in the GOM, but is most active in the summer when herring are more abundant in coastal waters. It is done at night, when herring are feeding near the surface. This fishing technique is less successful when fish remain in deeper water and when they do not form "tight" schools. Herring fishermen rely on directional sonar systems to locate schools of fish.

In the menhaden fishery, small airplanes are used to locate schools of menhaden. When a school is located, two purse boats, each carrying half of the net, encircle the school and close the net. The mother ship then comes alongside and pumps the fish aboard. A few small vessels have only one purse boat. The typical menhaden purse seine net ranges in length from 300 to 430 m (980 to 1410 ft), and is 20-27 m (66-89 ft) deep (ASMFC 1999b).

Use of herring and tuna purse seines is managed under federal FMPs, but the menhaden fishery is managed by the ASMFC.

Drift Gill Nets

Drift gill nets are designed to float from the sea surface and extend downward into the water column, and are used to catch pelagic fish. In this case, the buoyancy of the floatline exceeds the weight of the leadline. Drift gill nets may be anchored at one end or set out to drift, usually with the fishing vessel attached at one end. This gear does not come in contact with the bottom.

The use of drift gill nets is managed under federal FMPs.

Pelagic Longline Gear

Pelagic or subsurface longlining is a technique used mostly in the open ocean to catch highly migratory species of tuna, swordfish, and sharks. The gear is typically set at depths from the surface to around 330 m (1080 ft). It can also be set with a mainline hanging in arcs below buoy droplines to fish a series of depths. The length of the mainline can be up to 108 km (67 mi), depending on the size of the vessel. If the mainline is set at a fixed depth, then the leader (*i.e.*, gangion) lengths vary from 2 to 40 m (7 to 131 ft), thus ensuring that the hooks are distributed over a range of depths. If a line-shooter is used to set the mainline in a catenary shape, then the gangions are usually a single minimal length, thus again ensuring that the hooks are distributed over a range of depths. Each gangion typically contains a baited hook and chemical night stick to attract the fish. Traditional or circle hooks may be used. Swordfish vessels typically fish 20-30 hooks per 1.6 km (1 mi) of mainline, which is between 5 and 54 km (3 and 34 mi) long. This gear does not contact the bottom.

The use of pelagic longlines to catch highly migratory species is regulated by the National Marine Fisheries Service (NMFS).

Troll Lines

Trolling involves the use of a baited hook or lure maintained at a desired speed and depth in the water. Usually, 2-4 or even more lines are spread to varying widths by the use of outrigger poles connected to the deck by hinged plates. Line retrieval is often accomplished by means of a mechanized spool. Each line is weighted to reach the desired depth and may have any number of leaders attached, each with a hook and bait or an appropriate lure. Troll lines are used to catch a variety of pelagic species in the region, including king mackerel (Table 3.1). This gear does not contact bottom habitats.

This activity is managed under federal FMPs.

OTHER GEAR

Rakes

A bull rake is manually operated to harvest northern quahogs (*Mercenaria mercenaria*), or hard clams, and consists of a long shaft with a rake and basket attached. The length of the shaft can vary, but usually does not exceed three times the water depth. The length and spacing of the teeth, as well as the openings of the basket, are regulated to protect juvenile clams from harvest. Rakes are typically fished off the side of a small boat. They are used in estuarine waters throughout the region.

This activity is not managed under federal FMPs.

Tongs

Tongs are used to harvest shellfish in shallow water. There are two principal types: shaft tongs and patent tongs. Manually operated shellfish tongs are used in nearshore and estuarine waters throughout the region, primarily to harvest hard clams and eastern oysters.

Shaft tongs are a scissorlike device with a rake and basket at the end of each shaft. The fisherman stands on the edge of the boat and progressively opens and closes the baskets on the bottom, gathering the shellfish into a mound. The tongs are closed a final time, brought to the surface, and the catch emptied on the culling board for sorting. The length of the shaft must be adjusted for water depth. Oysters are traditionally harvested with shaft tongs in water depths up to 6 m (20 ft), with the shaft tongs themselves being 8 m (26 ft) long.

Patent tongs are also used to harvest hard clams and oysters. They are opened and closed with a drop latch or with a hydraulic ram, and require a mechanized vessel with a mast or boom and a winch.

This activity is not managed under federal FMPs. Patent tongs are regulated by state fisheries agencies according to weight, length of teeth, and bar spacing in the basket.

Line Fishing

Hand Lines/Rod and Reel

The simplest form of hook-and-line fishing is the hand line, which may literally be fished "by hand" or using a rod and reel. The gear consists of a line, sinker, leader, and at least one hook. The line is usually stored on a small spool and rack and varies in length. The sinkers vary from stones to cast lead. The hooks vary from single to multiple arrangements in "umbrella" rigs. An attraction device must be incorporated into the hook, usually a natural bait or an artificial lure. Hand lines can be fished in such as manner as to hit bottom and bounce, or to be carried by currents until retrieved.

Hand lines and rods and reels are used in the Northeast Region to catch a variety of demersal and pelagic species (federally managed species are listed in Table 3.1), including species of tuna, sharks, billfish, and swordfish.

This activity is managed under federal FMPs.

Mechanized Line Fishing

Mechanized line-hauling systems have been developed to allow more lines to be worked by smaller crews, and to use electrical or hydraulic power to work the lines on the spools or jigging machines. These reels, often termed "bandits," are mounted on the vessel bulwarks and have a spool around which the mainline is wound. Each line may have a number of branches and baited hooks, and the line is taken from the spool over a block at the end of a flexible arm. Hooks and sinkers can contact the bottom, depending upon how the gear is used.

Jigging machine lines are generally fished in waters up to 600 m (1970 ft) deep. Jigging refers to the action of jerking a line with several unbaited hooks up in the water to snag a fish in its body. Jigging is commonly used to catch squid.

This gear is used to catch a variety of demersal and pelagic species, including highly migratory species of tuna, sharks, and swordfish. The use of this gear is managed under federal FMPs.

Hand Hoes

Intertidal flats are harvested for baitworms (*Glycera dibranchiata* and *Nereis* spp.) and softshell clams by using handheld hoes. These hoes are short-handled, rakelike devices that are often modified gardening tools (Creaser *et al*. 1983). Baitworm hoes have 5-7 tines which are 21-22 cm (8.3-8.7 in) long when used for bloodworms, and which are 34-39 cm (13-15 in) long when used for sandworms. Clam hoes in Maine typically have 4-5 tines which are 15 cm (6 in) long (Wallace 1997).

This activity is not managed under federal FMPs.

Diving

Divers, either free diving or using SCUBA, harvest a variety of benthic invertebrate species -- including sea urchins, scallops, and quahogs -- in relatively shallow coastal and inshore waters throughout the region. Often, a support vessel is used to transport the diver(s) to the fishing site and carry the catch to shore. Divers often use small rakes or hoes to scrape animals off rocks or dig them out of the seafloor. Generally, the catch is placed in bags that are either towed to the surface by the boat or floated to the surface using an air source and a lift bag.

This activity is not managed under federal FMPs.

Spears and Harpoons

Spears with long shafts (gigs) are used by fishermen in small boats to catch fish in shallow water, and by divers. Harpoons are used offshore to fish for certain highly migratory species.

The use of spears in state waters is not managed under federal FMPs, but the use of harpoons in the tuna fishery is managed by NMFS.

Table 3.1. Percentage of landings (1% or more by weight) by fishing gear type for federally managed species and species groups in the Northeast Region in 2004. (Does not include highly migratory species, *i.e.*, tuna, sharks, swordfish, and billfish.)

Gear	**Species and Species Groups**																		
	American Plaice	**Atlantic Cod**	**Atlantic Halibut**	**Atlantic Herring**	**Atlantic Mackerel**	**Atlantic Surfclam**	**Barndoor Skate**	**Black Sea Bass**	**Bluefish**	**Butterfish**	**Clearnose Skate**	**Cobia**	**Goosefish**	**Haddock**	**Hake, Red & White**	**King Mackerel**	**Little Skate**	**Longfin Inshore Squid**	**Northern Shortfin Squid**
By hand																			
Dip net																			
Dredge, clam						6.6													
Clam dredge, hydraulic																			
Dredge, other						2.6				1.5			2.0				1.0	2.7	1.3
Dredge, sea scallop													2.1						
Dredge, surfclam + ocean quahog						90.2													
Gill net, drift									1.0										
Gill net, fixed or anchored, sink	1.8	30.0	13.2		9.5			1.7	44.4	4.1	66.2	28.4	53.7	2.3	6.3				
Gill net, other														2.5	5.6				
Gill net, run-rround																			
Gill net, set/stake									14.4			34.9				19.8			
Handline		3.9						5.1	3.5			14.0		3.2	3.5	5.1			
Haul seine, beach																			
Haul seine, long																			
Longline, bottom		1.6	3.9											3.3	1.6				
Longline, pelagic												4.4							
Pot/trap, lobster, inshore																			
Pot/trap, lobster, offshore																			
Pots + traps, crab, other																			
Pots + traps, fish								3.7											
Pots + traps, other								28.0	1.1										
Pound net, fish									1.4	7.1		3.7							
Pound net, other		1.0						1.2	1.4	1.1		2.2		1.2					
Purse seine, herring				2.5															
Purse seine, other				9.3															
Rake, other																		1.8	
Trawl, otter, bottom, fish	92.5	58.5	60.3	29.8	8.8			41.8	13.8	69.3	32.3	1.3	35.8	82.4	21.0		98.2	83.3	93.4
Trawl, otter, bottom, scallop								1.4											
Trawl, otter, bottom, other								2.0	2.0			2.4							
Trawl, otter, midwater				30.0	43.0			2.4		1.2								3.4	
Trawl, midwater, paired				25.1	38.1							2.2							
Troll line, other				2.2						1.0					50.6	66.3		1.5	
Troll and handline, combined																7.2			
Unknown	4.4	3.0	20.7				100	10.2	14.8	13.4	1.5	4.6	4.3	4.5	5.4			5.7	4.4

Table 3.1. Percentage of landings (1% or more by weight) for federally managed species and species groups by fishing gear type in the Northeast Region in 2004. (Does not include highly migratory species, *i.e.*, tuna, sharks, swordfish, and billfish.)

	Species and Species Groups																		
Gear	**Ocean Pout**	**Ocean Quahog**	**Offshore Hake, Unclassified**	**Pollock**	**Red Deepsea Crab**	**Red Drum**	**Red Hake**	**Redfish**	**Rosette Skate**	**Scup**	**Sea Scallop**	**Silver Hake**	**Skates**	**Smooth Skate**	**Spanish Mackerel**	**Spiny Dogfish**	**Squids, Unclassified**	**Summer Flounder**	**Thorny Skate**
By hand			17.1																
Dip net																			
Dredge, clam																			
Clam dredge, hydraulic		3.3																	
Dredge, other			3.9				2.4				56.7	11.2						1.3	
Dredge, sea scallop											33.9								
Dredge, surfclam + ocean quahog		96.6																	
Gill net, drift						1.4													
Gill net, fixed or anchored, sink				37.5		7.9			4.2	2.9			17.7	97.6	3.4	75.1		1.3	46.7
Gill net, other						1.5							8.0			2.6			
Gill net, run-around						3.3													
Gill net, set/stake						79.8									79.2				
Handline	12.2							2.3		4.5						2.2		1.5	
Haul seine, beach						1.2													
Haul seine, long						2.7													
Longline, bottom	6.2				1.8			78.4					1.1	1.7		1.5			
Longline, pelagic																			
Pot/trap, lobster, inshore	3.0																1.6		
Pot/trap, lobster, offshore																			
Pots + traps, crab, other					18.7														
Pots + traps, fish	7.1																		
Pots + traps, other	3.3				79.5			3.7		1.8									
Pound net, fish														13.7					
Pound net, other										13.7			6.2						
Purse seine, herring																			
Purse seine, other																			
Rake, other																			
Trawl, otter, bottom, fish	63.7		46.2	59.2			84.7	12.5	95.8	54.0	6.2	76.9	62.1		1.0	13.7	71.3	81.2	51.9
Trawl, otter, bottom, scallop											1.2								
Trawl, otter, bottom, other										1.2							1.9		
Trawl, otter, midwater																			
Trawl, midwater, paired																			
Troll line, other										1.7						1.6			
Troll and handline, combined																			
Unknown	2.9		32.0	1.1			10.2	3.2		15.8	1.5	10.4	3.7		1.1	1.6	23.6	7.5	

Table 3.1. Percentage of landings (1% or more by weight) for federally managed species and species groups by fishing gear type in the Northeast Region in 2004. (Does not include highly migratory species, *i.e.*, tuna, sharks, swordfish, and billfish.)

	Species and Species Groups																
Gear	**Tilefish**	**White Hake**	**Windowpane**	**Winter Flounder**	**Winter Skate**	**Witch Flounder**	**Yellowtail**	**ALL SPECIES**									
By hand								0.05									
Dip net				1.0				0.02									
Dredge, clam								0.56									
Clam dredge, hydraulic								0.18									
Dredge, other							1.6	5.78									
Dredge, sea scallop								3.03									
Dredge, surfclam + ocean quahog								12.82									
Gill net, drift								0.01									
Gill net, fixed or anchored, sink	6.5	24.2	1.5	4.6	9.7	1.2	2.8	5.87									
Gill net, other								0.21									
Gill net, run-around								0.00									
Gill net, set/stake								0.23									
Handline	3.6							0.35									
Haul seine, beach								0.00									
Haul seine, long								0.02									
Longline, bottom	60.9	1.4						0.36									
Longline, pelagic								0.00									
Pot/trap, lobster, inshore								0.01									
Pot/trap, lobster, offshore								0.03									
Pots + traps, crab, other								0.10									
Pots + traps, fish								0.04									
Pots + traps, other								0.61									
Pound net, fish							4.8	0.05									
Pound net, other			1.6	9.5				0.68									
Purse seine, herring								0.61									
Purse seine, other								2.25									
Rake, other								0.07									
Trawl, otter, bottom, fish	19.2	71.5	91.2	76.2	82.7	89.8	81.7	35.81									
Trawl, otter, bottom, scallop								0.19									
Trawl, otter, bottom, other								0.39									
Trawl, otter, midwater								14.29									
Trawl, midwater, paired								12.16									
Troll line, other								0.74									
Troll and handline, combined								0.01									
Unknown	9.4	2.3	3.9	6.6	6.9	7.1	8.1	2.41									

Table 3.2. Percentage of landings for all species (1% or more of state total landings by weight) by fishing gear type for states in the Northeast Region in 2004

	STATE											
Gear	**ME**	**NH**	**MA**	**RI**	**CT**	**NY**	**NJ**	**MD**	**DE**	**VA**	**NC**	**ALL**
By hand									4.6			
Diving gear, urchins	1.7											
Dredge, clam						11.1						
Dredge, clam, hydraulic					6.6							
Dredge, crab									9.5			
Dredge, other	4.1		5.5	2.3		4.9	5.0			2.7		3.6
Dredge, oyster									1.8			
Dredge, sea scallop			3.7		11.2		1.8			1.1		1.5
Dredge, surfclam + ocean quahog			6.6	2.7	6.5	5.5	33.0	14.7				6.5
Dredge, sea urchin	1.1											
Dredge, whelk									10.4			
Gill net, fixed or anchored, sink	1.4	14.5	8.2	3.8	1.7	3.6	2.8	1.3		2.6	15.0	
Gill net, drift								1.5	5.3			4.1
Gill net, set/stake									10.0		10.5	
Handline			1.0			1.2			1.4			
Longline, bottom						3.1						
Longline, pelagic											3.4	
Pot/trap, lobster, inshore	23.6			1.5	2.9							3.8
Pot/trap, lobster, onshore, wire			3.7									
Pot/trap, lobster, offshore	1.9											
Pots + traps, blue crab							1.8	45.8	47.6	4.8	15.5	3.9
Pots + traps, eel									3.2			
Pots + traps, other	1.7	1.1	2.7	2.4					2.1			1.1
Pots + traps, whelk									1.1			
Pound net, fish								10.1		2.8	16.8	1.3
Pound net, other			1.1	1.5								4.0
Purse seine, herring	1.9	1.0										
Purse seine, menhaden							6.8			73.7		25.2
Purse seine, other	7.4	1.0								8.1		
Rakes, other				1.4		2.9			1.1			
Tongs and grabs, other						3.2						
Trawl, otter, bottom, fish	11.8	69.3	29.7	65.4	37.1	42.4	22.4	2.0		1.4		18.6
Trawl, otter, bottom, other											28.4	
Trawl, otter, bottom, shrimp	1.0	1.5									3.6	
Trawl, otter, midwater	17.5	3.7	15.8	3.6			7.6					7.3
Trawl, midwater, paired	4.1	5.9	16.6	6.7			12.2					6.2
Troll line, other					2.9	1.0					1.7	
Trot line with bait								20.9				
Unknown	17.4		2.4	6.0	28.2	18.6	2.9					4.8

Table 3.3. Fishing gears and techniques used in the Northeast Region, categorized by the waters in which they are used, by whether or not they contact the bottom, and by whether or not their use is regulated by federal FMPs. (Includes all gears that accounted for 1% or more of any state's total landings, and all gears that harvested any amount of any federally managed species, based upon 2004 landings data and an ASMFC report on gear impacts to submerged aquatic vegetation (Stephan *et al.* 2000).)

	Water Type			**Contacts Bottom**	**Federally Regulated**
Gear	**Estuary or Bay**	**Coastal (0-3 mi)**	**Offshore (3-200 mi)**		
By hand	X	X			X
Diving	X	X	X		
Dredge, clam	X	X	X	X	X
Dredge, crab	X	X		X	
Dredge, mussel	X	X		X	
Dredge, oyster	X			X	
Dredge, bay scallop	X			X	
Dredge, sea scallop		X	X	X	X
Dredge, sea urchin		X	X	X	
Dredge, whelk	X			X	
Floating trap	X	X		X	X
Fyke and hoop net, fish	X	X		X	
Gill Net, drift			X		X
Gill Net, run-around	X			X	
Gill Net, sink/anchor	X	X	X	X	X
Gill Net, stake	X	X	X	X	X
Handline	X	X	X		X
Haul seine, beach	X	X		X	
Haul seine, long	X	X		X	
Haul seine, long (Danish)		X	X	X	X
Hoe	X			X	
Longline, bottom		X	X	X	X
Longline, pelagic		X	X		X
Otter trawl, bottom, crab	X	X	X	X	
Otter trawl, bottom, fish	X	X	X	X	X
Otter trawl, bottom, scallop		X	X	X	X
Otter trawl, bottom, shrimp	X	X	X	X	X
Otter trawl, midwater		X	X		X
Pots and traps, crab, blue	X	X		X	
Pots and traps, crab, other	X	X	X	X	X
Pots and traps, eel	X	X		X	
Pots and traps, fish	X	X	X	X	X
Pots and traps, lobster, inshore	X	X		X	
Pots and traps, lobster, offshore			X	X	X
Pots and traps, whelk	X	X		X	
Pound nets, crab	X	X		X	
Pound nets, fish	X	X		X	
Purse seines, herring		X	X		X
Purse seines, menhaden		X	X		
Purse seines, tuna		X	X		X
Rakes	X			X	
Reel, electric or hydraulic		X	X		X
Rod and reel	X	X	X		X
Scottish seine		X	X	X	X
Scrapes	X			X	
Spears	X	X	X		
Stop seines	X			X	
Tongs and grabs, oyster	X			X	
Tongs, patent, clam, other	X			X	
Tongs, patent, oyster	X			X	
Trawl, midwater, paired		X	X		X
Troll line, other		X	X		X
Trot lines, with bait		X	X		X
Weirs	X			X	

4. GEOGRAPHIC DISTRIBUTION OF FISHING ACTIVITY BY GEAR TYPE

The information in this section of the document was compiled as part of an overall effort to determine the potential effects of fishing on benthic marine habitats in the Northeast Region. The objective of this information compilation was to calculate the spatial distribution of fishing activity by the principal gear types used in regional commercial fishing operations. The data used in these calculations were extracted from the NOAA Fisheries Service fishing vessel trip report (FVTR) and clam logbook databases for the years 1995-2001. The clam logbook program was implemented in 1991, and the FVTR data collection program in 1994, to monitor the geographic distribution of catches of federally regulated species in the region. Both data collection systems are mandatory, and the data are collected by fishermen. This is the first time that either of these databases has been utilized for estimating the spatial distribution of fishing activity throughout the region.

Previous attempts to determine the spatial distribution of fishing activity in the Northeast Region have been restricted to a single gear type -- bottom otter trawls -- and have described trawling activity that occurred during the mid-1980s and early 1990s, before the closing of three areas on Georges Bank to all gear used to catch groundfish, including bottom trawls and scallop dredges. These closures, which were implemented in December 1994 (see Figure 4.1) as part of an overall effort to restore depleted groundfish stocks, greatly affected the subsequent distribution of trawling and dredging operations in the region. Additional year-round groundfish closures (also shown in Figure 4.1) were established in the western GOM in May 1998, and in the vicinity of Cashes Ledge in the central GOM in August 2001.

Earlier analyses of bottom trawling activity in the region relied on information collected by NOAA Fisheries Service port agents who interviewed fishermen after their vessels returned to port. Interviews were conducted for about 60% of all trips. Data from interviewed trips included the number of days (to the nearest 0.1 day) that a vessel trawled in each 10' “square” (TMS) of latitude and longitude. (A TMS represents 10' (*i.e.*, one-sixth of a degree) of latitude along each side, and 10' of longitude along the top and bottom. Because of the curvature of the earth’s surface, TMSs north or south of the Equator are actually rectangles that diminish in size as the meridians of longitude converge at the poles. Within the range of latitudes in the Northeast Region, TMSs range in size from 109.65 km^2 in the south to 94.20 km^2 in the north. Because the projection used to display the FVTR and clambook data in this document is a Mercator projection, the TMSs in Figures 4.2-4.13 appear to be the same size.) Interview information (average numbers of days fishing per trip) was applied to the noninterviewed trips, but the estimated fishing time for these trips was assigned to 30' squares. (One 30' square is one-half of a degree of latitude and longitude on each side, and contains nine TMSs.) Churchill (1989) used data from all trips made in 1985 to estimate the percentage of area trawled in individual 30' squares between Cape Cod and North Carolina, using an average trawl width (door to door, while underway) of 40 m, and an average towing speed of 5.5 km/hr. These same methods were applied to data collected by port agents in 1993 for Georges Bank and the GOM (analysis by Churchill in NRC 2002).

A more recent analysis of 1991-1993 data for interviewed and noninterviewed bottom trawl trips was prepared for a National Research Council report on trawling and dredging effects (NRC 2002). In this case, the results for 10' and 30' squares were combined in one map, and displayed as low, medium, and high numbers of days of fishing per 10' square. No attempt was made to estimate the area swept by the gear within each square. This analysis was flawed by the fact that the extrapolated 30'-square fishing effort estimates were assigned to the single 10' square at the center of each 30' square. This biases the results and produces a “checkerboard” effect in the mosaic of 10' squares.

METHODS

Data Analysis

The geographic distribution of fishing activity during 1995-2001 was calculated by TMS for 12 commonly used, bottom-tending gear types in the Northeast Region. Data reported south of Cape Hatteras (35°N) and north of 45°N latitude in the GOM were excluded from analysis. Data for gear used mostly in state waters and/or for gear that is not well represented in the FVTR or clam logbook databases (*e.g.*, mussel and sea urchin dredges, nonhydraulic quahog dredges, Danish seines, shrimp pots) or for gear that does not normally contact the bottom (*e.g.*, purse seines, mid-water trawls, pelagic longlines, floating gill nets) were not analyzed.

The FVTR and clam logbook data are provided by vessels operating with federal permits and participating in the following fisheries: Northeast multispecies, sea scallop, surf clam and ocean quahog, goosefish, summer flounder, scup, black sea bass, squid, Atlantic mackerel, butterfish, spiny dogfish, bluefish, Atlantic herring, and tilefish. There is no requirement for vessels permitted in just the offshore lobster fishery to report or log their activities. However, vessels permitted in both the offshore lobster and Northeast multispecies fisheries must report on their lobster fishing activity. Consequently, the data for lobster pots were provided by those vessels with multispecies and offshore lobster permits.

Vessels that operate strictly within state waters (0-3 mi from shore) are not required to have a federal permit, and therefore do not submit trip reports. For this reason, fishing trips in nearshore TMSs that include a significant proportion of state waters are under-represented in the data.

Permit holders are required to fill out a FVTR form or make a logbook entry for each trip made by the vessel (*i.e.*, each time the vessel leaves and returns to port). Fishermen report the general location where most of their fishing effort occurs during a trip, and the date and time that the vessel leaves and returns to port. (Fishermen are also asked to answer questions regarding the quantity and size of gear used during a trip, how many tows or sets were hauled, and what was the average tow or soak time. However, because this information is either not reported at all, or is reported in an inconsistent manner, it is not reliable and was not used in this analysis.) Fishermen are also given the choice of reporting the location of a trip as a point (*i.e.*, latitude and longitude) or simply assigning it to a statistical area (these areas are quite large and include many TMSs). Only trips that were reported as a point location and therefore could be assigned to a TMS were included in this analysis. Most trips are reported this way, but not all (Table 4.1).

For most of the analyzed, mobile, bottom-tending gear (*i.e.*, scallop dredges and three types of otter trawl), fishing activity was calculated as the total number of days absent from port during the 7-yr period. Days absent for each scallop dredge and otter trawl trip were calculated based on the date and time of departure from, and return to, port in hours, and were then converted to fractions of 24-hr days. Days-absent calculations for trawl and scallop dredge vessels are clearly preferable to simply summing the number of trips, but overestimate actual fishing time since they include travel time and any other non-fishing-related activity while the vessels are away from port. For clam dredges, fishing activity was calculated as the actual hours spent fishing during the 7-yr period, and was then converted to fractions of 24-hr days. For fixed gear (*i.e.*, bottom longlines, sink gill nets, and five types of pots), fishing activity was calculated as the total number of trips during the 7-yr period.

This method of compiling the data by TMS was considered to be preferable to plotting individual trip locations as point data, since many trips, especially for vessels using mobile gear, last for many days and can extend over fairly large areas. For these trips, even data compiled by TMS only approximate the actual spatial distribution of fishing activity throughout the region. For trips of shorter duration that do not extend over large areas, the figures in this document are more representative of actual fishing activity distributions. For this reason, and because some fishing trips in the FVTR database are not assigned to a point location and could not be included in this analysis, the values associated with each TMS are not provided in this document.

Data Portrayal

The calculated data have been portrayed in Figures 4.2-4.13 using geographical information systems (GIS) software (ArcView 3.2, ESRI, Inc.). These geographic portrayals of the relative nature of fishing activity for each gear type were achieved by ranking the TMSs in order from those with the most fishing activity to those with the least activity. TMSs were categorized according to the cumulative percentage of the overall activity (*i.e.*, the total number of days or trips during the 7-yr time period) which they represented.

Those TMSs which had the most activity and which cumulatively accounted for 50% of the overall activity were assigned to a "high" or 50th percentile category. Those TMSs which cumulatively accounted for the next 25% of overall activity were assigned to a "medium" or 75th percentile category. Those TMS which cumulatively accounted for the next 15% of overall activity were assigned to a "low" or 90th percentile category. For the 9 of the 12 gear types that had <100,000 trips or days of fishing reported during the 7-yr period, just the 50th, 75th, and 90th percentile categories were portrayed. For the three gear types that had >100,000 trips or days of fishing reported during the 7-yr period, the 95th percentile category was also portrayed. Exclusion of extreme "low end" data (*i.e.*, those TMSs which would fall into a higher percentile category than 90th or 95th, as appropriate) eliminated a large number of spatially misreported trips from the figures.

Fishing activity categories in the figures are labeled according to the range in the number of days or trips that were reported within each TMS. Tables 4.2 and 4.3 show the ranges, the total amount of fishing activity represented by all the TMSs in each category, and the total amount of fishing activity (100% of the frequency distribution of days or trips) throughout the region for each gear type.

RESULTS

Bottom Otter Trawls -- Fish

Most of the reported otter trawl activity during 1995-2001 was directed at the capture of fish (Figure 4.2) rather than shrimp or scallops (Figures 4.3 and 4.4). There was more than twice as much fishing activity reported for this gear than for scallop dredges (Table 4.2). Bottom otter trawling for fish was widespread in coastal and offshore waters throughout most of the Northeast Region, easily accounting for more TMSs than any other gear (Figure 4.14). Areas of highest activity were located in southwestern and central portions of the GOM, along the western side of the Great South Channel (east of Cape Cod), north of Closed Area I and on the northern part of Georges Bank west of Closed Area II, in coastal waters of Rhode Island and Long Island, in the mid-shelf region of

Southern New England, and along the edge of the shelf, especially along the 40th parallel of N latitude between 70º and 73º W longitude and in the Hudson Canyon area. Bottom trawling was prohibited in the three groundfish closed areas on Georges Bank during the entire 1995-2001 period, and was absent, or nearly so, in a large area of the continental shelf off southern New Jersey, Maryland, and Virginia. The distribution of fish trawling activity among TMSs within the range fished by this gear was intermediate [*i.e.*, it was neither heavily concentrated nor widely dispersed (Figure 4.15)].

Bottom Otter Trawls -- Shrimp

Shrimp trawling was localized in two areas: the coastal waters of the GOM between Cape Ann and Penobscot Bay, and in nearshore waters of North Carolina, particularly inside the barrier islands (Figure 4.3). Shrimp trawling was reported within a relatively small number of TMSs (Figure 4.14), and was evenly distributed among those TMSs (Figure 4.15). The total number of reported days at sea was also fairly low (Table 4.2).

Bottom Otter Trawls -- Sea Scallops

Scallop trawling was conducted on the outer Mid-Atlantic shelf, primarily between 40º and 37ºN (Figure 4.4). The total number of reported days absent from port and the total number of "populated" TMSs were low (Table 4.2; Figure 4.14). Scallop trawling was concentrated in a small proportion of the total number of TMSs where this gear was used (Figure 4.15).

Scallop Dredges

Scallop dredges were used primarily in a broad area of the Mid-Atlantic shelf from Long Island to Virginia, in Massachusetts Bay (north of Cape Cod) and the Great South Channel, in localized TMSs on Georges Bank northeast of Closed Area I and west of the northern portion of Closed Area II, and in a larger area on the southeast flank of the bank that included the southern portion of Closed Area II that was opened to limited scallop dredging in 1999 (Figure 4.5). Some scallop dredging was also reported from eastern Maine coastal waters. No active scallop dredging was reported in shallow open areas on Georges Bank, in Southern New England, nor in inner shelf waters of the MAB. Some scallop dredging also occurred in portions of the other two closed areas on Georges Bank that were temporarily opened to this gear during 1995-2001. Compared to the other gear types, the number of TMSs with reported scallop dredging covered an area of intermediate size (Figure 4.14), and fishing activity was fairly evenly distributed among TMSs (Figure 4.15).

Hydraulic Clam Dredges

The largest area of intensive hydraulic clam dredging activity was located off the central New Jersey coast, with smaller areas extending north and east to Southern New England and south to the Delmarva Peninsula (Fig. 4.6). The total number of TMSs within which clam dredging took place during 1995-2001 was low (Figure 4.14), and fishing was concentrated in a relatively small proportion of those TMSs (Figure 4.15).

Bottom Longlines

Longline trips during 1995-2001 were reported primarily in TMSs in the western GOM (Massachusetts Bay) and along the western side of the Great South Channel (Figure 4.7). A few trips were reported in deep water along the edge of the shelf, in Rhode Island and central Maine coastal waters, and in offshore locations of the GOM. The total number of TMSs within which bottom longlines were used was relatively low (Figure 4.14), and fishing was evenly distributed among those TMSs (Figure 4.15).

Bottom Gill Nets

Bottom gill net trips were reported in the western GOM and along the western side of the Great South Channel, extending as far north as Cape Ann and Jeffreys Ledge, and in a few TMSs in the outer gulf (Figure 4.8). Gill nets were also used in Rhode Island coastal waters, along the outer shore of Long Island, off northern New Jersey, the Delmarva Peninsula, and in North Carolina. Gill net fishing activity was highest in the western GOM and the Great South Channel in areas that were also actively fished with longlines, bottom trawls, and scallop dredges. The total area fished, as represented by TMSs within which any amount of fishing activity was reported, was relatively large (Figure 4.14), and fishing was well distributed among those TMSs (Figure 4.15).

Lobster Pots

The lobster pot fishery is the most active fixed-gear fishery in the Northeast Region. During 1995-2001, there were almost three times as many trips reported for this gear than for bottom gill nets, the second-most actively used bottom-tending fixed gear (Table 4.3). Fishing activity for this gear is under-reported to a greater degree than for the other gears because nonfederally permitted vessels (which are active in this fishery) are not required to submit reports. Lobster pot trips were reported primarily in coastal waters of the GOM from the Canadian border to Cape Cod, in Rhode Island coastal and inner-shelf waters, and in the New York Bight (Fig. 4.9). Fewer trips were made to more offshore locations in Southern New England, along the edge of the shelf, on eastern Georges Bank, and along the U.S.-Canada border north of the bank. Lobster pots were deployed in a very large number of TMSs within the region (Figure 4.14), and because of the large number of low-activity TMSs (which are not shown in Figure 4.9), their use was very evenly distributed among those TMSs (Figure 4.15).

Fish Pots

Most fish pot trips were reported on the south shore of Massachusetts and Rhode Island, Long Island, and off southern New Jersey, Delaware, and Maryland (Fig. 4.10). Other areas where fewer trips were reported were located on Jeffreys Ledge in the western GOM, east of Long Island and south of Nantucket and Martha's Vineyard, along the outer edge of the continental shelf in the southern MAB, and off the entrance to Chesapeake Bay. Fish pot trips were reported from a small number of TMSs during 1995-2001 (Figure 4.14), and the even-ness of their distribution among TMSs was intermediate between the heavily concentrated (*e.g.*, crab and hagfish pots) and more evenly dispersed (*e.g.*, lobster pots) fixed gears (Figure 4.15).

Whelk Pots

Most fishing activity was reported in Nantucket Sound and inshore waters of southern Massachusetts, in a single TMS south of Rhode Island, and in coastal waters of southern New Jersey and the Delmarva Peninsula, extending south to North Carolina (Fig. 4.11). Fishing with this gear was reported within a very small number of TMSs (Figure 4.14), and was less evenly distributed among TMSs than fishing with fish pots, but more evenly distributed than crab or hagfish pot trips (Figure 4.15).

Crab Pots

Crab pot trips were reported in a small number of TMSs in deep water along the edge of the shelf from eastern Georges Bank all the way to Cape Hatteras, in a single TMS south of Nantucket, in several nearshore locations in the GOM, Nantucket Sound, Cape May , and in inshore waters behind the North Carolina barrier islands (Fig. 4.12). Very few trips were reported (Table 4.3). Fishing was very spread out among a few isolated TMSs (Figure 4.14), but was highly concentrated within those few TMSs (Figure 4.15).

Hagfish Pots

Hagfish pots were used exclusively in the southwestern GOM, in both shallow and deep water (Figure 4.13). Only a few trips were reported within a small number of TMSs (Table 4.3; Figure 4.14), and fishing activity was very un-evenly distributed among TMSs (Figure 4.15).

Table 4.1. Total number of trips by gear type in the FVTR database for 1995-2000, before and after removing trips that did not meet the criteria established for analysis (see text), and the percentage of analyzed trips (information for 2001 was not available)

Gear Type	**Reported Trips**	**Analyzed Trips**	**Percent Analyzed**
Bottom gill net	86,580	66,096	76.3
Bottom longline	18,261	13,614	74.6
Lobster pot	241,725	171,564	71.0
Fish pot	13,323	9,779	73.4
Crab pot	1,609	1,050	65.3
Whelk pot	2,448	1,700	69.4
Bottom otter trawl (fish)	218,668	174,617	79.9
Bottom otter trawl (shrimp)	43,353	30,865	71.2
Bottom otter trawl (scallops)	1,952	1,702	87.2
Scallop dredge	32,248	23,206	72.0
TOTAL	660,167	494,193	74.8

Table 4.2. Fishing activity reported by federally-permitted fishing vessels using mobile, bottom-tending gears in the Northeast Region (35-45ºN) during 1995-2001. (Data shown as ranges in number of 24-hr days per 10′ square (TMS) of latitude and longitude, and as cumulative number of 24-hr days (in parentheses), associated with percentiles of total reported fishing activity that are mapped in Figures 4.2-4.6. Number in last column is the total number of days at sea in all TMSs in the region for that gear type, as calculated from the time absent from port for each reported trip. Note: Not all trips in fishing vessel trip database could be assigned to TMSs (see Table 4.1).)

Gear	**Activity Metric**	**Percentile of Fishing Activity**				
		50%	**75%**	**90%**	**95%**	**100%**
Otter trawls (fish)	Days absent from port	603-5,058 (175,907)	333-602 (263,176)	136-331 (315,582)	63-135 (333,105)	348,841
Otter trawls (shrimp)	Days absent from port	409-1,677 (11,837)	137-399 (17,986)	32-136 (21,591)	---	23,891
Otter trawls (scallops)	Days absent from port	183-653 (5,888)	66-175 (8,816)	16-66 (10,596)	---	11,720
Scallop dredges	Days absent from port	732-3,371 (78,831)	338-724 (118,850)	95-333 (142,493)	34-93 (150,392)	157,507
Hydraulic clam dredges	Days fishing	133-517 (8,027)	64-126 (11,990)	31-63 (14,412)	---	15,951

Table 4.3. Fishing activity reported by federally-permitted fishing vessels using fixed gear in the Northeast Region (35-45ºN) during 1995-2001. (Data shown as ranges in number of trips per 10′ square (TMS) of latitude and longitude, and as cumulative number of trips (in parentheses) associated with percentiles of total reported fishing activity that are mapped in figures 4.7-4.13. Number in last column is the total number of trips reported in all TMSs in the region for that gear type. Note: Not all trips in fishing vessel trip database could be assigned to TMSs (see Table 4.1).)

Gear	**Activity Metric**	**Percentile of Fishing Activity**				
		50%	**75%**	**90%**	**95%**	**100%**
Bottom longlines	Trips	412-1,269 (8,211)	129-314 (12,345)	11-126 (14,914)	---	16,483
Bottom gill nets	Trips	520-3,831 (43,194)	167-511 (65,220)	50-167 (78,156)	---	86,403
Lobster pots	Trips	2,084-10,895 (115,726)	816-2,009 (173,326)	161-759 (208,362)	45-160 (219,906)	230,300
Fish pots	Trips	120-434 (4,740)	41-118 (7,088)	9-39 (8,523)	---	9,423
Whelk pots	Trips	109-260 (1,172)	21-86 (1,859)	8-20 (2,235)	---	2,471
Crab pots	Trips	89-227 (678)	13-44 (1,093)	2-13 (1,312)	---	1,450
Hagfish pots	Trips	50-323 (1,202)	22-49 (1,822)	8-21 (2,195)	---	2,430

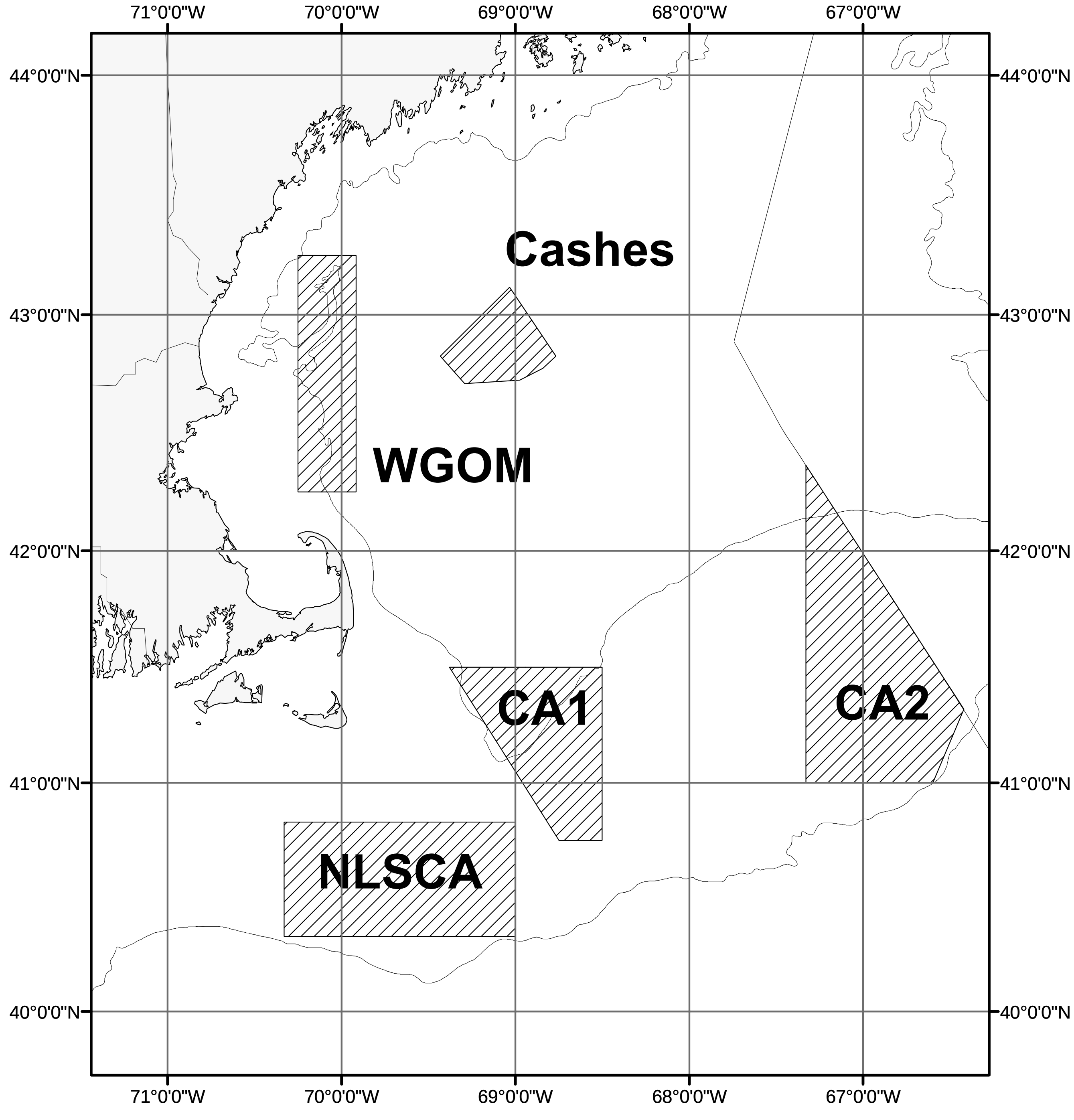


Figure 4.1. Location of five year-round groundfish closed areas in the Gulf of Maine - Georges Bank region. (Cashes = Cashes Ledge; WGOM = western Gulf of Maine; NLSCA = Nantucket Lightship Closed Area; CA1 = Closed Area I; and CA2 = Closed Area II.)

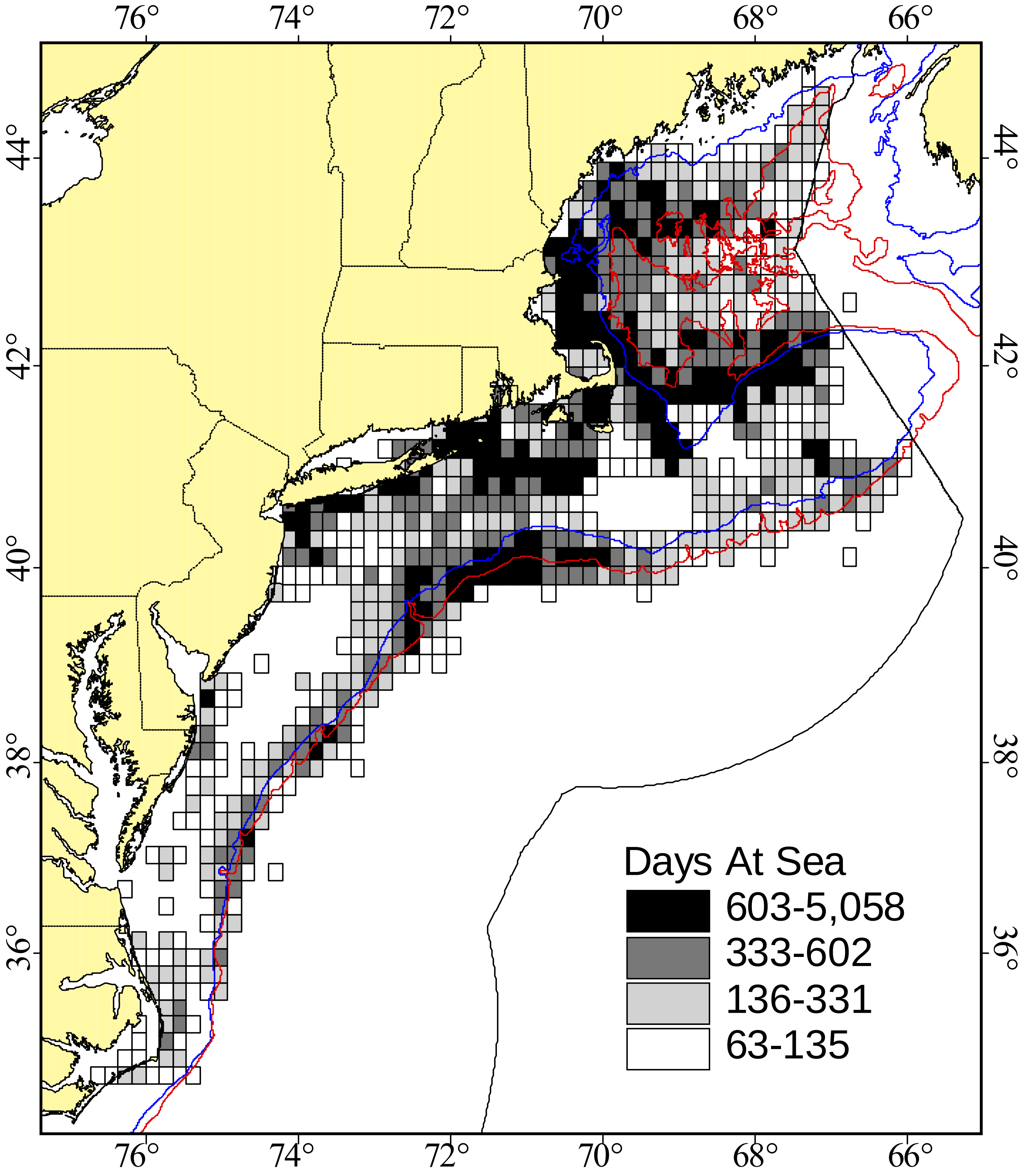


Figure 4.2. Bottom otter trawl (fish) fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), low (90% cumulative), or very low (95% cumulative) category of fishing activity level (*i.e.*, number of 24-hr days absent from port). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.2 for the ranges of fishing activity associated with each cumulative percentage category.)

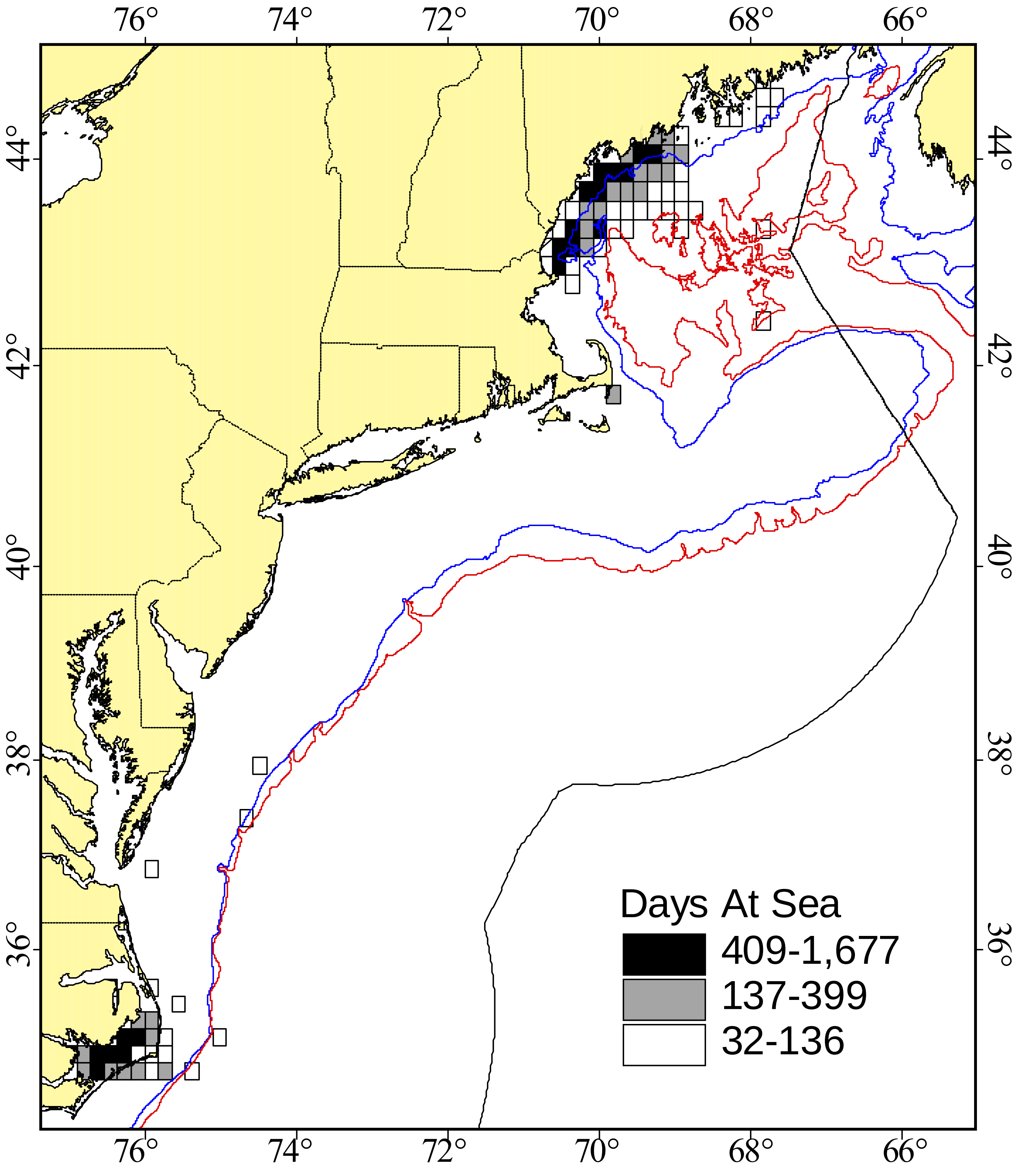


Figure 4.3. Bottom otter trawl (shrimp) fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of 24-hr days absent from port). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.2 for the ranges of fishing activity associated with each cumulative percentage category.)

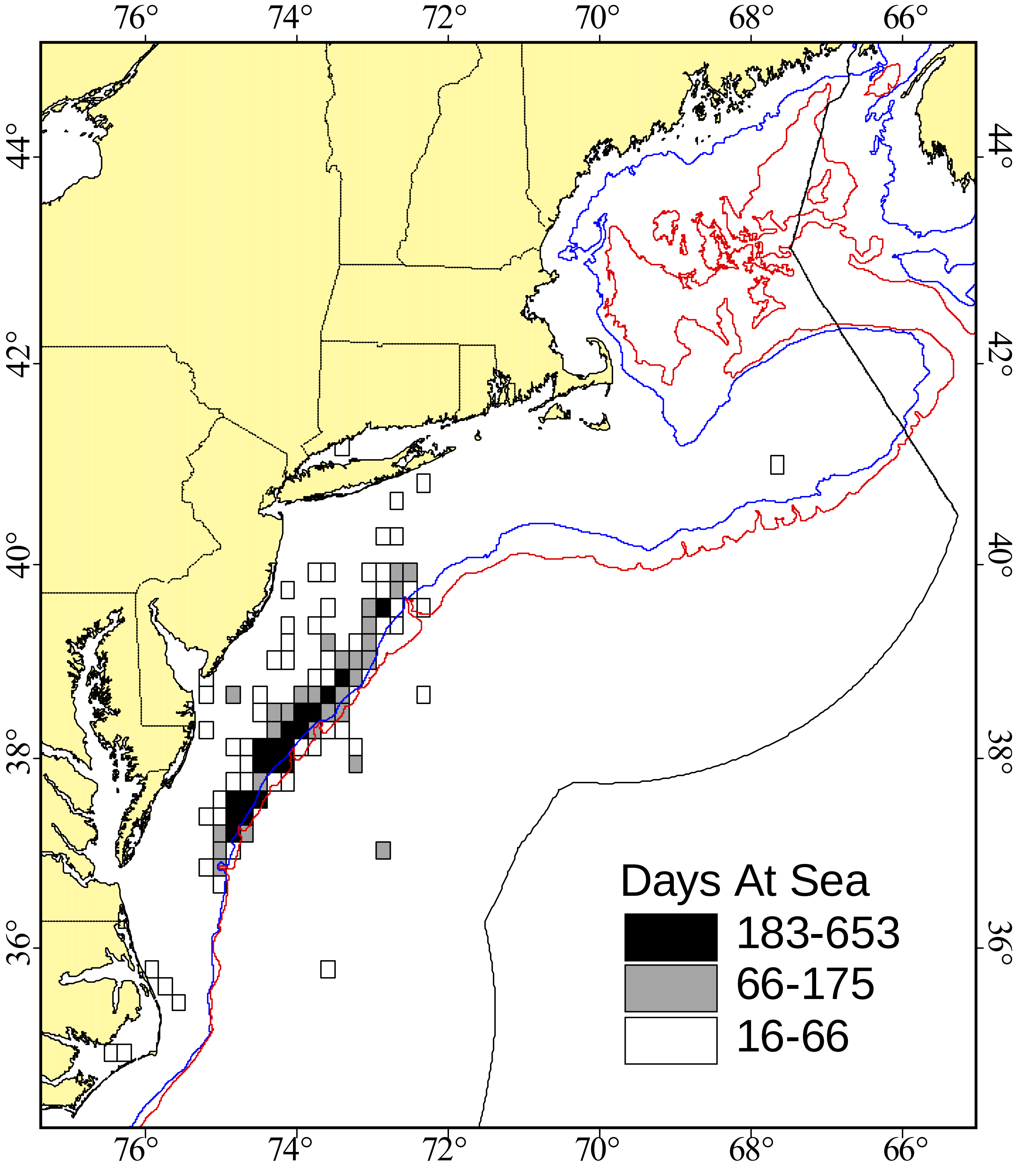


Figure 4.4. Bottom otter trawl (scallop) fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of 24-hr days absent from port). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.2 for the ranges of fishing activity associated with each cumulative percentage category.)

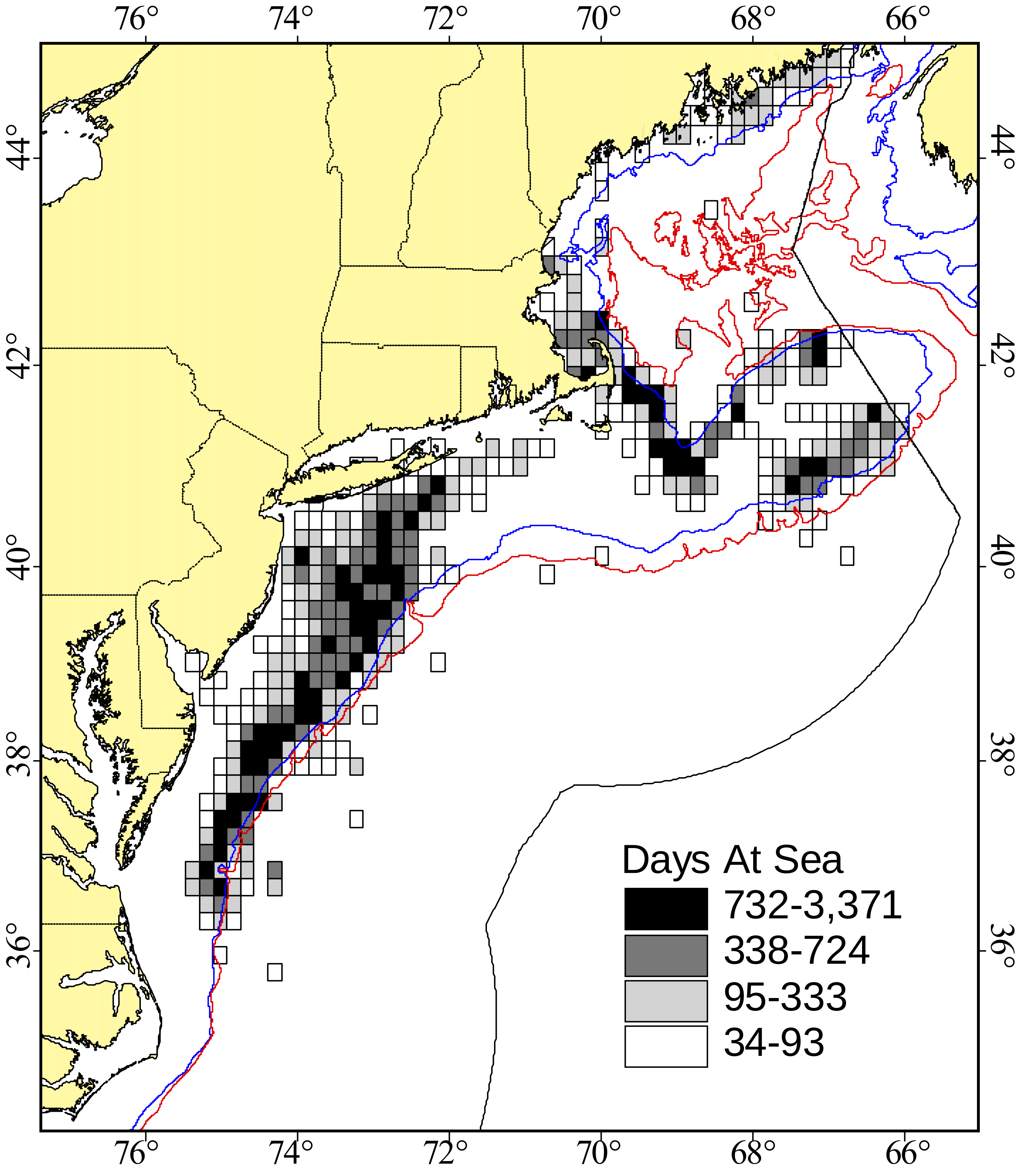


Figure 4.5. Scallop dredge fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), low (90% cumulative), or very low (95% cumulative) category of fishing activity level (*i.e.*, number of 24-hr days absent from port). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.2 for the ranges of fishing activity associated with each cumulative percentage category.)

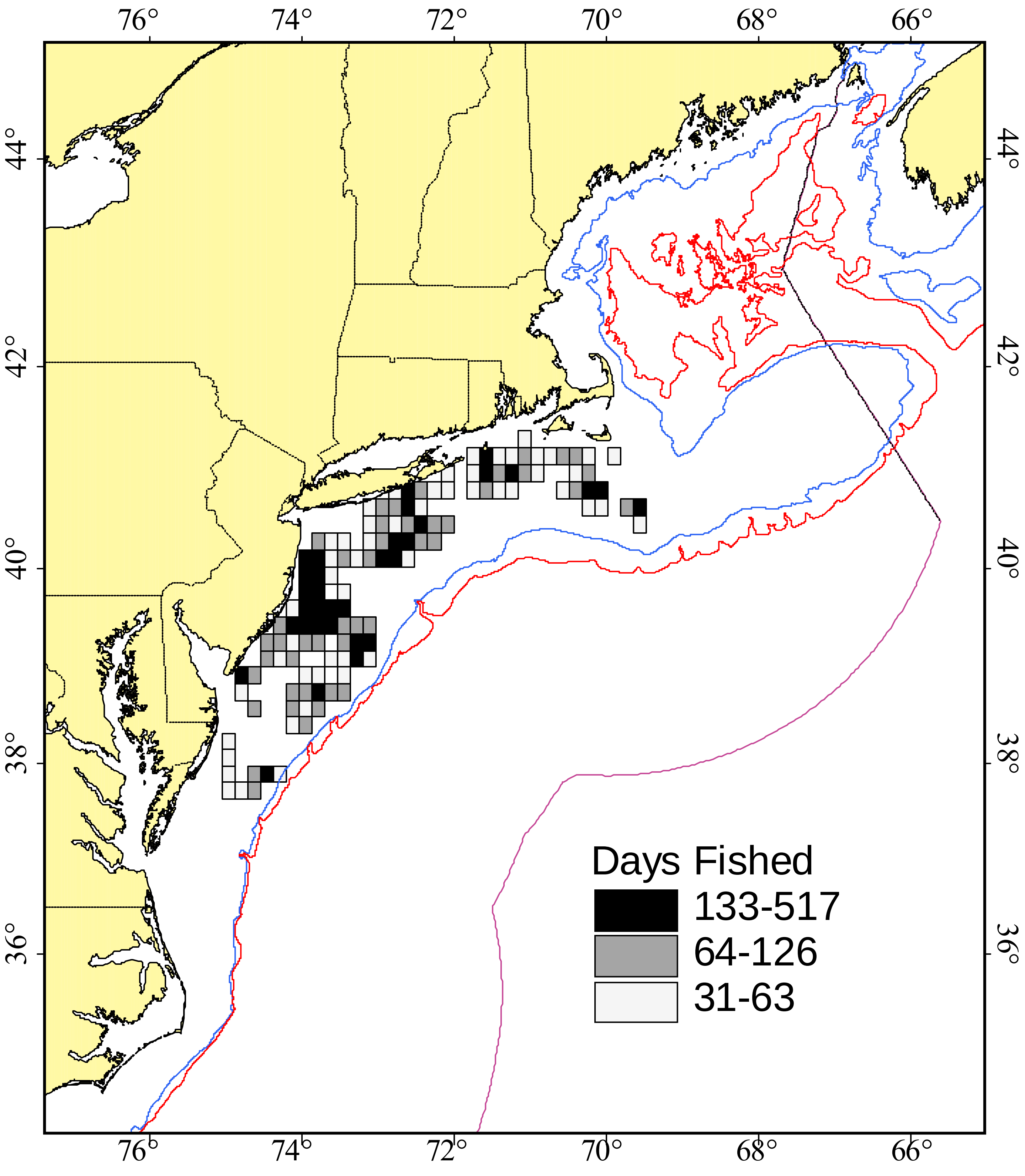


Figure 4.6. Hydraulic clam dredge fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of 24-hr days of fishing). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.2 for the ranges of fishing activity associated with each cumulative percentage category.)

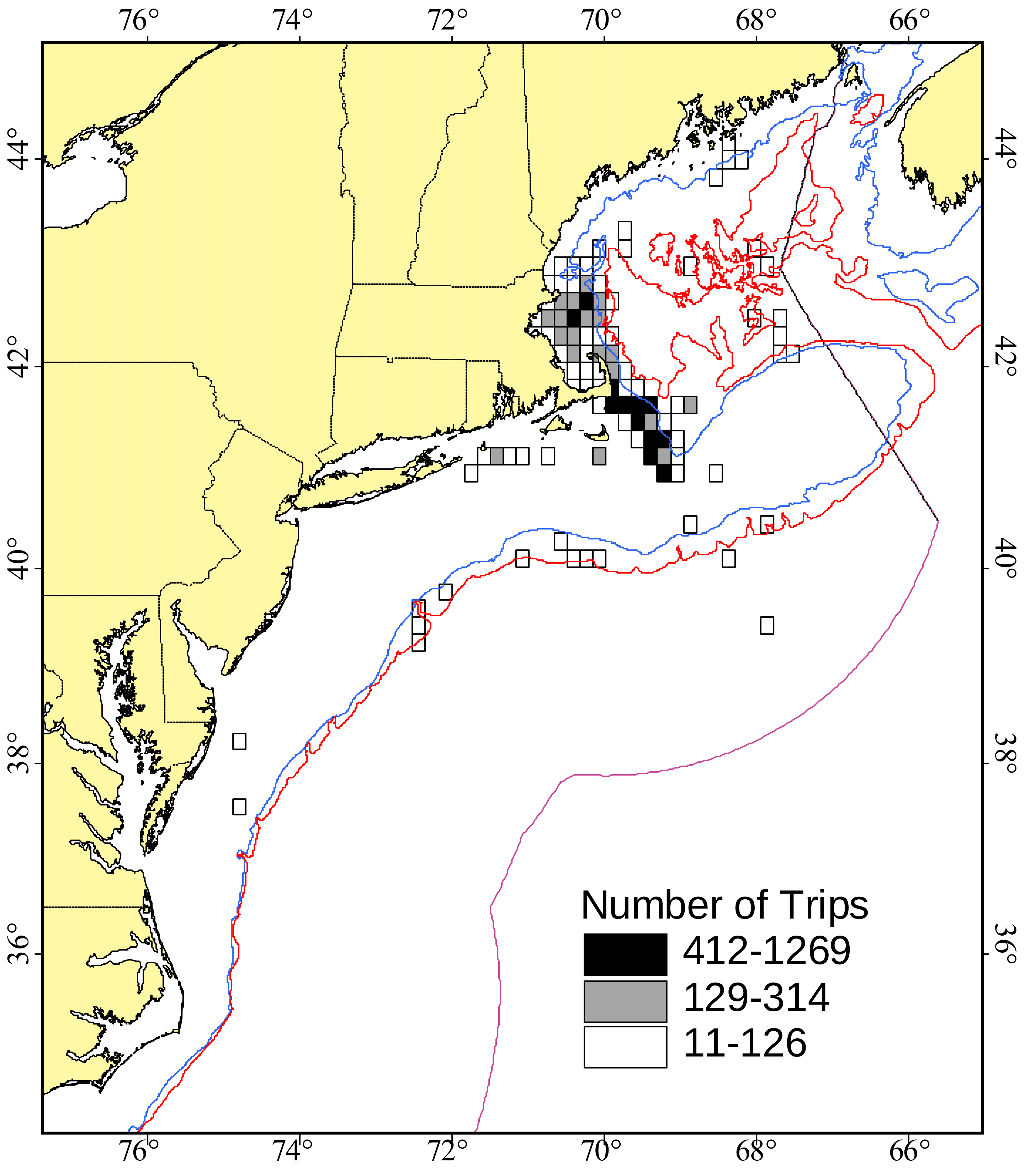


Figure 4.7. Bottom longline fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of trips). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.3 for the ranges of fishing activity associated with each cumulative percentage category.)

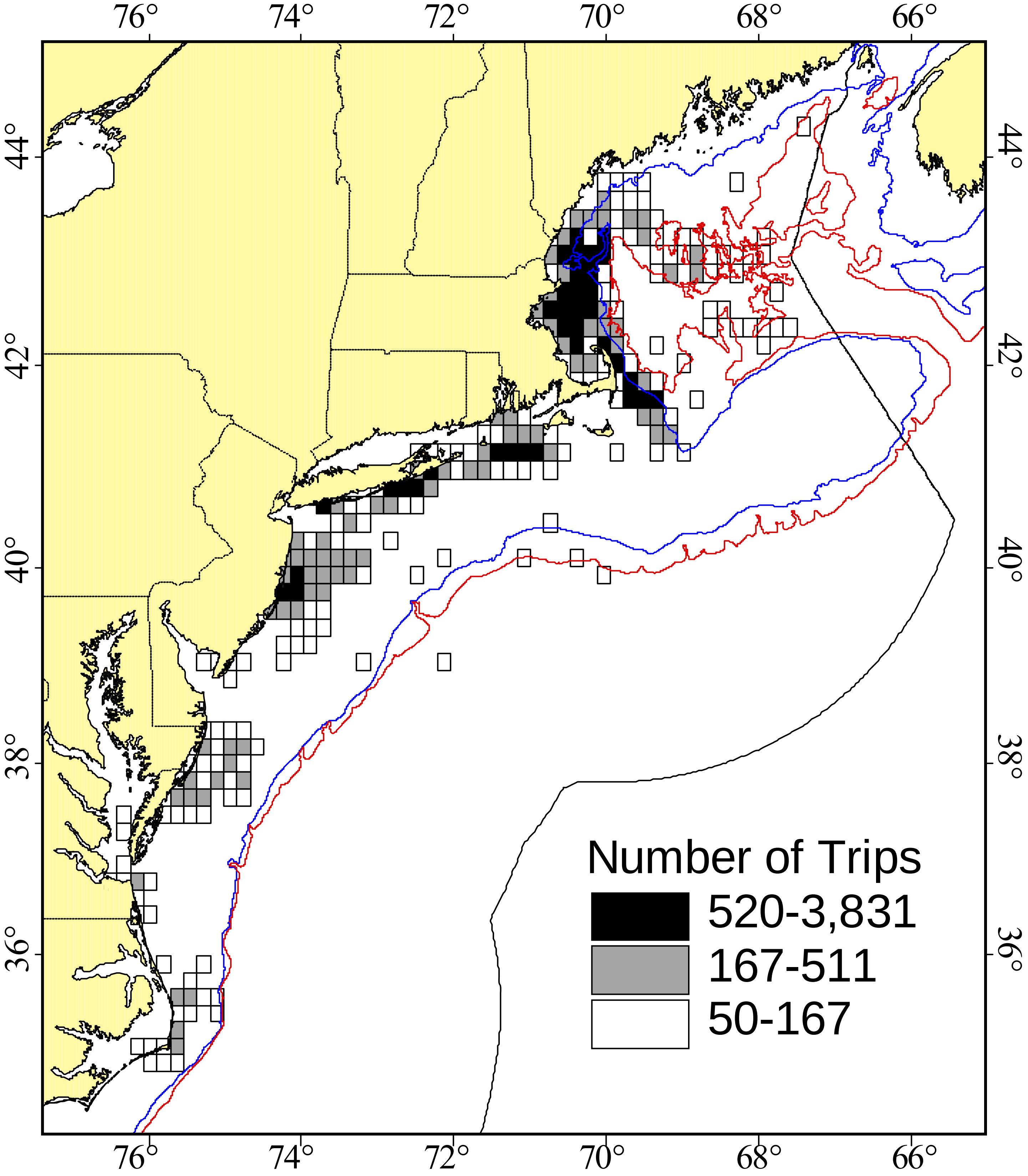


Figure 4.8. Bottom gill net fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of trips). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.3 for the ranges of fishing activity associated with each cumulative percentage category.)

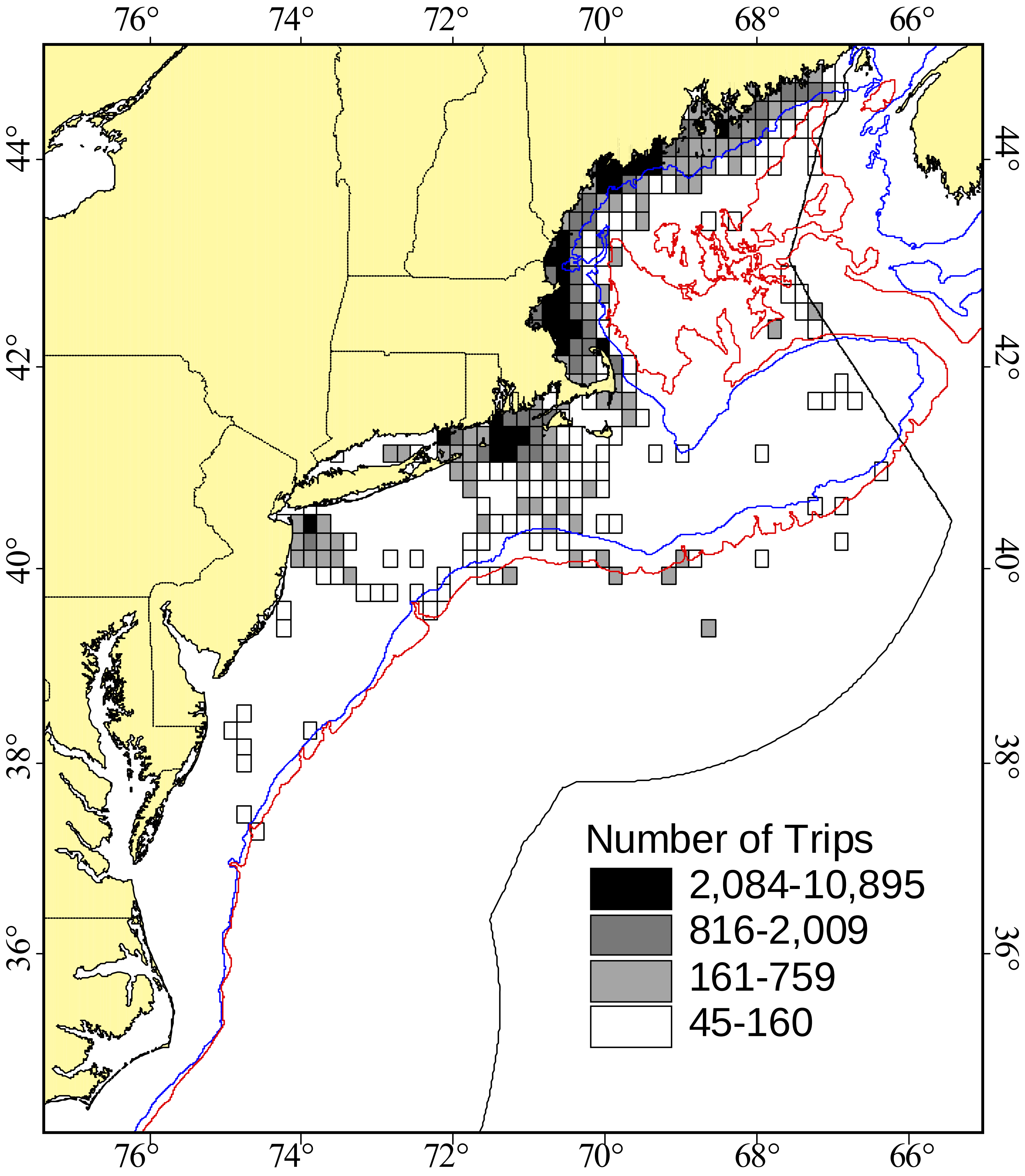


Figure 4.9. Lobster trap or pot fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), low (90% cumulative), or very low (95% cumulative) category of fishing activity level (*i.e.*, number of trips). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.3 for the ranges of fishing activity associated with each cumulative percentage category.)

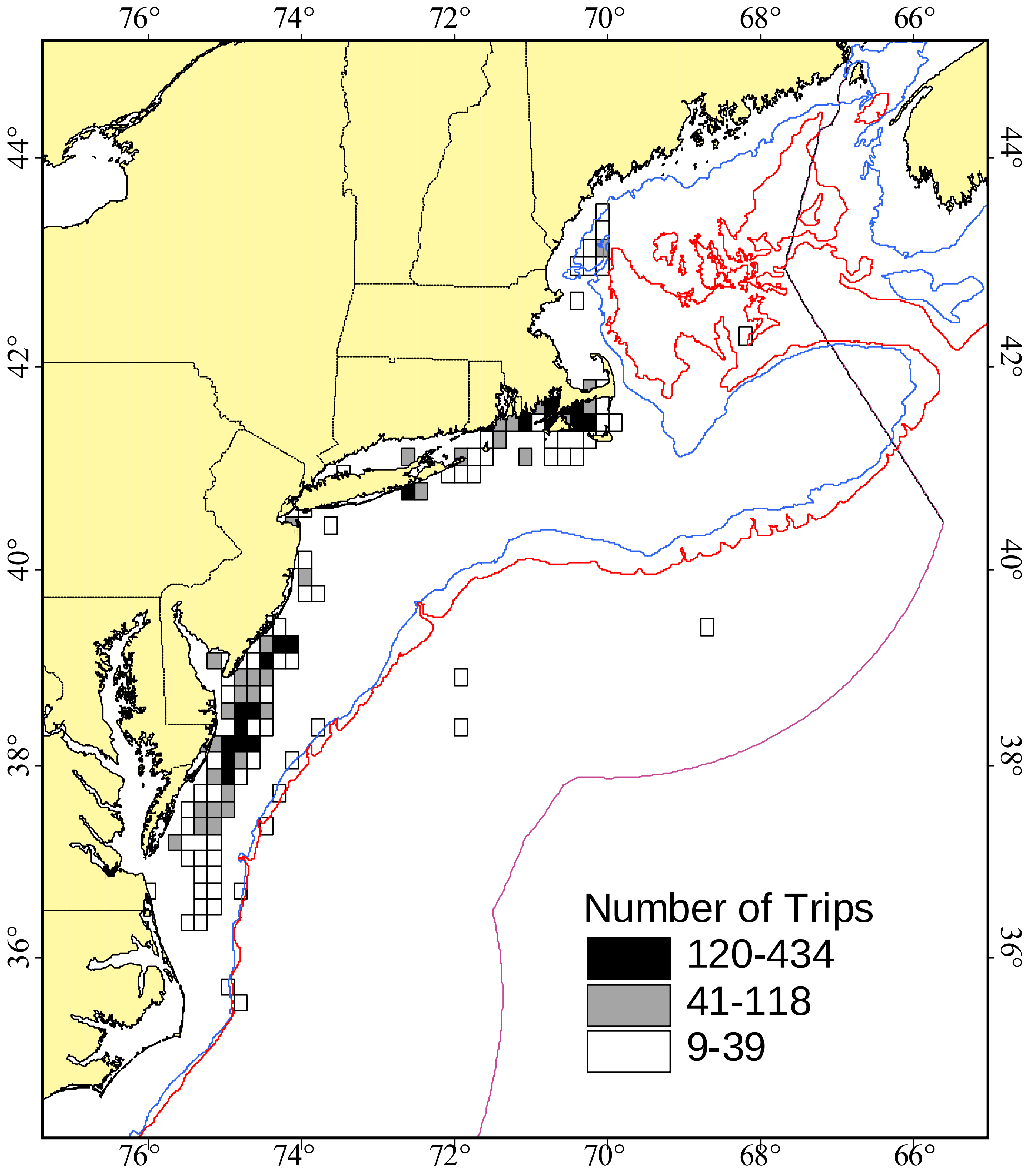


Figure 4.10. Fish pot fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of trips). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.3 for the ranges of fishing activity associated with each cumulative percentage category.)

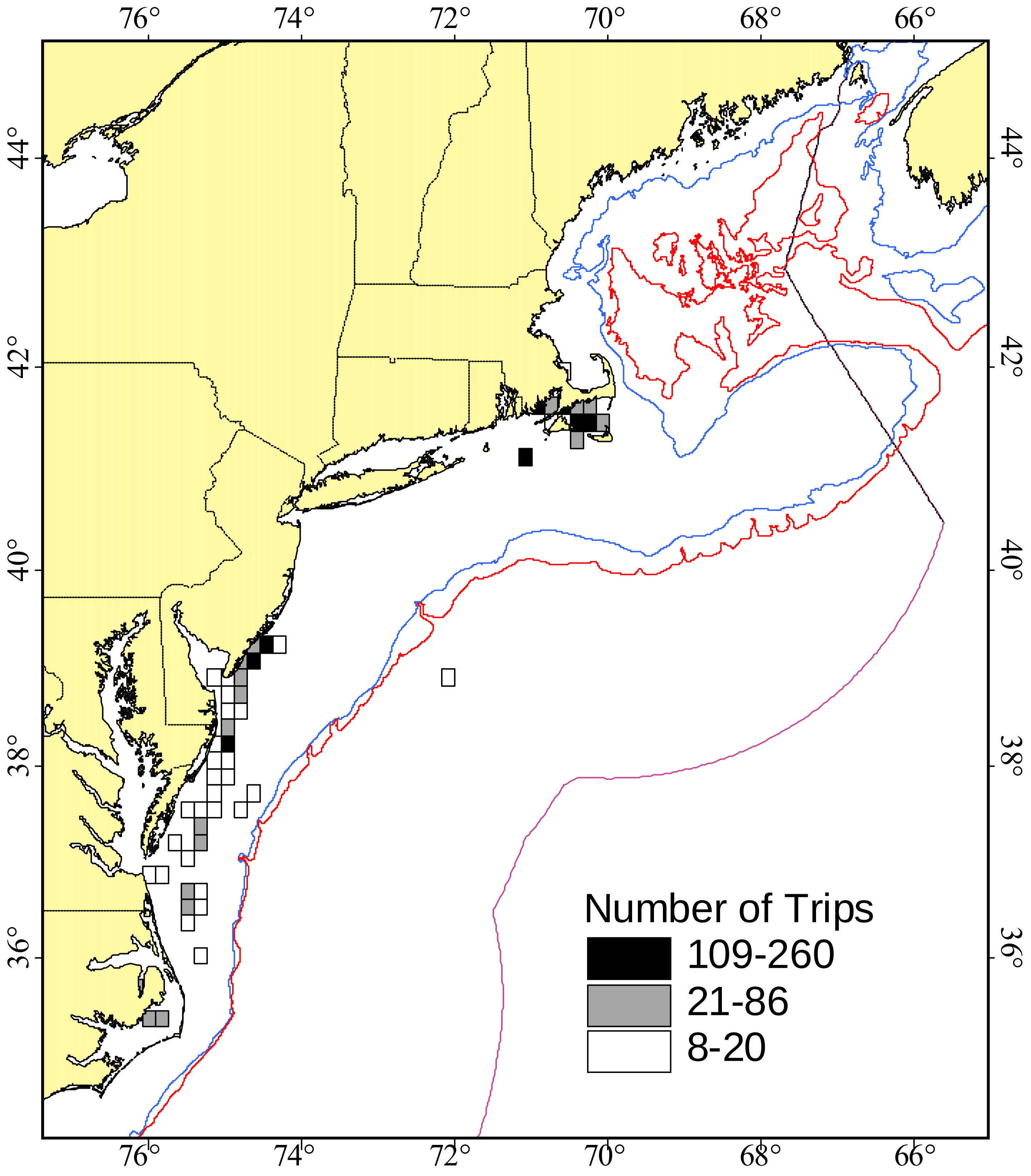


Figure 4.11. Whelk pot fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of trips). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.3 for the ranges of fishing activity associated with each cumulative percentage category.)

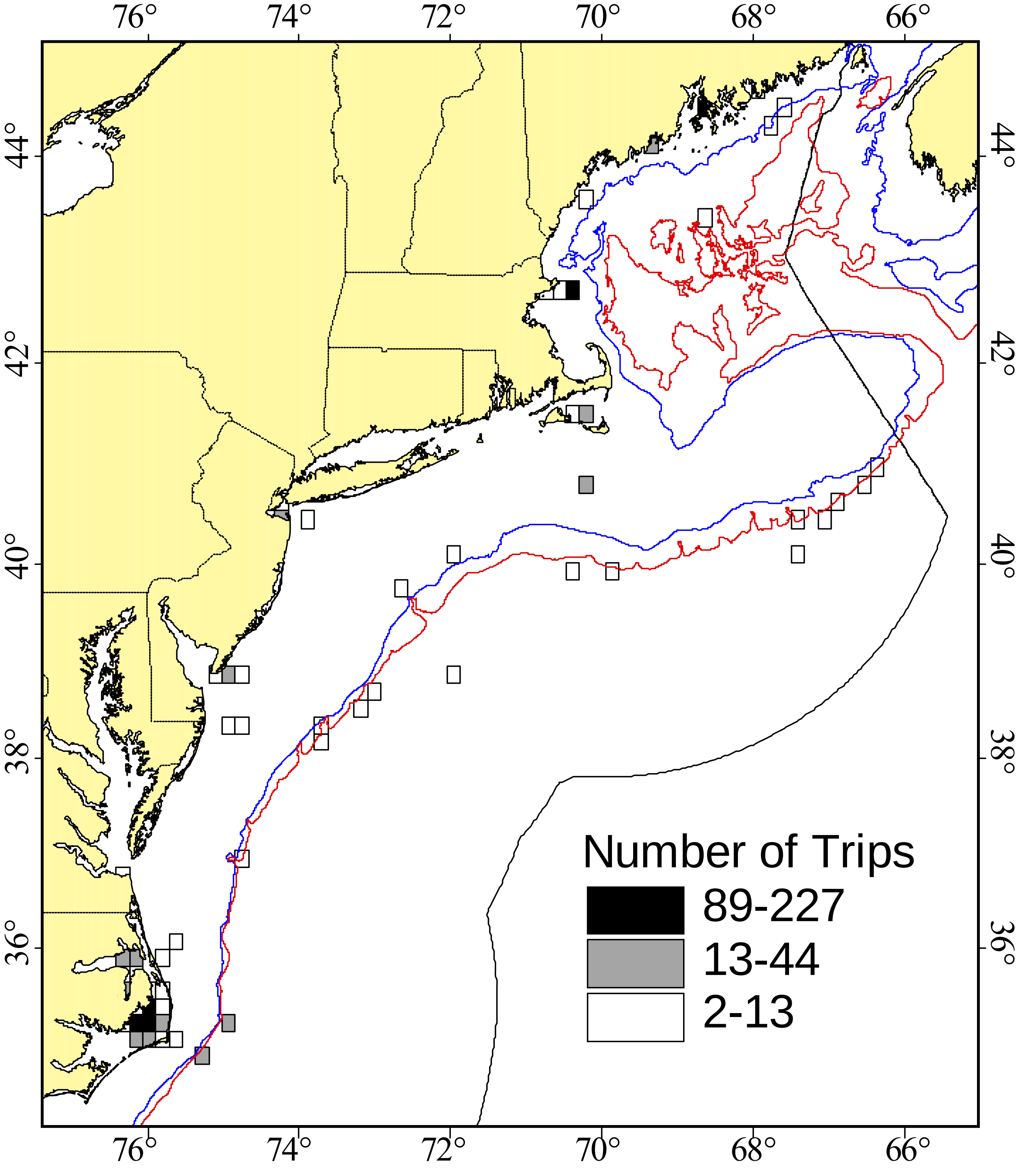


Figure 4.12. Crab pot fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of trips). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.3 for the ranges of fishing activity associated with each cumulative percentage category.)

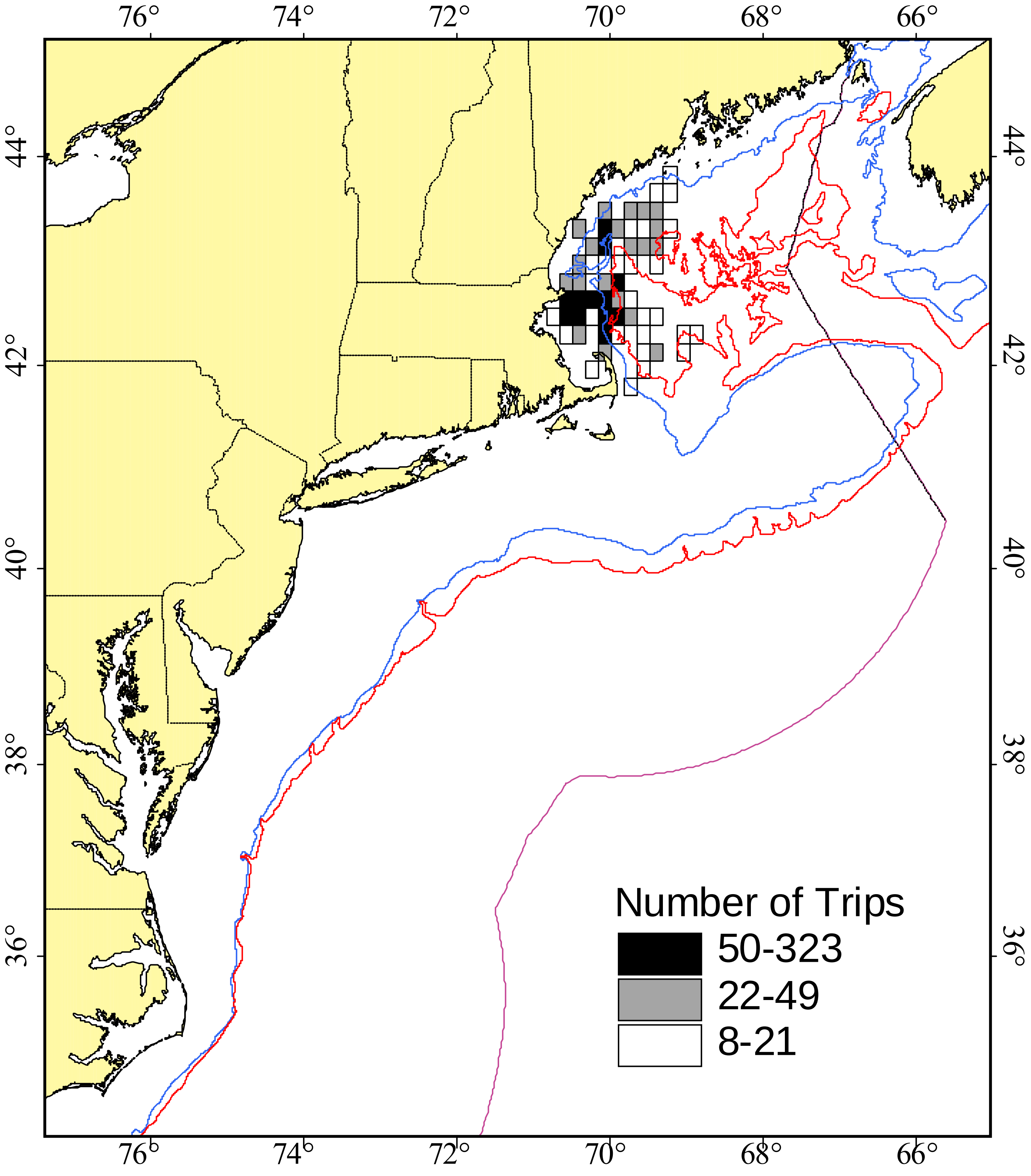


Figure 4.13. Hagfish pot fishing activity in the Northeast Region during 1995-2001. (Each TMS is associated with either a high (50% cumulative), medium (75% cumulative), or low (90% cumulative) category of fishing activity level (*i.e.*, number of trips). See the text for further explanation of cumulative percentages, or "percentiles," and Table 4.3 for the ranges of fishing activity associated with each cumulative percentage category.)

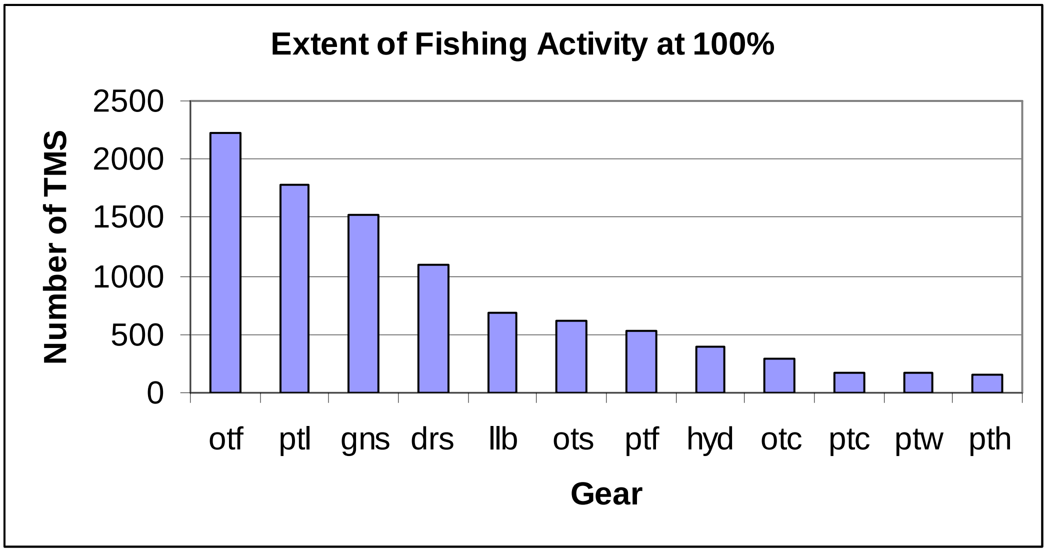


Figure 4.14. Number of 10' squares (TMSs) within which any amount of fishing activity was reported (*i.e.*, the 100th percentile) during 1995-2001 by gear type. (Note: Important to show because the maps stop at the 90th or 95th percentile, and do not show the full extent of fishing activity (*i.e.*, TMSs with just a small amount of activity, as well as TMSs with activity that is misreported by fishermen). Key: drs = New Bedford-style scallop dredge; gns = sink gill net; hyd = hydraulic clam dredge; llb = bottom longline; otc = otter trawl (scallop); otf = otter trawl (fish); ots = otter trawl (shrimp); ptc = pots & traps (crab); ptf = pots & traps (fish); pth = pots & traps (hagfish); ptl = pots & traps (lobster); and ptw = pots & traps (whelk).)

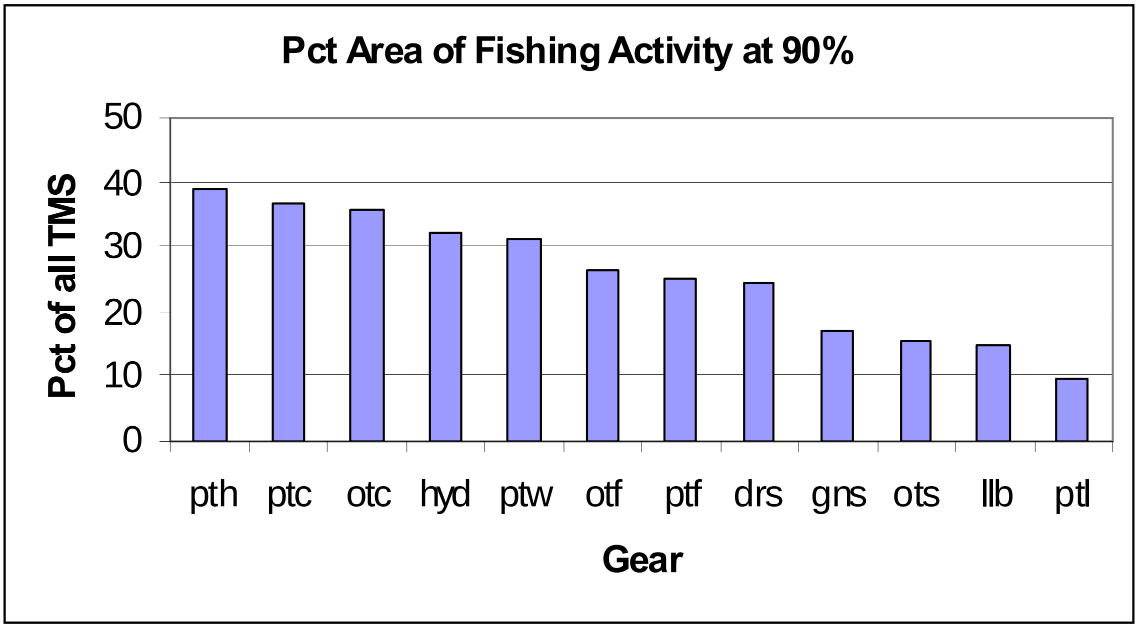


Figure 4.15. Proportion of area fished [all 10' squares] at the 90th percentile, an index of how evenly distributed the days or trips were among 10' squares, during 1995-2001 by gear type. (Note: For gears at the high end, most of the fishing activity was concentrated in a relatively small percentage of the total area fished (aggregated), and for gears at the low end, fishing activity was more evenly dispersed among TMSs. Key: drs = New Bedford-style scallop dredge; gns = sink gill net; hyd = hydraulic clam dredge; llb = bottom longline; otc = otter trawl (scallop); otf = otter trawl (fish); ots = otter trawl (shrimp); ptc = pots & traps (crab); ptf = pots & traps (fish); pth = pots & traps (hagfish); ptl = pots & traps (lobster); and ptw = pots & traps (whelk).)

5. REVIEW OF LITERATURE ON FISHING GEAR EFFECTS

Seventy-three publications were included in the gear-effects literature review. An attempt was made to include all available, relevant, English language scientific publications in order to determine the effects on benthic marine habitat types of the principal commercial fishing gears used in the Northeast Region. Habitat types were defined by the predominant substrate. Gear types that were selected were those that are currently used in the region, or those that are used elsewhere but were judged to have similar effects as gears that are used in the region. Gears that are used strictly in state waters to harvest species that are not federally managed were not included.

This review details individual scientific studies and summarizes what is known about each combination of gear and substrate type. Both peer-reviewed and non-peer-reviewed publications were included, but the emphasis was on the former. Information summarized in this review was based, in all cases, on primary source documents. An attempt was made to include all relevant publications available through early 2002.

This document differs in several important ways from other recent reviews of the gear-effects literature (Jennings and Kaiser 1998; Auster and Langton 1999; Collie *et al.* 2000) and from recent broadscale assessments of the effects of commercial fishing gear on benthic marine habitats and ecosystems (Dayton *et al*. 2002; NRC 2002). Rather than emphasizing general conclusions that apply to combined gear types (*e.g.*, "reduction of habitat complexity by mobile bottom-tending gear"), this document provides detailed summaries, in text and tabular format, of individual studies of relevance to the Northeast Region. The intention was to provide enough information in each summary for the reader to understand where and how the research was conducted and what the principal results were. Each such summary table contains information on location, depth, substrate, effects, recovery, and the methodological approach. No attempt was made to critically evaluate the research approach or the validity of the results, unless there were issues (*e.g.*, a failure to replicate treatment sites, not enough samples) identified as problems by the authors themselves. Most of the studies summarized in this document were also summarized in less detail in an earlier NMFS report that included gear types not used in the Northeast Region (Johnson 2002).

METHODS

The review is organized by combinations of gear and substrate types. Nine of the seventy-three reviewed studies included information for more than one gear type, or for one gear type in more than one substrate or study area, and were therefore summarized in more than a single gear/substrate category. In all, there were 80 descriptions for seven gear types and five substrates (Tables 5.1-5.3). Cases in which the effects of more than one gear type were evaluated in a single study and could not be distinguished were categorized as multiple gears. The same approach was used for studies conducted in mixed substrates that could not be defined as mud, sand, gravel/rock, or biogenic.

Over half (65%) of the descriptions in this document are for otter trawls and scallop dredges, and all but one are for different kinds of mobile bottom-tending gears. Thirty-four of the studies were done in sandy substrate, twelve in mud, seven in different types of biogenic substrate, five in gravel and rocky bottom, and twenty-two in mixed substrate. Most studies were peer reviewed, and most were published after 1990. Geographically, 21 were conducted in the northeastern United States (North Carolina to Maine), 19 elsewhere in North America (United States and Canada), 28 in Europe and Scandinavia, and 12 in Australia and New Zealand.

Individual Studies

Within each gear/substrate subsection, individual studies are described in one to two paragraphs that include the following information, when available:

- citation (authors and date of publication)
- location of study
- depth
- substrate type and/or composition
- detailed information on gear used, especially for otter trawls
- type of study (observational or experimental)
- whether experiments were set up to test for time and location effects
- type(s) of organisms sampled (infauna versus epifauna)
- duration and intensity of fishing (number of tows, duration of each fishing event, total duration of fishing disturbance, frequency of fishing events, etc.)
- timing of sampling or observations (how often, how long before or after fishing, etc.)
- timing and frequency of sampling or observations to determine recovery
- whether study was done in a commercially exploited or unexploited area
- if unexploited, for how long and what gears were excluded

Details that were not generally included were descriptions of sampling gears and procedures, sample processing information (*e.g.,* the mesh size used to sieve grab samples), taxonomic categories used (families, groups of species, individual species), and data analysis procedures (*e.g.,* statistical tests). General conclusions, when they are included, were the own statements of the respective study's author(s); neither speculations regarding the study in question nor any restatements made by the authors regarding anybody else's research were included. Results which are described as "significant" are results that were statistically significant. To avoid confusion, the term was not used in any other context.

Each gear/substrate category also includes a table summarizing the setting (location, depth, and sediment type), general methods, and primary results of each study. The listing of results in these tables is divided into an effects column and a recovery column. Results summarized in the tables include positive and negative results (*e.g.,* increases and decreases in abundance caused by fishing, as well as instances when there were no detectable effects of fishing). Blank cells in the recovery column indicate that the study was not designed to provide information on recovery times. Information in the last column includes the nature of the research (experimental or observational), whether or not the study area was being commercially fished at the time of the study, and how the experimental fishing was conducted (single or multiple tows, discrete or repeated disturbance events, and, if known, the average number of tows to which any given area of bottom was exposed).

Summaries

This section also summarizes results for all studies combined in each gear/substrate category. Each such summary begins with an introductory paragraph that includes general information, such as:

- the number of studies that examined physical and biological effects
- how many studies were done in different geographic areas and depth ranges
- how many studies examined recovery of affected habitat features
- the number of studies performed in areas that were closed to commercial fishing versus areas that were commercially fished at the time of the study
- how many studies involved single versus multiple tows
- how many studies were conducted either during a single discrete time period or during a more prolonged period of time that was intended to simulate actual commercial fishing activity

Physical and biological effects for each gear/substrate category are summarized in separate paragraphs. When necessary, biological effects are presented separately for single disturbance and repeated disturbance experimental studies, and for observational studies.

RESULTS

Otter Trawls

Otter Trawls -- Mud (Table 5.4)

1. Ball *et al.* (2000) sampled benthic macrofauna before and 24 hr after trawling at a heavily fished site within an offshore prawn (*Nephrops*) trawl fishing ground in the Irish Sea and at an unfished "pseudo-control" site near a shipwreck at the same depth (75 m) that had not been fished for about 50 yr. Sediments were sandy silt. No information on the duration of experimental trawling or the type of net used was provided.

Due to few organisms and low biomass, and to the resulting high intersample variance, it was not possible to quantitatively evaluate the short-term effects of trawling at the fished site. There were, however, considerably fewer species and individuals, and lower species diversity and richness, in the commercially trawled area than near the shipwreck.

At the shipwreck site, the number of species, number of individuals, and biomass decreased with increasing distance from the wreck. High intersample variance in biomass estimates near the wreck impeded comparisons with the trawled site. Sixty-nine species found at the wreck site were not found at the experimental fishing site. These included polychaetes, crustaceans, bivalve mollusks, gastropods, and echinoderms. Large specimens of some mollusks and echinoderms were most common near the wreck, whereas only juveniles of these species were sampled in the trawled area.

2. Brylinsky *et al.* (1994) examined physical and biological effects of 18-24 m wide flounder trawls with 180-270 kg doors, 29-cm-diameter rubber rollers, and no tickler chains in an intertidal estuary in the upper Bay of Fundy, Nova Scotia. The study area was commercially fished for flounder by trawlers. Four trawling experiments were conducted at two sites in 6-8 m of water (at high tide) in 1990 and 1991. Repeated tows were made during a single day at each site, but not over the same bottom area. Samples of macrobenthos, meiofauna, and chlorophyll were collected at each site at variable intervals for 1.5-4 mo after trawling. One site had sand overlain with several centimeters of silt; the other site had siltier sediment to a depth of at least 10 cm. The study area is a high-energy environment, owing to the extreme tidal range (average 11 m with a maximum of 16 m) and tidal currents that frequently exceed 2 knots.

Trawl doors made furrows 1-5 cm deep and berms that were visible for at least 2-7 mo. The rollers compressed sediments. The amount of disturbance varied markedly and seemed to be influenced primarily by the kind of sediment and the type of door used, being more pronounced in the finer sediments and when heavier doors were used. Benthic diatoms (measured as chlorophyll *a*) decreased in door furrows at some stations, but recovered within 1-3 mo. No significant effects were observed on macrobenthos, which was dominated by polychaetes. The numbers of nematodes in door furrows were reduced, but only for 1-1.5 mo, and may only have been displaced by the doors. Benthic taxa such as mollusks, crustaceans, and echinoderms that are known to be more susceptible to trawling were not present in the study site.

3. DeAlteris *et al.* (1999) analyzed data from a 1995 sidescan sonar survey to locate and map trawl tracks in shallow sand and mud sediments in lower Narragansett Bay, Rhode Island. At the deeper (14-m) mud-bottom site, trawl doors produced smooth tracks 5-10 cm deep with berms on the inside edge that were 10-20 cm high.

The longevity of hand-dug trenches (dug to simulate tracks left by trawl doors) was monitored using SCUBA divers. The trenches were observed unchanged for the duration of the study (>60 days), and were occupied by Atlantic rock crabs. Natural erosion at this site was predicted to occur <5% of the time.

4. Drabsch *et al.* (2001) used divers to sample benthic infauna before and after experimental trawling in an area of South Australia (Gulf of St. Vincent) where little or no fishing had occurred for 15 yr. Three study sites were used (one in mud and two in sand), with adjacent trawled and control corridors at each site. (See "Otter Trawls -- Sand, 4. Drabsch *et al*. (2001)" for a summary of results at the two sandy study sites.) Two series of 10 adjacent tows were made in a single trawl corridor at the mud treatment site during 1 day in October 1999 using triple prawn trawls with two doors (1x2 m, 200 kg each) and a combined sweep length of about 20 m. Bottom sediments at the mud study site were fine silt sediments and the depth was 20 m.

Trawl doors left tracks, and the footline and net smoothed topographic features and removed 28% of the epifauna (not differentiated between mud and sand substrates). Remaining epifauna in the trawled corridor showed signs of damage. Total infaunal abundance and the abundance of one family of polychaetes (Ctenodrilidae) were significantly reduced 1-wk after trawling. No significant changes were evident for any other taxon.

5. Frid *et al.* (1999) examined the long-term effects of fishing with prawn (*Nephrops norvegicus*) otter trawls by comparing changes over 27 yr on macrobenthic communities at a lightly fished (LF) and a heavily fished (HF) location off the northeastern coast of England (North Sea). Fishing activity within the statistical area that includes both sites was divided into three periods of low (1971-1981), high (1982-1989), and moderate (1990-1997) fishing effort. The depth at the HF site was 80 m, and the substrate was predominantly (>50%) silt-clay. Grab samples were collected at the HF site every year during January. Benthic taxa in the samples were divided into two groups that were predicted to respond negatively (*i.e.*, decreased number of individuals, or "abundance") or positively (*i.e.*, increased abundance) to increased trawling activity, based on published accounts.

The total abundance of taxa in the positive response group conformed to predictions by increasing significantly between the periods of low and high fishing effort, and then declining when fishing effort dropped to moderate levels. The total abundance of taxa in the negative response group did not vary significantly between time periods. Errant polychaetes were the only taxonomic group in the negative response group to increase significantly at high fishing effort. Starfish and brittle stars were more abundant at high fishing effort, but not significantly. Sea urchins, as predicted, decreased in abundance (to zero) at high fishing effort. Sedentary annelids and large bivalve mollusks were taxa in the negative response group that did not decrease in abundance. Benthic macrofaunal abundance at the HF site was low at the beginning of the time series when phytoplankton production was also low, but once fishing effort increased, there was no longer any correlation between the two. (See "Otter Trawls -- Sand, 5. Frid *et al*. (1999)" for a summary of results at the LF site that had a sandy substrate.)

6. Hansson *et al.* (2000) examined the effects of trawling on clay bottom habitats at 75-90 m depths in a Swedish fjord. The benthic infauna was collected 1-5 mo before trawling began at three experimental sites and three control sites, and during the last 5 mo of a 1-yr trawling experiment. All sites were located in an area that had been closed to fishing for 6 yr. The otter trawl that was used was a commercial shrimp trawl with a 14-m ground rope with 20 kg of lead distributed along it, and 125-kg otter boards. Eighty hauls were made at each treatment site during a 1-yr period starting in December 1996, at a frequency of two hauls per week. It was estimated that any given area was passed over 24 times by the trawl during the experiment.

For 61% of the species sampled, abundances tended to be negatively affected by trawling (*i.e.*, abundances decreased more or increased less in the trawled sites compared to the control sites during the experiment). Total biomass decreased significantly at all three trawled sites, and the total number of individuals decreased significantly at two trawled sites, but in both cases significant reductions were also observed at one of the control sites; thus, these changes could not be attributed solely to trawling. Total abundance and biomass at trawled sites was reduced by 25% and 60%, respectively, compared to 6% and 32% in control sites. Individual phyla responded differently to trawling. Echinoderm (mostly brittle star)abundance decreased significantly, polychaete abundance was not affected although some families increased and some families decreased, and amphipod and mollusk abundances were not affected.

7. Mayer *et al.* (1991) examined the immediate effects of a single tow with an otter trawl on mud substrate at a depth of 20 m in a bay on the coast of Maine. The trawl had an 18-m footrope with an attached tickler chain and 90-kg doors. Sediment core samples (to a sediment depth of 18 cm) were taken inside and outside the drag line the day after trawling, and were analyzed for porosity, chlorophyll, pheophytin, total organic matter, protein, extracellular proteolytic activity, and beryllium-7.

Downcore profiles were similar between the dragged and control sites, indicating that trawling did not "plow" the bottom and bury surficial sediments. The trawl doors did produce furrows several centimeters deep, and the chain and net caused a very thin, and inconsistent, planing of surficial features. A high value of beryllium-7 in surficial sediments at the control site, but not at the trawled site, indicated that fine sediments were dispersed laterally, away from the area of dragging.

8. Pilskaln *et al.* (1998) collected large infaunal worms in sediment traps deployed 25-35 m above the bottom in two deep (250-m) basins in the GOM during 1995.

Many more worms were collected in Wilkinson Basin, which is located in a more heavily trawled area in the Gulf, than in Jordan Basin, which is located in a region of the Gulf with very little trawling activity. Higher abundance coincided with seasons of greater trawling activity in the southwestern GOM.

The authors concluded that the worms are dislodged and suspended in the near-bottom water column by trawling because there was no other reason why they would leave their natural habitat in the bottom. They also noted that the resuspension of fine sediment by bottom trawls releases nutrients such as nitrogen and silica from bottom sediments.

9. Sanchez *et al.* (2000) examined the effects of otter trawling in a commercially trawled area with muddy substrate (depth 30-40 m) in the northwest Mediterranean Sea off the coast of Spain. A commercial otter trawl was towed repeatedly during daylight for 1 day (3.5 hr of towing) at one site and during a 23-hr period (7 hr of towing) at a second site in July 1997, so that each trawl wayline was swept entirely either once or twice. Infaunal grab samples were collected prior to fishing and at various times after fishing (up to a maximum of 150 hr) in each trawl wayline and at unfished sampling locations adjacent to each wayline.

A number of taxa (mostly families) were significantly more abundant in the lightly trawled wayline than in the adjacent untrawled area after 150 hr, primarily due to decreased abundance outside the wayline. The total numbers of individuals and taxa were also significantly reduced outside, but not inside, the lightly trawled wayline 150 hr after trawling. There were no differences in the number of taxa or individuals inside and outside the more intensively trawled wayline after 72 hr.

The percentage composition of abundance of major taxa (*i.e.*, polychaetes, crustaceans, and mollusks) was similar in both trawled waylines and in the control locations throughout the experiment, and trawling produced no changes in community structure in either wayline. Sidescan sonar images of the trawl waylines showed furrows left by the trawl doors that remained visible throughout the experiment.

10. Sparks-McConkey and Watling (2001) investigated the effects of trawling on geochemical sediment properties and benthic infauna in Penobscot Bay, Maine. The study site was selected because it was deep (60 m) and bottom sediments were not exposed to storm events or tidal scouring. Sediment particle size was homogeneous spatially and temporally within the study area. There had been no commercial trawling in the area for 20 yr. Trawling was conducted at two stations in December 1997 with a 12-m commercial silver hake net that was modified (increased mesh size and decreased diameter of float rollers) to reduce effects to the seafloor. Four tows were made at each station during 1 day. An attempt was made to tow the same area of bottom each time. Sampling was conducted at the experimental stations and at seven reference stations for a year before trawling, and 5 days, 3.5 mo, and 5 mo after trawling. An underwater video camera was used to verify that post-trawl grab samples were taken in trawl tracks.

Trawling caused immediate and significant reduction in porosity, an increase in the food value of surface sediments (upper 2 cm), and stimulated chlorophyll production, but none of these properties were any different at the trawled stations after 3.5 and 5 mo. Trawling also had immediate and significant effects on benthic infauna, reducing the number of individuals and species, reducing taxonomic diversity, and increasing species dominance. There were no longer any significant differences in any of these parameters after 3.5 mo when mobile species recruited to the benthos. Four polychaete species were significantly less abundant at the trawled stations 5 days after trawling, but three of them were present in equal densities at treatment and control stations 3.5 mo later. Two species of bivalve mollusks were reduced in abundance by trawling, one of them for 3.5 mo. Nemerteans were significantly more abundant at the trawled stations during all three post-trawl sampling dates.

11. Tuck *et al.* (1998) conducted experimental trawling in a sea loch in Scotland that had been closed to fishing for over 25 yr. Trawling was conducted 1 day/mo (for 7.5 hr) for 16 mo in a single treatment site (95% silt-clay, depth 30-35 m) starting in January 1994. Infaunal surveys were completed in the trawled site and a nearby reference site prior to, after 5, 10, and 16 mo of disturbance, and, once trawling ended, after 6, 12, and 18 mo of recovery.

Trawl doors produced furrows in the sediment, which were still evident in sidescan sonar images after 18 mo.

Trawling had no effect on sediment characteristics, but bottom "roughness" in the trawled area increased during the disturbance period and declined during the recovery period.

There were no significant differences in the number of infaunal species in the experimental and reference sites prior to the beginning of the experiment or during the first 10 mo of disturbance, but there were more species in the trawled site after 16 mo of disturbance and throughout the recovery period. In contrast, there were significantly more individuals in the trawled site before trawling began. This difference was maintained after 10 and 16 mo of fishing, and after 6 and 12 mo of recovery, but after 18 mo, there was no difference between the two sites. Taxonomic diversity and evenness indices were significantly lower in the experimental site for the first 22 mo of the experiment, but after 12 mo of recovery there were no longer any differences. Some species (primarily opportunistic polychaetes) increased significantly in abundance in the trawled plot in response to the disturbance, while others (*e.g.,* bivalve mollusks) declined significantly in abundance relative to the reference area. Biomass was significantly higher in the control site before trawling started, but not during the rest of the experiment. Two different measures of community structure were applied. One of them indicated that the two sites became significantly different after only 5 mo of disturbance and remained so throughout the experiment. According to the other one, the treatment site reached a similar condition to the reference site at the end of the recovery period. Trawling effects on epifauna could not be evaluated in this study because organisms were present in very low densities and because the trawl was not equipped with a net, thus any effects on epifauna would have been underestimated.

Summary

Results of 11 studies are summarized. All of the studies were conducted during 1991-2001, five in North America, five in Europe, and one in Australia. One study was performed in an intertidal habitat, one in very deepwater (250 m), and the rest in a depth range of 14-90 m. Eight of them were experimental studies and three were observational. Two studies examined only physical effects, six assessed only biological effects, and three examined both physical and biological effects. One study evaluated geochemical sediment effects.

In this habitat type, biological evaluations focused on infauna: all nine biological assessments examined infaunal organisms, and four of them included epifauna. Habitat recovery was monitored on five occasions. Two studies evaluated the long-term effects of commercial trawling, one by comparing benthic samples from a fishing ground with samples collected near a shipwreck, while another evaluated changes in macrofaunal abundance during periods of low, moderate, and high fishing effort during a 27-yr period. Four of the experimental studies were done in closed or previously untrawled areas and three in commercially fished areas. One study examined the effects of a single tow, and six involved multiple tows. Five studies restricted trawling to a single event (*e.g.,* 1 day) and two examined the cumulative effects of continuous disturbance.

Physical Effects

Trawl doors produce furrows up to 10-cm deep and berms 10-20 cm high on mud bottom. Evidence from three studies (2, 3, 9) indicates that there is a large variation in the duration of these features (2-18 mo). There is also evidence that repeated tows increase bottom roughness (11), fine surface sediments are resuspended and dispersed (7), and rollers compress sediment (2). A single pass of a trawl did not cause sediments to be turned over (7), but single and multiple tows smoothed surface features (4, 7).

Biological Effects -- Single-Disturbance Experimental Studies

Three single-event studies (1, 2, 9) were conducted in commercially trawled areas. Experimental trawling in intertidal mud habitat disrupted diatom mats and reduced the abundance of nematodes in trawl door furrows, but recovery was complete after 1-3 mo (2). There were no effects on infaunal polychaetes (2). In a subtidal mud habitat (30-40 m deep), the benthic infauna was not affected (9). There were no obvious effects on macrofauna at a deeper (75 m) site, but there were fewer organisms and species there than at an unexploited site near a shipwreck (1).

In two assessments performed in areas that had not been affected by mobile bottom gear for many years (4, 10), effects were more severe. Total infaunal abundance (4, 10) and the abundance of individual polychaete (4, 10) and bivalve mollusk (10) species declined immediately after trawling.

In one of these studies (10), there were also immediate and significant reductions in the number of species and species diversity. Other effects included reduced porosity, increased food value, and increased chlorophyll production in surface sediments. Most of these effects lasted <3.5 mo.

In the other study (4), two tows removed 28% of the epifauna on mud and sand substrate (not differentiated), and epifauna in all trawled quadrats showed signs of damage. These results were not reported separately for mud bottom.

Biological Effects -- Repeated-Disturbance Experimental Studies

Two studies of the effects of repeated trawling were conducted in areas that had been closed to fishing for 6 yr (6) and >25 yr (11). In one study (6), multiple tows were made weekly for a year, and in the other (11), monthly for 16 mo.

In one case (6), 61% of the infaunal species sampled tended to be negatively affected, but significant reductions were only noted for brittle stars.

In the other case (11), repeated trawling had no significant effect on the numbers of infaunal individuals or biomass. In this study, the number of infaunal species increased by the end of the disturbance period. Some species (*e.g.,* polychaetes) increased in abundance, while others (*e.g.,* bivalve mollusks) decreased. Community structure was altered after 5 mo of trawling, and (because of mixed results from the analyses) if it did fully recover, then it did not do so until at least 18 mo after trawling ended.

Biological Effects -- Observational Studies

An analysis of benthic sample data collected from a fishing ground over a 27-yr period of high, medium, and low levels of fishing effort showed an increased abundance of organisms belonging to taxa that were expected to increase at higher disturbance levels, whereas those that were expected to decrease did not change in abundance (5). Trawling in deepwater apparently dislodged infaunal polychaetes, causing them to be suspended in near-bottom water (8).

Otter Trawls -- Sand (Table 5.5)

1. Ball *et al.* (2000) sampled benthic macrofauna at a lightly fished inshore prawn trawl fishing ground in the Irish Sea before and 24 hr after trawling and at an unfished (for about 50 yr) "pseudo-control" site near a shipwreck. Sediments at these two sites were muddy sand, and the depth was 35 m. No information on the duration of experimental trawling or the type of net used was provided.

There were no obvious short-term effects of experimental trawling. Chronic effects, as indicated by differences between the fished site and the wreck site before experimental trawling began, were similar in kind, but less pronounced than at the heavily fished, mud-bottom offshore site (see "Otter Trawls -- Mud, 1. Ball *et al.* (2000)"). Mean numbers of species and total numbers of individuals for both infaunal and epifaunal species were higher at the unfished wreck site, as were indices of species diversity and richness. High intersample variance in biomass estimates near the wreck impeded comparisons with the trawled site. Fifty-eight species found at the inshore wreck site were not found at the experimental fishing site. These species included predatory and tube-dwelling polychaetes as well as a number of bivalve mollusks and echinoderms. Other types of polychaetes were more common at the fished site.

2. Bergman and Santbrink (2000) calculated mortality rates for a number of sedentary and relatively immobile megafauna (*i.e.*, >1 cm in maximum dimension) caught or damaged by a flatfish otter trawl at six commercially exploited sites in the southern North Sea during 1992-1995. The substrate at two deeper sites (40-50 m) was silty sand (3-10% silt), and at four shallower sites (<30-40 m) was sand (1-5% silt). At each site, benthic invertebrates were sampled before and 24-48 hr after trawling in four corridors with a dredge that was designed to sample relatively large, relatively low-abundance , infaunal and epifaunal species. The fishing gear was a commercial flatfish trawl that measured 35-55 m between the doors (15-20 m between the wings) when underway, with 20 m of net (32 m with bridles) in contact with the seafloor, 20-cm roller gear, and 8-10 cm mesh in the cod-end. Three corridors were trawled in silty sand substrate and one in sandy substrate. The surface of each corridor was trawled on average 1.5 times.

Mortalities were calculated as the percent reduction from initial density after a single trawl tow, and ranged from <0.5 to 52% for nine species of bivalve mollusks, from 16 to 26% for a sea urchin, from 3 to 30% for a crustacean, and from 2 to 33% for other species. Overall, mortality rates for six species ranged from 20 to 50%, and for 10 other species were < 20%. Significant before-and-after differences were detected on only 11 of 54 occasions. Some species experienced higher mortalities in the silty sand substrate and some in the sandy substrate.

3. DeAlteris *et al.* (1999) used divers to determine that simulated (*i.e.*, dug by the divers) trawl door tracks only lasted 1-4 days at a 7-m deep sandy site in Narragansett Bay, Rhode Island. Natural erosion at this site was predicted to occur on a daily basis, much more rapidly than in deeper water with a mud substrate (see "Otter Trawls -- Mud, DeAlteris *et al.* (1999)" for a summary of the mud-bottom results).

4. Drabsch *et al.* (2001), in addition to sampling a mud-bottom site in South Australia before and after trawling (see "Otter Trawls -- Mud, Drabsch *et al.* (2001)"), also sampled two additional sites (20-m depth) with medium-coarse sand sediments and shell fragments. Trawling effects were evaluated at one of the sites 1 wk after fishing, and at the second site 3 mo after fishing.

Trawl doors left tracks in the sediment, and the footline and net smoothed topographic features and removed epifauna. In contrast to results obtained at the mud-bottom site, trawling at the sand-bottom sites did not significantly affect infaunal abundance. The only significant change to infauna that could be attributed to trawling was a reduction in density of one order of crustaceans (Tanaidaceae) 1 wk after trawling. Three months after trawling, infaunal abundance had declined dramatically in both the treatment and reference sites, and there were no significant differences between them.

5. Frid *et al.* (1999) examined the long-term effects of fishing with prawn otter trawls in the North Sea by comparing changes on macrobenthic communities at an LF sand-bottom site and an HF mud-bottom site during three time periods when fishing effort was either low, moderate, or high (see "Otter Trawls -- Mud, Frid *et al*. (1999)" for results at the HF site). The LF site was located in 55 m of water and had a predominantly sand substrate (20% silt-clay). Benthic taxa collected at the LF site were divided into two groups that were predicted to respond either negatively (decreased abundance) or positively (increased abundance) to increased trawling activity, based on published accounts.

Fluctuations in macrofaunal abundance at the LF site were correlated with the abundance of phytoplankton 2 yr previously, indicating that benthic organisms were more abundant when greater amounts of organic matter were available to stimulate benthic production and vice-versa. There was no correlation with changes in fishing effort and no change in the proportions of organisms in the positive and negative response groups over time.

6. Gibbs *et al.* (1980) sampled benthic epifauna and infauna prior to and immediately after 1 wk of repeated experimental trawling (with a 10-m otter trawl with 1-m x 0.5-m flat otter boards and chain spiders) in a shallow estuary in New South Wales, Australia, during October 1975. The experimental trawling was conducted before the opening of a 6-mo-long prawn fishing season. Additional samples were collected at the end of the season. Grab samples were taken over muddy sand (0-30 % mud-clay) at three sites within the fishing grounds in Botany Bay and at an unfished control site in Jervis Bay, located about 200 km south of Botany Bay.

Trawl footropes lightly skimmed the bottom and disturbed very little sand. Trawling did create a plume of sand, but after repeated trawls, the seafloor was only slightly modified. Community diversity indices were not significantly different among the three study sites and the control site before and immediately after experimental trawling or after the fishing season. The authors therefore concluded that there were no detectable effects of trawling.

7. Gilkinson *et al.* (1998) studied the effects of trawl door scouring on several species of infaunal bivalve mollusks by observing an otter door model deployed in a test tank with a sand bottom, designed to simulate the sediment of the northeastern Grand Banks.

The trawl door created a berm in the sediment (average height 5.5 cm) with an adjacent 2-cm-deep scour furrow. All 42 bivalve mollusks within the scour path were displaced, but only two were damaged.

8. Hall *et al.* (1993) sampled benthic infauna from a fishing ground in the North Sea using distance from a shipwreck as a proxy for changes in trawling intensity. The sediment was coarse sand and the depth was 80 m. The benthic infauna was sampled at intervals along three transects that started 5 m from the wreck and extended to 350 m from the wreck.

Infaunal community structure was closely related to grain size and organic carbon content that varied within concentric rings or linear waves of coarser and finer sand, but not to distance from the wreck. The authors concluded that the observed differences in infaunal abundance did not appear to be consistent with an effect of fishing disturbance, which would most likely not follow the same pattern of fluctuating high and low intensity at increasing distance from the wreck. Epifaunal taxa were not included in this analysis.

9. McConnaughey *et al.* (2000) examined chronic trawling effects on epifauna in a high-energy sandy habitat in the eastern Bering Sea, Alaska. Samples were collected in 1996 just inside and outside an area that had been closed to trawling since 1959, using an otter trawl modified to improve the catch and retention of large epibenthic organisms. The small-mesh net had a 34-m footrope with a tickler chain and a hula skirt, and 1-mt steel V-doors with 55-m paired dandylines (bridles). Each lower dandyline had a 0.6-m chain extension connected to the lower wing of the net to improve bottom-tending characteristics. Sampling sites were selected along the outside edge of the closed area where commercial trawling is intense, and inside the closed area within 1 nmi of the intensely trawled sites. The bottom in the study area was 44-52 m deep, had sand ripples and strong rotary tidal currents, and was well within the depth range affected by storm waves.

Sedentary taxa (*e.g.,* anemones, whelk eggs, soft corals, stalked tunicates, bryozoans, and sponges) were more abundant in the unfished (UF) area than in the heavily fished (HF) area. Differences (*i.e.*, UF>HF) were significant for sponges and anemones. Mixed nonsignificant responses were observed within motile groups (*e.g.,* crabs, starfish, and buccinid whelks) and infaunal bivalve mollusks. Species diversity of sedentary epifaunal taxa was significantly higher in the UF area, owing to the greater dominance of a starfish in the HF area. Attached epifauna (*e.g.,* sponges, anemones, soft corals, and stalked tunicates) had a significantly more patchy distribution in the HF area.

10. Moran and Stephenson (2000) conducted an experimental study of otter trawling effects on an unexploited area with dense macrobenthos at depths of 50-55 m on the continental shelf of northwest Australia. No information on bottom type was provided, but it was presumed to be sand (see Sainsbury *et al.* 1997). A video camera mounted on a sled was used to survey attached epifauna (>20 cm in maximum length) before and after individual trawling events in experimental and control sites. There were four trawling events scheduled at 2-day intervals. During each trawling event, four tows were required to cover the area of each of two experimental blocks so that any unit area of bottom was trawled once. Trawled and control sites were surveyed before and after each trawling event and on alternate days during trawling.

Mean density of benthos declined exponentially (and significantly) with increasing tow numbers, with four tows reducing density by about 50%, and a single tow reducing density by about 15%. This estimated removal rate is much lower than what was estimated by Sainsbury *et al.* (1997) for sponges in the same general location (89%, see below). The authors believe this disparity may be explained by the fact that the trawl used in their study was lighter, with 20-cm disks separated by 30-60 cm long spacers of 9-cm diameter, and may have lifted over some benthic organisms rather than removing them. In addition, sponges are more susceptible to removal than other benthic organisms.

11. Sainsbury *et al.* (1997) reported the results of surveys on the continental shelf (<200 m) in northwestern Australia that documented a shift in the dominance of fish species from those (*Lethrinus* and *Lutjanus*) that occur predominantly within habitats that contain large epibenthic organisms to those (*Nemipterus* and *Saurida*) that favor open sandy habitats, in conjunction with the development of a commercial stern and pair trawling fishery. Five years after trawl closure areas were implemented (in response to these shifts in species dominance), there were increased catch rates of *Lutjanus* and *Lethrinus*, increased abundances of small benthos (<25 cm), and no changes in abundances of large benthos. The abundance of these fishes and of both the large and small benthos continued to decrease in the area left open to trawling.

These results increased the probability placed on a habitat limitation model and decreased the probability of an intraspecific control model (Sainsbury 1991), indicating that changes in species abundance and composition were at least in part a result of the damage inflicted on the epibenthic habitat by demersal trawling gear. Video observations provided by a camera mounted on a trawl showed that during those encounters with the groundline where the outcome was observable, sponges >15 cm were removed from the substrate 89% of the time. The groundline consisted of a 15-cm-diameter rubber roller made from rubber disks packed together and threaded on the groundline, with 14-cm spacers between packs of disks.

Grand Banks, Newfoundland: A number of investigators (see next three summaries) have examined the physical and biological effects of sustained otter trawling in a relatively deep sand habitat (120-146 m) in a 100-nmi^2 area of the Grand Banks, Newfoundland, that was closed to commercial trawling in 1992. Analysis of fishing effort records indicated that it had not been fished intensively since the early 1980s (Kulka 1991). (A 1990 estimate of the intensity of seafloor disturbance by otter trawling in the study area was <8% per year per unit of bottom area, or one set every 12 yr).

Sediments at this site were moderately to well sorted, fine to medium-grained sand. The seafloor is smooth and relatively stable with no evidence of wave- induced ripples. However, interannual variations in grain size and acoustic properties were observed during the study, possibly caused by winter storms (Schwinghamer *et al.* 1998).

Twelve experimental trawl tows (31-34 hr of total trawling) were made in three 13-km long corridors with an Engel 145 otter trawl with 1250-kg oval otter boards and 46-cm diameter rock hopper gear during a 5-day period in late June - early July of 1993, 1994, and 1995. Since the width of the trawl opening (60 m) was considerably less than the width of the disturbance zones created (120-250 m), the average experimental trawling intensity was estimated to be 3-6 sets per year per unit of bottom area.

Physical and biological effects of trawling were evaluated in two of the three experimental corridors. The corridors were sampled just before and just after (within a few hours or days) the experimental trawling ended, as well as 1 yr later. Additionally two reference corridors -- each located parallel to an experimental corridor -- were sampled just before the experimental trawling. Samples were also collected in the reference and experimental corridors in September 1993, 2 mo after trawling.

12. Kenchington *et al.* (2001) analyzed the effects of otter trawling at the Newfoundland study site on benthic infauna and epifauna collected in grab samples in two of the three experimental corridors.

The most prominent feature of the sample data was a significant natural decline in the total number of individuals (or total abundance), the number of species, and the numbers and biomass of several selected species in both the trawled and untrawled corridors between July 1993 and July 1995. The total abundance declined by 50% during the 2-yr period.

There were also significant effects of trawling on the mean total abundance per sample of all taxa and on the individual abundances of 15 taxa (mostly polychaetes), but only in 1994. In that year, immediate declines in abundance for these 15 taxa ranged from 33 to 67%. There were no significant trawling-induced changes in total biomass at any point during the experiment. Likewise, none of the community indices (taxonomic diversity and evenness) showed a significant effect of trawling in any of the years, and the only change in community structure that could be attributed to trawling occurred in 1994. Recovery for species that were affected by trawling in 1994 required <1 yr. Within this time frame, however, the actual recovery period could not be determined.

The authors concluded that there was no consistent, long-term effect that could be attributed to trawling, and that the effects of otter trawling on benthic infauna and infauna in this relatively stable, deepwater sand habitat were limited and short-term. When trawling disturbance was indicated, it appeared to mimic natural disturbance.

13. Prena *et al.* (1999) examined trawl bycatch and the effects of trawling on benthic epifauna, using an Engel 145 otter trawl. The epifauna (and some infauna) were collected with an epibenthic sled in two reference corridors before trawling, and in two experimental corridors before and after trawling (see earlier).

There was a significant reduction in trawl bycatch biomass during the first six sets (15-17 hr) due primarily to a decline in snow crabs, and a relatively constant level of such biomass during the last six sets due to snow crabs migrating into the trawled corridors to feed on dead and damaged organisms.

Epifaunal biomass was lower (by 24%on average) in trawled corridors than in reference corridors in all 3 yr, and remained relatively constant with time, whereas biomass in reference corridors was highly variable from year to year. There were significant trawling and year effects on total epifaunal biomass, and significant trawling effects on mean individual epifaunal biomass, indicating that individuals in the trawled corridors had a smaller average size.

At the species level, the biomass of five of the nine dominant epifaunal species (a sand dollar, brittle star, soft coral, snow crab, and sea urchin) was significantly lower in the trawled corridors than in the reference corridors. There was also a general trend of greater damage to benthic invertebrates in the trawled corridors, especially for three species of brittle star, sea urchin, and sand dollar. There were no significant effects on the abundance of four dominant mollusk species.

14. Schwinghamer *et al.* (1998) sampled surface sediments (top 2 cm) and conducted video and acoustic surveys at the Newfoundland study site before, during, and after trawling in two experimental corridors. Tracks and berms left by the trawl doors increased bottom relief and roughness. In 1993, door tracks 5 cm deep and 1 m wide were still clearly visible in sidescan sonar records after 2 mo, but they were not visible at the beginning of trawling in 1994. Tracks made in 1994 were faintly visible at the beginning of trawling in 1995.

On a small scale, trawling suspended and dispersed sediment, flattened the seafloor, and removed biogenic mounds and organic matter deposited in depressions. Seafloor topography recovered within 1 yr. Sediment grain size varied significantly between corridors and among years, but there was no evidence that it was affected by trawling.

Large, epibenthic organisms (*e.g.,* basket stars, snow crabs, and brittle stars) were readily visible in experimental and reference corridors, but tended to be arranged in linear features parallel to the axis of trawling in the experimental corridors.

The authors concluded that even at a depth of 120-146 m, natural disturbances such as bioturbation and storms might cause more pronounced physical changes to the bottom than those caused by trawling.

Summary

Results of 14 studies are summarized. One of them was described in a 1980 publication; the rest have been published since 1993. Six studies were conducted in North America (three in a single long-term experiment on the Grand Banks), four in Australia, and four in Europe. Ten were experimental studies. Eight of them were done in depths <60 m, one at 80 m, and four in depths >100 m. One study examined just the physical effects of trawling, nine examined just the biological effects, and four examined both. Six of the biological studies were restricted to epifauna, two were restricted to infauna, and five included both epifauna and infauna.

The only experiment that was designed to monitor recovery was the one on the Grand Banks, although surveys conducted in Australia documented changes in the abundance of benthic organisms in an area after 5 yr of fishery closures, and in an area after 15 yr of little or no fishing activity. Two studies compared benthic communities in trawled areas of sandy substrate with those in undisturbed areas near a shipwreck. Six studies were performed in commercially exploited areas, five were performed in closed areas, and two compared closed and open areas; one was done in a test tank.

All the experimental studies examined the effects of multiple tows (up to six per unit area of bottom), and the study in Australia assessed the effects of 1-4 tows on emergent epifauna. Trawling in four studies was limited to a single event (*i.e.*, 1 day to 1 wk), whereas the Grand Banks experiment was designed to evaluate the immediate and cumulative effects of annual 5-day trawling events in a closed area over a 3-yr period.

Physical Effects

A test tank experiment showed that trawl doors produce furrows in sandy bottom that are 2 cm deep, with a berm 5.5 cm high (7). In sandy substrate, trawls smoothed seafloor topographic features (4, 14), and resuspended and dispersed finer surface sediment, but had no lasting effects on sediment composition (14).

Trawl door tracks lasted up to 1 yr in deep water (14), but only for a few days in shallow water (3). Seafloor topography in deep water recovered within a year (14).

Biological Effects -- Single-Disturbance Experimental Studies

Three single-event studies (1, 2, 6) were conducted in commercially trawled areas. In one of these studies (2), otter trawling caused high mortalities of large (>1 cm) sedentary and/or immobile epifaunal species. In another study (6), there were no effects on benthic community diversity. Neither of these studies investigated effects on total abundance or biomass. In the third study (1), there were no obvious effects on macrofauna, but there were fewer organisms and species there than at an unexploited site near a shipwreck.

Two studies (4, 10) were performed in unexploited areas. In one study (10), single tows reduced the density of attached epifauna (>20 cm) by 15%, and four tows reduced it by 50%. In the other study (4), two tows removed 28% of the epifauna on mud and sand substrate, and the epifauna in all trawled quadrats showed signs of damage. (These results were not reported separately for sand bottom.) In this latter study, total infaunal abundance was not affected, but the abundance of one family of polychaetes was reduced.

Biological Effects -- Repeated-Disturbance Experimental Studies

Intensive experimental trawling on the Grand Banks reduced the total biomass of epibenthic organisms and the biomass and average size of a number of epibenthic species (13). Significant reductions in total infaunal abundance and in the abundance of 15 selected taxa (mostly polychaetes) were detected during only 1 of 3 yr, and there were no effects on biomass or taxonomic diversity (12).

Biological Effects -- Observational Studies

Changes in benthic macrofaunal abundance in a lightly trawled location in the North Sea were not correlated with historical changes in fishing effort (5). Changes in infaunal community structure at increasing distances from a shipwreck in the North Sea were related to changes in sediment grain size and organic carbon content (8).

The Alaska study (9) showed that the epifauna attached to sand was more abundant inside a closed area, significantly so for sponges and anemones. A single tow in a closed area in Australia removed 89% of the large sponges in the trawl path (11).

Otter Trawls -- Gravel/Rocky Substrate (Table 5.6)

1. Auster *et al.* (1996) observed bottom conditions during a July 1987 submersible dive at a depth of 94 m near the northern end of Jeffreys Bank, in a gravel area where there were large (>2-m diameter) boulders. A thin layer of mud covered the gravel and boulders, and the rock surfaces supported large numbers of erect sponges, sea spiders, bryozoans, hydroids, anemones, crinoid sea feathers, and ascidians. Smaller mobile fauna, including several species of crustaceans, snails, and scallops, was also abundant.

When the area was resurveyed in August 1993, much of the mud veneer was gone and there was evidence that boulders had been moved. Abundance of erect sponges was greatly reduced, and most of the associated epifaunal species were not present. The authors attributed this disturbance to otter trawling which was occurring in the area during the second survey, and which was conducted in this area only after 1987, when modifications to fishing gear allowed fishermen to trawl rocky, boulder habitat in the GOM.

2. Freese *et al.* (1999) documented the effects of single tows with a bottom trawl in an area that had been exposed to very little or no commercial trawling since the 1970s in the eastern Gulf of Alaska. The trawl was a 42.5-m "Nor'easter" otter trawl with 0.6-m diameter rubber tire groundgear attached to the footrope, and with 0.45-m diameter rockhopper disks and steel bobbins along the wings. Eight tows were made on predominantly pebble substrate (some cobble and boulders were also present) at depths of 206-274 m in August 1996. Quantitative video transects, using a two-man submersible, were made down the center of each trawl path within 2-5 hr after each tow, and in adjacent reference areas.

The trawl moved 19% of the boulders (median size of 0.75 m) it encountered. On less compact substrate, tire gear left a series of furrows that were 1-8 cm deep. On compact substrate (*i.e.*, with a greater percentage of cobble), the tire gear left no furrows, but the trawl removed an overlying layer of silt.

Single tows caused significant decreases in the density of undamaged vase sponges, morel sponges, sea whips, and anemones. Nonsignificant reductions in the density of undamaged organisms were also observed for finger sponges, brittle stars, sea urchins, and one species of sea cucumber. None of the five groups of motile invertebrates showed a significant reduction in density because of trawling. In fact, arthropods and mollusks were more abundant in the trawled areas.

Trawling also caused considerable damage to sponges and sea whips. More than 50% of the vase sponges and sea whips in the trawl transects were either damaged or removed from the substrate. Morel sponges were also damaged, but damage could not be quantified because this species is much more brittle and friable than the vase sponges, and specimens crushed by the trawl were completely torn apart and scattered. Some finger sponges were also knocked over onto the substrate. Brittle stars were also damaged, but reticulate anemones and motile invertebrates were not.

Observations of fishes made during this study showed that rockfish (*Sebastes* spp.) use cobble-boulder and epifaunal invertebrates for cover.

3. Dolah *et al.* (1987) assessed the effects of a single trawl tow on attached sponges and corals in an unexploited area on the coast of Georgia, in the southeastern United States. The bottom (depth 20 m) was smooth rock with a thin layer of sand and an extensive sessile invertebrate growth. The trawl was a 40/54 fly net with a 12.2-m headrope and a 16.5-m footrope equipped with six 30-cm rubber rollers separated by numerous 15-cm diameter rubber disks, and was attached to 1.8x1.2-m China-V doors using 30.5-m leglines.

Densities of three of the most abundant large sponges, three dominant soft corals, and one hard coral were determined by divers before trawling, immediately after trawling, and 12 mo after trawling, both inside and outside the trawl path. Sponges and soft corals <10 cm high were not counted, but all hard corals were counted. In addition, the degree of damage was evaluated.

The trawl damaged some specimens of all species, sponges more notably than corals. Immediately after trawling, undamaged sponges were less abundant, significantly so in two transects that had higher pre-trawl sponge densities. Damage was noted for 31.7% of the sponges that remained in the trawled transects immediately after trawling. Most of the reduction in, and damage to, sponges was for the most abundant species, a barrel sponge. For the other large sponges -- vase sponges and finger sponges -- there were no significant differences in density between sampling periods, although there was some evidence of trawl damage. Twelve months after trawling, sponges in the trawled quadrats were at pre-trawl densities or higher, and all damaged sponges had regenerated new tissue.

Total abundance of soft corals declined in the trawl alley immediately after trawling, and a few damaged specimens were found, but effects were minimal compared to the sponges. There were no differences between pre-trawl and post-trawl density estimates for fan and whip corals. The more abundant stick coral was less abundant immediately after trawling, but had recovered completely 12 mo later.

Divers counted 30% fewer undamaged stony corals in the trawled quadrats immediately after trawling, although the reduction was not significant. Of the seven colonies of stony coral affected by the trawl, four were moderately to heavily damaged, and three were only slightly damaged. Twelve months later, stony corals were more abundant than they were before trawling, and no damage could be detected.

Summary

Three studies of otter trawl effects on gravel and rocky substrate are summarized in this document. All three were conducted in North America. Two were done in glacially affected areas in depths of about 100-300 m using submersibles, and the third was done in a shallow coastal area in the southeastern United States.

One study involved observations made in a gravel/boulder habitat 6 yr apart (*i.e.*, before and after trawling affected the bottom). The other two were experimental studies of the effects of single trawl tows. One of these experimental studies was done in a relatively unexploited gravel habitat, and the other on a smooth rock substrate in an area not affected by trawling.

Two studies examined effects to the seafloor and on attached epifauna and one only examined effects on epifauna. There were no assessments of effects on infauna. Recovery was evaluated in one case for 1 yr.

Physical Effects

Trawling displaced boulders and removed mud covering boulders and rocks (1). Rubber tire groundgear left furrows 1-8 cm deep in less compact gravel sediment (2).

Biological Effects

Trawling in gravel and rocky substrate reduced the abundance of attached benthic organisms (*e.g.,* sponges, anemones, and soft corals) and their associated epifauna (1, 2, 3), and damaged sponges, soft corals, and brittle stars (2, 3). Sponges were more severely damaged by a single pass of a trawl than soft corals, but 12 mo after trawling all affected species, including one species of stony coral, had fully recovered to their original abundance, and there were no signs of damage (3).

Otter Trawls -- Mixed Substrates (Table 5.7)

1. The Canadian Department of Fisheries and Oceans (DFO 1993) conducted a sidescan sonar survey in the Bras D'Or Lakes system in Nova Scotia to document the physical effects of various mobile fishing gears 1 yr after the area was closed to mobile gear. Water depths ranged from 10 to 500 m, and bottom sediments included rich organic mud, clay, pebbly mud, well sorted sand, gravel, and boulders.

Otter doors left parallel marks in the sediments, with spoil ridges or berms faintly visible along their inner margins, and fainter marks between the two door marks apparently produced by the trawl footgear. These marks were seen predominantly in muddy sediments.

2. Engel and Kvitek (1998) compared a lightly fished (LF) and a heavily fished (HF) area off central California with similar sediments (gravel, sand, silt-clay) and depths (180 m) using still photographs and videotapes taken from a submersible in October 1994, and grab samples collected during 1994, 1995, and 1996. There were no differences in sediment composition between the two study sites. They estimated that any square meter of bottom area in the HF area was exposed to 12 times more trawling effort during 1989-1996 than any square meter of bottom area in the LF area.

Results indicated that the HF area had significantly more trawl tracks, shell fragments, and exposed sediment, significantly fewer rocks and biogenic mounds, and significantly less flocculent material. Based on the 1994 video transects, the densities of all six large invertebrate epifauna were higher in the LF area, significantly so for sea pens, starfish, sea anemones, and sea slugs. Based on the grab samples, the number of polychaete species was higher in the LF area in 1994 and 1996, and the densities of nematodes, oligochaetes, and brittle stars were higher in the HF area in all 3 yr (although differences, in most cases, were insignificant). No consistent (or significant) differences were detected for crustaceans, mollusks, or nemerteans. One polychaete species that was the most important prey item for three species of flounder was more abundant in the HF area in all 3 yr, significantly so in 1994 and 1996.

The authors concluded that trawling reduces habitat complexity and biodiversity, while increasing opportunistic infauna and prey important in the diet of some commercially important fish species, but that, since the study lacked controls, there was no way to be sure that the observed differences between the two areas were, in fact, due to differences in trawling intensity.

3. Smith *et al.* (1985) reported that diver observations and videotapes showed minor surface sediment disturbance (<2.5 cm deep) within the sweep path of an otter trawl with 6-ft (1.8-m) doors and 3/8-in (1-cm) footrope chain in Long Island Sound. Sediments in the study area were described as sand with mud and clay.

Much of the observed disturbance was created by turbulence suspending small epifaunal organisms, silt, and flocculent material as the net passed, rather than by direct physical contact of the net with the bottom. Trawl door tracks (<5 cm deep in sand; 5-15 cm deep in mud) were the most notable evidence of trawl passage. These tracks were soon obscured by the effect of tidal currents, but attracted mobile predators. Alteration of existing lobster burrows was minor and appeared easily repairable by resident lobsters. The use of roller gear of unspecified size on mud bottom left shallow scoured depressions; the use of spacers between disks reduced such scouring.

Summary

Three studies of the effects of otter trawls on mixed substrates are summarized. All three were conducted in North America and relied on sidescan sonar and/or observations made by divers or from a submersible.

One study (2) combined submersible observations and benthic sampling to compare the physical and biological effects of trawling in both a lightly fished and heavily fished location in California. Both locations had the same depth and a variety of sediment types. The other two studies were a survey of seafloor features produced by trawls in a variety of bottom types (1), and primarily an examination of the physical effects of single trawl tows on sand and mud bottom (3).

Physical Effects

Trawl doors left tracks in sediments that ranged from <5 cm deep in sand to 15 cm deep in mud (1, 3). In mud, fainter marks were also made between the door tracks, presumably by the footgear (1).

A heavily trawled area had fewer rocks, shell fragments, and biogenic mounds than a lightly trawled area (2).

Biological Effects

The heavily trawled area in California had lower densities of large epifaunal species (*e.g.,* sea slugs, sea pens, starfish, and anemones) and higher densities of brittle stars and infaunal nematodes, oligochaetes, and one species of polychaete (2). There were no differences in the abundance of mollusks, crustaceans, or nemerteans between the two areas. However, since this was not a controlled experiment, these differences could not be attributed to trawling.

Single trawl tows in Long Island Sound attracted predators and suspended epibenthic organisms into the water column (3).

New Bedford-Style Scallop Dredges

New Bedford-Style Scallop Dredges -- Sand (Table 5.8)

1. Auster *et al.* (1996) mapped Stellwagen Bank (GOM) in 1993 (depth 20-55 m) using sidescan sonar, and showed it to be covered by large expanses of sand, gravelly sand, shell deposits, and gravel. Waves produced by large storms from the northeast create ripples in coarse sand measuring 30-60 cm between crests and 10-20 cm high, and deposit large sheets of fine sand with low sand waves 15-35 m between crests. The troughs of these sand waves are filled with shell debris.

Gear tracks produced by trawls and scallop dredges could be distinguished in the sonar images. Examination of gear tracks in sonar images showed that scallop dredges disturb sand ripples and disperse shell deposits.

2. Langton and Robinson (1990) analyzed visual and photographic observations made during submersible transects on an offshore bank in the GOM (Fippennies Ledge) in July 1986 and June 1987. There was little evidence of scallop dredging at the dive site in 1986, but it was heavily dredged sometime between the 1986 and 1987 submersible observations (Langton and Robinson 1988). Depth near the study transects (southeastern end of the ledge) ranged from 80 to 100 m. In the areas of highest sea scallop density, the surficial sediments were usually sand with occasional shell hash and small rocks. Where there were tubes formed by amphipods or polychaetes, the sediment surface was visually a more silty organic sand. Grain size analysis revealed that the upper 5 cm of sediment was uniform throughout the area, and averaged 84% sand, with some gravel.

Dredged areas observed in 1987 were clearly distinguishable from undredged, or not recently dredged, areas. The most obvious result of dredging was a change from organic silty sand to gravelly sand. This was apparently due to the disruption of amphipod tube mats. Occasionally, piles of rock and scallop shells were observed, apparently deposited there when dredges were emptied at the surface.

Densities of three dominant megafaunal species (sea scallops, burrowing anemones, and a tube-dwelling polychaete) declined significantly between 1986 and 1987, apparently because of dredging.

3. Watling *et al.* (2001) evaluated the geochemical and biological effects of scallop dredging in an estuary (Damariscotta River, Maine). The study site was located on an unexploited side of the estuary in a shallow (15 m), silty sand area with a low density of sea scallops. Bottom samples for sediment chemistry, microbiology, and fauna were collected by divers in a control and an experimental plot before and after intensive dredging (23 tows in 1 day) using a 2-m-wide chain-sweep dredge towed at 2 knots. Sampling of benthic macrofauna (primarily infauna) was conducted 4 and 5 mo before dredging, immediately before and after (1 day) dredging, and 4 and 6 mo after dredging, by divers with push cores.

The immediate effects of dredging were the loss of fine material from the top few centimeters of the sediment surface, and a reduction in its food value (significant reductions in enzymatically hydrolysable amino acids and total microbial biomass). There was little discernible difference in the number of macrofauna taxa present after dredging, but the numbers of individuals were greatly (and significantly) reduced. Some taxa (families) showed little difference between the control and treatment site the day after dredging, while others were reduced in abundance. Significant reductions were noted for one family each of polychaetes (Nephtyidae) and amphipods (Photidae).

In the experimental plot, fine sediments still had not been restored 6 mo after dredging, whereas the food value of the sediments had completely recovered after 6 mo. Total macrofaunal abundance was still significantly lower 4 mo afterwards, but after 6 mo there was no longer any significant difference in the number of individuals in the two plots. Some taxa recovered sooner than others.

Summary

Three studies of the effects of New Bedford-style scallop dredges on sand substrate are summarized, and all were performed since 1990. One was conducted in an estuary on the Maine coast (3) and two on offshore banks in the GOM (1, 2). Two of them were observational in nature, but didn't include any direct observations of dredge effects. The other one was a controlled experiment conducted in an unexploited area in which a single dredge was towed repeatedly over the same area of bottom during 1 day.

One study examined physical effects and two examined physical and biological effects. One of them included an analysis of geochemical effects to disturbed silty sand sediments.

Physical Effects

Dredging disturbed physical and biogenic benthic features [sand ripples and waves (1), shell deposits (1), and amphipod tube mats (2)], caused the loss of fine surficial sediment (3), and reduced the food quality of the remaining sediment (3). Sediment composition was still altered 6 mo after dredging, but the food quality of the sediment had recovered by then.

Biological Effects

There were significant reductions in the total number of infaunal individuals in the estuarine location immediately after dredging and reduced abundances of some taxa (particularly one family each of polychaetes and amphipods), but no change in the number of taxa (3). Total abundance was still reduced 4 mo later, but not after 6 mo.

The densities of two megafaunal species (a tube-dwelling polychaete and a burrowing anemone) on an offshore bank were significantly reduced after commercial scallop vessels had worked the area (2).

New Bedford-Style Scallop Dredges -- Mixed Substrates (Table 5.9)

1. Caddy (1968) described diver observations of dredge effects in shallow sea scallop beds in the Northumberland Strait (Gulf of St. Lawrence, Canada). The depth was about 20 m and the sediments ranged in texture from mud to clean sand. Fishing operations were conducted with a 2.4-m-wide, offshore chain-sweep scallop dredge (no teeth) that was modified to reduce its weight by replacing the forward drag bars with chains. The dredge weighed 0.36 mt (800 lb) out of the water. Divers attached to the dredge made direct observations during two 5-min tows that were made at about 2 knots.

The lateral skids, located at each end of the pressure plate produced two parallel furrows approximately 3 cm deep; a series of smooth ridges between them were caused by the rings in the chain belly of the dredge. Dislodged pieces of dead shell were more evident within the drag tracks than on the surrounding bottom.

2. Caddy (1973) used a two-man submersible to observe the effects of a 2.4-m-wide, chain-sweep dredge (no teeth, weight 0.6 mt or 1300 lb out of the water) and a gang of three 0.8-m-wide, Alberton-style, toothed dredges in a previously dredged area of Chaleur Bay in the Gulf of St. Lawrence (Canada). (See "Toothed Scallop Dredges -- Mixed Substrates, 4. Caddy (1973)" for a summary of the toothed-dredge results.) Observations were made inside and outside dredge tracks within 1 hr of each tow. Depth varied from 40 to 50 m, and the substrate was sand overlaid by glacial gravel, 1-10 cm in diameter, with occasional boulders up to 60 cm in diameter embedded in the gravel.

Dredging suspended fine sediments and reduced visibility from 4-8 m to <2 m within 20-30 m of the track, but the silt cloud dispersed within 10-15 min of the tow, coating the gravel in the vicinity of the track with a thin layer of fine silt. The chain-sweep dredge left a flat track that increased in depth from just below the sediment surface to several centimeters deep at the end (tows were 0.8-1.2 km long). Over areas of sand and fine gravel, marks were left by individual belly rings, and the tow bar left a narrow depression in the center of the track. The edge of the track was sometimes marked by an impression left by the lateral skids.

Gravel fragments were less frequent inside the track, and many were overturned. Rocks 20-40 cm in diameter were dislodged every 10-30 m of track. Some boulders were overturned and others were plowed along, leaving a groove several meters long. Empty holes left by some of the rocks were evident.

3. Mayer *et al.* (1991) investigated the effects of scallop dredging at a shallow (8 m) nearshore site on the Maine coast with a mixed mud, sand, and shell hash substrate. The site was dragged with a New Bedford-style, chain-sweep dredge (presumably once, although no information was provided), and core samples were collected before dredging and 1 day after dredging inside and outside the dragged track.

Dredging lowered the substrate by 2 cm and tilled the sediment to a depth of 9 cm, causing finer material (sand and mud) to be injected into the lower 5-9 cm of the sediment profile, and increasing mean sediment grain size to >5 cm. (No statistical tests were performed with these data). Organic matter profiles were strongly affected by dredging. Total organic carbon and nitrogen at the new sediment-water interface were markedly reduced in concentration after dredging, and carbon concentrations in the 5-9 cm sediment depth interval were considerably higher in the dredged site.

A diatom mat on the surface of the sediment was disrupted by the dredge and partially buried. The microbial community of the surface sediments increased in biomass following dredging.

Summary

Three studies have been conducted on mixed glacially derived substrates, two of them over 20 yr ago and one 10 yr ago. All were done in the Northwest Atlantic (one in the United States and two in Canada) at depths of 8-50 m.

Two observational studies examined physical effects and one experimental study examined effects on sediment composition to a sediment depth of 9 cm. The experimental study evaluated the immediate effects of a single dredge tow. None of these studies evaluated habitat recovery or biological effects, although one (3) examined geochemical effects.

Physical Effects

Direct observations in dredge tracks in the Gulf of St. Lawrence documented a number of physical effects to the seafloor, including bottom features produced by dredge skids, rings in the chain bag, and the tow bar (1, 2). Gravel fragments were moved and overturned, and shells and rocks were dislodged or plowed along the bottom (2).

Sampling 1 day after a single dredge tow revealed that surficial sediments were resuspended and lost, and that the dredge tilled the bottom, burying surface sediments and organic matter to a depth of 9 cm, increasing the mean grain size of sediments to >5 cm, and disrupting a surface diatom mat (3). Microbial biomass at the sediment surface increased because of dredging (3).

Toothed Scallop Dredges

Toothed Scallop Dredges -- Sand (Table 5.10)

Port Phillip Bay, Australia: The physical and biological effects of toothed scallop dredges were evaluated at three sites in a large, relatively low-energy, predominantly tidal embayment in southeast Australia in 1991 that had been commercially dredged for *Pecten fumatus* since 1963. Habitat-related objectives of these studies were to test whether dredging alters turbidity and sedimentation patterns in the bay, to evaluate the physical effects of dredging on the seafloor, and to determine the magnitude and direction of changes to the benthic community caused by dredging. These studies were described in four separate publications (see below).

Depths at the three sites were similar (about 15 m), but each site had different sediments and was exposed to different current strengths and wave characteristics. Sediments at the three sites were: 1) fine and very fine sand with 15% silt-clay (St. Leonards); 2) medium fine sand with 7% silt-clay (Dromana); and 3) muddy sand with shell fragments and 30% silt-clay (Portarlington).

Three large (0.36-km^2) experimental plots (one per site) located within larger (20-30 km^2) areas which were closed to dredging in 1991 were dredged repeatedly by a fleet of 5-7 commercial dredge vessels using 3-m-wide "Peninsula"-style box dredges fitted with cutter bars that did not extend below the skids. Experimental dredging intensity at Portarlington (716 tows in 4 days during a 3-wk period) was equivalent, on average, to four tows per unit of area, and duplicated heavy commercial dredging intensity, based on historical levels of fishing effort in the bay. Dredging at the other two sites was less intensive (382 and 459 tows, and an average of two tows per unit of area) and limited to 2- or 3-day periods. The amount of commercial dredging activity in the bay declined dramatically after 1987 (Currie and Parry 1996), so the study sites had been virtually undisturbed for 4 yr when the research was conducted.

Black and Parry (1994[1], 1999[2]) and **Currie and Parry (1996[3], 1999b[4])** evaluated the physical effects of experimental dredging in Port Phillip Bay by using a variety of field sampling techniques at all three sites. Turbidity levels and dredge penetration depths were measured immediately after dredging. Visually apparent changes to the seafloor were assessed by divers with video cameras at various times before and after dredging. The last observations were made at St. Leonards 11 mo after dredging, at Portarlington 7 mo after dredging, and at Dromana 5 days after dredging.

Dredging disturbed the top 1-2 cm of sediment, but sometimes penetrated up to 6 cm in softer sediments. Turbidity plumes extending 1-2 m into the water column were created immediately behind the dredge, reaching turbidity levels within 2-16 sec after dredging which were 2-3 times greater than the turbidity caused by storms. Dredging-related turbidity levels returned to natural storm levels after about 9 min at sites which were 60 and 80 m downcurrent of the nearest boundary of the experimental dredging plots.

Video observations showed that the sediment plume was entrained across the full width of the dredge, mostly by the cutterbar. As the dredge traveled across the rough seafloor, the cutterbar trimmed off the high regions, creating turbulent pulses of sediment. Smaller sediment plumes were also produced by the skids.

Dredging at one of the experimental sites had a graderlike effect on the seafloor, flattening low-relief mounds produced by burrowing callianassid shrimp, and filling in depressions between them. Parallel tracks up to 2.5 cm deep were produced by the dredge skids. The mounds reformed after 6 mo. Flat areas between the mounds were still visible after 6 mo, but 11 mo after dredging there were no visible differences in topography between the control plot and the dredged plot. The tracks were still visible a month after dredging, but not after 6 mo.

At one of the other two sites (*i.e.*, Dromana), small parallel sand ripples in part of the dredged plot were obliterated by dredging, but reformed immediately following a storm that occurred 5 days after the area was dredged. Mounds were reformed 7 mo after dredging, but were still smaller than in the control plot.

Currie and Parry (1996[3], 1999b[4]) evaluated the biological effects of dredging on benthic infauna in Port Philip Bay. At the most intensively sampled site (St. Leonards), grab samples were collected in both a dredged plot and an adjacent control plot on three occasions before dredging, immediately after dredging, and at 3 wk and at 3.5, 5, 8, and 14 mo after dredging. Sampling at the other two sites was intended to evaluate very short-term biological effects, and was limited to the dredged plots: grab samples were taken 8 days before and 2 days after dredging at Dromana, and 10 days before and 1 day after dredging at Portarlington. In addition, a plankton net was attached to the top of the dredge to sample animals thrown up by the dredge during each tow at St. Leonards.

At the St. Leonards site, there was a significant decrease in the number of infaunal species in the dredged plot relative to the control plot 3 wk after dredging that persisted for 14 mo, but there was no effect on the total number of individuals.

In the 3.5 mo following dredging, six of the ten most common benthic species showed significant decreases in abundance of 28-79% on at least one-half of the experimental plot; most species decreased in abundance by

20-30%. At the other two sites (Portarlington and Dromana), two and three of the ten most common species, respectively, were significantly reduced in abundance within 1-2 days after dredging, but reduced sampling intensity limited the statistical power of the tests. Of the six species whose abundance was reduced significantly over the first 3.5 mo at the St. Leonards site, two were affected for 3.5 mo, two for 8 mo, and two for 14 mo. Dredging effects at this site became undetectable for most species following their annual recruitment; most species recruited within 6 mo, but a few still had not recruited after 14 mo.

Species that occurred on or near the sediment surface (*e.g.,* tube-dwelling amphipods) were released into the water column right away, whereas species inhabiting deeper sediments (*e.g.,* burrowing polychaetes) were dislodged as dredging continued. More mobile, opportunistic species inhabiting surface sediments increased in abundance during the 3.5 mo after dredging, perhaps because the removal of other species increased their food supply. Dissimilarity measures between the two plots increased after dredging, reaching a maximum 3 wk after dredging, and suggesting that there were delayed effects on community structure such as increased predation of infaunal organisms that were uncovered by dredging.

Although this research clearly demonstrates that there were biological effects of scallop dredging to benthic habitats in Port Phillip Bay, the reductions in density caused by dredging were small compared to natural changes in population densities during the year (Currie and Parry 1996**)**. Furthermore, changes to infauna caused by dredging in 1991 were smaller than the cumulative changes to infaunal community structure in Port Philip Bay over the preceding 20 yr (Currie and Parry 1999b). Currie and Parry (1999a) also concluded that changes to benthic community structure (species composition) caused by dredging in the bay were small compared with natural differences between study areas.

5. Butcher *et al.* (1981) documented diver observations of scallop dredging in Jervis Bay, New South Wales, Australia, over large-grained firm sand shaped in parallel ridges at depths >13 m. The dredge design was not described, but had teeth that extended up to 5 cm below the leading edge of the dredge.

Dredging flattened sand ridges and produced a sediment plume extending up to 5 m into the water column that settled out within 15 min. Dredge paths were clearly visible, and “old” dredge paths could be seen.

6. Eleftheriou and Robertson (1992) examined the incremental effects of repeated scallop dredge tows in Firemore Bay, a shallow sandy bay in Loch Ewe on the west coast of Scotland in July-August 1985. The depth at the study site was about 5 m, and the sediment was well sorted sand. It was a high-energy environment exposed to wave action. Fishing (divers and beam trawls) took place in the bay during the 1970s and 1980s.

A 1.2-m-wide, Newhaven-style scallop dredge with nine, 12-cm-long teeth was towed 25 times over the same track during a 7-day period (*i.e.*, two tows on day 2, two on day 3, eight on day 4, and thirteen on day 8). The chain bag was removed from the dredge so that all organisms that passed through the mouth of the dredge were returned to the bottom for observation.

Grab samples were collected in the dredge track before and after each set of tows. Qualitative assessments of the epifaunal and large-specimen infaunal community were conducted by divers using still cameras. There was no control (undredged site) in this study, and thus no means to statistically evaluate the effects of location or natural changes on the abundance or composition of the benthic community in the bay that could have occurred during the course of this study.

Dredge teeth penetrated the bottom 3-4 cm. Dredging created furrows, eliminated natural bottom features, and dislodged large shell fragments and small stones. Sediments in this location are well-mixed by wave action to a depth below 3-4 cm, thus the dredge had no effect on the vertical distribution of grain size, organic carbon, or chlorophyll *a*. Grooves and furrows created by the dredge were eliminated shortly after dredging, the length of time depending on wave action and tidal conditions.

Infaunal invertebrates that were adapted to the stresses of a high-energy environment (*e.g.,* amphipods and bivalve mollusks) were not affected in any significant way. Sedentary polychaetes declined in abundance after 12 tows, then increased after 25 tows. Small crustaceans -- mostly cumaceans – increased in abundance after the first two tows and between tows four and twenty-five. There were no significant changes in biomass of the different infaunal taxa.

Organisms such as small infaunal crustaceans, crabs, and starfish were attracted to, and fed on, dead and damaged organisms left behind the dredge. Visual counts of living, damaged, and dead epifaunal organisms before and after each dredging event indicated some damage and mortality to organisms such as sea urchins, starfish, scallops, and crabs. Razor clams were dug up by the dredge and lay partially buried with their valves gaping and large numbers of sand lances (*Ammodytes* spp.) were killed. The plowing effect of the dredge buried, damaged, or chased away organisms such as brittle stars, burrowing anemones, and swimming crabs.

7. Thrush *et al.* (1995) conducted an experimental study of scallop dredging at two sites 14 km apart in the Mercury Bay area of the Coromandel Peninsula in New Zealand in 1991. One site was a commercial scallop fishing ground and the other site was not. The sediment at both sites was coarse sand, but was more poorly sorted and had a large fraction of shell hash at the exploited site. The depth was about 24 m at each site.

At each site, half of a plot measuring 70x20 m was dredged (five parallel tows in 1 day) using a 2.4-m-wide box dredge with 10-cm-long teeth on the lower leading edge of the dredge. Divers collected core samples and made visual observations in the dredged and undredged halves of each plot before dredging, within 2 hr after dredging, and 3 mo after dredging. Results from the two sites were treated separately because the macrobenthic communities were distinctly different. Both sites were dominated by small, short-lived benthic species.

At both sites, the dredge broke down the natural surface features (*e.g.,* emergent tubes and sediment ripples), and the teeth created grooves approximately 2-3 cm deep.

Dredging produced changes in benthic community structure that persisted for 3 mo at both sites. Significant differences in the numbers of individuals and taxa and in the densities of common macrofauna (both infauna and epifauna) were apparent immediately after dredging. The initial community-level responses at both sites were negative; there were significantly lower total densities and numbers of taxa in the dredged half-plots than in the adjacent reference half-plots.

The responses noted 3 mo later were more complex, with differences between the two sites. Effects were more pronounced and more often negative at the previously unexploited site where total density remained significantly lower in the dredged half-plot 3 mo after dredging. Six of the 13 most common taxa at this site were significantly less abundant in the dredged half-plot plot 2 hr after dredging, and five of them (*i.e.*, two phoxocephalid amphipods and three polychaetes) were still less abundant 3 mo later.

In contrast, there was a significant recovery in total density in the dredged half-plot at the exploited site after 3 mo, to the point that the total densities in the adjacent half-plots at that site were the same. Four of the thirteen most common taxa at this site were significantly less abundant 2 hr after dredging, and three of them (*i.e.*, ostracods and two species of bivalve mollusks) still had not recovered 3 mo later. Four taxa that were negatively affected 2 hr after dredging at the exploited site were more abundant in the dredged half-plot than in the control half-plot 3 mo after dredging.

The authors concluded that the differences in the recovery processes at the two sites were likely related to differences in the initial community composition and to differing environmental characteristics.

Summary

Seven studies of the effects of toothed scallop dredges on sandy bottom habitat are summarized in this document, six of them for box dredges in Australia and New Zealand, and one for Newhaven-style dredges in Scotland (6). All of the studies except one (5) were published during the 1990s. Four of the Australian studies (1-4) were done in the same location (Port Phillip Bay), at three sites that had not been disturbed by commercial dredging for 4 yr prior to the beginning of the studies. All were performed in relatively shallow water (5-24 m). Five of these studies were controlled experiments, and two (5, 6) were observational in nature. Three studies (1, 2, 5) examined just physical effects, and four evaluated both physical and biological effects. One study (7) compared effects at commercially exploited and unexploited sites with different benthic communities.

The Australian experimental studies (1-4) simulated commercial dredging activity, whereas the New Zealand study (7) evaluated the effects of multiple side-by-side tows, and the Scottish study (6) examined the incremental effects of multiple tows on the same area of bottom. In all cases, experimental dredging was limited to a single event that never lasted for more than 1 wk. In those studies (3, 4, 7) in which recovery was monitored, it ranged from 3 mo (7) to 14 mo (3, 4).

Physical Effects

Physical effects included sediment plumes (which lasted up to 15 min), the smoothing of the seafloor, tracks made by dredge skids, and furrows up to 4 cm deep created by the dredge teeth (1-7). Dredging disturbed bottom sediments to a maximum depth of 6 cm (1, 2). At a shallow, high-energy site, there was no effect on sediment composition, and dredge tracks were obliterated within a few days (6). At a deeper, less-exposed site, sand ripples that had been smoothed by dredging reformed within 5 days (4), biogenic mounds were restored after 6-7 mo (3, 4), and dredge tracks that were still visible after 1 mo had disappeared after 6 mo (4).

Biological Effects

Biological effects were variable and depended on the degree of natural disturbance, how well individual species were adapted to sediment disturbance, and whether a single dredge tow or multiple tows were made over the same area of bottom.

Two studies conducted at the St. Leonards site in the relatively low-energy, enclosed Port Phillip Bay in Australia showed that the abundance of most infaunal species was reduced by 20-30% during the first 3.5 mo after the area was dredged repeatedly during a 3-day period (3, 4). There were no effects of dredging on the total number of individuals, but there were significantly fewer species in the dredged plot 3 wk after dredging. Dredging significantly reduced the densities of six of the ten most common infaunal taxa, and increased the abundance of more mobile, opportunistic species within the first 3.5 mo of the experiment. (Two and three of the ten most common taxa were significantly reduced in abundance 1-2 days after dredging at two other sites in the bay [4]).

Research at the St. Leonards site also revealed that the surface-dwelling infauna is released into the water column right away, whereas burrowing organisms are released during later dredge tows. Most of the affected species at the St. Leonards site recovered within 8 mo, but some were still less abundant after 14 mo.

At two slightly deeper, open coastal sites in New Zealand, single tows resulted in immediate and significant decreases in the number of macrobenthic individuals and species (7). The immediate effects of dredging at an unexploited site were more pronounced and, for individual taxa, more often negative (significant reductions in six of the thirteen most common taxa) than at the site that was located in a commercial scallop dredging ground (significant reductions in four of 13 taxa). In addition, at the exploited site, total abundance was the same in the dredged and control half-plots 3 mo after dredging, but at the unexploited site, total density was still significantly higher in the control half-plot.

Repeated dredge tows in a very shallow, high-energy location in Scotland significantly increased the abundance of certain species of small infaunal crustaceans, and initially reduced but then increased the abundance of sedentary polychaetes (6). Taxa that are adapted to dynamic environments (*e.g.*, amphipods and bivalve mollusks) were not significantly affected. Dredging also caused considerable damage and mortality to large epifauna and infauna in this study.

Toothed Scallop Dredges -- Biogenic Substrate (Table 5.11)

Hall-Spencer and Moore (2000a) described the effects of scallop dredging on maerl beds, a biogenic substrate which is derived from living calcareous rhodophytes. These beds take hundreds to thousands of years to accumulate because the growth rates of the macroalgae are very slow and are particularly vulnerable to damage from mobile bottom fishing gear (Hall-Spencer and Moore 2000b).

Single tows were made at depths of 10-15 m along three 100-m transects in an area in the Clyde Sea (Scotland) that had been commercially dredged for 40 yr, and as well as along three 100-m transects in an area of the Clyde Sea that had been previously undredged. Tows used a gang of three Newhaven dredges with 10-cm-long, spring-loaded teeth mounted 8 cm apart on a horizontal metal bar that was held off the seafloor by a rubber roller at each end. Immediate effects of dredging were noted and one transect at each site was monitored by divers 2-4 times a year over the following 4 yr.

Video recordings showed, at both sites, that the rollers and chain rings were in contact with the bottom while the dredge teeth projected fully into the maerl substratum (10 cm) and harrowed the seafloor, creating a cloud of suspended sediment. Rocks and boulders <1 m^3 in diameter were dislodged and overturned, and cobbles were often wedged between the teeth and dragged through the sediment. Dredges created 2.5-m-wide tracks along which natural bottom features (*e.g.,* crab pits and burrow mounds) were erased. Sand and silt was brought to the sediment surface, and living maerl was buried. Dredge tracks remained visible for 0.5-2.5 yr depending on depth and exposure to wave action.

Most megafauna on or within the top 10 cm of the maerl was either caught in the dredges or left damaged in the dredge track. Large, fragile organisms (*e.g.,* sea urchins and starfish) were usually broken on impact, whereas strong-shelled organisms (scallops, gastropods) usually passed into the dredge intact. Deep-burrowing species escaped dredge damage. Predatory species (*e.g.,* whelks, crabs, and brittle stars) rapidly aggregated in the dredge track to feed.

Recovery rates for affected benthic species also varied considerably. Species with regular recruitment and rapid growth recovered quickly, as did mobile epibenthic species that migrated into test plots soon after dredging. Slow-growing species and/or infrequently recruiting sessile organisms remained depleted on test plots at the undredged site 4 yr after dredging occurred, whereas the previously dredged macrobenthic community returned to pre-experimental status within 2 yr.

Summary

The immediate physical and biological effects of single dredge tows were evaluated on maerl substrate in Scotland. Recovery was monitored over 4 yr.

Dredging penetrated the seafloor to a depth of 10 cm, suspending sediment, overturning boulders, erasing bottom features, and burying living maerl in dredge tracks. Some dredge tracks were only visible for 6 mo, while others remained visible for 2.5 yr, depending on depth and exposure to wave action.

Most of the megafauna in the top 10 cm of substrate was either caught in the dredge or left damaged in the dredge track. Large, fragile organisms were most vulnerable. Recovery of the epibenthic community was complete at a previously dredged site within 2 yr, but some species at an unexploited site still had not recovered after 4 yr. Slow-growing species, and species that infrequently recruited to the benthos, took much longer to recover than species with regular recruitment patterns and faster growth rates.

Toothed Scallop Dredges -- Mixed Substrates (Table 5.12)

1. Bradshaw *et al.* (2002) compared historical and recent benthic sample data from seven sites located south and west of the Isle of Man (in the Irish Sea) exposed to different amounts of fishing effort since the late 1930s. Sample data were available for 1938-1952 when scallop dredging in the area was very limited, and for the 1990s. Some of these data were analyzed earlier by Hill *et al.* (1999).

Analysis of sediment samples indicated that five of the sites were predominantly sand, and two were gravel. No depth information was provided. Fishing disturbance for each site was evaluated in terms of: 1) total fishing effort by a sample fleet during 1981-1993, and that effort's inverse coefficient of variation (*i.e.*, higher values indicate a more even distribution of fishing disturbance from year to year); 2) the number of years since fishing began; and 3) a fishermen's ranked index of total fishing effort at each site since the start of the fishery. Smallscale (*e.g.,* grab) and largescale (*e.g.,* trawls) samples were pooled for each site so that the analysis would include the greatest possible range of infaunal and epifaunal animals.

There was a significant temporal effect across all sites, and at two sites where spatial and temporal replicate samples were available, the historical samples were distinct from the recent samples. Taxa that decreased in abundance between the two time periods included species of brittle stars, hydroids, upright and encrusting bryozoans, encrusting worms, and barnacles. Taxa that increased in abundance between the two time periods included large-bodied tunicates, mobile crustaceans (shrimp, spider crabs, and squat lobsters) and robust scavengers (whelks, hermit crabs, and starfish). Taxa that became more abundant, on average, scored higher in terms of life history characteristics that would increase their ability to survive dredging (highly mobile, deep burrowers, scavengers, mud/sand sediment preference, robust body types, and good regeneration and recolonization powers) than those that became less abundant (sessile, shallow burrowers/nest builders, suspension or filter feeders, shell/stone substrate preference, fragile body types, and poor regeneration and recolonization powers).

For individual sites, mean faunal similarities between the two time periods decreased significantly as the fishermen's index of effort and the number of years since fishing began increased. Similarly, the proportion of species "lost" between the two sampling periods increased significantly as the number of years of fishing increased. Faunal similarities and proportions of lost species between time periods were not significantly related to increased fishing effort, as estimated from fishermen's logbooks. These results suggested to the authors that it was the length of time over which fishing occurred, rather than absolute levels of effort, which was important in structuring benthic communities.

For all sites, there was also no clear evidence of a relationship between changes in taxonomic diversity and fishing effort, although taxonomic distinctness -- probably the best indicator of changes in biodiversity – decreased over time at two of the most heavily fished sites.

2. Bradshaw *et al.* (2000) analyzed density estimates of epibenthic animals made during diver surveys in the undisturbed portion of a 2-km^2 area near the Isle of Man, in the Irish Sea, that was closed to commercial fishing by towed gear in 1989. The entire area adjacent to and inside the closed area had been heavily dredged for 50 yr prior to the closure. Depth in the study area ranged from about 25 to 40 m, and the seafloor was a mixture of gravel, sand, and mud. The diver surveys started in 1989, the year the area was closed, and were repeated in 1990 and then in every other year until 1998.

A number of epifaunal species increased significantly in abundance over the 9-yr period, including brittle stars, a spider crab, scallops, hermit crabs, and one species of starfish. The most significant changes occurred in the fifth, seventh, and ninth years after the area was closed.

3. Bradshaw *et al.* (2001) assessed the effects of scallop dredging on benthic communities inhabiting mixed substrates in the closed area described in the preceding review [Bradshaw *et al*. (2000)]. Two experimental plots inside the closed area were each dredged every 2 mo or so from January 1995 to 1998, using two sets of four, spring-loaded, Newhaven scallop dredges towed 10 times along a single dredge track. Two control plots were established inside the closed area. Three additional plots were located outside the closed area in a commercial scallop dredging ground. Grab samples were collected twice a year starting in 1995 in all seven plots.

After the first 6 mo of experimental dredging, benthic community structure in the experimental plots was more similar to the commercially dredged plots, and less similar to the control plots, than it had been before dredging began. This trend continued over the next 3 yr of the experiment. However, none of these differences were significant, nor were there any clear trends for particular species or groups of species.

Dredging also had no significant effect on total species numbers or richness, but there was evidence that dredging reduced benthic community heterogeneity. Sessile epifaunal organisms were considered to be especially sensitive to dredging disturbance and were analyzed separately; one dataset (March 1998) revealed that encrusting bryozoans, encrusting sponges, and small ascidians were more common in dredged plots, while upright forms such as bryozoans and hydroids were more common in the undredged plots.

4. Caddy (1973) used a two-man submersible to observe the effects of 0.8-m-wide toothed dredges in Chaleur Bay, Gulf of St. Lawrence, in August 1971. A gang of three dredges was attached to a common steel towing bar. The upper and lower edges of each dredge mouth were armed with blunt teeth 4 cm long. Observations were made inside and outside dredge tracks within 1 hr of each tow. Depth varied from 40 to 50 m, and the substrate was sand overlaid by glacial gravel and cobble, 1-10 cm in diameter, with occasional boulders up to 60 cm across embedded in the gravel.

Tracks left by these dredges were shallow with a flat floor. Gravel was sparser inside than outside the track, and dislodged boulders were commonly observed. Tooth marks were seen over sandy bottom. Spoil ridges were left between adjacent dredges, and piles of small rocks were seen at intervals along the track. Small rocks were also "bulldozed" along in front of the dredge.

5. The Canadian Department of Fisheries and Oceans (DFO 1993) conducted a sidescan sonar survey in the Bras D'Or Lakes system in Nova Scotia to document the physical effects of various mobile fishing gears 1 yr after the area was closed to mobile gear. Water depths ranged from 10 to 500 m.

Dredge tracks consisting of a series of parallel furrows made by the dredge teeth were observed in gravelly bottoms and occasionally in silty bottoms. On the older or degraded dredge tracks, the furrows left by the teeth were not always resolved. In a soft bottom area, berms were visible at the outer edges of the dredge track. Similar berms were not seen in harder bottom areas.

6. Kaiser, Hill, *et al.* (1996) compared the immediate effects of beam trawling and scallop dredging on large epibenthic fauna on a heavily fished scallop ground off the southwest coast of the Isle of Man, adjacent to the closed area studied by Bradshaw *et al.* (2001). Three parallel waylines, 500 m apart and 1 nmi long, were established: one was fished 10 times with a 4-m commercial beam trawl fitted with an 80-mm diamond-mesh cod-end, one was left undisturbed, and one was fished 10 times with two gangs of four Newhaven spring-toothed dredges. The benthos in all three waylines was surveyed using a 2.8-m beam trawl with a 40-mm square-mesh cod-end before, and 24 hr after, fishing.

Prior to fishing, there were no significant differences between the epibenthic communities on the three waylines. Both gears greatly reduced the abundance of most species and altered community structure, but there were no significant differences in community structure between the two experimental waylines after fishing. The scallop dredges caught a lower proportion of nontarget species.

7. Kaiser, Ramsay, *et al.* (2000) examined the structure of infaunal and epifaunal benthic communities exposed to either high or low scallop dredging activity, based on fishing effort data, in the Irish Sea between 1986 and 1996. Samples were collected with an anchor dredge, a grab sampler, and a small beam trawl from five sites subjected to low fishing effort, and from five sites subjected to high fishing effort. Only large infaunal organisms (>10 mm) were retained in sediment samples since they were judged more sensitive to physical disturbance. The study area was located south of the Isle of Man, in the Irish Sea, in the center of one of the most heavily fished scallop grounds in Europe, in gravel and coarse sand sediments.

After accounting for habitat effects (caused by variations in median sediment grain size and depth), the only significant response to increased fishing was a higher number of epifaunal organisms. There were no significant effects on the number or diversity of epifaunal species nor on any of the community indices for infauna.

Benthic communities in the heavily fished areas were dominated by higher abundances of smaller-bodied species, whereas the less intensely fished areas were dominated by lower abundances of larger-bodied species. Species with higher mean densities or catch rates in the low-effort sites included a soft coral, two species of sea urchin, a bivalve mollusk, and two gastropods. Species that were more abundant in the high-effort sites included three species of brittle star and a sea urchin.

8. Veale *et al.* (2000) compared samples of epibenthic organisms collected with a gang of four Newhaven type spring-toothed scallop dredges in 1995 on 13 commercial fishing grounds in the Irish Sea that had been exposed to different amounts of fishing effort during the preceding 60 yr. The dredges were equipped with short teeth (76 mm) and small belly rings (57 mm). Annual estimates of fishing effort were available from detailed, high-resolution fishermen's logbooks. Depths ranged from 20 to 67 m, and sediment types were generally coarse sand and gravel, overlain with pebbles, cobbles, and dead shell.

Of all environmental parameters examined (including depth and bottom hardness and texture), a combination of long- and short-term fishing effort best explained the observed differences in dredge bycatch assemblages across sampling sites. Species diversity and richness, total number of species, and total number of individuals all decreased significantly with increasing fishing effort. Total abundance, biomass, and production, and the production of most of the major individual taxa investigated, decreased significantly with increasing effort. Species that were more abundant at the high-effort sites included starfish, soft corals, spider crabs, and the crab *Cancer pagurus*. Spider crabs and soft corals were also more abundant at the medium-effort sites.

Summary

This section summarizes the results of eight studies that assessed the effects of toothed scallop dredges on mixed glacially derived substrates. All but one (4) of these studies were done since 1993. Six of them were conducted in the Irish Sea and two in eastern Canada. The Canadian studies (4, 5) examined physical effects to the seafloor, and the Irish Sea studies evaluated effects on benthic infauna and epifauna.

Two of the Irish Sea studies (2, 6) were experimental. One study (1) compared benthic sample data collected at sites exposed to variable amounts of historical fishing effort, and another (3) involved diver surveys in a closed area. One of the two experimental studies (6) evaluated the effects of a discrete scallop dredging and beam trawling event on large epifauna in a commercially exploited area, and the other (2) examined the incremental effects of repeated, bimonthly tows over a 3-yr period in a closed area.

Physical Effects

Physical effects of scallop dredging in mixed substrates included furrows made by the teeth, shallow, flat tracks with spoil ridges or berms at the edges, dislodged boulders, and the "bulldozing" of small rocks by the dredge (4, 5). No information on recovery times was available.

Biological Effects

In the closed area study (3), 6 mo of experimental dredging (total of 30-40 tows per dredge track with eight dredges on three or four different occasions) following a 6-yr period with no dredging altered benthic community structure, but not significantly. There were no trends in the abundance of individual species or number of species, but there was evidence of reduced benthic community heterogeneity. Three years after dredging began, upright species were less abundant, and encrusting species were more abundant. (These changes may have occurred earlier, but this could not be verified). A number of epifaunal species increased significantly in abundance in the closed area 5-9 yr after the area was closed (2).

Experimental dredging in commercial fishing grounds in the Irish Sea altered the community structure of large epifaunal populations (6), while areas exposed to 10 yr of high fishing effort were characterized by significantly higher numbers of epifaunal organisms (7). Chronic exposure to high fishing effort did not significantly affect infaunal communities, and there were no significant effects of increased scallop dredging activity on the number of epifaunal species or species diversity, but there was a shift from benthic communities dominated by greater numbers of larger species to fewer numbers of smaller species (7).

Sites exposed to low fishing activity during the late 1930s to early 1950s, and high fishing activity during the 1990s, were characterized by fewer "disturbance-vulnerable" species and more "disturbance-tolerant" species (1). Furthermore, faunal differences and the percentage of species "lost" between the low- and high-effort time periods increased as the number of years since fishing began increased. Overall, there was no clear evidence of reduced species diversity between the two time periods.

Invertebrate bycatch collected in dredges at high-effort sites was composed of significantly fewer species and individuals than at low and medium-effort sites, and total abundance, biomass, and production, and the production of individual taxa declined significantly with increasing fishing effort (8).

Other Nonhydraulic Dredges

Other Nonhydraulic Dredges -- Biogenic Substrate (Table 5.13)

1. Fonseca *et al.* (1984) conducted research near Beaufort, North Carolina, in 1982 to determine the effects of small, hand-pulled, bay scallop dredges on eelgrass. Two, 65-cm-wide, lightweight dredges (no teeth on the dredge foot) were fixed to a single tow bar. Two study sites were selected, an exposed site with compacted silty sand sediments (19.8% silt-clay), and a protected site where sediments were less compact and had a slightly higher silt-clay content (22.3%). Three small quadrats at each site were dredged 15 times, three were dredged 30 times, and three were not dredged at all.

There was a significant decrease in both the number of eelgrass shoots and the biomass of eelgrass leaves with increasing dredging effort at each site. Both shoot number and leaf biomass were reduced to zero at the soft bottom site after 30 dredge pulls, but the hard-bottom site lost more biomass than the soft-bottom site because the initial biomass there was higher. The proportional reduction in shoot number was greater at the soft-bottom site.

The authors concluded that intensive scallop dredging for bay scallops with this gear or with the heavier dredges that are pulled by powerboats has the potential for immediate as well as long-term reduction of eelgrass nursery habitat.

2. Langan (1998) conducted a study in 1994 to determine the effects of dredge harvesting on an eastern oyster population and its associated benthic community in the Piscataqua River, which divides the states of New Hampshire and Maine. An oyster bed approximately 18 acres in size in the river channel is divided nearly equally by the border between the two states. Maine allowed commercial harvesting of oysters, but New Hampshire did not, for many years prior to the study. The dredge used on the Maine side of the river was 30 in (76 cm) wide, weighed approximately 27 kg, had blunt 8-mm teeth, and had a chain-mesh bag. Commercial dredging on the Maine side of the river (with one dredge, about twice a week) had continued for 5 yr prior to the study. A limited number of benthic samples were collected by divers on each side of the river on one sampling occasion. Turbidity was measured during a single dredge tow.

No significant differences were found in the number, species richness, or diversity of epifaunal or infaunal invertebrates between the two areas. The concentration of suspended sediment in near-bottom water during the dredge tow was slightly more than double the ambient level 10 m behind the dredge, and dropped off to the ambient level 110 m behind the dredge.

3. Lenihan and Peterson (1998) conducted a study in the Neuse River estuary in North Carolina to determine if the loss of eastern oysters from the river was in part due to the lowering of oyster reefs by oyster dredges. Eight, 1-m-tall, oyster-shell reefs were constructed in two depths (3 and 6 m). Nineteen months later, four of the eight reefs were dredged by a commercial dredge vessel for 1 wk until the catch of market-sized oysters in each haul declined to near zero and remained constant. The height of harvested and unharvested reefs was measured 3 days before dredging started and 2 days after dredging stopped.

Dredging reduced the mean height of the 1-m reefs by 29±6 cm. Unharvested reefs lost only 1±1 cm of height over the 1-wk duration of the experiment.

4. Riemann and Hoffmann (1991) assessed the effects on the water column of mussel dredging in a shallow eutrophic sound (Limfjord) in Denmark that had a mean depth of 7 m and a maximum depth of 15 m. Suspended particulate matter, oxygen, and nutrient (phosphorus and ammonia nitrogen) levels were measured at a number of stations throughout the water column at a dredged and a control site before dredging, immediately afterwards, and 30 and 60 min later. No information on sediment type was given. Dredging was performed for 15 min with a 2-m-wide mussel dredge weighing about 100 kg.

Average suspended particulate matter increased significantly immediately after dredging, but returned to pre-dredge levels 60 min later. Particulate matter also increased markedly on a day with high wind velocity. Oxygen decreased significantly immediately after dredging, particularly near the bottom. Average ammonia content also increased after dredging, but large horizontal variations prevented detailed interpretation of these increases.

Summary

Four studies are summarized. Three studies were conducted on the U.S. Atlantic coast, and one was conducted in Denmark. All studies were performed in shallow water, two in rivers and two in coastal waters with a maximum depth of 15 m. Two studies evaluated biological effects, one examined physical effects, and one examined geochemical effects in the water column. Three studies were experimental and one was observational.

Physical and Biological Effects

These studies showed that dredging lowered the height of oyster reefs (3) and, in a shallow enclosed fjord, temporarily increased water column turbidity and lowered dissolved oxygen concentrations, especially near the bottom (4). There were no detectable effects after 5 yr of oyster dredging on benthic invertebrate abundance, species richness, or diversity (2). Repeated tows with hand-hauled bay scallop dredges significantly reduced eelgrass biomass (1).

Hydraulic Clam Dredges

Hydraulic Clam Dredges -- Mud (Table 5.14)

Hall and Harding (1997) evaluated the effects of experimental suction dredging on intertidal infaunal communities in Auchencairn Bay, on the north side of the Solway Firth, on the west coast of Scotland. Sediments were 60-90% silt-clay in the inner bay and 25-60% silt-clay in the middle and outer bay. Commercial dredging for the cockle *Cerastoderma edule* in the bay was prohibited 4.5 mo before experimental dredging began. Core samples were collected in control plots prior to each dredge tow, and in experimental plots immediately after, and 1, 4, and 8 wk after each dredge tow.

Dredge tracks could not be seen after the first day. The total number of infaunal individuals and species increased in both plots over time, but were significantly lower in the experimental plots than in the control plots immediately after dredging and after 4 wk. Species diversity also increased significantly over time, but was not significantly different in the two plots at any point during the experiment. Three of the five dominant species were significantly reduced by dredging over the course of the study. By the end of the study (8 wk), much of the difference between dredged and control sites had been lost.

Summary

Results of a single experimental study are summarized. It examined the physical and biological effects of individual suction dredge passes in an intertidal mud habitat, and monitored recovery for 8 wk.

Dredging produced dredge tracks that disappeared after 1 day. There were significant reductions in the total number of infaunal individuals and species that lasted 4 wk, and three out of five dominant species were reduced in abundance during the entire 8-wk duration of the experiment. However, infaunal community structure recovered nearly completely by the end of the experiment.

Hydraulic Clam Dredges -- Sand (Table 5.15)

1. Hall *et al.* (1990) studied the physical and biological effects of a commercial escalator dredge used to harvest razor clams (*Ensis* spp.) in a shallow sea loch (Loch Gairloch) on the west coast of Scotland in November 1989. The depth at the study site was 7 m, and the sediment was fine sand. The study site was located near a recently dredged area, but was not exploited itself. Experimental and control plots were visually inspected and sampled by divers immediately after dredging and 40 days later. Each experimental plot was dredged intensively for approximately 5 hr in order to simulate commercial fishing activity.

After dredging, the experimental plots were criss-crossed by shallow trenches (0.5 m wide and 0.25 m deep) interspersed with larger holes (up to 3.5 m wide and 0.6 m deep) that were presumably produced when the dredge remained stationary for a brief period. Sediment in the holes and trenches was "almost fluidized," and sediment in the fished area had a significantly higher median particle size than sediment in the control plots. After 40 days, however, none of these features remained.

The number of infaunal species and individuals were reduced in the experimental plots immediately after dredging (significantly, for individuals), but there were no detectable differences between experimental and control plots 40 days later. There were no significant differences in the abundance of individual species in the control and experimental plots on either sampling occasion.

The authors concluded that dredging caused a short-term, nonselective reduction in the numbers of all infaunal species and that recovery from physical effects was accelerated by a series of winter storms and considerable sediment disturbance in the study area. No attempt was made to assess the mortality of: 1) large polychaetes and crustaceans that were observed to be retained on the wire-mesh conveyor belt or that fell off the end of the belt, or 2) ocean quahogs that were often cracked by the dredge.

2. Kaiser, Edwards, *et al.* (1996) investigated the effects of suction dredging for cultivated manila clams (*Tapes philippinarum*) [since reclassified and renamed as Japanese littleneck clam (*Venerupis philippinarum*)] on a muddy sand intertidal flat in southeastern England during December 1994. Samples of benthic infauna and sediment were collected prior to, 3 hr after, and 7 mo after harvest in one cultivated plot and in nearby control locations.

There were significantly higher densities of infaunal organisms in the cultivated plot versus the control plots prior to dredging, but no differences in the number of species or in four indices of taxonomic diversity. During dredging, large amounts of fine sand were resuspended by the dredge, exposing the underlying clay. Immediately after dredging, there were significant reductions in the mean numbers of infaunal species and individuals in the cultivated plot, resulting in levels that were statistically the same as in the control plots. Crustaceans and bivalve mollusks were particularly affected. Seven months later there were no significant differences between the benthic community in the harvested plot and in the control plots, and the proportion of fine sand in the harvested plot had increased significantly, indicating that recovery from the effects of clam cultivation and harvesting was complete.

3. MacKenzie (1982) sampled the benthic invertebrate assemblages of three ocean quahog beds with contrasting fishing histories located about 65 km east of Cape May, New Jersey, in the MAB, during October 1978. One bed had never been fished, one had been actively fished for 2 yr, and one had been fished for about a year but then abandoned 4-5 mo prior to this study. All three beds were in very-fine-to-medium sand sediments in 37 m of water. Commercial dredging was conducted with cage dredges in this area. Sampling was limited to a total of 30 grab samples from all three sites.

No significant differences were found in numbers of invertebrate individuals or species, nor in species composition, between the recently abandoned and never dredged sites, or between the actively dredged and never dredged sites. Hydraulic dredging thus did not appear to have any lasting effect on the invertebrate populations in these beds. Comparison of samples from the recently abandoned and never dredged sites also indicated that hydraulic jetting of the bottom re-sorts bottom sediments, leaving shell fragments on the surface and coarser sediments at the bottom of dredge tracks.

4. Maier *et al.* (1995) assessed the effects of escalator dredges in four muddy sand tidal creeks in South Carolina by comparing pre- and post-dredging turbidity levels and benthic infaunal assemblages. Turbidity was monitored 2 wk before, during, and 2 wk after dredging at one location, and during and immediately after dredging at another. Infaunal samples were collected 3 wk before and 2 wk after dredging in a creek that had been commercially dredged 5 yr prior to the study, and in a creek that had never been dredged before.

Turbidity was elevated near the dredge and immediately downstream while it was operating, but the sediment plumes only persisted for a few hours. Sampling failed to detect any significant changes in the abundance of dominant infaunal taxa, or in the total numbers of individuals, after dredging.

5. Medcof and Caddy (1971) utilized divers and a submersible to compare the physical effects of a hydraulic cage dredge in shallow-water (7-12 m) sand inlets in southern Nova Scotia, Canada.

On sand and sand-mud habitats, hydraulic dredges left smooth tracks with steeply cut walls that averaged 20 cm deep, and then slowly filled in by slumping. The hydraulic dredge raised a sediment cloud that seldom exceeded 0.5 m high and usually settled within 1 min. Dredge tracks were still easily recognizable after 2-3 days.

6. Meyer *et al.* (1981) observed the effects of a small (1.2-m-wide) hydraulic clam cage dredge in an Atlantic surfclam bed located near Rockaway Beach on the south shore of Long Island, New York. The study was conducted in 1977, 3 yr after the area was closed to commercial clamming. The sediment in the study area was fine-to-medium sand covered with a 7.5-cm-thick layer of silt, and the maximum water depth was 30 m. The study area was exposed to strong bottom currents that caused considerable movement of sand. As part of a larger study to evaluate gear performance, the effects of dredging on bottom substrate and fauna were assessed by divers during, immediately after, and 2 and 24 hr after, a single 2-min tow.

The dredge formed trenches that were initially rectangular, as wide as the dredge, and over 20 cm deep. Mounds of sand 15-35 cm wide and 5-15 cm high were formed on either side of the trench. The dredge raised a cloud of silt 0.5-1.5 m high, which settled within 4 min. Slumping of the trench walls began immediately after the tow and became more apparent with time. Two hours after dredging, slumping of the trench walls had rounded the depression. After 24 hr, the dredge track was less distinct, appearing as a series of shallow depressions, and was difficult to recognize.

The dredging attracted predators, with lady and Atlantic rock crabs preying on damaged clams, and with starfish, horseshoe crabs, and moon snails attacking exposed but undamaged clams. By 24 hr after dredging, the abundance of predators appeared to have returned to normal, and the most obvious evidence of dredging was whole and broken clam shells without meat.

7. Pranovi and Giovanardi (1994) studied the effects of a 2.7-m-wide hydraulic cage dredge in 1.5-2 m depths in the Venice Lagoon (Italy, Adriatic Sea). Divers collected samples of sediment and benthic organisms from experimentally dredged and control areas at two sites located inside and outside a commercial fishing ground immediately after experimental dredging and every 3 wk for 2 mo. A single tow was made at each site.

The dredge created 8-10 cm deep furrows, one of which was clearly visible 2 mo later. In this study, sediment grain size was not significantly affected by dredging, although portions of the fishing ground which had been predominantly silt and clay 15 yr earlier had a considerably higher sand content at the time of the study. Hydraulic dredging in this area often cracks the shells of bivalve mollusks.

Inside the fishing ground, total numbers and biomass of benthic infauna and epifauna were significantly reduced in the experimental plot immediately following dredging. Densities, especially of small species and epibenthic species, recovered 2 mo later, but biomass did not. Inside the fishing ground, there were also fewer species in the dredged area than in the control area immediately after, and 3 and 6 wk after, dredging, but no differences 2 mo afterwards. Outside the fishing ground, immediately after passage of the dredge, there were no significant faunal differences between dredged and undredged areas.

8. Tuck *et al.* (2000) examined in March 1998 the effects of hydraulic dredging on the seafloor and benthic community in a shallow (2-5 m) site that is located in the Outer Hebrides (Sound of Ronay) on the west coast of Scotland, and that was closed to commercial dredging. Sediments in the study area consisted of moderately well sorted medium or fine sand, and tidal currents reached speeds as high as 3 knots. Divers collected core samples and made observations and video recordings before, during, and immediately after dredging inside and outside six dredge tracks, and then returned to re-examine the site 5 days and 11 wk after dredging. The dredge was a commercial dredge that is used to harvest razor clams and that employs a hollow blade that protrudes 0.3 m into the sediment and that has holes to direct pressurized water forward into the sediment.

Immediately after dredging, the track had distinct vertical walls and a depth similar to the dredge blade. However, once the dredge was hauled, the sidewalls collapsed and the tracks had a flat-bottomed “V” shape. The sediment within the base of the tracks was fluidized to a depth of approximately 0.3 m and within both sidewalls to approximately 0.15 m. The tracks were still clearly visible after 5 days, but less pronounced, and the depth of fluidized sediment remained the same. After 11 wk, the tracks were no longer visible, but 0.2 m of sand was still fluidized. Immediately after fishing, there was significantly less silt in the sediments inside the tracks than outside, but there was no difference after 5 days.

Numerically, the infauna at the study site was dominated by polychaetes. There was a significant decrease in the proportion of polychaetes, and an increase in amphipods, in the dredge tracks within 5 days of dredging, but not after 11 wk. Bivalve mollusks -- other than razor clams -- were not affected by dredging. Within a day of dredging, the total number of species and individuals was significantly lower in the dredge tracks, but there was no difference after 5 days. Dredging had an immediate positive and negative effect on the abundance of a number of individual species. For some species, the effect persisted for 5 days, but no effects were detected 11 wk after dredging. Owing to the strong currents, there was a very sparse epifauna in the area; the only observed effect of dredging was the attraction of crabs into the area to scavenge on material disturbed by the dredge.

Summary

Results of eight hydraulic dredge studies in sandy substrates are summarized. Five studies examined the effects of “cage” dredges of the type used in the Northeast Region of the United States (3, 5-8), two examined the effects of escalator dredges, and one examined the effects of suction dredges. Three of them were published prior to 1990, and five since then. Four were performed in North America, one in the Adriatic Sea, and three in the United

Kingdom. One study was conducted on the U.S. continental shelf at a depth of 37 m, five in shallower nearshore waters (1.5-12 m), and two in intertidal environments. Three studies were observational in nature (3, 5, 6), and five were controlled experiments (1, 2, 4, 7, 8).

Three studies (2, 3, 7) compared effects in commercially dredged and undredged areas, and four (1, 4, 6, 8) were conducted in previously undredged areas. Six studies examined the effects of individual dredge passes (2, 4-8), one evaluated the effects of repeated passes in the same area during a short period of time (1), and one compared infaunal communities in an actively dredged, a recently abandoned, and an never dredged location (3). Seven studies examined physical and biological effects, and one was limited to physical effects (5). All of the biological studies examined effects to infauna. Recovery was evaluated in four cases for periods ranging from 40 days to 7 mo (1, 2, 7, 8).

Physical Effects

Hydraulic clam dredges created steep-sided trenches 8-30 cm deep that started deteriorating immediately after they were formed (1, 5-8). Trenches in a shallow, inshore location with strong bottom currents filled in within 24 hr (6). Trenches in a very shallow, protected, coastal lagoon were still visible 2 mo after they were formed (7).

Hydraulic dredges also fluidized sediments in the bottom and sides of trenches (1, 8), created mounds of sediment along the edges of the trench (6), resuspended and dispersed fine sediment (1, 2, 4-6, 8), and caused a re-sorting of sediments that settled back into trenches (3). In one study (8), sediment in the bottom of trenches was initially fluidized to a depth of 30 cm, and in the sides of the trench to 15 cm. After 11 wk, sand in the bottom of the trench was still fluidized to a depth of 20 cm. Silt clouds only last for a few minutes or hours (4-6).

Complete recovery of seafloor topography, sediment grain size, and sediment water content was noted after 40 days in a shallow sandy environment that was exposed to winter storms (1).

Biological Effects

Some of the larger infaunal organisms (*e.g.,* polychaetes and crustaceans) retained on the wire mesh of the conveyor belt used in an escalator dredge, or that drop off the end of the belt, presumably die (1). Benthic organisms that are dislodged from the sediment, or damaged by the dredge, temporarily provided food for foraging fish and invertebrates (6, 8). Predator densities returned to normal within 24 hr in one study (6).

Hydraulic dredging caused an immediate and significant reduction in the total number of infaunal organisms in three studies (1, 2, 8), and in the number of both infaunal and epifaunal organisms in a fourth study (7). There were also significant immediate reductions in the number of species of infauna in two cases (2, 8), and in the number of species and biomass of both infauna and epifauna in a third case (7).

In one study using a hydraulic cage dredge, polychaetes were the most affected in the short term (7); in another study using a suction dredge, crustaceans and bivalve mollusks were the most affected in the short term (2). Two studies of the effects of escalator dredging failed to detect any reduction in the abundance of individual taxa (1, 4). In one of them (4), dredging did not reduce the number of infaunal organisms. Evidence from the study conducted off the New Jersey coast indicated that the number of infaunal organisms and species, and the species composition, were the same in actively dredged and never dredged locations (3).

Recovery times for infaunal communities were estimated in four studies. Three of these studies (1, 7, 8) were conducted in very shallow (1.5-7 m) water, and one (2) in an intertidal environment. Total infaunal abundance and species diversity had fully recovered only 5 days after dredging in a location where tidal currents reach maximum speeds of 3 knots (8). In the latter study, all species which had been initially reduced due to dredging had recovered after 11 wk. In another study, total abundance recovered 40 days after dredging (when the site was first revisited) at a site exposed to winter storms (1). Total infaunal abundance, but not biomass, recovered within 2 mo at a commercially exploited site, but not at a nearby unexploited site (7). Full recovery at the intertidal site was noted when it was first revisited 7 mo after it was suction dredged (2). Actual recovery times at this site and at one of the exposed subtidal sites (1) may have been much quicker than 7 mo and 40 days.

Hydraulic Clam Dredges -- Mixed Substrates (Table 5.16)

Murawski and Serchuk (1989) used manned submersibles to observe effects of hydraulic dredging on sand, mud, and gravel bottom habitats in a number of offshore locations in the MAB between Delaware Bay and Long Island (water depths not reported).

They reported that hydraulic cage dredges penetrate deeper into the sediments and, on a per-tow basis, result in greater short-term disruption of the benthic community and underlying sediments than do scallop dredges (no data were provided). In coarse gravel, the sides of hydraulic dredge trenches soon collapsed, leaving little evidence of dredge passage. There was also a transient increase in bottom-water turbidity. In finer-grained, hard-packed sediments, tracks persisted for several days after dredging.

Nonharvested benthic organisms (*e.g.,* sand dollars, crustaceans, and polychaetes) were substantially disrupted by the dredge. Sand dollar assemblages appeared to recover quickly, but short-term reductions in infaunal biomass were considered likely. Numerous predatory fish (*e.g.,* red hake, spotted hake, and skates) and invertebrates (Atlantic rock crabs and starfish) were observed consuming broken quahogs in and near dredge tracks. Densities of crabs and starfish were estimated to be two-and-a-half times higher in dredge tracks than in nearby undredged areas within 1 hr of experimental tows, and >10 times higher 8 hr after dredging. Presumably, the benthic infauna "tilled up" by the dredge was also being consumed, since not all predators observed foraging in the dredge paths were eating damaged shellfish.

Summary

An in situ evaluation of hydraulic dredge effects in sand, mud, and coarse gravel in the MAB indicated that trenches fill in quickly -- within several days in fine sediment, and more rapidly than that in coarse gravel. Dredging dislodged benthic organisms from the sediment, attracting predators.

Hydraulic Clam Dredges -- Biogenic Substrate (Table 5.17)

1. Godcharles (1971) experimentally evaluated the physical effects of escalator dredging in seagrass (*Thallasia testudinum* and *Syringodium filiforme*) beds, *Caulerpa* algae beds, and bare sand bottoms (depth not given) in Tampa Bay, Florida, in 1968. Dredging was conducted with a commercial dredge at six sites. Water jets penetrated sediments to a maximum depth of 45 cm and left trenches that varied from 15 to 45 cm deep.

Trenches were deeper in shallow areas where propeller wash scoured loose sediments from trenches and prevented redeposition of suspended sediments. The proportion of fine sediment in some trenches decreased immediately after passage of the dredge. Virtually all attached vegetation in the path of the dredge was uprooted, leaving open bottom areas.

Trenches in grass beds remained visible the longest (up to 86 days), while those in sandy areas filled in immediately. Most fluidized sediments hardened within 1 mo, but some spots were still soft 500 days after dredging. Differences in silt-clay content between tracks and undisturbed areas became negligible after a year, but seagrasses had still not recolonized disturbed areas. New algal growth was noted in some dredged areas after 86 days, and after 1 yr, dredge tracks were completely covered.

2. Orth *et al.* (1998) assessed damage to submerged aquatic vegetation caused by escalator dredges in Chincoteague Bay, Virginia, during 1996, 1997, and 1998. They reported a large number of circular "scars" in the vegetation, with 70-100% seagrass cover outside the scarred areas, and an abrupt reduction to 15% or less at the scar edge. The percent cover of seagrass was low across the scar except for an abrupt increase in cover at the center, where seagrass had not been disturbed.

There were no measurable differences in percent cover estimates in the scarred portions of areas that were dredged during the 3 yr of observation, indicating that revegetation was proceeding very slowly. There were two factors that the authors believed were delaying revegetation: an increase in depth of 10-20 cm in the dredge tracks, and large holes inside the unvegetated portions of the scars made by organisms such as foraging cownose rays. The authors concluded that even the most lightly effected areas would require a minimum of 5 yr to fully recover.

Summary

Two studies were performed in the southeastern United States in shallow, subtidal, vegetated habitats. One study was a controlled experiment that compared the effects of escalator dredges in vegetated (seagrass and algae) and unvegetated areas; the other study evaluated damage to seagrass beds caused by commercial escalator dredging.

In the experimental study (1), water jets penetrated sand substrate to a maximum depth of 45 cm, created trenches up to 30 cm deep, uprooted vegetation, and decreased the proportion of fine sediments in dredge tracks. Recovery times were extremely variable. In some cases, trenches were visible for only 1 day, and in other cases for 3 mo. In most cases, sediments hardened within 1 mo, but in some tracks, sediments were still fluidized 500 days after dredging. After 1 yr, sediment composition in dredge tracks had returned to normal, but seagrass had not recolonized disturbed areas.

In the observational study (2), there were no signs of recovery of seagrass in commercially dredged areas 3 yr after dredging.

Pots and Traps

Pots and Traps -- Mixed Substrates (Table 5.18)

Eno *et al.* (2001) evaluated the effects of crab and lobster pots on attached epibenthic megafauna (sponges, bryozoans, ascidians, soft corals, and tube worms) at three locations in Great Britain: one each off Scotland, Wales, and England.

Off the west coast of Scotland (Badentarbet Bay), the effects of dropping pots onto sea pens were observed by divers in a soft-mud, pot fishing ground for Norway lobster (*Nephrops* sp.) in 1995. In addition, three experiments were conducted to assess sea pen survival and recovery following dragging, uprooting, and smothering by lobster pots. In one experiment, divers dragged pots over marked areas of the seafloor and recorded the fate of sea pens for 3 days after the disturbance. In the second experiment, groups of sea pens removed from the seafloor by the pots were relocated to an undisturbed location, and their behavior and survival were observed over a 4-day period. In the third experiment, 60 pots were dropped onto individual or small groups of sea pens and then removed after 24 or 48 hr to simulate the effects of smothering that would occur during commercial operations.

Video observations at the Scottish site showed that the pressure wave created by pots as they sink to the bottom was sufficient to bend sea pens away from the pot just before contact. Results of the three experiments revealed that all sea pens were able to fully recover from pot impact. Furthermore, all sea pens recovered from the effects of dragging within 24-72 hr. Uprooted sea pens reinserted themselves into the sediment, providing the peduncle gained contact with the mud surface. Following smothering for either 24 or 48 hr, it took 72-96 and 96-144 hr, respectively, for all three species of sea pen to fully recover an upright position.

At five coastal sites in Lyme Bay, southwest England, SCUBA divers assessed the immediate effects of pot hauling in different habitats at depths of 14-20 m in September and October 1995. Habitats varied from exposed limestone slabs and bedrock covered by sediment, to large boulders with mixtures of various rocky substrates interspersed with coarse sediment. A variety of fragile epifaunal species, including a sea fan and Ross coral, were present. Two lines of three pots were deployed at each site. Divers videorecorded pots as they landed on the seafloor, and as they were hauled back, and then videorecorded back along the path of each pot after its removal.

There were very few signs of effect on epifaunal species at any of the five sites. Gorgonians (soft corals) were frequently seen to bend under the weight of pots, then spring back once the pots had passed. When pots were hauled back along the bottom, a track was left in the sediments.

At Greenala Point, Wales, and in Lyme Bay, the effects of potting on selected epibenthic species were quantified by diver observations at sites with rocky substrates, water depths <23 m, and fragile epifaunal species. Common epifaunal species included a sea fan and a colonial emergent bryozoan. A commercial pot fishery for crabs (*Cancer pagurus*) and lobsters (*Homarus gammarus*) was carried out in these two locations. Each location was divided into two control and two experimental plots. Pots were set in the experimental plots and hauled every 2 or 3 days for 4 wk, such that at least 30 pots and 10 anchor weights landed in each experimental plot over the course of the study.

At the Greenala Point site, the abundance of four sponge species increased significantly in the experimental plots after 4 wk of potting, but not in the control plots. At the Lyme Bay site, one species of sponge, an ascidian, and a bryozoan increased significantly in abundance in the experimental plots only.

Summary

Observations and experiments were carried out in a single study conducted at three coastal locations in Great Britain to evaluate the effects of crab and lobster pot fishing on attached epibenthic megafauna. Sea pens underneath pots were bent over and some were uprooted when pots were dragged over mud sediments, but they fully recovered within 72-144 hr after pots left on the bottom for 24 or 48 hr were removed. When pots were dragged over the bottom they left tracks, but 4 wk of simulated commercial pot fishing had no negative effect on the abundance of attached benthic epifauna. In fact, seven taxa (five sponges, an ascidian, and a bryozoan) increased in abundance after 4 wk of fishing..

Multiple Gear Types

Multiple Gear Types -- Sand (Table 5.19)

1. Almeida *et al.* (2000) surveyed the southern half of Closed Area II on Georges Bank in June 1999, 4.5 yr after that area was closed to gear used to catch groundfish (bottom trawls, scallop dredges, longlines, and gill nets). This portion of the closed area ranges in depth from slightly <50 m to slightly >90 m, the substrate is sand, and there are sand ripples and bedforms in the shallower, northwest, "high-energy" portion of the survey area where bottom tidal currents are stronger. These features are generally absent from the deeper (>65 m), "low-energy," southeast portion of the survey area. Still photographs and video imagery were used to assess the relative abundance of seven microhabitats at a series of paired stations just inside and outside the closed area boundary.

No significant differences were found for any microhabitat type except for the emergent sponge epifauna (*e.g., Suberites ficus* and *Polymastia* sp.) microhabitat type that was more abundant inside the closed area.

2. Kaiser, Spencer, *et al.* (2000) sampled infauna and epifauna with a 2-m beam trawl and an anchor dredge along the south Devon coast in England of three high-fishing-effort areas open to all fishing (otter trawl, beam trawl, scallop dredge, and pots), in two medium-fishing-effort areas open to mobile gear for 6 mo out of the year and to pots year-round, and in one low-fishing-effort area only open to pots. Sampling within each of the six areas was distributed among three sites. At each trio of sites, sediments followed a gradient from fine sand to medium sand to coarse-medium sand. Fine-sand sites (inshore) were located in 15-17 m depths. The medium sand and coarse-medium sand sites (offshore) were located in 53-70 m depths.

For epifauna, there were significant habitat effects (*i.e.*, depth and substrate) on the numbers of species and individuals, and on two indices of species diversity, but there were no significant fishing effort effects (high versus low) on any of these parameters. In general, however, as fishing disturbance increased, less mobile, larger-bodied, and more fragile epifaunal species decreased in abundance, while mobile, more resilient species increased in abundance. Areas closed to draggers had higher abundances of emergent fauna (*i.e.*, soft corals and hydroids) that increased habitat complexity.

For infauna, there were significant habitat effects (*i.e.*, depth and substrate) on the number of species and on one index of species diversity between the two offshore sites, but no consistent fishing effort effects across all three sites, and only one significant fishing effort effect (on species diversity) between the two deeper offshore sites (*i.e.*, greater effect at the coarse-medium sand sites). Infaunal biota in the three different habitats were affected to different extents by increasing levels of fishing. In particular, the deeper, medium-coarse sand habitat seemed most severely affected by fishing. Several infaunal species in this habitat had significantly lower biomasses and abundances.

Areas subjected to low fishing effort were dominated by epifaunal and infaunal species with relatively high biomass, whereas areas subjected to high fishing effort had fewer high-biomass species and greater abundances of smaller-bodied species.

Summary

The results of two observational studies of multiple gear types on sand habitats (at depths that varied from 15 to >90 m) are summarized. A recent study in U.S. waters on eastern Georges Bank (1) compared the amount of cover provided by different habitat types inside and outside an area closed to trawls, dredges, longlines, and gill nets for 4.5 yr. Another recent study (2) compared sandy shallow and deepwater sites on the south coast of England that were exposed to low, medium, and high levels of fishing effort by mobile and fixed gears.

On Georges Bank, the only significant difference was a higher abundance of emergent sponges inside the closed area (1). On the south coast of England, low-effort areas that were closed to trawls and dredges had more emergent epifauna (soft corals and hydroids) and were dominated by relatively high-biomass epifauna and infauna, whereas high-effort areas fully exposed to fixed and mobile gears had higher abundances of small-bodied organisms (2). Deep (53-70 m), coarse-medium sand, offshore sites were more affected by fishing than deep, medium sand, offshore sites, or shallow (15-17 m), fine-sand, inshore sites (2).

Multiple Gear Types -- Gravel/Rock (Table 5.20)

1. Collie *et al.* (1997) sampled two relatively shallow (42-47 m) and four relatively deep (80-90 m) gravel sites in U.S. and Canadian waters on the northern edge of eastern Georges Bank during two cruises in 1994. Bottom substrates at the sites were predominantly pebble-cobble with or without encrusting organisms, with some overlying sand. The sites were classified as disturbed (D) or undisturbed (U) by bottom-tending mobile gear based on the number of dredge and trawl tracks in sidescan sonar images, the presence or absence of large boulders and epifauna in bottom photographs, and 1993 records of scallop dredging effort in TMSs of latitude and longitude in U.S. waters on the bank. There were three U sites and one D site in deep water, and one U and one D site in shallow water.

Quantitative samples of epibenthic organisms (>10 mm) were collected with a 1-m-wide naturalist dredge fitted with a 6.4-mm square-mesh liner. Organisms such as colonial sponges, bryozoans, hydroids, and the tube-dwelling polychaete *Filograna implexa* that were not quantitatively sampled by the dredge were excluded from analysis.

There were significant effects of fishing and depth combined on total density, biomass, and an evenness diversity index based on abundance, as well as some evidence of a gradient in abundance, biomass, and species diversity from deep undisturbed sites (high values) to shallow disturbed sites (low values). However, because of the significant depth effects and depth-disturbance interactions, fishing disturbance alone was not a significant factor.

Cluster analysis identified a group of six species that were abundant at U sites, rare or absent at D sites, and not affected by depth. This group included two species of shrimp, a tube-dwelling polychaete, a nemertean, horse mussels, and a bloodstar. Six other species groups were defined by either depth or some combination of depth and disturbance level, or included species that were ubiquitous.

2. Collie *et al.* (2000), in a follow-up publication, analyzed video images and still photographs recorded at five of the six study sites surveyed in the two 1994 research cruises to George Bank (*i.e.*, one of the deep U sites was not included).

In the videotapes, the U sites at both depths had slightly coarser sediments (higher frequency of pebble-gravel than sand-gravel); in the still photos, there was a higher frequency of sand and cobble in U sites and a lower frequency of pebbles. Bottom photos showed a high percent cover of colonial hydroids and bryozoans at one of the deep U sites, and of the rock encrusting polychaete *Filograna implexa,* at both deep U sites. In contrast, at the D sites, the gravel was free of epifaunal cover, and few animals were visible. Statistical analysis confirmed that the

U sites had a significantly higher percent cover of *Filograna implexa*. However, cover provided by this species was also significantly greater in deeper water than in shallow water.

Emergent hydroids and bryozoans were significantly more abundant at the deep U sites than they were at the shallow U site. Overall, the percent cover of all emergent epifauna was significantly higher at the deep sites, but there was no significant disturbance effect.

Summary

Two recent observational studies of mobile gear effects on sediments and epifauna in gravel bottom habitat on the northern edge of eastern Georges Bank (42-90 m) are summarized. Study sites were distinguished by depth and the presence or absence of fishing disturbance. Sediments in undisturbed sites were slightly coarser with more sand and cobble. There were significantly more organisms, higher biomass, and greater species diversity at the undisturbed sites in both depths, but there were also significantly higher values in disturbed and undisturbed deep sites than in disturbed and undisturbed shallow sites.

Percent cover of an encrusting colonial polychaete was also significantly higher at the deep sites and at the undisturbed sites. Emergent hydroids and bryozoans were significantly more abundant in deep undisturbed sites, and at shallow disturbed sites. Overall, emergent epifauna was more abundant in deep water, but there was no significant disturbance effect.

Multiple Gear Types -- Mixed Substrates (Table 5.21)

1. Auster *et al.* (1996) used a remotely operated vehicle (ROV) in July 1993 to compare conditions inside and outside an inshore area (depth 30-40 m) in the GOM that was closed to mobile fishing gear in 1983. On sand-shell bottom, video transects indicated that habitat complexity was provided mostly by sea cucumbers attached to shell and other biogenic debris, and by bottom depressions created by mobile fauna. Both of these habitat features were significantly less common outside the closed area, a difference that was attributed to the incidental exploitation of sea cucumbers and the harvest of lobsters, sea scallops, crabs, and white hake -- all animals that produce depressions.

On cobble-shell bottom, habitat complexity was provided mostly by emergent epifauna (*i.e.*, hydroids, bryozoans, sponges, and serpulid worms) and sea cucumbers. These species were less common outside the closed area. Their reduced abundance was attributed to removal by mobile fishing gear.

Cleared swaths in epifaunal cover were observed at the border of the closed area and were presumed to be caused by scallop dredges and trawl doors.

Auster *et al.* (1996) also conducted sidescan sonar surveys and ROV observations of Stellwagen Bank (GOM) in 1993 (depth 20 -55 m). The sonar images showed that showed large expanses of sand, gravelly sand, shell deposits, and gravel. The authors reported that waves produced by large storms from the northeast create ripples in coarse sand that measure 30-60 cm between crests and 10-20 cm in height, and deposit large sheets of fine sand with low sand waves 15-35 m between crests. The troughs of these sand waves are filled with shell debris (mostly ocean quahogs). Examination of the sonar images also showed scallop dredge and trawl tracks that disturbed sand ripples and dispersed shell deposits.

The ROV observations on Stellwagen Bank's crest (32-43 m deep) indicated that aggregations of emergent hydrozoans were missing, and that benthic microalgal cover was disturbed in gear tracks. Observations on the crest of the bank in July 1994 showed that an ascidian species was widely distributed, but was not present in otter trawl tracks.

2-4. Reise (1982), Riesen and Reise (1982), and Reise and Schubert (1987) compared invertebrate surveys in the Wadden Sea (Netherlands) made between 1869 and 1986. Bottom sediments in these areas currently range from mud to coarse sand and some pebbles. The area is made up of tidal flats, shallow subtidal banks, and channels that reach depths of 23 m. Surveys were completed using oyster dredges and grabs.

During the time period encompassed by the various surveys, abundant oyster reefs were overexploited, seagrass beds were lost to a natural epidemic, and *Sabelleria* reefs were destroyed by heavy trawl gear. The area is now dominated by soft sediments and mussel beds, which prior to 1920 were restricted to very shallow water. Comparisons show that 28 mollusk and amphipod species (including eight associated with oyster beds, eight with *Sabelleria*, and seven with seagrasses) have declined in abundance. Twenty-three species (many of them polychaetes) that were missing or rare in earlier surveys were common in 1986. The epifauna was more abundant in the 1920s, and the infauna was more abundant in the 1980s.

5. Thrush *et al.* (1998) tested 10 predictions regarding the effects of increasing fishing pressure on benthic communities in the Hauraki Gulf, New Zealand. Core, grab, and suction dredge samples were taken from 18 stations exposed to varying levels of commercial fishing effort by otter trawls, Danish seines, and toothed scallop dredges. Additional data were obtained from video images using an ROV, and from sediment samples collected by divers. Sediments ranged from sand (<1% silt and clay) to mud (nearly 50% silt-clay) and depths from 17 to 35 m.

After accounting for the effects of location, depth, and sediment characteristics (grain size and organic matter content), 15-20% of the variability in macrofauna (>0.5 mm) community composition was attributed to fishing pressure.

Most of the predictions were supported by analysis of the core-sample data; fewer predictions were supported by other sample types. Three predicted results of increasing fishing pressure were confirmed at $P<0.05$: decreased density of large epifauna (video transects), decreased species diversity and richness (core samples), and decreased density of echinoderms (cores). Four additional predictions were confirmed at $P<0.10$: decreased number of individuals (grabs), increased density of small opportunistic species (cores), decreased density of long-lived surface dwellers (cores), and increased density of deposit feeders (cores). The large members of the epifauna were also less abundant in grab samples collected from more heavily fished sites ($P<0.10$).

Results, in some cases, were not consistent among sample types. Species diversity and richness, for example, were not even identified as significant model variables in the grab sample data, nor was the number of individuals in the core samples, and deposit feeders collected in grab samples were significantly less abundant at sites exposed to increased fishing pressure.

Two predictions were contradicted by the results of this study: the ratio of polychaetes to mollusks (in cores) decreased rather than increased with greater fishing pressure, and the ratio of small to large individuals, for one common species of sea urchin, increased rather than decreased (also in cores). Further, scavengers (large, mobile benthic organisms such as crabs and starfish) were predicted to increase with increasing fishing pressure, but there was no evidence from this study that they responded either positively or negatively to changes in fishing intensity.

6. Valentine and Lough (1991) used sidescan sonar and a submersible to describe the effects of scallop dredges and bottom trawls on sand and gravel habitats on eastern Georges Bank. They noted that the most evident signs of disturbance occurred on gravel pavement where they observed long, low mounds of gravel that presumably had been produced by trawling and dredging. In some areas, the seafloor was covered by trawl and dredge tracks.

Gravel areas that were not accessible to bottom-tending mobile gear (due to the presence of large boulders) had a biologically diverse community with abundant attached organisms. Conversely, the attached epifaunal community was sparse, and the bottom was smoother, in areas that had been disturbed by dredging and trawling.

Summary

Six observational studies of the effects of multiple gear types on mixed substrates are summarized. Surveys were conducted in the GOM inside and outside an inshore area closed to mobile fishing gear, and in an offshore area that was disturbed by mobile fishing gear (1). A series of three publications examined long-term (100+ yr) changes in benthic habitats and communities in the Wadden Sea, some of which were attributed to fishing (2-4). A study in New Zealand (5) tested 10 predictions of how increasing fishing activity affects benthic communities by comparing benthic samples and underwater video footage from areas exposed to varying degrees of commercial fishing effort. A sixth study (6) examined areas on eastern Georges Bank that were affected by mobile bottom gear.

Significant increases were observed in the abundance of sea cucumbers and emergent epifauna, and in the number of bottom depressions created by organisms such as lobsters, sea scallops, and crabs, on sand-cobble-shell substrate inside the GOM closed area (1). Sidescan sonar and ROV surveys of Stellwagen Bank revealed evidence that otter trawls and New Bedford-style scallop dredges disturb sand waves and ripples, disperse shell deposits, remove emergent epifauna, and disturb microalgal cover (1). Disturbed sand and gravel areas of Georges Bank were characterized by trawl and dredge tracks, sparse epifauna, mounds of gravel presumably produced by fishing gear, and smoother bottom (6). In the New Zealand study (5), there were four significant effects of increased fishing activity by bottom trawls, Danish seines, and toothed scallop dredges in mud and sand substrates that were consistent across all sampling methods. These effects were reduced density of large epifauna, echinoderms, and long-lived surface-dwelling organisms, and an increased density of small, opportunistic species. The loss of biogenic reefs and changes in benthic community composition (fewer mollusk and amphipod species and more polychaete species) in the Wadden Sea were in part attributed to fishing activity (2-4).

Table 5.1. Number of studies included in this review, by gear and substrate type. (PR = peer-reviewed; NPR = non-peer-reviewed.)

Gear	**Substrate**	**1990-2002**			**Pre-1990**			**Total**
		PR	NPR	Total	PR	NPR	Total	
Otter Trawls	Mud	9	2	11	0	0	0	11
	Sand	10	2	12	1	0	1	13
	Gravel/Rock	2	0	2	1	0	1	3
	Mixed	1	1	2	0	1	1	3
	All	22	5	27	2	1	3	30
NB Scallop Dredges	Sand	3	0	3	0	0	0	3
	Mixed	1	0	1	2	0	2	3
	All	4	0	4	2	0	2	6
Toothed Scallop Dredges	Sand	6	0	6	0	1	1	7
	Biogenic	1	0	1	0	0	0	1
	Mixed	6	1	7	1	0	1	8
	All	13	1	14	1	1	2	16
Hydraulic Clam Dredges	Mud	1	0	1	0	0	0	1
	Sand	4	1	5	2	1	3	8
	Biogenic	0	1	1	0	1	1	2
	Mixed	0	0	0	0	1	1	1
	All	5	2	7	2	3	5	12
Other Dredge	Biogenic	2	1	3	1	0	1	4
Multiple Gears	Sand	2	1	3	0	0	0	3
	Gravel/Rock	2	0	2	0	0	0	2
	Mixed	2	1	3	3	0	3	6
	All	7	1	8	3	0	3	11
Lobster Pots	Mixed	1	0	1	0	0	0	1
Total	**All**	**53**	**11**	**64**	**11**	**5**	**16**	**80**

Table 5.2. Number of studies included in this review, by substrate type. (PR = peer-reviewed; NPR = non-peer-reviewed.)

Substrate	**1990-2002**			**Pre-1990**			**Total**
	PR	NPR	Total	PR	NPR	Total	
Mud	10	2	12	0	0	0	12
Sand	25	4	29	3	2	5	34
Gravel/Rock	4	0	4	1	0	1	5
Biogenic	3	2	5	1	1	2	7
Mixed Substrate	11	3	14	6	2	8	22
Total	**53**	**11**	**64**	**11**	**7**	**18**	**80**

Table 5.3. Number of studies included in this review, by geographical area. (PR = peer-reviewed; NPR = non-peer-reviewed.)

Gear	**Northeast Region**	**Other North America**	**Europe and Scandinavia**	**Australia and New Zealand**	**Total**
Bottom Otter Trawl	7	10	8	5	30
New Bedford Scallop Dredge	4	2	0	0	6
Toothed Scallop Dredge	0	2	8	6	16
Hydraulic Clam Dredge	2	5	5	0	12
Other Dredge	3	0	1	0	4
Multiple Gears	5	0	5	1	11
Lobster Pot	0	0	1	0	1
Total	**21**	**19**	**28**	**12**	**80**

Table 5.4. Effects of otter trawls on mud substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	Ball *et al.* 2000	Irish Sea	75 m	Sandy silt	Reduced infaunal and epifaunal richness, diversity, number of species, and individuals in fishing ground compared to wreck site, but no obvious effects on macrofauna 24 hr after trawling.		Experimental trawling in heavily fished prawn fishing ground, unfished area near a shipwreck used as control.
2	**Brylinsky *et al.* 1994**	Bay of Fundy, Nova Scotia, Canada	Intertidal	Silt and coarse sand overlain with silt	Door tracks in sediment, rollers compressed sediment; S decrease in nematodes and benthic diatoms in door tracks, no effects on larger infaunal organisms (mostly polychaetes).	Furrows visible 2-7 mo; nematodes recovered in 1-1.5 mo, diatoms in about 1-3 mo.	Four trawling experiments (repeated tows during a single day) at two locations in a trawled area, effects evaluated for 1.5-4 mo.
3	DeAlteris *et al.* 1999	Narragansett Bay, Rhode Island, USA	14 m	Mud	Doors produced tracks 5-10 cm deep and adjacent berm 10-20 cm high.	No changes in hand dug trenches for >60 days.	Diver observations.
4	**Drabsch *et al.* 2001**	Gulf of St. Vincent, South Australia	20 m	Fine silt	Trawl door tracks, smoothing of topographic features; S decrease in total infaunal abundance and one group of polychaetes, damaged epifauna.		Experimental trawling (two tows per unit of area in 1 day) in area with no trawling for 15 yrs (one site); effects evaluated after 1 wk.
5	**Frid *et al.* 1999**	Northeast England (North Sea)	80 m	Silt-clay	S increase in total number of individuals in taxa predicted to increase at high fishing effort and number of errant polychaetes; no effect of increasing effort on total number of individuals expected to decrease, but S decline in sea urchins.		Related changes in benthic fauna in a heavily trawled location to low, high, and moderate fishing activity and to changes in phytoplankton production over 27 yr.
6	**Hansson *et al.* 2000**	Fjord on the west coast of Sweden	75-90 m	Clay	Abundance of 61% infaunal species negatively affected and S reductions in abundance of brittle stars during last 5 mo of disturbance period; S reductions in total biomass at 3 of 3 trawled sites and 1 of 3 control sites, and in number of individuals at 2 of 3 trawled sites and 1 of 3 control sites; abundance of polychaetes, amphipods, and mollusks not affected.		Experimental trawling for 1 yr (two tows per wk, twenty-four tows per unit of area) in area closed to fishing for 6 yr (three treatment and three control sites); effects evaluated during last 5 mo of experiment.
7	**Mayer *et al.* 1991**	Maine coast, USA	20 m	Mud	Dispersal of fine surface sediment; doors made furrows several cm deep; some planing of surface features, but no plowing of bottom or burial of surface sediments.		Experimental trawling (single tow); examined immediate effects on sediment composition and food value to sediment depth of 18 cm.
8	**Pilskaln *et al.* 1998**	Gulf of Maine, USA	250 m	Mud	Greater abundance of suspended infaunal polychaetes in more heavily trawled area.		Deployed sediment traps in fishing grounds 25-35 m above substrate.
9	**Sanchez *et al.* 2000**	Coast of Spain, Mediterranean Sea	30-40 m	Mud	Door tracks in sediment; no change in number of infaunal individuals or taxa, or in abundance of individual taxa; no changes in community structure.	Door tracks still clearly visible after 150 hr.	Experimental trawling in trawled area at two sites swept once and twice in a single day; effects evaluated after 24, 72, 102, and 150 hr.

Table 5.4 (cont.). Effects of otter trawls on mud substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
10	**Sparks-McConkey and Watling 2001**	Penobscot Bay, Maine, USA	60 m	Mud	S decline in porosity, increased food value, and increased chlorophyll production of surface sediments; S reductions in number of infaunal individuals and species, species diversity, and abundances of 6 polychaete and bivalve species, S increase in nemerteans.	All geochemical sediment properties and all but one polychaete/bivalve species recovered within 3.5 mo, nemerteans still more abundant after 5 mo.	Experimental trawling (four tows in 1 day) in untrawled area; pre-trawl sampling of sediments and infauna for a year; recovery monitored for 5 mo.
11	**Tuck *et al.* 1998**	West coast of Scotland	30-35 m	Fine silt	Tracks in sediment, increased bottom roughness; no effect on sediment characteristics; S increase in number of infaunal species at end of 16 mo disturbance period and during 18 mo recovery period; no change in biomass or number of individuals at end of recovery period; S increase in polychaetes, S decrease in bivalves; mixed results of analyses of community structure, S reduction in diversity during first 22 mo.	Door tracks still evident after 18 mo; bottom roughness recovered after 6 mo; nearly complete recovery of infaunal community within 12 mo, complete after 18 mo.	Experimental trawling for 1 day/mo (one and a half tows per unit of area) for 16 mo in area closed to fishing for >25 years; recovery monitored after 6, 12, and 18 mo.

Table 5.5. Effects of otter trawls on sand substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	Ball *et al*. 2000	Irish Sea	35 m	Muddy sand	Lower number of infaunal and epifaunal species and individuals, and lower species diversity and richness, compared to wreck site.		Experimental trawling in a heavily fished fishing ground; unfished area near a shipwreck used as control.
2	Bergman and van Santbrink 2000	Southern North Sea (Dutch coast)	<30-50 m	Silty sand and sand	High (20-50%) mortalities for six sedentary and/or immobile megafaunal (>1 cm) species, <20% for 10 others, from a single pass of the trawl; S effects on 11 of 54 occasions.		Experimental trawling (one- and-a-half tows per unit of area) in commercially trawled area; effects assessed after 24-48 hr.
3	**DeAlteris *et al.* 1999**	Narragansett Bay, Rhode Island, USA	7 m	Sand	No tracks found.	Hand dug trenches not visible after 1-4 days.	Diver observations.
4	**Drabsch *et al.* 2001**	Gulf of St. Vincent, South Australia	20 m	Coarse sand with shells	Trawl door tracks; smoothing of topographic features; removal of, and damage to epifauna; no S effects on total infaunal abundance; S reduction in density for one order of crustaceans 1 wk of trawling.		Experimental trawling (two tows per unit area) in area with no trawling for 15 yr; effects assessed after 1 wk (site one) and 3 mo (site two).
5	**Frid *et al.* 1999**	Northeast England (North Sea)	55 m	Sand	Total abundance of benthic macrofauna increased as phytoplankton abundance increased; no correlation with fishing effort.		Related changes in benthic fauna in a lightly trawled location to low, high, and moderate fishing activity, and to changes in phytoplankton production over 27 yr.
6	**Gibbs *et al.* 1980**	Botany Bay, New South Wales, Australia	Shallow estuary	Sand with 0-30% silt-clay	Sediment plume; no consistent effects on benthic community diversity; very little disturbance of seafloor.		Sampling before, immediately after, and 6 mo after 1 wk of experimental trawling in a fished location; control area located 200 km away.
7	**Gilkinson *et al.* 1998**	Test tank to simulate Grand Banks of Newfoundland		Sand	Trawl door created 5.5-cm berm adjacent to 2-cm furrow; bivalves displaced, but little damage.		Observed effects of commercial otter door model in test tank.
8	**Hall *et al.* 1993**	North Sea	80 m	Coarse sand	Abundance of infauna related to changes in sediment type and organic content, not distance from shipwreck.		Sampled infauna at increasing distance from a shipwreck (proxy for increasing fishing effort).
9	**McConnaughey et al. 2000**	Eastern Bering Sea, Alaska	44-52 m	Sand with ripples	Reduced abundance (S for sponges and anemones); more patchy distribution; S decrease in species diversity of sedentary epifauna; mixed responses of motile taxa and bivalves.		Compared abundance of epifauna caught in small-mesh trawl inside and outside an area closed to trawling for almost 40 yr.

Table 5.5 (cont.). Effects of otter trawls on sand substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
10	**Moran and Stephenson 2000**	Northwest Australia	50-55 m	Not given, presumed to be sand	Single tow reduced density of macrobenthos (>20 cm) by 15%, 4 tows by 50%.		Video surveys before and after four experimental trawling events (one tow per unit area) at 2-day intervals in unexploited area.
11	**Sainsbury et al. 1997**	Northwest Australia	<200 m	Calcareous sands	Decreased abundance of benthic organisms and fish associated with large epifauna; removal of attached epifauna (single tow removed 89% of sponges >15 cm).	Increased catch rates of fish associated with large epifauna and small (<25 cm) benthos within 5 yr; recovery of large epifauna takes >5 yr.	Compared historical survey data (before and after fishing started) to data collected in area that remained open to commercial trawlers and to area closed for 5 yr.
12	**Kenchington *et al.* 2001**	Grand Banks, Newfoundland	120-146 m	Fine to medium grain sand	S short-term reductions in total abundance and abundance of 15 infaunal and epifaunal taxa (mostly polychaetes) in only 1 of 3 yr; no short-term effects on biomass or taxonomic diversity; no long-term effects.	Benthic organisms that were reduced in abundance in 1994 had recovered a yr later.	Experimental trawling (3-6 tows per unit of area) in closed area 1, 2, and 3 yrs after closure; lightly exploited for >10 yrs; effects evaluated within several hours or days after trawling and after 1 yr.
13	**Prena et al. 1999**	Grand Banks, Newfoundland	120-146 m	Fine to medium grain sand	24% average decrease in epibenthic biomass; S reductions in total and mean individual epifaunal biomass, and biomass of five of nine dominant species; damage to echinoderms.		Experimental trawling (3-6 tows per unit of area) in closed area 1, 2 and 3 yr after closure, lightly exploited for >10 yr.
14	**Schwinghamer et al. 1998**	Grand Banks, Newfoundland	120-146 m	Fine and medium grain sand	Tracks in sediment; increased bottom roughness; sediment resuspension and dispersal; smoothing of seafloor and removal of flocculated organic material; organisms and shells organized into linear features.	Tracks last up to 1 yr; recovery of seafloor topography within 1 yr.	Experimental trawling (3-6 tows per unit area) in closed area 1, 2 and 3 yr after closure, lightly exploited for >10 yr.

Table 5.6. Effects of otter trawls on gravel/rock substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	**Auster *et al.* 1996**	Jeffreys Bank, Gulf of Maine	94 m	Gravel/boulder with thin mud veneer.	Gravel base exposed; boulders moved; reduced abundance of erect sponges and associated epifaunal species; changes attributed to trawling.		Submersible and video observations in same location in 1987 and 1993.
2	**Freese *et al.* 1999**	Gulf of Alaska	206-274 m	93% pebble, 5% cobble, 2% boulder.	Boulders displaced; groundgear left furrows 1-8 cm deep in less compact sediment; layer of silt removed in more compact sediment; S reductions in abundance of sponges, anemones, and sea whips; damage to sponges, sea whips and brittle stars.		Video observations from a submersible 2-5 hr after single trawl tows in area exposed to little or no commercial trawling for about 20 yr.
3	**Dolah *et al.* 1987**	Georgia, SE U.S. coast	20 m	Smooth rock with thin layer of sand and attached epifauna.	Damage to sponges and corals, mostly to sponges; S reductions in density of undamaged barrel sponges in high-density transects; no S effects on densities of vase sponges, finger sponges, or stony corals.	Full recovery of damaged organisms and density within 12 mo.	Experimental study using diver counts of large sponges and corals before, immediately after, and 12 mo after, a single tow of a "roller" trawl in an unexploited area.

Table 5.7. Effects of otter trawls on mixed substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	DFO 1993	Bras d'Or Lakes, Nova Scotia, Canada	10–500 m	Mud, sand, gravel, and boulders	Trawl doors left parallel marks (furrows and berms), fainter marks from footgear, primarily in mud.		Sidescan sonar survey after area was closed to mobile gear for 1 yr.
2	**Engel and Kvitek 1998**	California, USA	180 m	Gravel, sand, silt, and clay	S fewer rocks and biogenic mounds, S less flocculent material, and S more exposed sediment and shell fragments in HF area; lower densities of large epibenthic taxa in HF area (S for sea pens, starfish, anemones, and sea slugs); higher densities of nematodes, oligochaetes, brittle stars and one species of polychaete in HF area; no differences between areas for crustaceans, mollusks, or nemerteans.		Used a submersible and grab samples (3 yr) to compare lightly trawled and heavily trawled commercial fishing sites with same sediments and depth.
3	Smith *et al.* 1985	Long Island Sound, New York, USA	Not given	Sand and mud	Tracks in sediment (<5 cm in sand, 5-15 cm in mud); attraction of predators; suspension of epibenthic organisms.	Tracks "naturalized" by tidal currents.	Video and diver observations.

Table 5.8. Effects of New Bedford-style scallop dredges on sand substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	**Auster *et al.* 1996**	Stellwagen Bank, Gulf of Maine, USA	20-55 m	Coarse sand	Smoothing of sand ripples and low sand waves; dispersal of shell deposits in wave troughs.		Examined gear tracks in sidescan sonar images.
2	**Langton and Robinson 1990**	Fippennies Ledge, Gulf of Maine, USA	80-100 m	Gravelly sand with some gravel, shell hash, and small rocks	Coarser substrate; disruption of amphipod tube mats; piles of small rocks and scallop shells dropped from surface; S reductions in densities of tube dwelling polychaete and burrowing anemone.		Submersible observations made 1 yr apart, before and after commercial dredging of area.
3	**Watling *et al.* 2001**	Damariscotta River, Maine, USA	15 m	Silty sand	Loss of fine surficial sediments; lowered food quality of sediment; reduced abundance of some taxa; no changes in number of taxa; S reductions in total number of individuals 4 mo after dredging.	No recovery of fine sediments, full recovery of benthic fauna and food value within 6 mo.	Experimental study (23 tows in 1 day); effects on macrofauna (mostly infauna) evaluated 1 day and 4 and 6 mo after dredging in an unexploited area.

Table 5.9. Effects of New Bedford-style scallop dredges on mixed substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	**Caddy 1968**	Northumberland Strait, Gulf of St. Lawrence, Canada	20 m	Mud and sand	Drag tracks (3 cm deep) produced by skids; smooth ridges between them produced by rings in drag belly; dislodged shells in dredge tracks.		Diver observations of physical effects of two tows.
2	**Caddy 1973**	Chaleur Bay, Gulf of St. Lawrence, Canada	40-50 m	Gravel over sand, with occasional boulders	Suspended sediment; flat track, marks left by skids, rings, and tow bar; gravel fragments less frequent (many overturned); rocks dislodged or plowed along bottom.		Submersible observations of tow tracks made <1 hr after single dredge tows.
3	**Mayer *et al.* 1991**	Coastal Gulf of Maine, USA	8 m	Mud, sand, and shell hash	Lowered sediment surface by 2 cm, injected organic matter and finer sediment into lower 5-9 cm; increased mean grain size in upper 5 cm; disruption of surface diatom mat; increased microbial biomass at sediment surface.		Experimental study, compared dredged and undredged sites before and 1day after a single dredge tow.

Table 5.10. Effects of toothed scallop dredges on sand substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1,2	**Black and Parry 1994, 1999**	Port Phillip Bay, SE Australia (three sites)	15 m	Sand (7-30% silt-clay)	Sediment plume; maximum depth of disturbance 4-6 cm into bottom; cutterbar trims off high regions of seafloor.	Turbidity returned to normal storm levels within 9 min.	Experimental dredging for 2-4 days (two to four tows per unit area) in three areas with no commercial dredging for 4 yrs.
3,4	**Currie and Parry 1996, 1999b**	Port Phillip Bay, SE Australia (St. Leonards site)	15 m	Fine/very fine sand	Flattening of low-relief biogenic mounds; depressions filled in; parallel tracks produced by skids; S fewer species after 3 wks; most species 20-30% less abundant 3.5 mo after dredging; S reduced abundance of 6 of 10 most common infaunal species within first 3.5 mo (S increase for one species); no effect on total number of individuals; surface-dwelling organisms released into water column right away, burrowing organisms as dredging continued; increased abundance of more mobile, opportunistic species within first 3.5 mo.	Mounds reformed after 6 mo; tracks visible after 1 mo, but not after 6 mo; most species recovered within 8 mo, but some had not after 14 mo.	Experimental dredging for 3 days (2 tows per unit of area) in an area with no commercial dredging for 4 yr; recovery of infauna monitored at 5 intervals during 14 mo; seafloor changes at 8 days and at 6 and 11 mo.
4	**Currie and Parry 1999b**	Port Phillip Bay, SE Australia (Dromana site)	15 m	Medium-fine sand	Removal of small, parallel sand ripples; S reductions in abundance of three of ten most common infaunal species within 2 days.	Ripples reformed after 5 days following storm.	Experimental dredging for 2 consecutive days (2 tows per unit of area) in an area with no commercial dredging for 4 yr; effects on infauna evaluated after 2 days, seafloor changes after 5 days.
		Port Phillip Bay, SE Australia (Portarlington site)	15 m	Muddy sand with shell fragments	Flattening of biogenic mounds; S reductions in abundance of 2 of 10 most common infaunal species within 1 day.	Mounds reformed 7 months after dredging, but were still smaller than in undredged area.	Experimental dredging for 4 days (four tows per unit area) in an area (Portarlington) with no commercial dredging for 4 yrs; effects on infauna evaluated after 1 day, seafloor changes after 7 mo.
5	Butcher *et al.* 1981	Jervis Bay, New South Wales, Australia	>13 m	Sand	Sediment plume up to 5 m off bottom, flattening of sand ridges.	Sediment plume settled out within 15 min.	Diver observations.
6	**Eleftheriou and Robertson 1992**	Firemore Bay, Loch Ewe, Scotland	5 m	Well-sorted sand	Dredge eliminated natural bottom features; teeth created 3-4 cm deep furrows; no effect on sediment characteristics; damage or mortality of larger epifauna, razor clams, and sand lance, attraction of predators; increase in some species of small infaunal crustaceans; initial reduction in polychaetes followed by increase; no effect on taxa adapted to dynamic environment (*e.g.*, amphipods, bivalves).	Grooves and furrows no longer visible shortly after dredging, duration depended on wave and current action.	Evaluation of incremental effects of dredging (25 tows in 1 wk) at a single site (no control).
7	**Thrush *et al.* 1995**	Mercury Bay, New Zealand	24 m	Coarse sand	Breaking down of surface sediment features; grooves 2-3 cm deep created by teeth; S declines in abundance of 6 of 13 most common taxa at unexploited site, and 4 of 13 most common taxa at exploited site; S reductions in total number of individuals and taxa at both sites.	General recovery of macrobenthic abundance at previously exploited site after 3 mo, but not at unexploited site.	Experimental dredging (5 parallel tows in 1 day) at a previously exploited and an unexploited site with different benthic communities; biological effects evaluated within 2 hr and 3 mo after dredging.

Table 5.11. Effects of toothed scallop dredges on biogenic substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.

Reference	Location	Depth	Sediment	Effects	Recovery	Approach
Hall-Spencer and Moore 2000a	Clyde Sea, Scotland	10-15 m	Live bottom (maerl) with some cobble and boulders	Disturbance of seafloor to 10 cm; overturned boulders; suspended sediment; erasure of bottom features and burial of living maerl in dredge tracks; most megafauna in top 10 cm either caught in dredge or left damaged in dredge track (large, fragile organisms more vulnerable); rapid aggregation of predatory species in track.	Dredge tracks remained visible for 0.5-2.5 yrs; some recovery rates of large epibenthic species variable, some recovering quickly, but others at unexploited site had not recovered 4 yr after dredging; macrobenthic community at previously exploited site recovered within 2 yr.	Observations of the effects of single dredge tows at a previously dredged and undredged site; immediate effects and recovery (after 4 yr) evaluated by divers using video cameras.

Table 5.12. Effects of toothed scallop dredges on mixed substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	**Bradshaw *et al.* 2002**	Isle of Man, Irish Sea	Not given	Sand and gravel	More vulnerable taxa less abundant in recent samples, less vulnerable taxa more abundant; faunal differences and proportion of species "lost" between time periods increased significantly as number of years since fishing began increased; no effect of increases in total effort; no clear evidence over all sites for reduced species diversity.		Recent benthic sample data collected at 7 sites exposed to varying amounts of fishing effort compared with data collected 50-60 yr ago, when scallop fishing was very limited.
2,3	**Bradshaw *et al.* 2000, 2001**	Isle of Man, Irish Sea	25-40 m	Gravel, sand, and mud	6 mo of experimental dredging in closed area altered community structure, no trends in abundance of individual species; no S effects on number of species, but community heterogeneity was reduced; encrusting species were more abundant and upright species less abundant in dredged plots than in control plots after 3 yr.	S increases in abundance of several epifaunal species in undredged portion of closed area 5-9 yr after closure.	Continuous experimental dredging (10 tows every 2 mo for 3 yr) in an area closed to commercial fishing for 6 yr; semi-annual grab sampling inside and outside closed area, and biannual diver surveys of epibenthic animals in closed area.
4	**Caddy 1973**	Chaleur Bay, Gulf of St. Lawrence, Canada	40-50 m	Gravel over sand, with occasional cobble and boulders.	Shallow, flat tracks; tooth marks in sand; boulders dislodged and small rocks "plowed" by dredge; spoil ridges at edges of track.		Submersible observations and photographs of tow tracks made <1 hr after dredging.
5	DFO 1993	Bras d'Or Lakes, Nova Scotia, Canada	10-500 m	Gravel and mud	Furrows left by dredge teeth; berms at outer edges of dredge track.		Sidescan sonar survey 1 yr after area was closed to mobile gear.
6	**Kaiser, Hill *et al.* 1996**	Irish Sea, southwest of Isle of Man	Not given	Not given, assume mixed substrates	Reduced abundance of most large epibenthic species; same effects on community structure as beam trawls, but lower bycatch.		Experimental study of effects of dredging (10 tows) and beam trawling on large epifauna; sampling with small-mesh (40mm) beam trawl both before and 24 hr after fishing.
7	**Kaiser, Ramsay *et al.* 2000**	Irish Sea	Not given	Coarse sand and gravel	S more epifaunal organisms in areas exposed to high fishing effort, no effects on infauna or on diversity or number of epifaunal species; shift from communities dominated by more larger-bodied to fewer smaller-bodied organisms.		Compared benthic communities in areas exposed to 10 yr of low and high fishing effort.
8	**Veale *et al.* 2000**	Irish Sea	20-67 m	Coarse sand or gravel, often overlain with pebbles, cobbles and dead shell.	S decreases in epibenthic species diversity and total number of species and individuals with increasing fishing effort; total abundance, biomass, and production and production of most taxa S decreased with increasing effort.		Compared dredge bycatch from fishing grounds exposed to varying amounts of fishing effort during previous 60 yr.

Table 5.13. Effects of other nonhydraulic dredges on biogenic substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	**Fonseca *et al.* 1984**	Beaufort, North Carolina, USA	Very shallow, subtidal	Silty sand with eelgrass	S reduction in number of eelgrass shoots and leaf biomass with increased dredging intensity at each of two sites, one hard bottom and one soft bottom.		Experimental study with lightweight toothless dredge; two levels of disturbance.
2	Langan 1998	Piscataqua River, Maine-NH, USA	Not given	Oyster bed	No detectable differences in the number of benthic invertebrates, species richness, or diversity; turbidity of near-bottom water doubled 10 m behind dredge.	Turbidity returned to normal 110 m behind dredge.	One-time sampling of benthic invertebrates in dredged and undredged sides of the river; turbidity measured during a single dredge tow.
3	**Lenihan and Peterson 1998**	Neuse River, North Carolina, USA	3 and 6 m	Oyster reefs	Dredging lowered mean height of 1 m reefs by ~30%.		Experimental study where 4 of 8 oyster-shell reefs were dredged for 1 wk to remove all market-sized oysters; sampled 3 days before and 2 days after dredging..
4	**Riemann and Hoffmann 1991**	Limfjord, Denmark	Mean depth 7 m, maximum 15 m	Not given (presumed mussel bed)	S increase in suspended particulate matter; S reduction in oxygen immediately after dredging, especially near the bottom.	Turbidity returned to normal within 1 hr.	Water column sampling of physical and chemical attributes with a 2-m mussel dredge before and after dredging (maximum 1 hr) at an experimental and a control site.

Table 5.14. Effects of hydraulic clam dredges on mud substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

Reference	Location	Depth	Sediment	Effects	Recovery	Approach
Hall and Harding 1997	Auchencairn Bay, Solway Firth, Scotland	Intertidal	Mud	Dredge tracks; S reductions in number of infaunal species and individuals persisted for 4 wk; 3 of 5 dominant species reduced in abundance throughout experiment (8 wk).	Nearly complete recovery of infaunal community after 8 wk, but some effects remained; dredge tracks not seen after first day.	Experimental study of the effects of single suction dredge passes in a commercially harvested area; recovery monitored 1, 4, and 8 wk after dredging.

Table 5.15. Effects of hydraulic clam dredges on sand substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	**Hall *et al.* (1990)**	Loch Gairloch, Scotland	7 m	Fine sand	Shallow trenches (25 cm deep) and large holes; sediment "almost fluidized"; median sediment grain size S higher in fished area; S reductions in numbers of infaunal organisms; no effect on abundance of individual species; some mortality (not assessed) of large polychaetes and crustaceans retained on conveyor belt or returned to sea surface.	Complete recovery of physical features and benthic community after 40 days; filling of trenches and holes accelerated by winter storms.	Experimental study in unexploited area to evaluate effects of simulated commercial escalator dredging activity; recovery evaluated after 40 days.
2	**Kaiser, Edwards *et al.* (1996b)**	SE England	Intertidal	Muddy sand	Resuspension and loss of fine sand from sediment surface; S reductions in total number of infaunal species and individuals.	Complete recovery of sediments and benthic community within 7 mo.	Experimental study; effects of suction dredging for cultivated clams evaluated after 3 hr and 7 mo.
3	**MacKenzie, 1982**	East of Cape May, New Jersey, USA	37 m	Very fine to medium sand	Resorting of sediments (coarser at bottom of dredge track); no effect on number of infaunal individuals or species, nor on species composition.		Comparison of actively fished, recently fished, and never fished areas on the continental shelf; dredging conducted with hydraulic cage dredges.
4	Maier *et al.* 1995	South Carolina, USA	Tidal creeks	Muddy sand	Turbidity plumes; no S effects on abundance of dominant infaunal taxa or total number of individuals.	Turbidity plumes persisted for a few hours.	Before and after study of commercial escalator dredging effects in four tidal creeks. Turbidity monitored 2 wk before, during, and 2 wk after dredging at one location, and during and immediately after dredging at another. Infaunal samples collected 3 wk before and 2 wk after dredging in a creek that had been commercially dredged 5 yr prior to the study and in a creek that had never been dredged before.
5	Medcof and Caddy 1971	Southern Nova Scotia, Canada	7-12 m	Sand and sand-mud	Smooth tracks with steep walls, 20 cm deep; sediment cloud.	Sediment plume lasted 1 min; dredge tracks still clearly visible after 2-3 days.	SCUBA and submersible observations of the effects of individual tows with a cage dredge.
6	**Meyer *et al.* 1981**	Long Island, New York, USA	11 m	Fine to medium sand, covered by silt layer	>20-cm-deep trench; mounds on either side of trench; silt cloud, attraction of predators.	Trench nearly indistinct, and predator abundance normal, after 24 hr; silt settled in 4 min.	SCUBA observations during and following a single tow with a cage dredge in a closed area; effects evaluated after 24 hr.
7	**Pranovi and Giovanardi 1994**	Venice Lagoon, Adriatic Sea, Italy	1.5-2 m	Sand	8-10 cm deep trench; S decrease in total abundance, biomass, and diversity of benthic macrofauna in fishing ground; no S effects outside fishing ground.	After 2 mo, dredge tracks still visible; densities (especially of small species and epibenthic species) in fishing ground recovered, biomass did not.	Experimental dredging with a cage dredge (single tows) in previously dredged and undredged areas in coastal lagoon; recovery monitored every 3 wk for 2 mo.
8	**Tuck *et al.* 2000**	Sound of Ronay, Outer Hebrides, Scotland	2-5 m	Medium to fine sand	Steep-sided trenches (30 cm deep); sediments fluidized up to 30 cm; S decrease in number of infaunal species and individuals within a day of dredging; S decrease in proportion of polychaetes and S increase in proportion of amphipods 5 days after dredging; S increases in abundance of some species and S decreases in abundance of other species.	Trenches no longer visible but sand still fluidized after 11 wk; species diversity and total abundance recovered within 5 days; proportions of polychaetes and amphipods, and abundances of individual species, returned to pre-dredge levels after 11 wk.	Experimental dredging with cage dredge (individual tows at 6 sites) in area closed to commercial dredging, effects evaluated 1 day, 5 days, and 11 wk after dredging.

Table 5.16. Effects of hydraulic clam dredges on mixed substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

Reference	Location	Depth	Sediment	Effects	Recovery	Approach
Murawski and Serchuk 1989	Mid-Atlantic Bight, USA	Not given	Sand, mud, and coarse gravel	Trench cut; temporary increase in turbidity, disruption of benthic organisms in dredge path; attraction of predators.	Trenches filled quickly in coarse gravel, but took several days in fine sediments.	Submersible observations following hydraulic cage dredge tows.

Table 5.17. Effects of hydraulic clam dredges on biogenic substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	Godcharles 1971	Tampa Bay, Florida, USA	Not given	Open sand, sand with seagrass, and sand with algae	Water jets penetrate to 45 cm, create trenches 15-45 cm deep; uprooted vegetation; decreased proportion of fine sediment in some dredge tracks.	Trenches lasted longer (up to 86 days) in grass beds, filled in immediately in open sand; most sediments hardened within 1 mo, some spots still soft 500 days after dredging; sediment composition returned to normal after 1 yr, but seagrass still had not recovered; new algal growth after 86 days, complete after a year.	SCUBA observations and sediment sampling before and after experimental escalator dredging in undisturbed sand, seagrass, and algae bottom habitats; recovery monitored for 16+ mo.
2	Orth *et al.* 1998	Chincoteague Bay, Virginia, USA	Not given	Seagrass beds	Circular “scars” left by dredges; loss of grass and large holes in dredge track.	No revegetation 3 yr after disturbance; recovery estimated to take at least 5 yr in lightly disturbed areas, longer in heavily disturbed areas.	Field observations of commercial escalator dredging effects over a 3-yr period.

Table 5.18. Effects of pots and traps on mixed substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

Reference	Location	Depth	Sediment	Effects	Recovery	Approach
Eno *et al.* 2001	Badentarpet Bay, west coast of Scotland	Not given	Soft mud	Bending and smothering of sea pens underneath pots; uprooting of some sea pens when pots are dragged over bottom.	Sea pens recover from effects of pot dragging within 24-72 hr, re-assume upright posture within 72-144 hr of pot removal, and re-root as long as “foot” remains in contact with bottom.	Diver observations and experiments to assess effects on, and recovery of, sea pens following dragging, uprooting, and smothering by lobster pots left on bottom for 24 or 48 hr.
Eno *et al.* 2001	Greenale Pt., Wales, and Lyme Bay, southwest England	14-20 m	Varied – from bedrock to boulders to coarse sediment – and interspersed.	Soft corals bent by pots, but spring back; pots leave tracks in bottom when hauled; increased abundance of 4 species of sponges, an ascidian, and a bryozoan in experimental plots after 4 wk, no changes in abundance of other epibenthic species.		Diver observations and experiments to assess effects of 4 wk of simulated commercial pot fishing on attached epifauna at two study sites.

Table 5.19. Effects of multiple gears on sand substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	Almeida *et al.* 2000	Eastern Georges Bank, USA	<50->90 m	Sandy	Microhabitat associated with two species of sponges more abundant inside closed area; no S differences for six other microhabitat types.		Analysis of still photos and video imagery inside and outside area closed to trawls, dredges, longlines, and gill nets 4.5 yr after it was closed.
2	**Kaiser, Spencer *et al.* 2000**	South Devon coast, England	15-70 m	Fine, medium, and coarse sand	No S effect of high fishing effort on numbers of infaunal or epifaunal species or individuals; in high-effort areas there were: 1) a lower reduced abundance of larger, less mobile, and emergent epifauna; 2) a higher abundance of more epifauna; and 3) fewer high-biomass species of epifauna and infauna; infauna in deeper coarse-medium sand habitat most affected by fishing.		Compared benthic communities in areas of high, medium, and low fishing effort by fixed and mobile gears; each area with three sites (shallow, fine sand, deep medium sand, and deep coarse-medium sand).

Table 5.20. Effects of multiple gears on gravel/rock substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1,2	**Collie *et al.* 1997, 2000**	Northern edge, eastern Georges Bank, U.S. and Canada	42-90 m	Pebble-cobble "pavement" with some overlying sand	S higher total densities, biomass, and species diversity in undisturbed sites, but also in deeper water (*i.e.*, effects of fishing could not be distinguished from depth effects); 6 species abundant at U sites, rare or absent at D sites; percent cover of tube-dwelling polychaetes, hydroids, and bryozoans S higher in deepwater, but no disturbance effect.		Benthic sampling, video, and still photos in 2 shallow (42-47 m) and 4 deep (80-90 m) sites disturbed (D) and undisturbed (U) by trawls and scallop dredges.

Table 5.21. Effects of multiple gears on mixed substrate habitat: summary of published studies. (S = statistically significant; citations in bold print are peer-reviewed publications.)

No.	Reference	Location	Depth	Sediment	Effects	Recovery	Approach
1	**Auster *et al.* 1996**	Coastal Gulf of Maine, USA	30-40 m	Sand-shell	S more sea cucumbers and bottom depressions inside closed area.		ROV and video observations inside and outside an area closed to mobile gear for 10 yr.
1	**Auster *et al.* 1996**	Coastal Gulf of Maine, USA	30-40 m	Cobble-shell	S more emergent epifauna inside closed area.		ROV and video observations inside and outside an area closed to mobile gear for 10 yr.
1	**Auster *et al.* 1996**	Stellwagen Bank, Gulf of Maine, USA	20-55 m	Sand with gravel and shell	Disturbed sand ripples and sand waves; dispersed shell deposits; absence of epifauna and reduced microalgal cover in trawl and dredge tracks.		Sidescan sonar survey and ROV observations.
2,3,4	**Reise 1982; Riesen and Reise 1982; Reise and Schubert 1987**	Wadden Sea, The Netherlands	<23 m	Mud, coarse sand, and some pebbles	Loss of oyster and *Sabellaria* reefs; decrease in abundance of 28 species (mollusks and amphipods); 23 “new” species (many of them polychaetes).		Compared benthic surveys conducted during time period when oysters were overexploited and trawl fishery developed on *Sabellaria* reefs (1869-1986).
5	**Thrush *et al.* 1998**	Hauraki Gulf, New Zealand	17-35 m	Mud and sand	S reductions in density of large epifauna, echinoderms, and long-lived surface dwellers; S increases in density of small, opportunistic species; some predictions contra-indicated by results; 15-20% variability in macrofaunal community composition attributed to fishing pressure.		Tested 10 predictions of the effects of increasing fishing intensity on benthic community structure by comparing samples and video images from 18 stations exposed to varying degrees of commercial fishing pressure by bottom trawls, Danish seines, and scallop dredges.
6	Valentine and Lough 1991	Eastern Georges Bank		Sand and gravel	Trawl and dredge tracks in sediments; sparse epifauna, gravel mounds, and smoother bottom in disturbed areas.		Sidescan sonar and submersible observations of area presumed to be disturbed by trawls and scallop dredges.

6. VULNERABILITY OF ESSENTIAL FISH HABITAT TO BOTTOM-TENDING FISHING GEARS

INFORMATION NEEDS AND SOURCES

This section evaluates potential adverse effects of bottom-tending fishing gears on benthic EFH in the Northeast Region. These gears are regulated by the MSA and the EFH final rule, 50 *CFR* 600.815(a)(2)(i). The EFH final rule recommends that the evaluation consider the effects of each fishing activity on each type of habitat found within the EFH for any affected species and life stage. The EFH rule further recommends that the following information be reviewed in making an evaluation: 1) intensity, extent, and frequency of any adverse effects on EFH; 2) the types of habitat within EFH that may be adversely affected; 3) habitat functions that may be disturbed; and 4) conclusions regarding whether and how each fishing activity adversely affects EFH.

The EFH final rule requires that EFH designations be based on the best available information. This information may fall into four categories that range from the least specific (Level 1) to the most specific (Level 4). These categories are defined as follows:

Level 1: Presence/absence data are available to describe the distribution of a species (or life history stage) in relation to potential habitats for portions of its range.

Level 2: Quantitative data (*i.e.*, density or relative abundance) are available for the habitats occupied by a species or life history stage.

Level 3: Data are available on habitat-related growth, reproduction, and/or survival by life history stage.

Level 4: Data are available that directly relate the production rates of a species or life history stage to habitat type, quantity, and location.

Existing EFH designations in the Northeast Region are based primarily on Level 2 information. This level of information is inadequate for making definitive determinations of the consequences of fishing-related habitat alterations on EFH for any species or life stage in the region because the habitat alterations caused by fishing cannot be linked to any known effect on species productivity. Therefore, this section of the document qualitatively evaluates the vulnerability of benthic EFH for each species and life history stage in the region to the effects of bottom-tending fishing gear. Vulnerability is defined as the likelihood that the functional value of benthic EFH would be adversely affected by fishing. Further, given the limited nature of the information available for this qualitative evaluation, emphasis was placed on the identification of potential adverse effects of fishing on benthic EFH.

Information used to perform these evaluations included: 1) the EFH designations adopted by the Mid-Atlantic, New England, and South Atlantic Fishery Management Councils; 2) the results of a Fishing Gear Effects Workshop convened in October 2001 (NREFHSC 2002); 3) the information provided in this document, including the results of existing scientific studies, and the geographic distribution of fishing gear use in the Northeast Region; and 4) the habitats utilized by each species and life stage as indicated in their EFH designations and as supplemented by other references. In most cases, habitat utilization was determined from the information provided in the EFH Source Documents (*NOAA Technical Memorandum NMFS-NE* Issues 122-152, 163, and 173-179), with additional information from Collette and Klein-MacPhee (2002).

EVALUATION METHODS AND RESULTS

Vulnerability of EFH to bottom-tending fishing gear was ranked as none, low, moderate, or high, based on a matrix analysis of three primary components: 1) benthic life stages of FMP-regulated species; 2) habitat function and sensitivity; and 3) gear usage. The matrix analysis initially ranked each habitat for its susceptibility to disturbance and each gear for its potential adverse effects, and then subsequently combined those two rankings with available information on the habitat usage by species/life stages and the distribution of gear usage, in order to obtain the EFH vulnerability rankings.

These evaluations are summarized in Table 6.1. Note in Table 6.1 that: 1) species and life stages for which EFH vulnerability was “not applicable” are not included; and 2) pots, traps, sink gill nets, and bottom longlines -- to which the EFH of all species and life stages showed “low” vulnerability -- are also not included.

The rationale for these evaluations is outlined by species in Tables 6.2-6.45, and was based on the authors’ following three assumptions. First, the habitat’s value to each species and life stage was characterized to the extent possible based on its function in providing shelter, food, and/or the right conditions for reproduction. For example, if the habitat provided shelter from predators for juvenile or other life stages, gear effects that could reduce shelter were of greater concern than other effects. Second, in cases where a food source was closely associated with the benthos (*e.g.,* infauna), the ability of a species to use alternative food sources (*e.g.,* generalist versus specialist species) was evaluated. Third, since benthic prey populations may also be adversely affected by fishing, gear effects that could reduce the availability of prey for bottom-feeding species or life stages were of greater concern than if the species or life stages were piscivorous.

The information in Tables 6.2-6.45 includes for each life stage the geographical extent of EFH, its depth range, its seasonal occurrence, and a brief EFH description that includes -- for benthic life stages -- substrate characteristics. The information presented in columns 2-5 of these tables is derived from EFH text descriptions and maps that originally appeared in the NEFMC Omnibus EFH Amendment (NEFMC 1998) and several FMPs prepared by the NEFMC and MAFMC. Additional information, where available, is provided at the bottom of each table to explain the rationale that was used in making the gear-specific EFH vulnerability rankings. EFH descriptions of depth, seasonal occurrence, and habitats (columns 3-5 in Tables 6.2-6.45) are not always consistent among life stages of an individual species. Spawning American plaice adults, for example, are described as occurring from March through June, but their eggs are described as occurring from December through June on Georges Bank (Table 6.2). In addition, the information in columns 3-5 in some cases does not completely agree with the information provided in the rationale.

The rest of this section details the methods that were used to perform the evaluations and assign the rankings.

Life Stages

Five life stages were evaluated: eggs, larvae, juveniles, adults, and spawning adults. Adult and spawning adult life stages were in most cases combined for evaluation purposes due to the difficulty in distinguishing between the two. In some cases (*e.g.,* pelagic life stages that are not vulnerable to bottom-tending fishing gear effects), a vulnerability ranking was not applicable.

Habitat Scoring and Ranking

Habitat rank was determined from four criteria that were qualitatively evaluated for each life stage based on existing information. Each evaluation resulted in a score based on predefined scoring criteria.

The first three criteria were related to habitat function, and included shelter, food, and reproduction. The fourth criterion was habitat sensitivity. Scoring of these criteria was determined as follows:

Shelter (scored from 0 to 2): If the life stage is not dependent on bottom habitat to provide shelter, then it was scored a 0. Almost every life stage evaluated has some dependence on the bottom for shelter, so, with the exception of a few egg stages, 0 was seldom selected. If the life stage has some dependence on unstructured or noncomplex habitat for shelter, then it was scored a 1. For example, flatfishes that rely primarily on cryptic coloration for predator avoidance, or on sand waves for refuge from bottom currents, were scored a 1. If the life stage has a strong dependence on complex habitats for shelter, then it was scored a 2. For example, juvenile Atlantic cod and haddock, which rely heavily on structure or complex habitat for predator avoidance, were scored a 2.

Food (scored from 0 to 2): If the life stage is not dependent on benthic prey, then it was scored a 0. For example, eggs were always scored a 0, as were life stages that fed exclusively on plankton. If the life stage utilizes benthic prey for part of its diet, but is not exclusively a benthic feeder, then it was scored a 1. For example, species feeding opportunistically on crabs as well as squid or fish were scored a 1. If the life stage feeds exclusively on benthic organisms and cannot change its mode of feeding, then it was scored a 2.

Reproduction (scored from 0 to 1): Limited knowledge of spawning behavior and habitat usage for many species made this the most difficult category to assess. In the opinion of the authors, the available information was insufficient to evaluate this criterion beyond a simple yes or no, resulting in a scoring of 0 or 1 for this factor. While this two-level scoring instead of three-level scoring may have unavoidably undervalued reproduction for some species in the overall scoring, it was decided that this was better than attempting to make finer distinctions that were unsupportable based on available evidence.

A score of 0 was selected for nonreproductive life stages (larvae and juveniles), and for species that are known to spawn in the water column and have only pelagic early life stages. A score of 1 was selected for species where a known association with the bottom exists for one or more aspects of the reproductive cycle.

Habitat Sensitivity (scored from 0 to 2): This criterion does not evaluate the function of the habitat, but instead accounts for its overall relative sensitivity to disturbance. The type of benthic habitat (defined primarily in terms of depth, energy regime, and substrate) inhabited by each species and life stage was based primarily upon its EFH designation.

If a habitat was not considered sensitive to disturbance, then it was scored a 0. However, a score of 0 was not used for any benthic habitat type. If the habitat was considered to have a low sensitivity to disturbance, then it was scored a 1. For example, habitats that are high-energy environments without structural complexity, or that have rapid recovery rates, were scored a 1 (*e.g.,* high-energy sand environments). If the habitat type was considered highly sensitive to disturbance, then it was scored a 2. For example, habitats that are structurally complex (*e.g.*, those supporting epibenthic communities or those with boulder piles), or that have very slow recovery rates (*e.g.*, low-energy deepwater environments), were scored a 2.

These scores were based on existing conceptual models that show a direct relationship between higher structural complexity of the habitat, longer recovery time, and increased vulnerability to disturbance (NREFHSC 2002; NRC 2002).

Habitat rank was defined as the sum of the scores for the four habitat criteria (shelter + food + reproduction + habitat sensitivity). Another way to characterize the habitat rank is the relative vulnerability of the habitat to non-natural physical disturbance. The habitat ranks ranged from 0 to 7, with 7 being the most vulnerable.

Gear Types, Scoring, and Ranking

Five fishing gear classifications were evaluated: otter trawls, New Bedford-style scallop dredges, hydraulic clam dredges, pots and traps, and sink gill nets and bottom long lines. The pot/trap and net/line gear types were considered to have the least effect of the five gear types evaluated. The panel of experts that met in October 2001 ranked their concerns over effects from fixed bottom-tending gear well below their concerns over the effects from mobile bottom-tending gear (NREFHSC 2002). Based on the limited information available (Eno *et al.* 2001; NREFHSC 2002), the vulnerability of all EFH for all benthic species and life stages to pot and trap usage was considered to be low. Similarly, there is little scientific information that evaluates the effects of sink gill nets and bottom longlines on benthic marine habitats, and none evaluates these effects in the Northeast Region. Consequently, like pots and traps, the vulnerability of all EFH for all benthic species and life stages to sink gill net and bottom longline usage was considered to be low. These rankings should be revisited as more information on gear effects becomes available.

The greatest concern is for the vulnerability of benthic EFH to mobile bottom-tending gears (see Chapters 3 and 4). In the northeastern United States, these gear types include various types of bottom otter trawls, New Bedford-style scallop dredges, and hydraulic clam dredges. Otter trawls are responsible for most of the fisheries landings throughout the Northeast Region, and are used in a variety of substrates, depths, and areas. Scallop dredges are used in sand and gravel substrates. Hydraulic clam dredges are used only in sand, shell, and small gravel within well-defined areas .

Rather than rate the relative effects of these three gear types on EFH, they were treated as having similar effects. The criterion for each gear type was based on the spatial distribution of gear use (scored from 0 to 2) in areas designated as EFH for a given species and life stage. If the gear is not currently used within the EFH area, then it was scored a 0. If the gear is currently used in only a small portion of the EFH area, then it was scored a 1. If the gear is currently used in more than a small portion of the EFH area, then it was scored a 2.

The spatial distribution of fishing activity for each gear was determined from reports of the number of days absent from port, or the days fishing, for individual TMSs of latitude and longitude during 1995-2001 (see Chapter 4). Maps of TMSs designated as EFH are available in NEFMC (1998) and in various fishery management plans developed by the Mid-Atlantic and South Atlantic Fishery Management Councils, and have not been reproduced for this document.

The gear rank assesses the overall effect on EFH from fishing with bottom trawls, scallop dredges, and clam dredges. This gear rank was defined as the product of the habitat rank and the gear distribution score. This relationship was chosen in order to ensure that the EFH vulnerability from gears not used in a particular habitat (*i.e.*, gear distribution = 0) would be 0, or, no effect.

EFH Vulnerability Ranking

Based on natural breaks in the frequency distribution of the gear rankings, the following vulnerability categories were defined:

0 = no vulnerability to the gear. This score could only be attained if the gear was not used in the habitat (gear distribution = 0).

1-6 = low vulnerability to the gear. This score generally occurred where the gear has minimal overlap with EFH (gear distribution = 1) and habitat rank was <7. Additionally, low vulnerability scores occurred in habitats with high gear overlap (gear distribution = 2) and habitat rank was 3.

7-9 = moderate vulnerability to the gear. This score typically occurred where gear overlap with EFH was high (gear distribution = 2) and habitat rank was 4, or, overlap with EFH was low (gear distribution = 1) and habitat rank was 7.

10-14 = high vulnerability to the gear. This score occurred only if the gear overlap with EFH was high (gear distribution = 2) and the habitat rank was 5.

Table 6.1. EFH vulnerability matrix analysis for benthic life stages of federally managed fish and invertebrate species in the Northeast U.S. Shelf Ecosystem

Species and Species Groups[a]	Habitat Criteria Scores				Habitat Rank[f]	Gear Distribution Scores[g]			Gear Rank[h]			EFH Vulnerability Category[i]		
	Shelter[b]	Food[c]	Repro-duction[d]	Habitat Sensitivity[e]		Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge
American Plaice (A)	1	2	1	1	5	2	2	0	10	10	0	High	High	None
American Plaice (J)	1	2	0	1	4	2	2	0	8	8	0	Mod	Mod	None
Atlantic Cod (A)	1	1	0	2	4	2	2	1	8	8	4	Mod	Mod	Low
Atlantic Cod (J)	2	1	0	2	5	2	2	0	10	10	0	High	High	None
Atlantic Halibut (A)	1	1	1	1	4	2	2	0	8	8	0	Mod	Mod	None
Atlantic Halibut (J)	1	2	0	1	4	2	2	0	8	8	0	Mod	Mod	None
Atlantic Herring (E)	0	0	1	1	2	2	2	0	4	4	0	Low	Low	None
Atlantic Herring (SA)	0	0	1	1	2	2	2	0	4	4	0	Low	Low	None
Atlantic Surfclam (A)	1	0	1	1	3	2	2	2	6	6	6	Low	Low	Low
Atlantic Surfclam (J)	1	0	0	1	2	2	2	2	4	4	4	Low	Low	Low
Barndoor Skate (A)	1	1	1	1	4	2	2	1	8	8	4	Mod	Mod	Low
Barndoor Skate (J)	1	2	0	1	4	2	2	1	8	8	4	Mod	Mod	Low
Black Sea Bass (A)	2	1	0	2	5	2	2	2	10	10	10	High	High	High
Black Sea Bass (J)	2	1	0	2	5	2	2	2	10	10	10	High	High	High
Clearnose Skate (A)	1	1	1	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Clearnose Skate (J)	1	2	0	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Golden Deepsea Crab (J,A)	1	1	1	2	5	1	0	0	5	0	0	Low	None	None
Goosefish (A)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Goosefish (J)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Haddock (A)	1	2	0	2	5	2	2	1	10	10	5	High	High	Low
Haddock (J)	2	2	0	2	6	2	2	1	12	12	6	High	High	Low
Little Skate (A)	1	1	1	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Little Skate (E)	0	0	1	1	2	2	2	2	4	4	4	Low	Low	Low
Little Skate (J)	1	2	0	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Ocean Pout (A)	2	2	1	2	7	2	2	2	14	14	14	High	High	High
Ocean Pout (E)	2	0	1	2	5	2	2	2	10	10	10	High	High	High
Ocean Pout (J)	2	2	0	2	6	2	2	2	12	12	12	High	High	High
Ocean Quahog (A)	1	0	1	1	3	2	2	2	6	6	6	Low	Low	Low
Ocean Quahog (J)	1	0	0	1	2	2	2	2	4	4	4	Low	Low	Low
Offshore Hake (A)	1	1	0	1	3	2	1	0	6	3	0	Low	Low	None
Offshore Hake (J)	1	1	0	1	3	2	1	0	6	3	0	Low	Low	None
Pollock (A)	1	1	1	1	4	2	2	1	8	8	4	Mod	Mod	Low
Pollock (J)	1	1	0	1	3	2	2	1	6	6	3	Low	Low	Low
Red Deepsea Crab (A)	1	1	1	2	5	1	0	0	5	0	0	Low	None	None
Red Deepsea Crab (J)	1	1	0	2	4	1	0	0	4	0	0	Low	None	None
Red Drum (A)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low

Table 6.1. EFH vulnerability matrix analysis for benthic life stages of federally managed fish and invertebrate species in the Northeast U.S. Shelf Ecosystem

Species and Species Groups[a]	Habitat Criteria Scores				Habitat Rank[f]	Gear Distribution Scores[g]			Gear Rank[h]			EFH Vulnerability Category[i]		
	Shelter[b]	Food[c]	Repro-duction[d]	Habitat Sensitivity[e]		Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge
Red Drum (J)	2	1	0	2	5	1	0	0	5	0	0	Low	None	None
Red Hake (A)	1	2	0	1	4	2	2	1	8	8	4	Mod	Mod	Low
Red Hake (J)	2	2	0	2	6	2	2	2	12	12	12	High	High	High
Redfish (A)	1	1	0	2	4	2	2	0	8	8	0	Mod	Mod	None
Redfish (J)	2	1	0	2	5	2	2	0	10	10	0	High	High	None
Rosette Skate (A)	1	1	1	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Rosette Skate (J)	1	2	0	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Scup (A)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Scup (J)	1	2	0	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Sea Scallops (A)	1	0	1	1	3	2	2	2	6	6	6	Low	Low	Low
Sea Scallops (J)	1	0	0	1	2	2	2	2	8	8	8	Low	Low	Low
Silver Hake (A)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Silver Hake (J)	1	1	0	2	4	2	2	2	8	8	8	Mod	Mod	Mod
Smooth Skate (A)	1	2	1	1	5	2	2	0	10	10	0	High	High	None
Smooth Skate (J)	1	2	0	1	4	2	2	0	8	8	0	Mod	Mod	None
Spiny Dogfish (A)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Spiny Dogfish (J)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Summer Flounder (A)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Summer Flounder (J)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Thorny Skate (A)	1	1	1	1	4	2	2	0	8	8	0	Mod	Mod	None
Thorny Skate (J)	1	2	0	1	4	2	2	0	8	8	0	Mod	Mod	None
Tilefish (A)	2	2	0	1	5	2	1	0	10	5	0	High	Low	None
Tilefish (J)	2	2	0	1	5	2	1	0	10	5	0	High	Low	None
White Hake (A)	1	1	0	1	3	2	2	0	6	6	0	Low	Low	None
White Hake (J)	1	2	0	1	4	2	2	0	8	8	0	Mod	Mod	None
Windowpane Flounder (A)	1	0	0	1	2	2	2	2	4	4	4	Low	Low	Low
Windowpane Flounder (J)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Winter Flounder (A)	1	1	1	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Winter Flounder (E)	0	0	1	1	2	2	2	2	4	4	4	Low	Low	Low
Winter Flounder (J)	1	1	0	1	3	2	2	2	6	6	6	Low	Low	Low
Winter Skate (J)	1	2	0	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Winter Skate (A)	1	1	1	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Witch Flounder (A)	1	2	0	1	4	2	1	1	8	4	4	Mod	Low	Low
Witch Flounder (J)	1	2	0	1	4	2	1	0	8	4	0	Mod	Low	None
Yellowtail Flounder (A)	1	2	0	1	4	2	2	2	8	8	8	Mod	Mod	Mod
Yellowtail Flounder (J)	1	2	0	1	4	2	2	2	8	8	8	Mod	Mod	Mod

Table 6.1. EFH vulnerability matrix analysis for benthic life stages of federally managed fish and invertebrate species in the Northeast U.S. Shelf Ecosystem

Species and Species Groups[a]	**Habitat Criteria Scores**				**Habitat Rank**[f]	**Gear Distribution Scores**[g]			**Gear Rank**[h]			**EFH Vulnerability Category**[i]		
	Shelter[b]	**Food**[c]	**Repro- duction**[d]	**Habitat Sensitivity**[e]		**Otter Trawl**	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Otter Trawl**	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Otter Trawl**	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**

a Life Stages: (E) = egg, (J) = juvenile, (A) = adult, and (SA) = spawning adult.

b Shelter Scores: 0 = no dependence; 1 = lower dependence, not reliant on complex structure; and 2 = strong dependence, reliant on complex structure.

c Food Scores: 0 = no dependence on benthic prey; 1 = includes benthic prey; and 2 = relies exclusively on benthic prey.

d Reproduction Scores: 0 = no dependence (*e.g.*, spawns in water column, or life stage not reproductive); and 1 = dependence (*e.g.*, spawns on or over bottom).

e Habitat Sensitivity Scores: 0 = not sensitive; 1 = low sensitivity (*i.e.*, no habitat structural/complexity issues, and rapid recovery rates) such as high-energy sand habitats; and 2 = high sensitivity (*i.e.*, habitat structural/complexity issues, and slow recovery rates) such as deepwater/low energy habitats.

f Habitat Rank: = Σshelter score + food score + reproduction score + habitat sensitivity score.

g Gear Distribution Scores: 0 = gear not utilized in this habitat; 1 = gear operates in a small portion of this habitat; and 2 = gear operates in much of this habitat.

h Gear Rank (*i.e.*, overall effect on EFH of this particular gear) = habitat rank x gear distribution score.

i EFH Vulnerability Category was assigned from gear ranks as follows: 0 = none, 1-6 = low vulnerability, 7-9 = moderate vulnerability, 10-14 = high vulnerability.

Table 6.2. American plaice EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GOM, GB, and estuaries from Passamaquoddy Bay to Saco Bay, and from Massachusetts Bay to Cape Cod Bay	30-90	All year in GOM, December to June on GB; peaks in April and May for both areas	Surface waters	NA	NA	NA	NA	NA
Larvae	GOM, GB, SNE, and estuaries from Passamaquoddy Bay to Saco Bay, and from Massachusetts Bay to Cape Cod Bay	30-130	Between January and August, with peaks in April and May	Surface waters	NA	NA	NA	NA	NA
Juveniles	GOM and estuaries from Passamaquoddy Bay to Saco Bay, and from Massachusetts Bay to Cape Cod Bay	45-150		Bottom habitats with fine-grained sediments or a substrate of sand or gravel	M	M	0	L	L
Adults	GOM, GB, and estuaries from Passamaquoddy Bay to Saco Bay, and from Massachusetts Bay to Cape Cod Bay	45-175		Bottom habitats with fine-grained sediments or a substrate of sand or gravel	H	H	0	L	L
Spawning adults	GOM, GB, and estuaries from Passamaquoddy Bay to Saco Bay, and from Massachusetts Bay to Cape Cod Bay	<90	March through June	Bottom habitats of all substrate types	H	H	0	L	L

Rationale: American plaice (*Hippoglossoides platessoides*) juveniles, adults, and spawning adults are concentrated in the GOM, where they occupy a variety of habitat types with substrates of gravel or fine-grained sediments including sand. Plaice avoid rocky and hard-bottom areas and prefer fine, sticky but gritty sand mixtures and mud, as well as oozy mud in deep basins (Klein-MacPhee 2002d). Plaice have been caught a considerable distance off the bottom, and move off the bottom at night (Klein-MacPhee 2002d). They feed primarily on epibenthic invertebrates (mostly echinoderms and amphipods), so there is a potential that prey resources may be adversely affected by otter trawls and scallop dredges, particularly in areas of lower energy and expected slower habitat recovery. EFH vulnerability to these gears was rated as high for adults and moderate for juveniles primarily because spawning occurs on the bottom. Since hydraulic clam dredges do not typically operate in the GOM, vulnerability for this gear was rated as none.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.3. Atlantic cod EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GOM, GB, eastern portion of continental shelf off SNE, and following estuaries: Englishman/ Machias Bay to Blue Hill Bay, Sheepscot R., Casco Bay, Saco Bay, Great Bay, Massachusetts Bay, Boston Harbor, Cape Cod Bay, and Buzzards Bay	<110	Begins in fall, peaks in winter and spring	Surface waters	NA	NA	NA	NA	NA
Larvae	GOM, GB, eastern portion of continental shelf off SNE and following estuaries: Passamaquoddy Bay to Penobscot Bay, Sheepscot R., Casco Bay, Saco Bay, Great Bay, Massachusetts Bay, Boston Harbor, Cape Cod Bay, and Buzzards Bay	30-70	Spring	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	GOM, GB, eastern portion of continental shelf off SNE and following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay, Boston Harbor, Cape Cod Bay, and Buzzards Bay	25-75		Bottom habitats with a substrate of cobble or gravel	H	H	0	L	L
Adults	GOM, GB, SNE, middle Atlantic south to Delaware Bay and following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay, Boston Harbor, Cape Cod Bay, and Buzzards Bay	10-150		Bottom habitats with a substrate of rocks, pebbles, or gravel	M	M	L	L	L
Spawning adults	GOM, GB, SNE, middle Atlantic south to Delaware Bay and following estuaries, Englishman/ Machias Bay to Blue Hill Bay; Sheepscot R., Massachusetts Bay, Boston Harbor, and Cape Cod Bay	10-150	Spawn during fall, winter, and early spring	Bottom habitats with a substrate of smooth sand, rocks, pebbles, or gravel	M	M	L	L	L

Rationale: Atlantic cod (*Gadus morhua*) are distributed regionally from Greenland to Cape Hatteras , from nearshore to depths >400 m. In U.S. waters, they are concentrated on GB and in the GOM, on rough bottom from 10-150 m (Fahay *et al*. 1999; Klein-MacPhee 2002a). Eggs and larvae are pelagic, so EFH vulnerability is not applicable. Juvenile cod are found mostly in nearshore shoal waters or on offshore banks. Cobble is preferred over finer grained sediments, and this life stage appears to use benthic structure and cryptic coloration to escape predation (Fahay *et al*. 1999). Juvenile cod may benefit, perhaps strongly, from physical and biological complexity (Lindholm *et al*. (2001); see discussion in Chapter 2 of this document). Otter trawls and scallop dredges have been shown to reduce habitat complexity (see Chapter 5), therefore EFH vulnerability to these gear types was rated as high since the gear may affect the functional value of EFH for this life stage. Vulnerability to clam dredges was rated as none since this gear is not operated in juvenile cod EFH (see Chapter 4). Adults and spawning adults occupy a variety of hard-bottom habitat types, including rock, pebbles, and gravel, and tend to avoid finer sediments. Cod eat a wide variety of prey, including fish, decapod crustaceans, amphipods, and polychaetes (Fahay *et al.* 1999). Although adult cod are primarily found on rough bottom, the scientific literature does not indicate that this habitat type serves the same function as it does for juvenile cod. Based on the variable diet and lack of evidence for direct functional value of benthic habitat, EFH vulnerability to otter trawls and scallop dredges was rated as moderate. Adult cod may use areas where clam dredges operate, such as the nearshore waters of New Jersey, on a seasonal basis. Clam dredges operate only in sand (NREFHSC 2002), and the recovery of benthic communities from the effects of clam dredging in nearshore, sandy habitats is rapid (Table 5.15). Clam beds are not chronically disturbed by dredging since the population of clams, which are benthic infauna, must recover before fishing is again profitable (NREFHSC 2002). Based on this information and the rationale described for otter trawls and scallop dredges, habitat vulnerability for hydraulic clam dredges was rated as low. EFH vulnerability for adults applies to spawning adults as well.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.4. Atlantic halibut EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GOM, GB		Between late fall and early spring, peaks in November and December	Pelagic waters to the seafloor	0	0	0	0	0
Larvae	GOM, GB			Surface waters	NA	NA	NA	NA	NA
Juveniles	GOM, GB	20-60		Bottom habitats with a substrate of sand, gravel, or clay	M	M	0	L	L
Adults	GOM, GB	100-700		Bottom habitats with a substrate of sand, gravel, or clay	M	M	0	L	L
Spawning adults	GOM, GB	<700	Between late fall and early spring, peaks in November and December	Bottom habitats with a substrate of soft mud, clay, sand, or gravel; rough or rocky bottom locations along slopes of the outer banks	M	M	0	L	L

Rationale: Atlantic halibut (*Hippoglossus hippoglossus*) are found in the temperate, boreal and subarctic Atlantic, south to New Jersey, and were once common from Nantucket Shoals to Labrador (Klein-MacPhee 2002d). They have been found at depths from 25-1000 m, but 700-900 m is probably the deepest they are found in any numbers. Atlantic halibut eggs are bathypelagic and are fertilized on the bottom (Cargnelli, Griesbach, and Morse 1999; Klein-MacPhee 2002d). Since eggs occur close to, but not on the bottom, scallop dredges, otter trawls, and hydraulic clam dredges are not expected to affect the functional value of the habitat for this life stage, and EFH vulnerability was rated as none. Juvenile, adult and spawning adult halibut occupy a variety of habitat types north of Nantucket Shoals. Adults are not found on soft mud or on rock bottom (Cargnelli, Griesbach, and Morse 1999). Spawning is occasionally associated with complex habitats. Juvenile halibut feed mostly on annelid worms and crustaceans, then transition to a diet of mostly fish as adults (Klein-MacPhee 2002d). EFH vulnerability to scallop dredges and otter trawls was rated as moderate for juveniles and adults. EFH vulnerability for clam dredges was rated as none since this gear type does not operate in halibut EFH (see Chapter 4 of this document).

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.5. Atlantic herring EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GOM, GB and following estuaries: Englishman/Machias Bay, Casco Bay, and Cape Cod Bay	20-80	July through November	Bottom habitats with a substrate of gravel, sand, cobble, shell fragments, and aquatic macrophytes, tidal currents 1.5-3 knots	L	L	0	L	L
Larvae	GOM, GB, SNE and following estuaries: Passamaquoddy Bay to Cape Cod Bay, Narragansett Bay, and Hudson R./ Raritan Bay	50-90	Between August and April, peaks from September to November	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	GOM, GB, SNE and Middle Atlantic south to Cape Hatteras and following estuaries: Passamaquoddy Bay to Cape Cod Bay, Buzzards Bay to Long Island Sound, Gardiners Bay to Delaware Bay	15-135		Pelagic waters and bottom habitats	NA	NA	NA	NA	NA
Adults	GOM, GB, SNE and middle Atlantic south to Cape Hatteras and following estuaries: Passamaquoddy Bay to Great Bay, Massachusetts Bay to Cape Cod Bay, Buzzards Bay to Long Island Sound, Gardiners Bay to Delaware Bay, and Chesapeake Bay	20-130		Pelagic waters and bottom habitats	NA	NA	NA	NA	NA
Spawning adults	GOM, GB, SNE and middle Atlantic south to Delaware Bay and Englishman/Machias Bay Estuary	20-80	July through November	Bottom habitats with a substrate of gravel, sand, cobble, and shell fragments, also on aquatic macrophytes	L	L	0	L	L

Rationale: Atlantic herring (*Clupea harengus*) is a coastal pelagic species ranging from Labrador to Cape Hatteras in the western Atlantic (Reid *et al.* 1999; Munroe 2002). For pelagic life stages (larvae, juveniles, adults) EFH vulnerability to bottom-tending fishing gears is not applicable. Atlantic herring eggs are laid in high-energy, benthic habitats on gravel, sand, or rocky substrates, and on macrophytes (Reid *et al.* 1999; Munroe 2002). These habitats are less susceptible to fishing gear impacts since they have evolved under a high-energy disturbance regime (strong bottom currents). Vulnerability of herring egg EFH to scallop dredges and otter trawls is considered low. Although these gears may directly affect the eggs, only the effect of the gear on the functional value of the habitat was considered for this evaluation. EFH vulnerability from clam dredges was considered to be none since this gear does not operate in areas of herring egg EFH. Spawning adults are closely associated with the bottom. Effects on the functional value of habitat from mobile gears are unknown, and were rated as low since spawning occurs on the bottom. EFH vulnerability from clam dredges was rated as none for the reasons described above. Spawning could be disrupted by noise associated with these gears, but this issue was not addressed as a habitat-related issue.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.6. Atlantic mackerel EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	Continental shelf from Maine through Cape Hatteras, also includes the following estuaries: Great Bay to Cape Cod Bay, Buzzards Bay to Long Island Sound, Gardiners Bay, and Great South Bay	0-15		Pelagic waters	NA	NA	NA	NA	NA
Larvae	Continental shelf from Maine through Cape Hatteras, also includes the following estuaries: Great Bay to Cape Cod Bay, Buzzards Bay to Long Island Sound, Gardiners Bay, and Great South Bay	10-130		Pelagic waters	NA	NA	NA	NA	NA
Juveniles	Continental shelf from GOM through Cape Hatteras, also includes the following estuaries: Passamaquoddy Bay, Penobscot Bay to Saco Bay, Great Bay, Massachusetts Bay to Cape Cod Bay, Narragansett Bay, Long Island Sound, Gardiners Bay to Hudson R./ Raritan Bay	0-320		Pelagic waters	NA	NA	NA	NA	NA
Adults	Continental shelf from GOM through Cape Hatteras, also includes the following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay to Long Island Sound, Gardiners Bay to Hudson R./ Raritan Bay	0-380		Pelagic waters	NA	NA	NA	NA	NA

Rationale: All life stages of Atlantic mackerel (*Scomber scombrus*) are pelagic, so their EFH is not vulnerable to bottom-tending fishing gear, and vulnerability was categorized as "not applicable."

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.7. Atlantic salmon EFH-vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	The following rivers from Connecticut to Maine: Connecticut, Pawcatuck, Merrimack, Cocheco, Saco, Androscoggin, Presumpscot, Kennebec, Sheepscot, Ducktrap, Union, Penobscot, Narraguagus, Machias, East Machias, Pleasant, St. Croix, Denny's, Passagassawaukeag, Aroostook, Lamprey, Boyden, and Orland rivers, and Turk, Hobart and Patten Streams, and the following estuaries and embayments for juveniles and adults: Passamaquoddy Bay to Muscongus Bay, Casco Bay to Wells Harbor, Massachusetts Bay, Long Island Sound, and Gardiners Bay to Great South Bay. EFH includes all aquatic habitats in the watersheds of the above listed rivers, including all tributaries to the extent that they are currently or were historically accessible for salmon migration.	30-31	Between October and April	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	NA	NA	NA	NA	NA
Larvae			Between March and June for alevins/fry	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	NA	NA	NA	NA	NA
Juveniles		10-61		Bottom habitats of shallow gravel/cobble riffles interspersed with deeper riffles and pools in rivers and estuaries, water velocities of 30-92 cm/s	NA	NA	NA	NA	NA
Adults				Oceanic adult Atlantic salmon are primarily pelagic and range from waters of the continental shelf off SNE north throughout the GOM, dissolved oxygen >5 ppm for migratory pathway	NA	NA	NA	NA	NA
Spawning adults		30-61	October and November	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	NA	NA	NA	NA	NA

Rationale: Atlantic salmon (*Salmo salar*) eggs and larvae are found in riverine areas where the fishing gears under consideration are not used, so EFH vulnerability is not applicable. It is important to note that these life stages are particularly vulnerable to non-fishing-related impacts such as point-source discharges and polluted runoff. Juveniles and adults are pelagic in nature, and vulnerability of EFH to bottom-tending fishing gear is not applicable for these life stages.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.8. Atlantic surfclam EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	Eastern edge of GB and the GOM throughout Atlantic EEZ	0-60, low density beyond 38		Throughout substrate to a depth of 3 ft within federal waters, burrow in medium to coarse sand and gravel substrates, also found in silty to fine sand, but not in mud	L	L	L	L	L
Adults	Eastern edge of GB and the GOM throughout Atlantic EEZ	0-60, low density beyond 38	Spawn summer to fall	Throughout substrate to a depth of 3 ft within federal waters	L	L	L	L	L

Rationale: Atlantic surfclams (*Spisula solidissima*) are found in sandy continental shelf habitats from the southern Gulf of St. Lawrence to Cape Hatteras, North Carolina (Cargnelli *et al*. 1999a). They burrow into substrates from fine to coarse sandy gravel, and are not found in mud. Although clam dredges remove clams from the sediment, the habitat's functional value is probably not affected. Juvenile and adult EFH vulnerability was therefore rated as low for all mobile gears. Surfclam eggs and larvae are pelagic, therefore EFH vulnerability is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.9. Barndoor skate EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	Eastern GOM, GB, SNE, Mid-Atlantic Bight to Hudson Canyon	0-750, mostly <150		Bottom habitats with mud, gravel, and sand substrates	M	M	L	L	L
Adults	Eastern GOM, GB, SNE, Mid-Atlantic Bight to Hudson Canyon	0-750, mostly <150		Bottom habitats with mud, gravel, and sand substrates	M	M	L	L	L

Rationale: Barndoor skate (*Dipturus laevis*) occur from Newfoundland south to Cape Hatteras, but are most abundant on GB and in the GOM. They are found on soft mud, sand, and gravel (Packer *et al*. 2003a). Barndoor skate feed on invertebrates usually associated with the bottom, including polychaetes, gastropods, and bivalves, as well as squid and fish. Smaller individuals feed primarily on polychaetes, copepods, and amphipods, while larger individuals capture larger and more active prey (McEachran 2002, Packer *et al*. 2003a). A single fertilized egg is encapsulated in a leathery capsule known as a "mermaids purse." The young hatch in late spring or early summer, and are thought to be about 18-19 cm in length, although very little information is available on this life stage (Packer *et al*. 2003a). Juvenile EFH was considered to be moderately vulnerable to otter trawls and scallop dredges because of the closer association of juveniles to a benthic invertebrate diet. Adult EFH vulnerability to otter trawls and scallop dredges was rated as moderate due primarily to their reproductive habits. EFH vulnerability to clam dredges was rated as low for juveniles and adults because this gear is not extensively used in EFH.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.10. Black sea bass EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	Continental shelf and estuaries from SNE to North Carolina; also includes Buzzards Bay	0-200	May to October	Water column of coastal Mid-Atlantic Bight and Buzzards Bay	NA	NA	NA	NA	NA
Larvae	Pelagic waters over continental shelf from GOM to Cape Hatteras; also includes Buzzards Bay	<100	May to November, peak June to July	Habitats for transforming (to juveniles) larvae are near coastal areas and into marine parts of estuaries between Virginia and NY; when larvae become demersal, found on structured inshore habitat such as sponge beds	H	H	H	L	L
Juveniles	Demersal waters over continental shelf from GOM to Cape Hatteras, also includes the following estuaries: Buzzards Bay to Long Island Sound, Gardiners Bay, Barnegat Bay to Chesapeake Bay, Tangier/Pocomoke Sound, and James R	1-38	Found in coastal areas (April to December, peak June to November) between Virginia and Massachusetts, but winter offshore from New Jersey south; in estuaries in summer and spring	Rough bottom, shellfish and eelgrass beds, man-made structures in sandy-shelly areas, offshore clam beds, and shell patches may be used during wintering	H	H	H	L	L
Adults	Demersal waters over continental shelf from GOM to Cape Hatteras, also includes the following estuaries: Buzzards Bay, Narragansett Bay, Gardiners Bay, Great South Bay, Barnegat Bay to Chesapeake Bay, Tangier/Pocomoke Sound, and James R	20-50	Wintering adults (November to April) offshore, south of New York to North Carolina; inshore, in estuaries from May to October	Structured habitats (natural and man-made), sand and shell substrates preferred	H	H	H	L	L

Rationale: Black sea bass (*Centropristis striata*) are found in coastal waters of the northwest Atlantic, from Cape Cod south to Cape Canaveral (Klein-MacPhee 2002e). Occasionally they stray as far north as the Bay of Fundy (GOM). Juveniles are common in high-salinity estuaries. Adults and juveniles are found in estuaries from Massachusetts south to the James River, Virginia (Stone *et al.* 1994). Black sea bass larvae are pelagic, but then become demersal and occupy structured inshore habitat such as sponge beds, eelgrass beds, shellfish beds, shell patches, and other rough bottoms (Steimle, Zetlin, Berrien, and Chang 1999) and offshore shell patches including clam beds (Able and Fahay 1998). The availability of structure limits successful post-larval and/or juvenile recruitment (Steimle, Zetlin, Berrien, and Chang 1999). Juveniles are diurnal visual predators that feed on benthic invertebrates and small fish. Adults are also structure oriented, and are thought to use structure as shelter during the day, but may stray off it to hunt at night. Each of these life stages is associated with structure that may be vulnerable to fishing gear impacts, so vulnerability was rated as high for all mobile gears. It is important to note that structured habitats comprised of wrecks or other artificial reefs prone to damage by mobile gear may be avoided by fishermen. This is true of high-relief natural areas as well. Black sea bass eggs are pelagic, so vulnerability to EFH is not applicable. Although larvae are pelagic, they do become demersal as they transition into juveniles. Therefore, larvae were rated the same as juveniles.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.11. Bluefish EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	North of Cape Hatteras--over continental shelf from Montauk Point south to Cape Hatteras; south of Cape Hatteras--over continental shelf through Key West, Florida	Mid-shelf depths	April to August	Pelagic waters	NA	NA	NA	NA	NA
Larvae	North of Cape Hatteras--over continental shelf from Montauk Point south to Cape Hatteras; south of Cape Hatteras--over continental shelf through Key West, the slope sea, and Gulf Stream between latitudes 29°N and 40°N; includes Narragansett Bay	> 15	April to September	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	North of Cape Hatteras--over continental shelf from Nantucket Island south to Cape Hatteras; south of Cape Hatteras--over continental shelf through Key West, the slope sea, and Gulf Stream between latitudes 29°N and 40°N; also includes the following estuaries: Penobscot Bay to Great Bay, Massachusetts Bay to James R., Albemarle Sound to St. Johns R.		North Atlantic estuaries from June to October; mid-Atlantic estuaries from May to October; South Atlantic estuaries from March to December	Pelagic waters	NA	NA	NA	NA	NA
Adults	North of Cape Hatteras--over continental shelf from Cape Cod Bay south to Cape Hatteras; south of Cape Hatteras--found over continental shelf through Key West: also includes the following estuaries: Penobscot Bay to Great Bay, Massachusetts Bay to James R., Albemarle Sound to Pamilco/Pungo R., Bougue Sound, Cape Fear R., St. Helena Sound, Broad R., St. Johns R., and Indian R.		North Atlantic estuaries from June to October; mid-Atlantic estuaries from April to October; South Atlantic estuaries from May to January	Pelagic waters	NA	NA	NA	NA	NA

Rationale: All life stages of bluefish (*Pomatomus saltatrix*) are pelagic, so their EFH is not vulnerable to bottom-tending fishing gears, and vulnerability is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.12. Butterfish EFH-vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	Over continental shelf from GOM through Cape Hatteras; also estuaries, including Massachusetts Bay to Long Island Sound, Gardiners Bay, Great South Bay, and Chesapeake Bay	0-1829	Spring and summer	Pelagic waters	NA	NA	NA	NA	NA
Larvae	Over continental shelf from GOM through Cape Hatteras; also estuaries, including Boston Harbor, Waquoit Bay to Long Island Sound, Gardiners Bay to Hudson R./Raritan Bay, Delaware Bay, and Chesapeake Bay	10-1829	Summer and fall	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	Over continental shelf from GOM through Cape Hatteras; also estuaries, including Massachusetts Bay, Cape Cod Bay to Delaware inland bays, Chesapeake Bay, York R., and James R.	10-365 (most <120)	Winter--shelf; spring to fall--estuaries	Pelagic waters (larger individuals found over sandy and muddy substrates)	NA	NA	NA	NA	NA
Adults	Over continental shelf from GOM through Cape Hatteras; also estuaries, including Massachusetts Bay, Cape Cod Bay to Hudson R./Raritan Bay, Delaware Bay and inland bays, York R., and James R.	10-365 (most <120)	Winter--shelf; summer to fall--estuaries	Pelagic waters (schools form over sandy, sandy silt, and muddy substrates)	NA	NA	NA	NA	NA

Rationale: All life stages of butterfish (*Peprilus triacanthus*) are pelagic, so their EFH is not vulnerable to bottom-tending fishing gear, and vulnerability is not applicable.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.13. Clearnose skate EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	GOM, along shelf to Cape Hatteras ; includes the estuaries from Hudson River/Raritan Bay south to the Chesapeake Bay mainstem	0 – 500, mostly < 111		Bottom habitats with substrate of soft bottom along continental shelf, and rocky or gravelly bottom	M	M	M	L	L
Adults	GOM, along shelf to Cape Hatteras ; includes the estuaries from Hudson River/Raritan Bay south to the Chesapeake Bay mainstem	0 – 500, mostly < 111		Bottom habitats with substrate of soft bottom along continental shelf, and rocky or gravelly bottom	M	M	M	L	L

Rationale: Clearnose skate (*Raja eglanteria*) occur in the GOM, but are most abundant from Cape Hatteras north to Delaware Bay. They are found over soft bottoms of mud and sand, as well as on rocky or gravelly bottoms. They have been captured from shore out to depths of 330 m, but are most abundant at depths less than 111 m (Packer *et al*. 2003b). Adults and juveniles feed on polychaetes, amphipods, decapod crustaceans, mollusks, and fish. Like barndoor skates, crabs and benthic invertebrates are more important for smaller, younger individuals, and the importance of fish in the diet increases with age (McEachran 2002; Packer *et al*. 2003b). A single fertilized egg is encapsulated in a leathery case. Eggs are deposited in the spring or summer, and hatch 3 mo later. Juvenile EFH was considered moderately vulnerable to otter trawls, scallop dredges, and clam dredges because of the close association of juveniles to a benthic invertebrate diet. Adult EFH vulnerability to otter trawls, scallop dredges, and clam dredges was rated as moderate due primarily to the species' reproductive habits.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.14. Cobia EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
All life stages	South Atlantic and Mid-Atlantic Bights			Sandy shoals of capes and offshore bars; high-profile rock bottoms and barrier island oceanside waters from surf zone to shelf break, but from the Gulf Stream shoreward; also high salinity bays, estuaries, seagrass habitat	NA	NA	NA	NA	NA

Rationale: All life stages of cobia (*Rachycentron canadum*) are pelagic, so their EFH is not vulnerable to bottom tending fishing gear, and vulnerability is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.15. Golden deepsea crab EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
All life stages	Chesapeake Bay to the south through the Florida Straight (and into the Gulf of Mexico)	290-570		Continental slope in flat areas of foraminifera ooze, on distinct mounds of dead coral, ripple habitat, dunes, black pebble habitat, low outcrop, and soft bioturbated habitat	L	0	0	L	L

Rationale: The golden deepsea crab (*Chaceon fenneri*) inhabits the continental slope of Bermuda and the southeastern United States from Chesapeake Bay south through the Florida Straight and into the Gulf of Mexico (SAFMC 1998). Although similar to the red deepsea crab, less is known about this species. They are categorized as opportunistic scavengers, and are found in depths from 290-570 m on substrates of foraminiferon ooze, dead coral mounds, deep ripple habitat, dunes, and black pebble habitat. Scallop dredges and clam dredges do not operate in golden crab EFH due to depth, so EFH vulnerability was rated as none. Most otter trawling operates in depths less than 200 m so EFH vulnerability was rated as low for this gear type.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.16. Goosefish EFH-vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GOM, GB, SNE, middle Atlantic south to Cape Hatteras	15-1000	March to September	Surface waters	NA	NA	NA	NA	NA
Larvae	GOM, GB, SNE, middle Atlantic south to Cape Hatteras	25-1000	March to September	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	Outer continental shelf in the middle Atlantic, mid-shelf off SNE, all areas of GOM	25-200		Bottom habitats with substrates of a sand-shell mix, algae-covered rocks, hard sand, pebbly gravel, or mud	L	L	L	L	L
Adults	Outer continental shelf in the middle Atlantic, mid-shelf off SNE, outer perimeter of GB, all areas of GOM	25-200		Bottom habitats with substrates of a sand-shell mix, algae-covered rocks, hard sand, pebbly gravel, or mud	L	L	L	L	L
Spawning adults	Outer continental shelf in the middle Atlantic, mid-shelf off SNE, outer perimeter of GB, all areas of GOM	25-200	February to August	Bottom habitats with substrates of a sand-shell mix, algae-covered rocks, hard sand, pebbly gravel, or mud	L	L	L	L	L

Rationale: Goosefish (*Lophius americanus*), are demersal anglerfish found from Newfoundland south to Florida, but are common only north of Cape Hatteras (Steimle, Morse, and Johnson 1999). Juveniles are primarily found at depths between 40 and 75 m, while adults are concentrated between 50-100 m. In the GOM, adults occur primarily between the depths of 130-260 m. Occasionally, adults are seen at the surface. Both juveniles and adults (including spawning adults) occur on substrates ranging from mud to gravelly sand, algae, and rocks. A goosefish has been observed digging depressions in the bottom substrate with its pectoral fins until its back was almost flush with the surrounding bottom (Caruso 2002). The goosefish is a sight predator that uses its highly modified first dorsal fin as an angling apparatus to lure small fishes towards its mouth (Caruso 2002). Goosefish eat a wide array of prey items, but mainly fish and cephalopods. Goosefish have been reported to ingest a variety of seabirds. There are no indications in the literature that any goosefish life stage is habitat limited or that the functional value of its habitat could be adversely affected by fishing. Vulnerability of adult and juvenile EFH to mobile fishing gear was rated as low. Goosefish eggs and larvae are pelagic, and vulnerability to bottom-tending fishing gear is not applicable.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.17. Haddock EFH-vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	**Geographic Area of EFH**[a]	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability**[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GB southwest to Nantucket Shoals, coastal areas of GOM, and the following estuaries: Great Bay, Massachusetts Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	50-90	March to May, peaks in April	Surface waters	NA	NA	NA	NA	NA
Larvae	GB southwest to Delaware Bay, and the following estuaries: Great Bay, Massachusetts Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay, and Narragansett Bay	30-90	January to July, peaks in April and May	Surface waters	NA	NA	NA	NA	NA
Juveniles	GB, GOM, and middle Atlantic south to Delaware Bay	35-100		Bottom habitats with a substrate of pebble and gravel	H	H	L	L	L
Adults	GOM, GB, Nantucket Shoals, and the Great South Channel	40-150		Bottom habitats with a substrate of broken ground, pebbles, smooth hard sand, and smooth areas between rocky patches	H	H	L	L	L
Spawning adults	GOM, GB, Nantucket Shoals, and the Great South Channel	40-150	January to June	Bottom habitats with a substrate of pebble, gravel, or gravelly sand	H	H	L	L	L

Rationale: Haddock (*Melanogrammus aeglefinus*) are found from Greenland to Cape Hatteras and are common throughout the GOM, Georges Bank, and SNE (Cargnelli, Griesbach, Berrien, *et al.* 1999; Klein-MacPhee 2002a). Juveniles older than 3 mo and adults are demersal and generally found in waters from 10-150 m in depth. Juveniles are usually found in waters shallower than 100 m. Haddock spawn over pebble and gravel substrate, and avoid ledges, rocks, kelp, and soft mud (Cargnelli, Griesbach, Berrien, *et al*. 1999). Haddock eggs and larvae are pelagic, and EFH vulnerability to fishing gear is not applicable. Juvenile haddock, like juvenile cod, may benefit, perhaps strongly, from physical and biological complexity (see discussion in Chapter 2). In general, haddock have a stronger benthic affinity than cod (Klein-MacPhee 2002a). Juvenile haddock are chiefly found over pebble and gravel substrates (Cargnelli, Griesbach, Berrien, *et al.* 1999). Once demersal, they feed on benthic fauna, and their primary prey items are crustaceans and polychaetes. The habitat complexity that appears to be important to juvenile haddock can be reduced by otter trawls and scallop dredges, and benthic prey may be affected (see Chapter 5). Juvenile haddock EFH are considered highly vulnerable to these two gear types. Vulnerability to clam dredges was rated as low since there is some use of this gear in juvenile EFH. Adult haddock are found on broken ground, gravel, pebbles, clay, smooth sand, and sticky sand of gritty consistency, with a preference for smooth areas around rock patches (Klein-MacPhee 2002a). They feed indiscriminately on benthic invertebrates, and occasionally on fish. Adults (including spawning adults) occupy a variety of habitat types that might be affected by otter trawls and scallop dredges. Adults may be less closely linked to complex habitats then juveniles, but there is still some association. Haddock are expected to be more strongly linked to benthic habitats than cod, since haddock primarily feed on benthic invertebrates, while cod are primarily piscivorous. Benthic prey resources for haddock may be adversely affected by scallop dredges or otter trawls in areas of lower energy and expected slower habitat recovery. Overall, adult EFH vulnerability to these gear types was rated as high. Clam dredges operate only in sand, and the associated recovery period is short (Table 5.15). Moreover, clam dredging is not expected to create a chronic disturbance in these areas since the population of clams, which are benthic infauna, must recover before fishing is again profitable; therefore, habitat vulnerability for clam dredges was rated as low.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.18. King mackerel EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
All life stages	South Atlantic and Mid-Atlantic Bights			Sandy shoals of capes and offshore bars; high-profile rock bottoms and barrier island oceanside waters from surf zone to shelf break, but from the Gulf Stream shoreward, also high salinity bays, estuaries, seagrass habitat	NA	NA	NA	NA	NA

Rationale: All life stages of king mackerel (*Scomberomorus cavalla*) are pelagic, so their EFH is not vulnerable to bottom-tending fishing gear, and vulnerability is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.19. Little skate EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GB to Cape Hatteras; includes the estuaries from Buzzards Bay south to the Chesapeake Bay mainstem	<27		Bottom habitats with sandy substrate	L	L	L	L	L
Juveniles	GB to Cape Hatteras; includes the estuaries from Buzzards Bay south to the Chesapeake Bay mainstem	0-137, mostly 73-91		Bottom habitats with sandy or gravelly substrate or mud	M	M	M	L	L
Adults	GB to Cape Hatteras; includes the estuaries from Buzzards Bay south to the Chesapeake Bay mainstem	0-137, mostly 73-91		Bottom habitats with sandy or gravelly substrate or mud	M	M	M	L	L

Rationale: Little skate (*Leucoraja erinacea*) range from Nova Scotia to Cape Hatteras, and are most abundant on GB and in coastal waters south to the mouth of Chesapeake Bay. They have been found at depths up to 500 m, but are most common at depths less than 111 m (Packer *et al*. 2003c). In SNE, juveniles and adults have been associated with microhabitat features including biogenic depressions and flat sand during the day (Auster *et al*. 1991, 1995). They are generally found on sandy or gravelly bottoms, but also occur on mud. They co-occur with winter skate, and are more active at night, although they appear to feed throughout the day and night. The most important prey are amphipods and decapod crustaceans, followed by polychaetes (Packer *et al*. 2003c). Prey items of minor importance include bivalves, isopods, and fish. Similar to barndoor and clearnose skates, the use of fish as a food source increases with increasing size. Smaller skates eat more amphipods, and larger skate consume more decapod crustaceans (Packer *et al*. 2003c). A single fertilized egg is encapsulated in a leathery case that is deposited on sandy substrate. The cases have sticky filaments that adhere to bottom substrates. In one study, eggs deposited in the late spring and early summer required 5 to 6 mo to hatch. Other studies have shown incubation to exceed 1 yr. When the young hatch, they are considered juveniles and are fully developed asuring from 93-102 mm in total length (Packer *et al*. 2003c). Vulnerability of juvenile EFH to mobile bottom gear was characterized as moderate because of the species dependence on benthic organisms in its diet. Vulnerability of adult EFH to mobile bottom geargears was characterized as moderate due to its reproductive habits. Little skate is the only skate species in which EFH has been designated for eggs. Although bottom-tending mobile gears may have adverse effects upon the eggs themselves, this was not considered to be a habitat impact. Since the bottom substrate appears to provide an attachment point for the eggs, the EFH vulnerability to mobile gear was rated as low instead of none.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.20. Longfin inshore squid EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	Over continental shelf from GOM through Cape Hatteras	0-213	Inshore spring to fall; offshore in winter	Pelagic waters	NA	NA	NA	NA	NA
Adults	Over continental shelf from GOM through Cape Hatteras	0-305	Inshore March to October; offshore in winter	Pelagic waters	NA	NA	NA	NA	NA

Rationale: Longfin inshore squid (*Loligo pealeii*) is a pelagic schooling species. It is distributed in continental shelf and slope waters from Newfoundland to the Gulf of Venezuela (Cargnelli, Griesbach, McBride, *et al*. 1999). Most life stages of longfin inshore squid are pelagic; however, encapsulated eggs are laid in masses, called "mops," that are attached to structures such as rocks and algae on substrates of sand, mud, or on hard-bottom in depths <50m (Cargnelli, Griesbach, McBride, 1999). As of this writing, EFH has not been designated for longfin inshore squid eggs.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.21. Northern shortfin squid EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	Over continental shelf from GOM through Cape Hatteras	0-182	Carried northward by Gulf Stream	Pelagic waters	NA	NA	NA	NA	NA
Adults	Over continental shelf from GOM through Cape Hatteras	0-182	Offshore late fall; spawn December to March	Pelagic waters	NA	NA	NA	NA	NA

Rationale: All stages of northern shortfin squid (*Illex illecebrosus*) are pelagic, so their EFH is not vulnerable to bottom tending fishing gear, and vulnerability is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.22. Ocean pout EFH-vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GOM, GB, SNE, middle Atlantic south to Delaware Bay, and the following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay, and Cape Cod Bay	<50	Late fall and winter	Bottom habitats, generally hard-bottom sheltered nests, holes, or crevices where they are guarded by parents	H	H	H	L	L
Larvae	GOM, GB, SNE, middle Atlantic south to Delaware Bay, and the following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay, and Cape Cod Bay	<50	Late fall to spring	Bottom habitats in close proximity to hard-bottom nesting areas	H	H	H	L	L
Juveniles	GOM, GB, SNE, middle Atlantic south to Delaware Bay, and the following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay, Boston Harbor, and Cape Cod Bay	<80		Bottom habitats, often smooth bottom near rocks or algae	H	H	H	L	L
Adults	GOM, GB, SNE, middle Atlantic south to Delaware Bay, and the following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay, Boston Harbor, and Cape Cod Bay	<110		Bottom habitats; dig depressions in soft sediments which are then used by other species	H	H	H	L	L
Spawning adults	GOM, GB, SNE, middle Atlantic south to Delaware Bay, and the following estuaries: Passamaquoddy Bay to Saco Bay, Massachusetts Bay, and Cape Cod Bay	<50	Late summer to early winter, peaks in September and October	Bottom habitats with a hard-bottom substrate, including artificial reefs and shipwrecks	H	H	H	L	L

Rationale: Ocean pout (*Zoarces americanus*) is a demersal species found in the western Atlantic from Labrador south to Cape Hatteras (Steimle, Morse, Berrien, Johnson, and Zetlin 1999). It can occur in deeper waters south of Cape Hatteras, and has been found as deep as 363 m (Klein-MacPhee and Collette 2002a). It is found in most estuaries and embayments in the GOM, and is caught by the NEFSC trawl surveys in greatest abundance off SNE (Steimle, Morse, Berrien, Johnson, and Zetlin 1999). Ocean pout eggs are laid in nests in crevices, on hard-bottom, or in holes and protected by the female parent for 2.5-3 mo until they hatch (Klein-MacPhee and Collette 2002a). Potential impacts to habitat from otter trawls, scallop dredges, and clam dredges include knocking down boulder piles, removing biogenic structure, and filling in bottom depressions, which may disturb nests and/or leave these areas less suitable for nests. In addition, fishing may frighten parents from nests leaving eggs susceptible to predation. Egg EFH is therefore considered to have a high vulnerability to all bottom-tending mobile gears. Ocean pout have a relatively short larval stage, and some authors (Klein-MacPhee and Collette 2002a) suggest that there is no larval stage (Steimle, Morse, Berrien, Johnson, and Zetlin 1999). Since the NEFMC designated EFH for this life stage, it is considered here. Larvae (hatchlings) remain near the nest site; however, there is little information on their use of habitats. Larvae do not appear to be as closely associated with the bottom as eggs or juveniles; however, it is anticipated that loss of structure may impact larvae to some degree. Larval EFH was determined to have high vulnerability to mobile bottom-tending gears. Juvenile pout are found under rocks, shells and algae, in coastal waters and are closely associated with the bottom (Steimle, Morse, Berrien, Johnson, and Zetlin 1999). They feed on benthic invertebrates such as gammarid amphipods and polychaetes. It is expected that loss of structure may significantly impact juvenile EFH. Vulnerability of juvenile EFH to all mobile gears was considered high. Adult pout are found in sand and gravel in winter and spring, and in rocky/hard substrate areas for spawning and nesting (Klein-MacPhee and Collette 2002a). They create burrows in soft sediments, and their diet consists mainly of benthic invertebrates including mollusks, crustaceans, and echinoderms. Because of the strong benthic affinity of ocean pout, it is anticipated that vulnerability of adult EFH to all mobile gears is high.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.23. Ocean quahog EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	**Geographic Area of EFH**[a]	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability**[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Juveniles	Eastern edge of GB and GOM throughout the EEZ	8-245		Throughout substrate to a depth of 3 ft within federal waters; occurs progressively farther offshore between Cape Cod and Cape Hatteras	L	L	L	L	L
Adults	Eastern edge of GB and GOM throughout the EEZ	8-245	Spawn May to December with several peaks	Throughout substrate to a depth of 3 ft within federal waters; occurs progressively farther offshore between Cape Cod and Cape Hatteras	L	L	L	L	L

Rationale: Ocean quahog (*Arctica islandica*) juveniles are found in offshore sandy substrate, and may survive in muddy intertidal areas (Cargnelli *et al.* 1999b). Adults are found in similar offshore habitats, just below the surface of the sediment, usually in medium- to fine-grained sand. Although clam dredges remove clams from the sediment, the habitat's functional value is probably not affected. Juvenile and adult EFH vulnerability was therefore rated as low for all mobile gears. Ocean quahog eggs and larvae are pelagic, therefore EFH vulnerability is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.24. Offshore hake EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	**Geographic Area of EFH**[a]	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability**[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	Outer continental shelf of GB and SNE south to Cape Hatteras	<1250	Observed all year and primarily collected at depths from 110-270 m	Pelagic waters	NA	NA	NA	NA	NA
Larvae	Outer continental shelf of GB and SNE south to Chesapeake Bay	<1250	Observed all year and primarily collected at depths from 70-130m	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	Outer continental shelf of GB and SNE south to Cape Hatteras	170-350		Bottom habitats	L	L	0	L	L
Adults	Outer continental shelf of GB and SNE south to Cape Hatteras	150-380		Bottom habitats	L	L	0	L	L
Spawning adults	Outer continental shelf of GB and SNE south to the Middle Atlantic Bight	330-550	Spawn throughout the year	Bottom habitats	L	L	0	L	L

Rationale: Offshore hake (*Merluccius albidus*) are distributed over the continental shelf and slope of the Northwest Atlantic, ranging from the Grand Banks south to the Caribbean and Gulf of Mexico (Chang, Berrien, Johnson, and Zetlin 1999; Klein-MacPhee 2002f). Juveniles and adults are found in deeper waters, and are most abundant at depths between 150-380 m. They are an important component in the slope community off Florida, and are reportedly caught near the outer edge of the Scotian Shelf, and on the slopes of deep basins in the GOM and the continental slope from the southeastern edge of GB south. Because of their depth preference, very little is known about the offshore component of the stock. Moreover, offshore hake are similar in appearance to silver hake, and may have been misidentified in earlier studies. They are taken commercially as bycatch in the silver hake fishery. No information is available on substrate preferences for juveniles and adults. Eggs and larvae are pelagic, and EFH vulnerability to fishing gears is not applicable. Juvenile and adult offshore hake appear to feed at or near the bottom, and are primarily piscivorous (feeding particularly on clupeids, anchovies, and lanternfishes), but they also eat crustaceans and squid (Klein-MacPhee 2002f). There is evidence of adult diel vertical migration. Only limited information exists about this species, and none of it indicates that offshore hake have a very strong bottom affinity, or that impacts from fishing gear would affect the functional value of their habitat. Although spawning occurs near the bottom, the actual use of benthic habitat during spawning is unknown. The vulnerability of adult and juvenile EFH to otter trawls and scallop dredges is expected to be low. Vulnerability to clam dredges was rated as none since the gear does not operate in the EFH of this species.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.25. Pollock EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GOM, GB, and the following estuaries: Great Bay to Boston Harbor	30–270	October to June, peaks November to February	Pelagic waters	NA	NA	NA	NA	NA
Larvae	GOM, GB, and the following estuaries: Passamaquoddy Bay, Sheepscot R., and Great Bay to Cape Cod Bay	10–250	September to July, peaks December to February	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	GOM, GB, and the following estuaries: Passamaquoddy Bay to Saco Bay, Great Bay to Waquoit Bay, Long Island Sound, and Great South Bay	0–250		Bottom habitats with aquatic vegetation or a substrate of sand, mud, or rocks	L	L	L	L	L
Adults	GOM, GB, SNE, and middle Atlantic south to New Jersey, and the following estuaries: Passamaquoddy Bay, Damariscotta R., Massachusetts Bay, Cape Cod Bay, and Long Island Sound	15–365		Hard-bottom habitats, including artificial reefs	M	M	L	L	L
Spawning adults	GOM, SNE, and middle Atlantic south to New Jersey, including Massachusetts Bay	15–365	September to April, peaks December to February	Bottom habitats with a substrate of hard, stony, or rocky bottom; includes artificial reefs	M	M	L	L	L

Rationale: Pollock (*Pollachius virens*) range from the Hudson straits to North Carolina (Klein-MacPhee 2002a), and are most common on the Scotian Shelf, Georges Bank, the Great South Channel, and GOM (Cargnelli, Griesbach, Packer, Berrien, Johnson, *et al.* 1999). They segregate into schools by size, and avoid water warmer than about 15ºC (Klein-MacPhee 2002a). They are active fish that live at any depth between the bottom and the surface, depending upon food supply. They are associated with coastal areas and offshore shoals, and are found from shore out to depths of about 325 m, but are most common from 75-175 m (Cargnelli, Griesbach, Packer, Berrien, Johnson, *et al.* 1999). Juveniles frequently occupy the rocky intertidal zone, which may serve as a nursery area (Klein-MacPhee 2002a). Neither adults nor juveniles are selective in substrate type. Pollock are opportunistic, and the diet of both juveniles and adults consists mainly of euphausiid crustaceans, but fish, other crustaceans and squid, are also eaten (Cargnelli, Griesbach, Packer, Berrien, Johnson, *et al.* 1999; Klein-MacPhee 2002a). Adults spawn over broken bottom and the slopes of offshore banks, and eggs are pelagic. Based on food habits, and the distribution and behavior of pollock, vulnerability of juvenile EFH to benthic mobile gear was characterized as low. Since pollock spawn on the bottom, the vulnerability of adult EFH to otter trawls and scallop dredges was rated as moderate. EFH vulnerability from clam dredges was rated as low for juveniles and adults since there is limited use of this gear in pollock EFH. Pollock eggs and larvae are pelagic, so EFH vulnerability to fishing gear is not applicable.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.26. Red deepsea crab EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	Southern flank of GB and south to Cape Hatteras	200-400		Attached to the underside of the female crab until hatched--see spawning adults	NA	NA	NA	NA	NA
Larvae	Southern flank of GB and south to Cape Hatteras	200-1800	January to June	Water column from surface to seafloor	NA	NA	NA	NA	NA
Juveniles	Southern flank of GB and south to Cape Hatteras	700-1800		Bottom habitats of continental slope with a substrate of silts, clays, and all silt-clay-sand composites	L	0	0	L	L
Adults	Southern flank of GB and south to Cape Hatteras	200-1300		Bottom habitats of continental slope with a substrate of silts, clays, and all silt-clay-sand composites	L	0	0	L	L
Spawning adults	Southern flank of GB and south to Cape Hatteras	200-1300		Bottom habitats of continental slope with a substrate of silts, clays, and all silt-clay-sand composites	L	0	0	L	L

Rationale: Red deepsea crab (*Chaeceon* (*Geryon*) *quinquedens*) are found on the outer continental shelf and slope of the western Atlantic from Nova Scotia into the Gulf of Mexico (Steimle *et al.* 2001). They are found on the bottom, chiefly in water depths of 200-1800. EFH depth range for juveniles is from 700-1800 m, and for adults is from 200-1300 m. They are found on substrates ranging from silt and clay to hard substrates. Red crab are opportunistic benthic feeders/scavengers, with a diet of epifauna and other opportunistically available items (Steimle *et al.* 2001). Post-larval juveniles feed on a wide variety of infaunal and epifaunal benthic invertebrates. Small crabs eat sponges, hydroids, gastropods, and other organisms. Larger crabs eat similar small benthic fauna and larger prey including demersal and midwater fishes. The only fishery using mobile bottom gear that operates in red crab EFH is the goosefish trawl fishery (NEFMC 2002). The vulnerability of adult and juvenile red crab EFH to otter trawls was characterized as low because of their opportunistic feeding habits. Vulnerability to scallop dredges and clam dredges was rated as none since those gears do not operate in red crab EFH. Larval red crabs are pelagic and EFH vulnerability is not applicable. The "habitat" for eggs is the female carapace, therefore EFH vulnerability for this life stage is also not applicable.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.27. Red drum EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Larvae	Along the Atlantic coast from Virginia through the Florida Keys	<50		Estuarine wetlands are especially important (flooded saltmarshes, brackish marsh, tidal creeks, mangrove fringe, seagrasses)	NA	NA	NA	NA	NA
Juveniles	Along the Atlantic coast from Virginia through the Florida Keys	<50	Found throughout Chesapeake Bay from September to November	Utilize shallow backwaters of estuaries as nursery areas and remain until they move to deeper water portions of the estuary associated with river mouths, oyster bars, and front beaches	L	0	0	L	L
Adults	Along the Atlantic coast from Virginia through the Florida Keys	<50	Found in Chesapeake in spring and fall, and also along eastern shore of VA	Concentrate around inlets, shoals, and capes along the Atlantic coast; shallow bay bottoms or oyster reef substrate preferred, also nearshore artificial reefs	L	L	L	L	L

Rationale: Red drum (*Sciaenops ocellatus*) are distributed in estuarine and coastal waters depending upon their stage of maturity (McGurrin 1994). Juvenile red drum are found in shallow estuarine backwaters, and as they grow, they move to deeper areas. Submerged aquatic vegetation (SAV) is particularly important habitat for juvenile drum. Subadult and adult red drum are found on estuarine bay bottoms or oyster reefs, and in nearshore coastal waters including the beach zone out to several miles from shore. Juvenile and adult red drum have a varied diet. Smaller juveniles eat copepods and mysids, while larger individuals eat decapod crustaceans (crabs and shrimp), fish, and plant material (McGurrin 1994). Although SAV is an important habitat for juvenile red drum, EFH vulnerability to otter trawls was rated as low since its use in SAV is limited. Scallop dredges and hydraulic clam dredges usually are not used in juvenile red drum EFH; therefore, EFH vulnerability for these gears was rated as none. Since red drum feed on a variety of organisms, and adults are found in many habitat types, vulnerability of adult EFH to mobile bottom gear was rated as low. Red drum eggs and larvae are pelagic; therefore, EFH vulnerability is not applicable.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.28. Red hake EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Sheepscot R., Great Bay to Cape Cod Bay, Buzzards Bay, and Narragansett Bay		May to November, peaks in June and July	Surface waters of inner continental shelf	NA	NA	NA	NA	NA
Larvae	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Sheepscot R., Massachusetts Bay to Cape Cod Bay; Buzzards Bay, Narragansett Bay and Hudson R./ Raritan Bay	<200	May to December, peaks in September and October	Surface waters	NA	NA	NA	NA	NA
Juveniles	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay, Massachusetts Bay to Cape Cod Bay, Buzzards Bay to Connecticut. R., Hudson R./ Raritan Bay, and Chesapeake Bay	<100		Bottom habitats with substrate of shell fragments, including areas with an abundance of live sea scallops	H	H	H	L	L
Adults	GOM, GB, continental shelf off SNE, and middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Saco Bay, Great Bay, Massachusetts Bay to Cape Cod Bay, Buzzards Bay to Connecticut R., Hudson R./Raritan Bay, Delaware Bay, and Chesapeake Bay	10-130		Bottom habitats in depressions with a substrate of sand and mud	M	M	L	L	L
Spawning adults	GOM, southern edge of GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Sheepscot R., Massachusetts Bay, Cape Cod Bay, Buzzards Bay, and Narragansett Bay	<100	May to November, peaks in June and July	Bottom habitats in depressions with a substrate of sand and mud	M	M	L	L	L

Rationale: Red hake (*Urophycis chuss*) is a demersal species that ranges from southern Newfoundland to North Carolina, and is most abundant between GB and New Jersey (Steimle, Morse, Berrien, and Johnson 1999). They occur at depths between 35-980 m, and are most common between 72-124 m (Klein-MacPhee 2002a). Larvae, juveniles, and adults have been found in estuaries from Maine south to Chesapeake Bay (NEFMC 1998). Eggs and larvae are pelagic, and EFH vulnerability to bottom-tending fishing gear is not applicable. Juvenile red hake are found in live sea scallops or empty scallop shells, and are associated with other objects such as other shells, sponges, and rocks (Klein-MacPhee 2002a). Shelter appears to be a critical habitat requirement for this life stage (Able and Fahay 1998), and physical complexity, including biogenic structure other than scallop shells, may be important (Auster *et al*. 1991, 1995). Their diet consists mainly of amphipods and other infauna and epifauna. Juvenile red hake EFH is considered highly vulnerable to all three mobile gear groups. Adult red hake feed mainly on euphausiids, and consume other invertebrates and fish (Klein-MacPhee 2002a). They are found mainly on soft bottoms (sand and mud) where they create depressions or use existing depressions. They are also found on shell beds, but not on open, sandy bottom. Otter trawls and scallop dredges operate in these soft bottom and shell bed areas and have been shown to affect the structural components of these habitats. Offshore in Maryland and northern Virginia, adult red hake are found on temperate reefs and hard-bottom areas. There is a potential that otter trawls could operate in hard-bottom areas and adversely affect the functional value of these reef habitats. Vulnerability of red hake EFH to otter trawls and scallop dredges was assessed as moderate. Clam dredges would not typically operate in these hard-bottom areas, or in the softer sediments with which red hake are usually associated in the northern extent of their range, but there is some overlap between adult EFH and clam dredge use in sandy habitats. EFH vulnerability to clam dredges was characterized as low.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.29. Redfish EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	Viviparous (eggs are retained in mother, released as larvae)				NA	NA	NA	NA	NA
Larvae	GOM and southern GB	50-270	March to October, peak in August	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	GOM and southern edge of GB	25-400		Bottom habitats with a substrate of silt, mud, or hard-bottom	H	H	0	L	L
Adults	GOM and southern edge of GB	50-350		Bottom habitats with a substrate of silt, mud, or hard-bottom	M	M	0	L	L
Spawning adults	GOM and southern edge of GB	5-350	April to August	Bottom habitats with a substrate of silt, mud, or hard-bottom	M	M	0	L	L

Rationale: There are four species of redfish in the Northeast Region. They are *Sebastes fasciatus* (Acadian redfish), *S. mentella* (deepwater redfish), *S. norvegicus* (golden redfish), and *Helicolenus dactylopterus* (blackbelly rosefish). These four species are difficult to discriminate at all life stages, hence they are usually combined (Pikanowski *et al*. 1999). Acadian redfish range from Iceland to New Jersey, and deepwater redfish occur from the GOM north. Where the species overlap, the deepwater redfish occurs in deeper water. They range in depth from 25-592 m (Klein-MacPhee and Collette 2002b), with adults most common from 125-200 m, and juveniles from 75 to 175 m (Pikanowski *et al*. 1999). In general, information about redfish is very limited. Females bear live young and larvae are pelagic, so habitat vulnerability is not applicable to eggs or larvae. Redfish are found chiefly on silt, mud, or hard-bottom and rarely over sand (Pikanowski *et al*. 1999). On the Scotian Shelf, they are strongly associated with a fine-grained, silt-clay bottom (Klein-MacPhee and Collette 2002b), as well as with deposits of gravel and boulders (Pikanowski *et al*. 1999). It is hypothesized that redfish do not prefer a particular bottom type, but may be more exposed to predation over a featureless bottom due to their sedentary nature. There is limited evidence that juveniles use anemones and boulders for cover (Pikanowski *et al.* 1999). Early demersal-phase Acadian redfish have been observed to occur primarily in piled boulder habitats, while late-juvenile redfish occur in both piled boulder, gravel, and dense cerianthid anemone habitats (Auster, Lindholm, and Valentine 2003). Acadian redfish have also been observed in association with deepwater corals and sponges in the GOM (Auster 2005). Habitat vulnerability from otter trawls and scallop dredges in boulder habitats is high since gear can overturn boulders and reduce the number of crevices, as well as dislodge cerianthid anemones from the bottom. Redfish are benthic during the day, and become more active at night when they rise off the bottom, following the vertical migration of their primary euphausiid prey (Pikanowski *et al*. 1999). They also eat some benthic fish. Adult EFH was determined to be moderately vulnerable to impacts from otter trawls and scallop dredges. Clam dredges do not operate in areas of redfish EFH, so vulnerability was rated as none.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.30. Rosette skate EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	Nantucket Shoals and southern edge of GB to Cape Hatteras	33-530, mostly 74-274		Bottom habitats with soft substrate, including sand/mud bottoms, mud with echinoid and ophiuroid fragments, and shell and pteropod ooze	M	M	M	L	L
Adults	Nantucket Shoals and southern edge of GB to Cape Hatteras	33-530, mostly 74-274		Bottom habitats with soft substrate, including sand/mud bottoms, mud with echinoid and ophiuroid fragments, and shell and pteropod ooze	M	M	M	L	L

Rationale: Rosette skate (*Leucoraja garmani virginica*) is a deeper water species that occurs along the outer shelf and continental slope from Nantucket Shoals to the Dry Tortugas, Florida. North of Cape Hatteras, it is most abundant in the southern section of the Chesapeake Bight. It occurs on soft bottoms, including sand and mud, at depths from 33-530 m, and is most common between 74-274 m (Packer *et al*. 2003d). Major prey items include polychaetes, copepods, cumaceans, amphipods, *Crangon*, crabs, squid, octopods, and small fishes. A single fertilized egg is encapsulated in a leathery case. Egg cases are found in mature females most frequently in the summer (Packer *et al*. 2003d). Information on rosette skate is very limited. Because of the limited information available, the apparent dependence of the juveniles of this species on benthic organisms in its diet, and the reproductive habits of the adults, EFH vulnerability to mobile bottom gear was characterized as moderate.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.31. Scup EFH-vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	**Geographic Area of EFH**[a]	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability**[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	SNE to coastal Virginia, including the following estuaries: Waquoit Bay to Long Island Sound, Gardiners Bay, and Hudson R./Raritan Bay	(<30)	May to August	Pelagic waters in estuaries	NA	NA	NA	NA	NA
Larvae	SNE to coastal Virginia, including the following estuaries: Waquoit Bay to Long Island Sound, Gardiners Bay, and Hudson R./Raritan Bay	(<20)	May to September	Pelagic waters in estuaries	NA	NA	NA	NA	NA
Juveniles	Continental shelf from GOM to Cape Hatteras, including the following estuaries: Massachusetts Bay, Cape Cod Bay to Long Island Sound, Gardiners Bay to Delaware inland bays, and Chesapeake Bay	(0-38)	Spring and summer in estuaries and bays	Demersal waters north of Cape Hatteras; inshore on various sand, mud, mussel, and eelgrass bed substrates	M	M	M	L	L
Adults	Continental shelf from GOM to Cape Hatteras, including the following estuaries: Cape Cod Bay to Long Island Sound, Gardiners Bay to Hudson R./Raritan Bay, Delaware Bay, Delaware inland bays, and Chesapeake Bay	(2-185)	Wintering adults (November to April) are usually offshore, south of New York to North Carolina	Demersal waters north of Cape Hatteras; inshore estuaries on various substrate types	L	L	L	L	L

Rationale: Scup (*Stenotomus chrysops*) is a temperate species that occurs primarily from Massachusetts to South Carolina, although it has been reported as far north as the Bay of Fundy and Sable Island Bank (Steimle, Zetlin, Berrien, Johnson, and Chang 1999a). Scup are primarily benthic feeders that use a variety of habitat types. Juveniles forage on epibenthic amphipods, other small crustaceans, polychaetes, mollusks, and fish eggs and larvae. They occur over a variety of substrates, and are most abundant in areas without structure. Limited observations of scup have shown periodic use of seafloor depressions for cover (Auster *et al*. 1991, 1995). Adults are found on soft bottoms or near structures. During the summer, they are closer inshore and are found on a wider range of habitats. In the winter, they congregate offshore in areas that are expected to serve as a thermal refuge (Klein-McPhee 2002c), particularly in deeper waters of the outer continental shelf and around canyon heads. Smaller adults feed on echinoderms, annelids, and small crustaceans. Larger scup consume more squids and fishes. Since juvenile scup are primarily benthic feeders, their EFH was rated as moderately vulnerable to impacts from mobile bottom gear. EFH vulnerability for adults was rated as low since there is less of a reliance on benthic prey items.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.32 Sea scallop EFH -- vulnerability to effects of bottom-tending fishing and rationale for evaluations

Life Stage	Geographic Area of EFH^a	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability^b				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GOM, GB, SNE, middle Atlantic south to Virginia-North Carolina border, and the following estuaries: Passamaquoddy Bay to Sheepscot R., Casco Bay, Massachusetts Bay, and Cape Cod Bay		May through October, peaks in May and June in middle Atlantic area, and in Sept. and Oct. on GB and in GOM	Bottom habitats	L	L	L	L	L
Larvae	GOM, GB, SNE, middle Atlantic south to Virginia-North Carolina border, and the following estuaries: Passamaquoddy Bay to Sheepscot R., Casco Bay, Massachusetts Bay, and Cape Cod Bay			Pelagic waters	NA	NA	NA	NA	NA
				Bottom habitats with a substrate of gravelly sand, shell fragments, pebbles, or on various red algae, hydroids, amphipod tubes, and bryozoans	L	L	L	L	L
Juveniles	GOM, GB, SNE, middle Atlantic south to Virginia-North Carolina border, and the following estuaries: Passamaquoddy Bay to Sheepscot R., Casco Bay, Great Bay, Massachusetts Bay, and Cape Cod Bay	18-110		Bottom habitats with a substrate of cobble, shells, and silt	L	L	L	L	L
Adults	GOM, GB, SNE, middle Atlantic south to Virginia-North Carolina border, and the following estuaries: Passamaquoddy Bay to Sheepscot R., Casco Bay, Great Bay, Massachusetts Bay, and Cape Cod Bay	18-110		Bottom habitats with a substrate of cobble, shells, coarse/gravelly sand, and sand	L	L	L	L	L
Spawning adults	GOM, GB, SNE middle Atlantic south to Virginia-North Carolina border, and the following estuaries: Passamaquoddy Bay to Sheepscot R., Casco Bay, Massachusetts Bay, and Cape Cod Bay	18-110	May through October, peaks in May and June in middle Atlantic area, and in Sept. and Oct. on GB and in GOM	Bottom habitats with a substrate of cobble, shells, coarse/gravelly sand, and sand	L	L	L	L	L

Rationale: Juvenile and adult sea scallops (*Placopecten magellanicus*) are found on the continental shelf of the Northwest Atlantic, from the Gulf of St. Lawrence south to Cape Hatteras, typically between 18 and 110 m, but also as shallow as 2 m in estuaries and embayments along the Maine coast, and as deep as 384 m (Packer, Cargnelli, *et al.* 1999). In the GOM, populations have been reported at depths of 170-180 m. Scallops are rarely found at depths <55 m in "southern areas." Scallop eggs are slightly heavier than seawater and are thought to remain on the bottom during development, but bottom habitats have no known functional value for eggs, and therefore, their vulnerability to fishing was rated as low for all gear types. There are four pelagic larval stages, and EFH vulnerability to fishing gear impacts for these larval stages is not applicable. However, the last larval stage is benthic; at this stage, larvae settle to the bottom (as "spat") and attach to hard surfaces (Packer, Cargnelli, *et al.* 1999). Settlement occurs in areas of gravelly sand with shell fragments. Spat are very delicate and do not survive on shifting sand bottoms. The availability of suitable surfaces on which to settle appears to be a primary requirement for successful reproduction (Packer, Cargnelli, *et al.* 1999). There is a close association between the bryozoan *Eucratea loricata* and spat. *Eucratea* attach to adult scallops, and have been found to contain large numbers of spat. EFH for benthic-phase larvae was given a low rating for vulnerability to all three mobile gear types because any disturbance of the bottom they would cause would most likely redistribute bottom sediments suitable for settlement (gravel, pebbles, shell fragments), but not reduce their availability. Juveniles are found mainly on gravel, small rocks, shells, and silt. During their second growing season (5-12 mm), sea scallops become mobile and leave the original substrate on which they settled, and then re-

Table 6.32 Sea scallop EFH -- vulnerability to effects of bottom-tending fishing and rationale for evaluations

Life Stage	**Geographic Area of EFH[a]**	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability[b]**				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
attach to shells and bottom debris. Otter trawls, scallop dredges, and hydraulic clam dredges are used in bottom habitats occupied by juvenile scallops, but the disturbance of the seafloor caused by these gears does not adversely affect the functional value of the habitat and, therefore, the vulnerability of juvenile scallop EFH to mobile benthic gears was rated as low. The same conclusion was reached for fixed gear which cause negligible disturbance to the seafloor. Juveniles and adults are found in benthic habitats with at least some water movement, which is critical for feeding, oxygen and removal of waste; optimal growth for adults occurs at 10 cm/sec (Packer, Cargnelli, *et al.* 1999). Adult scallops inhabit coarse substrates, usually gravel, shell, and rock. Because fine clay particles interfere with feeding activity, scallops are not usually found on muddy bottom. No scientific information exists that indicates mobile fishing gears have a negative impact on the functional value of adult scallop EFH. The vulnerability of adult scallop EFH to mobile benthic gears was therefore rated as low.									

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.33. Silver hake EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Merrimack R. to Cape Cod Bay	50–150	All year, peaks June to October	Surface waters	NA	NA	NA	NA	NA
Larvae	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Massachusetts Bay to Cape Cod Bay	50–130	All year, peaks July to September	Surface waters	NA	NA	NA	NA	NA
Juveniles	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Passamaquoddy Bay to Casco Bay, and Massachusetts Bay to Cape Cod Bay	20–270		Bottom habitats of all substrate types	M	M	M	L	L
Adults	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Passamaquoddy Bay to Casco Bay, and Massachusetts Bay to Cape Cod Bay	30–325		Bottom habitats of all substrate types	L	L	L	L	L
Spawning adults	GOM, GB, continental shelf off SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Massachusetts Bay and Cape Cod Bay	30–325		Bottom habitats of all substrate types	L	L	L	L	L

Rationale: Silver hake or whiting (*Merluccius bilinearis*) range from Newfoundland south to Cape Fear, NC, and are most common from Nova Scotia to New Jersey (Morse *et al*. 1999). They are distributed broadly, and are found from nearshore shallows out to a depth of 400 m (Klein-MacPhee 2002f). All life stages have been found in estuaries from Maine to Cape Cod Bay (Morse *et al*. 1999). The vertical movement of silver hake is governed chiefly by their pursuit of prey; both juveniles and adults show a vertical migration off the bottom at night when feeding activity is greatest. In the Mid-Atlantic Bight, juvenile silver hake have been found in greater densities in areas with greater amphipod tube cover (Auster *et al*. 1997). Further, silver hake size distributions in sand wave habitats are positively correlated with sand wave period (*i.e.*, the spacing between sand waves), suggesting energetic or prey capture benefits in particular sand wave environments (Auster, Lindholm, Schaub, *et al.* 2003). Juveniles are primarily found on silt or sand substrate, and feed mainly on crustaceans, including copepods, amphipods, euphausiids, and decapod crustaceans (Morse *et al*. 1999). The vulnerability of juvenile EFH to mobile gear was rated as moderate because of the potential connection between structure and habitat suitability for this life stage. Adult silver hake rest on the bottom in depressions by day, primarily over sand and pebble bottoms, and rarely in rockier areas. In the Mid-Atlantic Bight, adults were found on flat sand, sand wave crests, shell, and biogenic depressions, but were most often found on flat sand. At night, adults feed on anchovies, herring, lanternfish, and other fishes (Klein-MacPhee 2002f). Piscivory increases with size for this species. Vulnerability of adult silver hake EFH to the three mobile gear types was rated as low because of silver hake's piscivorous food habits and preference for higher energy sand environments which recover quickly from fishing gear impacts (see Chapter 5 of this document). Eggs and larvae of this species are pelagic, so habitat vulnerability to fishing gear is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.34. Smooth skate EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	Offshore banks of GOM	31–874, mostly 110-457		Bottom habitats with a substrate of soft mud (silt and clay), sand, broken shells, gravel, and pebbles	M	M	0	L	L
Adults	Offshore banks of GOM	31–874, mostly 110-457		Bottom habitats with a substrate of soft mud (silt and clay), sand, broken shells, gravel, and pebbles	H	H	0	L	L

Rationale: Smooth skate's (*Malacoraja senta*) center of abundance is the GOM. It occurs along the Atlantic coast from the Gulf of St. Lawrence south to South Carolina, at depths between 31-874 m (Packer *et al*. 2003e). It is most abundant between 110-457 m. Analysis of NEFSC trawl survey data found juvenile skate most abundant between depths of 100 -300 m during 1963-1969. Smooth skate are found mostly over soft mud and clay of the GOM's deepwater basins, but also over the gulf's offshore banks with substrates of sand, shell, and/or gravel (Packer *et al*. 2003e). The diet of smooth skate is generally limited to epifaunal crustaceans, with decapod shrimp and euphausids as the most common prey, followed by amphipods and mysids. The diet shifts from amphipods and mysids to decapod crustaceans as smooth skate grow (Packer *et al*. 2003e). The diet of smooth skate is more restricted than that of other skate species (McEachran 2002). The vulnerability of juvenile smooth skate EFH to otter trawls and scallop dredges was characterized as moderate because of the dietary habits of this species. The vulnerability of adult EFH was rated as high for otter trawls and scallop dredges because of the benthic diet as well as the reproductive habits of the species. Vulnerability to clam dredges was considered to be none for juveniles and adults since this gear is not used in the GOM.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.35 Spanish mackerel EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
All life stages	South Atlantic and Mid-Atlantic Bights			Sandy shoals of capes and offshore bars; high-profile rock bottoms and barrier island oceanside waters from surf zone to shelf break, but from the Gulf Stream shoreward	NA	NA	NA	NA	NA

Rationale: All life stages of Spanish mackerel (*Scomberomorus maculatus*) are pelagic, so their EFH is not vulnerable to bottom-tending fishing gear, and vulnerability is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.36. Spiny dogfish EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	Across the continental shelf from GOM to Cape Hatteras, and south of Cape Hatteras through Florida; also includes the following estuaries: Passamaquaddy Bay to Saco Bay; Massachusetts Bay, and Cape Cod Bay	10-390		Continental shelf waters and estuaries	L	L	L	L	L
Adults	Across the continental shelf from GOM to Cape Hatteras, and south of Cape Hatteras through Florida; also includes following estuaries: Passamaquaddy Bay to Saco Bay, Massachusetts Bay, and Cape Cod Bay	10-450		Continental shelf waters and estuaries	L	L	L	L	L

Rationale: The spiny dogfish (*Squalus acanthias*) is a coastal shark with a circumboreal distribution, and is one of the most abundant sharks in the western North Atlantic (McMillan and Morse 1999). Female dogfish are viviparous, so EFH designations were limited to juveniles and adults. Smaller dogfish have been reported to feed primarily on crustaceans, with an increase in piscivory in larger individuals (Burgess 2002). Fish, mainly schooling pelagic species, constitute 50% of their diet. Their voracious and opportunistic feeding behavior was emphasized by McMillan and Morse (1999). Since neither of these life stages appears to be closely tied to benthic organisms, the vulnerability of their EFH to mobile gear was rated as low.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.37. Summer flounder EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description		EFH Vulnerability[b]				
						Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	Over continental shelf from GOM to Florida	30-70 in fall; 110 in winter; 9-30 in spring	October to May	Pelagic waters; heaviest concentrations within 9 mi of shore off New Jersey and New York		NA	NA	NA	NA	NA
Larvae	Over continental shelf from GOM to Florida; also includes the following estuaries: Waquoit Bay to Narragansett Bay, Hudson R./Raritan Bay, Barnegat Bay, Chesapeake Bay, Rappahannock R., York R., James R., Albemarle Sound, Pamlico Sound, and Neuse R. to Indian R.	10-70	Mid-Atlantic Bight from September to February; southern part of range from November to May at depths of 9-30 m	Pelagic waters; larvae most abundant 19-83 km from shore		NA	NA	NA	NA	NA
Juveniles	Over continental shelf from GOM to Florida; also includes the following estuaries: Waquoit Bay to James R., and Albemarle Sound to Indian R.	0.5–5 in estuary		Demersal waters, on muddy substrate but prefer mostly sand; found in the lower estuaries in flats, channels, salt marsh creeks, and eelgrass beds	HAPC	H	0	0	NA	NA
					Non-HAPC	L	L	L	0	0
Adults	Over continental shelf from GOM to Florida; also includes the following estuaries: Buzzards Bay, Narragansett Bay, Connecticut R. to James R., Albemarle Sound to Broad R.; St. Johns R., and Indian R.	0-25	Shallow coastal and estuarine waters during warmer months; move offshore on outer continental shelf at depths of 150 m in colder months	Demersal waters and estuaries	HAPC	H	0	0	NA	NA
					Non-HAPC	L	L	L	0	0

Rationale: Summer flounder (*Paralichthys dentatus*) occur in the shallow estuarine waters and outer continental shelf from Nova Scotia to Florida, with the center of their range located in the Mid-Atlantic Bight (Packer, Griesbach, *et al*. 1999). Juvenile summer flounder are opportunistic feeders, and their diet includes fish, mysids, and some other crustaceans (Packer, Griesbach, *et al*. 1999). There are gradual changes in the diet of summer flounder, with fish becoming more important as a food source as individuals get older and larger. Adults are also opportunistic feeders, with fish and crustaceans making up a significant portion of their diet. Eelgrass and macroalgae beds have been designated as habitat areas of particular concern (HAPC) for adult and juvenile summer flounder. Stephan *et al*. (2000) determined that otter trawls could result in below-ground impacts to submerged aquatic vegetation (SAV), which, of all the impacts to SAV possible from fishing gear, was ranked as the impact of greatest concern. Based on potential impacts to SAV, the vulnerability of the summer flounder HAPC to otter trawls was rated as high. Sea scallop and surfclam/quahog dredges are not used in estuaries where SAV is found. Fixed, bottom-tending gears, such as pots, traps, and sink gillnets, may be used in inshore SAV beds, but if so, their use is not federally-regulated. Thus, the vulnerability of juvenile and adult HAPCs to the effects of these gear types is not applicable. Since adults and juveniles are both opportunistic feeders, the vulnerability of EFH that is not designated as HAPC was rated as low for bottom trawls and dredges. Summer flounder eggs and larvae are pelagic, so EFH vulnerability is not applicable.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.38. Thorny skate EFH--vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Juveniles	GOM and GB	18-2000, mostly 111-366		Bottom habitats with a substrate of sand, gravel, broken shell, pebbles, and soft mud	M	M	0	L	L
Adults	GOM and GB	18-2000, mostly 111-366		Bottom habitats with a substrate of sand, gravel, broken shell, pebbles, and soft mud	M	M	0	L	L

Rationale: Thorny skate (*Amblyraja radiata*) range from Greenland south to South Carolina. In the Northeast Region, this species is most commonly seen in the GOM and on the Northeast Peak and in the northern portion of the Great South Channel of GB. It is one of the most common skates in the GOM, and occurs over a wide variety of bottom substrates, including sand, gravel, and broken shell to mud (Packer *et al*. 2003f). It is found at depths ranging from 18-1200 m, and is reported to be most common between 50-350 m. A single fertilized egg is encapsulated in an egg case. Females with fully formed egg cases have been captured year-round, though the percentage of mature females with egg cases is higher in the summer (Packer *et al*. 2003f). The primary prey of thorny skates are polychaetes and decapod crustaceans, followed by amphipods and euphausiids. Fish and mysids are also consumed in lesser quantities. According to a survey from Nova Scotia to Cape Hatteras, thorny skate prey varies with skate size. Skates less than 40 cm total length feed mostly on amphipods, skates greater than 40 cm fed on polychaetes and decapod crustaceans, and fishes were a major dietary component for skates larger than 70 cm. In general, with increasing size, mysids decreased in the diet while fishes increased (Packer *et al*. 2003f). Since juvenile thorny skate appear to be more reliant on benthic invertebrates, vulnerability of EFH to otter trawls and scallop dredges for this life stage was characterized as moderate. For adults, EFH vulnerability to otter trawls and scallop dredges was characterized as moderate because of their reproductive habits. EFH vulnerability to clam dredges was rated as none for juveniles and adults since there is no overlap between thorny skate EFH and areas in which clam dredges are used.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.39. Tilefish EFH--vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	U.S./Canadian boundary to Virginia/North Carolina boundary (shelf break: GB to Cape Hatteras)	76-365	Serial spawning from March to November; peaks during April to October	Water column	NA	NA	NA	NA	NA
Larvae	U.S./Canadian boundary to Virginia/North Carolina boundary (outer continental shelf: GB to Cape Hatteras)	76-365	February to October; peaks during July to October	Water column	NA	NA	NA	NA	NA
Juveniles	U.S./Canadian boundary to Virginia/North Carolina boundary (shelf break, submarine canyon walls, and flanks: GB to Cape Hatteras)	76-365	All year; may leave GB in winter	Rough bottom, small burrows, and sheltered areas; substrate rocky, stiff clay, human debris	H	L	0	L	L
Adults	U.S./Canadian boundary to Virginia/North Carolina boundary (shelf break, submarine canyon walls, and flanks: GB to Cape Hatteras)	76-365	All year; may leave GB in winter	Rough bottom, small burrows, and sheltered areas; substrate rocky, stiff clay, human debris	H	L	0	L	L

Rationale: Tilefish (*Lopholatilus chamaeleonticeps*) are restricted to the continental shelf break south of the Gulf of Maine (Steimle, Berrien, Johnson and Chang 1999). They occupy a number of habitats, including scour basins around rocks or other rough bottom areas that form burrow-like cavities, and pueblo habitats in clay substrate. The dominant habitat type is a vertical burrow in a substrate of semi-hard silt-clay, 2 - 3 m deep and 4 - 5 m in diameter with a funnel shape. These burrows are excavated by tilefish, secondary burrows are created by other organisms, including lobsters, conger eels, and galatheid crabs. Tilefish are visual daytime feeders on galatheid crabs, mollusks, shrimps, polychaetes, and occasionally fish. Mollusks and echinoderms are more important to smaller tilefish. Little is known about juveniles of the species. A report to the Mid-Atlantic Fishery Management Council (Able and Muzeni 2002), based upon a review of archived video surveys in areas of tilefish habitat, did not find visual evidence of direct impacts to burrows due to otter trawls. The Northeast Region EFH Steering Committee Workshop (NREFHSC 2002) concluded that there was the potential for a high degree of impact to the physical structure of hard clay outcroppings (pueblo village habitat) by trawls that would result in permanent change to a major physical feature which provides shelter for tilefish as well as their benthic prey. Although Able and Muzeni's (2002) review did not offer any evidence of this type of negative effect, their sample size for this habitat type was very small. Due to the tilefish's reliance on structured shelter and benthic prey, as well as the benthic prey's reliance on much of the same habitat, and the need for further study, the vulnerability of tilefish EFH to otter trawls was ranked as high. Clam dredges operate in shallow, sandy waters typically uninhabited by tilefish, so EFH vulnerability was rated as none for this gear. Scallop vessel monitoring data (Section 4) indicate that scallop dredges operate to a small extent in areas overlapping tilefish EFH; therefore, EFH vulnerability to scallop dredges was ranked as low. Tilefish eggs and larvae are pelagic; therefore, EFH vulnerability is not applicable.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.40. White hake EFH-vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	New Bedford-Style Scallop Dredge	Hydraulic Clam Dredge	Pots and Traps	Sink Gill Nets and Bottom Longlines
Eggs	GOM, GB, SNE, and the following estuaries: Great Bay to Cape Cod Bay		August to September	Surface waters	NA	NA	NA	NA	NA
Larvae	GOM, southern edge of GB, SNE to middle Atlantic, and the following estuaries: Massachusetts Bay to Cape Cod Bay		May in mid-Atlantic area, August and September in GOM, GB area	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	GOM, southern edge of GB, SNE to middle Atlantic, and the following estuaries: Passamaquoddy Bay to Great Bay, and Massachusetts Bay to Cape Cod Bay	5-225	May to September	Pelagic stage--pelagic waters; demersal stage--bottom habitat with seagrass beds or substrate of mud or fine-grained sand	M	M	0	L	L
Adults	GOM, southern edge of GB, SNE to middle Atlantic, and the following estuaries: Passamaquoddy Bay to Great Bay, and Massachusetts Bay to Cape Cod Bay	5-325		Bottom habitats with substrate of mud or fine-grained sand	L	L	0	L	L
Spawning adults	GOM, southern edge of GB, SNE to middle Atlantic	5-325	April to May, southern part of range; August to September, northern part of range	Bottom habitats with substrate of mud or fine-grained sand in deepwater	L	L	0	L	L

Rationale: White hake (*Urophycis tenuis*) adults co-occur geographically with red hake, and their habits are similar, but white hake are distributed in a wider range of depths and temperatures (Chang, Morse, *et al*. 1999; Klein-MacPhee 2002a). They are found from Labrador south to North Carolina, and occasionally stray as far as Florida and Iceland. They inhabit coastal estuaries and occur across the continental shelf to the submarine canyons along the upper continental shelf, and in the basins of the GOM. Adult distribution in the region is focused in the GOM and along the southern slope of Georges Bank. All life stages are found in estuaries near the GOM (NEFMC 1998). Most pelagic juveniles cross the shelf and enter estuaries from Canada south to the Mid-Atlantic Bight, although some may also settle to the bottom in unknown shelf habitats (Klein-MacPhee 2002a). Demersal juveniles are found in nearshore waters out to a depth of about 225 m (Chang, Morse, *et al*. 1999). Eelgrass is an important habitat for juveniles, but its functional importance is unknown; this life stage is not necessarily dependent upon structure (Able and Fahay 1998). Young-of-the-year white hake feed mainly on shrimp, mysids, and amphipods. Since otter trawls and scallop dredges can negatively impact eelgrass (Stephan *et al*. 2000) in estuaries, vulnerability of juvenile white hake EFH to these gears was characterized as moderate. Hydraulic clam dredges are not utilized in estuaries of the GOM, so vulnerability to this gear was rated as none. Adults prefer benthic deposits of fine-grained sediments (Chang, Morse, *et al*. 1999). They feed primarily on fish, cephalopods, and crustaceans. Since they are not benthivores and have not been documented to use benthic habitats for cover, EFH vulnerability to otter trawls and scallop dredges was characterized as low. Clam dredges are not operated in areas of adult EFH, and vulnerability to this gear was rated as none.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.41. Windowpane EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH[a]	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GOM, GB, SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Passamaquoddy Bay to Great Bay, and Massachusetts Bay to Delaware inland bays	<70	February to November, peaks May and October in middle Atlantic, July to August on GB	Surface waters	NA	NA	NA	NA	NA
Larvae	GOM, GB, SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Passamaquoddy Bay to Great Bay, and Massachusetts Bay to Delaware inland bays	<70	February to November, peaks May and October in middle Atlantic, July to August on GB	Pelagic waters	NA	NA	NA	NA	NA
Juveniles	GOM, GB, SNE, middle Atlantic south to Cape Hatteras, and the following estuaries: Passamaquoddy Bay to Great Bay, and Massachusetts Bay to Chesapeake Bay	1-100		Bottom habitats with substrate of mud or fine-grained sand	L	L	L	L	L
Adults	GOM, GB, SNE, middle Atlantic south to Virginia/North Carolina border, and the following estuaries: Passamaquoddy Bay to Great Bay, and Massachusetts Bay to Chesapeake Bay	1-75		Bottom habitats with substrate of mud or fine-grained sand	L	L	L	L	L
Spawning adults	GOM, GB, SNE, middle Atlantic south to Virginia/North Carolina border, and the following estuaries: Passamaquoddy Bay to Great Bay, and Massachusetts Bay to Delaware inland bays	1-75	February to December, peak in May in middle Atlantic	Bottom habitats with substrate of mud or fine-grained sand	L	L	L	L	L

Rationale: Windowpane flounder (*Scophthalmus aquosus*) is distributed in coastal waters from the Gulf of St. Lawrence to Florida, and are most abundant on GB and in the New York Bight (Klein-MacPhee 2002b). Windowpane are abundant in estuaries from Maine through Chesapeake Bay (NEFMC 1998). They are a shoal-water fish, with a depth range of up to 200 m, but are most abundant in waters less than 50 m deep. Both juveniles and adults are found on muddy sediments in the GOM, and fine, sandy sediments on GB and in New England and the Mid-Atlantic Bight. Mysids are the main prey item of juveniles (Klein-MacPhee 2002b). Adults have been shown to feed exclusively on nekton and show little need for bottom structure (Chang, Berrien, Johnson, and Morse 1999). EFH vulnerability to the three types of mobile gear was rated as low for both these life stages. Windowpane eggs and larvae are pelagic, so EFH vulnerability to fishing gear is not applicable for these two life stages.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.42. Winter flounder EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	Geographic Area of EFH^a	Depth (m)	Seasonal Occurrence	EFH Description	EFH Vulnerability^b				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GB, inshore areas of GOM, SNE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware inland bays	<5	February to June, peak in April on GB	Bottom habitats with a substrate of sand, muddy sand, mud, and gravel	L	L	L	L	L
Larvae	GB, inshore areas of GOM, SNE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware inland bays	<6	March to July, peak in April and May on GB	Pelagic and bottom waters	L	L	L	L	L
Juveniles	GB, inshore areas of GOM, SNE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Chincoteague Bay	0.1–10 (1-50, age 1+)		Bottom habitats with a substrate of mud or fine-grained sand	L	L	L	L	L
Adults	GB, inshore areas of GOM, SNE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Chincoteague Bay	1-100		Bottom habitats including estuaries with substrates of mud, sand, gravel	M	M	M	L	L
Spawning adults	GB, inshore areas of GOM, SNE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware inland bays	<6	February to June	Bottom habitats including estuaries with substrates of mud, sand, gravel	M	M	M	L	L

Rationale: Winter flounder (*Pseudopleuronectes americanus*) range from Labrador to Georgia, and are most abundant from the Gulf of St. Lawrence to Chesapeake Bay (Klein-MacPhee 2002d). Juveniles and adults are found in waters less than 100 m deep, and most are found from shore to 30 m. They range far upstream in estuaries, and have been found in freshwater. Winter flounder lay demersal adhesive eggs in shallow water less than 5 m in depth, with the exception of spawning areas on GB and Nantucket shoals (Pereira *et al*. 1999). Substrates include sand, muddy sand, mud, and gravel, with sand the most common. Although otter trawls, scallop dredges, and clam dredges may affect the eggs directly, this was not considered a habitat impact. Since there is no indication that the eggs rely on any structure, egg EFH vulnerability to these three gears was rated as low. Since early stage larvae are associated with the bottom and are at times demersal (Able and Fahay 1998), larval EFH vulnerability to all gears was also rated as low instead of none. Juvenile and adult winter flounder are found on mud and sand substrates, and adults are seen on cobble, rocks, and boulders (Pereira *et al*. 1999). Both life stages can be opportunistic feeders, however, their main prey items are infaunal invertebrates. Because of their reliance on infauna and their ability to use alternative food supplies, EFH vulnerability to the three mobile gear types for these life stages was ranked as moderate.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.43. Winter skate EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	**Geographic Area of EFH**[a]	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability**[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Juveniles	Cape Cod Bay, GB, SNE shelf through Mid-Atlantic Bight to North Carolina; includes estuaries from Buzzards Bay south to Chesapeake Bay	0-37, mostly <111		Bottom habitats with substrate of sand and gravel or mud	M	M	M	L	L
Adults	Cape Cod Bay, GB SNE shelf through Mid-Atlantic Bight to North Carolina; includes estuaries from Buzzards Bay south to Chesapeake Bay	0-371, mostly <111		Bottom habitats with substrate of sand and gravel or mud	M	M	M	L	L

Rationale: Winter skate (*Leucoraja ocellata*) are found from Newfoundland south to Cape Hatteras. They are most abundant on GB and in coastal waters south to the mouth of the Hudson River. They are found over substrates of sand, gravel, and mud, in depths from shore out to 371 m, and are most common in <111 m of water (Packer *et al*. 2003g). Females deposit single fertilized eggs in egg capsules, which are deposited on the bottom during summer in the northern portion of the range. Deposition has been reported to extend through January off SNE. Young are fully developed at hatching (Packer *et al*. 2003g). Polychaetes and amphipods are the most important prey items, followed by decapod crustaceans, isopods, bivalves, and fish. In general, crustaceans make up over 50% of the diet for skate smaller than 61 cm, and fish and bivalves are a major component of the diet for skates larger than 79 cm (Packer *et al*. 2003g). Crustaceans generally declined in importance with increasing skate size, while polychaetes increased, until skates reached 81 cm. Since juvenile winter skate appear to be more reliant on benthic invertebrates, vulnerability of EFH to mobile gear for this life stage was characterized as moderate. For adults, EFH vulnerability to mobile gear was characterized as moderate because of their reproductive habits.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.44. Witch flounder EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	**Geographic Area of EFH[a]**	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability[b]**				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GOM, GB, continental shelf off SNE, and middle Atlantic south to Cape Hatteras	Deep	March to October	Surface waters	NA	NA	NA	NA	NA
Larvae	GOM, GB, continental shelf off SNE, and middle Atlantic south to Cape Hatteras	Deep	March to November, peaks from May to July	Surface waters	NA	NA	NA	NA	NA
Juveniles	GOM and outer continental shelf from GB south to Cape Hatteras	50-450		Bottom habitats with fine-grained substrate	M	L	0	L	L
Adults	GOM and outer continental shelf from GB south to Chesapeake Bay	25-300		Bottom habitats with fine-grained substrate	M	L	L	L	L
Spawning adults	GOM and outer continental shelf from GB south to Chesapeake Bay	25-360	March to November, peaks from May to August	Bottom habitats with fine-grained substrate	M	L	L	L	L

Rationale: Witch flounder (*Glyptocephalus cynoglossus*) range from Newfoundland south to Cape Hatteras. In U.S. waters, this species is common throughout the GOM, and is found in the deeper areas of and adjacent to GB and along the continental shelf edge and upper slope (Cargnelli, Griesbach, Packer, Berrien, Morse, *et al.* 1999, Klein-MacPhee 2002d). Juvenile and adult witch flounder are found mainly over fine muddy sand, or mud. Their diet is comprised mainly of polychaetes, and they feed on other invertebrates as well (Cargnelli , Griesbach, Packer, Berrien, Morse, *et al.* 1999). Since these life stages occur in areas of lower natural disturbance and rely on infauna, EFH vulnerability to impacts from otter trawls were rated as moderate. Impacts from scallop dredging may be less severe, since scallop dredges are not usually used in muddy habitat; however, vessel trip reports indicated scallop dredging in areas of witch flounder EFH (see Chapter 4 of this document). Therefore, vulnerability to scallop dredges was rates as low. Juvenile EFH vulnerability to clam dredges was rated as none since clam dredges are not used in mud or in water depths where juvenile witch flounder are primarily found. However, EFH vulnerability to clam dredges for adults was rated as low since clam dredges do operate in adult EFH. Eggs and larvae of witch flounder are pelagic, so vulnerability of EFH to fishing gear impacts is not applicable.

a EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.
b EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

Table 6.45. Yellowtail flounder EFH -- vulnerability to effects of bottom-tending fishing gears and rationale for evaluations

Life Stage	**Geographic Area of EFH**[a]	**Depth (m)**	**Seasonal Occurrence**	**EFH Description**	**EFH Vulnerability**[b]				
					Otter Trawl	**New Bedford-Style Scallop Dredge**	**Hydraulic Clam Dredge**	**Pots and Traps**	**Sink Gill Nets and Bottom Longlines**
Eggs	GB, Massachusetts Bay, Cape Cod Bay, SNE continental shelf south to Delaware Bay, and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay to Cape Cod Bay	30-90	Mid-March to July, peaks in April to June in SNE	Surface waters	NA	NA	NA	NA	NA
Larvae	GB, Massachusetts Bay, Cape Cod Bay, SNE continental shelf, middle Atlantic south to Chesapeake Bay, and the following estuaries: Passamaquoddy Bay to Cape Cod Bay	10-90	March to April in New York Bight; May to July in SNE and southeastern GB	Surface waters	NA	NA	NA	NA	NA
Juveniles	GB, GOM, SNE continental shelf south to Delaware Bay, and the following estuaries: Sheepscot R., Casco Bay, Massachusetts Bay to Cape Cod Bay	20-50		Bottom habitats with substrate of sand or sand and mud	M	M	M	L	L
Adults	GB, GOM, SNE continental shelf south to Delaware Bay, and the following estuaries: Sheepscot R., Casco Bay, Massachusetts Bay to Cape Cod Bay	20-50		Bottom habitats with substrate of sand or sand and mud	M	M	M	L	L
Spawning adults	GB, GOM, SNE continental shelf south to Delaware Bay, and the following estuaries: Massachusetts Bay to Cape Cod Bay	10-125		Bottom habitats with substrate of sand or sand and mud	M	M	M	L	L

Rationale: Yellowtail flounder (*Limanda ferruginea*) are found from the Gulf of St. Lawrence south to the Chesapeake Bay (Johnson *et al*. 1999; Klein-MacPhee 2002d). They are most abundant on the western half of GB, western GOM, east of Cape Cod, and off SNE (Johnson *et al*. 1999). Their usual depth range is from 10-100 m (Klein-MacPhee 2002d). Juveniles and adults are found in some New England estuaries, while eggs and larvae are found more frequently in these habitats (NEFMC 1998). Yellowtail eggs and larvae are pelagic, so EFH vulnerability is not applicable. Yellowtail flounder feed mainly on benthic macrofauna, primarily amphipods and polychaetes (Johnson *et al*. 1999). Adults eat mostly crustaceans while juveniles focus on polychaetes. Both life stages are found on substrates of sand or sand and mud. Vulnerability of juvenile and adult EFH to the three types of mobile gear was rated as moderate because of the potential effect of these gears on infaunal yellowtail prey.

[a] EFH Geographic Areas: GOM = Gulf of Maine; GB = Georges Bank; and SNE = Southern New England.

[b] EFH Vulnerability Category (derived from the matrix analysis in Table 6.1): NA = not applicable; 0 = no vulnerability; L = low vulnerability; M = moderate vulnerability; and H = high vulnerability.

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Tables should be prepared with a table formatting function. Each figure should be supplied both on paper and on disk, unless there is no digital file of a given figure. Except under extraordinary circumstances, color will not be used in illustrations.

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Authors must submit one paper copy of the double-spaced manuscript, one disk copy, and original figures (if applicable). NEFSC authors must include a completely signed-off "NEFSC Manuscript/Abstract/Webpage Review Form." Non-NEFSC authors who are not federal employees will be required to sign a "Release of Copyright" form.

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

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Resource Survey Report (formerly *Fishermen's Report*) -- This information report is a quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

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